Chapter 7

Manufacture of Metallurgical Coke and Recovery of Coal Chemicals

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7.1 Introduction

7.1.1 Carbon as a Reducing Agent

Although the oxides of iron may be reduced to metallic iron by many agents, carbon (directly or indirectly) is the reducing agent found to be best suited for the economical production of iron. Carbon of suitable reactivity and physical strength was at one time produced from wood by distillation, yielding wood charcoal; but for the operation of a modern large blast furnace the carbon required for the smelting of iron is obtained from the destructive distillation of selected coking coals at temperatures in the range from 900°C to 1095°C (1650°F to 2000°F).

7.1.2 Chemical Effects of Coking

Coal is made up principally of the remains of vegetable matter which has been partially decomposed in the presence of moisture and the absence of air and subjected to variations in temperature and pressure by geologic action, see Chapter 6. It is a complex mixture of organic compounds, the principal elements of which are carbon and hydrogen with smaller amounts of oxygen, nitrogen and sulfur. It also contains some noncombustible components called ash. The ash consists primarily of inorganic compounds which became imbedded in the coal matrix during the coalification process.

The chemical compounds making up coals, like most of those in animal and vegetable life, are unstable when subjected to a high degree of heat or thermal treatment. When heated to high temperatures, in the absence of air, the complex organic molecules break down to yield gases, together with liquid and solid organic compounds of lower molecular weight and a relatively non-volatile carbonaceous residue (coke).

Coke, then, is the residue from the destructive distillation of coal. Structurally, it is a cellular, porous substance which is heterogeneous in both physical and chemical properties. The physical properties of metallurgical coke, as well as its composition, depend largely upon the coal used and the temperature at which it is carbonized. Not all coals will form coke, and not all-coking coals will give the same firm, cellular mass characteristic of coke suitable for metallurgical purposes. Some coals will produce an acceptable coke without blending with other coals, while others are usable only as constituents of blends. The type and method of operation of coking facilities also exert a profound influence on the quality and yield of coke for the blast furnaces.

7.1.3 Kinds of Coke

There are three principal kinds of coke, classified according to the methods by which they are manufactured: low-, medium- and high temperature coke. Coke used for metallurgical purposes must be carbonized in the higher ranges of temperature (between 900°C and 1095°C) (1650°F and 2000°F) if the product is to have satisfactory physical properties. Even with good coking coal, the product obtained by low temperature carbonization between 480°C and 760°C (900°F and 1400°F) is unacceptable for good blast furnace operation.

7.1.4 Important Properties of Metallurgical Coke

Probably the most important physical property of metallurgical coke is its strength to withstand breakage and abrasion during handling and its use in the blast furnace. In the United States, the standard ASTM tests used to evaluate these properties are the stability index for breakage and the hardness index for abrasion. Both of these tests involve tumbling coke of selected size in a standard drum rotated for a specific time at a specific rate. The stability index and the hardness index are the percentages of coke remaining on 1 in. and ¼ in. screens, respectively, when the coke is screened after tumbling.

In modern blast furnace practice, the trend is toward use of iron-bearing burden materials of controlled size such as sinter and pellets; thus, the size of the coke used in the burden assumes more importance then in the past when only crude ore was used. The size of coke produced in byproduct ovens is somewhat dependent upon the type of coal, heating rate, width of the ovens, and the bulk density of the coal charge, greater amounts of low-volatile coal, wider ovens and greater bulk density of the coal charge generally tend to produce larger coke while faster heating rates tend to produce smaller coke. Because relatively uniform size is desired, crushing and screening of the coke must be resorted to when controlled size is desired. Most blast furnace operators prefer coke sized between about 18.5 and 76 mm (¾ in. and 3 in.) for optimum furnace performance. Other physical properties of the coke such as porosity, density and combustibility are controllable only to a small extent, and their importance in affecting blast furnace operation has not been definitely established.

7.1.5 Methods of Manufacturing Metallurgical Coke

There are two proven processes for manufacturing metallurgical coke, known as the beehive process and the byproduct process. In the beehive process, air is admitted to the coking chamber in controlled amounts for the purpose of burning therein the volatile products distilled from coal to generate heat for further distillation. In the byproduct method, air is excluded from the coking chambers, and the necessary heat for distillation is supplied from external combustion of some of the gas recovered from the coking process (or, in some instances, cleaned blast furnace gas or a mixture of coke oven and blast furnace gas). With modern byproduct ovens, properly operated, all the volatile products liberated during coking are recovered as gas and coal chemicals, and, when coke oven gas alone is used as fuel, about 40% of the gas produced is returned to the ovens for heating purposes. While the beehive process was the leading method for manufacture of coke up to 1918, largely the byproduct process as discussed later in this chapter now has replaced it. There is a difference of temperature of coking in the two processes, that of the byproduct being somewhat lower than the beehive. Beehive coke is usually larger, though not as uniform in size. In general, properly carbonized beehive coke and byproduct coke both are silvery gray in appearance. A modification of the beehive technology, known as non-recovery ovens, is gaining prominence and is discussed in Section 7.8.

Other processes for producing metallurgical coke are known as continuous processes; many variations have been proposed but none has been adopted on a commercial scale. In one continuous process, finely pulverized coking or non-coking coal is dried and partially oxidized with steam or air in fluidized bed reactors to prevent agglomeration when coking coal is used. The reactor product is carbonized in two stages a successively higher temperatures to obtain a char. Using a binder produced from tar obtained in the carbonization stages, the char is briquetted in roll presses. The “green” briquettes are cured at low temperatures, carbonized at high temperatures, and finally cooled in an inert atmosphere to produce a metallurgical coke of low volatile content. This type of coke often is referred to as formcoke. Briquetting will be discussed again later in this chapter.

7.1.6 Products of Coal Carbonization

The reactions occurring during the carbonization of coal for the production of metallurgical coke are complex. The process can be considered as taking place in three steps: (a) primary breakdown of coal at temperatures below 700°C (1296°F) yields decomposition products some of which are water, oxides of carbon, hydrogen sulfide, hydroaromatic compounds, paraffins, olefins, phenolic, and nitrogen-containing compounds; (b) secondary thermal reactions among these liberated primary products as they pass through hot coke, along hot oven walls and through highly heated free space in the oven involve both synthesis and degradation. A large evolution of hydrogen and the formation of aromatic hydrocarbons and methane occur in the stage above 700°C (1296°F). Decomposition of the complex nitrogen-containing compounds produces ammonia, hydrogen cyanide, pyridine bases and nitrogen; (c) progressive removal of hydrogen from the residue in the oven produces hard coke.

During carbonization, from 20–35% by weight of the initial charge of coal is evolved as mixed gases and vapors which pass from the ovens into the collecting mains and are processed through the coal-chemical recovery section of the coke plant to produce coal chemicals. When the production of coke is accomplished in modern byproduct coke ovens with equipment for recovering the coal chemicals, one ton of coking coal in typical American practice yields about the following proportions of the coke and coal chemicals presented in Table 7.1, depending upon the type of coal carbonized, carbonization temperature and method of coal-chemical recovery.

The coke oven gas contains the fixed gases so classified because they are gases at 760 mm (29.92 in.) pressure and 15.5°C (60°F). They are: hydrogen, H_2; methane, CH_4; ethane, C_2H_6; carbon monoxide, CO; carbon dioxide, CO_2; illuminants which are essentially unsaturated hydrocarbons, such as ethylene, C_2H_8; and acetylene, C_2H_2. Other fixed gases present are: hydrogen sulfide, H_2S; ammonia, NH_3; oxygen, O_2; and nitrogen, N_2.

Table 7.1 Coke and Coal Chemical Typical Yields Following Carbonization

	Per Metric Ton	**Per Net Ton**
Blast Furnace Coke	600–800 kg	1200–1400 lb
Coke Breeze	50–100 kg	100–200 lb
Coke Oven Gas	296–358 m^3	9500–11,500 ft^3
Tar	30.3–45.4 litres	8–12 gal
Ammonium Sulfate	10–13.8 kg	20–28 lb
Ammonia Liquor	56.8–132.5 litres	15–35 gal
Light Oil	9.5–15.1 litres	2.5–4 gal

Other substances in the raw gases and vapors leaving the ovens, which are liquids at ordinary temperatures and pressures, are discussed here.

7.1.6.1 Ammonia Liquor

Primarily this is the water condensing from the coke oven gas and is an aqueous solution of ammonium salts of which there are two kinds—free and fixed. The free salts are those which are decomposed on boiling to liberate ammonia. The fixed salts are those which require boiling with an alkali such as lime to liberate the ammonia.

7.1.6.2 Tar

Tar is the organic matter that separates by condensation from the gas in the collector mains. It is a black, viscous liquid, a little heavier than water. The following general classes of compounds may be recovered from tar: pyridine, tar acids, naphthalene, creosote oil and coal-tar pitch.

7.1.6.2 Light Oil

Light oil is a clear, yellow-brown oil somewhat lighter than water. It contains varying amounts of coal-gas products with boiling points from about 40°C to 200°C, and benzene, toluene, xylene and solvent naphthas are the principal products recovered from it.

7.1.7 Recovery of Coal Chemicals

In the recovery of coal chemicals, the first step is the recovery of the basic crude materials (coke oven gas, ammonia liquor, tar and light oil) as a primary operation in accordance with commercial practice. Secondary operations consist of the processing of these primary products to separate them into their components as discussed in detail in Section 7.7 of this chapter.

In addition, environmental regulations have been enacted which stipulate maximum allowable levels of sulfur-bearing compounds in coke oven gas. These limits are generally expressed in terms of equivalent H_2S units. In the United States the limit is expressed in grains per 100 dscf and range up to 50 gr/dscf. To satisfy the sulfur regulation, many coke plants have installed coke oven gas desulfurization systems.

7.2 Coals for Metallurgical Coke Production

7.2.1 Selecting Coals for Quality Coke

7.2.1.1 Introduction

Most coal and coke producers follow the practice of coal blending in order to conserve the limited resources of high cost, prime coking coals. This is also due to the fact that a single coal does not usually meet all the requirements of coke quality and cokemaking. The challenge to a coke producer is in designing a blend that on carbonization would consistently produce a low cost, high quality coke with safe oven pushing performance. More rigid coke quality requirements will be placed on coke producers as ironmakers try to increase productivity and reduce costs by reducing the coke rate and by increasing the pulverized coal injection rate. The success of a coke production facility, thus, would be dependent upon whether a balance can be achieved between the competing sets of requirements such as throughput, high quality, and cost efficiency all the while keeping importance of the battery life in mind.

With the above requirements in mind, the coal design efforts can be grouped into the following categories:

Table 7.2 Procedure for Coking Coal Selection *(modified from Ref. 1)*

Vendor's Data	Laboratory Testing	Pilot Oven Carbonization	Plant Trial
1) Obtain coal quality data sheet.	1) Predict coking quality from 5 lb. sample.	1) Conduct test on 100% coal.	1) Monitor plant trial.
2) Predict coking quality.	2) Conduct economic evaluation.	2) Conduct test on blend.	2) Adopt coal for plant use.
3) Assess cost/ availability.	3) Order coal for pilot oven carbonization.	3) Conduct contraction and gas pressure test.	
4) Request 5 lb. coal sample.		4) Recommend for plant trial.*	

*Final selection also takes into account price, mine, preparation plant, and quality control capabilities and nature of quality variation from future mining areas as assessed through a mine visit.

1. Coal blend design to satisfy coke physical properties.
2. Coal blend design to satisfy coke chemical properties.
3. Coal blend design to satisfy coke oven pushing performance.
4. Coal blend design to satisfy maximum usage of low value carbon materials.
5. Economic evaluation of the designed blend.
6. Assurance of high quality coal shipments.

Usually, the coal blend design is done through a series of steps. An example of coal selection and blend design is shown in Table 7.2.[1]

After screening the desired coals from vendor data sheets, the coal qualities are generally determined through various analytical techniques. Thereafter, the coke qualities are predicted via coke prediction models and cost effective blend is designed. Then the designed coal blend is tested in a pilot oven, which is then implemented in the commercial batteries. Once the confidence is built through use of coke quality and oven pushing performance models, the pilot oven tests can be bypassed and a coal can be directly implemented in the commercial blends through use of prediction models only. It should be kept in mind that the properties predicted are only valid for the range of coals used and the controlled conditions of carbonization and whenever possible, the coke quality should be determined via pilot oven carbonization.

Only the use of coal inherent properties for coal blend design will be discussed here. Those coal and coke properties and analytical tests and predictive methods that are commonly used in designing coal blends are described.

7.2.1.2 Coal Blend Design to Satisfy Physical Properties

Below the cohesive zone in the blast furnace, coke is the only solid material remaining; hence, coke provides the strength and the void spaces. Therefore, for a stable blast furnace operation, the physical properties of coke are of paramount importance. A large mean coke size with narrow size variations help maintain a stable void fraction for the flow of gases and molten products and consequently improves blast furnace productivity. Coke size for blast is typically controlled by screening. In terms of coke strength, the coke strength after reaction with CO_2 (CSR) and drum index (such as ASTM stability) are the most important parameters. CSR and stability are primarily controlled by coal properties and secondarily by battery operations.[2–4]

7.2.1.2.1 Blend Design for Coke Strength in a High Temperature Environment Tests indicating coke strength in a high temperature environment are increasingly being used for coke quality evaluation.[5] CSR, as determined through Nippon Steel Corporation (NSC) method, is widely used to assess coke's behavior inside a blast furnace.[6] CSR measures the potential of the coke to break up under a high temperature CO_2 environment, which occurs in the blast furnace.

The use of CSR as a coke quality tool has been in use for about 20 years. CSR prediction models have been developed and successfully adopted. The models are used to design blends and to monitor changes in blend design.

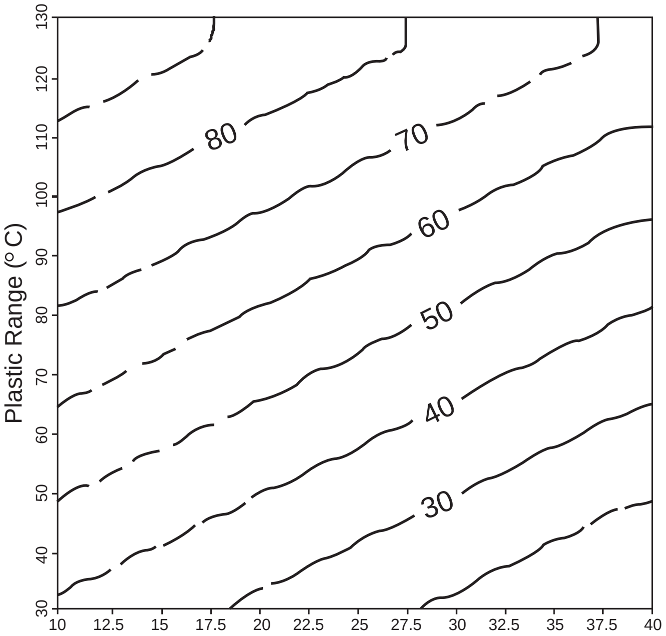


Fig. 7.1 Ispat Inland CSR prediction model.

At Ispat Inland, CSR is predicted by measuring many local characteristics: these include the plastic range of coal, as determined by the Giesler Plastometer, and the catalytic index (CI) of CO_2 gasification (Fig. 7.1). The catalytic index is comprised of the alkali index and sulfur. The alkali index is calculated as a product of coal ash content times the weight percent ration of $(CaO+MgO+Fe_2O_3+Na_2O+K_2O)/(SiO_2+Al_2O_3)$. According to this model, CSR increases with an increase in the plastic range and decreases with an increase in Catalytic Index. This is explained by the fact that the increase in plastics range optimizes the extent and size of anisotropic carbon form from mesophase which, in turn, reduces the CO_2 gasification.[7] The increase in alkalies, Fe_2O_3, and sulfur may affect CSSR in two ways: (a) by creating functional groups between the elements affecting fluidity and inhibiting of nematic liquid crystals and (b) by simply acting as a catalyst of CO_2 gasification.[8]

It has been shown that CSR is a linearly additive property. Thus, the CSR of coke produced from blended coals can be predicted from individual coal characteristics through the application of the additivity law (Fig. 7.2). The line connecting the composition points for two coals such as A-B and C-D (Fig. 7.2) delineates all the blend compositions that could possibly result from mixing A and B or C and D coals. CSR prediction models can also be used for monitoring the incoming coal quality, blend quality, reserve evaluation, and mine and preparation plant design and control.

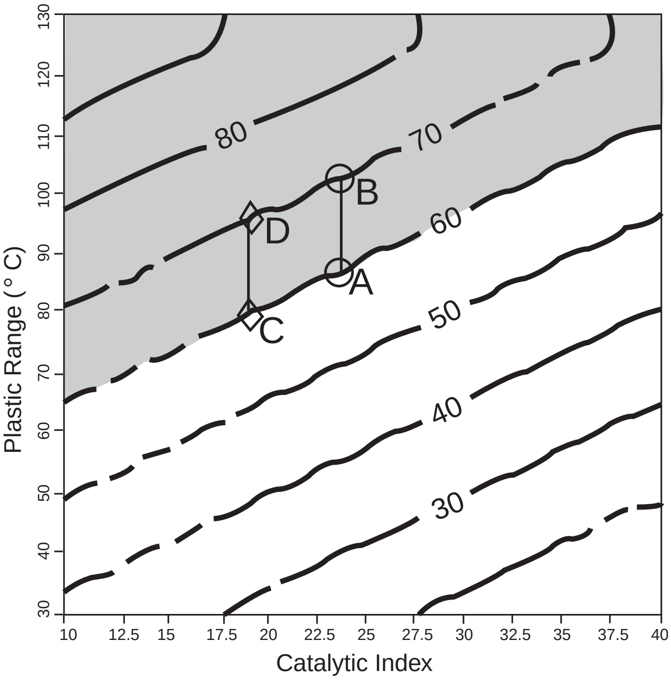


Fig. 7.2 Ispat Inland CSR blend prediction.

7.2.1.2.2 Blend Design for Coke Strength in an Ambient Temperature Condition

Coke strength properties measured in an ambient condition are generally referred to drum strength properties as determined using a tumbler. These indices measure the ability of coke to withstand breakup at room temperature and reflect coke handling behavior outside the blast furnace and coke breakage in the upper part of the blast furnace. ASTM Tumbler Test (stability and harness), Micum Test, IRSID Test, and Japanese Tumble Test are variations of drum tests to characterize breakage and abrasion of coke. Blend design techniques have been developed based on these tests. Various coal characteristics are used to predict the drum indices. Of those, petrographic analysis has become the prime analytical tool for predicting the drum strength index of coals. Various blend design techniques to achieve desirable coke strength are presented below.

7.2.1.2.2.1 Coal Petrography Petrographic analysis of a coal is a major tool for predicting coke strength.[9, 10] Prediction through petrography is done in three steps. First step involves the identification of macerals which are describes as microscopically distinct organic entities in coal. Thereafter, the macerals are grouped into reactive, semi-inert, and inert categories. These categories are partially based on maceral behavior during carbonization. Lastly, the rank of coal is determined by measuring the reflectance and calculating the strength of the binding materials created through carbonization of reactives. Using these characteristics, the strength (rank) and inert indices are calculated and coke strength is predicted.

The petrographic coke strength (ASTM Stability factor) prediction method developed at U.S. Steel (U.S.S.) is shown in Fig. 7.3. Coke of high stability can be produced from coal blends which have an optimum ration of reactive components to inert components. The reactive components contribute fluidity to the coal and act as binders, while the inert components (either organic or inorganic) act as fillers in the formation of the coke structure. On the other hand, the Ispat Inland stability prediction method, Fig. 7.4, considers inerts to be detrimental to stability. Some Japanese steelmakers use modifications of the U.S.S. method; however, the iso-stability lines are replaced by JIS D130/15 lines, Fig. 7.5. The optimum coal blend area is shown by the boxed area (Fig. 7.3) or the hatched zone (Fig. 7.5).

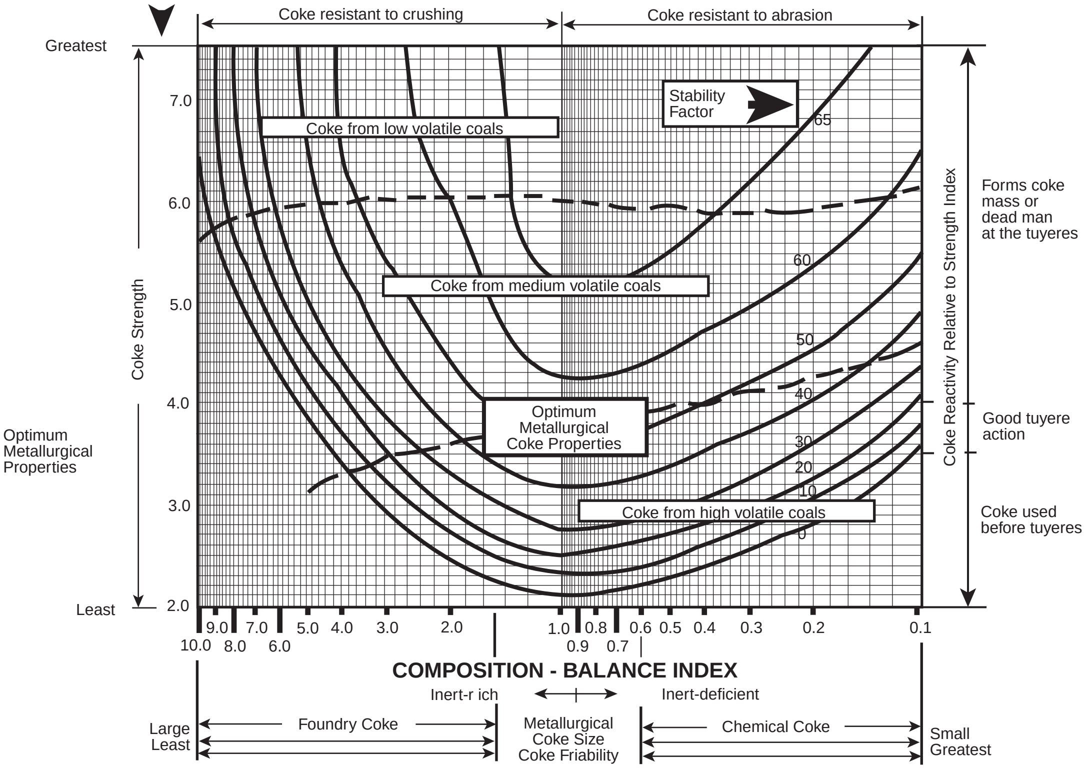


Fig. 7.3 U.S.S. stability prediction method. *(Adopted from Ref. 26)*

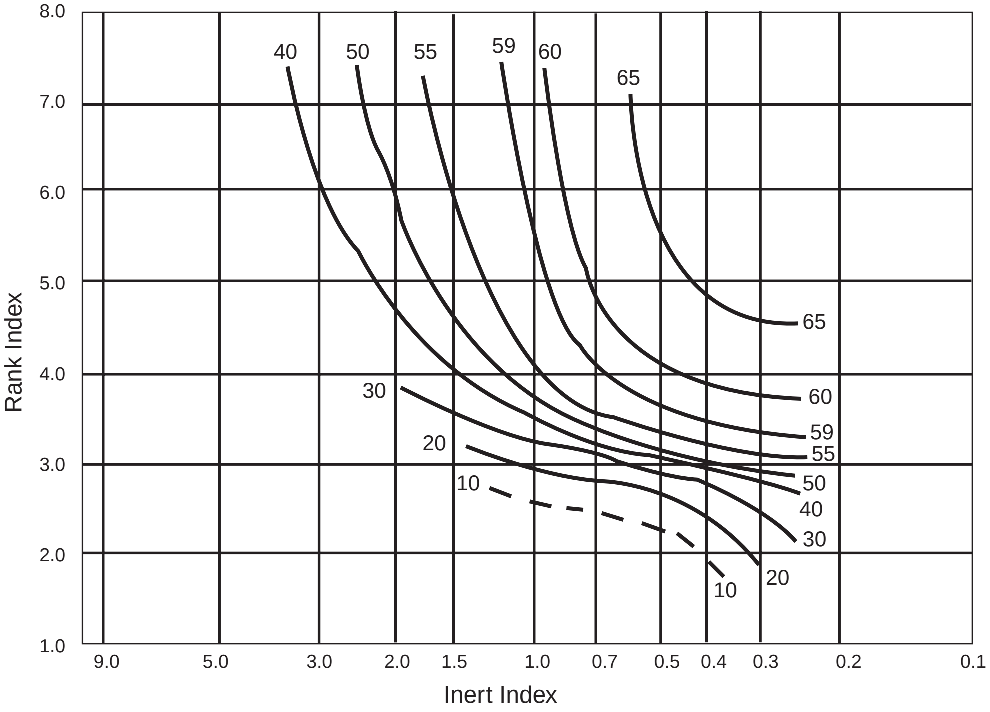


Fig. 7.4 Ispat Inland stability prediction method. *(From Ref. 11)*

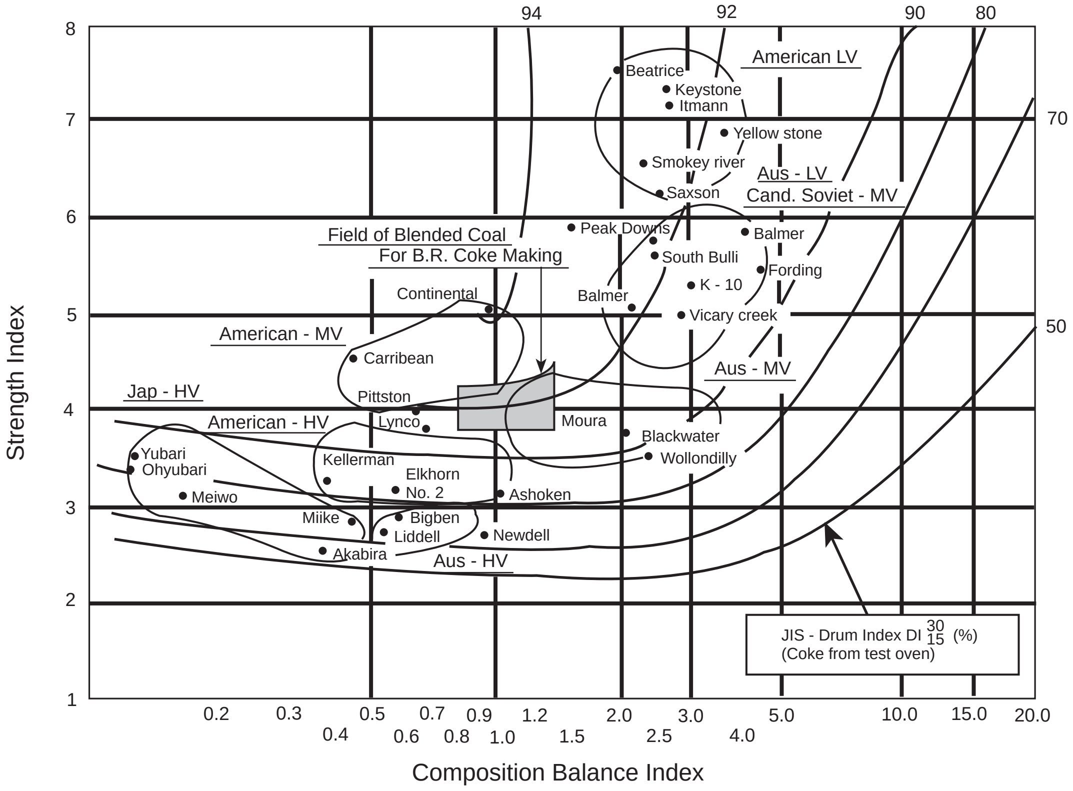


Fig. 7.5 Japanese D130/15 prediction method. *(From Ref. 12)*

7.2.1.2.2.2 Gieseler Plastometry Some[8, 13] have indicated that the fluidity of coal is an important parameter affecting coke stability by providing bonding to various coal components. In order to ensure optimum coal particles interaction, it is important that the temperature intervals of the plastic state for coals constituting a blend should overlap. The longer the overlapping of maximum activity intervals of two particles, the more the number of chemical bonds formed in the contact area.

The Japanese have[13] used reflectance and the maximum fluidity to define optimum blends that would produce high strength coke, Fig. 7.6. The graph can be dissected into four quadrants. Coals from quadrants I and II provide fluidity to the blend (bonding and high CSR), whereas coals from quadrant IV provide rank (coke strength) to the coal blend. Those coals representing lower ranks in quadrant III would provide filler and the most opportunities for cost reductions to a coke producer. Reflectance and maximum fluidity values have also been used to predict stability with special reference to Canadian coals, Fig. 7.7. The desired blending area suitable for Canadian coals is shown by the cross-hatched zone.

7.2.1.2.2.3 Dilatometer Some measure coke strength through the use of dilatometry which is much prevalent in some European countries. Dilatation is measured using either Arnu or Ruhr dilatometers. Dilatation can be used to predict Micum Indices (M40 and M10). A cokability factor called G-Factor has been developed. One application of the G-Factor[15], shown in equation. 7.2.1, is to predict M40, shown in equation 7.2.2.

$$\text{G - Factor} = E + \frac{V^1k}{2} + \frac{d}{V^1k} + Ed \qquad (7.2.1)$$

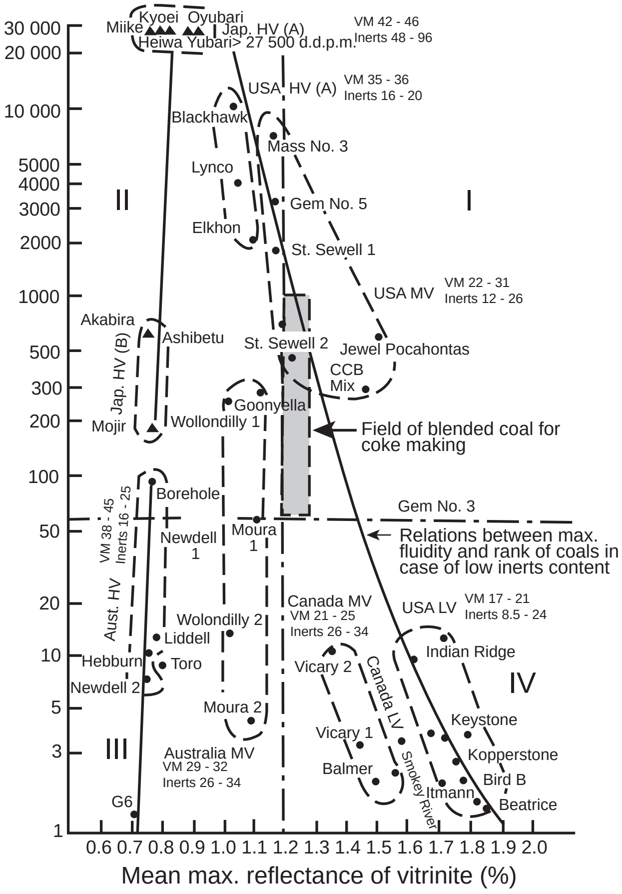


Fig. 7.6 D130/15 Prediction using reflectance and maximum fluidity. *(From Ref. 13)*

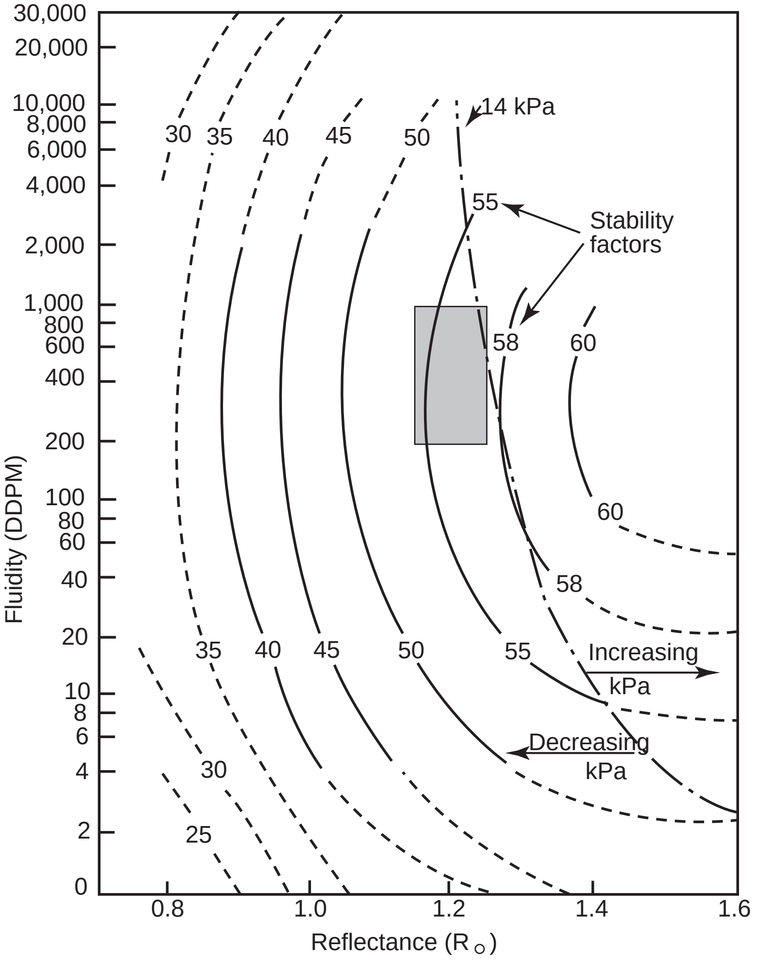


Fig. 7.7 Stability prediction with special reference to Canadian coals. *(From Ref. 14)*

where:

E = softening temperature (°C)
V^1 = resolidification temperature (°C)
k = % contraction
d = % dilatation.

Thus,

$$M = 103.9 + 24.8G + \frac{1.196V^5}{10^6} + \frac{2.57V^2}{T} - \frac{88V}{T} \qquad (7.2.2)$$

where:

V = volatile matter of blend (dry ash free %)
T = time (h) of carbonization to a center temperature of 900°C in an oven of average width of 46 cm.

The G-Factor for most medium and strongly caking coals is usually between 0.95–1.15. It has been shown to be linearly additive for blends and can be used in equations to predict coke strength.[16]

Others have used a relationship between the total dilatation and reflectance to predict the ASTM stability factor, Fig. 7.8. It should be noted that the stability factor lines in the graph are not based

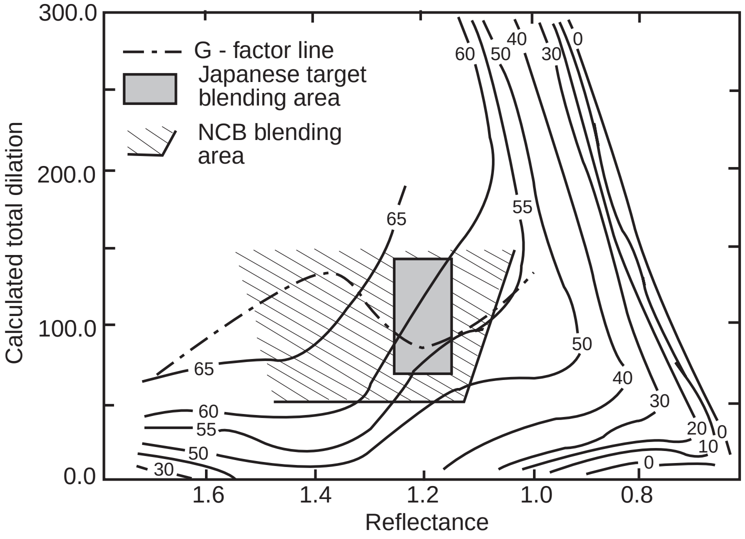


Fig. 7.8 Stability prediction using total dilatation and rank. *(From Ref. 14)*

on actual coke stability measurements but are calculated using reflectance and inert contents of coals. The blend target areas as defined by the National Coal Board (NCB) and by Japanese steelmakers are also shown in Fig. 7.8.

7.2.1.2.2.4 Free Swelling Index (Crucible Swelling Index), Gray-King Coke Test, and RogaTest These tests give an indication whether a coal will carbonize to form a coherent coke or not. Table 7.3 shows an approximate comparison between the three indices.[15] These tests are used only to assess the coking ability of a coal.

7.2.1.2.3 Blend Design for Coke Size The as-formed size of the coke is influenced by the amount of inert components of the coal lend. As the inert content decreases, the size of coke decreases. Thus, the coal type influences the coke size. The coke size is also highly dependent on operating variables. Various additives such as coke breeze, anthracite, petroleum coke when added to a coal blend, can result in an increase in coke size. In normal practice, the coke size for blast furnace is mostly controlled by screening.

7.2.1.2.4 Blend Design for Coke Yield The amount of coke produced in a coke oven will be inversely proportional to the coal volatile matter. The relationship used at Ispat Inland is given in Fig. 7.9.[17]

Table 7.3 Comparison Between Free Swelling Index, Gray-King Coke Type, and Roga Index

Free Swelling Index	Gray-King Coke Type
0–½	A–B
1–4	C–G2
4½–6	F–G4
6½–8	G3–G9
8½–9	G7 and above

Free Swelling Index	Roga Index
0–½	0–5
1–2	5–20
2½–4	20–45
>4	>45

In North America, the coal volatile matter range of 29–31% (dry, ash free) is generally desired for the production of high strength coke.

7.2.1. 3 Coal Blend Design to Satisfy Chemical Properties

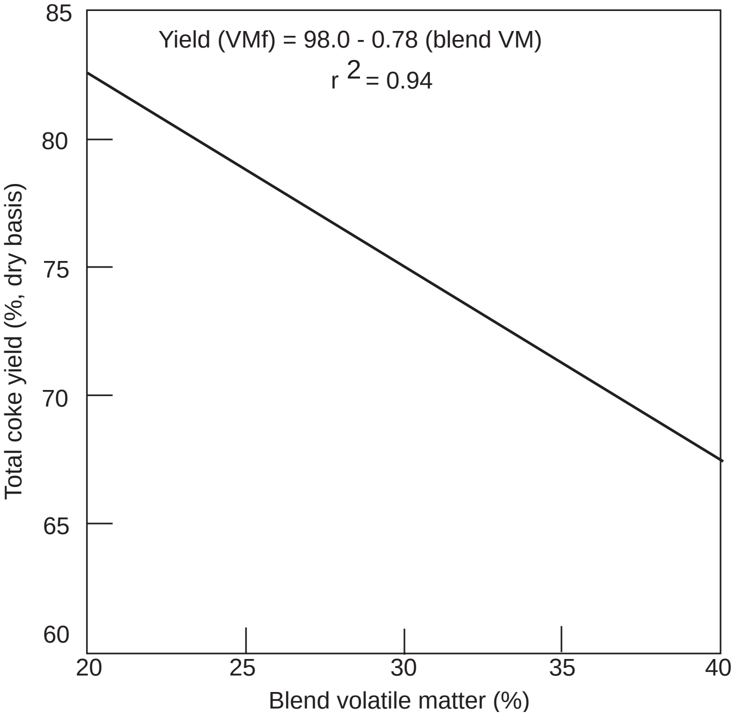


Fig. 7.9 Relationship between coal volatile matter and coke yield. *(From Ref. 17)*

With a physically stable set of raw materials in the blast furnace, further control of the blast furnace process is achieved through control of the chemical properties. The most important coke chemical properties are moisture, fixed carbon, ash, sulfur, phosphorus and alkalies. Most of these properties are primarily dependent on the coals used. Coke ash and sulfur affect stability negatively. Similarly, the coke ash, sulfur, and alkalies affect CSR negatively. However, phosphorous affects CSR positively,[18] but it is undesirable as it goes completely into the hot metal. In order to obtain a high quality coke with high yield, it is desirable that the coal blend should contain low amounts of moisture, ash sulfur, alkalies, phosphorus and high fixed carbon content.

7.2.1.4 Coal Blend Design to Satisfy Coke Oven Pushing Performance

7.2.1.4.1 Coking Pressure Direct measurement of coking (wall) pressure can be obtained in a movable wall pilot oven. This type of oven is widely used in order to estimate coking pressure of different coals and different process conditions. The maximum coking pressure should not exceed 14 kPa (2 psi). Of all the inherent coal properties, rank and inert content appear to be of primary importance, Fig. 7.10. The rank has a direct relation with coking pressure. Low volatile coals exert excessive coking pressure; however, they also contribute to high coke strength and produce high coke yields. Coals of similar rank but possessing high inertinites produce lower pressure. Western Canadian and Australian low volatile coals generally produce low wall pressure and are included in blends to reduce the coking pressure.

Because of the difficulty of measuring the coking (wall) pressure in a commercial oven, the wall pressure and gas pressure measurements from a pilot oven are usually correlated with gas pressure measurements in commercial ovens. Once the correlation is established, the gas pressure measurements at the commercial facility are used to monitor the coking pressure. Gas pressure increases with rank, Fig. 7.11, and decreases with inertinite content.

7.2.1.4.2 Charge Contraction Coal charge contraction occurs during two different phases of the coking process, the first phase is present during plastic layer information is mainly dependent on coal properties. Once the plastic layers have transformed to semi-coke, the second phase begins during the shrinkage of the semi-coke and is mainly dependent on the operating conditions. At Ispat Inland, during the earlier years, sole heated oven (SHO) measurements were adopted to characterize the first phase and the coke mass vertical shrinkage measurements were adopted to simulate the second phase.[21] Thereafter, new procedures were developed to measure lateral contraction.[22] Two sources of information were used for prediction and evaluation of the contraction behavior of

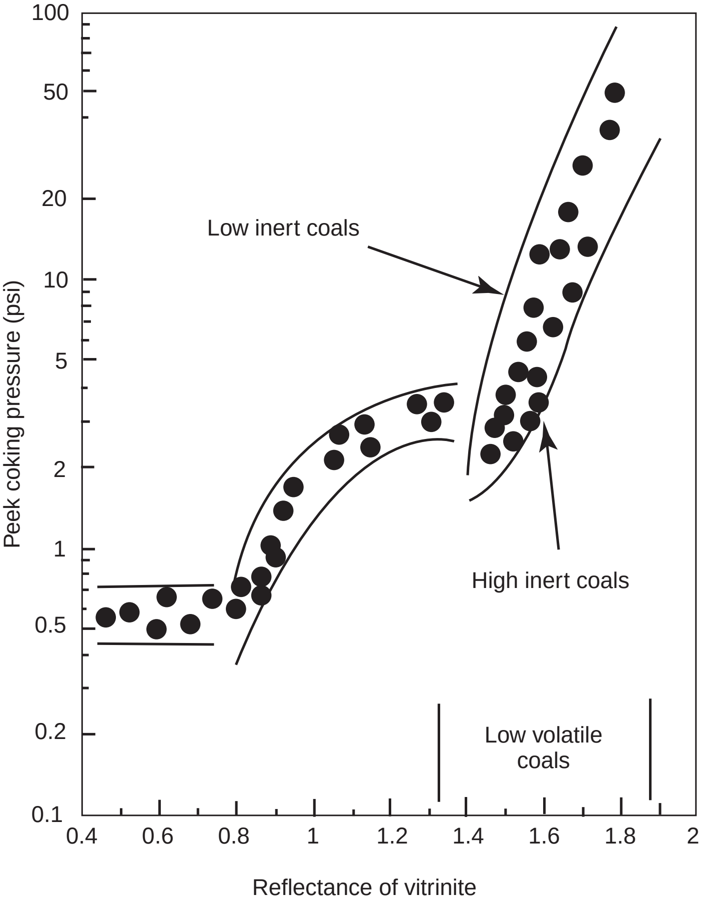


Fig. 7.10 Effect of coal rank and coal type on wall pressure. *(From Ref. 19)*

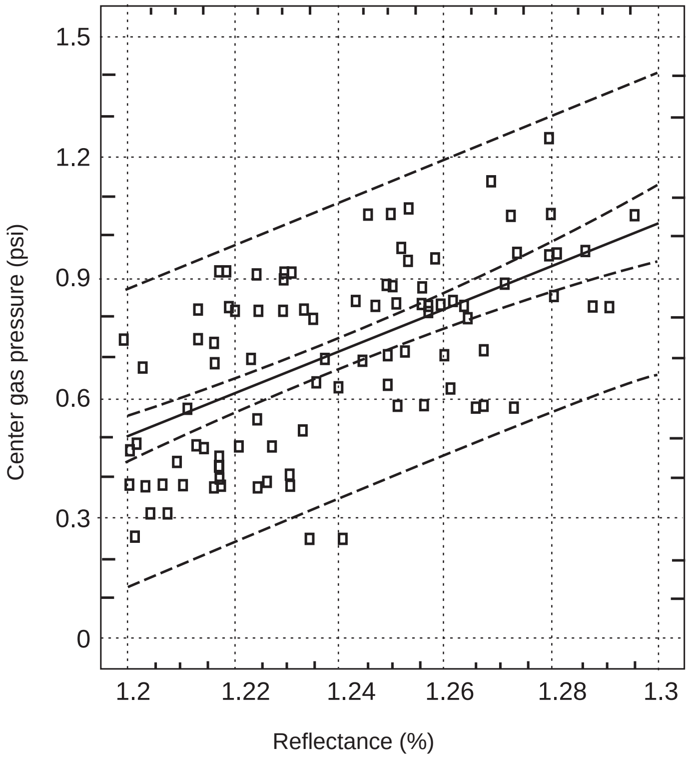


Fig. 7.11 Effect of rank on gas pressure. *(From Ref. 20)*

new coal blends. SHO contraction and Gieseler maximum fluidity values are used to predict Phase I of the lateral contraction. Blends with high SHO contraction and high fluidity produced higher lateral contraction. This is followed by measurements of the vertical shrinkage taken directly at the battery; this is mainly dependent on operating parameters such as coking temperature and heating rate.

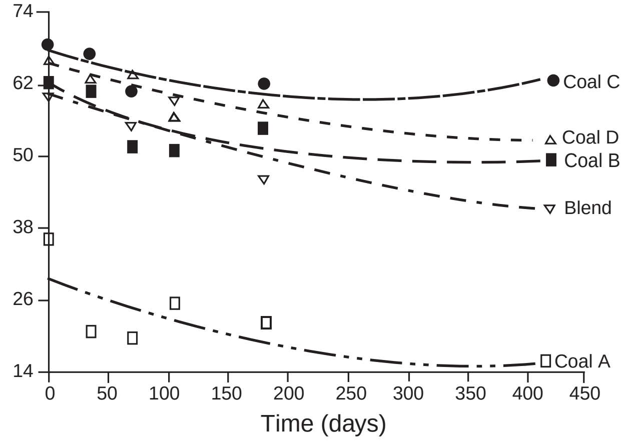


Fig. 7.12 Effect of oxidation on CSR. *(From Ref. 24)*

7.2.1.5 Coal Blend Design to Maximize Usage of Low Value Carbon Materials

In order to lower the operations costs while maintaining the coke quality, low value carbon materials are added in varying amount to the commercial blends. Coal fines, coke breeze, coal tar, petroleum coke, asphaltene, and non-coking coals have been shown to have a positive effect on coke quality and coking operation, provided they are added in the right amount and to the right kind of blend.[23] Such practices have resulted in lower cost, better operation, and conservation of resources.

Oxidized (weathered) coals could also be considered as low value carbon material as the oxidation generally results in a drop in CSR, stability, coke size, coke yield, and generally worsens the expansion and wall pressure characteristics.[24] CSR is most sensitive to coal oxidation; the magnitude of CSR drop is higher for the lowest rank coals, Fig. 7.12. Hence, the use of oxidized coal should be minimized.

7.2.1.6 Economic Evaluation of the Designed Blend

The technological evaluation of the coal blend is supplemented by an economic evaluation and an evaluation of the utilization cost of the coke produced. Coke plant operation and blast furnace operation models are used to assess the cost competitiveness of various blends.

7.2.1.6.1 Coke Plant Operation Model The coal quality parameters are entered into the program. The computer first calculates the predicted coke properties such as blend CSR, blend stability, blend reflectance, coke ash, coke sulfur, yield, production of coke over gas, tar, light oils. Thereafter, the processing cost per ton of coal is predicted. The most cost effective blends are selected for further evaluation through a blast furnace operation model.

7.2.1.6.2 Blast Furnace Operation Model Blast furnace rules of thumb are used to evaluate the utilization cost of cokes that would be produced from carbonization of the most cost-effective blends as selected through the coke plant operation model. Using predicted coke quality and coke rate, the quality-adjusted price of blends are determined. The blend that would produce coke with highest potential cost savings at the blast furnace is recommended for implementation at the coke plant.

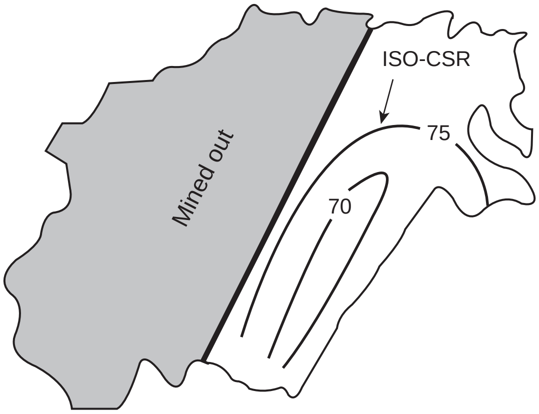


Fig. 7.13 Coal reserve evaluation for CSR. *(From Ref. 1)*

7.2.1.7 Assurance of Coal Quality Shipments

Blend design is half of the job. The other half is to make sure that consistent quality coke is produced from the batteries. In order to produce a consistent high quality coke, the producer must monitor the coal quality and forecast the reserve quality. Petrographic, rheologic, chemical and ash chemistry characteristics are some of the inherent coal quality variables that should be monitored on a routine basis for coal shipments.[1, 25] In addition to monitoring shipments, it is essential to forecast the coal quality data for the coal reserves and incorporate the quality data into the mining plan.[1, 25] This will assure consistent quality coal shipments in the future. An example of a reserve evaluation map is shown in Fig. 7.13.

It should be noted that the coal blend design helps to achieve the potential mean value of a desired coke property. Thereafter, the control of the battery operation is effectively used to reduce the variability.

Applying the coal selection procedure described in this section, cokemakers can achieve a balance between the requirements of throughput, high coke quality, battery life, and cost efficiency with an assurance of a consistent supply of high quality coals from the future mining areas.

7.2.2 Preparation of Coal Charge for Byproduct Ovens

The importance of coal preparation cannot be overemphasized. It is a very important step in the coke-making process in terms of coke quality and uniformity. The proper preparation of the coal blend affects both the smoothness of operation and the productivity of the coke battery.

A simplified flow diagram of a typical coal handling and preparation facility is shown in Fig. 7.14. A brief description of the elements of this system and its operation follows.

7.2.2.1 Coal Unloading

Coals are received at coke plants by rail, river barge or, in some cases, by motor truck. Railroad cars usually are unloaded by rotary dumpers or bottom dumping. Rotary car dumpers usually are preferred.

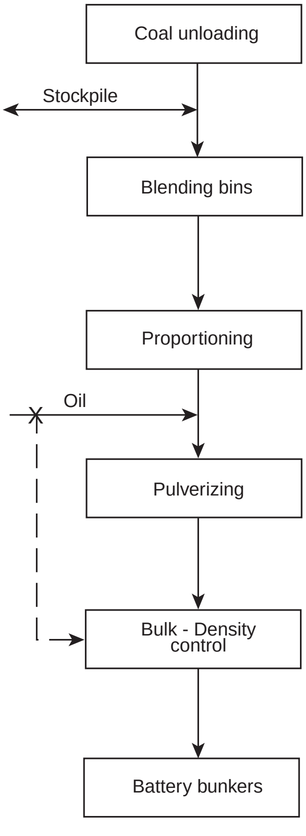


Fig. 7.14 Schematic diagram of a typical coal preparation facility. Coal reserve evaluation for CSR. *(From Ref. 1)*

Since coal freezes to the railroad cars during the winter months, a car thawing facility is provided to thaw the coal prior to dumping. Some coal mines spray de-icing compounds on the coal as it is loaded at the mines to prevent freezing.

Throughout the unloading operation, coal identity must be maintained so that selected coals always are unloaded to the proper bin or stockpile. Any coal misplaced to the wrong storage bins can cause serious operating problems and possibly damage the coke batteries in addition to having a negative affect on coke quality.

7.2.2.2 Bed Blending

The coals as received can vary in sulfur and ash content. One of the methods used to reduce this variability is to bed blend about ten days supply of coal in horizontal layers and reclaim it vertically. Individual coals, according to classification, can be bed blended prior to coal preparation. A minimum of two stockpiles for each classification of coal is required; one being stockpiled and one being reclaimed. Usually, a more uniform quality coke is produced from coals that have been bed blended, which has a beneficial effect on blast furnaces operating at high production rates. Coal bed blending can be accomplished either by use of stacker/reclaimers or by utilizing mobile equipment such as carryalls, trucks and front end loaders.

7.2.2.3 Primary Crushing

Coal received at the coke plant varies in size from run-of-mine, which includes large lumps, to crushed coal which could be essentially 100% –19 mm (–¾ in.). In addition, large chunks of frozen coal are not uncommon during the winter months, and contaminants such as wood, rock and metal are usually present.

Primary crushers are used to break up the large coal with a minimum of fines generation. Not all plants are equipped with primary crushers, but plants that are equipped usually employ roll type crushers or Bradford breakers, Fig. 7.15. The Bradford breaker is a large rotating drum over 6 m (20 ft) long and about 4.2 m (14 ft) in diameter, with holes about 63 mm (2.5 in.) in diameter spaced uniformly over the entire shell. Baffle plates inside the drum lift and drop the coal as the drum rotates. This repeated impact crushes the coal, which then passes through the holes in the shell to a conveyor. The rock, slate and extraneous refuse are discharged from the end of the drum. Plants not equipped with breakers of this type usually use magnetic separators and/or scalping screens to separate foreign material.

7.2.2.4 Blending Bins and Weigh Feeders

Blending bins and weigh feeders are used for blending the individual coals in proportion to the final coal blend which will be charged to the coke ovens from the bunker located above the coke batteries. This operation can be performed either before or after pulverization. Some plants have raw coal bins ahead of the pulverizers plus coal bins for storing pulverized coal prior to blending. Other plants pulverize the coal as it is unloaded and accumulate the pulverized coal in bins prior to blending.

In a well designed plant, blending bins are provided for each coal or groups of coals. The number and size of the bins is determined by the number of coals to be blended and the daily throughput of coal. The bins can be either round or rectangular with conical bottoms constructed of concrete or steel. However, they should be designed with mass-flow bottom discharge. Bins usually are grouped together to facilitate distribution of coal to the top of the bins and to shorten the conveyor lengths required at the bottom discharge.

Quality analysis proves that a consistently well-proportioned coal blend is essential to the production of the highest quality, most uniform coke possible from the coals supplied. In any given situation, regardless of the design or age of the facility, every effort should be made to get the

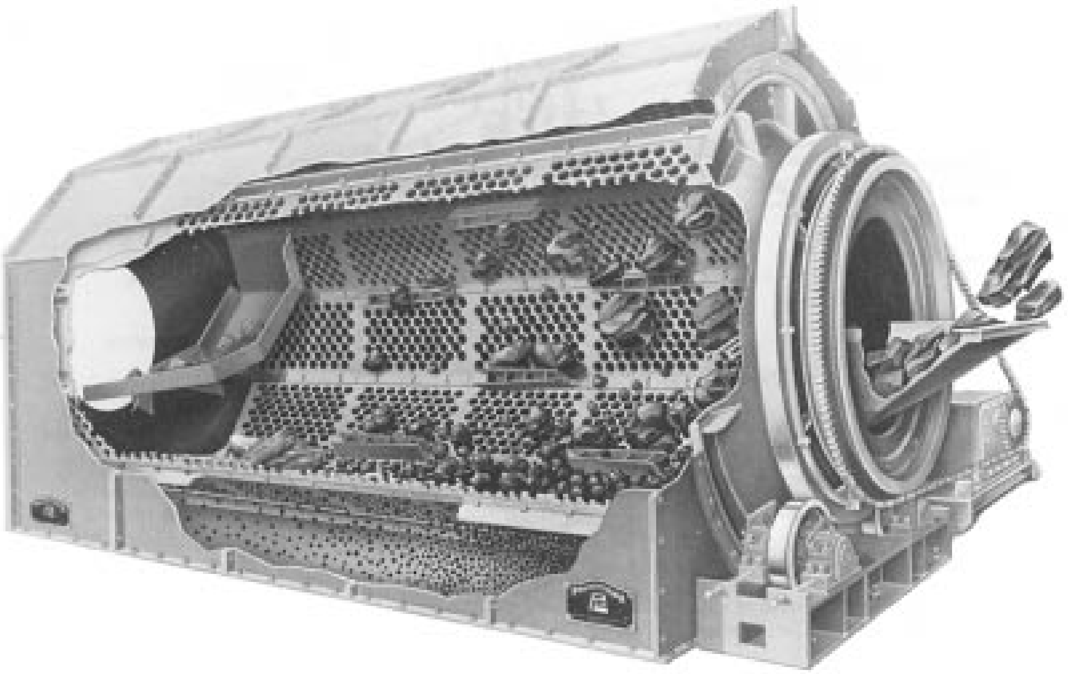


Fig. 7.15 Cut-away view of a rotary Bradford breaker.

maximum performance from the combined mixing bin and weigh feeder systems. Coal proportioning is too important to take lightly or to ignore simply because the facility is too old to maintain properly or because repair parts are difficult to obtain. The benefits in uniform coke quality and in the resultant blast furnace performance justify a concerted operating effort and an adequate maintenance program.

Each bin is provided with a discharge weigh belt for controlling the weight of the coal delivered. Coal weight control is accomplished by scales and control circuitry which regulates either the speed of the belt carrying a constant depth of coal or the depth of the coal on a constant-speed belt. There is probably little difference in the performance of these two types of weigh feeders provided the machines are of modern design and well maintained. Usually, if the weigh feeders and control circuits are in good condition and an error exists, it is probably due to the bin above the feeder. If the flow from the bin is not constant because of poor bin design or because of wet coal or extraneous material, the weigh feeder cannot deliver the required flow rate. The subject of bin design and mass flow of materials from bins is too extensive to discuss in detail here. Suffice it to say that the bin and feeder must be treated as an integral unit if accurate proportioning is to be accomplished. The best feeder is useless without a proper bin above it.

7.2.2.5 Coal Screening

Most of the coals received at the coke plants contain large amounts of –3 mm (–⅛ in.) coal. Screens are sometimes installed in the pulverizers (described below) to remove and bypass this fine coal around the pulverizers. This reduces pulverizing costs, reduces plugging problems caused by wet fines, reduces the amount of very fine coal (–147 micron or –100 mesh) produced. These screens, however, tend to plug or blind, reducing efficiency especially when the coal is wet. Without constant cleaning, this blinding permits a large portion of the fine coal to pass over the screens and through the pulverizers. Because of this problem, larger screen openings are sometimes used and this allows larger coal to by pass the pulverizers. This negates the effectiveness of the pulverizers, resulting in an oversized coal blend and lower coke strength.

7.2.2.6 Secondary Crushing (Pulverizing)

Many different types of pulverizers are available for crushing coal, but three types find wide application in coke plants: these are the hammer mill (Fig. 7.16), the impact mill and cage mill.

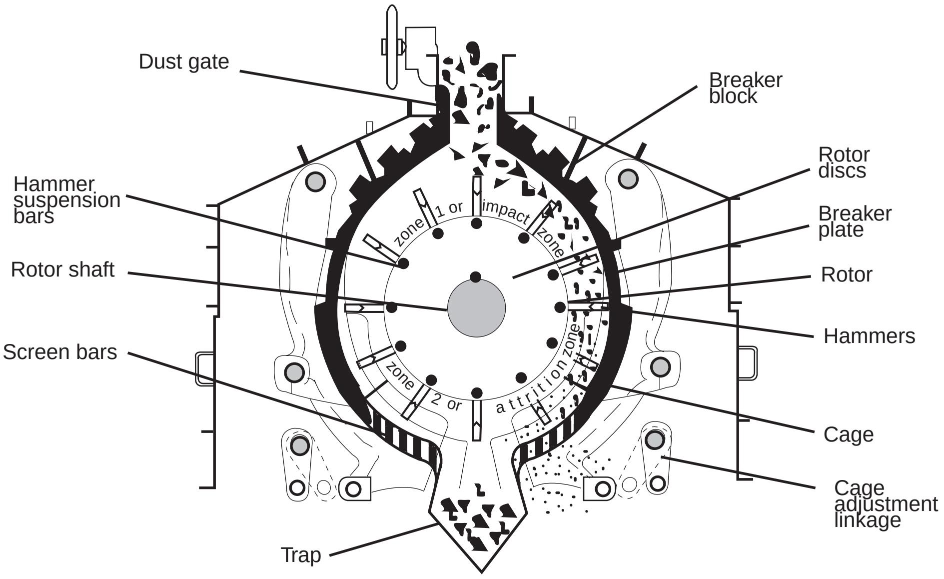


Fig. 7.16 Sectional view of a reversible hammer mill.

The hammer mill is a commonly used type. In this machine, hammers made of flat steel bars or cast steel sections swing freely on eight to ten steel shafts which rotate in the mill at speeds of up to 100 rpm. The hammers first impact and grind the coal against heavy plates and finally force it though a bar screen. The degree of pulverization is determined by the speed of the hammers and the openings in the bar screen. The hammer mill is an excellent heavy duty machine which can withstand the abuse of oversize material and tramp metal, usually without serious damage. One important disadvantage however, is its tendency to generate a large amount of fine coal (–147 micron or –100 mesh) by the grinding action of the hammers forcing the coal through the bar screen. This fine coal is undesirable in cokemaking as much of it is carried out of the ovens into the gas collector mains during charging, adversely affecting tar quality.

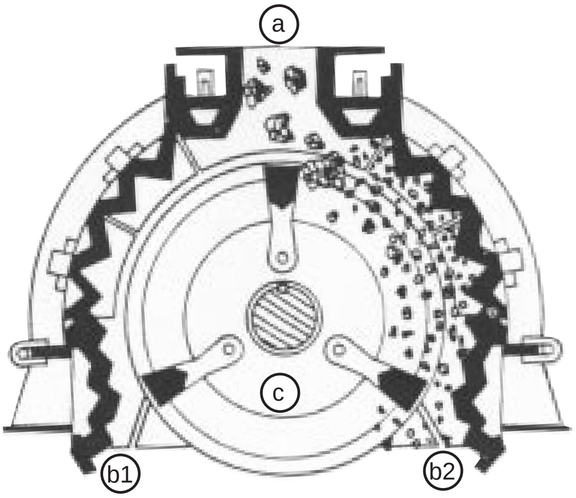


Fig. 7.17 Reversible impactor for pulverizing coal: (a) feed chute, (b) breaker plates, (c) rotor.

Impact mills are essentially hammer mills with the bar screen removed and fitted with special impact plates, Fig. 7.17. Coal enters the top of the machine where the coal particles are struck by the rapidly moving hammers and thrown against the impact plates which are located at various positions outside the path of the hammers. The impact shatters the coal particles, usually along natural cleavage lines. The degree of pulverization depends on the hammer speed, the number of hammers and impact plates, and the hammer-to-plate spacing. Impact mills are as rugged as hammer mills but have an added advantage of providing a high degree of pulverization with a lower level of fine coal generation. Because of this, impact mills are the most commonly used pulverizers in coke plants at this time.

The third type of pulverizer commonly used in coal pulverization is the cage mill, Fig. 7.18. In this machine, two cages, one inside the other, are rotated in opposite directions at speeds of up to 500 rpm. Coal enters the center of the machine, is struck by the impact plates of the inside cage and thrown into the plates of the outside cage, which is rotating in the opposite direction, and is discharged out of the machine. The degree of pulverization is controlled by the rotational speed and the spacing between the cages. The advantage of this machine is that it provides a high level of pulverization and good control of top size, with low levels of fine coal generation. The disadvantages are its susceptibility to damage by tramp metal and plugging by softer material such as wood and rags. Each cage mill installation must be protected by installing both magnets and metal alarms on the conveyors ahead of the pulverizers. With this protection, the cage mill is probably the best pulverizer for coal preparation in coke plants.

Constant monitoring of the performance of the crushers by screen analysis of the crushed-coal product is essential if consistently high quality coke is to be produced. When the pulverization level falls, immediate corrective action must be taken to assure a production of high quality coke.

7.2.2.7 Bulk Density Control

The last step in the process of preparing coal for coking is adjustment of the bulk density of the coal blend. If some form of control is not practiced, the bulk density of the coal blend charged to the ovens could easily vary as much as 64–80 kg/m^3 (4–5 lb/ft^3) over short periods of time (minutes) and even more over longer periods as weather conditions might affect moisture content of the coal. Additionally, without control, the average bulk density of the coal blend would usually be significantly lower than desired in most cases. This is particularly true considering the high coal pulverization levels now considered to be standard practice at all coke plants.

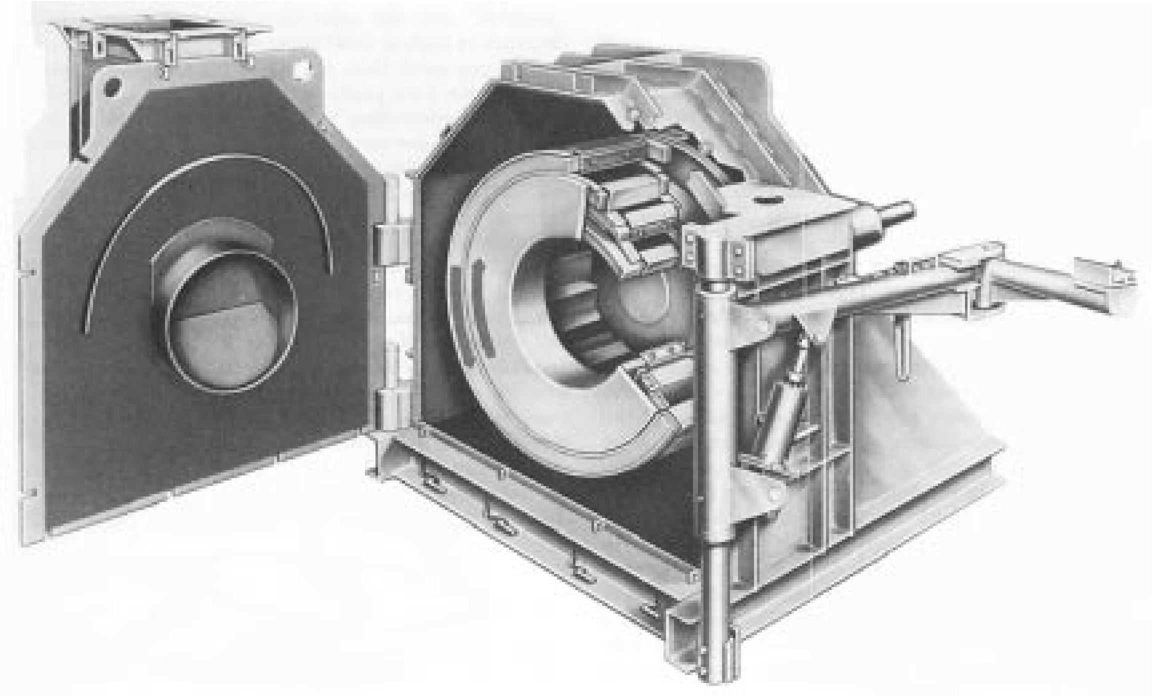


Fig. 7.18 Cut-away view of a cage mill for pulverizing coal.

A coke battery cannot be operated smoothly and efficiently without bulk density control. It would be impossible to heat the battery properly, coal level in the ovens would be variable, stickers and oven damage by high coking pressure and insufficient contraction could occur and coke strength would be variable.

Bulk density of the coal blends is affected by moisture content, as shown in Fig. 7.19. For example, coal with a bulk density of 700 kg/m^3 (43.7 lb/ft^3) containing 8% moisture actually contains only 644 kg of dry coal per cubic metre (40.3 lb/ft^3). Consequently, it is desirable to maintain a constant moisture content in the coal blend by adding water if necessary.

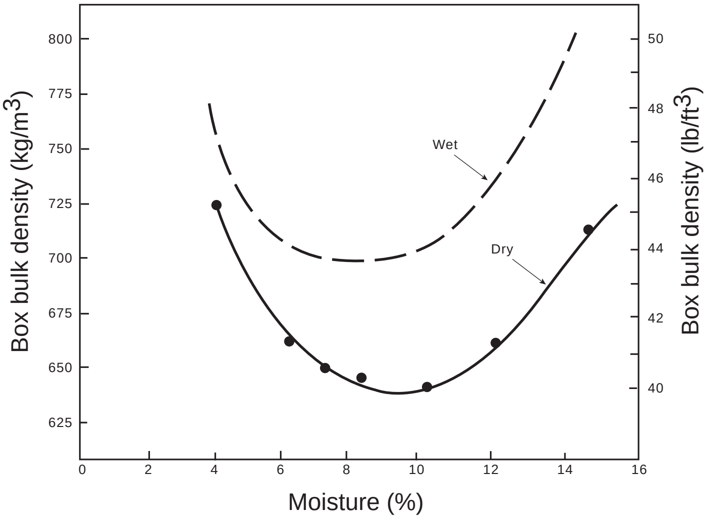


Fig. 7.19 Effect of moisture content on the bulk density of selected (Concord) coal.

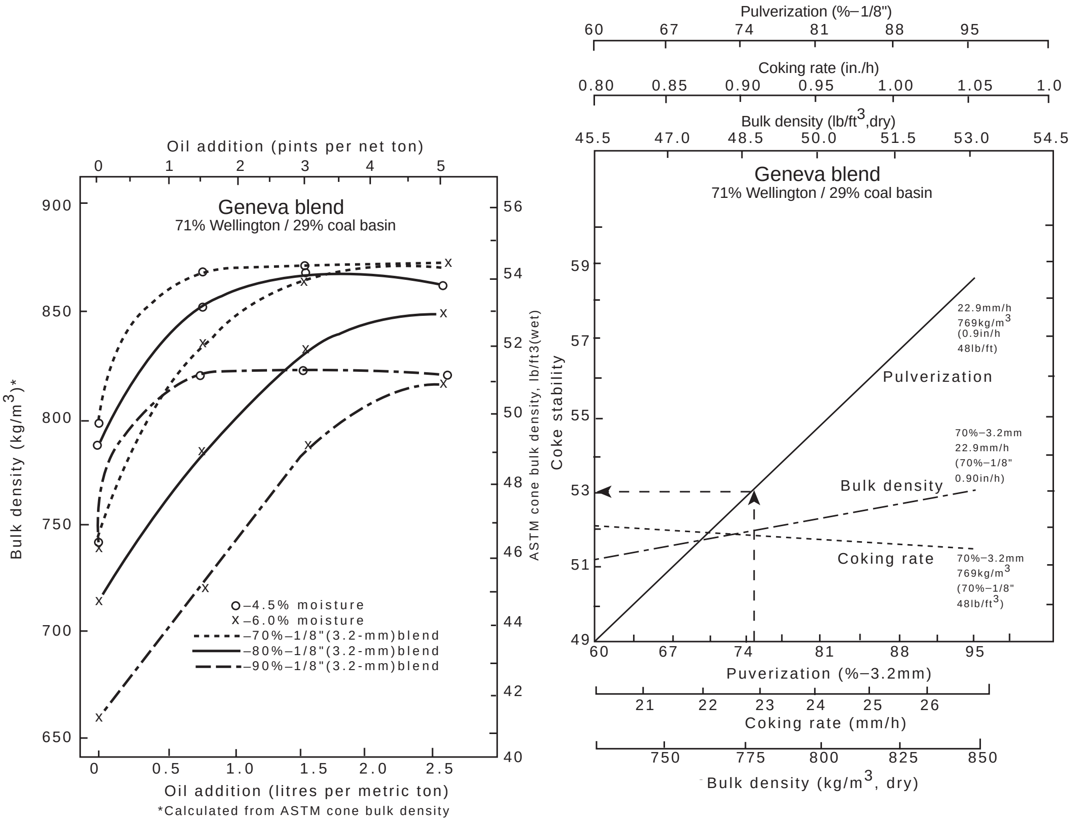
Most bulk density control systems are based on the use of No. 2 or diesel grade oil, or other similar oils, to increase bulk density of the coal blend. In a manual system, bulk density measurements are made regularly (usually every hour) by hand in an ASTM bulk density box, and the oil flow rate is adjusted manually as required to hold bulk density at the control point.

There are two systems for automatic control of bulk density; namely, mechanical weigh belts and gamma ray units. The bulk density of the coal as it leaves the pulverizer or coal mixer is measured continuously by either of these systems and the amount of oil needed to attain the control point is automatically adjusted. The oil is sprayed onto the coal stream just ahead of the pulverizers or mixers where it is distributed and mixed with the coal blend.

The gamma ray unit, when applied to measuring bulk density of coal, is a very complex system in which many factors influence the measurement. Some of the more important factors are: (1) the depth of the coal on the belt as it passes under the radioactive source; (2) changes in the radiation absorption coefficient of the coal; (3) dust or other material in the signal path; (4) temperature of the detector; (5) thickness and tension of the conveyor belt; and (6) size consistency, moisture content and temperature of the coal. The advantages of the gamma ray system are that it is less expensive than the weigh belt system and is less expensive to operate and maintain. Both systems, properly maintained, can perform with an accuracy of at least ±16 kg/m^3 (1 lb/ft^3).

Fig. 7.20(a) shows the effect of oil addition on coal bulk density for a typical coal blend and Fig. 7.20(b) shows the changes in coke stability which result from changes in coal pulverization, bulk density and coking rate for the same coal blend.

The use of oil is not the only means available to increase and/or control coal blend bulk density. In Japan, many coke plants add water to the coal in the stockpiles as it is being conveyed into the plant to control moisture content to about 9%. This is done primarily to control dust, but the operators also aim for uniform moisture content. This uniform moisture content, in combination with a uniform coal blend pulverization level, results in a uniform bulk density for the coal blend. In most cases, the bulk density is quite low, averaging only about 688 kg/m^3 (43 lb/ft^3). Some Japanese plants briquette about one-third of their coal blend; this increases bulk densities and also improves coke quality (see Section 7.5). In the Saar region of West Germany, a process called stamp charging is employed to increase the bulk density of the fine, high moisture coals used in that area. In



(a)

(b)

Fig. 7.20 (a) Bulk density response to oil additions for a coal blend; (b) changes in coke stability resulting from changes in coal pulverization, bulk density and coking rate.

this latter process, a large compacting device located on the pusher side of the battery is used to compress the coal blend into a rectangular mass slightly smaller in size than the coking chamber of an oven. This stamped charge is then inserted into the oven from the pusher side. Bulk densities as high as 1040 kg/m^3 (65 lb/ft^3) are not uncommon when using this practice. Coal preheating can also be considered as a means of controlling bulk density because the moisture content (0%) and the pulverization level are controlled.

7.2.2.8 Coal Mixing

The use of the pulverizer for mixing blended coals can be considered adequate provided the coals are layered properly on the conveyor feeding the pulverizer. However, hammer-type pulverizers provide little or no mixing from side to side; so, if one of the coals is loaded into one side of the conveyor, it will come out of the pulverizer in the same location and will not be mixed with the rest of the coals. If this situation exists because of the arrangement of the coal conveyors and weigh feeders, it can be partially corrected by the use of belt plows or belt mixers.

Some plants install continuous mechanical mixers after the pulverizers and prior to conveying the coal to the coal bunker to ensure thorough mixing of the blended coals. There are numerous types of solid-solid continuous mixers such as ribbon, paddle and zigzag blenders. The choice of mixers for a specific installation is a function of many variables such as throughput, coal size and moisture content, retention time required, space availability, cost and so on, and the choice is usually made after an engineering evaluation.

7.3 Metallurgical Coke Production Processes

7.3.1 The Beehive Process for Carbonizing Coal

Until 1918, most of the coke produced in the United States was made in beehive coke ovens. Beehive ovens usually were located close to coal mines so that freshly mined coal could be charged directly into the ovens; no provision was made for stocking or mixing coal at the oven site. The beehive process has virtually been phased out of production in the United States. Lack of coals suitable for the process and more stringent rules regarding air pollution were the major factors causing the decline of the process. Refer to Section 7.8 for a thorough discussion of modern non-recovery oven technologies.

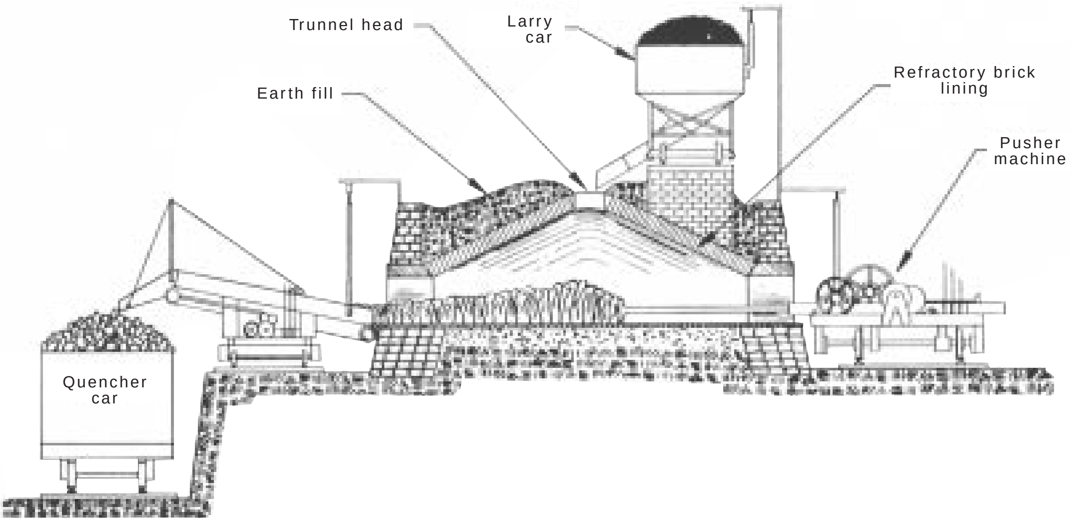


Fig. 7.21 Ideal section of a beehive coke oven in a single block battery, showing refractory lining, earth fill, larry car, pusher, quencher car and other details, including the trunnel head at the top through which the coal was charged and the volatile products escaped. Vertical lines in the coke bed indicate the fissures that developed during coking, giving beehive coke its characteristic columnar structure.

A beehive coke oven was a circular, domed firebrick structure with a flat floor that sloped toward the door through which coke was removed when the coking process was completed. An opening called the trunnel head in the center of the domed roof permitted coal to be charged into the oven and allowed the gases generated during the coking process (called foul gas) to escape into the atmosphere. A typical oven was about 3.7 m (12 ft) in diameter and processed about 4.5–6.3 tonnes (5–7 tons) of coal per charge. From 48 to 72 hours were required to complete a coking cycle.

Beehive coke oven plants were constructed according to three general arrangements: (1) the bank system, in which the ovens were built in a single row against a bank of earth, natural or artificial, with a retaining wall in front of the ovens; (2) the single block system, which consisted of a single row of ovens, all facing the same way, with retaining walls at both the front and back of the row, Fig. 7.21; and (3) the double block system, in which the ovens, in a double row, were built back to back or staggered with a retaining wall extending along the front of each row. In all cases, the space above the ovens between the bank and the retaining wall or between the two retaining walls was filled with earth. Tracks were laid on top of the rows to carry larry cars from which coal could be charged directly into the ovens; other tracks at yard level in front of the ovens carried cars which received the coke as it was removed from the ovens.

7.3.1.1 Charging

Beehive ovens were charged as soon as practicable after drawing the coke from the oven at the end of the previous cycle, in order that stored heat from the previous charge would be sufficient to start the coking process. New ovens had to be heated gradually to the coking temperature by wood and coal fires, after which small charges of coal were coked until the ovens reached normal working conditions. With the oven in readiness for charging, the door was partially bricked up and the coal charge was dropped through the trunnel head from the larry car above, leaving the coal in a cone-shaped pile in the oven. In order to secure uniform coking of the coal, this pile had to be leveled so that the coal would lie in a bed of uniform depth of about 46–610 mm (18–24 in.) over the entire floor of the oven. This leveling was done by machine or by hand. In works not equipped with a machine, the leveling was accomplished with a long-handled scraper, operated through the door of the oven, which was purposely bricked up to only two-thirds of its height at the time of charging. After leveling the coal, the door opening was bricked up to within about 38 mm (1.5 in.) from the top.

7.3.1.2 Coking Process

The coking process began very soon after leveling was completed, as the oven retained enough heat in the brick of the walls and the earth fill to start liberation of volatile matter from the coal. As the temperature of the coal charge increased, the temperature of the combustible volatile gases soon reached the kindling (ignition) point and, in presence of the air admitted to the oven, they ignited with a slight explosion at first and then continued to burn quietly in the crown of the oven or as small candle-like flames at the surface of the coking mass, thus supplying heat to continue the process. Coking proceeded from the top of the coal downward, so that the coking time depended upon the depth of the coal. The generation of gas from the coal rapidly approached a maximum which was maintained for a period and then declined to practically nothing. The burning of the volatile matter during this period was regulated by gradually closing up the opening at the top of the door for the admission of air. This regulation was necessary to maintain the temperature at a maximum and conserve coke, as an excess of air at the beginning of the coking period tended to cool the oven and later consumed some of the carbon of the coke. The yield was also reduced by improper leveling. If the coal was not of uniform depth, the thin portions coked through before the thick, and some of the thin sections was consumed while the coking of the thick sections was being completed. On the other hand, if the process was stopped when the thin areas had coked through, there was a loss due to uncoked butts on the thick areas. Coking proceeded downward from the top of the charge, in which the coal at increasing depths passed through a plastic stage as the temperature rose. This produced expansion and contraction of the charge with the result that the coke was ramified by a great number of irregular vertical fissures that divided the coke mass into very irregular columnar pieces that extended from the top to the bottom of the mass.

7.3.1.3 Watering and Drawing

At the end of the coking period, the brickwork closing the door was torn out and the coke was watered out by spraying with a stream of water directed through the door of the oven or, in later ovens, by the use of a spraying device inserted through the door. After watering, the coke was removed from the oven by hand or by machine. Fig. 7.21 shows the use of a pusher to remove the coke.

7.3.2 The Byproduct Process for Carbonizing Coal

7.3.2.1 Introduction

Byproduct coke ovens are those designed and operated to permit collection of the volatile material evolved from coal during the coking process, as opposed to beehive and other types of ovens that allow the volatile products to escape. An overall view of a byproduct coke oven battery is shown in Fig. 7.22. A variety of valuable substances are recovered from the volatile material by suitable chemical processes, as discussed in Section 7.7 of this chapter.

Because of the physical dimensions of the coking chamber of byproduct ovens (narrow, long and tall) they sometimes are referred to as slot ovens. They are called recovery type ovens also, because their design permits recovery of the volatile products of the coking operation.

In this section, reference is made to furnace plants and merchant plants for byproducts cokemaking. Furnace plants generally are owned by or affiliated with iron and steelmaking companies and produce coke mainly for use in the blast furnaces of the companies. Merchant plants include those that manufacture metallurgical and industrial grades of coke for sale on the open market; those associated with chemical companies or gas utilities; and those that supply only a small part of their output to blast furnaces of local iron works with which they are affiliated.

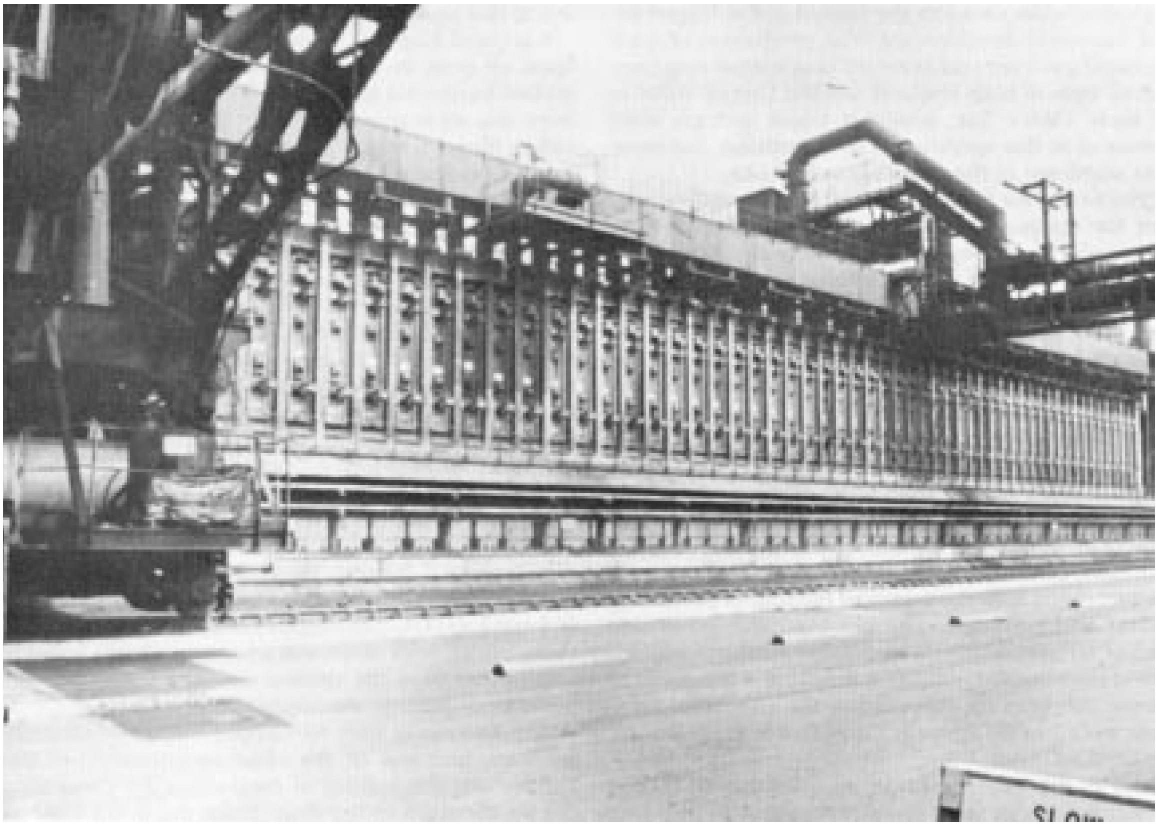


Fig. 7.22 Overall view of the pusher side of a typical byproduct coke oven battery.

7.3.2.2 Foundry Coke Production

While the discussion in this section will be primarily about plants producing blast furnace coke, it would not be complete without some reference to facilities and procedures for making foundry coke.

In 1997, there were six merchant coke producers in the United States that make foundry coke for melting iron in ironmaking cupolas. Seven operating coke plants involving 17 coke oven batteries were available for this service. Annual capacity for producing foundry coke from these batteries was estimated to be 1.8 million tonnes (2.0 million tons).

Annual consumption of foundry grade coke has been in the 1.4 million metric ton (1.5 million net ton) range. A consensus exists that annual foundry coke requirements will average between 1.3 and 1.5 tonnes (1.4 and 1.7 million tons) during the next five years.

The production of coke for use in foundry cupolas generally involves the use of a blend of six to eight coking coals in which the volatile content of the blend is in the range of 20–24%. Coke temperatures are significantly lower than in the production of blast furnace coke and seldom exceed 1150°C (2101°F) in the heating flues. Normal coking cycles are longer than in blast furnace coke production, usually in the 28 to 30 hour ranges. However, it is not uncommon to exceed 32 hours as a maximum and 26 hours as a minimum coking time.

Coke size requirements for use in cupolas are a function of the cupola diameter, and a rule-of-thumb generally gives a 10:1 ration of cupola diameter to normal coke size. Nominal sizes for foundry coke shipments are: (1) 228 mm (9 in.) top size to 152 mm (6 in.) bottom size; (2) 152 mm (6 in.) top size by 101-mm (4-in.) bottom size; and (3) 228 mm (9 in.) top size by 101 mm (4 in.) bottom size, which is most frequently shipped.

Proximate analysis of foundry coke normally shows less than 0.7% volatile matter, less than 0.65% sulfur, less that 7.0% ash, less than 1% moisture and a fixed carbon content of 92% or better.

Most foundry coke is shipped via trucks; however, a significant amount is shipped in railroad hopper cars. Just in time delivery resulting in less than one day delivery and the possibility of maintaining minimum coke inventories at the foundries is common.

7.3.2.3 Evolution of Byproduct Ovens for Carbonizing Coal

7.3.2.3.1 Early Developments Construction and operation of byproduct coke ovens in the United States lagged behind European development. The production of manufactured gas from coal in retorts was started on a commercial basis in both England and the United States in the early 1800s. Tar, ammonia liquor and gas were recovered in this operation. These ventures, however, were unrelated to the manufacture of coke.

Prior to and for fully 50 years after industrial installations for making manufactured gas, repeated efforts were made to develop a single facility that could produce coke similar in quality to that made in beehive ovens and also provide for recovery of products such as those obtained in gas producing retorts. Attention was being directed similarly during this period to the design of an oven that utilized a principle of coking different from those currently practiced. The se developments were confined largely to Europe because of the inadequacy of the methods then used in producing coke of suitable quality from some of the more weakly coking coals known at the time to exist in various foreign countries but not in the United States.

In 1856, in Commentry, France, Knab built a group of retort ovens with the principal purpose of producing gas, tar and ammonia. The gas from the ovens was freed of tar and ammonia in suitable chemical apparatus and then burned in heating flues under the ovens to provide the heat for carbonizing the coal. The Knab ovens were 7 m (23 ft) long; 2 m (6 ft, 6¾ in.) high; and 1 m (39.5 in.) wide.

Prior to this time, however, an oven that embodied vertical flues in its walls was developed in France and used both in that country and in the Ruhr district of Germany for producing coke. The purpose of that design was to exclude air from the coking chamber to the greatest degree possible during the carbonization of coal. The volatile gases were drawn by stack draft through orifices in the top of the coking chamber into vertical flues in the oven walls. Gas from the ovens and air were mixed and burned in a downward direction in these flues and passed to the stack through sole flues under the oven. Known as the Francois oven when built in France and as the Rexroth oven when used in Germany (hence the combination name, Francois-Rexroth), this so-called waste heat oven was 8 m (26 ft) long, 1.5 m (5 ft) high, and 0.9 m (35 in.) wide.

In the earliest development of the industry, therefore, various facilities were developed for different purposes. From the standpoint that the Francois-Rexroth oven was a rectangular, vertical coking chamber, which embodied vertical heating flues, it could lay claim to the distinction of being the forerunner of the modern coking oven, notwithstanding the fact that it was not of the recovery type and that it was designed primarily to overcome some of the objections to the then prevailing coking method. The Knab oven similarly could be placed in the category of a pioneer among recovery type ovens, despite its shortcomings in heating facilities. Both the Francois-Rexroth and the Knab ovens were departures from the then contemporary practice in that air was excluded from the coking chamber and external heat was supplied for carbonization.

7.3.2.3.2 Development of Vertical Flue Ovens The course that was pursued later in improving oven performance led to two separate and distinct developments.

Carves of England, using the Knab principle, developed an oven in 1862 (Knab-Carves design) that embodied horizontal heating flues in the oven walls. This oven was an improvement over the Knab design, providing for greater yield of coke and requiring less time for carbonization. The principal contribution by Carves, however, was the addition of an exhauster in the chemical recovery apparatus. In the Carves oven system, gas was drawn from the oven by the exhauster, pumped through the chemical recovery apparatus, and returned to the ovens for use as fuel, the present method of recovering coal chemicals being based on this same principle. Because of the inclusion of horizontal flues in the oven walls, the Carves system can claim the distinction of being the originator of the horizontal flue system of oven heating.

Almost simultaneously with the Carves development, Coppee in Belgium, using the basic principles of the Francois-Rexroth oven, introduced the innovation of reducing the width of the oven and providing additional vertical heating flues in the oven walls. The ovens built by Coppee at that time were about 9 m (30 ft) long; 1 m (3 ft, 7 in.) high; and 0.5 m (18 in.) wide. In these ovens, stack draft was used to draw the gases of combustion from the vertical downdraft flues through waste heat boilers, recovering the sensible heat as steam. The ovens built by Coppee embodied 28 vertical flues, and one of the chief contributions of this builder was the control of combustion by dampering the air admitted to the flues. Since the ovens built by Coppee conformed more nearly to present day conventional width ovens and also contained a substantial number of vertical flues in the oven walls, this oven may, in some respects, be considered the true predecessor of the modern coke oven.

Up to that time, all these developments took place in Europe, although ovens of the Coppee or Belgian design were built and operated in the United States. The installations were made at both the Johnstown plant of the Cambria Iron Company and the Holidaysburg plant of the Blair Iron and Coal Company, both in Pennsylvania.

Ovens of the Coppee design were built in the Ruhr district of Germany by Dr. C. Otto and Company, who added further refinements to the earlier Francois-Coppee design. Attempts at converting these ovens from the so-called waste heat type to the recovery type byproduct ovens have been credited to this builder. In the ovens of Otto design, the volatile products from the coal were removed from an opening in the top of the oven and the gas, after passing through the chemical recovery apparatus, was returned to the flues in the walls of the ovens. The flow of combustion gases in this oven was different from that of the early Coppee design, with products of combustion rising and descending in alternate flues, thus forming the basis for the later ovens of hairpin flue design.

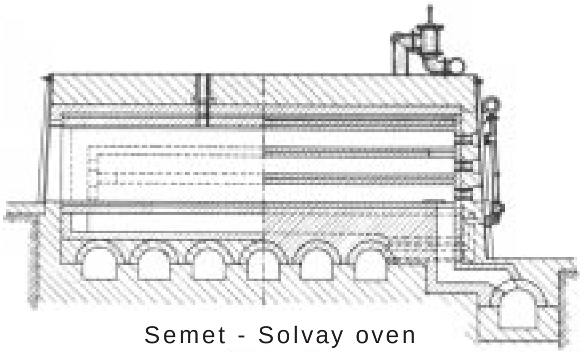
Heating of these ovens was rather crude and inefficient. Nevertheless, this early Otto-Coppee development is significant because it was the first vertical flue oven of the recovery type built with flues completely surrounding the oven chamber.

7.3.2.3.3 Horizontal Flue Ovens Evolution of the horizontal flue oven was also proceeding, but improvements were largely in the direction of byproduct recovery rather than in coke oven design. The basic design of the Carves-Knab oven was improved later by Heussner in Germany and Simon in England. Heussner, in 1881, developed the Heussner-Carves oven along more conventional lines by reducing the width and improving the heating system, making available a small quantity of surplus gas. Following this development, recovery type ovens were established more firmly in Germany.

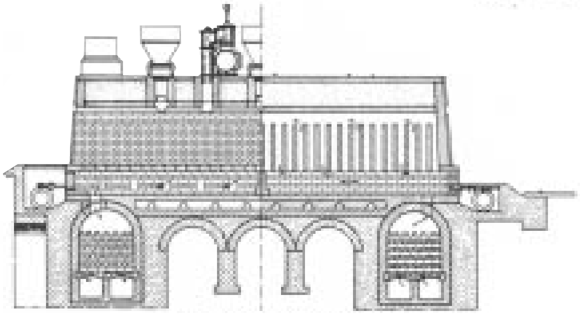
Simon, in England, also revised the Carves oven design and, in 1883, erected a plant in Durham, England embodying recuperators for the transfer of heat from waste gases to incoming air. A reduction of coking time to 48 hours was the principal contribution of this Simon-Carves oven.

In 1885, Louis Semet, chief engineer of the Brussels Gas Works, and his brother-in-law, Ernest Solvay, built 25 ovens sized at four tons each near Mons, Belgium. The Semet-Solvay design, Fig. 7.23, was based on the Carves principle of horizontal flues. Solvay's interest involved supplying the lime kilns with coke and the soda process with ammonia. It is of interest to recall that the ovens of horizontal flue design did not embody regenerators, such facilities being included sometime later.

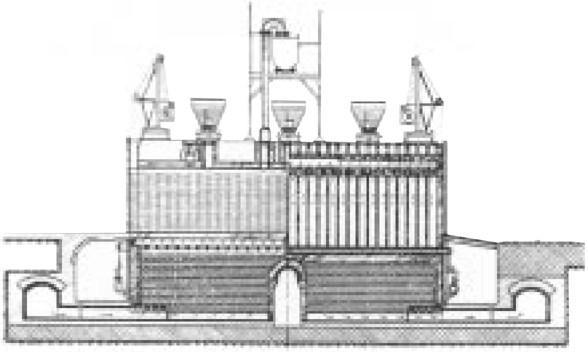
The Rothberg oven, a half-divided horizontal flue oven, was developed in 1902; the first of these ovens in the United States began operation in 1903.



Semet - Solvay oven



Otto - Hoffman oven



Koppers original cross - regenerative oven

Fig. 7.23 Early designs of recovery type coke ovens, not to same scale.

7.3.2.3.4 Improvements in Heating Facilities Despite the fact that ovens of Coppee, Knab, Carves, Heussner, Semet-Solvay, Otto and others represented appreciable progress compared with the simple beehive system such facilities were lacking in heat economy. Temperatures in the ovens were not high enough to produce an acceptable metallurgical coke, notwithstanding return to the oven for heating purposes of all or nearly all of the volatile gases from the coal. These ovens left much to be desired in uniformity of temperature. Their coke product did not compare favorably in quality with that produced in beehive ovens. As a result of inferior quality and lack of uniformity of the produced coke, the use of recovery type byproducts ovens for producing metallurgical coke was viewed with skepticism, until further improvements were made in both design and operation.

The criticism leveled against this system of coking resulted in greater efforts to improve the facilities. In the ovens of vertical flue design, attention was directed to the improvement of the heating system. Following the invention of the Siemens regenerator for preheating combustion air used in steelmaking furnaces, a patent embodying the use of this principle on coke ovens was obtained by

Gustave Hoffmann in Germany. This application brought about far-reaching improvements in byproduct ovens.

The Otto firm purchased the patents from Hoffmann and in 1883 added these facilities to the Otto-Coppee oven. This type, known as the Otto-Hoffman oven, Fig. 7.23, was equipped with regenerators, parallel to the length of the battery, for preheating both combustion air and fuel gas. The deposit of carbon from the cracking of preheated coke oven gas in the regenerators soon dictated abandonment of fuel preheating. Other structural and operational disadvantages required an early revision of the basic Otto-Hoffmann design but the basic principles of the oven were of unquestionable value as witnessed by their widespread use in later years.

In order to provide further regularity of temperature and to increase the capacity of recovery type ovens, G. Hilgenstock in 1895, using the Otto-Hoffman design as a base, fundamentally altered the oven originally built by Otto. The changes made by Hilgenstock consisted of providing gas inlets to the combustion flues beneath the oven bases. Air for combustion was added through small flues provided in the side of the brick work. The upper terminus of the gas ducts was in the base of the vertical flues at the approximate level of the oven floor. The use of the under-oven principle for controlling admission of fuel gas eliminated the gas flues, which in previous designs were a source of difficulty. This was a marked advance, although the underjet principle of fuel-gas control was not exploited until much later.

To obviate some of the criticism of the fairly excessive initial investment cost of the recovery type oven, which in some respects resulted from the inclusion of regenerators, this feature was eliminated from the Otto-Hilgenstock design. This phase in the evolution of the recovery type oven is significant because it provides a clue to the rather slow adoption of this procedure by the iron and steel industry. From an economic standpoint, the beehive oven was cheap to build, could be operated with a minimum of help, and was capable of being shut down or restarted with little or no difficulty. The recovery type oven, however, was costly to build and difficult as well as expensive to operate, because of the size of the units and the need for skilled personnel. Consequently, the incentives for building recovery type ovens were lacking in the steel industry until the economic advantages of the ability of the integrated steel plant to use the excess gas had been clearly established. The industry then began widespread adoption of this process.

Later installation of the Otto-Hilgenstock oven (also variously known as the United-Otto or Schniewind oven) was equipped with regenerators. A still further modification of this oven included Cowper regenerative stoves, where special requirements indicated their use.

Until the end of the 19th century, all the ovens equipped with regenerators were built with these facilities parallel to the length of the battery. The operational difficulties in regulation and control of air to the individual vertical heating flues presented many problems. An oven design by Heinrich Koppers (1904) was developed to overcome such difficulties. In the Koppers design, Fig. 7.23, the regenerators were placed directly underneath the heating flues and parallel with the length of the oven; called cross regenerators, this type of regenerator became standard in the coke oven industry following the expiration of the Koppers patent in 1918. The first oven of this type was built by the Illinois Steel Company at Joliet, Illinois and the first coke was pushed in September, 1908. The plant consisted of four batteries of 70 ovens each with coal chemical recovery facilities.

Although silica brick as a coke oven refractory was first used in this country by the Cambria Steel Company at Johnstown, Pennsylvania in the 1890s, a controversy existed between European and American designers as to its use for coke oven wall construction. In order to obtain an answer to this problem, the various batteries at Joliet were constructed of different kinds of brick; No. 1 battery was constructed of silica brick and No. 2 battery was built of St. Louis quartzite, the raw material for which was composed mostly of Missouri clays. Quartzite brick imported from Germany was used in erecting Nos. 3 and 4 batteries. Results demonstrated the superiority of the silica brick and its use eventually became general.

Aside from the various constructional features, an innovation provided by Koppers was the inclusion of the gas fun flue, by which gas was fed to the base of each vertical flue through a ceramic flue and nozzles. The nozzles were removable and made with orifices of various sizes. This permitted control of the volume of gas to individual flues and provided for the replacement of nozzles when required.

The next significant development in byproduct coke ovens was the erection of Koppers ovens for the Coal Products Company at Joliet in 1912. These ovens were arranged with combination cross regenerators to provide for simultaneous preheating of air and producer gas for coke oven underfiring. By this procedure an additional amount of the richer coke oven gas was released for sale. This type was the predecessor of the combination oven, so-called because the regenerators are arranged to preheat both air and fuel gas in separate chambers.

Difficulties were experienced with the single horizontal flue (bus flue) above the vertical heating flues through which the products of combustion passed from the heating flues to the downflow flues of the early cross regenerative ovens because it had to be quite large to handle the volume of combustion gases generated.

This condition was aggravated as ovens of greater capacity were built and increasing use was made of lean fuels such as blast furnace gas and producer gas. This problem was solved in various ways by different designers during the 1920s.

One solution to the horizontal bus flue problem was the Koppers-Becker design which incorporated an entirely new system of heating, as shown later in Fig. 7.58. In these ovens, first installed as an experimental battery in Chicago in 1922, gas is burned in all of the flues on one wall of an oven at the same time. The products of combustion from groups of two or more adjacent vertical flues of the wall in which fuel gas is burning enter short horizontal bus flues and are then conducted over the top of the oven coking chamber through crossover flues to a companion series of bus flues, whereby the vertical flues of the entire opposite wall are simultaneously conducting waste gases to the regenerator. On reversal of this process, the opposite conditions are obtained.

Another solution to the horizontal flue problem is exemplified by the Wilputte double-divided oven, see Fig. 7.58. The size of the flue is limited in these ovens by dividing it at the center of the oven. Each half of the flue then serves an inner an outer zone of the heating system. Gas is burned alternately in the two outer zones with the products of combustion being carried by the horizontal flues to the two inner zones and then to the regenerators. On reversal, gas is burned in the two inner zones and the products of combustion pass to the regenerators through the two outer zones; in effect, these designs constitute two short cross regenerative ovens placed end to end.

Various improvements in the design of regenerative systems were made by different builders, and the systems employed in some modern byproduct ovens are discussed extensively in Section 7.6 of this chapter.

As vertical flue ovens of greater height came into use, the uniform heating of the flues in the high walls from top to bottom became a problem, especially when heating with rich gas that has a characteristically short flame. Some of the solutions for this problem included: (1) dilution of fuel gas with waste gases to produce a longer flame (Koppers); (2) introducing combustion air in successive vertical stages along the height of the heating flue (Carl Still); and (3) using high and low burners in alternate heating flues (Wilputte). Application of these and other combustion control principles to some modern byproduct coke ovens also is discussed Section 7.4 of this chapter.

7.3.2.3.5 The Byproduct Oven in the United States Although reasonable success had been achieved abroad with the byproduct oven, it was not used in the United States prior to 1890. It is pertinent to recall that the first ovens of the byproduct type installed in the United States were not for production of metallurgical coke. The distinction for launching the industry must be accredited to the Solvay Process Company, which was interested in establishing the soda ash industry in this country. The plant that was built in Syracuse, New York and placed in operation in 1893 consisted of 12 Semet-Solvay ovens.

It was not until two years later that recovery type (byproduct) ovens were installed in the United States for producing blast furnace coke. In 1895, the Cambria Steel Company at Johnstown, Pennsylvania built a battery of 60 Otto-Hoffman ovens.

Until 1900, only nine plants with 1081 byproduct ovens had been constructed in the United States. From 1900 through 1910, however, there was a period of rapid industrial expansion, particularly in the iron and steel industries, and the number of byproduct coke plants more than tripled while the number of byproduct ovens increased four-fold.

The need for coal tar dyes and explosives in World War I added impetus to this expansion, and by 1918 the byproduct coke industry had 59 plants with over 9000 ovens.

The construction of byproduct ovens for gas utilities in the 1920s further expanded the industry and, by 1930, there were 89 plants with 12,771 ovens in existence.

Due to a worldwide economic depression, construction of byproduct ovens was halted during the 1930s and by 1940 there were fewer ovens in existence than during the 1930s. However, World War II started a new construction era and between 1940 and 1950, 2359 ovens were added to the industry total for ovens. The increase in total ovens, however, only partially indicates the vast construction program of this period because many of the ovens constructed were replacements or rebuilds of ovens originally built during World War I. Actually, over 5000 ovens were constructed during this period.

The construction of byproduct ovens continued after 1950, and in 1958 the number of ovens reached an all-time peak of 16,244. Although ovens increased in number because of the expansion of blast furnace plants, the number of byproduct coke plants in existence decreased to 77 during this period, because seven gas utility plants were abandoned as markets for coke oven gas were lost to natural gas which became available in many areas through the extension of gas pipelines after World War II.

Since 1960, the total number of byproduct coke ovens in the United States started to decline, due to a steady reduction in steelmaking output, environmental controls, more efficient coke-to-hot metal rations achieved in blast furnaces, and ovens with larger capacity coking chambers. By early 1998 the total number of slot type ovens in the United States had declined to 3,409 from 6,350 in 1983. Correspondingly, coke capacity has dropped from 32 to 20 million tonnes annually over the same period of time.

7.4 General Design and Operating Principles of Modern Byproduct Ovens

7.4.1 Principal Oven Components

The byproduct coking process, being a true distillation process, involves the use of retort ovens. While there are many modifications, these ovens consist essentially of three main parts, namely: the coking chambers, the heating flues and the regenerative chambers—all constructed of refractory brick. The following discussion of components applies generally to all types of ovens, but is related principally to those used in the United States.

Ovens are constructed in batteries that have contained from as few as ten to over 100 ovens. In the United States, large batteries of 45 or more ovens generally have been preferred, while batteries of fewer ovens have been more common elsewhere.

Coking chambers in a battery alternate with heating chambers so that, in effect, there is a heating chamber on each side of a coking chamber. The regenerative chambers are underneath the heating and coking chambers. Separating walls between regenerators also serve as foundation walls for the heating and coking chambers. The entire structure is supported either from the ground or by columns under a reinforced concrete or structural steel base.

The coal is charged through openings in the top of the oven and, after the coal has become coke, the coke is pushed out from one end by a power driven ram, or pusher, Fig. 7.24. During the coking period, the ends of the coking chamber are closed by refractory lined doors, which are constructed to completely seal the ends of the ovens. The ovens first constructed in the industry provided a space between the door and the jamb which was filled with a special luting mixture to seal the oven prior to charging. Later, several types of self-sealing doors were developed, which seal the opening when put in place and require no luting; several of these are described later in this section.

To permit the escape of volatile matter driven from the coal during coking, an opening is provided at the top of the oven at either one or both ends of the coking chamber. Each such opening is fitted with an offtake pipe, which connects the oven with the gas collecting main for the battery.

The combustion chambers consist of a large number of flues which permit uniform heating of the entire length of the coking chamber. Ovens have been built with either horizontal heating flues or vertical heating flues, but vertical flues are used almost exclusively in present installations. Some of the older ovens employed the recuperative principle for preheating combustion air. Modern practice utilizes the regenerative principle to achieve higher thermal efficiency whereby less gas is required to heat the ovens. In all modern oven batteries, individual regenerators are provided for each heating wall and are located under each oven. This permits separate control of the flow of preheated air for combustion to individual vertical heating flue walls and allows close control of heating. An advantage of individual regenerators is that the control of heating for each oven is relatively independent of the operation of the remainder of the battery.

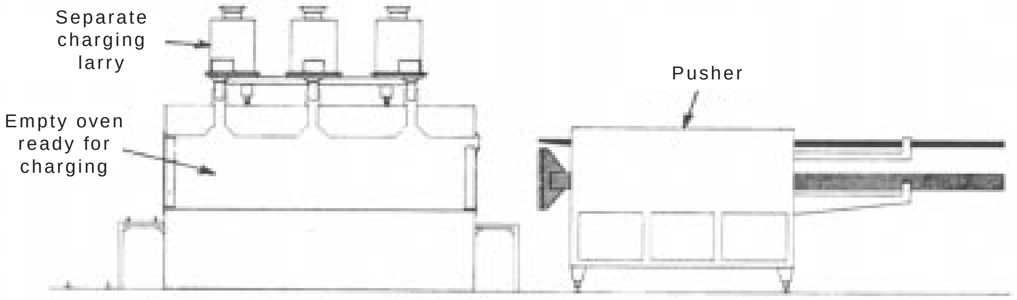
7.4.1.1 Coking Chamber Design

The dimensions of the coking chamber are usually a compromise of many interrelated variables that will best suit the expected production requirements while making the best quality of coke within practical limits. Past experience with coals of similar properties is the best guide, as there is no well-defined theoretical method of arriving at definite oven dimensions for specific coals.

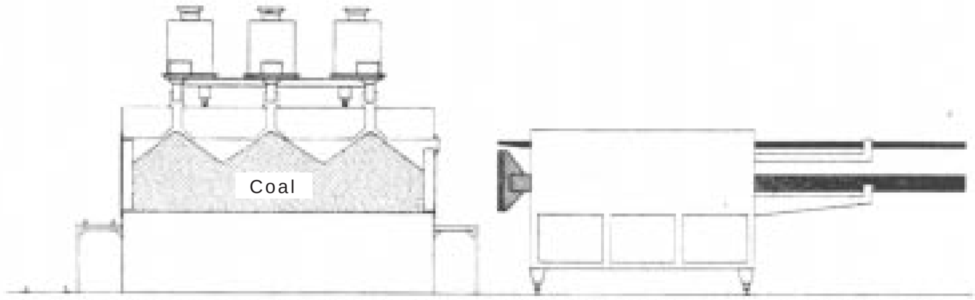
In general, the dimension of coking chambers built in North America have ranged from 1.82 m (6 ft) to 6.7 m (22 ft) in height, 9.14 m (30 ft) to nearly 15.5 m (52 ft) in length, and 304 mm (12 in.) to 550 mm (22 in.) in average width. Some recent ovens have coking chambers 15.25 m (50 ft) in length and 6.5 m (21 ft) in height. Generally, the preferred width of coking chambers in this country has been 460–488 mm (18–19 in.) average because: (1) coking chambers of these widths normally produce coke of a size similar to that desired by blast furnace operators, and (2) the time required to coke coal in chambers in this width range is acceptable. Narrower chambers (e.g., 356 mm or 14 in. wide) permit a more rapid rate of coking and are used to produce an acceptable blast furnace coke from western United States coals that make poor blast furnace coke when processed in wider chambers. However, the lower productivity of the narrower width ovens precludes their use except where some such special conditions exist. The latest development is coke ovens with wide chambers of 600 to 620 mm (23–24 in.), 18 m (59 ft) length and 7.8 m (25 ft) height. Several such large coke oven plants have been built and are operating successfully in Germany. The main advantages of the larger ovens are higher productivity and reduced emissions per ton of coke produced.

The coal is charged into the coking chamber through charging holes provided in the roof of the oven. The coking chamber and the heating system are designed to process a coal charge of definite volume, having a level top surface about one foot below the oven roof. The number of charging holes and the flow characteristics of the coal control the time required to charge an oven with coal.

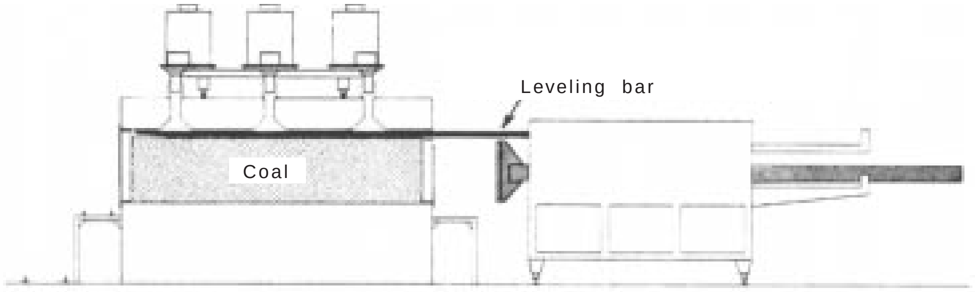
To prevent escape of gases from the oven during charging in most plants, a steam jet or high pressure flushing liquor aspirator is used to draw gases from the space above the charged coal into the collecting main; this practice is called charging on the main. Because this puts the oven under a slight negative pressure, air is drawn into the oven through the charging holes and leveler door. It is impossible to prevent the introduction of some air into the gas recovery equipment; this is one



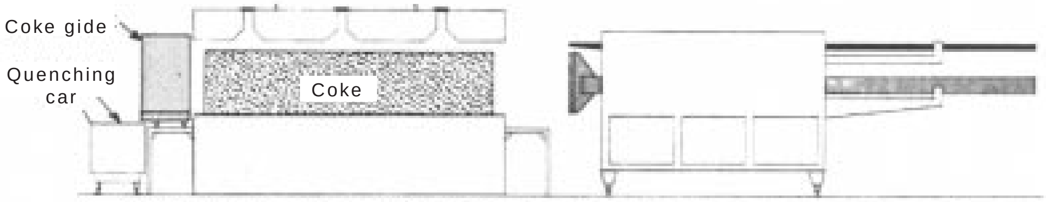
(a) The charging larry, with hoppers containing measured amounts of coal, is in position over charging holes from which covers have been removed. The pusher has been moved into position.



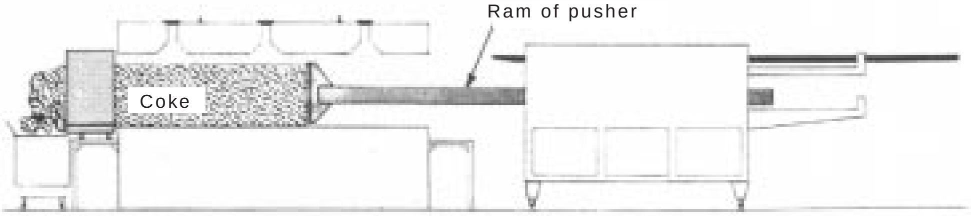
(b) The coal from the larry hoppers has dropped into the oven chamber, forming peaked piles.



(c) The leveling door at the top of the oven door on the pusher side has been opened, and the leveling bar on the pusher has been moved back and forth across the peaked coal piles to level them. The bar next is withdrawn from the oven, the leveling door and charging holes are closed, and the coking operation begins.



(d) Coking of the coal originally charged into the oven has been completed (in about 18 hours) and the oven is ready to be "pushed." The oven doors are removed from each end, and the pusher, coke guide and quenching car are moved into position.



(e) The ram of the pusher advances to push the incandescent coke out of the oven, Through the coke guide and into the quenching car.

Fig. 7.24 Schematic presentation of the sequence of operations involved in charging, leveling and pushing in one coking cycle of a byproduct coke oven.

of the reasons for keeping the time required for charging to a minimum. Excessive leveling of the charged coal not only extends the time during which the leveler door is opened, but also tends to pack the coal at the top of the charge, particularly under the charging holes, and may cause localized erosion of the oven wall.

The coking chambers are narrower on the pusher side and taper from 50 to 100 mm (2 to 4 in.) toward the coke side. The extent of taper depends upon the expanding properties of the coals to be coked. The heating walls on either side of the coking chambers are built of specially designed shapes of high quality silica brick, set in silica mortar that forms ceramic bond at the high operating temperature. The coking-chamber floor may be of either first-quality fireclay blocks, or silica bricks.

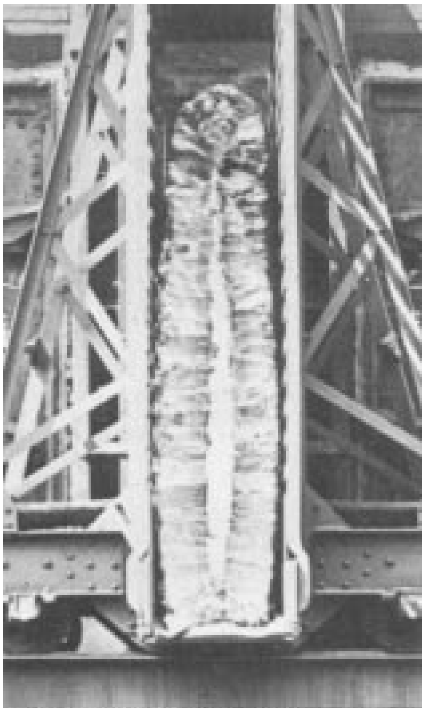


Fig. 7.25 View of coke being pushed from oven, showing central line of cleavage and block-like structure of the coke.

Effectively, all of the heat for coking the coal is conducted through the coking chamber liners. The coking therefore, starts in the coal at the walls and progresses from both walls to the center of the oven. As coking proceeds in this manner, the coke in the center is not fused together, Fig. 7.25. This limits the length of any piece of coke to half the width of the coking chamber minus any shrinkage that may have occurred. The structure of the coke mass at the end of the coking period is that of two parallel slabs of irregular interlaced pieces. These have sufficient strength to be pushed from the oven by the pushing ram and exert very little lateral pressure on the oven side walls. However, the oven walls must be designed with sufficient structural strength to resist a high lateral pressure should the structure of the coke mass be broken for any reason during the pushing. Additionally, these walls must be gas-tight to prevent any leakage of gases between the oven and the heating flues.

7.4.1.2 Heating System Design

Practically all heating systems may be grouped into two general classes: the gun flue type shown later in Figs. 7.60–7.62, and the underjet type shown in Figs. 7.63–7.65. In the gun flue type, the gas is introduced through horizontal gas ducts extending from both sides to the center of each heating wall. Short connecting ducts lead vertically upward to a replaceable nozzle brick at the bottom of each of the vertical heating flues. In the underjet type, the fuel gas is introduced into each heating flue from the gas distribution piping in the basement of the battery through gas ducts built integrally into the regenerator division and flue supporting walls. Each of these separate gas risers is equipped with a regulating nozzle to control the flow of gas to each flue.

There are many variations of both general types. All attempt to heat the coal being coked at a controlled rate and temperature, uniformly from end to end of the oven, and from top to bottom of the charge (with the exception of the top few centimetres or inches which may be held slightly lower for the better control of coal chemical yields) and at the lowest rate of heat consumption per kilogram or pound of coal carbonized.

In recent years, larger, faster operating ovens have been constructed. Designs have been keyed to higher production rates at lower operating costs, with the use of automation and mechanization. The higher production rates have been achieved with larger ovens and denser brick, and with special design features described in Section 7.6, where more recent designs of byproduct coke ovens are discussed.

Heating of individual ovens is controlled so that the temperature at the base of the heating flues does not exceed about 1425–1535°C (2600–2800°F). This is considered the maximum safe temperature range to which silica coke oven refractories should be heated. With the flues operating within this temperature range, time required to coke the coal depends primarily upon the width of the coking chamber and the nature of the coals being coked, although a few other factors are involved. In general, a coking time is selected that will produce a uniform skin temperature of the block of coke in the coking chamber of 1040–1095°C (1900–2000°F) at the time the charge has been coked all the way through to the center. The skin temperature referred to above applies to the coke adjacent to the walls of the coking chamber. The time required for coking coal under the above operating conditions generally varies from 16 to 20 hours. Normally, the average time is 17 to 18 hours.

Because the flue temperature should not exceed 1535°C (2800°F), the heating system must be reversed on a regular basis. The frequency with which the firing of byproduct coke ovens is reversed generally has been established on a 30 minute cycle. Batteries which require a higher average temperature level to sustain high production rates can be reversed on either a 15 minute or 20 minute cycle without exceeding maximum permissible temperatures.

Of particular importance in flue design is the position of the gas inlet in the vertical flue in relation to the air port, and the manner in which the gas and preheated air are mixed at the base of the flue. Excessive turbulence at this point will result in quick combustion, and a short, intense flame will cause local overheating at the base of the vertical flue.

Control of the rate of flame propagation and flame length in the vertical flues is desirable. This has been accomplished in several ways. In some batteries, blast furnace gas is mixed with rich fuel gas to lower the heating value of the latter and alter its combustion properties. One system recirculates waste gas from the flues containing waste gas to the nozzle where fuel gas is being burned. This feature is contained in the Koppers-Becker design, Fig. 7.62. By this recirculation, the flame length can be controlled without cooling or purification of the waste gas and without having to heat the diluent as would be required with external mixing. The ratio of recirculated waste gas to fuel gas is controlled by the orifice size and the fuel gas pressure, and normally approximates one volume of waste gas to one volume of fuel gas. Waste gas recirculation also prevents the accumulation of carbon in the underjet gas ducts, as the contained carbon dioxide and water vapor both tend to inhibit carbon deposition. In ovens not recirculating waste gas, air must be introduced into the gas ducts during the gas off periods for decarbonization of the nozzles.

A feature of the Wilputte double divided oven shown later in Fig. 7.64 and Fig. 7.65, especially for those over ten feet in height, is the high-low burner construction. Low burners in flues alternating with high burners in adjacent flues prevent overheating at the bottom of the flues and improve the vertical heat distribution.

The latest development is the air stage heating system. In this system gas is fed to the heating flues through short burners at the bottom which all have the same height, approximately 300 mm (1 ft).The necessary combustion air enters the heating flues through air outlets located in most cases at two different heights, but as many as six different heights. Instead of the very hot local flames of a gas stage system, this results in an area of combustion with more even heat development over the heating wall area. The result is a lower average heating flue temperature at the same coking time. The emissions (NOx) are reduced as peak temperatures are lower. All presently active coke oven builders have changed to the air stage system.

7.4.1.3 Gas for Heating

When blast furnace gas or other gases having a low calorie (Btu) content (lean gases) are used for oven heating, supplementary heating with gas of a higher calorific value may be needed in order to maintain coke production at as high a rate per oven per operating hour as when firing with a straight high calorie (rich) gas. It is not practical to add more than a limited amount of rich gas to the lean gas before the mixture enters the regenerators, as the rich component of the mixed gas can decompose (crack) partially while passing through the regenerators and cause an objectionable deposit of carbon. Because of this, any additional rich gas needed is fed through its own gas system for burning in the flues at rates needed to achieve the required temperature.

Some modern coke oven designs can be heated with pure coke oven gas or blast furnace gas. Because the calorific value of blast furnace gas varies based on the operating conditions of the furnace it is stabilized in an automatic mixing station by the addition of a small amount of coke oven gas in order to ease the coke oven heating operation.

The rich fuel gas is heated to above its dew point. The fuel gas mains located in the alleys on both the pusher and coke side (or in the basement in the case of an underjet battery) are insulated to limit condensation in the headers and to keep the gas at a uniform temperature throughout the length of the header. Other designs keep the basement/alley temperature controlled in a range which makes any insulation unnecessary.

7.4.1.4 Air for Combustion

In the gun flue type of oven, the air required for combustion is taken into the sole flue at the base of the regenerator chambers through an air box equipped with small slats (finger bars) that can be adjusted to regulate the amount of air taken from the alleys. The temperature, the velocity and the direction of the wind may have a noticeable effect on the heating and should be compensated for. In the underjet type, the air for combustion may be taken from the enclosed basement and is therefore independent of wind velocity, direction and temperature.

In the Wilputte design of underjet ovens, the basements are sealed and kept at a constant air pressure with only the air required for combustion entering the basement through a wind tunnel extending along the entire length of the battery. When operating on a fast coking time with lean gas, a fan is used to deliver sufficient air to the wind tunnel. Spaced along the length of the basement are suitable openings equipped with regulating louvers to distribute the air uniformly throughout the basement. In this design, only the air required for combustion is available for basement cooling.

In Koppers-Becker underjet ovens, the air for combustion is introduced in much the same manner as that just described, with the exception that air in excess of the amount required for combustion is forced into the basement, the excess finding its way through suitable openings around the buckstays on the pusher side (the wind tunnel being on the coke side of the basement). In this arrangement, air in addition to that required for combustion may be circulated through the basement for cooling.

In Thyssen Still Otto underjet ovens the air passes through the basement without the aide of any fan or duct equipment. The required amount of combustion air, the necessary air exchanges per hour to avoid any gas pockets, and the temperature differences (summer/winter) are all controlled by adjustable openings in the alleys.

7.4.1.5 Importance of Heat Control

Faulty heating affects not only the quality and quantity of the coke and coal chemicals produced, but also the ultimate life of the ovens. The most serious damage to the ovens is caused by fluxing or slagging of exposed brick surfaces due to local overheating beyond the critical temperature of the brick. This may occur in zones that are not readily accessible for repair. The advantages of an even and controlled heat throughout the oven cannot be overemphasized and remains a constant challenge.

When a new battery, or an old battery that has been allowed to go cold, is to be put into operation, great care must be taken in bringing the battery up to operating temperature. The major high temperature portion of the battery is high grade silica brick which has a high coefficient of thermal expansion at lower than operating temperatures, see Chapter 3. Therefore, the rate of heating must be slow enough to ensure maximum temperature equalization throughout the entire battery structure. In practice, the heating from cold to operating temperature takes from seven to ten weeks. This same practice must be reversed when a battery of ovens is taken out of operation for repairs or an extended shutdown and allowed to go cold. Because the regenerator walls can not be tightened up properly again, such a repaired battery can not be operated on blast furnace gas.

The usual method of heating up a battery begins by burning gas in the coking chambers, using burners inserted through an opening in the door at each end of each oven. The products of combustion are allowed to enter the heating system at the horizontal or bus flue elevation through suitable openings provided for this purpose, which later are plugged and sealed. The hot gases during the initial or drying out period are vented down through the vertical flues and regenerators to the stack flue and stack. When the flues become hot enough to ignite fuel gas, the gas is introduced through the normal heating ducts. Where other gas is not available for heating up, liquid butane or propane may be vaporized and used. In the earlier period, coal or coke has been used for heating up by substituting a brick bulkhead for the oven door, leaving openings for firing and ash removal. The same type of false hearth is used to protect the oven liner brick. After heating up, the false hearth and bulkhead are removed and the oven door is installed.

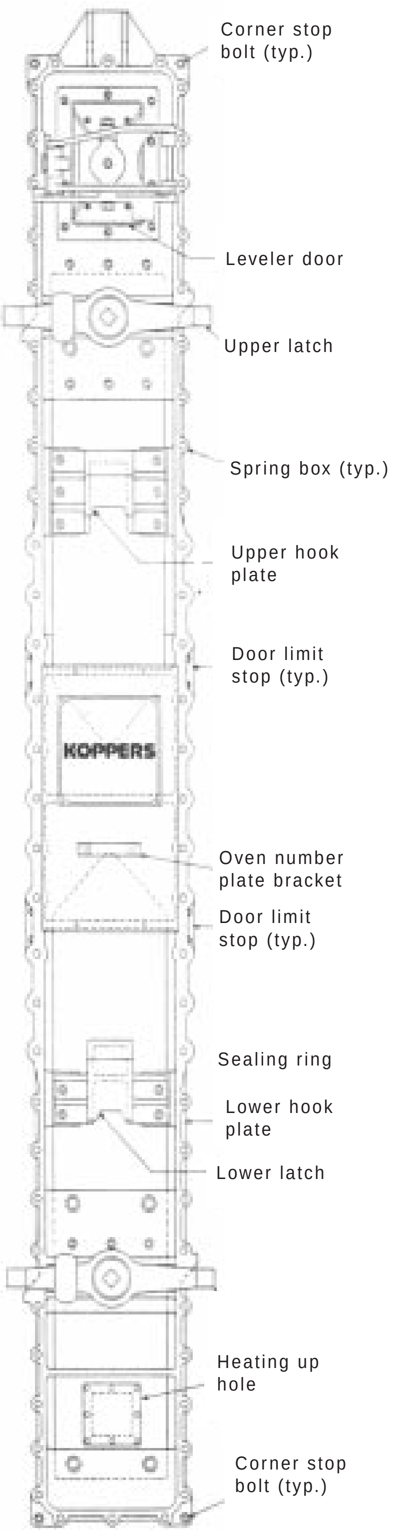


Fig. 7.26 Face view of a Koppers coke oven door of the self-sealing type.

7.4.1.6 Oven Doors

As has been mentioned, the ends of the oven are equipped with removable, refractory lined doors. After a coal charge is fully coked, suitable machinery located on both the pusher and coke sides of the battery is used to remove the doors and hold them during the pushing operation. After pushing, the doors are replaced and sealed preparatory to recharging the oven.

The original method of sealing the doors was to trowel and smooth ground refractory mud into a V-shaped opening between the door and the doorjamb. In recent years there have been developed self-sealing doors that do not required luting, sealing with mud. In principle, the self-sealing door has finally developed into a spring loaded door that depends on a metal-to-metal contact between the door and the continuous machined surfaced cast iron or ductile iron jamb.

Oven door expense is a large factor in overall repair and maintenance costs. This expense can be controlled by careful design of door handling equipment and strict adherence to good operating practice. The lining of the door is usually sectionalized and made up of clay brick shapes. In some plants the doors have a monolithic lining of lumnite cement made with an aggregate of various grades of crushed brick and ganister which give good service. The thickness of the lining and the position of the inside face of the lining relative to the end vertical flue of the oven are important as they influence the heating of the ends of the coal charge.

Six popular types of coke oven doors are discussed in detail.

7.4.1.6.1 Koppers Door The Koppers door has a U-shaped sealing ring on a cast iron door, with a series of spring loaded plungers that force the sealing ring to conform to the oven door jamb, Fig. 7.26 and Fig. 7.27.

7.4.1.6.2 Wilputte Door The Wilputte fabricated steel door incorporates a heavy, reinforced channel frame with a sealing diaphragm with a renewable flexible stainless steel sealing edge. Heavy duty springs mounted at the locking bar and acting through a series of heat resistant spring loaded plungers provide a constant force to conform the sealing edge to the

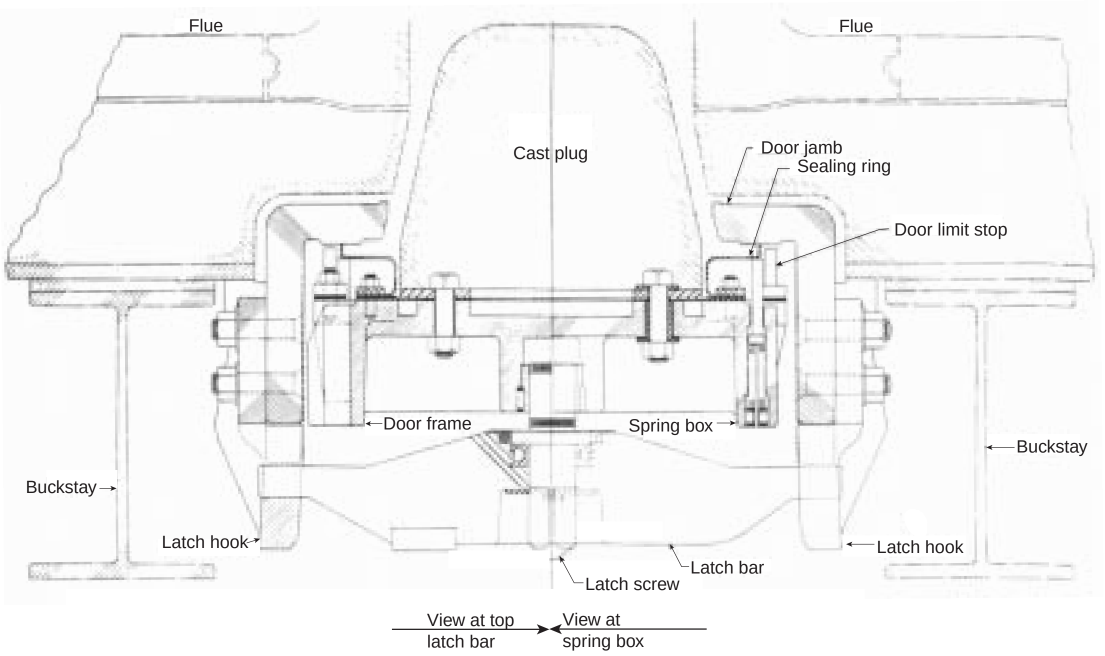


Fig. 7.27 Horizontal section of the self-sealing coke oven door shown in Fig. 7.26.

oven doorjamb. The Wilputte leveler door is constructed with a heavy ductile iron casting with insulation and a stainless steel sealing edge that is adjusted by set screws. The leveler door latch spring is made from a heat resistant stainless steel, Fig. 7.28 and Fig. 7.29.

7.4.1.6.3 Thyssen Still Otto Door The Thyssen Still Otto type self-sealing door with its spring-loaded sealing strip is well illustrated in Fig. 7.30. The door body is a heavy casting. The Z-shaped sealing fram from special stainless steel is adjusted to the contour of the chamber by separate adjusting bolts and not by the sealing springs. The sealing spring pressure is 100% available as sealing force.

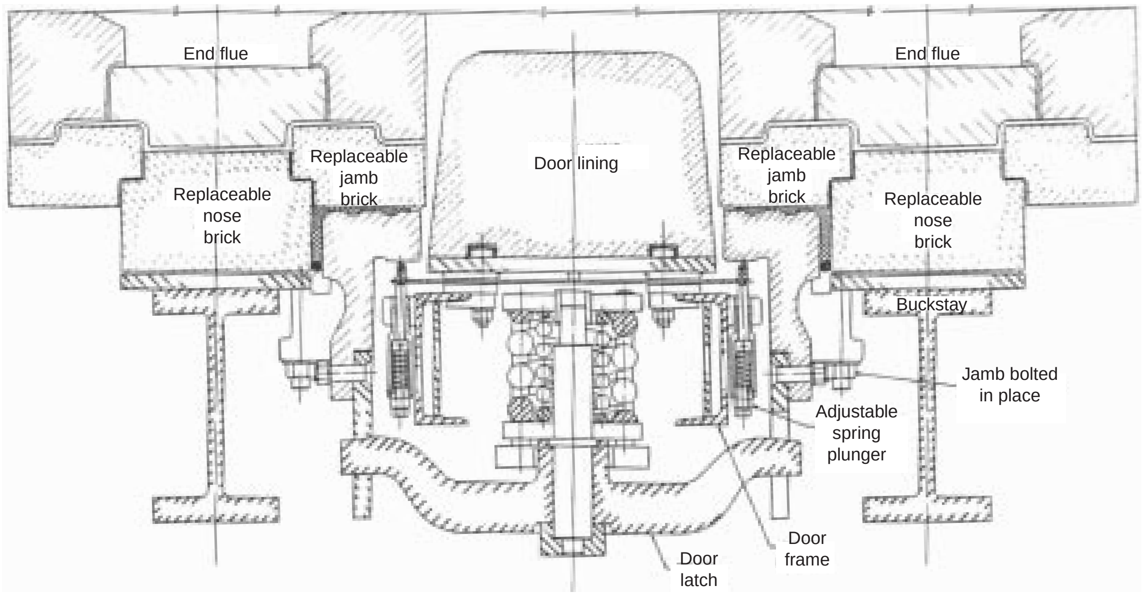


Fig. 7.28 Cross-section of a Wilputte door and door jamb arrangement.

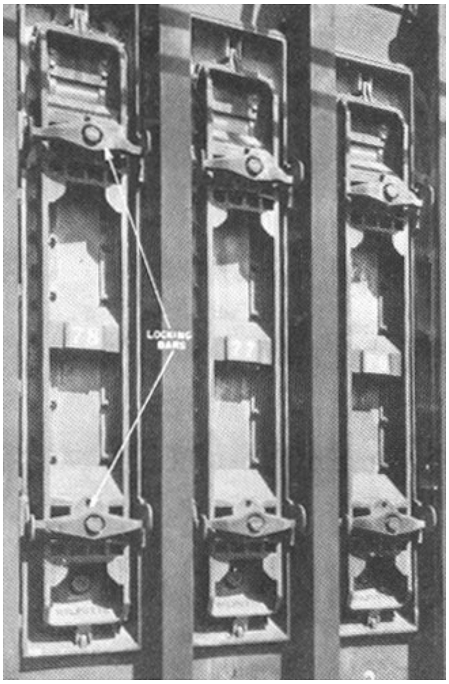


Fig. 7.29 Wilputte design of self-sealing coke oven doors, showing spring loaded bars that maintain metal-to-metal contact between the door and jamb.

7.4.1.6.4 Krupp-Uhde Door In response to increasing environmental controls on door leakage, Krupp-Uhde developed the Flexit™ door. The design incorporates a new type of door body with a certain flexibility which, together with the flexible diaphragm seal, can adapt to the door jamb deflections during operation. The sealing strip is held on to the doorjamb via springs. The refractory door plug is designed to expand independently on the door body and has lateral gas ducts to assure rapid flow of the coke oven gas into the gas collecting space. The sealing diaphragm is made of heat and corrosion resistant steel. The diaphragm has a relatively long free leg and small wall thickness which provides a very elastic and wide deflection range, Fig. 7.31.

7.4.1.6.5 Saturn Coke Oven Door Saturn doors incorporate a patented leaf spring supported Inconel seal in combination with supporting spring plungers and a rigid but adjustable doorframe. The Inconel seal and supporting leaf springs attach to a diaphragm plate. Inconel is used to produce a seal which can withstand the high temperatures and corrosive conditions without deterioration or significant dimensional distortion, Fig. 7.32 and Fig. 7.33.

The seal contacts the jamb surface at an angle thereby allowing for greater elevational flexibility. The door incorporates two means of adjustment in order to secure full contact between the door seal and the jamb sealing surface. The primary means of adjustment is the turnbuckle adjusted, segmented, flexible doorframe. The second means of seal adjustment are the spring plungers located above the seal and

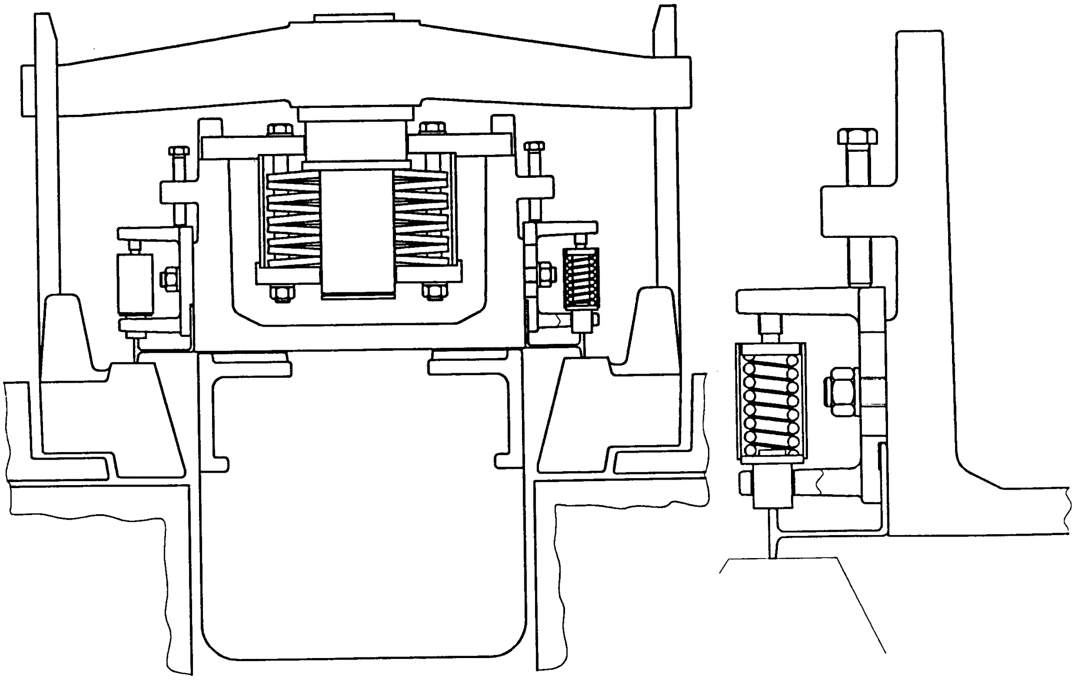


Fig. 7.30 Thyssen Still Otto self-sealing coke oven door with spring loaded sealing strips.

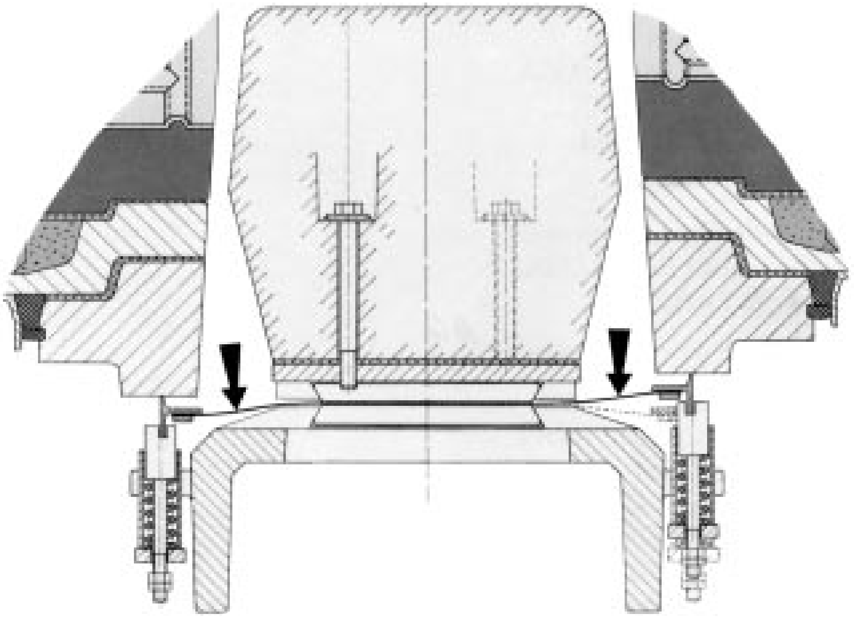


Fig. 7.31 Cross-section of Krupp-Uhde door.

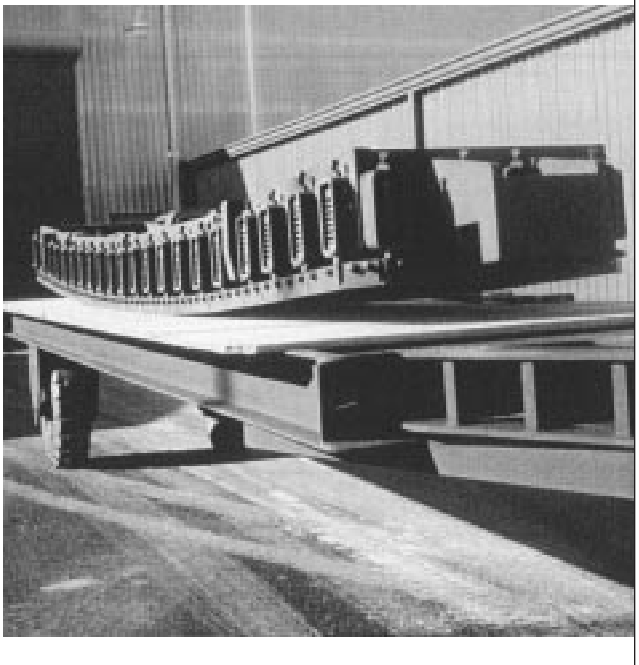


Fig. 7.32 Saturn door awaiting installation.

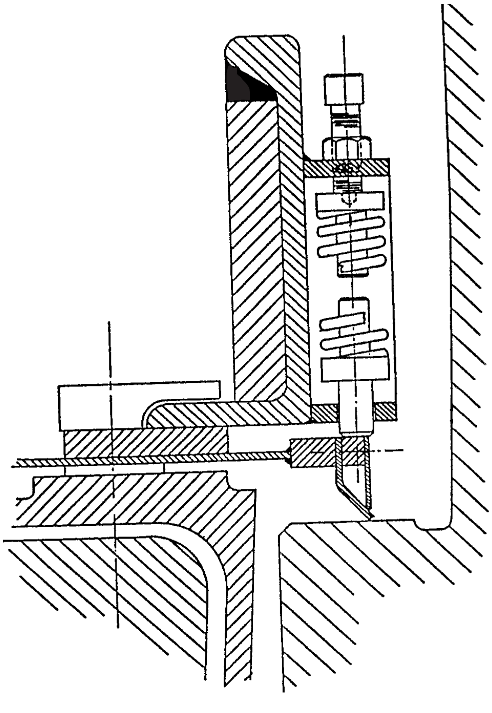


Fig. 7.33 Saturn door cross-section through retrofit seal.

around the entire door. Basic sealing pressure is applied to the Inconel seal through the plungers while an even pressure is maintained around the entire length of the seal by leaf spring.

7.4.1.6.6 Thyssen Still Otto Door Thyssen Still Otto has developed the Autoseal™ door which incorporated the Z-type sealing strips. By adapting the sealing strip to the doorjamb contour, the door can be adjusted without reducing the required forces exerted by the sealing strip. Sealing is

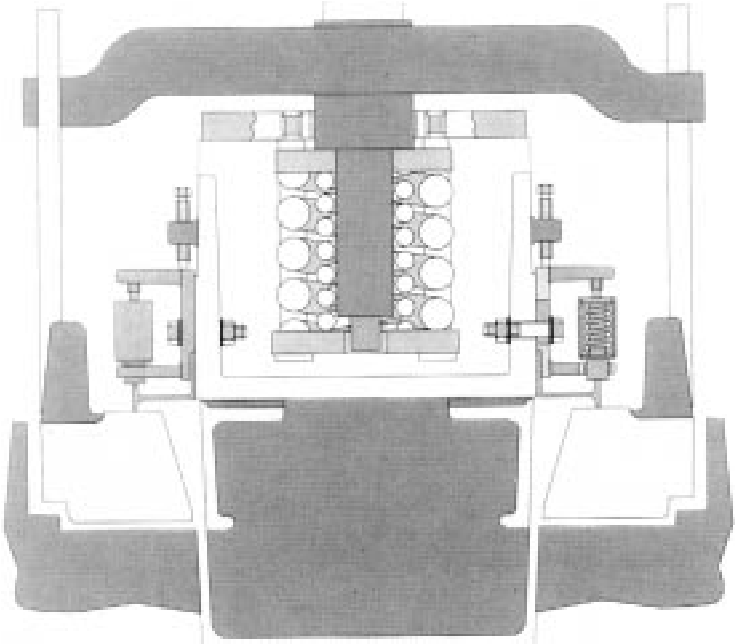


Fig. 7.34 Cross-section through the Thyssen Still Otto Autoseal^{TM} door with automatic adjustment of the contact pressure by means of compressing spring system.

obtained by action of a compression spring system to permit a mechanical self-regulation of the contact pressure, Fig. 7.34.

7.4.1.7 Gas Collecting System

The oven may be equipped with one or two offtakes to carry off the volatile products liberated in the coking process. Where one offtake is provided, it is through the oven roof at one end of the oven, and where two are provided, there is one at each end of the oven. In either case the volatile products pass through the duct or ducts in the oven top and enter a refractory lined standpipe (sometimes referred to as an ascension pipe) which in turn is connected to a collecting main through a damper valve, Fig. 7.35 and Fig. 7.36. Between the damper valve and the oven the standpipe is equipped with a cap valve, or elbow cover, which, when open, vents the oven to the atmosphere.

The damper valve is usually a liquid-sealed valve, so designed that the cooling spray furnishes the seal when the damper valve is in the closed position, the excess spray overflowing into the collecting main. With this arrangement, the cooling spray is always on. The liquid called flushing liquor, used in damper and collection main flushing, is the condensate from the volatile products driven off in the coking process.

In the Thyssen Still Otto design illustrated in Fig. 7.35 the standpipe is from fabricated steel and the standpipe elbow is from cast steel. The standpipe cap is a standard vessel bottom and is tightened on the inside by a metal-to-metal seal and on the outside by a water seal. The flexible connection between the standpipe elbow and the collecting main is a liquor seal filled with bitumen. The collecting main body is round for ease of manufacturing and to avoid corrosion on horizontal surfaces.

In the Wilputte design illustrated in Fig. 7.36, the standpipe is fabricated steel and the standpipe elbow is cast steel. The elbow is equipped with a spring loaded locking cover and fitted with a renewable stainless steel sealing edge that provides a gas-tight seal. The elbow can be fitted with a renewable flanged sealing surface.

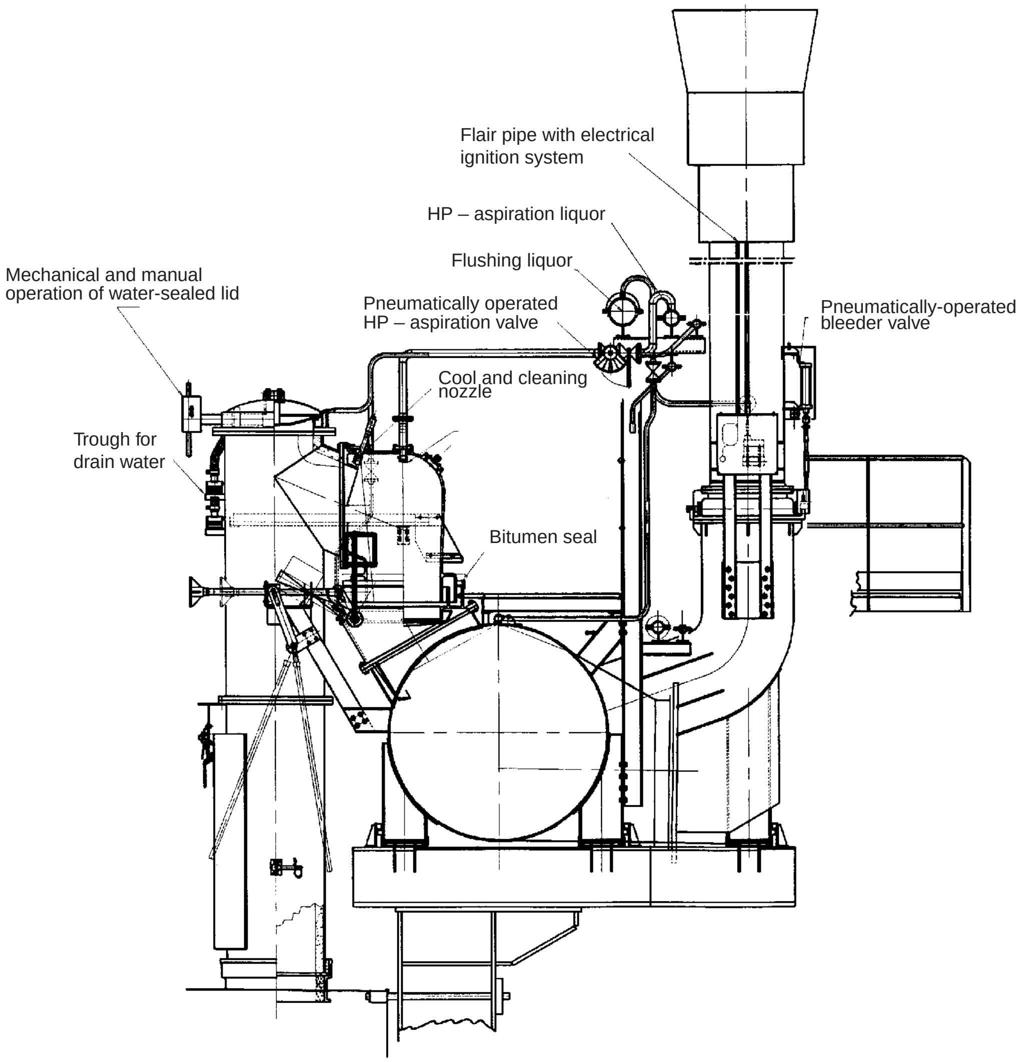


Fig. 7.35 Thyssen Still Otto collecting main and ascension pipe with oval water-sealed cap for automatic gooseneck cleaning.

The flushing liquor spray nozzle is recessed in the standpipe elbow and protected by a shroud. The nozzle provides 360° spray coverage of the elbow interior, to maintain maximum cooling and cleaning. Easy access to the spray nozzles is provided.

The standpipe is lined with refractory brick or castable with a layer of insulation. The elbow is lined with anchored castable refractory. The lined standpipe and elbow maintain the oven offtake gas at a temperature high enough to minimize deposition on the walls until the spray in the elbow can cool the gas and flush any deposits into the collecting main.

A gas-tight floating elbow connection to the collecting main is accomplished by the use of a flushing liquor seal. Additional sprays located in the collecting main provide a flushing spray to the damper valve housing to maintain trouble free valve operation. The height of the elbow cover permits inspection of the inside of the elbow and the spray pattern when the oven is off the main.

All ovens of a battery thus are connected to a single or multiple pressure equalized collecting main on either or both sides of the battery. The function of either the single or double collecting main is not only to collect gas from the ovens but also to maintain at all times an accurately controlled pressure in the oven during the coking process. Pressure in the oven during coking has a pronounced effect on the coke and coal chemicals. The pressure in the collecting main usually is kept at a point

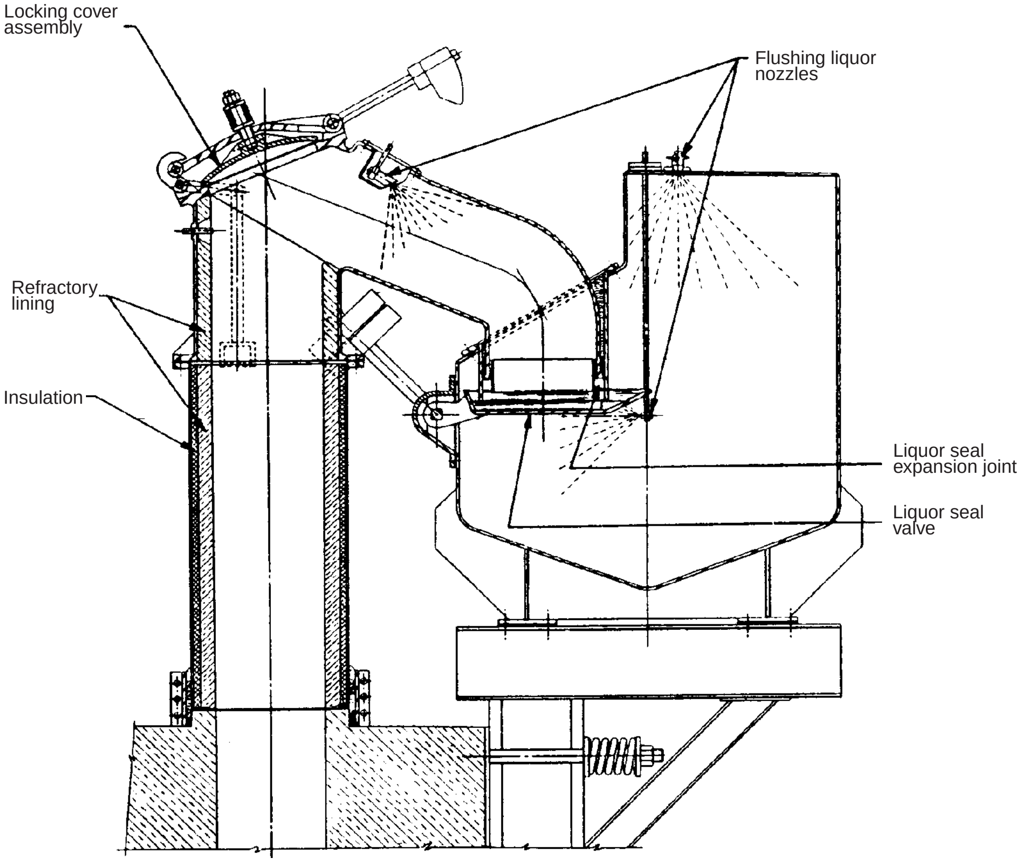


Fig. 7.36 Wilputte arrangement of standpipe, liquid-sealed damper valve, collecting main and automatic elbow cleaner.

that will give about 2 mm (0.078 in.) water gauge pressure at the bottom of the oven at the end of the coking period. The pressure is regulated by a controller located in the connection between the collecting main and the suction main which carries the gas to the coal chemical recovery units. The collecting main also serves to transport to the tar decanters the products condensed from the gas by the flushing liquor.

The gas passing from the ascension pipe to the collecting main is shock cooled with a flushing liquor spray which causes precipitation of tar from the gas, and cooling of the gas to the desired temperature.

7.4.2 Accessory Oven Equipment

7.4.2.1 Coal Storage Bins and Charging Larries

To provide coal for the ovens, every modern plant has an overhead coal bin at the ovens of sufficient surge capacity to permit flexibility in coal preparation without interference to the scheduled uniform operation of the ovens. The number and size of bins required are determined for each individual plant.

All modern byproduct coke ovens are designed to take a definite volume of coal per charge, and are charged from a larry car operating between the overhead coal storage bin and the ovens on a track supplied by the battery top, Fig. 7.37 and Fig. 7.38.

The desired amount of coal for an oven charge is drawn from the storage bin and is measured, usually by using either the track scales at the loading station, or by volumetric sleeves (choke boxes) on the larry car. When the separate hoppers of the larry, one for each charging hole, are equipped

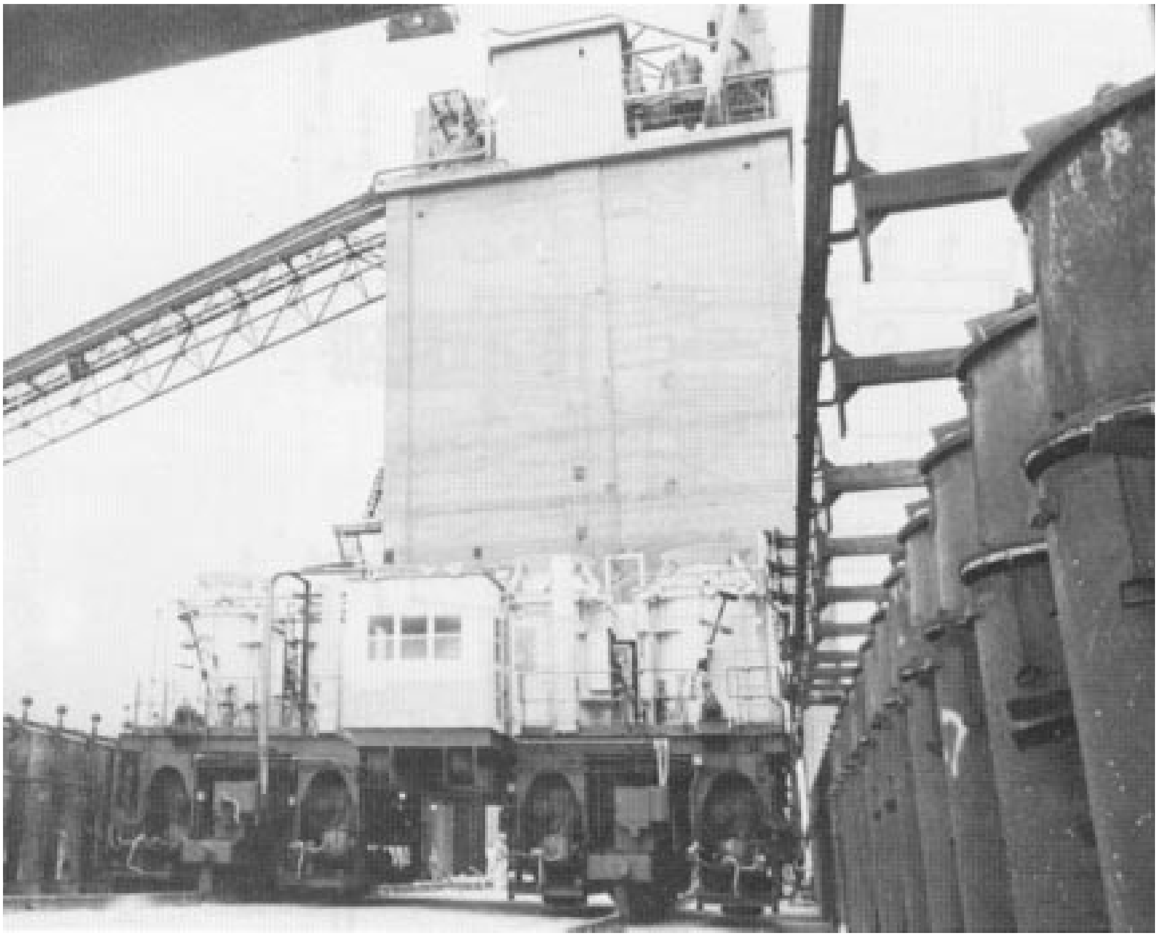


Fig. 7.37 View of a coal storage bin and larry car on top of a modern coke oven battery equipped with a double collecting main.

with volumetric sleeves, the gates usually are linked together and power operated as all gates may be left open until the hoppers are full and the flow of coal is stopped by the sleeves.

The larry car in principle is designed in connection with the number of charging holes per oven so that a predetermined quantity of coal is charged into the oven through each charging hole, the mechanism for controlling discharge from each hopper being independently operated by powered drives on new installations and by gravity on older batteries.

Improvements in larry cars, particularly the method of discharging coal, have been directed toward making possible better charging practices. The aim has been to reduce the charging time; to reduce the number of passes of the leveling bar necessary for leveling; to make a smokeless charge; to prevent hanging up of the coal in the larry hoppers; and to make a uniform charge, regardless of coal bulk density.

On more recent installations, Fig. 7.39, automatic lid lifters are provided to dispense with manual removal of the charging hole covers.

The gravity discharge larry and the mechanically unloaded larry are the two main types in use at the present time. The gravity discharge larry is equipped with conical shaped hoppers, shear gates, and drop sleeve mechanisms. With this type, the coal charge flows by gravity from the hoppers into the ovens. There are two designs of mechanically unloaded larry cars in use at present; namely, the turntable and screw discharge types. The turntable larry is equipped with a revolving table serving as the bottom of each hopper. The revolving table forces the coal through an opening in the side of

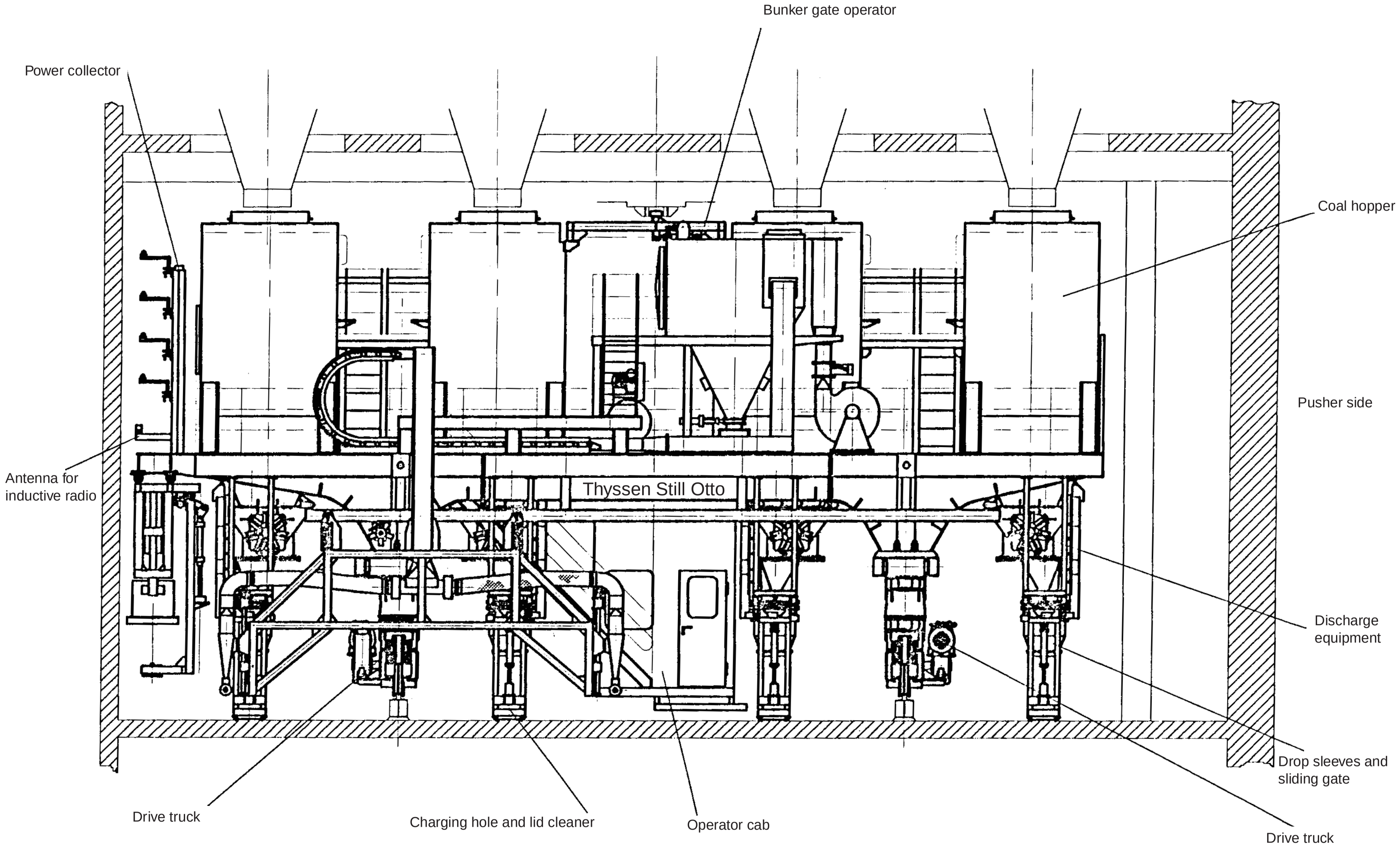


Fig. 7.38 Front elevation of a coal charging larry for a modern byproduct coke oven.

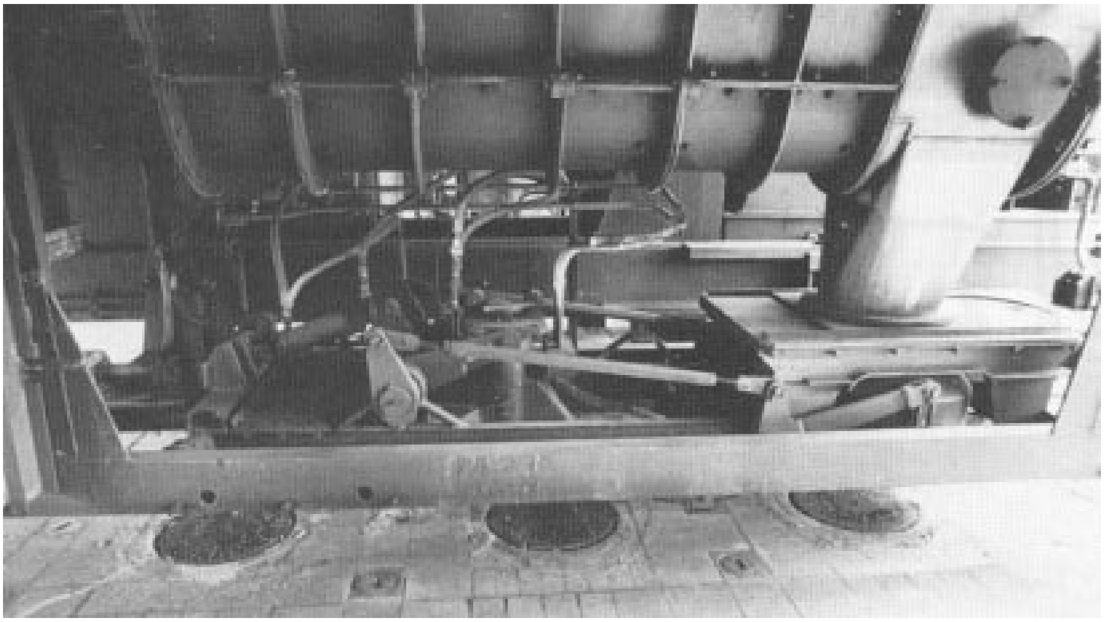


Fig. 7.39 View of an automatic charging hole lid lifter assembly as mounted on a coal charging car.

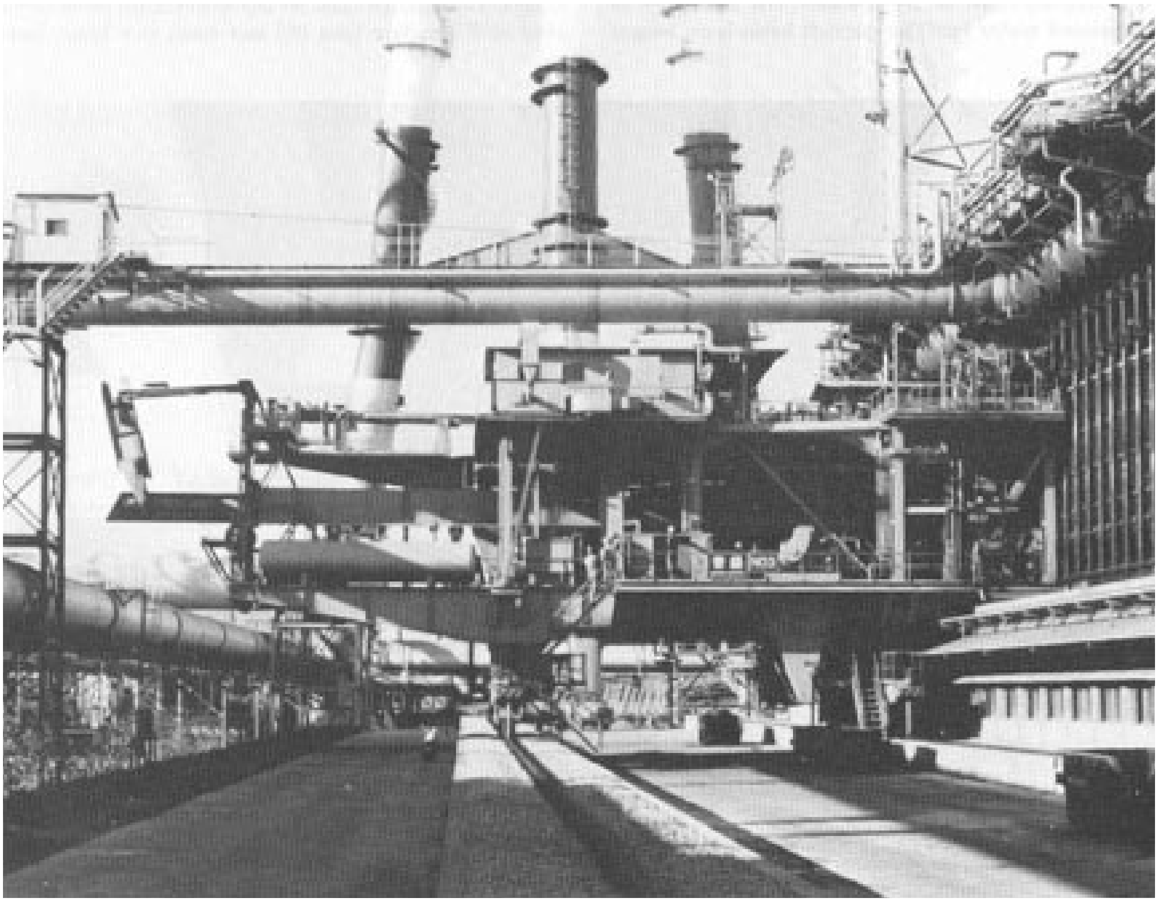


Fig. 7.40 Pusher side equipment of a battery of byproduct coke ovens, showing the machine which is equipped to level the coal charge in the oven and also push the finished coke out of the oven, as well as remove and replace oven doors before and after the pushing operation.

the hopper leading to the shear gate and drop sleeve and thence to the oven. The screw discharge larry is equipped with rectangular shaped hoppers with the lower section tapering to a small opening directly over the screw trough. The trough contains the screw conveyor that forces the coal horizontally to the vertical drop sleeve and shear gate section.

To reduce emissions to the atmosphere a stage charging practice has been adapted, see Fig. 7.71. With this concept, the two outer hoppers of the charging car, each of which contains approximately 40% of the coal charge, discharges coal into the oven while the charging hole lids of the inner charging holes are still in place. When coal discharge from the outer hoppers is completed, the outer lids are replaced and the lids from the inner charging holes are sequentially removed and the remainder of the coal is charged into the oven. At a predetermined time during the discharge into the inner charging holes, the leveler bar levels the coal in the oven. With stage charging, the oven charging takes between three and eight minutes as compared to approximately two minutes required when coal was discharged from all hoppers simultaneously.

Nearly all modern plants worldwide today use screw feeder coal charging cars as they are a well-proven design, provide better control over the charging operation, and can be easily integrated into modern process control systems.

7.4.2.2 Pusher Side Equipment

The pusher side equipment, shown in Fig. 7.40 and Fig. 7.41, is generally similar on all types of ovens. The pusher is, in general, a combination of three machines: a pusher, a leveler and a door extractor. It is designed to operate on a track parallel to, but independent of, the battery.

The function of the door extracting element of this machine is to remove and hold the pusher side door during the pushing operation. It is either electrically and/or hydraulically operated from the elevated cab which contains all of the machine controls. With self-sealing doors, an important feature of the door extractor design is that its speed be relatively slow and easily controllable and the alignment be accurate to avoid damage to the sealing edges of the door. Contained in the head of the extractor is a mechanism for latching the door.

The function of the pushing element, Fig. 7.24(e) and Fig. 7.41, is to push the coke cake from the oven. This is done by an electrically powered rack and pinion operated ram, equipped in front with a suitable head that, when spotted immediately in front of the oven to be pushed, may be moved forward until all the coke has been pushed from the oven and through the coke guide into the quenching car.

The ram is equipped with a rider shoe located a short distance behind the pushing head to support the ram during its passage through the oven. This rider shoe is replaceable, as it is subject to considerable abrasion sliding over the brick floor of the oven, especially as there is always considerable coke breeze on the oven floor during the pushing and return. The ram is either a built up box girder, H-beam or electrically welded open lattice structure. The open lattice construction seems to be currently in favor as it is more easily repaired and resists the tendency to warp, due to more even cooling regardless of wind direction. With the box girder type ram, it is necessary to have wind and rain guards for the ram in its retracted position. The pushing speed of the ram is roughly 15–20 m (50–60 ft) per minute, and the maximum pressure exerted is controlled by overload relays to prevent damage to the oven brickwork.

The function of the leveling element, Fig. 7.24(b) and (c), is to level the coal charge in the oven, leaving a free gas space below the roof of the charged oven. This is done by an electrically operated leveling bar carried by the pusher machine structure in such a position that it may be introduced through a suitable opening in the top of the pusher side door. The leveling bar is a fabricated section consisting of two side plates held apart by vertical plates spaced at approximately 0.6–1.2 m (2–4 ft) which also serve as scrapers. When this bar is moved in and out of the oven, the scraper plates level the peaks of coal beneath the charging holes into the valleys and, on removal from the oven, drag out all excess coal into a chute discharging into a receiving bin carried by the pusher machine. This excess coal periodically is dropped into a ground level hopper or container for return to the coal bunker (bin).

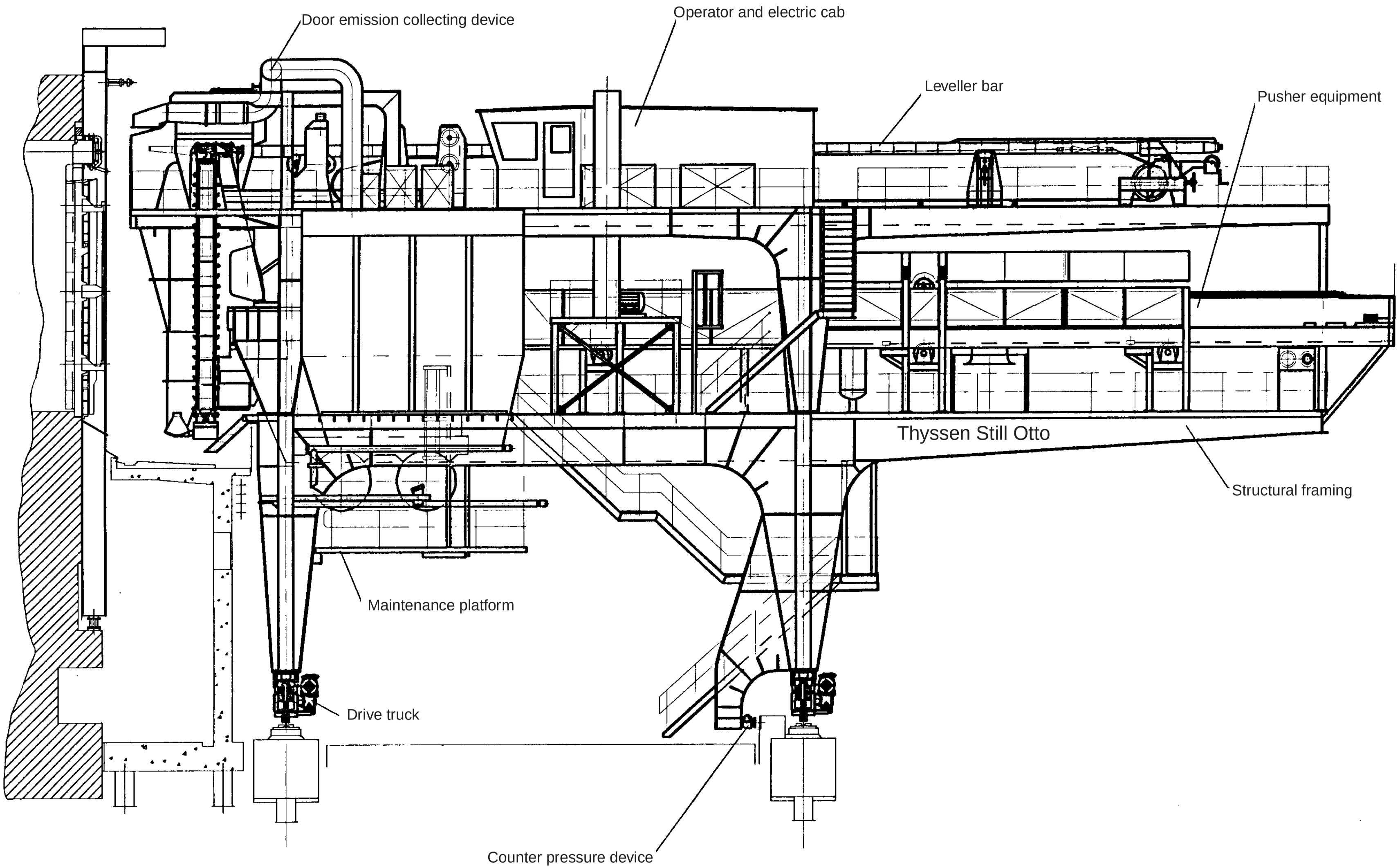


Fig. 7.41 Byproduct coke oven pusher machines, equipped to level the coal charge in the oven, push the finished coke out of the oven and to remove and replace oven door before and after the pushing operation.

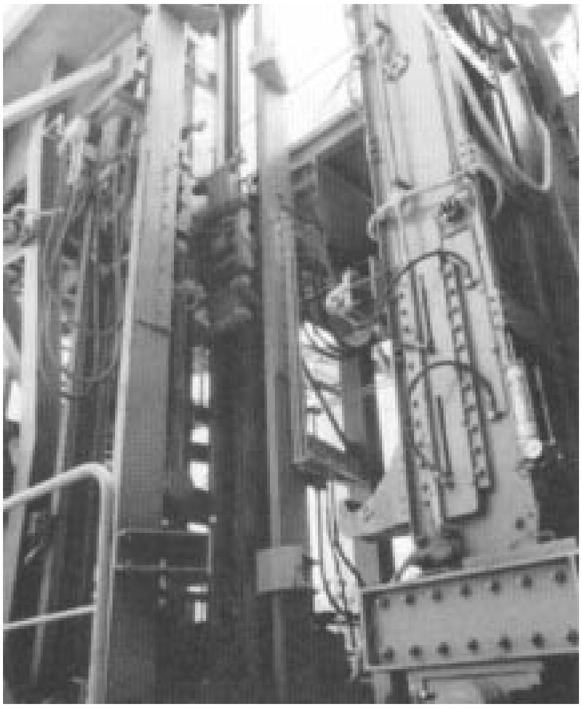


Fig. 7.42 Jamb cleaner mounted on a pusher machine, in position to remove carbon deposits.

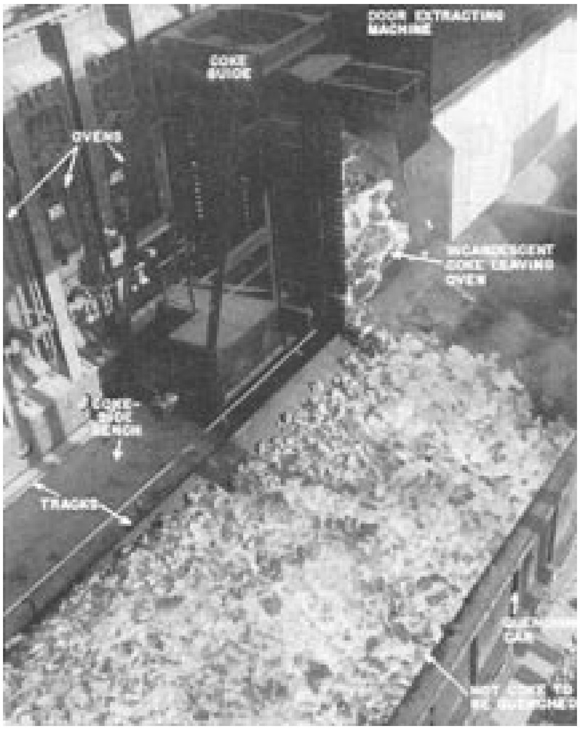


Fig. 7.43 Coke side of a battery of byproduct coke ovens during the process of pushing the coke out of one of the ovens. The quenching car is self-propelled, and carries the coke to a quenching station where it is sprayed with water before being dumped on the coke wharf.

The various platforms, control rooms and operating cab of the pusher machine should be designed to facilitate comfortable operation and accessibility for lubrication, adjustment and repair.

The modern pusher machine is equipped with devices to remove the carbon buildup from the doors and jambs so that the door can seat tightly in place against the jambs to prevent emission of gases during the coking cycle, Fig. 7.42.

The battery has a bench serving as a walkway along its entire length and as a working platform for servicing the doors and jambs. The level of this bench is about 0.76–0.91 m (2.5–3 ft) below the oven floor level so that the pusher ram may pass over the top of the bench railing.

7.4.2.3 Coke Side Equipment

The coke side of the battery is equipped with a door extracting machine and a coke guide. The coke side equipment operates on a track integral with the coke side bench, as shown in Fig. 7.43.

The function of the door machine is to remove and hold the coke side door during the pushing of an oven, and to place an attached coke guide in the proper position to conduct the coke across the coke side bench into a quenching car operating on a ground level track parallel to the battery; these operations are shown in Fig. 7.43.

The design and operation of the door extractor of the door machine is generally similar to the door extractor of the pusher machine. Recent developments place the extracted door behind a heat shield and have details of design that facilitate door cleaning.

The coke guide is attached to the door extractor machine by a disconnecting coupler. At modern plants, the coke guide is equipped with a movable lattice framework that is power operated from the door machine. When spotted at the oven to be pushed this movable framework is moved into the space between the buckstays and against the doorjamb, thus preventing spillage of coke at this point during pushing. The door extracting machine is equipped similar to the pusher machine with mechanical devices for cleaning doors and jambs.

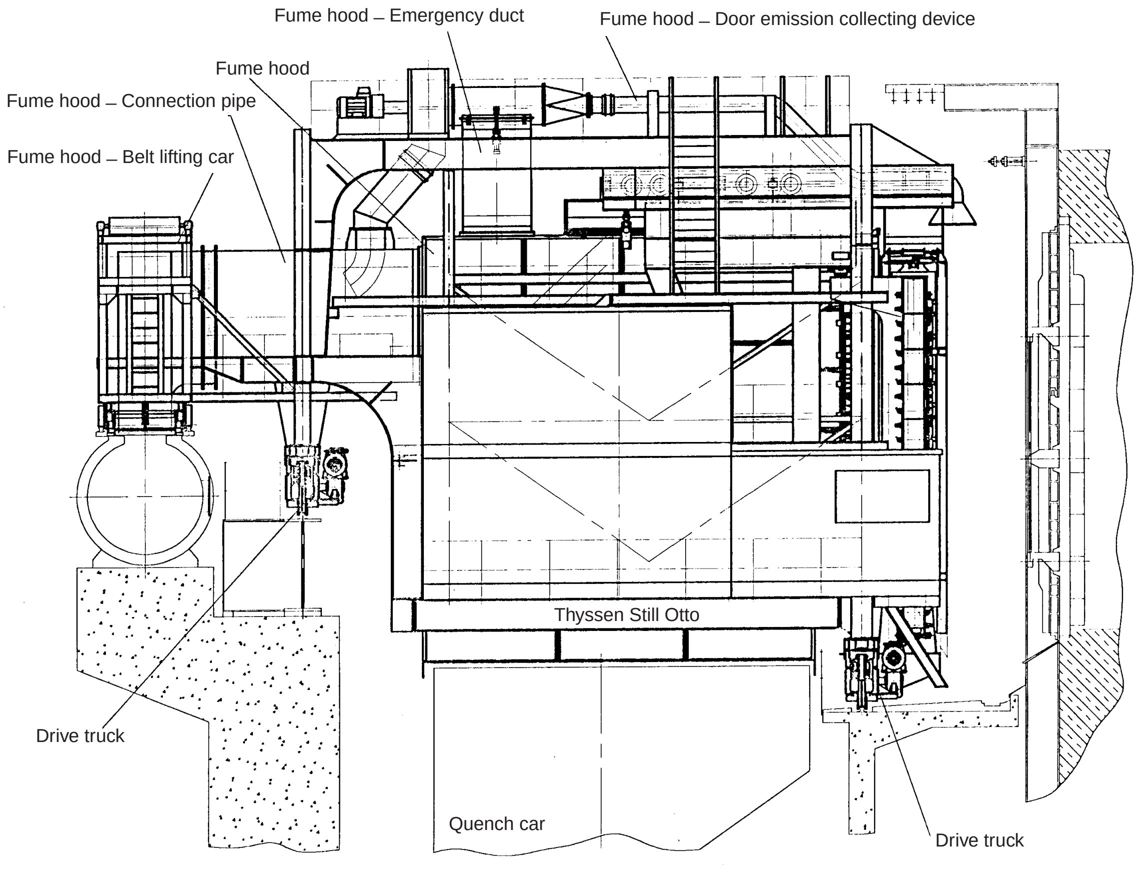


Fig. 7.44 Thyssen Still Otto modern coke transfer car.

The latest design machines for the coke side, Fig. 7.44, are called coke transfer cars and combine in one machine the functions of coke guide, door extractor, door and jamb cleaner as well as the hood for collection of the pushing emissions. They travel with only one row of wheels on the outside of the bench, thus keeping a greater distance between the machine and the battery clear for more safety The other row of wheels travels either on the ground or on the collecting duct supporting structure.

Generally, most coke oven machinery in the United States operates on direct current (DC) power; however, on many new installations oven machinery is powered by alternating current (AC) motors instead of DC motors and AC power generated at the plant can be used without rectification.

Use of AC motors is made possible by silicon controlled rectifiers. There are several advantages in this method of control. With silicon-controlled rectifiers (SCR), stepless control is obtained and the movement of machines is fast and smooth with reduced stress on equipment.

7.4.3 Coke Quenching

There are two methods for quenching the hot coke pushed from the ovens, namely, wet quenching and dry quenching, the latter being used mainly in Japan, Europe, Russia and other states of the former Soviet Union.

7.4.3.1 Wet Quenching of Coke

Wet quenching in most modern plants is accomplished by receiving the charge of hot coke from the ovens in the quenching station by a locomotive, where the coke is quenched by water. The car is then taken to a coke wharf where the coke is discharged. The handling of the coke from the wharf will be discussed later.

The quenching car is designed so that by moving the car during the pushing operation the coke is caught in a relatively uniform bed about two feet thick on the sloping bottom of the car, Fig. 7.43. The quenching car has gates at the low side of the sloping bottom, operated by electric or air power, so designed and arranged that the quenching water not evaporated may drain readily from the car. When the charge of hot coke has arrived at the quenching station, it is spotted under a system of stationary sprays located in the quenching tower that is operated by remote control. The purpose of quenching, obviously, is to cool the coke rapidly to stop any further combustion. However, it must be recognized that coke with a low moisture content is desired. This is accomplished by so arranging the sprays and the time of quenching that sufficient heat will remain in the center of the individual coke lumps to evaporate excess water. The usual practice is to aim at an average moisture content of 2.5% in the metallurgical coke after screening.

Modern quenching stations are of the recirculating type in which the water drainage from the quench car discharges into a settling basin where the coke fines collected with the excess quench water settle out. The clear water is then reused for quenching. Because of environmental regulations, the makeup water to the quench stations must be fresh water; the discharge of contaminated water into the quench basin is no longer permitted.

Baffles have been installed near the top of some quenching station stacks to minimize carryover of entrained dust and water droplets out of the top of the stacks by the steam generated in quenching. These eliminators consist of wooden grid-type baffles, provided with auxiliary water sprays for periodic flushing to remove accumulations of dust.

7.4.3.2 Dry Quenching of Coke

When pushed from the oven chamber, the hot coke has a temperature of about 1000°C (1800°F) and has to be cooled before it can be further handled and used. The usual cooling method in the United States is wet quenching accomplished by spraying the coke with water in a quenching tower. This results in heat loss to the atmosphere. With dry quenching (cooling), however, the sensible heat of the hot coke is recovered and utilized for the generation of steam.

Dry quenching is a proven process but it was not much used in the past because of high investment costs and technical problems and because it was uneconomical. There is a growing interest in dry quenching due to changes in the economic section in particular, and the more stringent regulations regarding pollution control and the reduction of emissions from coke oven plants.

Since 1965, more than 50 dry quenching units, some rated at 57 tonnes (63 tons) per hour, have been installed in the former Soviet Union. NKK of Japan has installed eight dry quenching units, rated at about 70 tonnes (77 tons) per hour, at their Ohgishima Works. Ruhrkohle AG installed a 250 ton per hour dry quenching plant at the Kaiserstahl Plant in Dortmund Germany in 1993.

In Europe dry quenching plants of up to 200 tonnes (220 tons) per hour have been installed and are operating successfully.

Fig. 7.45 illustrates a method of dry quenching in which hot coke is pushed from an oven into a hot coke bucket mounted on a car running on railway tracks. The car transfers the loaded bucket to a hoisting tower which lifts the bucket to the top of the quench tower where the hoist trolley moves the bucket into position over one of the quenching chambers. The top cover of the chamber is removed, the hot coke is discharged from the bottom of the bucket into the chamber, and the cover is replaced.

The coke is cooled from 1000°C to 200°C (1832°F to 392°F) as it descends through the refractory lined chamber in 2.5 hours, by recirculating inert gases passing upward through the chambers. The cooled coke is discharged in 2 metric ton (2.2 net ton) batches through lock hoppers under the chamber onto the conveyor belt that carries it to a screening station. The inert gas which cools the coke contains 12% CO_2 8.5% CO, 3.0% H_2 and 76.5% N_2. The gas enters the bottom of

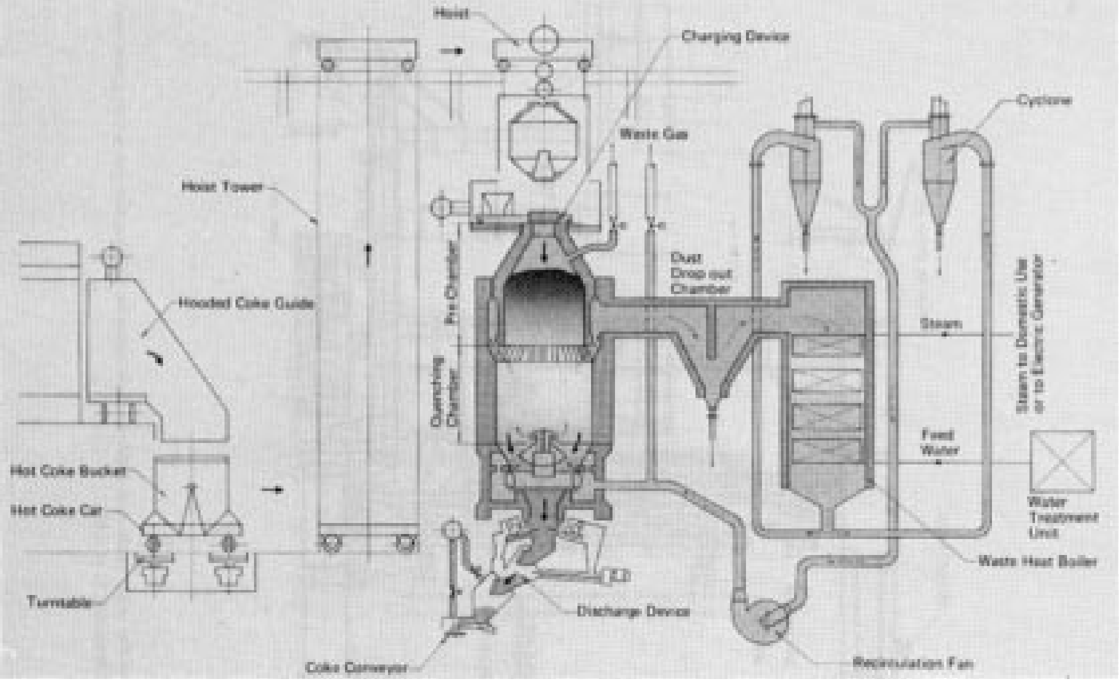


Fig. 7.45 Flow diagram of a dry-quenching system

the quenching chamber at 175°C (347°F) and exits at about 800°C (1472°F). This inert gas flows from the top of the chamber through a dropout chamber to remove coke particles and then enters the waste heat boiler that serves as a steam generator. Cooled gas at 175°C (347°F) flows through cyclones for dust removal prior to entering the recirculating fan. Depending upon the intended application, as much as 0.46 tonnes (0.5 tons) of steam at 3920 kPa (60 kg/cm^2 or 70 psi) and 440°C (824°F) can be generated per ton of coke.

7.4.4 Charging and Pushing Schedules

A coke oven battery contains many ovens which, obviously, cannot all be charged or pushed at the same time. The amount of heat required at various stages of the conversion of coal to coke varies during the time a charge remains in the oven. For these reasons and the necessity of balancing the heat, operating and combustion requirements for the many ovens contained in a single battery, specific sequences for servicing the ovens have been developed. The sequence that has the most widespread use in the United States, developed by Koppers Company, numbers all of the ovens in a battery in order, using a base nine series of numbers; that is, no zero, (10, 20, etc.) appears. The ovens then are serviced by pushing and charging in sequence all the ovens whose numbers end with the numeral 1 (1, 11, 21, 31, etc.); next those ovens who numbers end with 3 (3, 13, 23, 33, etc.) and so on until all of the odd-numbered ovens have been serviced. Next, all the ovens ending in even numbers, beginning with all the 2's, are similarly serviced. This results in a favorable local heating balance with respect to the particular oven to be serviced. At the time any given oven is scheduled to be pushed according to this system, the oven next to it on its left is 55% of the way through its allotted cooking time and the cooking cycle of the one on its right is 45% complete.

In another system, termed the Marquard system after its inventor, the ovens in a battery are divided into three groups identified as A, B, and C. The ovens within each group are then numbered consecutively (including those numbers ending with zero). The order of servicing the ovens then proceeds with pushing and charging all the odd-numbered ovens starting with A-1 (A-1, B-1, C-1; A-3, B-3, C-3; and so on). The even-numbered ovens are then pushed in a similar sequence, beginning with A-2. With this system, when an oven is to be pushed, the coking cycle of the oven next to it on its left is about 52% complete and that of the adjacent oven to its right is about 48% complete. This system requires that the two odd-numbered ovens be next to each other where the sections adjoin.

Two other pushing systems used in the United States coke plants are the even-odd series, or 2-1 series, and the 5-2 series. These pushing series are more popular in coke plants in Europe and Japan. In both of these systems ovens are numbered consecutively.

The even-odd sequence, or 2-1 sequence, is the most basic as all of the even numbered ovens are pushed in sequence followed by all of the odd numbered ovens in the next round of pushing, i.e., 1, 3, 5, 7, etc., 2, 4, 6, 8, etc. This pushing sequence allows the ovens adjacent to the oven being pushed to be about 51% and 49% through the coking cycle.

In the 5-2 series, ovens adjacent to the oven being pushed are 61% and 39% through the coking cycle. Ovens are numbered consecutively. The first number, 5, indicates the sequence in consecutive ovens pushed in a round from end to end on the battery. The second number, 2, indicates the difference in the ovens pushed first in each round of pushing. The first oven pushed using this schedule would be oven No. 1 followed by oven No. 6 (1+5), oven No. 11 (6+5), oven No. 16 (11+5), etc., until the end of the battery is reached. The next round begins with oven No. 3 (1+2), followed by oven No. 8 (3+5), then oven No. 13 (8+5), etc., until this sequence is completed to the end of the battery. The cycle is then repeated at oven No. 5 (3+2) and ovens No. 10, No. 15, No. 20, etc. are pushed. The full sequence would be: 1, 6, 11, 16, …; 3, 8, 13, 18, …; 5, 10, 15, 20, …; 2, 7, 12, 17, …; 4, 9, 14, 19, …; and then begin again at 1, 6, 11, 16, …

The Marquard pushing system, the 2-1, and the 5-2 sequence make it possible to design one spot pusher machines for pushing and charging operations. This is desirable when pushing fast operating rates since the machinery operating sequence and travel time are more efficient. The system presently preferred internationally in modern plants is the 5-2 system as it: features pusher machines that operate pushing and leveling from one spot, reduces machinery sizes, reduces the traveling distances and provides favorable coking conditions for the ovens next to the one to be pushed.

7.4.5 Instrumentation and Control

Most instrumentation on coke oven batteries is confined to the heating, pushing and foul gas handling facilities. As has been mentioned, the variable controls such as orifices in the air boxes and restriction dampers in waste heat boxes are so adjusted that master controls may be installed for each battery. In this manner, single machines, meters, gauges and other devices control the various function of the battery system after the individual oven controls have been adjusted. Thus the gas for underfiring is metered in the battery header, but the correct distribution of the gas to the individual heating walls is controlled by a fixed orifice in the gas system at each wall entry. Within each heating wall, downstream from the control orifice, nozzles of graduated orifice size control distribution of the gas to each heating flue. The air and waste gases are likewise controlled by individually adjustable orifices in the air and waste heat boxes. Finger bars are used to control the air box openings and butterfly valves control the outlet of waste gas to the stack canal.

A draft regulator operates a butterfly valve to maintain a preset stack draft on the battery.

The choice of a flow meter for the underfiring gas will be influenced in large part by its accuracy over a wide range of flow. The meter should be recording, preferably one adapted to a uniform graduated chart for reasons of legibility and computation facility. It is also necessary to control accurately the pressure in the fuel gas main with an instrument capable of close control at relatively low pressure. It may be desired to have a recording of these pressures. A recording thermometer is installed also in the fuel gas header so that the gas quantities may be computed to standard conditions. The battery also is equipped with recording draft gauges, waste heat recording thermometers, and various indicating gauges. Portable pressure gauges, thermometers and pyrometers are used in the setting of individual oven controls. Another instrument used is a portable pyrometer with which periodic temperature readings are taken of the flues and emerging coke. Probably the most widely accepted pyrometer for the latter purposes is of the incandescent filament type. Newer pyrometers which can collect temperature data for downloading into computers for records and analysis are in common use. Recording pressure and temperature gauges also are installed in the gas collecting mains.

The pressure in the collecting main is controlled by a back pressure regulator located at the junction of the collecting main with the suction main; its function is to maintain a closely controlled pressure in the ovens during coking.

Many plants record the regularity of oven operation by some related activity, such as the time of pushing by the peak-load recording of the pusher power circuit, or by recording the time of quenching of each charge. All utilities have the usual types of instrumentation.

7.4.5.1 Computer Controlled Battery Heating

In general, the control of coke battery heating today still depends on human experience and skill using the meters, gauges, and manual control valves described above. Because of the complexity of the heating systems, this function requires relatively large numbers of skilled operators making numerous manual temperature measurements and adjustments. Difficulties with battery heating control can result in low fuel efficiency, environmental problems, and poor quality coke. Therefore, to improve control of this critical battery function, computer controlled battery heating systems are now being developed and adapted to selected coke batteries both domestically and abroad. These new systems are proving to be quite successful in optimizing battery heating uniformity. Japanese and German coke producers have expended considerable effort in battery automation, and U.S. Steel has installed an automatic system at its Clairton plant. The Clairton system is based on feedforward control developed in-house.

The U.S. Steel feedforward heating system is a predictive system requiring specific knowledge of coal properties prior to charging, fuel gas prior to burning, and periodic final coke temperatures. The computer control system shown schematically in Fig. 7.46, comprises four, essentially independent, subsystems: (1) coal tracking and calculation of battery heat requirements, (2) an underfiring gas flow control loop, (3) flue gas oxygen cascade control, and (4) a coke temperature feedback system. One element, coal heat of carbonization, has yet to be defined and measured with the necessary accuracy. In the present system, as shown, feedback of final coke temperature is necessary to compensate for changes in heat of carbonization and for changes in battery efficiency.

The coal proportioning runs are tracked through the coal handling system to the battery. Coal bulk density and moisture are entered into a computer for each coal run. The battery heat requirement is computed based on the coal in the battery at any time, operating rate and battery efficiency. Oven push count inputs from the pusher machine are used to monitor the operation and charge the coal into the computer model.

The calculated battery heat requirement is used as the setpoint for the underfiring gas flow control loop which uses the fuel gas Wobbe Index to control the gas flow to maintain the desired heat input.

The excess oxygen cascade control adjusts the stack draft to maintain a constant stack oxygen for efficient combustion and proper vertical temperature distribution in the flues. The cascade control is independent of the computer but the stack draft setpoint, consistent with desired heat input, is adjusted by the computer to keep within the range of the cascade control.

To account for changes in battery efficiency and heat of carbonization, a coke temperature feedback system was developed to close the control loop. Coke temperature is sensed using an infrared pyrometer mounted on the coke guide and is transmitted to the computer which adjusts the heat requirement computation to maintain the desired final coke temperature.

Automatic battery heating control systems, in addition to automatic control systems for all other parts of the coke plant, are today standard equipment in modern plants and are provided by all

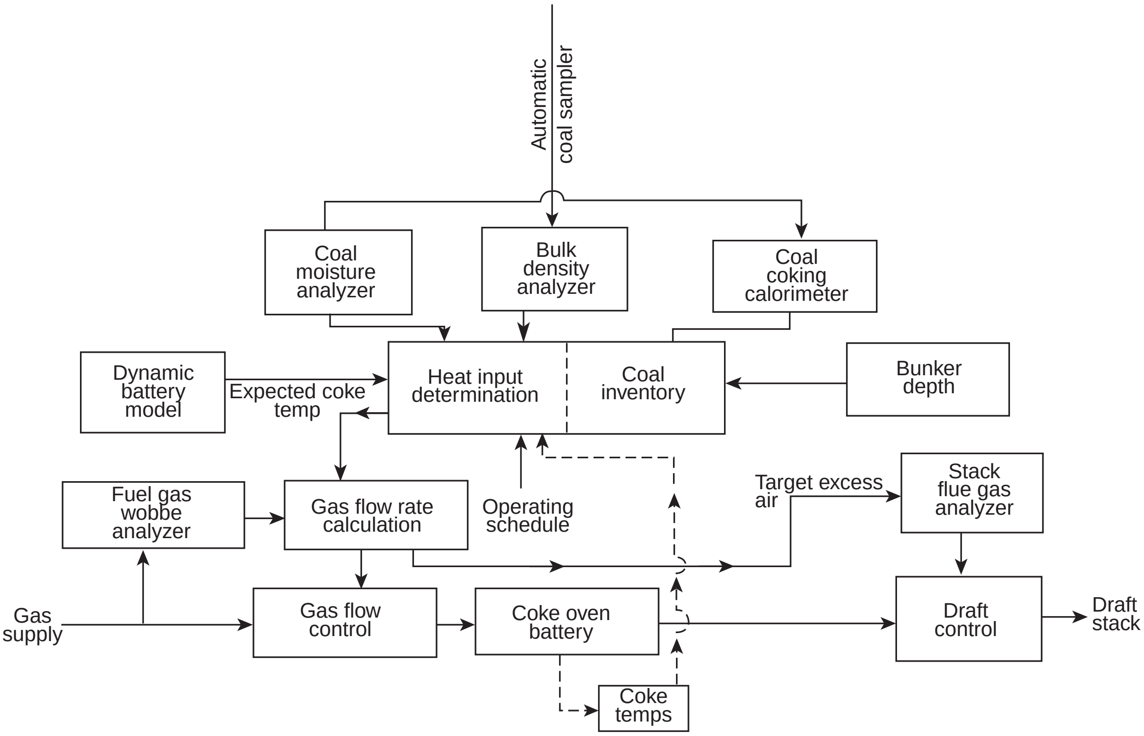


Fig. 7.46 Feedforward coke oven battery heating control system.

active coke oven building companies. The use of the computer to manage the very complex overall battery heating strategy and to make continuous overall underfiring adjustments allows operators the time to maintain underfiring components, such as gas nozzles, and to fine-tune individual oven temperature profiles which can be done only by manual adjustments.

7.4.6 Pushing Emissions Control Systems

With the advent of the Clean Air Act of 1990 significant environmental pressures were placed on the steel industry and in particular coke making facilities. Coke pushing emissions were singled out as a primary source of air pollution. Subsequently considerable emphasis was given to reducing pushing emissions through the development of pushing emissions control systems.

The four alternative types of systems considered by the industry are: (1) sheds, (2) bench mounted hoods with fixed ducts, (3) enclosed hot coke cars with mobile scrubbing systems and (4) water spray systems.

Enclosed cars, coke side sheds and hood systems traveling on the bench with collecting duct and stationary gas cleaning systems have demonstrated effective capture of pushing emissions. Enclosed cars are not generally used any more because of the high operating and maintenance costs. Most modern plants are equipped with a hood system traveling on the bench, a collecting duct along the battery and a stationary gas cleaning system on the ground. Capture efficiency of one shed has been estimated at about 90%, and enclosed cars have been judged to achieve about the same degree of capture. Even higher efficiencies are achieved today with modern baghouse cleaning plants.

Many of the new systems use baghouses rather than venturi scrubbers to control particulates because of the lower pressure drop and reduced power requirements.

7.4.6.1 Coke Side Shed

The basic design concept of a shed is to completely capture all of the emissions generated during the pushing cycle, as well as smoke emitting from coke oven doors on the coke side of the battery. The coke oven shed is constructed to span the entire coke side of the battery including the coke side bench, hot car tracks and coke side doors. The internal support structure, geometric shape and method of fume transmission and scrubbing vary with respect to the manufacturer's design and customer's local requirements.

The shed is simply a large structure with enough cubic capacity to hold all the emissions for a single push. These emission are held in the shed's upper portion until system exhaust fans have had sufficient time to direct all captured gases through an appropriate cleaning system and return clean air to the atmosphere.

The first shed in the United States was erected and in operation during the first quarter of 1972. Since then, many sheds have been installed at various steel plants throughout the United States and Canada. Each of these installations is unique in that they all incorporate modifications to the first prototype, i.e., different shed dimensions, changes due to local plant conditions, and unlike fume cleaning systems, Fig. 7.47. Outside of the basic concept, each shed has its own inherent design and working parameters.

7.4.6.2 Traveling Hoods

The movable hood concept incorporates the addition of a large hood over the hot car from which the fumes generated during pushing are trapped and conducted to the selected gas cleaning system. This system was first developed by Mitsubishi and has been installed on many coke oven batteries in Japan since 1970. Several versions of this Mitsubishi system are in operation within the United States.

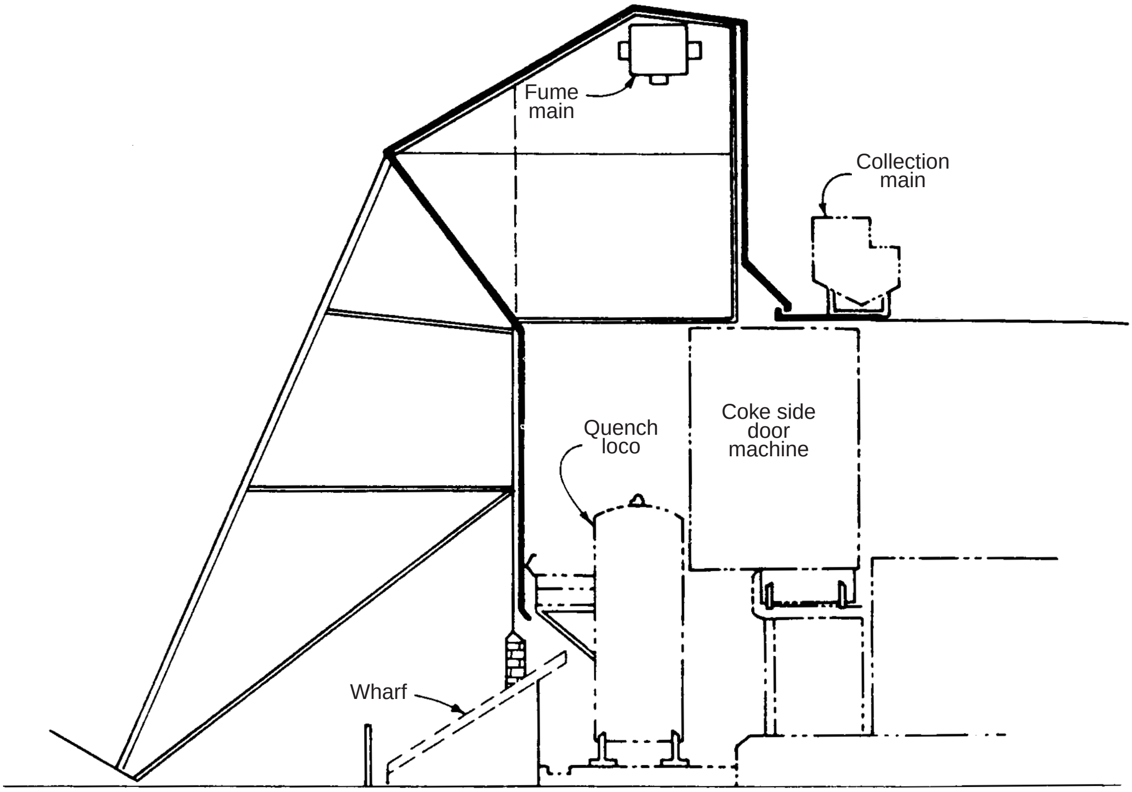


Fig. 7.47 Coke side shed for collecting emissions from a byproduct coke oven during the pushing operation.

In this system, an enclosure hood is suspended from the door machine and is fabricated over the coke guide and extends to cover the hot car. The emissions from the push are pulled by fan into a large duct extending the full length of the battery. This duct is stationary but allows for the interconnection between the hood transition piece and the duct at each oven by designing an appropriate opening at each oven. As the gases are collected in the hood during the push, the hot car moves under the hood and collects the coke. The effectiveness of the traveling hood design depends mainly on the designer being able to keep all interface openings between moving parts to an absolute minimum; that is, the interface points between the coke guide, oven jamb, enclosure hood and the hot car.

Another similar hooded system is the Minister-Stein system. The basic differences of the Minister-Stein system are: (1) the fume collecting duct is located outside the hot car track on heavy structural supports; (2) the duct is covered with a rubber belt and a mobile tripper carried with the hood is used for introducing the pushing emissions under the belt at the location of the push; (3) a large heat exchanger is carried with the hood to control the emissions and to protect the rubber belt while atmospheric air cools the heat exchanger between pushes; and (4) a third rail mounted on the duct bearing structure supports the hood and heat exchanger.

Fig. 7.48. Thyssen Still Otto modern coke side duct.

Modern design traveling hood systems, Fig. 7.48, are provided by all coke oven building companies. In the latest designs the hood is an integral part of the coke transfer car operating during all coke side functions.

7.4.6.3 Enclosed Quench Cars with Mobile Gas Scrubbing Systems

The use of these systems was stopped in the late 1980s due to excessively high operating and maintenance costs.

7.4.6.4 Wet Spray Pushing Emission Control Systems

Wet-spray systems are not literally a capture system, but an attempt to prevent the escape of emissions from the coke battery. These systems consist of a spray header with a series of spray nozzles which are directed at the coke as it is pushed from the oven.

Various systems for wet spraying coke have been tried with little or no success. Wet spraying has been judged by trained observers to be strictly cosmetic and not effective with regard to capture of particulate matter generated during the pushing operation.

7.4.7 Coke Screening and Handling

7.4.7.1 Coke Wharf

A coke wharf is substantially a long, narrow inclined platform with the shorter dimension sloping away from the quenching car track toward a conveyor belt that runs along the lower side of the structure. A properly designed wharf should be of such size that it will serve as surge storage for quenched coke ahead of the screens so that the short delays incidental to screening and loading

Fig. 7.49 General view of a manually-operated coke wharf showing freshly quenched coke being discharged from the gates of the quenching car onto the brick paved sloping wharf. When the wharf gates are opened, coke slides down the wharf as at the lower left onto a conveyor belt that carries it to the screening station

operations will not interrupt the desired regularity in oven pushing sequence. Most modern wharves are paved with hard-burned clay brick.

The coke wharf receives the quenched coke from the quenching car. The coke is spread out on the wharf in a thin bed for quick drying and visual inspection for the detection of unquenched coke. Manually directed streams of water are used to quench any still-hot coke detected on the wharf before the coke is conveyed on rubber belt conveyors to the screens.

The coke is retained on the wharf by a series of gates which, when opened, permit the coke to slide down the wharf and onto the belt conveyor to be delivered to the screening station. Fig. 7.49 shows a manually-operated coke wharf. The present trend is to use automatic mechanically-operated wharf gates, Fig. 7.50, with automatic sequence and memory circuits to maintain proper utilization of the wharf for surge capacity for the screens and the quenching car. In either case, whether operated automatically or manually, the wharf design and construction is the same.

The more modern coke wharves are provided with rotating coke plows. The coke wharf is designed with a flat shelf at the bottom of the sloping wharf. The coke plow consists of a multi-bladed variable speed rotating unit mounted on a frame which automatically travels back and forth over the length of the wharf. During travel in both directions, the rotating unit discharges coke from the wharf shelf onto the wharf belt. As the coke belt leaves the wharf, a temperature sensing device monitors the temperature of the coke and activates water sprays to cool any hot portions of coke.

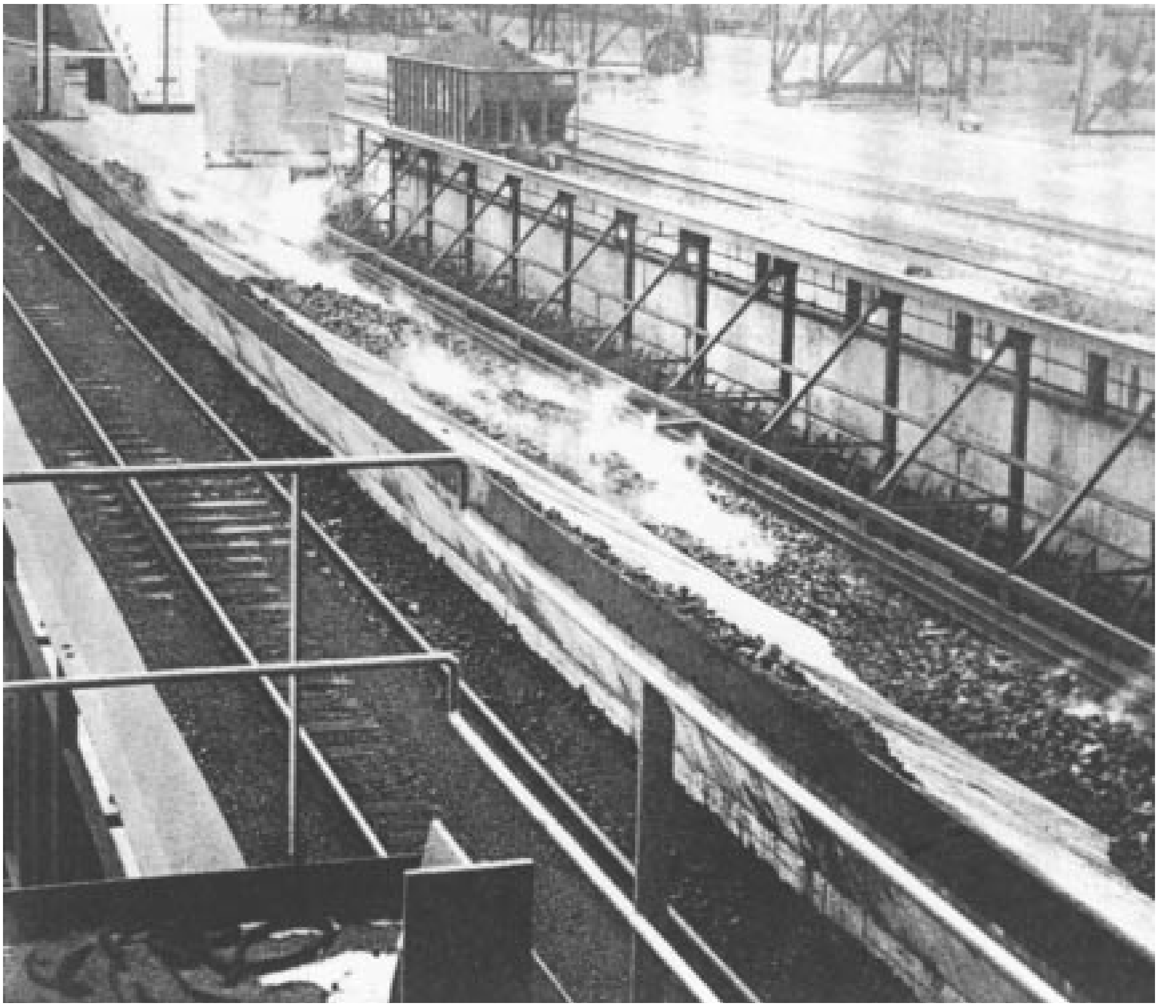


Fig. 7.50. General view of part of a modern coke wharf with automatic mechanically-operated gates.

7.4.7.2 Conveyor System for Coke

The transfer of coke from the wharf to the screening station now is accomplished almost universally by a system of rubber-belt conveyors and chutes.

7.4.7.3 Screening and Crushing

The purpose of coke screening and crushing is to provide coke of a controlled size for blast furnace use from which fines and, in some cases, pieces over a set maximum size are removed. The latter are crushed and screened before use. The very small pieces, commonly called coke breeze, usually are used in the coke plants as a boiler fuel, in sintering plants as sinter fuel, or screened for use in chemical or metallurgical processes.

7.4.7.4 Storage and Shipping

In the loading of blast furnace coke and the subsequent transportation to the blast furnaces, care must be taken to prevent additional breakage. For this reason, the coke is loaded into railroad cars and, where practical, is consigned directly to the blast furnaces, as additional handling into and out of stock results inevitably in coke degradation. When the blast furnaces are located close to the coke plant, belt conveyors often are used to conduct the coke from the screening station to the blast furnace stockhouse bins.

7.4.8 Refractory Materials used in Coke Battery Construction

A coke battery is basically a structure made of refractory materials held together by a steel exoskeleton. While constructed at ambient temperature, it is designed to operate at maximum temperatures up to 1455°C (2650°F). During operation, the maximum temperature can be expected to cycle downward by as much as 110°C (200°F) as part of normal battery operation. Consequently, the battery must be constructed of refractory materials that: (1) can withstand the maximum as well as the cyclic temperatures, and (2) have known and predictable properties related to thermal expansion, strength and creep, see Chapter 3.

7.4.8.1 Silica Brick

The most abundant refractory used in the construction of a coke battery is silica brick. Silica brick is manufactured primarily from the mineral quartz in finely crystalline form, and having the proper characteristics for conversion to cristobalite and tridymite, which are high-temperature crystalline forms of silica.[27] The quartz is obtained primarily from crushed quartzite rock, which is washed to remove natural impurities. The crushed and washed quartzite is ground further and sized into specific fractions which are then reblended in specific proportions, along with 2.0–3.5% (CaO), water and organic binders to achieve the proper brick chemistry. [27]

Brick shapes are produced by power and impact pressing, and those shapes that either cannot be mechanically formed or are only required in small numbers are hand made. [27] Immediately after forming, the green brick, held together by the organic binders, is dried. The two manufacturers of coke oven silica shapes in the United States have stopped the production of silica material. Silica brick is fired in periodic kilns and in some more modern production plants in continuous car tunnel kilns. The brick is fired to convert the quartz to cristobalite and tridymite, the stable high temperature forms of silica, which in turn renders the brick volume stable for service. It is necessary to maintain a carefully planned time-temperature cycle during firing because there are critical temperature ranges through which the silica brick must pass so that a strong, well-bonded brick results. The normal permanent expansion of silica brick during firing is 12–15%.

Silica brick has a relatively high melting temperature, 1695–1710°C (3080–3110°F), and it has the ability to withstand a 172 to 345 kPa (25 to 50 psi) load to within 28–56°C (50–100°F) of the ultimate melting point; therefore, it has excellent creep properties. The purity of the brick is important; for example, if the sum of alumina, titania, and alkalies content in a brick is 1.0%, the load to failure will be 28–50°C (50–90°F) lower than in another brick in which this sum is only 0.5%. At temperatures about 593°C (1100°F), silica brick is nearly volume stable and virtually free from thermal spalling, while at temperatures below 593°C (1100°F) silica brick is highly susceptible to thermal spalling.

Since the later 1950s there had been a general trend in the industry to use high bulk density silica brick (greater than 1858 kg/m^3 or 116 lb/ft^3) in coke oven battery construction, because increasing bulk density is accompanied by corresponding increases in cold strength and thermal conductivity. Therefore, it was presumed that higher heat transfer rates from flue to oven would be realized because of the higher thermal conductivity.

Measurement of flue to oven temperature differentials on operating batteries conducted by U.S. Steel showed that higher bulk density silica brick did not result in improved heat transfer over regular bulk density, 1740–1804 kPa (108–112 lb/ft^3) silica brick. In addition, a series of tests on silica brick of varying bulk density showed that the hot strength in the range of 649–1316°C (1200–2400°F) did not appreciably change as a function of bulk density, and that the lower bulk density brick were less brittle and less susceptible to failure from thermal cycling.

7.4.8.2 Fireclay Brick

Fireclay brick is used throughout the cooler parts of the battery, including the regenerator chambers, checker, battery roof, in the pinion walls, and in the coke wharf. According to ASTM standards, there are five general classes of fireclay brick: super duty, high duty, semi-silicas, medium duty, and low duty. Fireclay brick used in coke oven battery construction is generally of the high duty class.

Blends of five or more ground and sized clays are used to make fireclay brick; some brick, especially those in the low duty class, may be made from one clay. Mixes for high duty brick commonly contain raw flint and bond clays, possibly with calcined clays. In the high duty class, a large proportion of the mix is precalcined to control firing shrinkage, as well as to stabilize the volume and control mineral composition of the final product.

Fireclay shapes are formed by power pressing, extrusion and repressing, air ramming and hand ramming. The method of forming is selected on the basis of shape complexity as well as the properties of the fireclay that are required; however, as with silica refractories, small lots of a given shape may be hand formed. Fireclay shapes formed by all processes are dried on hot floors or in tunnel or humidity driers. After drying, the shapes are usually fired in continuous car type tunnel kilns; periodic type, downdraft kilns are rarely used. The firing temperature is dependent on the nature of the clays used and on the intended service of the brick. Free and combined water are lost during firing, and iron and sulfur compounds as well as organic matter are oxidized. The particles of clay are ceramically bonded together to form a strong refractory. High duty fireclay shapes are more resistant to spalling than medium and low duty products, and they are burned hard enough so that they are highly resistant to carbon monoxide disintegration.

High duty fireclay brick for coke oven battery construction generally is refractory to about 1704°C (3100°F); however it does not have the creep resistance of silica brick. High duty fireclay can be expected to deform 0.5% to as much as 4.0% under a 172 kPa (25 psi) load at 1349°C (2460°F). Fireclay brick has nearly a linear thermal expansion from ambient temperature to battery operating temperatures, as compared to silica brick, which has nearly all of its expansion taking place below 593°C (1100°F). As a result high duty fireclay brick can be repeatedly cycled through low temperature ranges without spalling failure. As mentioned previously, medium and low duty fireclay refractories, being more dense, are more susceptible to thermal shock.

7.4.8.3 Mortars

There are two primary types of mortars used in coke oven battery construction, silica coke oven mortar and fireclay coke oven mortar. The silica mortar is further divided into a heat-set and an air-set type; normally the silica brick in a battery is laid up with the heat-set type.

Silica mortars are made from a sized silica sand for aggregate along with some small amount of bond clay. The air-set silica mortar is the same composition, but is has a small amount of dry sodium silicate added. The fireclay mortar is made from a sized calcined kaolin with a small amount of bond clay. No mortar used in battery construction contains any type of cementitious bond. Silica mortars are refractory up to about 1682°C (3060°F) and clay mortars up to about 1604°C (2920°F). Shrinkage on drying from a workable or trowelable consistency is an important parameter, and is specified as less than 2.5% and 4.0% for silica and clay mortars, respectively.

Mortars used in coke oven battery construction do not develop a coherent bond with the refractory to which they are applied at normal battery operating temperatures. Mortars therefore do not contribute to the structural integrity of a battery. The mortar used in a battery serves two primary functions. It is used to compensate for inconsistencies in brick size, and it acts as a sealant between brick to prevent gas leakage among the combustion air, fuel gas, and foul gas systems within the battery.

7.4.8.4 Castables

Refractory concretes made with calcium aluminate (CA) cements and various refractory aggregates, are used in various locations in a coke oven battery. The service capability of a castable is dependent on the purity level of the CA cement as well as of the aggregate. There are three purity levels of CA cement, low purity, medium purity and high purity. The aggregates can range from calcined clays to high purity tabular alumina. Size grading of castable aggregates can also vary considerably.

From a practical standpoint, many castables are used in coke oven battery construction. These include low and medium purity castables. In addition to regular cement castables, low cement and ultra-low cement castables are used.

Low purity castables are used to line the waste heat tunnels and flues; it can be formed up and cast in place or it can be gunited. The gunite application is faster and lower cost. Low purity castables are also applicable to areas in the battery top, for example as a filler material in the parapet area. Low purity castables used in battery construction or repairs are generally specified to satisfy strength requirements and carbon monoxide resistance.

Medium purity castables are used for the higher temperature areas in a battery to which castables are applicable, for example door plug refractories and standpipe lining.

7.4.8.5 Expansion Joint Fillers

Expansion joints may be filled with vermiculite, an expanded mica, or with ceramic fiber bats of adequate density and refractoriness.

7.4.8.6 Packing Materials

Packing materials are used to seal between metal components and refractory brick, for example between the jamb and jamb brick, in stand-pipe split rings and slip joints and around air and waste-heat boxes. Asbestos rope had been the preferred and most commonly used packing material, but asbestos has long been replaced by synthetic fiber ropes.

7.4.8.7 Insulating Materials

Various types of insulating materials are used in battery construction, from insulating fire brick to low refractoriness insulating concrete made of an expanded clay or shale aggregate and calcium aluminate cement. Insulating fireclay bricks which are available from an 871°C (1600°F) class to a 1760°C (3200°F) class are used to insulate the battery top, areas behind the buckstays, regenerator walls and pinion walls. Block insulation can be used in non load bearing areas. Insulating concretes can be employed as fillers for irregular areas throughout lower temperature areas of the battery.

7.4.8.8 Acid Resistant Refractory Construction

The battery stack lining is of acid resistant construction, which consists of high density acid resistant fireclay brick laid up with acid resistant mortars. Acid resistant brick are usually made by the stiff mud process and are high fired so that low porosity (6–11%) and permeability result. Acid resistant mortars are generally potassium and sodium silicate bonded fireclay aggregate.[27] Ambient temperature levels are critical for good acid resistant construction. Mortars generally will not cure at temperatures below 13°C (55°F).

7.4.8.9 Fire Fused Silica

Silica (quartz) that is electrically fused, cooled, reground, then formed and refired is referred to as a fire fused silica shape. Fused silica is essentially amorphous (non-crystalline), containing low levels of quartz and cristobalite. Fired fused silica has a nearly flat thermal expansion curve, expansion being on the order of 0.72 K^{-1} (0.4×10^{-6} in./in./ °F); therefore, it has excellent resistance to thermal shock. A fairly common use of fired fused silica is for door plug refractories; however, refractory cost is two to three times that of a castable or brick door plug. Fired fused silica has also been used as jamb brick with varying degrees of success. Fused silica is useful where resistance to carbon buildup is desired.

Fused silica grain along with calcium aluminate cement is used to make fused silica castables. The castables, however, do not have the thermal expansion properties of the fired bodies. In general, the castables made with fused silica aggregates are subject to similar temperature-volume relationships as normal silica alumina castables in that aggregate sizing and cement content can have marked effects on volume stability.

7.4.8.10 Common Brick

Common red brick is used in a number of non-critical areas in battery construction, primarily in areas of low temperature and minimal exposure to thermal cycling. Common brick is a dense fired clay body. It is used as a filler in the battery roof, backup material in the pinion walls and often as an underlying course on the pad.

7.4.9 Coke Oven Repair Work

Coke oven batteries will have an operating life of twenty to forty years, depending upon operating conditions and battery maintenance. Usually, after twenty to thirty years of service, a battery will require specific repairs to the refractories, steelwork or machinery. These repairs, if properly performed, will require specific repairs to the refractories, steelwork or machinery. These repairs, if properly performed, will extend the life of the battery.

Because the coke oven repair work requires considerable expertise, only a few companies are qualified to make battery repairs. The complexity of coke oven repairs will not permit a detailed description of the procedures; however, Krupp-Wilputte Corporation, offers the following general description of coke oven repair work.

Brickwork repairs usually undertaken are the replacement of end flues, the replacement of oven walls between oven floor and oven roof, and emergency repairs inside the oven chamber.

Depending on how well a battery has been maintained, an end flue repair (usually two flues or more) is undertaken after about 20 to 25 years of service. This repair can be performed while the battery is in the hot condition making coke or after the battery has been completely cooled to atmospheric temperature. During the repair the buckstays may be replaced and work may be done on the oven doors, collecting mains and oven top. An end flue repair is estimated to last for five to ten years, after which additional repairs may be required.

Oven wall brickwork repair may consist of the placement of through walls (pusher side to coke side) above the oven floor and below the oven roof. At the same time brickwork repairs may be done in the corbel area, and face brickwork and individual oven roofs may be replaced.

If only a few oven walls are to be replaced, the repair is done with the battery in the hot condition with one or two buffer ovens (empty ovens) on each side of the wall being repaired. The other ovens of the battery may be producing coke. Before demolition of the damaged wall, roof support beams must be added in the adjacent ovens, insulating panels must be installed on the adjacent hot walls, charging car rail bridges must be installed on the oven top, and support provided for the oven roof under which the wall will be replaced. Care must be taken to maintain the heat in the regenerators and on the adjacent walls. On an individual oven wall replacement, the heatup period for the repaired oven is approximately 15 days.

If an entire battery of through walls is to be replaced from the oven floor to the underside of the oven roof, the repair may be performed with the battery in the idle hot condition or with the battery refractory cooled to atmospheric temperature.

The idle hot condition means that the ovens are maintained hot while the repairs are done. Pairs of walls are replaced together with the adjacent ovens maintained in the hot condition. Each pair of walls being replaced is called an increment and work may proceed on several increments at one time. The heating of each increment of the repaired walls takes approximately 15 days. Ovens may be placed back in service before all the walls have been replaced.

The replacement of the through walls of an entire battery may also be accomplished by permitting the battery to be cooled down to the cold condition under controlled conditions before the repairs are made. The cool down may take up to 21 days during which time pressure is maintained on the oven walls by adjusting the upper and lower tie rods. The oven roofs must be supported as described for the hot repair procedure. After the walls are rebuilt and before heatup, all the checkers must be removed from the regenerator and any cracks in the pillar walls must be cleaned and packed with ceramic floss before the checkers are replaced so as not to hinder brickwork expansion during heatup. The repaired battery is heated up in the same manner as a new battery.

A repaired battery with all new through walls, with proper maintenance can be expected to have a life of approximately 15 to 20 years at a fraction of the cost of a new coke oven battery.

With through wall replacement of an entire battery, with the repairs done in either the hot or cold condition, additional items usually replaced include the side buckstays above the bench, collecting mains, doors and jambs, oven top paving, and tie rods and springs.

Two other repair techniques have come into prominence. Ceramic welding is used to repair cracks, open joints and spalls in the refractory by fusing a ceramic material to the existing brick. Zero expansion brick repairs are used for panel patches or end flue repairs. Zero expansion brick repairs are used for panel patches or end flue repairs. The zero expansion brick repairs can be made under hot conditions without an allowance for expansion.

Today repairs in hot idle condition are preferred. In the case of a cold repair, the refractory block of a battery may be heavily damaged during cooling down by the contracting material. Bracing systems, even with increased forces, can not prevent these damages. If all damage can not be repaired on cold batteries, operation with blast furnace gas may not be possible due to unavoidable leakages in the regenerator area. Hot idle battery repairs are somewhat more expensive but provide the operators with the maximum life expectancy for the ovens.

7.5 Preheating, Stamp Charging and Briquetting of Coals

The growing worldwide shortage of high quality coking coal necessitates developments and measures which will enable the present range of coking coal to be augmented by coals which are less suitable for cokemaking. Therefore, in addition to the conventional method of preparing coal and charging it into byproduct coke ovens, several other methods of coal preparation and charging exist. Some of these latter methods have gained wide acceptance in the coking industry.

7.5.1 Coal Preheating

Coal drying and preheating prior to charging the coal to the battery ovens is not a novel idea. Thermal treatment of coals has been investigated since the 1920s. Earlier work involved heating the coal to reduce the moisture content to 1–2% and then charging the coal at ambient temperature into the coke ovens. In the 1950s studies were made of preheating the coal to elevated temperatures, up to 300°C (570°F), in an essentially inert atmosphere so as not to affect the coking characteristics of the coal by softening, devolatization or oxidation. The major problem encountered with the preheated coal was the potential hazard in charging the ovens. In the 1960s and 1970s serious interest in pilot plant scale activity became strong in Europe and the United States, culminating in the construction of commercial coal preheating facilities in England, South Africa, France, the United States and Japan, Fig. 7.51.

The major advantages of carbonizing preheated coal are listed below:

1. Coal preheating improves the strength and hardness of coke and allows the use of poorer quality coals. The coke produced from preheated coal is of closer size range, has smaller pores, higher true and apparent densities and a more homogeneous structure.
2. Preheated coal increases oven throughput because of reduction in coking time. The full extent of the production increases has not been realized because of lower than anticipated bulk density of coal in the oven associated with preheated coal charging.
3. The drying and preheating of coal in a flash dryer or fluidized bed is more efficient than in a battery oven. The higher thermal efficiency of coal preheating systems allows reduction in overall fuel requirements.
4. Charging preheated coal of fairly uniform moisture content results in more uniform heating of the batteries and less thermal shock to the refractory brickwork when compared to wet coal charging.

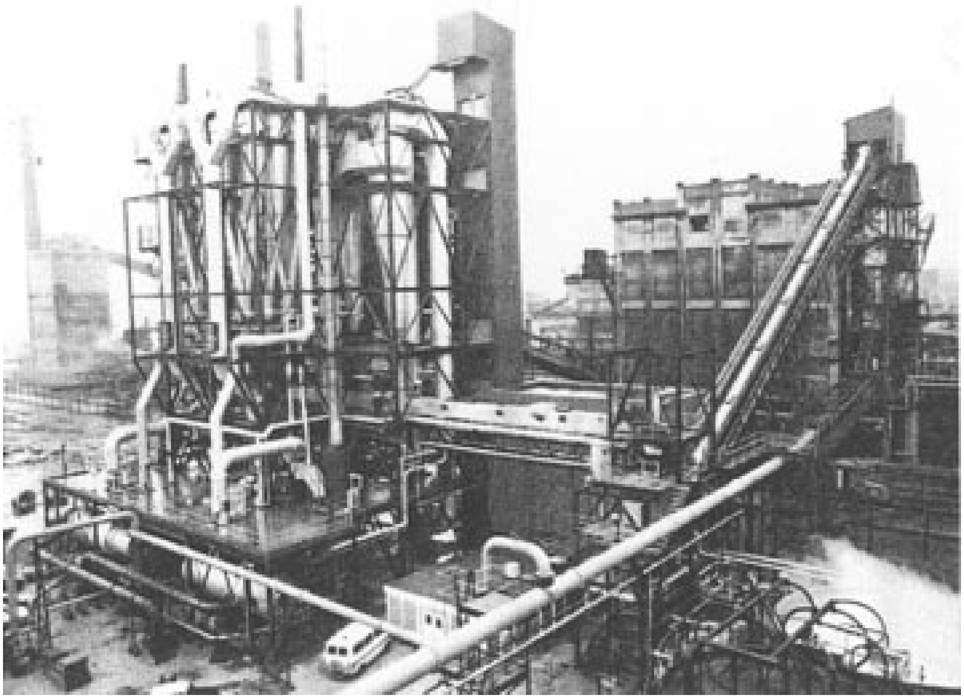


Fig. 7.51 Overall view of a coal preheating facility.

5. Closed oven charging via pipeline or chain conveyors has a potential of eliminating emissions during the coal charging phase.

The disadvantages of coal preheating are the potential safety and operational problems associated with preheating and handling of very fine hot coal, overfilling of battery ovens, high initial evolution of gases during the charging step and increased amount of coal carryover to the byproduct area.

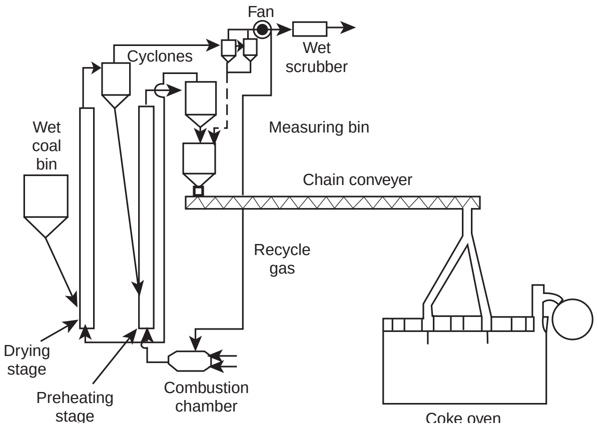


Fig. 7.52 Schematic arrangement of a Rosin-Buttner type of coal preheating unit.

7.5.11 Preheating Systems

Basically two different coal preheating systems are used in drying and preheating of the coal: (1) the flash drying and preheating system such as Rosin-Buttner shown in Fig. 7.52 and (2) a fluidized bed and entrainment system such as Cerchar shown in Fig. 7.53. Other processes use combinations of different preheaters, conveying and charging systems.

The Rosin-Buttner type preheating unit is a two stage entrainment dryer/preheater. Wet coal is fed by a centrifugal feeder into the first stage where it is flashdried and preheated to approximately 80°C (175°F) and 2–3% moisture by concurrent flow of hot gases from the second stage unit. The entrained coal is separated from the gas in a cyclone and is conveyed to the second stage unit in which the coal is preheated to 200–230°C (390–445°F). The hot gases flowing concurrently are supplied in part by burning natural gas or coke oven gas in a combustion chamber supplemented by a recycle stream of inert gas from the first stage. The preheated coal is separated from the gas stream by a series of cyclones and is conveyed to a set of storage bins to be charged to the battery ether by drag conveyors or a hot coal larry car. Part of the process gas from the first stage is scrubbed or cleaned in the electrostatic precipitator and the rest is recycled back to the combustion chamber.

The Cerchar preheater is a single stage fluidized bed and entrainment unit. The wet coal is fed by a double screw conveyor into a flash drying section. The velocity of gases is high enough to transport

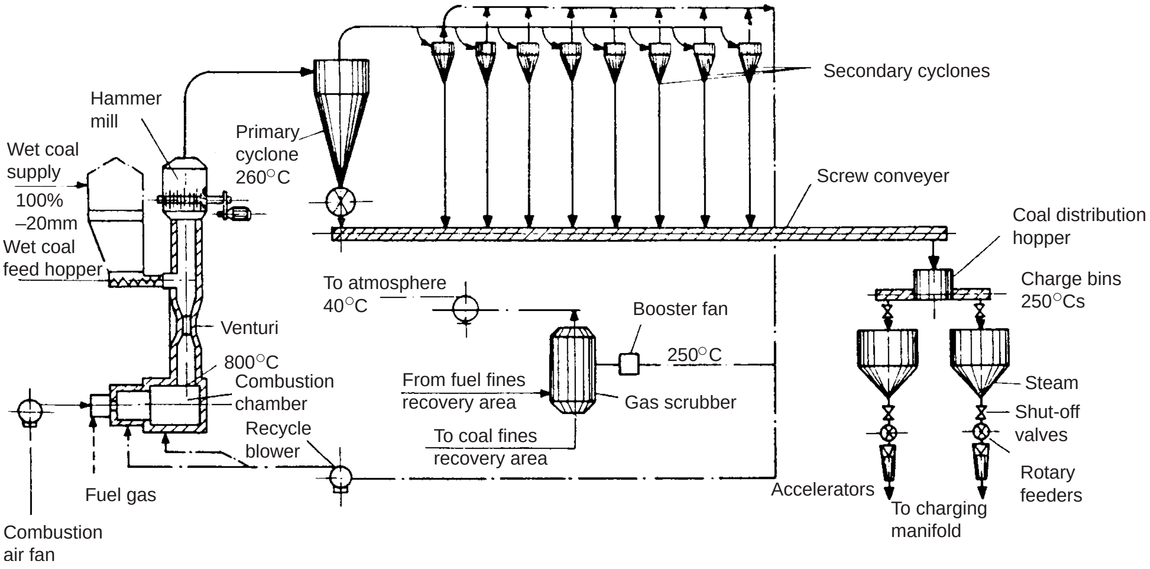


Fig. 7.53 Schematic arrangement of a Cerchar type of coal preheating plant.

all the coal upward. The coal is dried and preheated in a fluidized bed in which a crusher disperser decreases the size of coal until it is removed from the preheater by entrainment. Coal is separated from the gas stream in a series of cyclones and is conveyed to a storage bin. The offgas is split, part of it returning back to the combustion chamber and part of it being cleaned in a wet scrubber.

The most common coal preheating processes operating in the world today are described below.

The Coaltek system is a combination of a Cerchar single stage fluidized bed entrainment preheater coupled with a pipeline charging system developed by Allied Chemical. The preheated coal is discharged from the storage bin to weigh bins. The bins are pressurized with steam after the proper amount of coal is loaded, and coal is then conveyed via a pipeline aided by additional steam jets to the battery oven. The coal and steam entering the oven are then separated by a specially designed baffle, and the gases emitted during charging are channeled to a specially designed collecting main.

The Precarbon process, developed by Bergbau-Forshung and Didier of Germany, utilizes a Rosin-Buttner type of double stage entrainment dryer/preheater coupled with sealed drag conveyor charging of the preheated coal by way of a charging chute system to the battery oven. The charging is accomplished by specially designed pneumatic level probes which automatically stop charging preheated coal when predetermined coal lines are obtained. Two of the three 6 metre batteries being operated by U.S. Steel at its Gary Works are equipped with Precarbon processes.

The Otto-Simon Carves system is a combination of a Rosin-Buttner type double stage entrainment preheating system and a hot larry charging system. This system was one of the first ones commercially installed in South Africa and in England.

A preheater developed by Buttner-Schilde-Haas of Germany was installed by U.S. Steel in 1978. The BSH process utilizes a single stage entrainment type preheater which is equipped with a solids recycle system. The classifier at the exit of the column allows recirculating of a variable amount of coarser material back to the preheat column. The preheat system is coupled with a hot larry car charging system.

The worldwide steel industry is challenged with providing facilities to produce high strength coke from increasingly poorer coking coals. Coal preheating combined with charging of preheated coal is an economically viable process that offers the steel industry a method for attaining this goal, as demonstrated by general acceptance of the practice of coal preheating.

7.5.2 Stamp Charging

Stamp charging is a process where the entire coal charge to the coke oven is stamped, or compressed, and then pushed into the oven for coking. It is an old process with the greatest amount of activity in the Saar Basin area near the France and Germany border, in Germany near the Polish border, and in Poland. Other areas of use include Eastern Europe and India. In the Saar Basin, stamp charging has been in use for over a hundred years. This process has never been used in the United States due to an abundance of good coking coals.

In the stamping process, the coal blend is charged into the stamping chamber, Fig. 7.54 and Fig. 7.55, which is part of the pusher machine and has slightly smaller dimensions than the coke oven. The charging to the stamping machine is done in layers, with each layer approximately 460–500 mm (18–20 in.) in thickness. Each layer is compressed using two stampers which are lifted mechanically and fall by their own weight on the coal. When enough layers to fill the oven have been made, the side walls of the chamber are withdrawn and the coal is pushed into the oven on the movable bottom. The front panel is removed on the coke side and the bottom is withdrawn. The stamping operation takes about 20 minutes, depending on the height of the oven.

The main advantage of stamp charging is the increased bulk density of the charge. Bulk densities of up to about 1.15 tonnes/m^3 (72 lb/ft^3) have been achieved using this process. Excessive coking pressure is avoided by the addition of coke breeze to the blend, which cuts down on blend expansion, and by using less pressure generating coals in the blend. The stamping process brings the coal particles

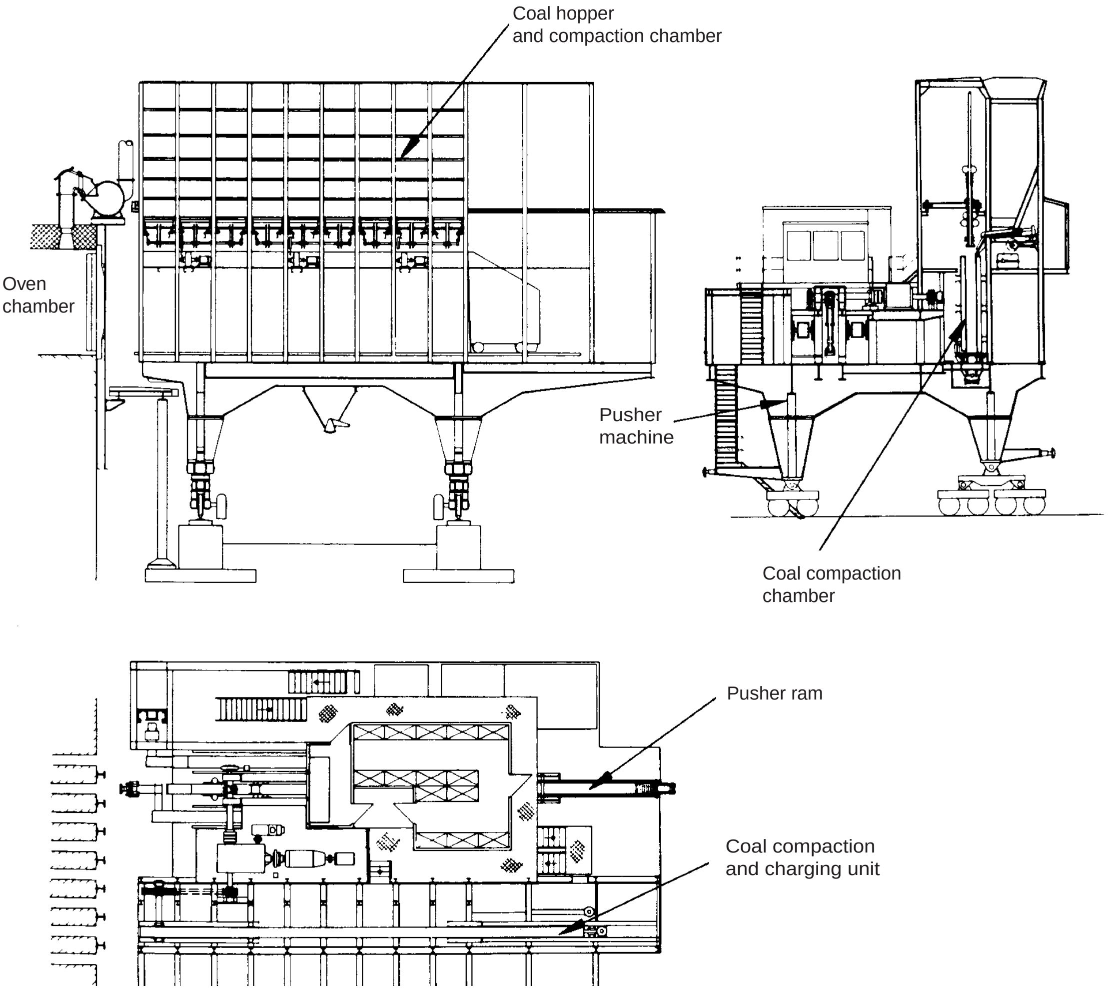


Fig. 7.54 Top, side and end elevations of a coke oven pushing machine incorporating a stamp charging unit.

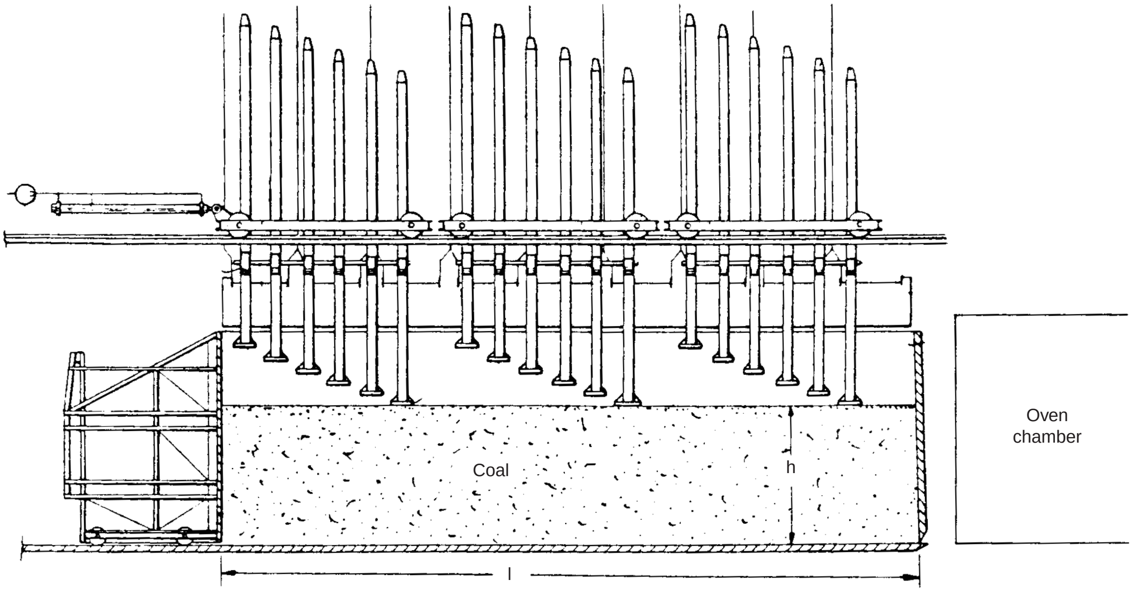


Fig. 7.55 Schematic section showing side view of a stamp charging unit.

into more intimate contact with each other, which enhances the coking properties. This process was developed as a way to make high strength coke from the relatively poor quality coking coals found in these areas. The coals are either too low in rank and/or too high in organic inert contents to produce strong coke by conventional means without bringing in expensive, better quality coking coals.

Stamp charging produces a more abrasion resistant coke, and the yield of blast furnace size coke is higher than with conventional charging. In addition, even though some coke oven volume is lost due to the thickness of the charging chamber floor and the oven taper, and longer coking times are required, the amount of coke throughput is increased about 5% over conventional charging.

The initial capital costs are high due to the expense of the combination stamping/pushing machine and the complex charging procedure. There is no need for a larry car, however. Gas emission problems used to occur during charging, but new procedures such as charging with suction have helped in this area. The need for better coke quality and higher coal throughputs dictates that stamp charging techniques must be improved and further developed, especially in view of the fact that chamber heights are continually being increased.

7.5.3 Briquette Blending

Sumitomo Metal Industries and Nippon Steel Corporation in Japan have been engaged for many years in producing high strength coke from partially briquetted coal blends. This enables them to use up to about 20% of what they consider to be non-coking or poorly coking coals. This was out of necessity due to the increasingly large amounts of Australian, Canadian and Russian coals they import. These coals have low fluidities and high organic inert contents which make them much poorer in coking quality than American medium and low volatile coals, but they are much less expensive than American coals, and the supply is more dependable. The processes described in this section involve partial briquetting of the coal blend with a binder, and charging the briquettes into the coke oven along with the unbriquetted coal blend.

7.5.3.1 Sumi-Coal System

In this system, about 30% of the coal blend is briquetted, with the briquettes containing about 7% tar or pitch as a binder. This process enables the use of high inert, low fluidity coals in the blend, while still producing high strength coke.

In the briquetting process, Fig. 7.56, coking coal is drawn from the fine coal circuit and crushed to about 85% –3 mm (–⅛ in.). The non-coking coals, which are used only in the briquettes, are crushed through a special hammermill also to about 85% -3 mm (–⅛ in.). The coals are mixed in a ratio of approximately 60–65% non-coking coals to 35–40% coking coal, and brought by chain conveyor to three briquetting line hoppers. Each hopper feeds two externally heated kneaders where the binder, which has been heated to above its softening point, is added, and the materials are well mixed. The heated mixture is conveyed by screw feeder to the briquetting machine where briquettes, approximately 19.665 cm^3 (1.2 in.^{3}) in size, are made in a double roll briquetting machine. Previously the unbriquetted material was recycled through the briquetting machine, but now it is fed to the fine coal conveyor belt. The briquettes are then mixed directly into the regular blend for charging.

The briquette blending in the Sumi-coal system enables the use of up to about 20% non or weakly coking coals in the blend without adversely affecting coke strength. Use of less than 20% results in improved coke strength. The improvement is believed to be due to the more intimate contact in the briquettes between coking and non-coking coal particles, the improvement in fluidity and dilatation due to the binder, and the approximately 48 kg/m^3 (3 lb/ft^3) increase in the bulk density of the charge. The bulk density increase, though, is offset by an approximately 10% longer coking time required, so that productivity is basically the same at the 30% briquette level.

Sumitomo feels some of the merits of the process are that it generates less coke breeze due to the increased strength, it provides stable blast furnace operation and a reduction in coke consumption in the blast furnace, and, therefore, a correspondingly lower amount of imported coal is needed.

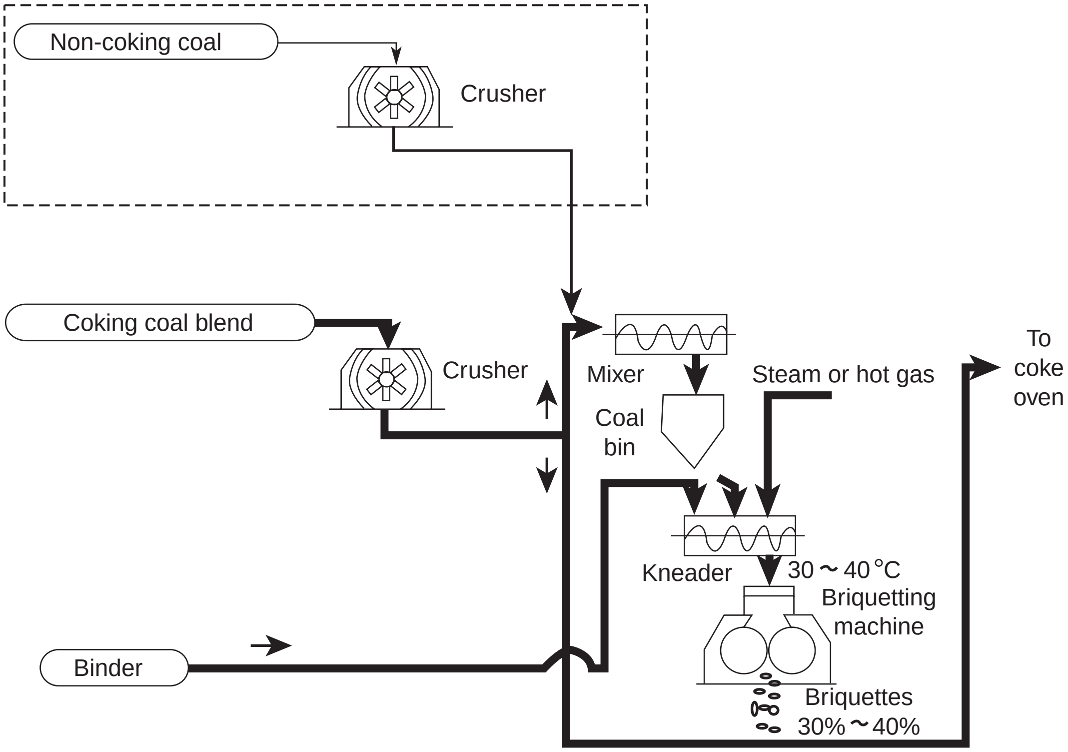


Fig. 7.56 Simplified flow diagram of Sumi-coal system.

In addition, Sumitomo lists advantages of the briquette blending over coal preheating to be that more of the cheaper non or poorly coking coal can be incorporated into the coal blend, operating costs are cheaper, simpler and more stable equipment is used, and installation into existing plants is easy.

7.5.3.2 Nippon Steel System

The briquette blending system employed by Nippon Steel, Fig. 7.57, is similar to that employed by Sumitomo. The principle of bringing the coal particles in more intimate contact in the briquettes and the effect of the binder are basically the same. The major differences are that:

1. The non-coking coal is used to replace approximately 10% of the American medium and low volatile coals, and the blend is adjusted accordingly.
2. The non-coking coal is not kept separately from the coking coal, but is in the blend; therefore, some of the non-coking coal is not briquetted.
3. In the mixing and kneading procedure a higher temperature is used, so that the briquettes are cooled before storage.
4. The briquettes are stored separately and not blended with the regular charge blend until just before entering the larry car for charging.

As with Sumitomo system, Nippon Steel uses approximately 30% briquettes in their coal blends. By 1976, about 27% of Nippon Steel's cokemaking capacity had briquette blending facilities. Their policy has been to use the briquette blending process on existing batteries, and to use coal preheating on new battery construction.

Nippon Steel began work on the briquette blending process in the later 1950s and early 1960s, with the first commercial use on-line in 1971.

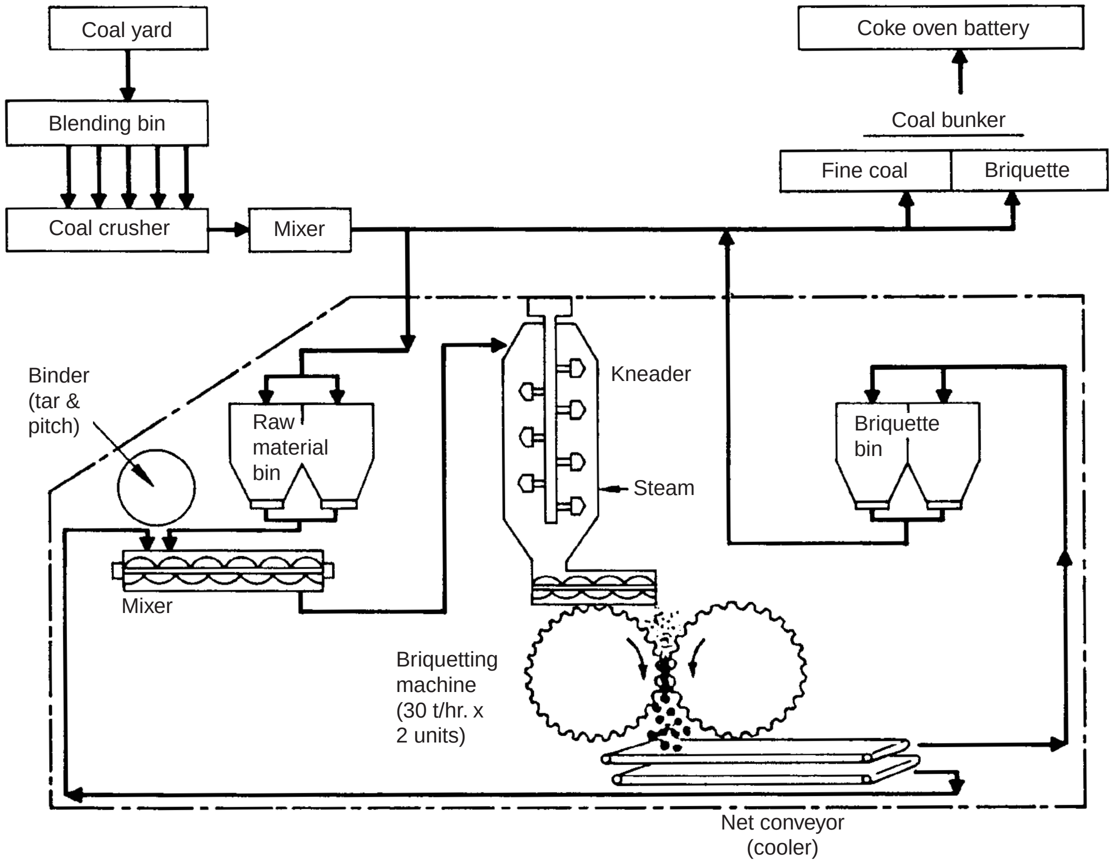


Fig. 7.57 Schematic flow of diagram of Nippon Steel's briquette blending system.

7.6 Some Proprietary Designs of Modern Byproduct Coke Ovens

7.6.1 Introduction

Since the publication of the 10th edition of *The Making, Shaping and Treating of Steel* in 1985,[28] there has been considerable consolidation among the prominent coke oven designers and builders. Koppers has become ICF Kaiser Engineers. Wilputte became Krupp Wilputte, a division of Krupp Uhde. Firma Carl Still and Dr. C. Otto combined to form Still Otto which was purchased by Thyssen and is now known as Thyssen Still Otto. This consolidation trend is expected to continue.

The most prevalent designs of byproduct coke ovens in the United States have been the Koppers and Koppers-Becker ovens and the double-divided (also called four-divided) oven design of Wilputte. Ovens of these designs comprise a majority of the byproduct coking capability of this country. Batteries designed by Thyssen Still Otto and Krupp Uhde, both of Germany, have gained popularity in recent years. Metallurgical coke is the primary product, since the coal chemicals recoverable in the byproduct coking process have strong competition from their counterparts derived from petroleum (petrochemicals).

Extensive descriptions about the Didier design, the Dr. C. Otto design, the Firma Carl Still design and the Nippon Steel Corporation design are presented in the 10th edition of *The Making, Shaping and Treating of Steel.*[28] Those designs will not be presented in this section. The reader is referred to pp. 206–229 of the 10th edition for further information concerning those proprietary design types.

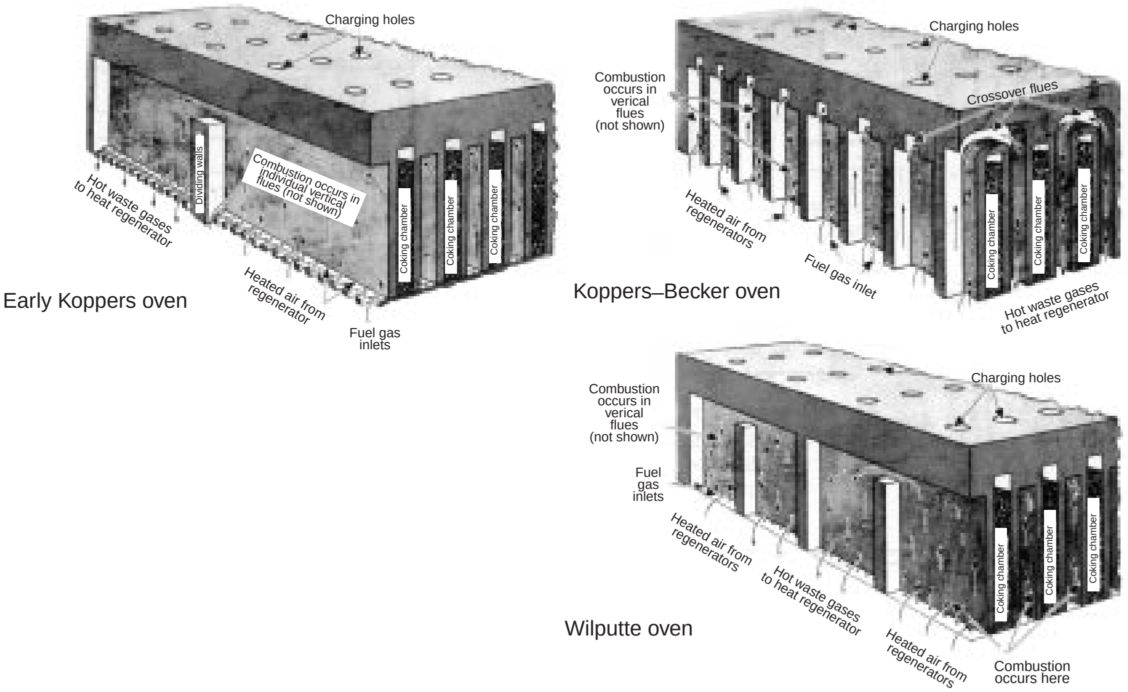


Fig. 7.58 Schematic representation of the differences in firing methods employed in the three most common types of byproduct coke ovens used in the United States. Individual flues are not shown. The firing procedures shown are for a single phase of heating which is reversed at the end of a specified period, at which time the flow directions indicated by the arrows become reversed.

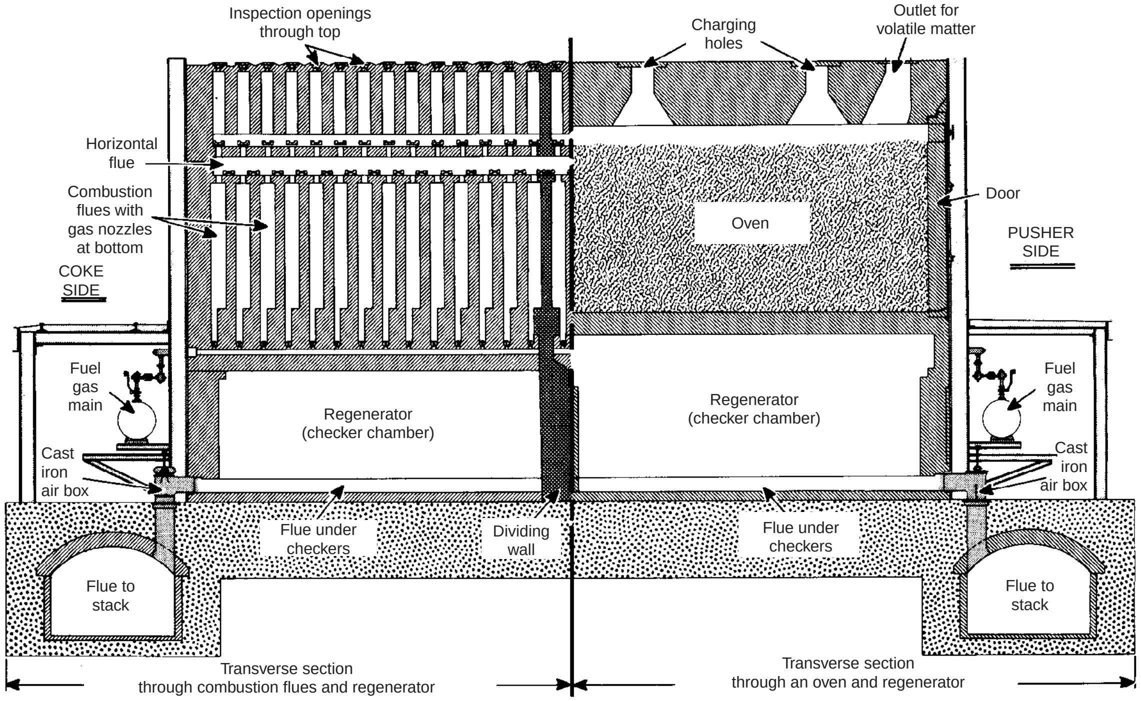


Fig. 7.59 Transverse sections of Koppers regenerative single-divided by product coke oven battery. Section at left is through combustion chambers (flues), that at right is through oven chamber.

The chief differences in the Koppers, Koppers-Becker and Wilputte design types are in the heating system. Fig. 7.58 illustrates, by simplified sketches, how each of these types is heated. A fourth general type, the hairpin- or twin-flue oven, is discussed later in Section 7.6.4.

The Koppers oven, more technically referred to as a regenerative, single-divided oven, was the most prominent from about 1916 to 1928, and many are still in operation. In a typical oven of this design, Fig. 7.58 and Fig. 7.59, all parts except the regenerator checkers and battery tip are constructed almost entirely of high-quality silica brick.

The majority of ovens of this type initially constructed in the United States had a coking volume of approximately 14 m^3 (500 ft^3). The general dimensions of these ovens were: length, 11.28 m (37 ft) from face to face of the doors; height, 3 m (9.8 ft) from floor to roof; and width, tapering from 430 mm (17 in.) at the pusher end to about 495 mm (19.5 in.) at the discharge end. Usually, four charging holes were provided in the top of each oven for admitting the coal charge, while a separate opening in the top at one end provided an outlet for volatile matter. The oven is of the vertical-flue type with individual regenerative chambers, Fig. 7.59. The heating chamber has a total of about thirty vertical flues per flue wall.

The flues are provided with openings to the regenerator chambers, the fuel-gas mains, and to a large horizontal flue on a level a little below the tope of the coking chamber. A dividing wall near the middle of the regenerators separates the heating system, except the horizontal flue, into two parts with (in the case of the thirty-flue wall) sixteen vertical flues on the narrower end of the oven and fourteen on the wider end. Each end, approximating half of the oven, thus may be heated alternately, and in practice the reversals are made at regular intervals for each battery of ovens by a reversing mechanism controlled by a timing device. Two large underground flues, one on each side, extending along both sides in front of and parallel to the battery, and connected to the checker chambers (regenerators) by cast iron air boxes, provide for escape of the products of combustion. These flues lead to a stack about 61 m (about 200 ft) high at one end of each battery to furnish the draft necessary to draw the gases through the heating system.

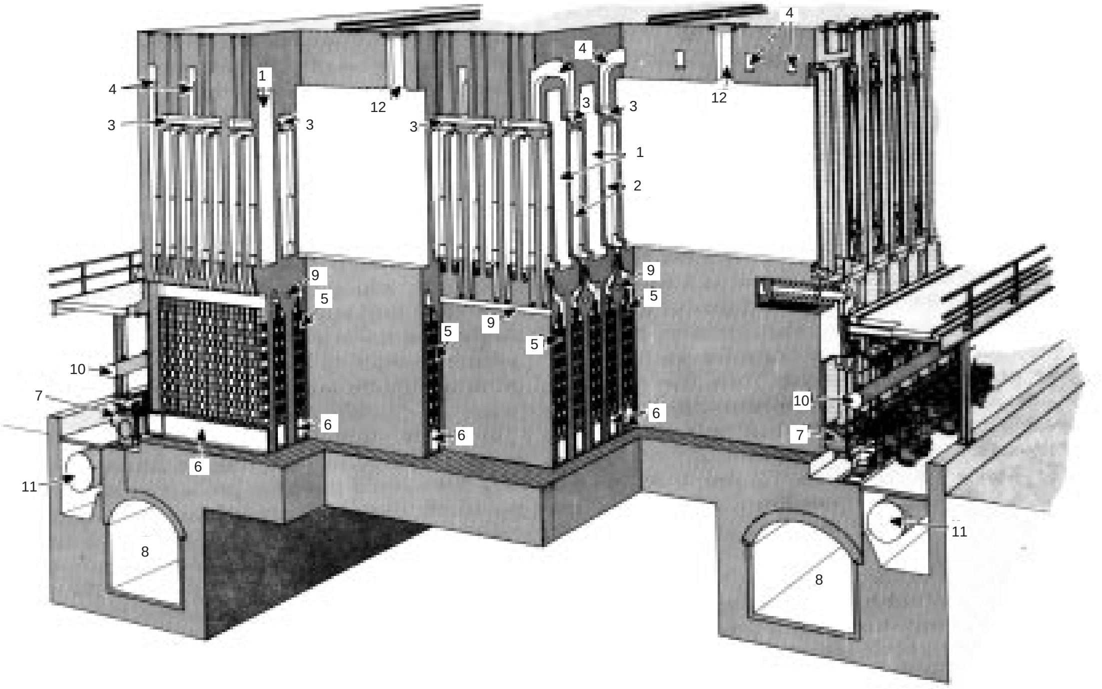
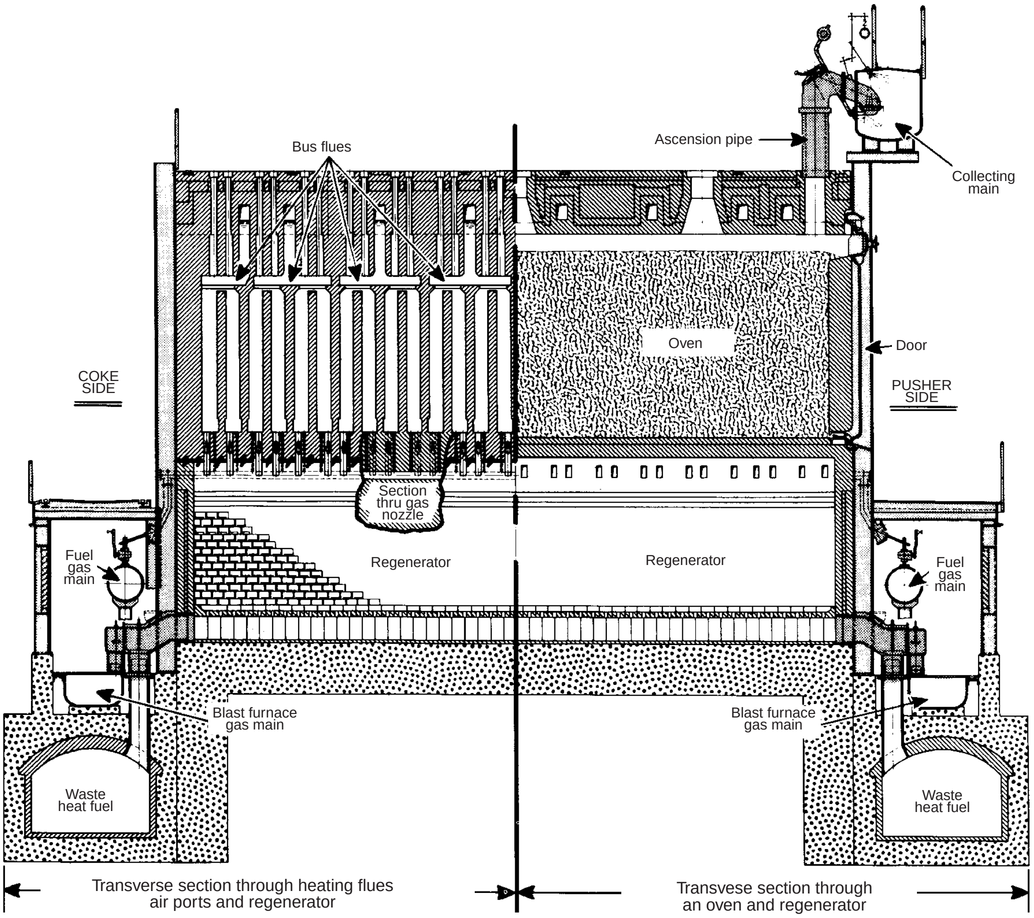
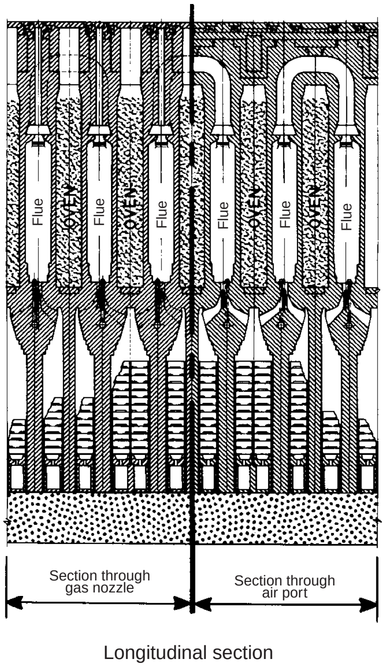


Fig. 7.60 General perspective cut-away section of Koppers-Becker combination ovens with gun-flue heating facilities (see Fig. 7.63 for underjet-fired type). Legend: 1. oven chamber; 2. vertical combustion flues; 3. horizontal flues; 4. cross-over flues; 5. regenerators; 6. oven sole flues; 7. gas and air connections to waste-gas flue; 9. gas ducts for coke oven; 10. oven gas main; 11. blast furnace gas main; 12. charging holes.



(a)



(b)

Fig. 7.61 (a) Transverse section though a Koppers-Becker combination gun-flue type byproduct coke oven battery; (b) longitudinal section (left) through gas nozzles and (right) through air ports of a portion of a Koppers-Becker combination gun-flue type byproduct coke oven battery.

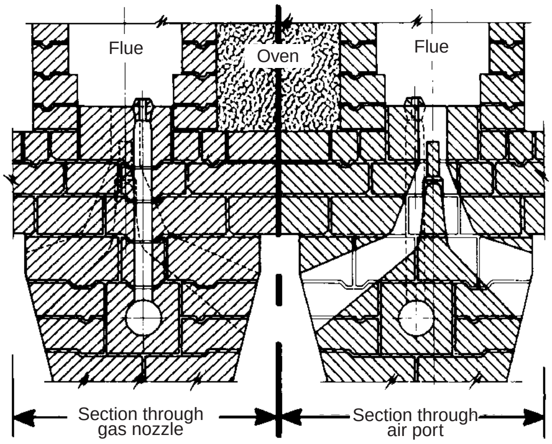


Fig. 7.62 Enlarged sections through gas nozzles and air ports of a Koppers-Becker combination gun-flue type of byproduct coke oven, showing detail of part of Fig. 7.61(b).

The Koppers-Becker oven (Fig. 7.58, Fig. 7.60, Fig. 7.61, Fig. 7.62 and Fig. 7.63) employs a different flue arrangement whereby gas is burned on an entire wall simultaneously (both pusher and coke sides). The products of combustion from two or more vertical flues of the "on" walls in which fuel gas is burning enter short bus flues and thence are conducted over the top of the oven through cross-over flues to a companion series of bus flues whereby the vertical flues of the entire "off" wall simultaneously are conducting waste gas to the regenerators. On reversal, the opposite conditions occur. This design, by eliminating the large horizontal flue, is well adapted to ovens of greater size, and to heating with blast furnace gas of low calorific value. Because the flues in each wall (coke side to pusher side) are connected only to the flues in its companion wall, there are cross-over flues over only every other oven, and the battery thus is limited to an uneven number of ovens.

The Wilputte byproduct coke oven is offered with various divided zone heating systems, each depending on the particular application. The double-divided or four-divided oven (Fig. 7.58, Fig. 7.64 and Fig. 7.65) has two outer zones and one double inner zone. Larger ovens with coking chambers of 39.64 m^3 (1400 ft^3) and over will be of similar design, but they will be six- or eight-divided, especially when required to operate on lean gas.

In recent years, larger and faster operating byproduct coke ovens have been constructed. Designs have been keyed to higher production rates and improved efficiency, with extensive use of automatic control and mechanization. Modern coke oven batteries planned and constructed with these features will be described in the remainder of Section 7.6. The designs to be described first originated in the United States and represent those of Koppers in Section 7.6.2 and Wilputte in Section 7.6.3. Descriptions of oven designs developed by Thyssen Still Otto Anlagentechnik GmbH are presented in Section 7.6.4.

7.6.2 Koppers Design

Modern byproduct coke oven batteries of the Koppers design include a number of different types and variations which can be tailored to the requirements of each individual installation. The Engineering and Construction Division of Koppers Co., Inc. was purchased by Kaiser Engineers in 1985. This sale included all patents and technical rights to the former Koppers Co. Inc. technology. Today, ICF Kaiser Engineers continues to offer this technology to the iron and steel industry.

The three types of ovens offered are: (1) the Koppers single-divided oven; (2) the Koppers-Becker oven; and (3) the Koppers twin-flue oven.

These oven types are built as either underjet or gun-flue ovens. The heating systems are designed as combinations for heating with either lean or rich gas, such as blast furnace gas or coke oven gas; or alternatively, for heating with rich gas only.

Oven dimensions vary considerably, depending upon whether the new ovens must meet some dimensions or clearances set by existing ovens or oven machinery. Where no such restrictions exist, the trend has been toward higher and longer ovens. Oven heights range from 3 m (9.8 ft) to 6.5 m (21.3 ft). Oven length ranges from about 11.3 m (37 ft) to about 16 m (52.5 ft). Oven average width usually is between 432 mm (17 in.) and 467 mm (18.4 in.), although some narrow ovens of 362 mm (14.3 in.) average width have been built to handle poorly coking coal.

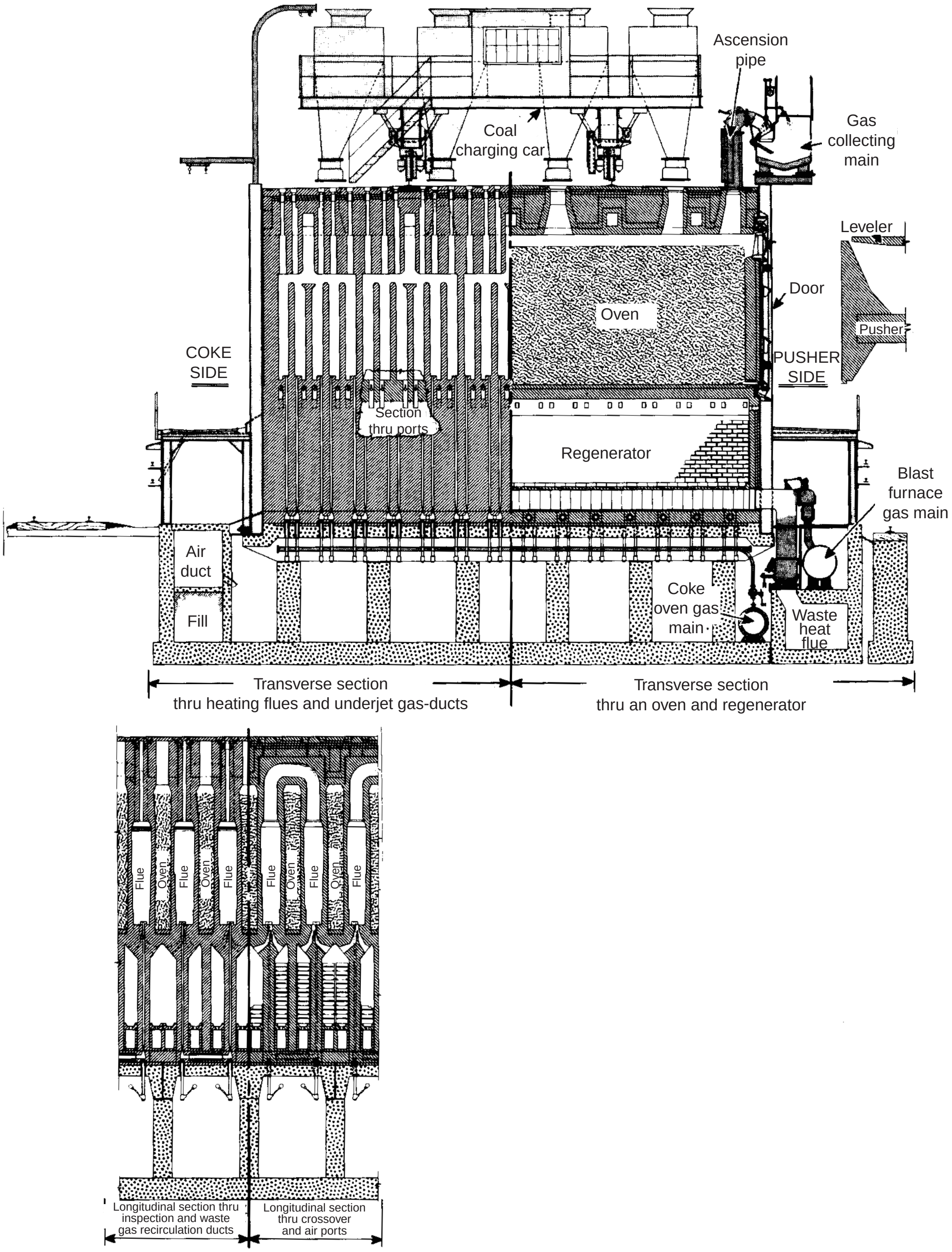


Fig. 7.63 Tranverse and longitudinal sections through Koppers-Becker combination gun-flue type of byproduct coke oven, showing detail of part of Fig. 7.61(b).

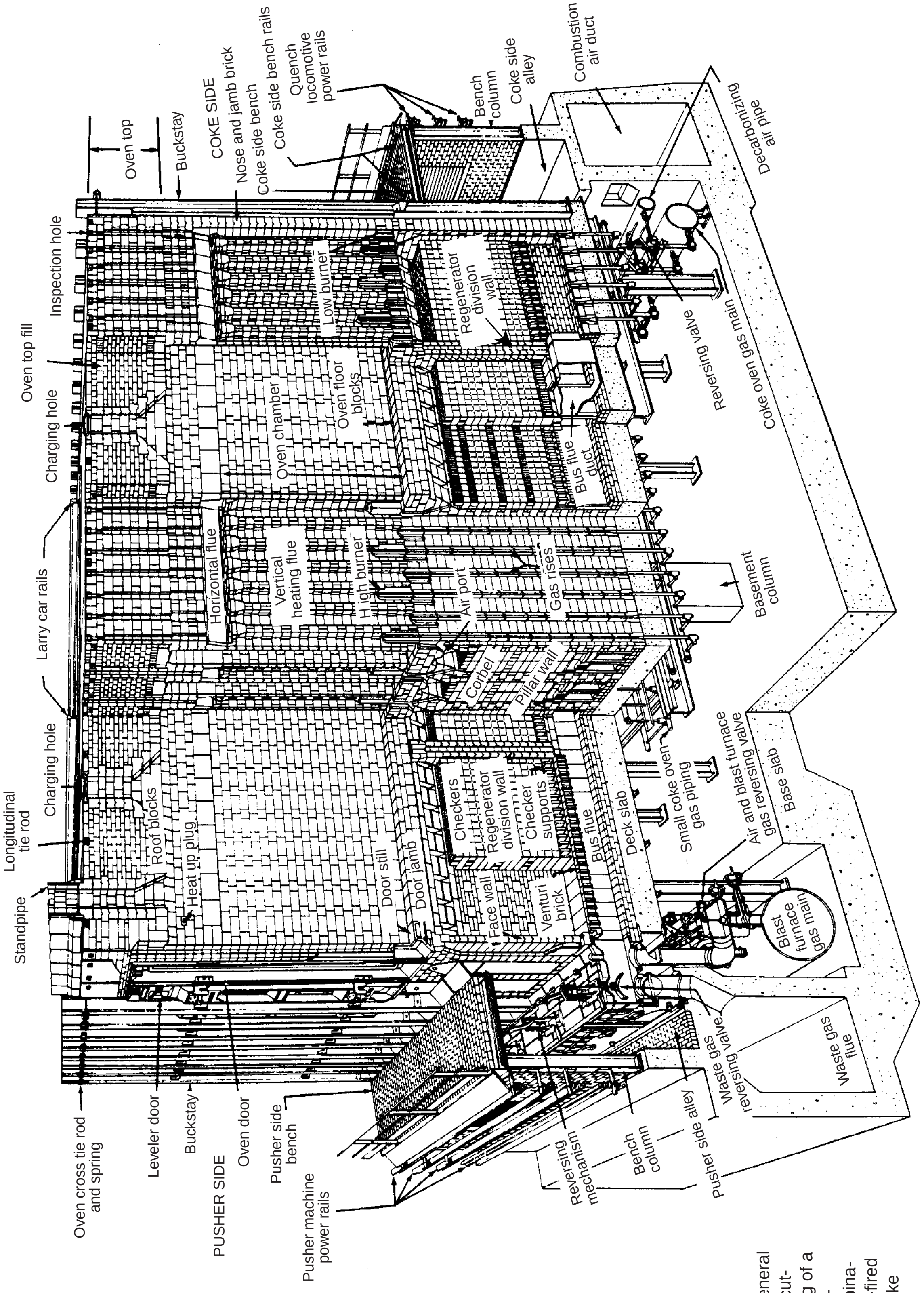


Fig. 7.64 General perspective cut-away drawing of a Wilputte four-divided combination underjet-fired byproduct coke oven.

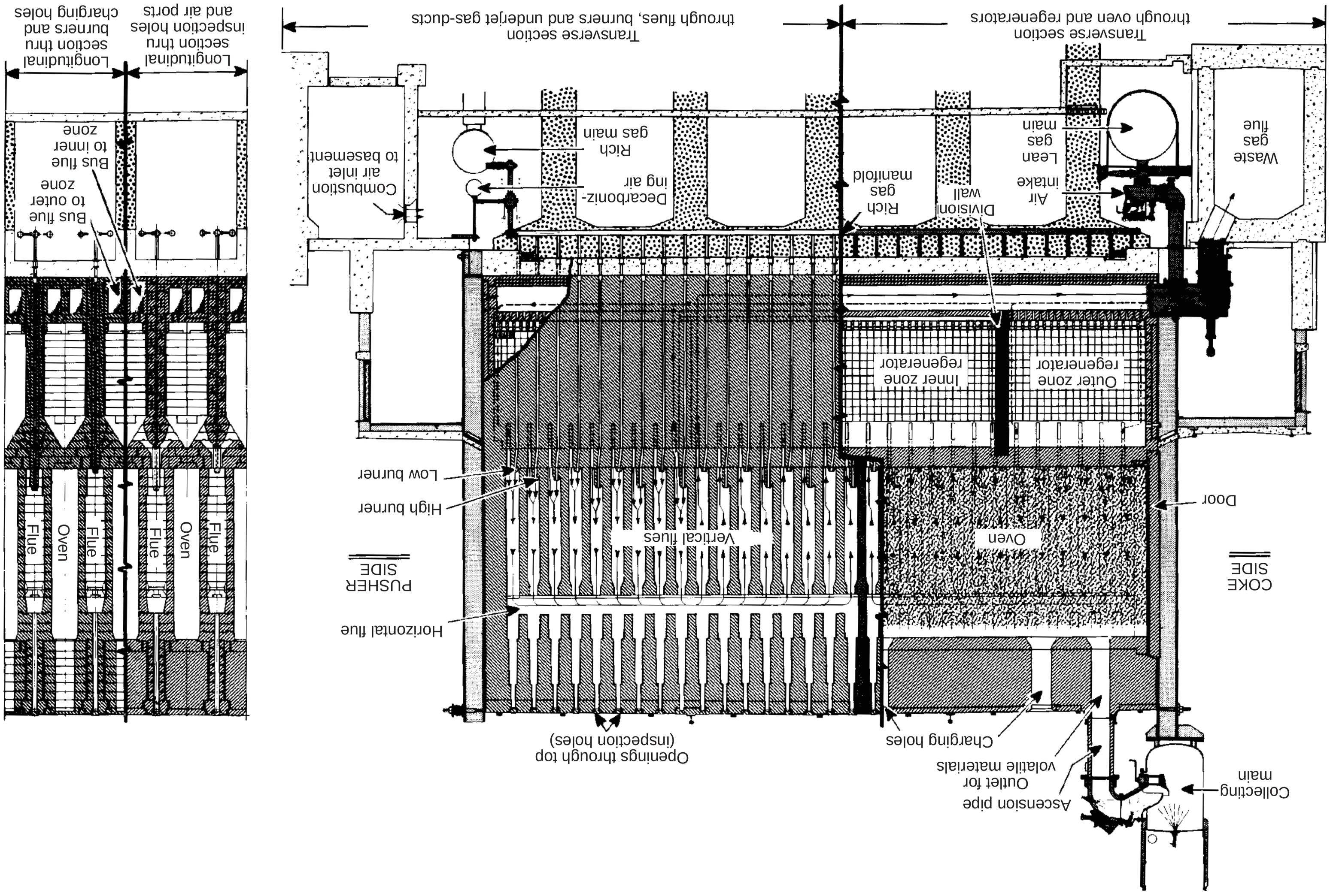


Fig. 7.65 Sections through a battery of Wilputte underjet, combination, byproduct ovens, designated as double-divided ovens, having two outer zones and one double inner zone in the heating system. The rich gas and lean gas referred to on the drawing are coke oven gas and blast furnace gas, respectively.

7.6.2.1 Koppers Single-Divided Oven

The Koppers single-divided oven was the original oven type developed by Koppers. Over the years the design details have been improved and the oven dimensions increased to the point where this design provides a rugged, simple battery where limited oven height (under 4.27 m or 14 ft) is required.

While most of the Koppers single-divided ovens have been built as gun-flue ovens, this design can be built as an underjet type. It is usually designed for heating with rich gas only.

The distinguishing features of the Koppers single-divided oven are the single division wall near the center of the regenerator chamber and the long horizontal flue connecting the tops of all the vertical heating flues in each flue wall. This design is illustrated in Fig. 7.59.

The Koppers single-divided oven is designed so that air flows upward on one reverse through all the regenerators and vertical combustion flues on the pusher side of the battery, while the products of combustion flow across the horizontal flue and down through the coke-side vertical flues and regenerators into the coke-side waste-heat flue. On the next reverse, the flow is upward through all the coke-side regenerators and vertical combustion flues, across the horizontal flue and down through the pusher-side vertical flues and regenerators into the pusher-side waste-heat flue. This arrangement is known as a cross-regenerative system, and is free of any possible cross-leakage between up-flow fuel gas and down-flow waste gas.

The proper flow of gas to each flue is controlled by calibrated nozzles, while the flow of air is controlled by setting sliding damper bricks in the horizontal flue at the top of each vertical flue. A single wide regenerator beneath each oven provides air to the flue wall adjacent to that oven.

High-quality silica brick is used throughout the entire regenerator walls and heating flue walls, eliminating the need for any sliding joints (a serious cause of potential leakage) that would be

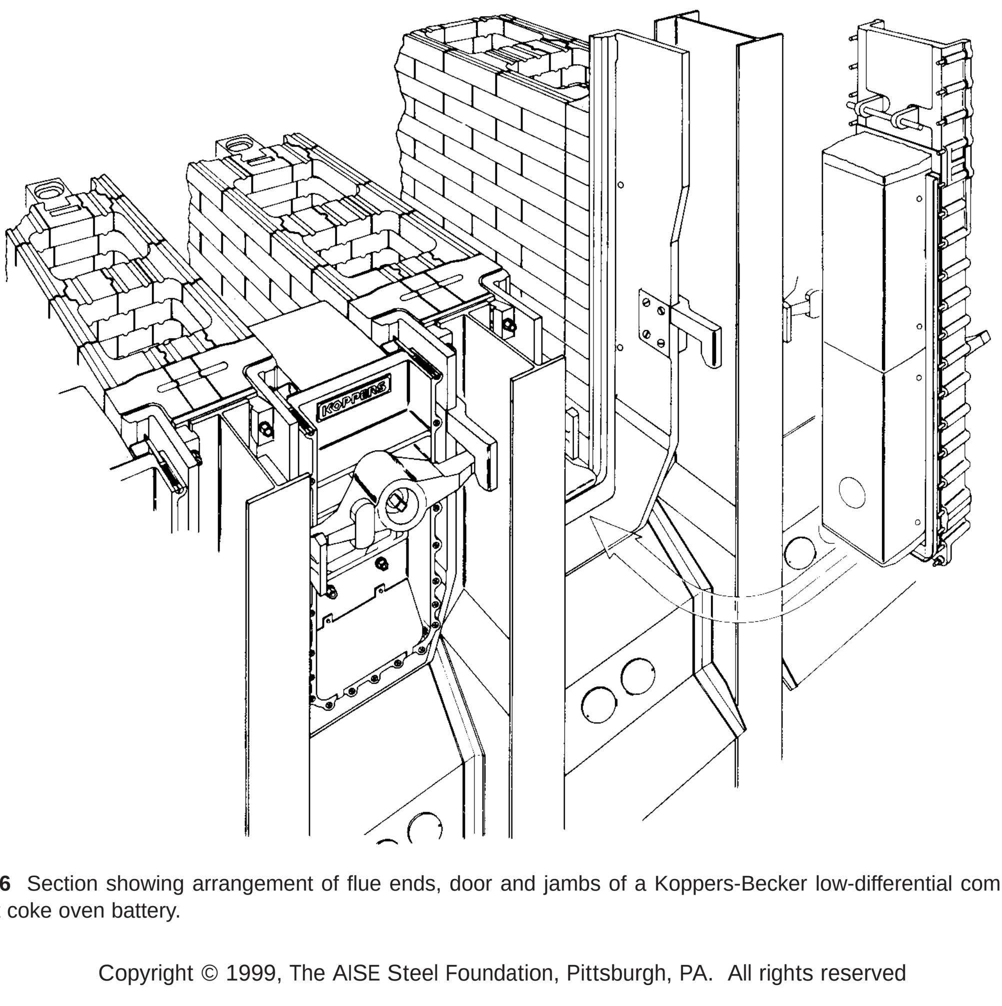


Fig. 7.66 Section showing arrangement of flue ends, door and jambs of a Koppers-Becker low-differential combination underjet coke oven battery.

required if clay or other dissimilar refractory materials were used in these important areas. The heating flue walls are constructed of vertically and horizontally tongued-and-grooved hammerhead and liner brick, spaced with sturdy flue partition shapes, Fig. 7.66. The oven ends are firmly supported by strong buckstays, face plates and rigid metal jamb castings bolted to the face plates. The jamb brick are provided with a vertical cleavage joint to permit expansion independently of the hotter interior heating flue brickwork. These features are all provided in all three types of ovens of the Koppers design.

Uniform distribution of up-flow air (and lean gas when used), as well as down-flow waste gas, between the sole flue and the regenerator chamber is accomplished by specially designed sole-flue ports. The size and taper of these ports are varied as required across the length of the regenerators and sole flues to force the desired distribution of gases. A patented system is also provided to supply more heat to the checkers at the ends of the regenerators to compensate for heat losses through the regenerator faces. A high-efficiency extended-surface checker brick is used in the regenerators to secure efficient heat recovery. These features also are provided in all three types of ovens of the Koppers design.

7.6.2.2 Koppers-Becker Oven

The Koppers-Becker oven was first developed and built in the 1920s to provide a system for heating taller ovens with either blast furnace gas or coke oven gas. This design has been refined and extended to permit uniform heating of modern tall ovens 6.5 m (21.3 ft) or higher. It provides a number of advantages that are unique to this design.

Many Koppers-Becker ovens have been built as either underjet or gun-flue ovens. The underjet design is preferred for the modern tall ovens to provide ease of access to the fuel-gas nozzles for better combustion control. The Koppers-Becker oven is most advantageous for combination ovens to be heated with blast furnace gas, although a great many have been built for heating only with coke oven gas.

The distinguishing features of the Koppers-Becker oven are the grouping of the vertical flues with short, relatively small horizontal flues connecting the tops of the vertical flues in each group, and with a connection between each horizontal flue section and the corresponding section in the adjacent companion heating flue wall by means of crossover flues extending up and over the intervening oven chambers. The regenerator chambers are arranged in groups of three, with a wide regenerator flanked by two narrow regenerators in each group. This design is illustrated in Fig. 7.67.

This arrangement provides for upward flow of air (and blast furnace gas, if used) through half the regenerator groups of three, and through the adjacent heating flue walls to which they are connected. These regenerators and flue walls burn upwardly on one reverse for their entire length from pusher side to coke side. The products of combustion flow out through the short horizontal flue sections and over the tops of the intervening ovens through the cross-over flues, passing down through all the vertical flues in the companion heating flue walls, down through the companion regenerator groups of three, and into the waste-heat flue. Each group of three regenerators feeds air (and blast furnace gas, if used) to two adjacent heating flue walls, so that every other pair of adjacent flue walls burns on one reverse, while the alternate pairs are “off” and receive downflow combustion products. On the next reverse the flow of combustion media and products of combustion is reversed. Waste-heat flues may be provided on one side or both sides as required.

The regenerator chambers are arranged in groups of three. In each group the flow of gases in all three chambers is in the same direction with substantially equal pressure (draft) conditions. The up-flow blast furnace gas regenerator chamber is always located between two up-flow air regenerator chambers, so that there is little or no tendency for any blast furnace gas leakage to occur. There is no possibility of dangerous leakage of gas into the down-flow waste gas regenerators or sole flues. It is only at every third regenerator wall that an up-flow regenerator chamber is located next to a down-flow one, but here the up-flow regenerator chamber always contains air, so that if leakage would occur the fuel gas for heating would not be lost, and no damage would result.

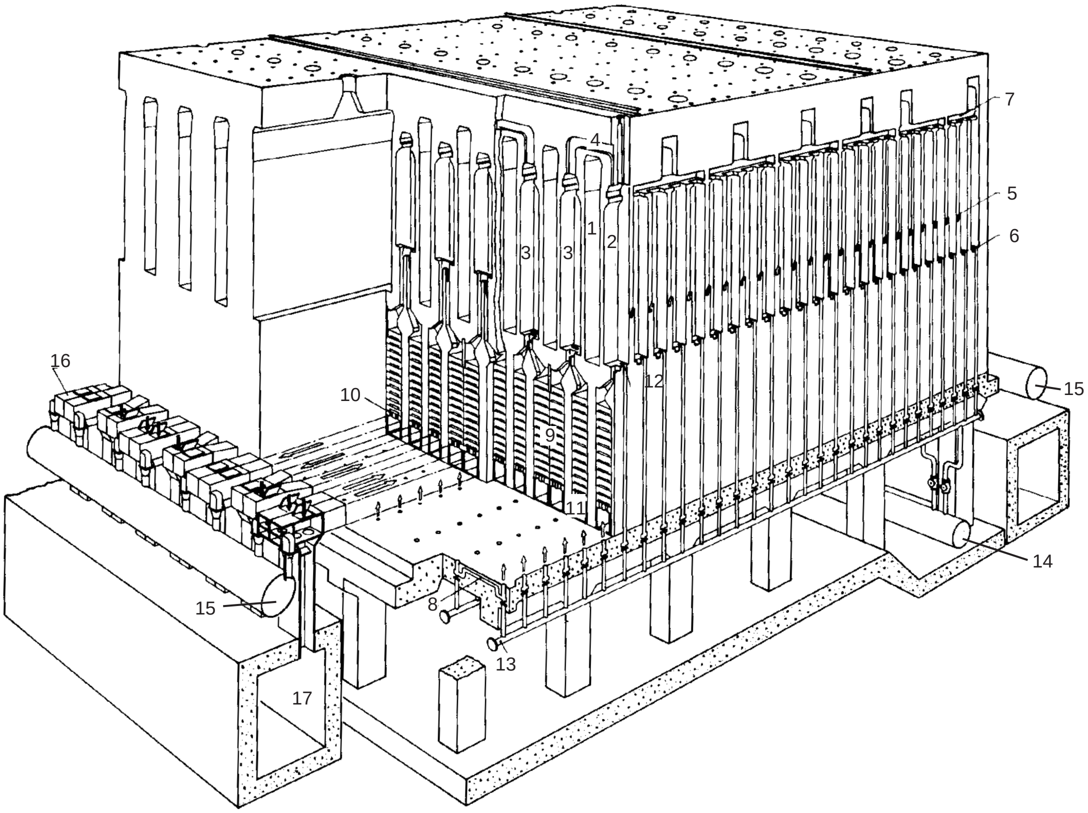


Fig. 7.67 Sectional view of a Koppers-Becker low-differential combination underjet coke oven battery operating on rich gas. Legend: 1. oven; 2. burning flue; 3. waste-gas flue; 4. cross-over flue; 5. high air port; 6. low air port; 7. horizontal collecting flue; 8. recirculating duct; 9. checker brick; 10. sole-flue parts; 11. sole flue; 12. gas port; 13. rich-gas manifold; 14. rich-gas main; 15. blast furnace gas main; 16. gas or air and waste heat boxes; 17. waste heat flue.

The corbel area between the regenerators and the ovens is strong and simple. Symmetrical, short and direct ducts connect with the regenerators immediately beneath the combustion flues, resulting in great strength and tightness.

The regenerators contain no transverse partition walls, but are open for their entire length. Blast furnace gas and air are metered to each vertical flue by ports at the base of the flues. The open regenerators supply gas and air at equalized pressure and temperature at the point of metering to each vertical flue. The open space above the checkers at the top of the regenerators acts as an equalizing chamber permitting continued good distribution of blast furnace gas and air to the vertical flues as the battery ages, even if portions of the regenerators become locally restricted as a result of blast furnace gas dust deposits.

The wide regenerators are divided longitudinally by specially designed checker brick, and above these by a baffle wall extending the length of the regenerator, providing for effective control of the distribution of blast furnace gas or combustion air to each individual flue wall. Pressure (draft) conditions at the top of the regenerators are easily controlled at the reversing boxes.

The vertical heating flues of the oven walls are arranged in small groups. Each group has its own cross-over flue. Regardless of the length or height of the oven each branch horizontal collecting flue remains small in cross-section and short in length, giving the walls extra strength where it is most needed. Low pressure drop through the horizontal flues and crossover flues results in a low overall pressure drop through the entire combustion system. A standard height stack can be used.

Air and blast furnace gas flows are metered to each flue by the air and blast furnace gas ports, where pressures and temperatures are equalized across the battery, and distribution does not change with coking rate changes. For tall ovens, in order to assure uniform heating for the full height of the oven, air and blast furnace gas are supplied through ports located part way up the flue, as well as at the bottom of the flue.

When underfiring with rich gas (coke oven gas), all of the fuel is supplied at the base of the flues. For tall ovens the combustion is staged by supplying a portion of the air required at the base of the flue and the remainder at a high elevation. This elongates the flame, creating uniform vertical heating and eliminating low temperatures near the oven top.

The up-flow rich gas risers are always at substantially the same pressure as the two adjacent regenerator chambers which contain up-flow air. There is no possibility of leakage of rich fuel gas into the down-flow regenerator chambers or sole flues.

To further lengthen the flame, assuring uniform vertical heating when underfiring with rich gas, an automatic waste gas recirculation system is used. Recirculating ducts connect the bases of the down-flow and up-flow rich gas risers which are provided with venturi throats, Fig. 7.68. The rich fuel gas flows through jet-type nozzles into the venturi sections, serving as eductors to aspirate a portion of the products of combustion from the down-flow flues, through the down-flow risers and horizontal recirculating ducts, mixing this recirculated portion of waste gas with the rich fuel gas in the up-flow risers to the burning flues. This results in dilution of the rich fuel gas with inert products of combustion. This mixture burns more slowly, producing a longer flame of lower luminosity, similar to a blast furnace gas flame.

The Koppers waste-gas recirculation system suppresses the tendency to form carbon near the top of the up-flow fuel gas risers. Any carbon that may be deposited on the up-flow cycle is automatically consumed during the down-flow cycle by reaction with the excess oxygen, water vapor and carbon dioxide in the recirculated waste gas. This eliminates the need for a separate decarbonizing air system.

7.6.2.3 Koppers Twin-Flue Oven

The Koppers twin-flue oven was first built in the early 1970s. This design was developed to provide a tall oven with a simplified refractory brick and oven-top construction. It has been built as an underjet battery, primarily for heating with rich gas, but is also adaptable to heating with blast furnace gas.

The distinguishing features of the Koppers twin-flue oven are the arrangement of the vertical flues of each heating wall in pairs connected at the top, and the use of regenerators which are unpartitioned for their entire length, Fig. 7.69. No horizontal flue is required, providing added strength to the walls in this critical area.

There is one wide regenerator (two narrow regenerators for combination ovens) under each oven, extending the full width of the battery, separated from the regenerators on both sides by substantial silica walls of tongued-and-grooved brick. During a given reverse, every other regenerator handles up-flow air, while the alternate regenerators handle down-flow products of combustion. Air passing up one regenerator supplies air to alternate up-flow flues in each of two adjacent flue walls. Down-flow waste gases from the corresponding down-flow twin flues pass to the down-flow regenerators on each side, and from there to the waste-heat flue.

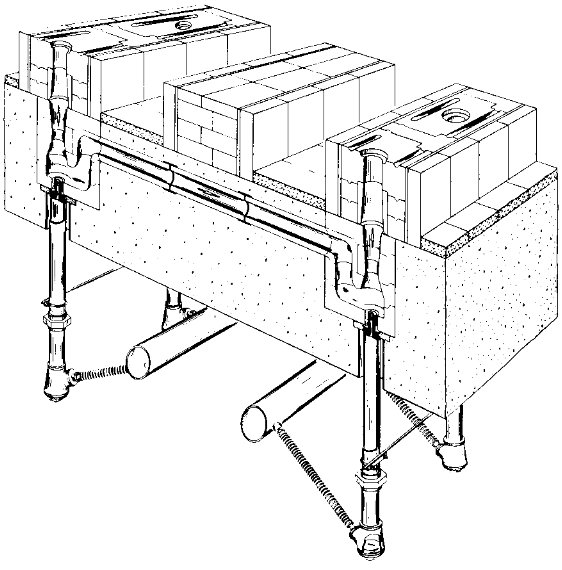


Fig. 7.68 Waste-gas recirculating duct arrangement for a Koppers-Becker low-differential combination underjet byproduct coke oven battery.

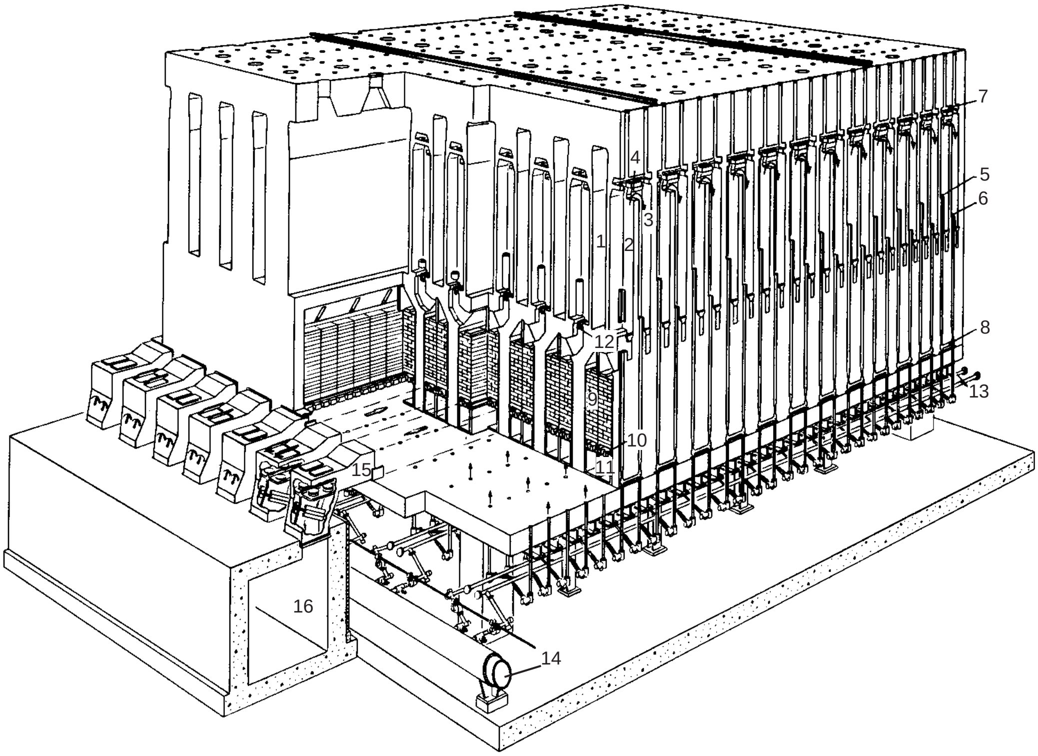


Fig. 7.69 Sectional view of a Koppers twin-flue underjet byproduct coke oven battery. Legend: 1. oven; 2. burning flue; 3. waste-gas flue; 4. turnaround; 5. high gas port; 6. low gas port; 7. differential heating flue; 8. recirculating duct; 9. checker brick; 10. sole-flue ports; 11. sole flue; 12. air port; 13. rich-gas manifolds; 14. rich-gas main; 15. air and waste-heat boxes; 16. waste-heat flue.

This twin-flue design incorporates most of the structural and design features that have been proven successful over the years in the Koppers single-divided and Koppers-Becker ovens, which have been described in the preceding sections. Automatic waste-gas recirculation is achieved by the use of recirculating ducts connecting the base of the rich-gas risers of each pair of twin flues. The recirculating ducts and venturi throats at the base of each riser are built into the silica brickwork of each heating flue wall. Alternating high and low coke oven gas burners are provided in alternate flues across each heating flue wall to assure uniform vertical heating of the modern tall twin-flue ovens.

7.6.2.4 Auxiliary Equipment

Some auxiliary equipment which can be used with any of the three types of Koppers oven is described in this section.

The Koppers doors are of ductile iron or fabricated steel, and have the desired amount of flexibility to conform to the general shape of the jambs, Fig 7.66. A U-shaped sealing diaphragm is provided which is backed up by a series of spring-loaded plungers. This arrangement provides added flexibility to permit the doors to conform automatically to minor differences in contour between the door and the sealing surface of the jamb. This feature permits door interchanging from oven to oven with automatic adjustment to the difference in contours. The two latches may be either of the screw type or spring-loaded type.

The door-extractor ram swings the door 90° and holds it in position in front of the cleaning station. The patented cleaner frame then moves forward to contact the door with the reciprocating scraping tools, which automatically clean the door sealing channel both vertically and horizontally, and also clean the bottom and sides of the door plug. The number of scraping motions may be adjusted to suit varying conditions.

The patented jamb cleaner is mounted on a separate ram which positions the cleaner against the door jamb. Variable settings automatically provide a programmed number of strokes for the scraping tools which effectively remove deposits from the jamb surfaces. An additional tool enters the oven at the floor, and as the cleaning head is retracted from the oven the bottom tool removes any floor deposits which would prevent the door from being properly replaced.

Foul gas is removed from each oven through single or double ascension pipes at the oven ends. The collecting main is shaped to allow the ascension pipes to be as short as possible, Fig. 7.70. Each ductile iron return-bend section contains two flushing liquor sprays and is connected to the collecting main by a sealed expansion joint. A liquor-sealed valve at the base of the return bend allows the oven to be isolated from the main. Charging steam is directed through the return-bend section to pull the gas and smoke generated during charging into the collecting main. A return-bend cover is provided for venting the oven to the atmosphere for decarbonizing purposes.

Mechanical-cleaning devices are provided on the coal charging car for removal of carbonaceous deposits from the return bend and ascension pipe. Other mechanical devices are available to manipulate the covers and dampers from the coal charging car.

7.6.2.5 Pollution Control

The Koppers designs offer facilities and systems to control environmental pollution from coke oven batteries. Equipment to control pollution is an essential part of all proposals for new coke ovens whether on new or existing sites throughout the world. The problems of making a coke oven battery essentially gas-tight are being resolved with improved engineering designs, consistent operating practices and modernized maintenance practices. To assist the coking industry in this

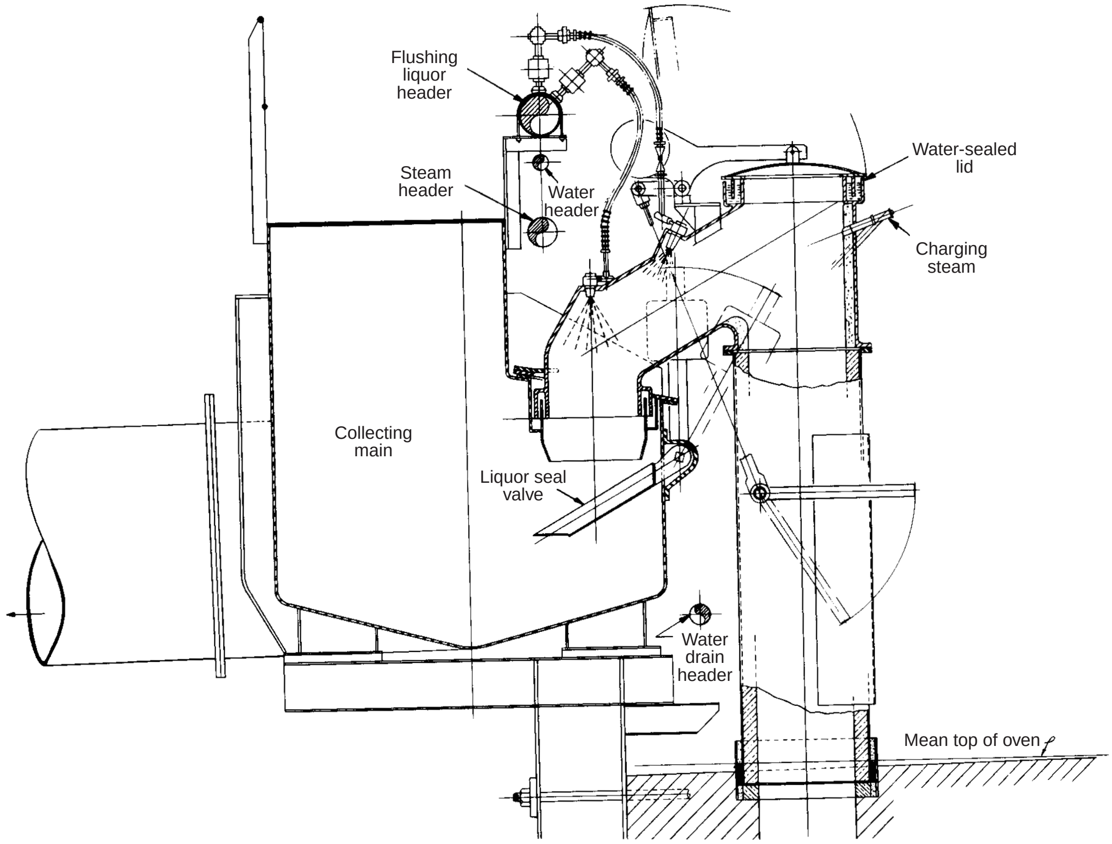


Fig. 7.70 Cross-section through a collecting main and ascension pipe on a byproduct coke oven charged with wet coal.

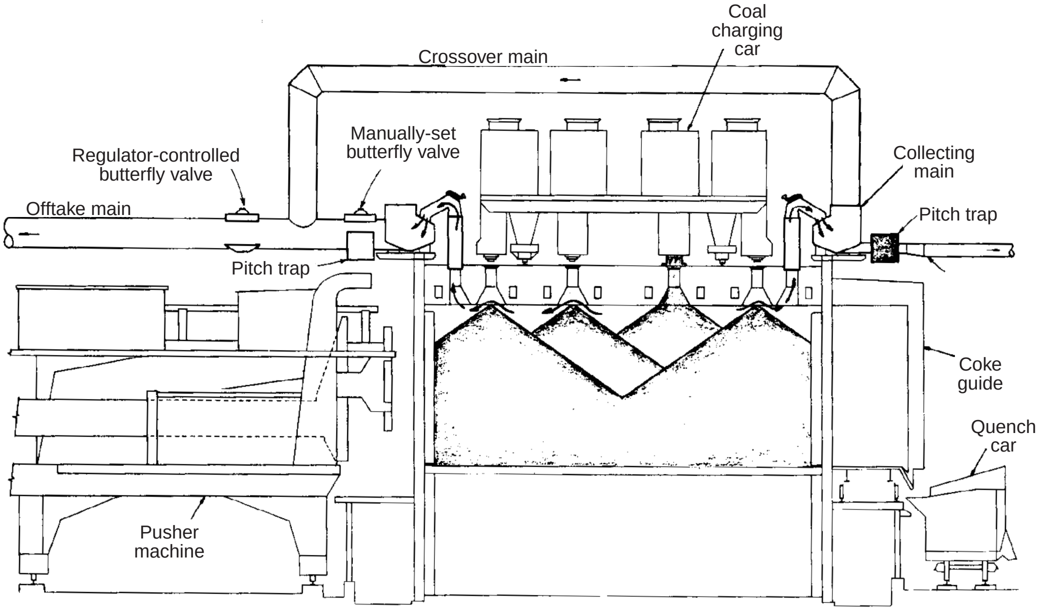


Fig. 7.71 Schematic arrangement of a coke oven equipped for staged charging or sequenced charging

emission control effort, the Koppers designs have available the following facilities and equipment for these major sources of coke oven emissions.

7.6.2.5.1 Charging Emissions An overall charging concept, commonly called staged charging or sequenced charging, is available. This system, Fig. 7.71, involves the ability to discharge the coal from the charging car hoppers in the proper sequence and at the proper times so that the blockages of the gas passageways from the oven are prevented. Double collector mains or jumper-pipe systems are available to provide a gas outlet at each end of the oven chamber. Suction is provided by aspirating steam at both gas outlets during a charge. Successful smokeless charging by this method is greatly aided by certain auxiliary control devices which include mechanical feeders to control the flow of coal from the hoppers to the ovens; automatic lid lifters with slide gates; automatic leveler-door operators with leveler-bar smoke seals; mechanical standpipe and gooseneck cleaners; and self-cleaning steam aspirating nozzles.

7.6.2.5.2 Pushing Emissions The Koppers designs have available a number of systems to reduce the emissions generated during the pushing operation. A coke-side enclosure or shed has been provided to contain and collect these emissions. Wet scrubbers and baghouses are being used to clean the captured emissions from the push and also the gases evolved from the coke-side oven doors.

Another system for control of pushing emissions is the Koppers-Ford system which consists of an enclosed coke guide with an attached hood that covers a quench car. The hood is connected to a fume main and a land-based gas scrubbing system to remove and clean the emissions.

7.6.2.5.3 Quenching Emissions Particulate matter entrained with steam from the quenching operation can be controlled with the use of mist suppressors installed in the quench station stacks. Usually these are wooden baffles arranged to cover the area of the stack and are installed with cleaning sprays to wash down the collected particulates.

Dry coke cooling is another method of controlling quenching emissions. In this process, hot coke is dumped into a chamber and inert gas is circulated through it to cool the coke. This gas is then passed through a waste-heat boiler where the heat from the coke is recovered and used to generate steam. Although this system does not emit a plume of steam with particulates, control devices are still used at coke transfer points and in the gas stream to collect and clean emissions.

7.6.3 Wilputte Design

Since the early 1960s, Wilputte has been engaged actively in the development of larger capacity ovens with increased coking rates. Today, Krupp Wilputte is the designer and constructor of this proprietary design type.

The first advance in this development program was the introduction of high-density silica oven liner brick. This was followed by the increase in height of the four-divided and twin-flue ovens to 5.2 m (17 ft) with a capacity of 31.15 m^3 (1100 ft^3). By 1978, 1150 Wilputte ovens, each with a capacity of 31.15 m^3 (1100 ft^3), had been constructed, with a designed coking rate of 16 hours. Experience gained with the operation of these ovens at a fast coking rate, using both coke oven and blast furnace gas firing, was combined with research and development work on yet higher and larger capacity ovens. This resulted in the construction of 6.21 m (20.3 ft) high ovens with a capacity of 39.64 m^3 (1400 ft^3).

Depending upon the particular application, the 31.15 m^3 (1100 ft^3) capacity ovens were either twin-flue with coke oven gas firing, or four-divided with combination-gas firing. Gas-gun or underjet firing systems were employed, depending upon the client's preference.

The 39.64 m^3 (1400 ft^3) capacity ovens and 44.46 m^3 (1570 ft^3) capacity ovens constructed up to 1969 were of the twin-flue design for coke oven gas firing. An underjet firing system is used exclusively for these largest ovens.

Dimensions of the coking chamber of a 39.64 m^3 (1400 ft^3) oven as compared with those of a 31.15 m^3 (1100 ft^3) oven are, respectively: heights, 6.21 m and 5.18 m (20.3 ft and 17 ft); lengths, 15.42 m and 14.94 m (50.6 ft and 49 ft). Average width for each is about 457 mm (18 in.).

The new generation of large-capacity Wilputte ovens accounted in 1969 for an installed carbonization capacity of 14.5 million tonnes (16 million tons).

Much of Krupp Wilputte's effort has been directed also toward the more efficient handling of coal and coke, control of the environmental discharges associated with normal coke oven operation, and the application of AC drives.

7.6.3.1 Twin-Flue Ovens

Twin-flue ovens are comprised of multiple vertical heating flues arranged in pairs and are designed to permit burning of gas simultaneously in alternate flues. Every 20 to 30 minutes the supply of fuel gas is reversed to allow burning in the flues which were carrying waste gas.

7.6.3.2 Four-Divided Ovens

The heating wall of the four-divided oven, Fig. 7.64 and Fig. 7.65, consists of 33 vertical flues; located between adjacent coking chambers are 17 outer and 16 inner flues. Nine of the outer flues are located on the coke side and eight are located on the pusher side. The outer flues are arranged to burn alternately with the 16 inner flues, reversing every 20 to 30 minutes.

7.6.3.3 Pillar Walls

The pillar walls of all sizes of Wilputte ovens are of all-silica construction from the deck slab up to provide a uniform material of construction without slip joints that could cause potential leaks in the regenerator. This design also eliminates the complex buckstay bracing system in the bench and below the oven floor.

7.6.3.4 Wall Construction with High-Density Liners

The wall liner brick in contact with the coal is high-density silica brick. This brick has a minimum density of about 1.84 g/cm^3 (115 lb/ft^3) as compared to standard lines with a density of about 1.71 g/cm^3 (107 lb/ft^3). The increased heat transfer rate and reduced thickness of this brick permit a lower average flue temperature than required for 114.3 mm (4.5 in.) thick liners of standard density, or an increased coking rate with the same temperature.

The heating walls are of interlocked header and stretcher brick construction with headers interlocked to each other and to the liners as well. Courses are not less than 152.4 mm (6 in.) in height, thereby reducing the number of joints substantially.

The ends of the heating walls can be constructed with removable nose and jamb brick made of silica clay or fused silica. The construction is such that all nose and jamb brick can be replaced without disturbing the end flues.

7.6.3.5 Heating

Wilputte coke oven batteries can burn either coke oven or blast furnace gas, or a combination of these. The changeover may be made from a central control room.

Alternating high and low burners are installed in the heating flues. This arrangement lengthens the initial vertical combustion zone when heating with rich gas and, by enabling the use of wall liners of uniform thickness from floor to roof, materially improves the vertical distribution of temperatures when underfiring with lean gas.

The regenerator distribution system using venturi ports which are graduated in size along the bus flue achieves uniform distribution of flow through the regenerator, thereby improving its efficiency. Also, this graduated venturi-port design, in that it compensates for adverse manifold effects in the bus flue, permits the use of a single side waste-gas flue.

7.6.3.6 Coke Oven Gas Firing

In Wilputte ovens, coke oven gas may be fired either through an underjet or gas-gun system.

When firing through an underjet system, coke oven gas under regulated pressure is delivered through the main coke oven gas manifold to the underjet system located in the battery basement. The underjet system comprises the individual wall manifolds with reversing cocks and connections to the individual flues, each having an orifice metering device. These metering devices are sized to accommodate the progressive increase in gas requirements toward the coke side of the oven to compensate for oven taper and to meet the additional gas requirements of the outer end flues. The rich fuel gas upon leaving the metering orifices travels upward through a duct in the pillar wall to a high or low burner.

Ovens with capacities up to 31.15 m^3 (1100 ft^3) may be equipped with a gun-type fuel gas system. In this system, gas guns deliver fuel gas through horizontal ducts from which it is distributed through conventional clay nozzles to the individual heating flues.

7.6.3.7 Blast Furnace Gas Firing

The combustion of low-Btu blast furnace gas must be initiated at the bottom of the heating flue to avoid a cool bottom condition. This is achieved in the four-divided oven by mixing the preheated lean gas and air at a point below the oven floor to promote proper flame propagation, and through the use of uniformly thick wall liners from wall to roof, which materially improves the vertical distribution of flue temperature.

7.6.3.8 Double Collecting Mains

In order to reduce atmospheric emissions during coal charging, most batteries being built in the United States are being provided with collecting mains on both sides of the battery so as to provide a free exit for handling the gas evolved during charging. Double collecting mains with stage charging can provide for smokeless charging as the gas escape path is unobstructed along the top of the oven to the standpipes.

With the double collecting main system, the space about the coal tends to be cooler in the latter portions of the coking cycle, thus reducing the tendency to form roof carbon. However, care must be exercised to close off the oven from one of the collecting mains in the latter part of the coking cycle to prevent the possibility of cool, wet raw gas being drawn into the oven chamber and possibly causing damage to the silica brickwork

Fig. 7.36, shown earlier, depicts the arrangement of the standpipe, damper valve and collecting main at one end of an oven.

7.6.3.9 Coal Charging

The Wilputte charging car is equipped with magnetic lifters, drop-sleeve assemblies, automatic gooseneck cleaners, coal bin operating mechanism, smoke abatement units and an operator's cab.

With one spotting of the car, the following functions are performed: (a) clean the standpipe elbows; (b) lift lids, drop the sleeves and charge the oven; and (c) lift the sleeves and replace the lids. With the automated charging car, the travel, loading and weighing of the coal and spotting are programmed and automatic, but the discrete functions (a), (b) and (c) are performed upon initiating signals from an operator.

A rotating table-type charging larry simultaneously discharges the coal contents evenly at a controlled rate into all charging holes. This results in an oven charge of uniform bulk density that normally requires only a single stroke for leveling.

7.6.3.10 Pusher Machine

The Wilputte portal-type pusher is designed for door removal, oven pushing and door replacement with one spotting of the machine. The hydraulically operated door cleaner locks into the retracted door, automatically cleaning the sealing edge and the door lining. Simultaneously, a hydraulically operated jamb cleaner, held in place by the door jamb latch keeper, moves into position for cleaning the face and inside of the door jamb.

The leveler bar, provided with a smoke sleeve for sealing the leveler door opening during operation, discharges the coal withdrawn by the retracting bar into a hopper located on the pusher.

A system of induction coil interlocks prevents pushing the oven before removal of the coke-side door and positioning the coke guide.

7.6.3.11 Hydraulic Door Machinery

The hydraulically operated door removal and replacement machine has an inherent ruggedness and reliability superior to the electric model with its multiplicity of gear reducers, brakes, torque-limiting devices, limit switches and interlocks.

The hydraulically operated door and jamb cleaner on the coke-side door machine is similar to the pusher-side machine and also locks onto the retracted door. The jamb cleaner is positioned by re-spotting the door machine during the door cleaning cycle and is held in place by the door jamb's latch keeper.

7.6.3.12 Tilting Quench Car

The quench car has a tilting floor design for uniform distribution of coke, reduction of the overall moisture content after quenching, and elimination of hot spots that might otherwise be found in coke after discharge onto the wharf.

7.6.3.13 Self-Sealing Doors

The sealing edge of the spring-loaded self-sealing doors, shown earlier in Fig. 7.29, is made of a renewable flexible stainless steel strip that is mounted on a flexible diaphragm and will adjust readily to the contour or the door frame sealing face. The leveler door also is self-sealing.

The Wilputte door jambs can be either the ell-shaped contour or the block contour, securely bolted to a steel nose plate behind the buckstay so that the jamb and steel nose plate can be held tightly against the brickwork despite any tendency of the buckstay to distort. This design also permits replacement of door jambs without removing buckstays while providing maintenance access to the nose brick.

7.6.3.14 Automation of Coke Wharf

The coke wharf gates are actuated pneumatically and are provided with a sequencing device for controlling the various movement patterns. Gates are interlocked with the air compressor and close automatically when the coke wharf conveyor belt stops. An automatic temperature and water spray system provides protection for the belt.

Another type of automatic wharf has a motor-operated plow running parallel with the coke conveyor to unload a run of coke from the wharf. This method of transferring coke onto the wharf belt promotes uniform screen loading and efficient screening.

7.6.3.15 Electrical Equipment

AC drives have been adopted for coke oven machinery in modern Wilputte installations. Operational advantages of AC over DC power are: (a) control consists mostly of solid-state components where the number of moving parts is minimized: (b) highly accurate, stepless and simple control is obtained; and (c) smooth starting, accelerating and decelerating are achieved.

7.6.4 Thyssen Still Otto Designs

In the 1980s, due to the more difficult business situation worldwide in the iron and steel industry, the coke oven building companies were also looking for higher efficiencies and a concentration of their resources.

In 1987 the two coke oven building companies Carl Still GmbH und Co. KG in Recklinghausen and Dr. C. Otto and Companie GmbH in Bochum merged and formed a new company. Thyssen Group, one of the largest groups of companies in Germany, held the majority of the shares. The new company was named Thyssen Still Otto Anlagentechnik GmbH, called TSOA hereafter in this section.

In 1990 the coke oven division of Didier Engineering was taken over by TSOA. Today, the know-how of the three coke oven building companies and the financial and management abilities of the Thyssen Group are concentrated in this new company.

TSOA is today the oldest and largest coke oven builder in the world. The coke oven types and heating systems of the former companies Still, Otto and Didier can still be provided and build by TSOA based on equipment existing in a plant and customer preference.

Extensive descriptions about the Didier design, the Dr. C. Otto design, and the Firma Carl Still design are presented in the 10th edition of *The Making, Shaping and Treating of Steel.*[28] Those designs will not be presented in this section. The reader is referred to pp. 206–224 of the 10th edition for further information concerning those proprietary design types.

In cases where none of these preconditions exist TSOA offers the following systems of newest design coke ovens optimized for low emissions, low energy consumption and low operation expenses. As a compound oven, heating with coke oven gas or blast furnace/mix gas, TSOA offers a twin-flue air stage oven of the underjet or gun-flue design. As a rich gas oven, heating with coke oven gas only, TSOA offers a double pair flue air stage oven of the underjet or gun-flue design.

Both systems use the newest air stage heating system were the combustion air enters the flues at different stages and the gas enters in all flues at the same height at the flue bottom. Only with this system is it possible to meet today’s stringent air pollution standards for NOx in waste gas. All presently active coke oven builders have changed to such air stage systems.

7.6.4.1 TSOA Twin-Flue Air Stage Compound Oven System

7.6.4.1.1 Heating System A major factor in modern cokemaking practice is to achieve optimum distribution of heat within the coke mass on completion of the carbonization cycle by an effective heating system.

In the event that there exists within the coke mass a significant temperature differential either in the vertical or horizontal direction it becomes necessary to overheat the major portion of the coke mass to ensure complete carbonization of the coolest portion. At these elevated temperatures the heat transfer efficiency of any coke oven is poor and energy is wasted.

As the bulk density of the coal varies in the vertical and horizontal directions the varying heat requirement of the charge has to be met by an adaptable heating system with possible adjustments for the oven taper and the end heating flues.

The TSOA twin-flue system for compound heating enables accurate distribution of the heating gases and air to be achieved, thus ensuring an even distribution of temperature within the coke.

7.6.4.1.2 Twin-Flue Heating Walls The TSOA heating wall consists of vertical heating flues arranged in pairs to form twin flues. This design has important technical features which should be noted.

There is high stability of the twin-flue heating wall because every second header wall is bound into the oven roof structure.

An even heat distribution over the length of the wall is maintained because every second heating flue is fired. The other flue of the pair is carrying the waste gas down to the regenerator. On the other side of the charge, the flues opposite the flues carrying waste gas are fired. Therefore, even heat distribution in horizontal direction of the heating wall is ensured.

Pressure losses and pressure differential are kept to a minimum by a nearly consistent cross-sectional area path for the combustion gases up the flue on fire, over the turnover point, and down the waste gas flue. Therefore, the likelihood for cross-leakage to occur within the refractory block as the battery ages is reduced.

In the case of coke oven gas heating, Fig. 7.72, the heating gas is introduced into the flue through one low burner which has the same height in all flues. Approximately 65% of the air preheated by the regenerator is entering at the flue bottom and approximately 35% enters as a second stage through a canal in the header wall through an opening located near the one-third of the chamber height.

In the case of blast furnace gas or mix gas, Fig. 7.73, heating gas and approximately 50% of the air preheated by the regenerator are introduced at the flue bottom. As a second stage, the balance of the air enters the flue through the higher air outlet.

The distribution of air to the two stages in different heights is adjusted to the heat requirements of the charge.

After an incomplete combustion in the lower part of the flue, the gas is diluted by the already developed waste gas and burned with excess air at the second stage in the upper part of the flue. This staged combustion reduces the production of NOx.

Any carbon deposits on the gas burners are burned away in the offgas phase by forced decarbonizing air.

The waste gas passes through the turnover point into the adjacent flue and is carried down to preheat the regenerator checkerwork.

For fine tuning the heat distribution across the heating wall according to the heat demand of the charge and the chamber taper, exchangeable metal nozzle plates with adjustable openings are arranged between sole flues and regenerators. Each twin flue is always serviced by the same regenerator compartments, thus forming a heating unit. Such a heating unit consists of the air/mix gas regenerator compartments, one twin flue, the waste gas regenerator compartments and the coke oven gas riser openings.

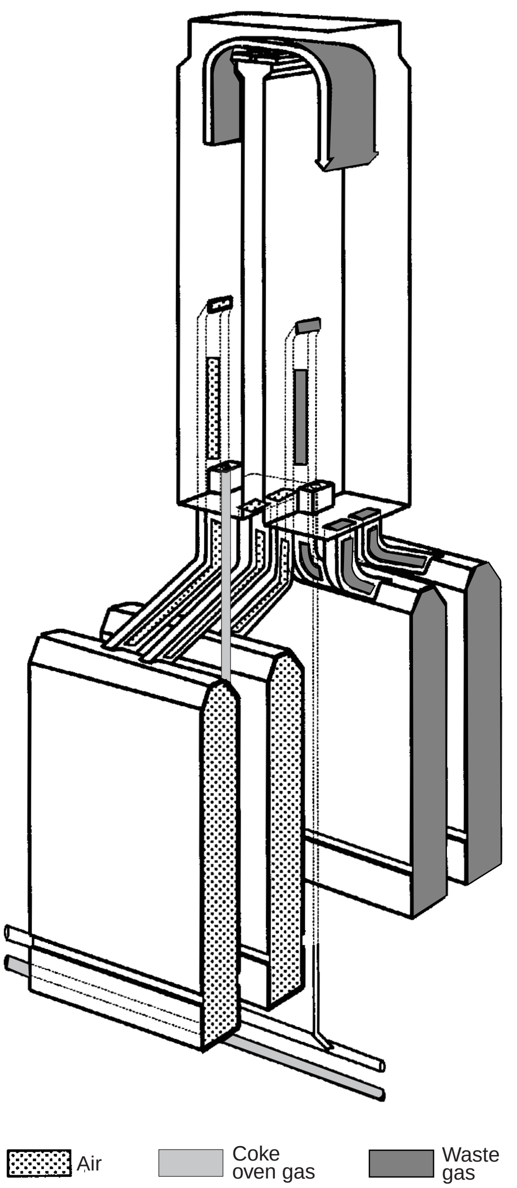


Fig. 7.72 TSOA twin-flue heating unit system operating on coke oven gas.

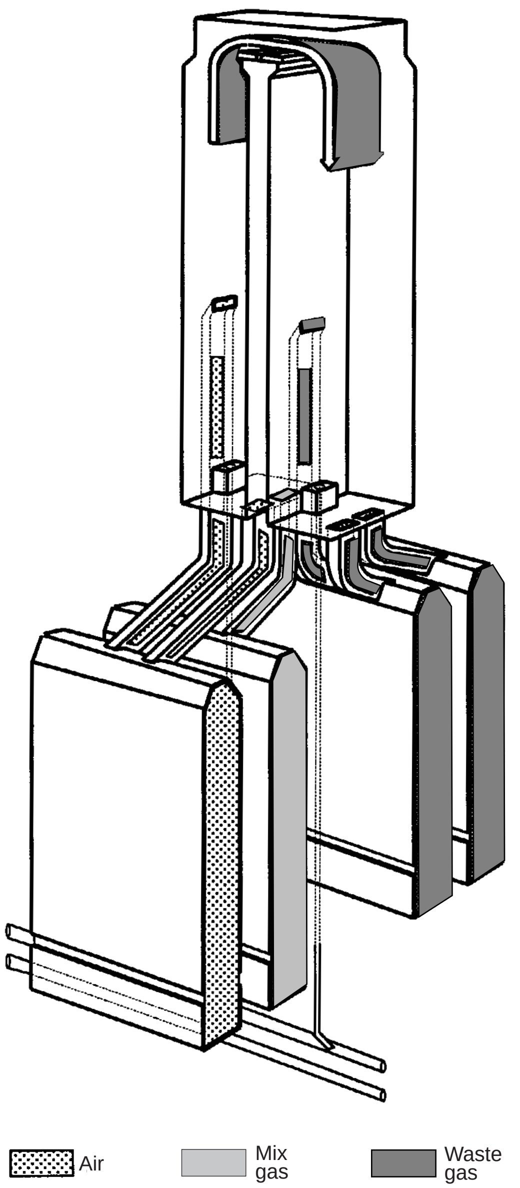


Fig. 7.73 TSOA twin-flue heating unit system operating on mix gas.

Each heating unit can be individually controlled and adjusted for optimum battery heating.

A number of these independent heating units arranged side-by-side form the heating wall of the TSOA oven.

7.6.4.1.3 Underjet System, Coke Oven Gas In the underjet system, coke oven gas is distributed in the battery basement under the nozzle deck by means of steel nozzle headers off the distribution main and through steel connections on the riser pipes and openings to the burners in the heating flues.

In the underjet system to coke oven gas is distributed in steel pipes which operate under pressure. Consequently, a good distribution can be obtained to ensure consistent flow of gas to the individual flues. By taking maximum advantage of the available fuel gas pressure, graded stainless steel metering nozzles are installed to ensure an accurate and consistent delivery of fuel gas to each individual burner.

These are external from the battery refractory block and are easily accessible within the basement.

In the underjet system the nozzle headers are supplied from a single distribution main and a progressive adjustment can be obtained across the length of the heating wall.

The coke oven gas is fed to individual burners in the heating flues through vertical openings within the refractory block. They are of small diameter, having no detrimental effect o the stability of the refractory block.

Tightness, especially in the regenerator walls, is achieved by tongue-and-groove brick design with staggered joints.

All TSOA heating systems may and have been provided as gun-flue systems, based on the special requirements of the owner.

7.6.4.1.4 Regenerator Arrangement The regenerators are located under the oven chambers and the heating walls and are continuous from pusher side to coke side. When heating with coke oven gas two adjacent regenerators are supplied with combustion air and one with mix gas. The regenerators exchange duties with each reversal.

The regenerators with their checker bricks are divided up lengthwise by partition walls into as many compartments as there are twin flues. Each twin flue is connected with its regenerator compartments by short ducts.

The sole flues form a composite part of the regenerator and do not require any lining. The checker bricks form the regenerator packing above the sole flues.

The packing is subdivided into separate compartments by tiles between the regenerator walls. These are inserted, dry tightened with ropes, and can be removed should it ever be necessary to repack the regenerator.

The majority of the checker bricks are manufactured from low alumina fireclay, but in higher temperature zones of the regenerator the top four layers are manufactured from 40% alumina fireclay.

Metal exchangeable nozzle plates with calibrated adjustable openings are located above the sole flues and below the regenerator compartments. The volume of air/mix gas, which is distributed to the regenerators and effectively into independent compartments, is determined by the adjustable openings of the nozzle plates. Thus, a uniform and controlled air/mix gas flow is obtained together with optimum heat recovery in the regenerator.

7.6.4.1.5 Heat Distribution across the Heating Wall Due to the taper of the oven chambers it is necessary to increase the heat input from pusher side to coke side. This is achieved by increasing the heating flue temperature from pusher side to coke side. Increasing amounts of gas and air have to be fed to the heating flues in order to adapt the heat distribution across the heating wall exactly to the heat requirements of the charge.

The major calibrations for this distribution are already built into the system based on design calculations.

For distribution of coke oven gas across the heating wall, steel nozzle headers are installed in the basement and are connected to each heating flue by riser openings. The calibrated stainless steel nozzles are exchangeable.

Air/mix gas is distributed to the checkerwork of the regenerators by adjustable metal nozzle plates arranged between sole flues and regenerator compartments. Waste gas is recollected to the sole flues by the same nozzle plates.

The fine tuning of the heat distribution across the heating walls is done during commissioning by adjusting the coke oven gas nozzles in the nozzle headers and the nozzle plates between the sole flue and the regenerator.

The heat distribution form pusher side to coke side, once adjusted properly, does not need to be readjusted with changing operating conditions. This is achieved by pause heating as described in Section 7.6.4.1.8.

The total amount of air fed to any heating wall and the total amount of waste gas collected from any heating wall are adjusted by finger plates at the air inlets and dampers at the waste gas valves, which are simple and specially designed for this function, thus ensuring an even and efficient regenerator loading.

The total amounts of coke oven gas and mix gas fed to any heating wall are adjusted by orifices installed downstream of the reversing cocks.

7.6.4.1.6 Vertical Heat Distribution A uniform vertical temperature distribution in the coke mass is of fundamental importance to avoid heat being wasted and to control coke quality.

For vertical heat distribution, the major calibrations are also built into the system based on design calculations. These are cross-section of the heating flues, cross-section of the air/mix gas entering the ports at the flue bottom, and cross-section and location of the second air stage.

The fine tuning of the vertical heat distribution is done during commissioning by adjusting the air inlet and draft at the air inlet boxes and the waste gas valves. For coke oven gas heating, additional adjustments are possible at the two air regenerators feeding different the different air stages.

Coke oven gas enters above the heating flue sole and partially burns with the air of the lower stage. Combustion is completed with the additional air at the higher air stage. During mix gas firing, mix gas and part of the air enter at the bottom of the heating flue. The balance of the air is added in a second higher stage. In both cases, this combustion results in a soft flame characteristic over the entire height of the heating flue.

Once the optimum flame length has been obtained, changes in coking rate can be achieved by using the pause heating facility described in Section 7.6.4.1.8. By using the pause heating facility, optimum vertical heat distribution will maintained at all times.

7.6.4.1.7 Heat Distribution in the Longitudinal Direction of the Battery In the longitudinal direction of the battery, equal amounts of air and gas must be distributed to each heating wall and, correspondingly, equal amounts of waste gas must be collected from each heating wall into the waste gas flue.

To avoid the wasting of heat, by increasing the amounts of gas/waste gas from the first to last heating wall, the amounts of gas/waste gas to and from the heating walls are controlled by throttling devices in the connections. On the inlet side these throttling devices are orifices in the branches from the coke oven gas or mix gas distribution main, arranged behind the reversing cocks of each heating wall.

On the outlet side, throttling dampers are installed in the connecting piece between the sole flues and the waste gas valves. In case the underfiring is changed from mix gas to coke oven gas, or vice versa, these dampers must be manually adjusted to the different amounts of waste gas. The air inlet fingers must also be adjusted.

In the case of changing operating conditions, with changing heat requirements for the battery unchanged, even heat distribution and optimum pressure and flow conditions are maintained by pause heating.

7.6.4.1.8 Pause Heating High efficiency of the heating system depends mainly on maintaining the optimum adjustment and control of the distribution and pressure conditions under all operating conditions.

This is achieved by pause heating, which keeps all operating parameters constant once they are adjusted.

During commissioning, the battery is adjusted to the shortest possible coking time, i.e. maximum possible heat requirement and maximum possible amounts of gas, air and waste gas. Under these conditions the battery will be operating at the minimum pause during the reversal of the regenerator half-periods.

If the heat requirements are reduced, i.e. in the case of longer coking times, the amounts of air and gas entering the system and amount of waste gas leaving the system per unit of time are kept constant and the reduced heat requirements are achieved by a pause between regenerator half-periods.

This simplifies the operation of a coke oven battery. All readjustments normally necessary with changing coking times are eliminated.

With pause heating, a single timer is set to a certain pause depending on the selected coking time. No further manual adjustments to the battery are necessary, except at very extreme coking times.

The amounts of gas, air and waste gas flowing constantly per unit of time result in an even distribution of heat in the longitudinal direction of the battery as well as across the heating wall. At the same time, a constant flame characteristic in the heating flues at normal coking times results in an even vertical heat distribution in the coke mass.

Operating times between the nominal coking time and 30% longer coking times are achievable with consistent, high thermal efficiencies. The consistent heating parameters for all coking times in this range result in evenly coked charges and consistent coke quality. Furthermore, pause heating reduces the manning/labor requirements for battery heating control, and therefore reduces operating costs.

7.6.4.1.9 Thermal Efficiency

The design features and operating modes outlined in this description ensure even heat distribution in the horizontal direction of the battery and the horizontal and vertical directions of the heating wall. These features combine to contribute to the high thermal efficiency associated with the TSOA oven.

Other factors which influence the thermal efficiency include optimum utilization of the regenerator filling, effective oven bracing system, insulation of the oven block, and the exclusion of cross-leakage in the regenerator area.

The TSOA checker bricks in the regenerator compartments offer a large exchange surface to the through-flowing media. The checker bricks are shaped so that the gas flow is split up into multiple streams. This ensures good heat transfer by their large surface area.

Pressure differentials are low because disturbances in the flow from the inlet checkerwork to the outlet checkerwork are minimal.

Horizontal surfaces which could collect dust in the regenerator are avoided.

7.6.4.1.10 NOx Formation in the Heating System As can be seen from the heating cross-section in Fig. 7.74, the TSOA oven is an “air stage oven” which ensures low NOx formation in case of heating with coke oven and mix gas.

In developing this heating system, TSOA embarked at first on a test program with extensive laboratory tests, which included tests on small heating flues as well as the construction of cold models to visualize the flow and mixing conditions in the heating flue.

Because of the results of these tests, test heating flues for 7.5 m high oven chambers were constructed in order to study all possible air and gas supply configurations and the resultant impact on the NOx formation and the vertical temperature distribution.

The outcome of this work was the air stage oven, a design which produces long flames with a low flame temperature and low NOx values for both mix gas and coke oven gas heating.

After this extensive testing, the heating system was successfully built for owners worldwide. Numerous batteries, with over 1000 ovens of this design, are in operation today.

7.6.4.1.11 Coke Oven Gas Heating To best illustrate the operation of a twin-flue air stage compound oven system with coke oven gas, Fig. 7.74 will be extensively referenced in this section. The numbers referenced in parentheses, ( ), apply to heating after reversal.

Coke oven gas is supplied to each heating wall from the coke oven gas distribution main, 13, which runs the length of the battery in the oven basement.

The gas flows through the reversing cocks into the nozzle headers, 15 (15a). Connections off the nozzle headers incorporate adjustable stainless steel nozzles, 16 (16a), through which the gas passes vertically upwards via the riser openings, 17 (17a), and enters the heating flues, 11 (11a), at the burners, 18 (18a).

The combustion air is drawn through the open flaps, 20 (20a), of the air inlets and the sole flues, 3 and 4 (3a and 4a), and distributed to the regenerator compartments, 6 and 7 (6a and 7a), via the metal nozzle plates, 5.

The heat stored in the regenerator, 6 and 7 (6a and 7a), during the previous reversal period as a result of the waste gas being drawn off is then transferred to the combustion air that enters the heating flue, 11 (11a), via short connecting ducts, 8 and 9 (8a and 9a), partially at the heating flue sole and partially at the higher air stage, 10 (10a).

Each twin flue forms a heating unit with the appropriate regenerator compartments to which it is connected by short ducts.

Coke oven gas and air flow up the heating flues, 11, during the two stage combustion and wasste gas flows down the adjacent heating flues, 11a. From there, the waste gas flows to the regenerator compartments, 6a and 7a (6 and 7), via the ducts.

The waste gas passes through the nozzle plates, 5, and is collected in the sole flues, 3a and 4a (3 and 4), from where it is drawn through the waste gas valves, 19 (19a), and the waste gas flue, 21, to the chimney. The two sole flues, 3a and 4a (3 and 4), lead to one waste gas valve, 19 (19a).

The coke oven gas burners not on fire are supplied with decarbonizing air. The air flows from the air main, 22, through the nozzle headers, 15 (15a), and the riser openings, 17 (17a), to the burners, 18 (18a), in order to burn away any carbon deposits.

7.6.4.1.12 Mix Gas Heating To best illustrate the operation of a twin-flue air stage compound oven system with mix gas (blast furnace gas stabilized with coke oven gas), Fig. 7.75 will be extensively referenced in this section. The numbers referenced in parentheses, ( ), apply to heating after reversal.

Mix gas is supplied to each heating wall from the mix gas distribution main, 1, which runs the length of the battery in the oven basement.

The gas flows through the reversing cocks, 2 (2a), and the sole flues, 4 (4a), and is distributed to the regenerator compartments, 7 (7a), through the metal nozzle plates, 5. The heat stored in the regenerators, 7 (7a), during the previous reversal period as a result of the waste gas being drawn off is then transferred to the mix gas which enters the heating flues, 11 (11a), via short connecting ducts, 9 (9a), at the heating flue sole.

The combustion air is drawn through the open flaps, 20 (20a), of the air inlets and the sole flue, 3 (3a), and distributed to the regenerator, 6 (6a), via the nozzle plates, 5.

The preheated air enters the heating flues, 11 (11a), via short connecting ducts, 8 (8a), partially at the heating flue sole and partially at the higher air stage, 10 (10a).

Mix gas and air flow up the heating flues, 11, during the two stage combustion and waste gas flows down the adjacent heating flues, 11a. From there, the waste gas flows to the regenerator compartments, 6a and 7a (6 and 7), via the ducts.

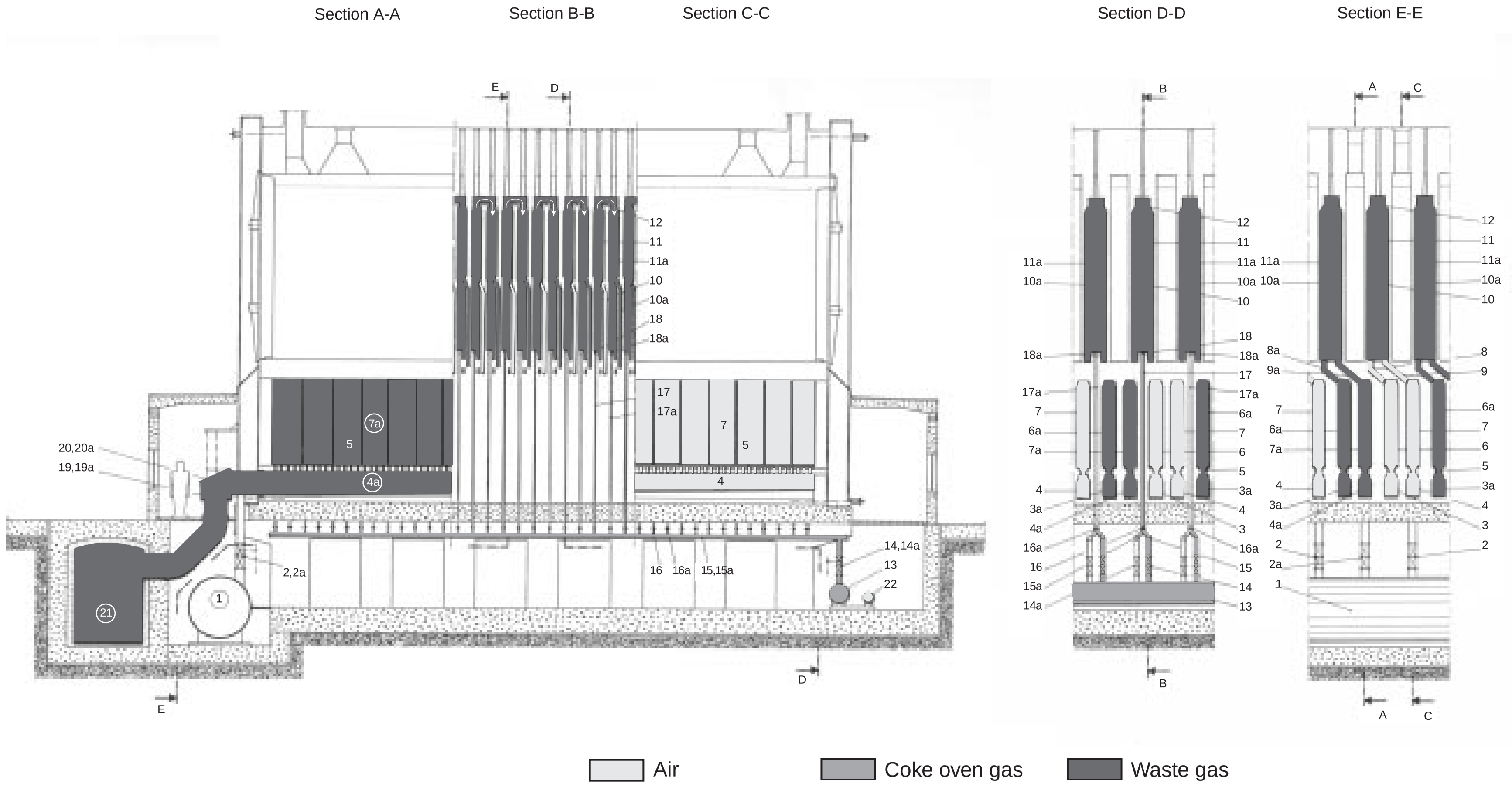


Fig. 7.74 Cross-section of the heating system for a twin-flue underjet-fired compound oven operating on coke oven gas.

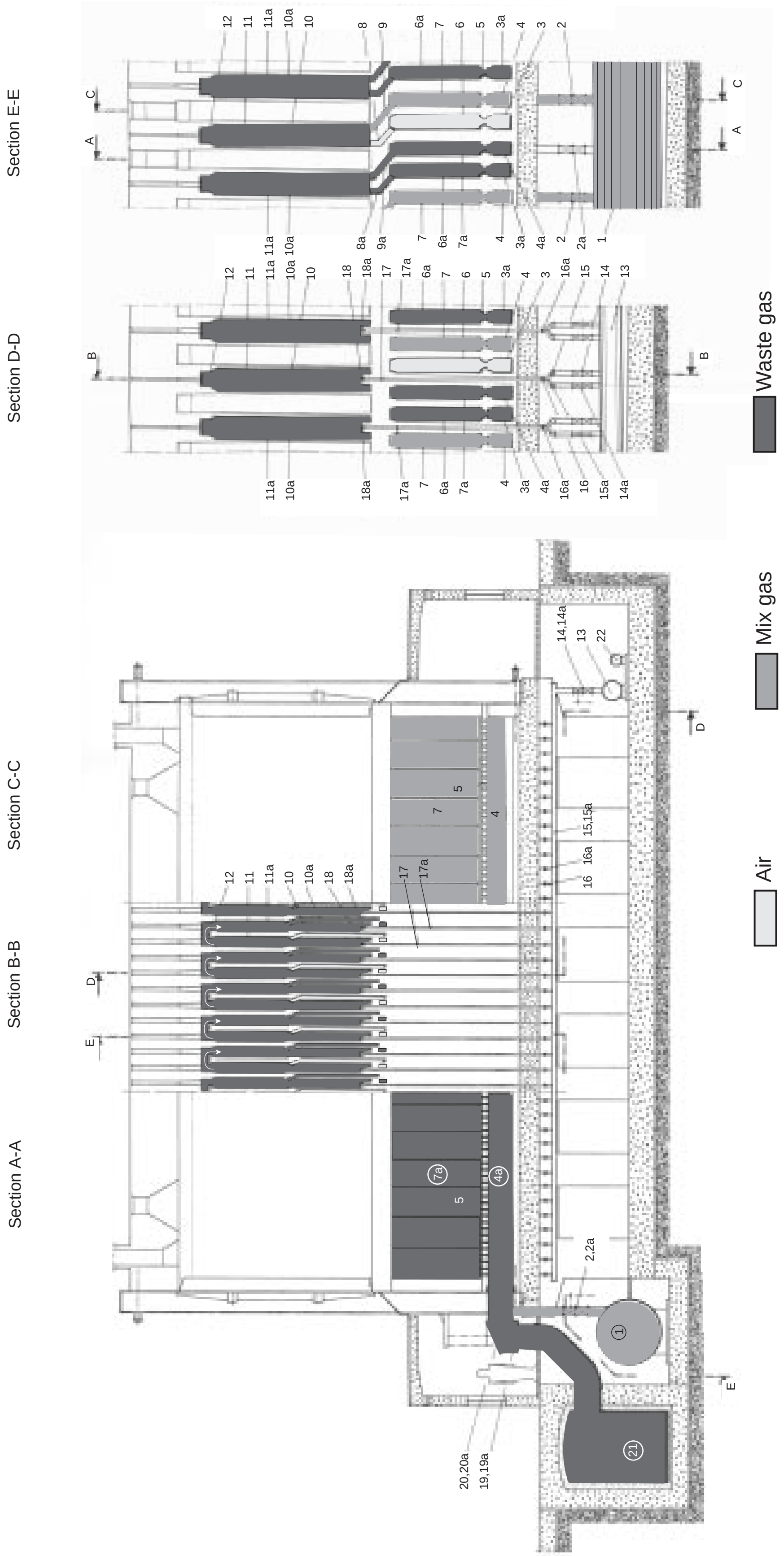


Fig. 7.75 Cross-section of the heating system for a twin-flue underjet-fired compound oven operating on mix gas (blast furnace gas stabilized with coke oven gas).

The waste gas passes through the nozzle plates, 5, and is collected in the sole flues, 3a and 4a (3 and 4), from where it is drawn through the waste gas valves, 19 (19a), and the waste gas flue, 21, to the chimney. The two sole flues, 3a and 4a (3 and 4), lead to one waste gas valve, 19 (19a).

7.6.4.1.13 Waste Gas Flues and Chimneys Batteries are drafted by one single waste gas flue on one side, which is connected to the chimney located in front of the battery. The waste gas flue is connected to the chimney by a chimney flue.

The waste gas flue contains a hand-operated damper for control during startup or in case of a failure of the main butterfly valve.

The chimney flue contains a butterfly valve as a main control damper. This damper is automatically controlled by a regulator.

7.6.4.1.14 Operation of the Battery Heating System The TSOA battery is noted for its ease of operation and maintenance. This is enhanced, of course, by the presence of single rows of equipment: a single row of waste gas valves with air inlets; a single coke oven gas main and reversing/isolating cocks; single mix gas main and reversing/isolating cocks; and a simple hydraulic reversing gear.

The battery is adjusted by the TSOA commissioning team and is fine-tuned for optimum performance before hand-over to the client. Thereafter, no adjustments to the heating system settings will be necessary between the nominal coking time and 30% longer coking times. However, should the operators wish to modify the battery settings for any reason, the facility is there and it is easily accesible.

Provided that the basic maintenance requirements as laid down in the operating and maintenance manuals provided are satisfied, the design performance of the battery heating system will be maintained for the major portion of the battery life. Data for a typical TSOA twin flue compound battery are presented in Table 7.4.

7.6.4.2 TSOA Double Pair Flue, Rich Gas Oven System

7.6.4.2.1 Double Pair Flue Heating Wall The TSOA heating wall consists of vertical heating flues arranged in double pairs. The design has important technical features which should be noted. High stability of the wall is achieved as only every second binder is a hollow binder, resulting in only half the number of ducts between the regenerators and the heating wall. Uniform vertical heat distribution on the wall is achieved by multi-stage combustion with low NOx formation. Pressure losses and pressure differentials are kept to a minimum by a nearly consistent cross-sectional area

Table 7.4 Data for a Typical TSOA Twin Flue Compound Battery

Year in Operation	1992
Number of Ovens	66
Chamber height, mm	6780
Chamber width, mm (average)	440
Chamber length, mm	16,597
Oven Type	Compound
Coke Oven Gas Firing	Underjet
Heating Wall	Twin Flue
Air Stages	2
Coking time, h	17.5
Heating Flue Temperature, °C (average)	1310
Heat Consumption of Coke Oven Gas, kcal/kg	513
Heat Consumption of Mix Gas, kcal/kg	552
NOx in Waste Gas from Coke Oven Gas, mg/m3	316
NOx in Waste Gas from Mix Gas, mg/m3	234

path for the combustion gases to travel up the flues on fire, over the turnover point and down the waste gas flues. Therefore, the likelihood of cross-leakage to occur within the refractory block as the battery ages is reduced.

Two adjacent heating flues burn in each double pair flue unit, while the other two discharge waste gas. The four flues are connected at the top by a small horizontal channel.

On the other side of the charge, the pair opposite the pair carrying waste gas is fired. With the reversing after each regenerator half-period, the pattern of firing is changed.

Rich gas controlled by the calibration of the nozzles is introduced only on the base of each heating flue via a short burner. Combustion air preheated in the regenerator is introduced in the individual heating flues through vertical hollow binders with calibrated slot openings at several elevations over the height of the heating flue. The calibrated slot openings feed the combustion air at a specific angle into the heating flue.

Each pair of heating flues has a central hollow binder channel directly connected to the regenerator. Through this channel each pair of flues is either supplied with combustion air or after the reversal, discharged of waste gas.

Solid header walls divide the individual flue groups within a heating wall and connect into the oven roof.

After an incomplete combustion at the lowest stage, the air/gas mixture is diluted by the already developed waste gas at each stage and finally burned with excess air at the highest stage in the upper part of the flue. This staged combustion reduces the production of NOx.

To burn away any carbon deposits at the burners, decarbonizing air is fed through the 3-way reversing cocks into the offgas nozzle headers by a forced air system.

The waste gas passes through the connecting canal into the adjacent flues and is carried down to preheat the regenerator checkerwork before it leaves the system via the single waste gas flue and the chimney.

Sliding bricks are arranged on top of the heating flues for fine tuning the heat distribution across the heating wall according to the heat demand of the charge and the chamber taper.

Each double pair flue is always serviced by the same regenerator compartments, thus forming a heating unit. One heating unit, Fig. 7.76, consists of the air regenerator cell, one group of heating flues, the waste gas regenerator cell and the straight coke oven gas riser openings. Each heating unit can be individually controlled and adjusted. Several heating units side-by-side build up the heating wall.

7.6.4.2.2 Underjet System for Coke Oven Gas In the underjet system, coke oven gas is distributed in the battery basement under the nozzle deck by means of steel nozzle headers off the distribution main and through steel connections to the riser pipes and openings to the burners in the heating flues. The coke oven gas is distributed in steel pipes which operate under pressure. Consequently, a good distribution can be obtained to ensure consistent flow of gas to the individual flues. By taking maximum advantage of the available fuel gas pressure, stainless steel metering nozzles are installed to ensure an accurate and consistent delivery of fuel gas to each individual burner. These are external from the battery refractory block and are easily accessible within the basement.

The nozzles headers are supplied in the underjet system from a single distribution main and a progressive adjustment can be obtained across the length of the heating wall.

The coke oven gas is fed to individual burners in the heating flues through vertical openings within the refractory block. They are of small diameter, having no detrimental effect on the stability of the refractory block.

Tightness, especially in the regenerator walls, is achieved by a tongue-and-groove brick design with staggered joints.

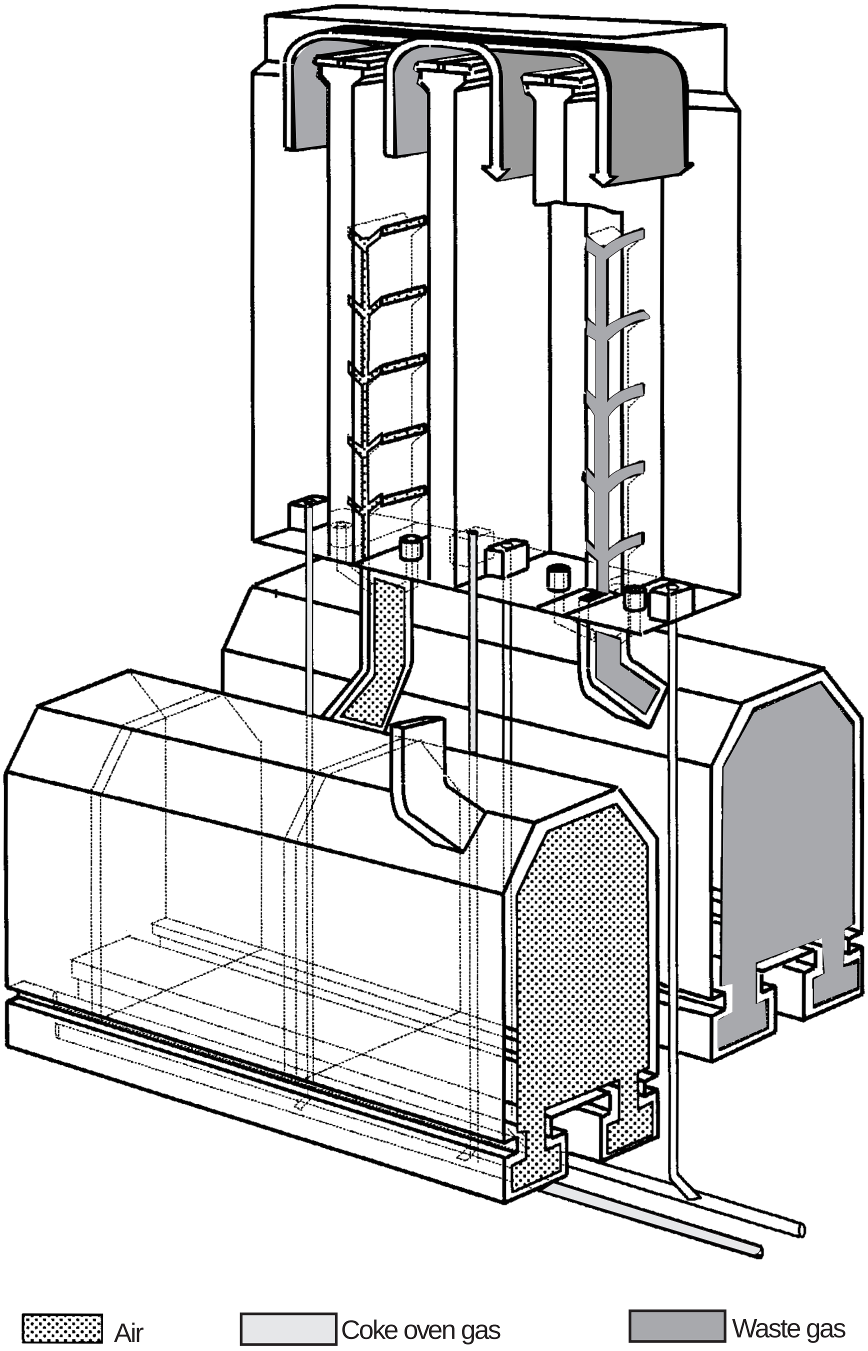


Fig. 7.76 Heating unit for a double pair flue underjet oven operating on coke oven gas.

All TSOA heating systems have also been provided as gun flue systems, based on the special requirements of the owner.

7.6.4.2.3 Regenerator Arrangement The regenerators are located under the oven chambers and heating walls and are continuous from the pusher side to the coke side. They are divided into simple, wide chambers. Each regenerator chamber operates on combustion air or waste gas. Two adjacent regenerators always operate on different media.

The regenerator chambers, with their checker bricks, are divided by partition walls into cells. The regenerator cells are calibrated to the different heat requirements of the heating flues due to the chamber taper by built-in flow resistance.

The corbel section contains only half of the number of connection ducts between regenerator cells and heating flues found in other designs as only every second binder wall has a canal.

The two tapered sole flues form a composite part of the regenerator and do not require any lining. The checker bricks, which form the regenerator packing, are supported by supporting bricks above the sole flues.

The packing is sub-divided into the separate compartments by tiles. These are inserted dry and can be removed should it every be necessary to repack the regenerator.

The majority of the checker bricks are manufactured from fireclay, but in the higher temperature zone of the regenerators the top four layers are manufactured from 40% alumina fireclay.

Distribution bricks with calibrated openings are located above the sole flues and below the regenerator cells. The volume of air which is distributed to the regenerators is effectively sub-divided into independent cells by the calibrated openings of the distribution blocks. Thus, a uniform and controlled air flow is obtained together with optimum heat recovery in the regenerator.

7.6.4.2.4 Heat Distribution across the Heating Wall Due to the taper of the oven chambers it is necessary to increase the heat input from the pusher side to the coke side. This is achieved by increasing the heating flue temperature from the pusher side to the coke side. Increasing amounts of gas and air must be fed to the heating flues to adapt the heat distribution across the heating wall exactly to the heat requirements of the charge.

The major calibrations for this distribution are built into the system based on design calculations.

For distribution of coke oven gas across the heating wall, steel nozzle headers are installed in the basement connected to each heating flue by riser openings. The calibrated stainless steel nozzles are exchangeable.

Air is distributed to the checkerwork of the regenerators by calibrated distribution bricks arranged between the sole flues and the regenerator compartments. Waste gas is recollected to the sole flues by the same calibrated distribution blocks. The different flow resistances necessary for the distribution of air and the recollection of waste gas is ensured by the configuration of the calibrated openings, which result in different flow resistances for different flow directions.

The amount of air fed to the heating flues is pre-calibrated by the built-in flow resistance of the cells.

The fine tuning of the heat distribution across the heating walls is done during commissioning by adjusting the coke oven gas nozzles in the nozzle headers and the sliding bricks arranged at the top of the heating flues.

The heat distribution from the pusher side to the coke side, once adjusted properly, does not need to be readjusted with changing operating conditions. This is achieved by pause heating as described in Section 7.6.4.2.7.

The total amount of air fed to and the total amount of waste gas collected from any heating wall are adjusted by finger plates at the air inlets and by dampers at the waste gas valves. These elements are simple and specially designed for this function to ensure a uniform and efficient regenerator loading.

The total amounts of coke oven gas fed to any heating wall are adjusted by orifices installed downstream of the reversing cocks.

7.6.4.2.5 Vertical Heat Distribution A uniform vertical temperature distribution in the coke mass is of fundamental importance to avoid heat being wasted and to control coke quality.

For vertical heat distribution, the major calibrations are also built into the system based on design calculations. These are cross-section of the heating flues, cross-section of the air canals in the binder walls, and cross-section and location of the air stages.

The fine tuning of the vertical heat distribution is done during commissioning by adjusting the air inlet and draft at the air inlet boxes and the waste gas valves.

Coke oven gas enters above the heating flue sole and partially burns with the air of the lower stage. Combustion is completed with the additional air at the higher air stage. This results in a soft flame characteristic over the entire height of the heating flue when burning high calorific gas.

Once the optimum flame length has been obtained, changes in coking rate can be achieved by using the pause heating facility described in Section 7.6.4.2.7. By using the pause heating facility, optimum vertical heat distribution will maintained at all times.

7.6.4.2.6 Heat Distribution in the Longitudinal Direction of the Battery In the longitudinal direction of the battery, equal amounts of air and gas must be distributed to each heating wall and, correspondingly, equal amounts of waste gas must be collected from each heating wall into the waste gas flue.

To avoid the wasting of heat, by increasing the amounts of gas/waste gas from the first to last heating wall, the amounts of gas/waste gas to and from the heating walls are controlled by throttling devices in the connections. On the inlet side these throttling devices are orifices in the branches from the coke oven gas distribution main, arranged behind the reversing cocks of each heating wall.

On the outlet side, throttling dampers are installed in the connecting piece between the sole flues and the waste gas valves.

In the case of changing operating conditions, with changing heat requirements for the battery unchanged, even heat distribution and optimum pressure and flow conditions are maintained by pause heating.

7.6.4.2.7 Pause Heating High efficiency of the heating system depends mainly on maintaining the optimum adjustment and control of the distribution and pressure conditions under all operating conditions.

This is achieved by pause heating, which keeps all operating parameters constant once they are adjusted.

During commissioning, the battery is adjusted to the shortest possible coking time, i.e. maximum possible heat requirement and maximum possible amounts of gas, air and waste gas. Under these conditions the battery will be operating at the minimum pause during the reversal of the regenerator half-periods.

If the heat requirements are reduced, i.e. in the case of longer coking times, the amounts of air and gas entering the system and amount of waste gas leaving the system per unit of time are kept constant and the reduced heat requirements are achieved by a pause between regenerator half-periods.

This simplifies the operation of a coke oven battery. All readjustments normally necessary with changing coking times are eliminated.

With pause heating, a single timer is set to a certain pause depending on the selected coking time. No further manual adjustments to the battery are necessary, except at very extreme coking times.

The amounts of gas, air and waste gas flowing constantly per unit of time result in an even distribution of heat in the longitudinal direction of the battery as well as across the heating wall. At the same time, a constant flame characteristic in the heating flues at normal coking times results in an even vertical heat distribution in the coke mass.

Operating times between the nominal coking time and 30% longer coking times are achievable with consistent, high thermal efficiencies. The consistent heating parameters for all coking times in this range result in evenly coked charges and consistent coke quality. Furthermore, pause heating reduces the manning/labor requirements for battery heating control, and therefore reduces operating costs.

7.6.4.2.8 Thermal Efficiency The design features and operating modes outlined in this description ensure even heat distribution in the horizontal direction of the battery and the horizontal and vertical directions of the heating wall. These features combine to contribute to the high thermal efficiency associated with the TSOA oven.

Other factors which influence the thermal efficiency include optimum utilization of the regenerator filling, effective oven bracing system, insulation of the oven block, and the exclusion of cross-leakage in the regenerator area.

The TSOA checker bricks in the regenerator compartments offer a large exchange surface to the through-flowing media. The checker bricks are shaped so that the gas flow is split up into multiple streams. This ensures good heat transfer by their large surface area.

Pressure differentials are low because disturbances in the flow from the inlet checkerwork to the outlet checkerwork are minimal.

Horizontal surfaces which could collect dust in the regenerator are avoided.

7.6.4.2.9 NOx Formation in the Heating System As can be seen from the heating cross-section in Fig. 7.77, the TSOA oven is an “air stage oven” which ensures low NOx formation in the case of heating with coke oven gas.

In developing this heating system, TSOA embarked at first on a test program with extensive laboratory tests, which included tests on small heating flues as well as the construction of cold models to visualize the flow and mixing conditions in the heating flue.

Because of the results of these tests, test heating flues for 7.5 m high oven chambers were constructed in order to study all possible air and gas supply configurations and the resultant impact on the NOx formation and the vertical temperature distribution.

The outcome of this work was the air stage oven, a design which produces long flames with a low flame temperature and low NOx values.

After this extensive testing, the heating system was successfully built for owners worldwide. Numerous batteries, with over 1000 ovens of this design, are in operation today.

7.6.4.2.10 Coke Oven Gas Heating To best illustrate the operation of a double pair flue with underjet firing operating with coke oven gas, Fig. 7.77 will be extensively referenced in this section.

The rich gas distribution main, 13, is arranged in the oven basement opposite the waste gas flue and extends the length of the battery. The gas supply to the individual heating walls is controlled by adjusting shut-off and reversing cocks with the gas being fed through the gas headers, 15, in the oven basement extending the longitudinal direction of the heating wall. From these gas headers, the gas flows via short connecting lines, 16, into the vertical rich gas risers, 17, and to the burners, 18, at the flue bottom. Control of the gas volume is effected by means of replaceable nozzles in the connecting lines, 16.

The decarbonizing air main, 22, is arranged beside the rich gas main and serves the purpose of feeding a minor amount of air to the rich gas burners, not on gas in the heating flues, via the relevant distribution pipes and rich gas risers. This enables the prevention and burning away of any carbon deposits on the burners.

Combustion air is taken in through the alley and open air intake flaps, 20 and 20a, and drawn into the sole flues, 3 and 4, from where it is distributed over the regenerator compartment, 7, via calibrated distribution bricks, 5. By means of throttling equipment mounted in the air intake boxes the air volume allowed to enter a heating wall can be controlled and adjusted. The stored heat, which the hot waste gas has conveyed to the checker bricks before heating system reversal, is absorbed by air flowing through the regenerators. Through connecting ducts, 8, in the regenerator covering and duct, 10, running up the binder, the hot air flows to the opening locations in the heating flue.

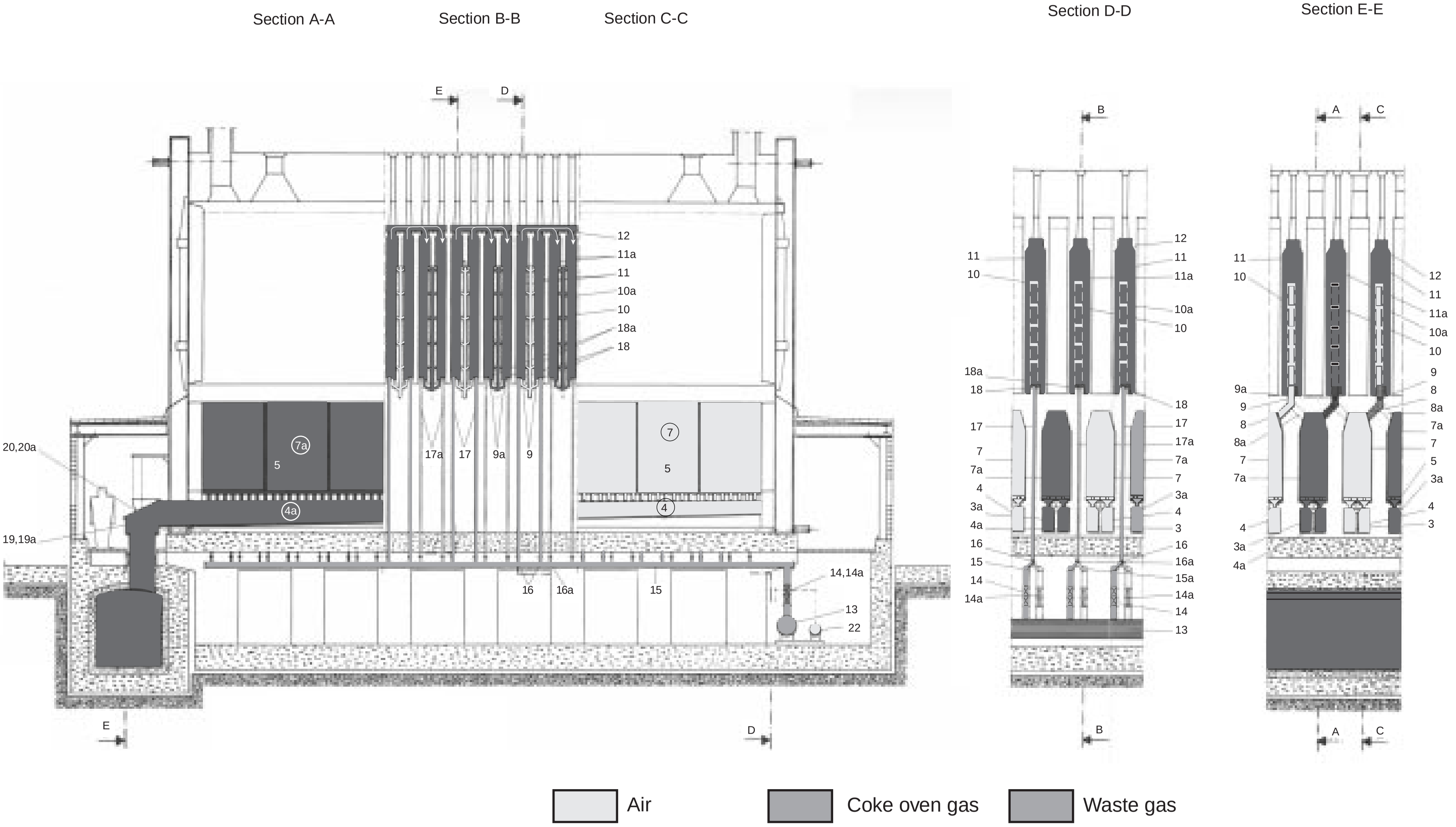


Fig. 7.77 Cross-section of the heating system of a double pair flue underjet heating oven operating on coke oven gas.

In the case of the double pair flue group carrying gas, the gas is burned in several stages according to the staged supply of air. The ascending combustion gases pass the reversal point of the double pair flue, flow downwards in the neighboring flue pair, and are then discharged through connecting ducts in the regenerator compartment, 7a, where the transfer of heat to the checker bricks takes place. Via the distribution bricks, 15, the cooled waste gas flows into the regenerator sole flues, 3a and 4a, and on to the chimney through waste gas valves, 19 and 19a, and the waste gas collecting flue.

When the regenerator heating system reversal has been effected, the flow of the media is reversed. The gas supply is changed over to the second gas header, 15a, of the heating wall and the other flue pair of the double pair flue is now on gas. The functions of the regenerator are also then reversed.

7.6.4.2.11 Waste Gas Flues and Chimneys Batteries are drafted by one single waste gas flue on one side, which is connected to the chimney located in front of the battery. The waste gas flue is connected to the chimney by a chimney flue.

The waste gas flue contains a hand-operated damper for control during startup or in case of a failure of the main butterfly valve.

The chimney flue contains a butterfly valve as a main control damper. This damper is automatically controlled by a regulator.

7.6.4.2.12 Operation of the Battery Heating System The TSOA battery is noted for its ease of operation and maintenance. This is enhanced, of course, by the presence of single rows of equipment: a single row of waste gas valves with air inlets; a single coke oven gas main and reversing/isolating cocks; and a simple hydraulic reversing gear.

The battery is adjusted by the TSOA commissioning team and is fine-tuned for optimum performance before hand-over to the client. Thereafter, no adjustments to the heating system settings will be necessary between the nominal coking time and 30% longer coking times. However, should the operators wish to modify the battery settings for any reason, the facility is there and it is easily accessible.

Provided that the basic maintenance requirements as laid down in the operating and maintenance manuals provided are satisfied, the design performance of the battery heating system will be maintained for the major portion of the battery life. Data for a typical TSOA double pair flue rich gas battery are presented in Table 7.5.

Table 7.5 Data for a Typical TSOA Double Pair Flue Rich Gas Battery

Year in Operation	1995
Number of Ovens	82
Chamber height, mm	6251
Chamber width, mm (average)	447
Chamber length, mm	15,424
Oven Type	Rich Gas
Coke Oven Gas Firing	Underjet
Heating Wall	Double Pair Flue
Air Stages	6
Coking time, h	18
Heating Flue Temperature, °C (average)	1310
Heat Consumption of Coke Oven Gas, kcal/kg	520
NOx in Waste Gas from Coke Oven Gas, mg/m3	223
CO in Waste Gas, mg/m3	90

7.6.4.3 TSOA Major Battery Equipment

TSOA uses for both coke oven systems, presented earlier, the same major battery equipment systems. Of course there are differences in the detail design based on the detailed heating differences. The following describes the systems for the example of the twin flue underjet compound coke oven.

7.6.4.3.1 Refractory Oven Block The traditional materials used in the construction of coke ovens are silica and fireclay. Both materials demonstrate different characteristics and both are markedly superior to one another under different conditions. The TSOA design employs the right materials in the right places, thus taking maximum advantage of the superior qualities of both silica and fireclay.

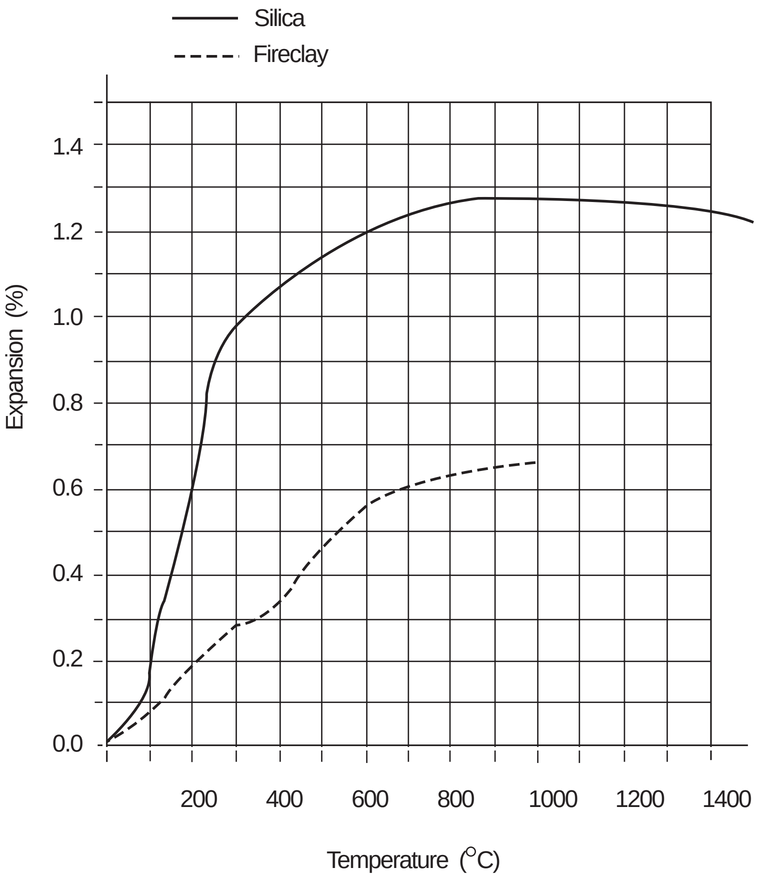


Fig. 7.78 Thermal expansion of silica and fireclay material.

7.6.4.3.2 Refractory Material Characteristics The graph in Fig. 7.78 illustrates the thermal expansion characteristics of fireclay and silica over the operating temperatures encountered in the coke oven battery. The following trends are noted. Silica undergoes practically no dimensional change between 800°C and 1400°C (1450°F and 2550°F). Fireclay undergoes a significant dimensional change over the range of 800°C and 1300°C (1450°F and 2350°F). At this upper temperature it has already reached its safe working limit beyond which its mechanical properties diminish.

Over the range 375–800°C (705–1450°F), silica undergoes some dimensional change, but far less than that of fireclay. Below 400°C (750°F) silica undergoes a dramatic, non-linear dimensional change. In contrast, fireclay undergoes a linear dimensional change below 400°C (750°F), a change which is far less severe than that of silica.

In addition to thermal expansion, other characteristics must be taken into account. Silica maintains its mechanical properties up to a temperature of 1600°C (2900°F), while low alumina fireclay is serviceable only up to temperatures of 1000°C (1830°F). Silica resists chloride attack, while fireclay is susceptible to attack from chlorides within the coal. The closed pore surface structure of fireclay provides a better resistance to sulfur attack than the open pore structure of silica.

7.6.4.3.3 Sole Flues and Lower Regenerator Section By design, the regenerators undergo a time-related temperature fluctuation, normally on a 30 min. cycle. The sole flue and the lower section of the regenerator (approximately 65% of the total regenerator height) operate within a range of 95–350°C (200–950°F). Within this range, silica undergoes a 1% linear expansion, an expansion which is critical in the range of 200–300°C (400–600°F).

In contrast, fireclay undergoes an expansion of less than half that of silica and the expansion curve is linear, thus there is no critical zone on the temperature curve.

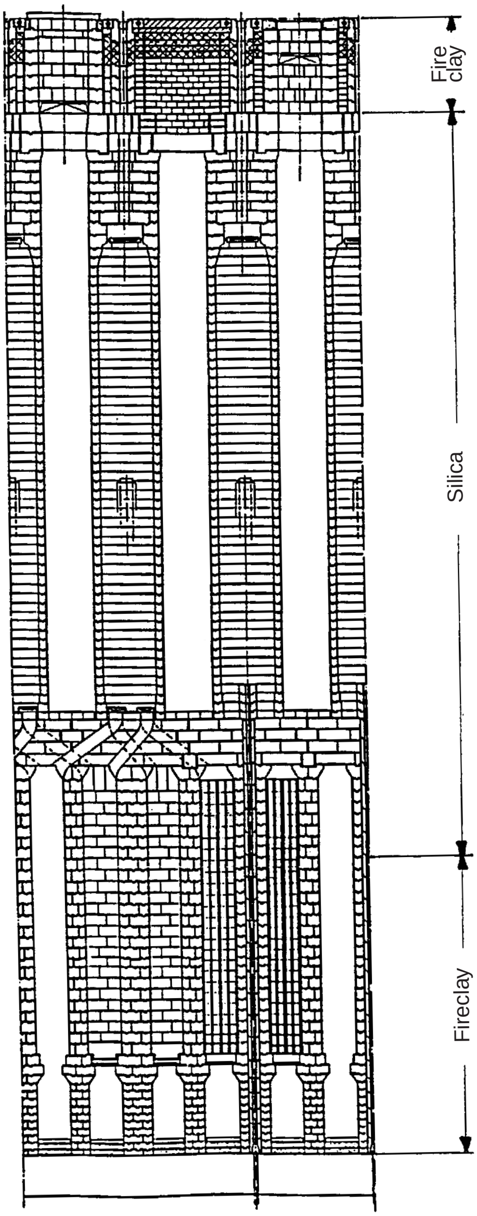


Fig. 7.79 Refractory cross-section of a twin flue underjet compound oven.

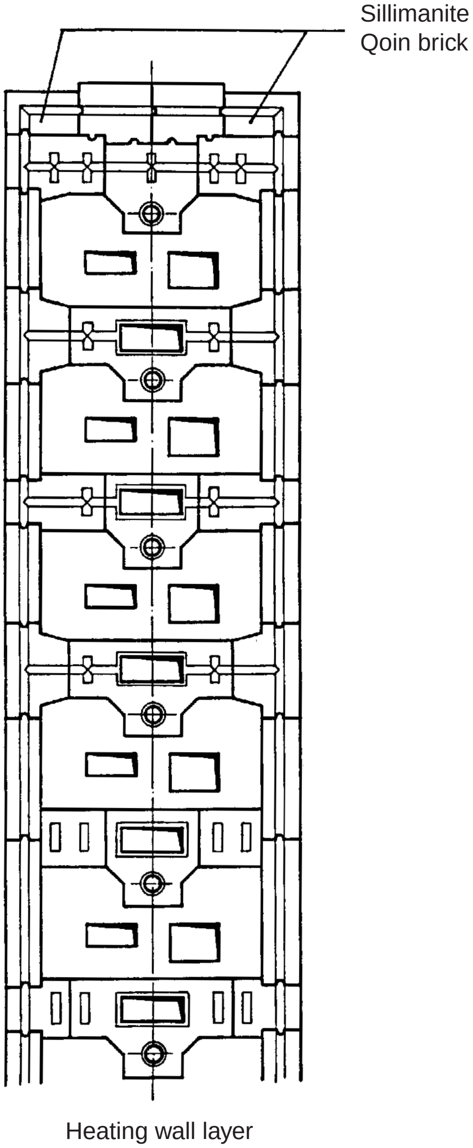


Fig. 7.80 Wall bond for a twin flue underjet oven system.

The TSOA oven design, Fig. 7.79, therefore employs fireclay for the construction of the regenerator sole flues and the major part of the regenerator walls.

Experience shows that a battery with regenerator walls constructed solely from silica will usually display signs of cross-leakage between regenerators after heatup, particularly in the critical zone where the normal reversal temperature fluctuations are in the region of 320°C (600°F). In contrast, a fireclay wall with proper bracing will remain tight for the duration of the battery life.

7.6.4.3.4 Upper Regenerator Section and Heating Walls Above the critical temperature of 800°C (1450°F) silica displays characteristics far superior to those of fireclay both in thermal expansion and in mechanical properties. Therefore, in the TSOA design the upper portion of the regenerator walls, the strong corbel section in the battery center, and the oven heating walls are constructed of silica and not fireclay, Fig. 7.80.

In the case of the heating walls, the wall surface temperature may fluctuate between 1000°C and 1250°C (1850°F and 2250°F) as hot coke is pushed and cold, wet coal is charged. However, the silica volume is stable over this temperature range and therefore negligible thermal stresses are developed within the walls.

7.6.4.3.5 Oven Roof By the same logic fireclay is more suitable than silica for the construction of the battery roof above the cover blocks of the oven chamber.

Temperature fluctuations occur within the oven roof and where this is constructed of silica a weakening will develop in the critical zone below 800°C (1450°F). By employing fireclay, the TSOA design in Fig. 7.81 enables the roof to be maintained tight and strong for the duration of the battery life.

7.6.4.3.6 Silica and Fireclay Interface There are few coke oven designers who would argue against the selection of fireclay as the most suitable material of construction for the regenerator walls. However, most important for the design is the achievement of an adequate joint between the silica and fireclay layers at their interface.

In the case of the TSOA oven, the design is based on many years of experience. A special sliding joint is constructed between the fireclay substructure and the upper silica section, a joint system which has been proven over many decades on tens of thousands of TSOA coke ovens of every size. The performance of the sliding joint is most important during the heat up of the coke oven battery,

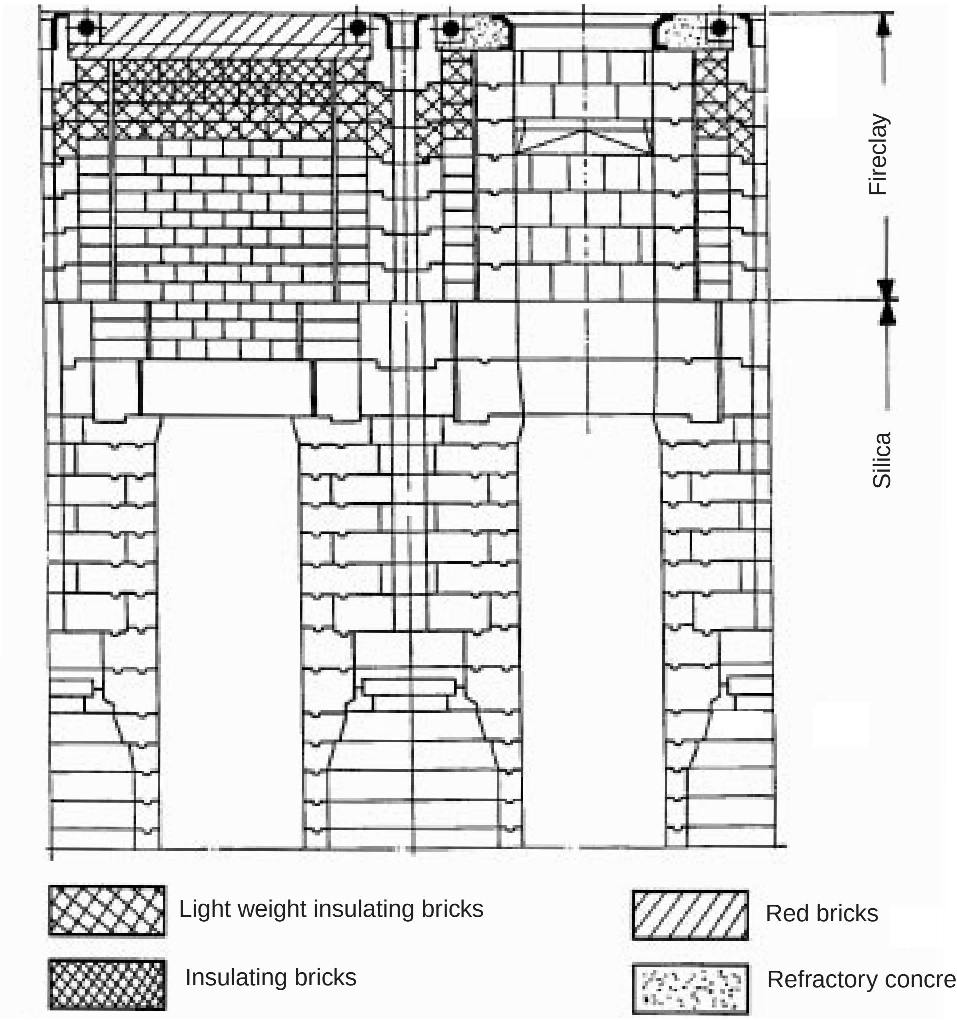


Fig. 7.81 Oven top design.

when silica and fireclay undergo their different expansions. This differential expansion is not only accommodated by the sliding joint, but also controlled precisely by the TSOA bracing system described in Section 7.6.4.3.9. The end result is a gas-tight joint necessary for the integrity of the overall battery structure.

A sliding joint is also employed between the silica and fireclay layers of the oven roof. Again, by special design of the joint and the controlled bracing, a gas-tight structure is assured.

It will be noted here that in the case of the coke oven gas riser pipes, trumpet bricks are provided at the interface between the concrete and fireclay and at the interface between fireclay and silica. This is a well-proven and practical method of accommodating the difference in expansion which may occur in deviation to the theoretical calculation. It ensures that there is no restriction within the riser pipe and that a clear through-way is available for rodding of the riser pipes following routine maintenance grouting. This design is a standard TSOA feature and is incorporated in all of the battery designs.

7.6.4.3.7 Quoin Design for the Heating Wall End The quoin brickwork is particularly vulnerable to temperature changes and is subject to thermal shock each time an oven door is removed. Silica can be used in the construction of the quoins, but in operational practice it tends to crack and spall, resulting in a high level of corrective maintenance.

In the TSOA design, Fig. 7.82, the silica bricks are replaced by special spall-resistant sillimanite bricks.

This material has proved eminently suitable for quoin duty on TSOA batteries around the world over many years.

The special bricks are bonded into the silica end brickwork. This ensures uniform expansion of the quoins as well as gas tightness in this critical zone of the heating wall. Should the need arise, the quoin brickwork can be replaced without opening or disturbing the brickwork of the last heating flue.

7.6.4.3.8 Insulation of the Oven Block In the design of the TSOA battery, particular attention is paid to thermal insulation. This promotes good thermal efficiency, comfortable working conditions, and minimizes heat degeneration of the battery steelwork and ironwork.

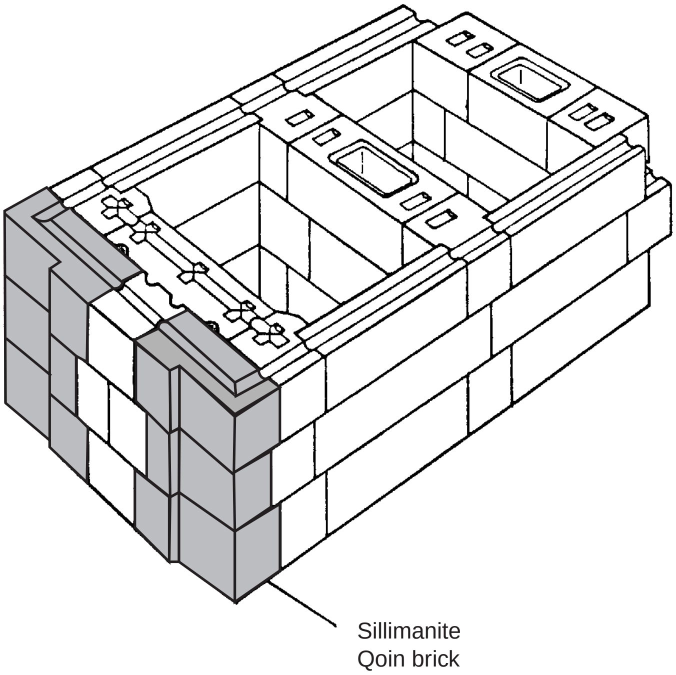


Fig. 7.82 End flue design, wall perspective.

Particular areas of insulation and the protection afforded are: concrete nozzle deck of the battery beneath the sole flues to prevent radiation into the basement; regenerator faces to reduce radiation into the alleys; brickwork at the battery ends to protect the buttress walls; and the large, flat oven roof to prevent radiation to the atmosphere.

The insulation is provided by courses of insulating brick.

Also, the charging hole lids are insulated against heat radiation by special design and being filled with an insulating compound.

7.6.4.3.9 Battery Bracing System In battery design, proper and effective bracing of the refractory block is considered to be of paramount importance, and the current TSOA design reflects many years of development, testing and site experience. The importance of the battery bracing is very often underestimated both by battery designers and operators, and it plays a different but equally important role during the heating up and subsequent operation of the battery. Many instances of premature battery failures around the world can be traced back to inadequate bracing control, either during the battery heatup or during its early years of operation.

The bracing system of a coke oven battery has to perform two functions: (1) restrain the fireclay refractory brickwork during the heatup expansion to allow the silica refractory brickwork to slide over or under it due to its higher expansion, and (2) to restrain the battery block during operation.

The vertical and longitudinal expansion of the refractory oven block is allowed for by expansion joints built into the brickwork.

The forces arising in the vertical direction are taken up by the weight of the oven block.

The bracing forces in the horizontal direction are adjusted such that the expansion joints are nearly closed and that the fireclay material is not taken apart at the sliding joints by the more expanding silica material in the lower temperature range.

Due to the higher expansion of silica compared with fireclay material, the silica part of the oven block is built up with recesses in the horizontal direction.

After complete expansion, a gap of 10–20 mm between the buckstay and the oven quoin avoids a direct heat transfer into the buckstay.

7.6.4.3.10 Buckstays and Tie Rods The buckstays represent the heart of the battery bracing system and it is from these that loads and forces are distributed to the critical areas of the refractory block to ensure that it is correctly restrained. On the one hand, the bracing system from the buckstays must be sufficiently flexible to allow the battery to breath and move normally throughout its life, while on the other hand it must be sufficiently strong to ensure that such movements are not unrestrained to the detriment of the battery life.

Opposite buckstays are drawn towards the oven heating walls by two upper cross-tie rods per heating wall inside protection channels made of stainless steel. Two bottom cross-tie rods per wall will be installed in the nozzle pad openings. The cross-tie rods are spring loaded from the buckstays and thus controllable and measurable forces are exerted at these points, ensuring that the correct pressure is maintained during heat up and operation. The springs are protected from heat and dirt accumulation and are equipped with spring position indicators.

Buckstays and upper and lower tie rods form a frame around the refractory block in the cross-direction of the battery.

The cumulative forces from the cross-tie rods are then distributed from the buckstay onto the refractory block through the bracing system. Furthermore, the buckstays are capable of supporting additional peripheral equipment, including gas collecting mains, coal charging car collectors wire supports and the like.

Against vertical loads during heat up, the buckstay bases are connected to the concrete waste gas flue/basement bottom slab by vertical anchors. The horizontal mobility of the buckstay bases is ensured by slotted holes and friction bearings.

In the longitudinal direction of the battery, a frame of the concrete bottom slab, the two pinion walls and the spring-loaded longitudinal tie rods are all bracing the oven block.

The tension of the longitudinal tie rods is also controlled by springs in order to ensure that the correct pressure is maintained through the pinion walls at all times during heat up and operation.

The longitudinal expansion in the area of the oven roof and the regenerator top is controlled in such a way that the expansion joints are closed during heat up to form a solid mass of refractory between the pinion walls.

Thus, it is ensured that during heat up the expansion joints in the horizontal direction are closed, the battery is restrained during operation, and the pinion walls are held in vertical position by the controlled forces applied to the longitudinal tie rods by the springs.

7.6.4.3.11 Heating Wall Armoring The heating wall ends are covered and protected by cast iron armoring plates and door frames. Controlled forces are applied from the buckstays via spring-loaded pressure bolts to the armoring plates, then from the armoring plates to the door frames by pressure bolts, and thus onto the liner walls, Fig. 7.84. Therefore, no load is applied to the center of the last heating flue.

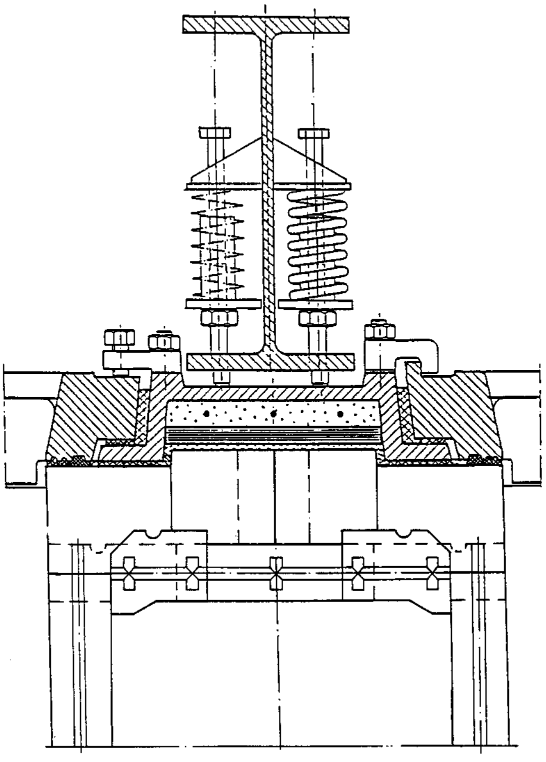


Fig. 7.84 Cross-section of the bracing system.

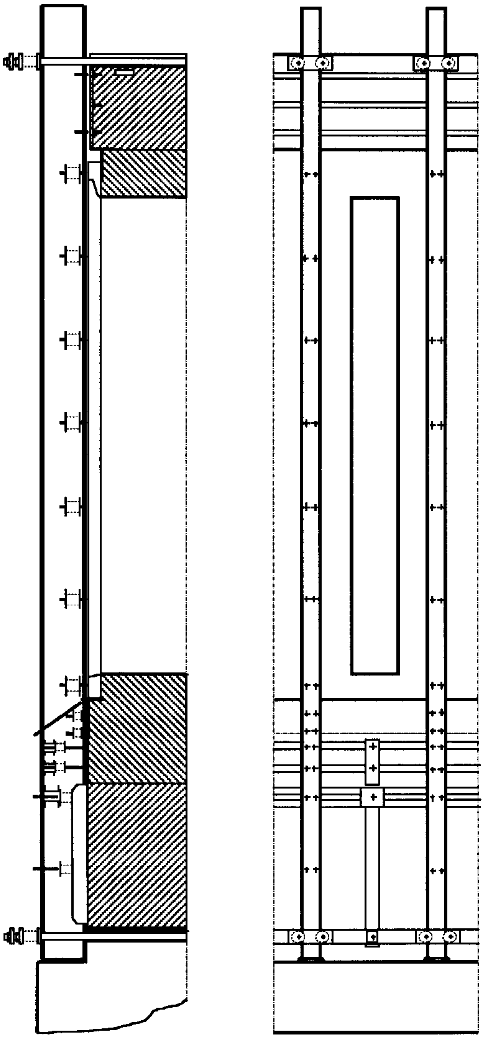


Fig. 7.83 Bracing system for a twin flue underjet oven system.

The load distribution from the buckstays onto the armoring plates is adjusted to the different requirements of the heating wall in the vertical direction. This non-uniform introduction of loads provides additional horizontal support to the heating walls and reduces movement in this area.

These forces also do hold the armoring plates and the door frames in position, and reduce door frame deflection due to temperature differences between the inner and outer surface.

In order to seal the armoring plates against the oven walls, all gaps are filled with a stamping compound. Cast-in grooves with gaskets are arranged at the back sides of the door frames. T-bars laid in between the roof brick layers and supported from the buckstays by pressure bolts hold the fireclay roof brickwork above the door frames on both the pusher side and the coke side of the oven. Steel plates located under and sloped downward from the oven doors to the bench are provided. They are designed to prevent coke spillage from passing between the battery and benches to the alleys below.

7.6.4.3.12 Regenerator Bracing In the TSOA design the lower portions of the regenerator walls are constructed from fireclay, which displays expansion characteristics different from those of silica. To prevent the fireclay from being torn apart by the silica material as it expands during heat up, a regenerator bracing is installed.

Controlled forces are applied by springs from the buckstays to hold the silica and fireclay parts of the regenerator top and regenerator wall sections together while the silica slides over the fireclay.

The regenerator wall under the chamber is held by a spring-loaded I-beam and the regenerator wall under the heating wall is held by a U-profile that is spring loaded from the buckstay.

7.6.4.3.13 Operation of the Bracing System

7.6.4.3.13.1 During Construction The pressure through the buckstays onto the wall armoring plates is set after construction so that as the main springs onto the cross-tie rods at the top and bottom of the buckstays are tensioned, the buckstays assume their correct position against the wall armoring plates.

The pressure bolts between the armoring plates and the door frames are tightened until the entire load is transferred by the frames to the liner walls and there is no load from the wall armoring plates onto the center of the heating wall end.

All springs of the roof and regenerator bracing are then adjusted to the heatup dimensions, which impart the heatup bracing load.

7.6.4.3.13.2 During Heat Up The heatup restraining load is maintained at all points throughout the heatup program by adjusting the springs to maintain a constant load. Thus, expansion of fireclay and silica is permitted to take place under a pre-determined load which ensures tight joints and proper performance of the sliding joint between the fireclay and the silica layers.

7.6.4.3.13.3 During Operation On completion of the battery expansion the individual springs of the bracing system are adjusted to their operating lengths which impart a different load than that required during heat up. Thus, an adequate restraint is maintained while permitting the battery to breath with its normal fluctuations in temperature.

7.6.4.3.14 Reversing System The mechanical reversing of the heating system is implemented by an electro-hydraulic reversing system. The reversing system changes the position of the coke oven gas and mix gas reversing cocks, the flaps of the air inlet boxes and the waste gas valves.

In case of a failure of the electric motor for the hydraulic operating pump, it is possible to operate the reversals by an air motor-driven hydraulic standby pump. In case the air motor should fail too it is possible to carry out two complete reversals with a piston-type accumulator in conjunction with nitrogen bottles. In addition, a hand pump is supplied.

The control voltage for the hydraulic valves is backed up by batteries. The reversing system is automatically controlled.

The reversing system consists mainly of the reversing rods and the hydraulic cylinders. The hydraulic cylinders operate the rods which are linked with the coke oven gas reversing cocks, mix gas reversing cocks, air flaps and waste gas valves. The reversing rods for the waste gas valves and flaps of the air inlet boxes are installed all around the battery in the upper area of the waste gas alley. They are redirected at the concrete pinion walls of the batteries by return chain pulleys.

The two reversing rods for the coke oven gas and mix gas reversing cocks are installed parallel to the coke oven gas and mix gas distribution mains in the basement and all around the battery similar to the upper area rods. The hydraulic cylinders and the hydraulic power unit are located in a separate room near the coal charging station.

In the event of a gas failure during a heating up period, the valves of the walls on fire are closed automatically. The position of the air inlet flaps and the waste gas valves remains unchanged and the battery is purged with air.

In the case of a gas failure during a reversing operation, the actual reversal of the flaps/valves is completed to achieve defined purging conditions as well.

To monitor the correct operation of the individual reversing elements, an infrared safety system is provided.

7.6.4.3.15 Raw Gas System Each battery normally incorporates a single gas collecting main on the pusher side or the coke side, Fig. 7.85. The gas collecting main handles the raw gas evolved from the battery when operating at its design maximum coking rate. The gas collecting main is divided down into sections based on the number of ovens, with each section incorporating a raw gas offtake.

A flushing liquor feed connection is installed at the end of each main to enable the mains to be flushed through at selected intervals.

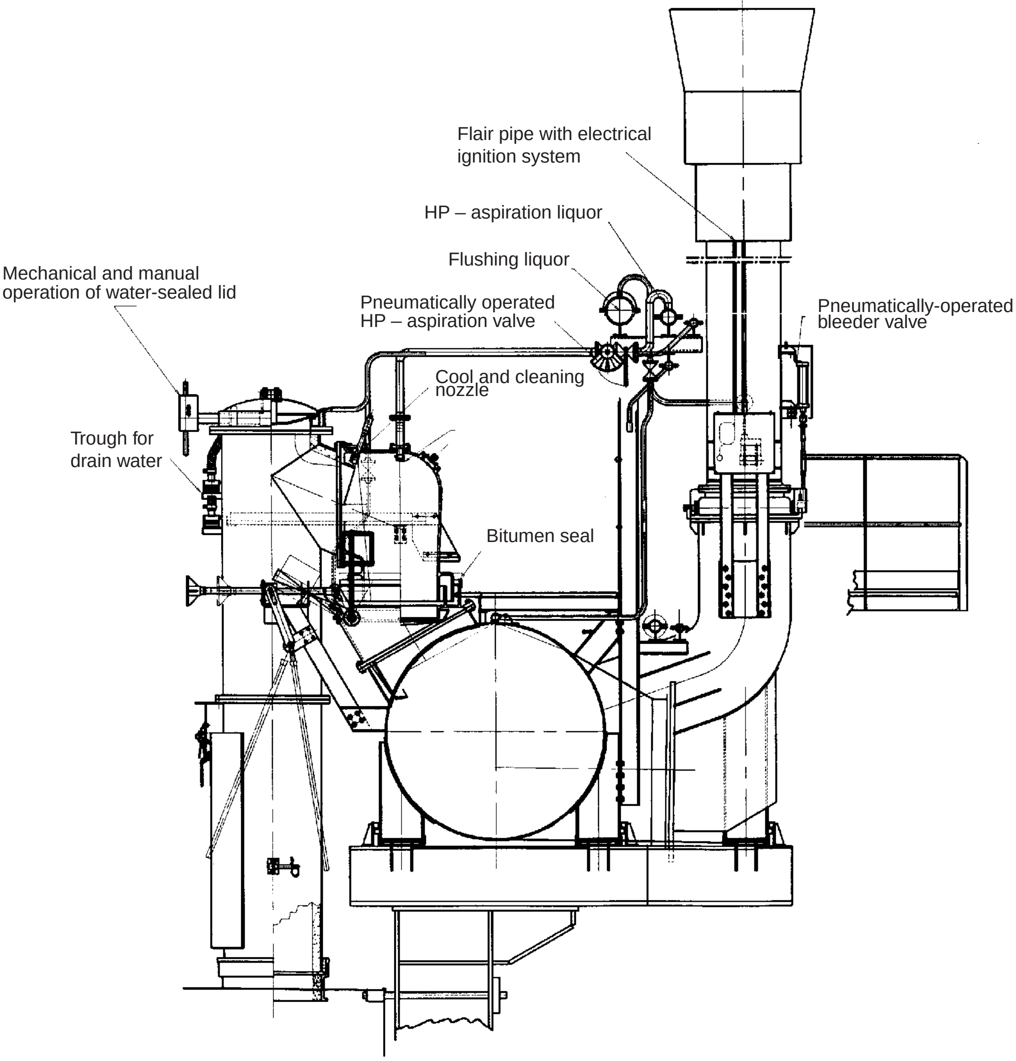


Fig. 7.85 Cross-section through the collecting main.

Each gas collecting main section is provided with two bleeder stacks, one at each end. Each bleeder stack is closed by a liquor-sealed valve which is actuated remotely and automatically in the event of high gas collecting main pressure. An electric system ensures ignition and a cowl induces air to the bleeder stack. The flame will be stabilized by the addition of steam to the center of the combustion burner.

The ascension pipes are mounted in cast iron base sockets which are set into the battery top. The ascension pipes have a refractory material lining.

The ascension pipe top section is of mild steel and is refractory lined as in the case of the ascension pipes. They are equipped with water-sealed ascension pipe caps, operated from the battery top, which consist of a cast iron water trough bolted to the ascension pipe top and a double skin lid. The lower plate of the lid is fabricated in steel and is designed to withstand the radiant heat from the oven. This plate forms a seal against the inner face of the cast iron trough. The upper plate is a standard vessel bottom from steel fitting into the water trough which is the primary seal. The air gap between the two plate ensures that the lower plate remains hot, thus preventing condensation of tar.

The goosenecks are cast iron and are equipped with wide-angled liquor sprays which ensure that the entire surface is wetted and remains clear of deposits. These normally remain clean down to bare metal.

This nozzle also cools the gas prior to entering the collecting main.

High pressure nozzles are installed in the goosenecks directed towards the collecting main valve. The positioning and design of these nozzles ensure maximum aspirating efficiency with minimum liquor consumption. The liquor valves associated with the nozzles are operated from the battery top.

Oven chamber isolation from the gas collecting main is possible by a cast iron collecting main valve which is irrigated by the flushing liquor to form a liquor seal. Each collecting main valve is housed in a separate casting external from the gas collecting main so that it can be easily maintained, and should the need ever arise, it can be replaced without undue difficulties. These valves are operated from the battery top.

A flushing liquor distribution main is installed along the coke side gas collecting main, complete with branches including isolation cocks to each flushing liquor spray in the goosenecks, collecting main and bleeder stack.

Additionally, branches are provided with valves to the ends of each gas collecting main.

Gas collecting main supports are secured to the top of the buckstays at every second oven.

Industrial water mains, complete with branches, are installed on the coke side of the battery along the length of the gas collecting mains to supply water to the troughs of each ascension pipe lid. Each branch is fitted with an isolation cock.

Water from the ascension pipe lid seals overflows through a coarse steel mesh filter into an open trough. Each trough is connected to a drain main on the coke side which runs the entire length of the battery. The water is collected in a closed recirculation and treatment system. The surplus water is discharged into the collecting main for final treatment in the byproduct plant.

An emergency water main is provided. This main is connected into the flushing liquor main adjacent to the battery. This main includes isolation valves.

7.6.4.4 TSOA Coke Oven Doors and Frames

7.6.4.4.1 Causes for Door Emissions

7.6.4.4.1.1 Thermal Deformation of Door Body and Chamber Frame The door body and the chamber frame are subjected to bending deformation, particularly in their longitudinal direction, due to thermal stresses whereas the deformation of the door body and the chamber frame may differ substantially depending on their design.

Moreover, deformations of door bodies and chamber frames vary both in the long and short term due to operationally conditioned temperature variations.

However, it is not the absolute temperature but rather the temperature gradient in the door body and the chamber frame that is the determinant of thermal deformation. The thermal deformation of the door body and/or the chamber frame can be determined by the following relationship:

$$Y_T = \frac{T \cdot \Delta T \cdot L^2}{8H} \tag{7.6.1}$$

where

Y_T = thermal deformation
T = thermal expansion coefficient
ΔT = temperature difference in the element
L = element length
H = door body web height.

The deformations due to thermal stress for a chamber frame and door body are plotted over the chamber height in Fig. 7.86. The resultant deformation difference, more or less wide gaps, must be closed by the sealing element.

7.6.4.4.1.2 Gas Pressure in Sealing Element Area The tightness of a coke oven door furthermore is influenced by the level of gas pressure in the sealing element area and by the configuration of the gas discharge duct which is formed by the heating wall door plug and sealing element.

The development of the gas pressure mainly depends on the type of charged coal (i.e. volatile matter, grain size and bulk density) and the coking time.

An example of the chronological development of gas pressure in the area of the door seal is presented in Fig. 7.87. The maximum is reached shortly after charging.

Measurements revealed that the gas pressure mostly is approximately 100 mm WG shortly after coal charging, although pressure peaks of 500 mm WG and more were also noted.

The gas pressure, however, can be influenced by the appropriate choice of the gas discharge duct. Fig. 7.88 shows the dependence of gas pressure on the cross-section of the gas discharge duct.

7.6.4.4.2 Demands on Modern Coke Oven Doors Modern coke ovens, with chambers up to 8 m (26.3 ft) tall and up to 600 mm (24 in.) wide, demand increased performance of the coke oven doors. Door

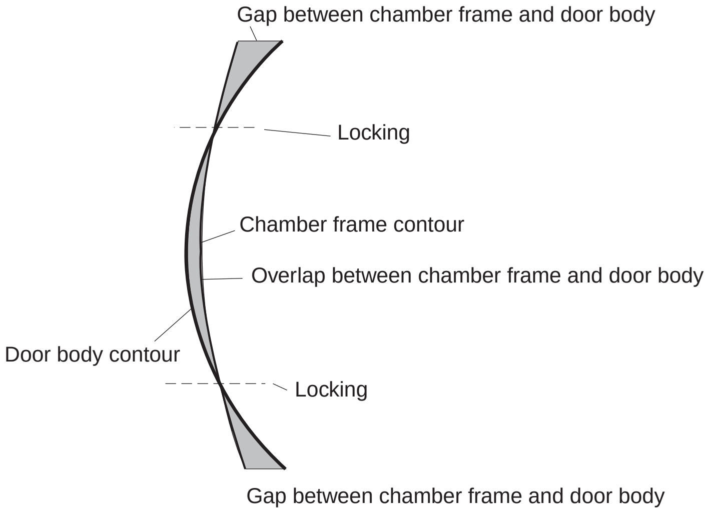


Fig. 7.86 Deformation differences between the chamber frame and the door body.

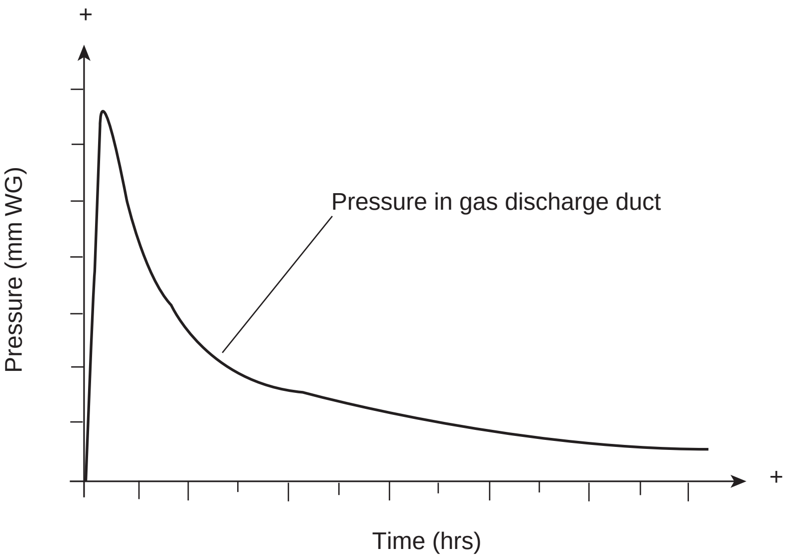


Fig. 7.87 Pressure development in the gas discharge duct after the start of the coking time.

emissions must be prevented. The sealing system must be flexible enough to seal even very tall oven chamber during normal operation ranges automatically, so as to maintain a positive pressure in the chamber. The sealing system must be adjustable to varying chamber frame and door body contours as well as local unevenness of the chamber frame surface, without any bending of the sealing frame profile and without loosing its flexibility. The sealing system must also maintain equal sealing strip compression forces. The adjustment must be possible with a low amount of work on only one element of the door. Ingress of air into the oven chamber must be prevented, even under negative pressure conditions. Heat losses from the oven chamber must be reduced. The doors, and especially the sealing element, must be strong enough for mechanical cleaning. These demands must all be met with low expenditures for maintenance and repair.

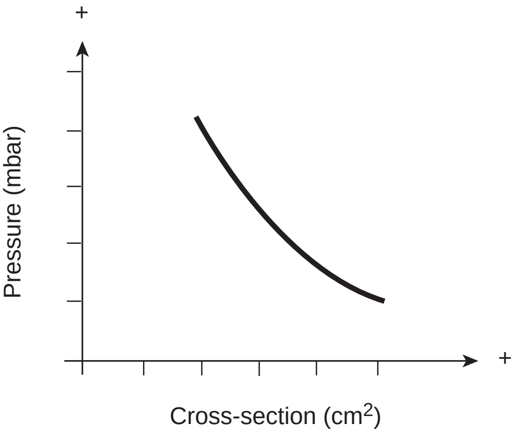


Fig. 7.88 Dependence of gas pressure on the gas discharge duct cross-section.

7.6.4.4.3 Description of TSOA Coke Oven Doors

7.6.4.4.3.1 Concept The TSOA door has been designed and developed to meet the demands in Section 7.6.4.4.2. In contrast to other systems, its sealing system can be adjusted to varying door body and chamber frame contours while maintaining the theoretical compressive forces of the sealing strip onto the chamber frame at the entire door circumference.

The door body is a U-cross-sectional casting of heat resistant cast iron. The door is locked onto the chamber frame latch hooks by two spring-loaded latch bars.

The compressive force effective at the sealing strip between the upper and lower latches amounts to approximately 10 N/mm^2 (14.5 ksi) and increases evenly outside the latches up to approximately 16 N/mm^2 (23.3 ksi) on the sealing strip length towards the door ends.

The coke oven door is vertically supported by means of a round carrier bar installed horizontally through the door body, resting on cams that are cast to the chamber frame.

Between the sloped inner surfaces of the chamber frame and the door plug side surface, gas escape channels are created on both sides that may be cleaned mechanically.

Gas developing behind the door seal can freely escape into the free gas space on top of the charge, and thus the buildup of an excessive gas pressure at the seal is safely prevented.

The distance between the door plug and the wall is approximately 20 mm (0.8 in.). This narrow gap prevents the ingress of coal into the gas escape channels and the resultant pressure accumulation at the seal.

7.6.4.4.3.2 Sealing System The efficiency of the TSOA door sealing system is based on the following features and properties.

The sealing strip is adaptable to variations in the frame and door contours and local unevenness, up to approximately 50 mm (2 in.), just by moving the sealing system (spring casing, sealing spring and sealing strip) with the set screws above the spring casings.

There is no bending to the cross-section of the Z-sealing strip profile. The 90° angle in the profile cross-section is maintained. The entire spring deflection of the sealing system is thereby retained for the automatic adaptation.

The theoretical spring forces and therefore the compressive force of the sealing strip onto chamber frame contact surface adjust themselves automatically.

At the same time, the adaptation of the sealing system to the chamber frame contour, as well as the spring forces onto the sealing strip, are adjusted by the set screws above the spring casings.

Automatic adaptation to variations in the bending line of the chamber frame and the door body due to temperature variations during the coking time are effected by the spring-loaded sealing strip.

Distances between adjustment points are approximately 200 mm (8 in.), making the adaptation for local unevenness of the chamber frame possible.

The door and especially the sealing element is strong enough to withstand mechanical cleaning.

Only by combining all of the above features can TSOA door, Fig. 7.89, fulfill and meet today's demands and requirements at normal temperatures.

7.6.4.4.3.3 Door Plugs The door plug must protect the door against overheating, reduce heat losses from the oven chamber, and bridge the gap between the door and the first heating flue to ensure coked out ends of the coke cake.

The door plugs can be of fireclay refractory brickwork and held in place by cast iron brick retainers or precast fused silica blocks.

7.6.4.4.3.4 Leveler Door The leveler door body is made of cast iron. A spring-loaded Z-shaped sealing strip is clamped to the leveler door body and automatically adapts itself to the machined surface of the leveler door frame contact surface.

The leveler door has a center spring-loaded latch which is hinge-mounted, opening upwards (to one side in most older plants).

7.6.4.4.3.5 Door Positioning in the Chamber Frame Adjustable stopper bolts, limiting the horizontal movement of the door toward the chamber frame, are installed to protect the sealing strip when the door is placed into the chamber frame.

Furthermore, the door is equipped with four guide pieces in the area of the latch hooks.

To avoid damage to the door as it is moved in and out, the distance of the guide pieces toward the latch hooks is adjusted by shims to 3mm (0.12 in.). Thereby, the gap between the chamber wall and the door plug on both sides is kept the same as much as possible.

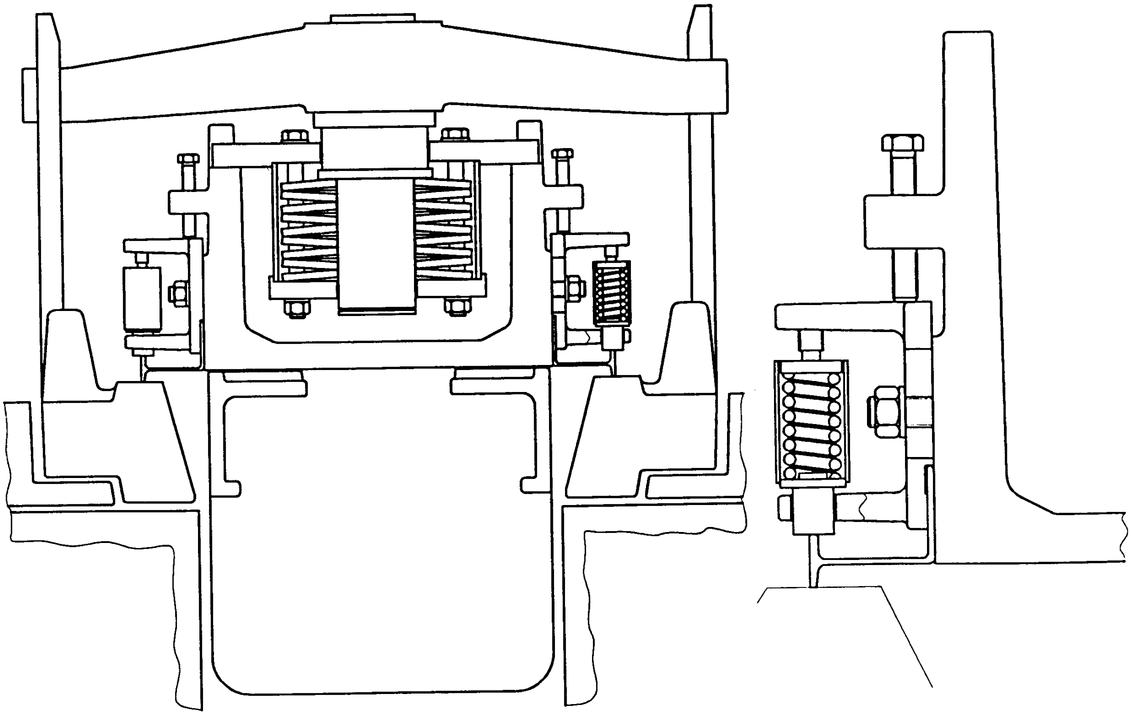


Fig. 7.89 Cross-section of a door and sealing element.

For vertical positioning, the door is equipped with a carrier bar resting on two cams cast to the frame.

The machining of these cams ensures an exact positioning of the door in the vertical direction.

7.6.4.4.3.6 Chamber Frame The pusher side and the coke side chamber frames are made of heat resistant cast iron.

They are easily replaceable in the oven without the necessity to loosen buckstays. Their nearly square cross-section keeps temperature differentials, and thereby deflection, low.

Pairs of latch hooks are bolted to each frame to accommodate the coke oven door.

Supporting cams are cast on to the chamber frame for vertical door supporting.

The chamber frame is held in position by pressure bolts from the wall armoring plates.

Devices placed on each side of the chamber frame and acting from the wall armoring plates prevent hour glassing.

The sealing surfaces on the chamber frame front are machined for contact with the door sealing strip.

7.7 Recovery of Coal Chemicals

7.7.1 Collection of Volatile Products from Ovens

In the collection system for the recovery of the volatile products from coal, the first operation reduces the temperature of these products, which are generally referred to as *foul gas*. This takes place in a system of gas mains through which the foul gas passes.

The foul gas passes out of the oven chamber through a refractory-lined ascension pipe and into a gooseneck which connects into the *collecting main* through a damper valve. The collecting main serves an entire battery of ovens, running parallel with the battery and extending above it on one side or on both sides, depending on whether it is a single or double collecting main operation.

The gas and vapors ordinarily leave the oven at temperatures in the range 600–700°C (1100–1300°F), and are shock-cooled by spraying with flushing liquor in the goosenecks and further cooled by spraying again with flushing liquor at different points along the collecting main. The cooling is effected by the evaporation of a portion of the water from the flushing liquor which removes some of the sensible heat from the gas and condenses some of the vapors, with the resultant condensation of heavy tar from the gas.

The gas and remaining vapors pass from the collecting main through one or more *cross-over mains* into the *suction main*. A pressure-regulating valve, automatically controlled, is located in each cross-over main. After the gas and vapors have passed this control valve their temperature drops to a range of 80–100°C (175–212°F), as a result of atmospheric cooling and further evaporation of the flushing liquor.

The *flushing liquor*, used for cooling in the spray system, is liquor which has been condensed in the mains, collected and recirculated, amounting to 3–4.5 m^3 (800–1200 gal) per ton of coal carbonized in coke oven batteries with a single collecting main and up to approximately 7.5 m^3 (2000 gal) on those with two mains. The flushing liquor, which cools and condenses various vapors in the gas, provides a carrying medium for the condensable tars and other compounds formed in the operations. These liquid materials flow from the collecting main through a seal into a downcomer and are delivered through the return flushing lines to a collecting unit customarily called a flushing liquor decanter, Fig. 7.90 and Fig. 7.91.

The uniform flow of gas and vapors into the system is accomplished by the charging of coal into the ovens at regularly prescribed intervals and the withdrawal of the evolved gases at a constant rate. This constant rate of removal of the gas is controlled by varying the speeds of the turbines and exhausters which pull the gas away from the ovens and by automatic pressure regulators in the cross-over main. This pressure regulator provides a slight pressure of about 1 mm (0.04 in.) of water at the base of the oven prior to pushing. This control of pressure is for the purpose of eliminating the infiltration of atmospheric air or gases from the heating system into the oven, which would have a deleterious effect on the quality and quantity of the coke and coal chemicals.

As a consequence of this practice, the pressure on the collecting main is about 8–12 mm (0.3–0.5 in.) of water with a variable suction of about 200–300 mm (8–10 in.) of water in the cross-over main after the regulating valve.

These pressure differentials are maintained by the use of either low speed positive turbo or centrifugal-type exhausters designed to remove the gases and vapors at a controlled rate.

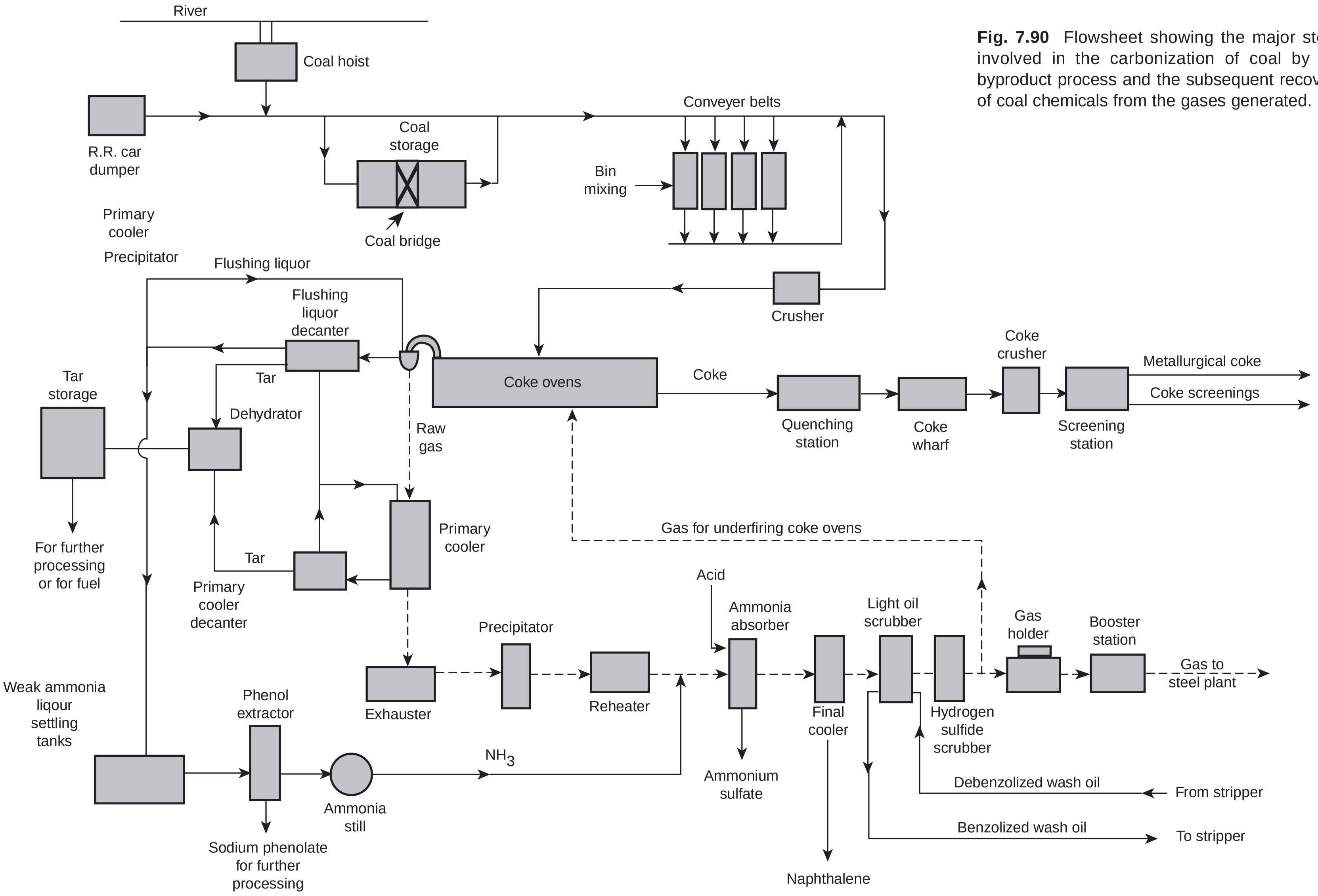
7.7.2 Recovery of Crude Coal Tar

7.7.2.1 Flushing Liquor Decanter Tank

The flushing liquor decanter tank, Fig. 7.91, serves a two-fold purpose in the processing of the liquid condensates and recirculating liquor in the primary liquid system: (1) it provides a settling basin in which the velocity of the tar and liquor is reduced to permit separation of the tar and liquor by the difference in specific gravity; and (2) it serves as the first settling point for carbonaceous and other finely divided material that is carried along with tar and liquor from the collecting main.

The flushing liquor decanter is a rectangular steel tank, inclined at one end to facilitate removal of solid accumulations. The tar and flushing liquor enter the decanter and flow into a trough which is designed to minimize agitation of the mixture in the decanter. The mixture overflows the trough into the main compartment, where the velocity is reduced to permit the tar, which has a higher specific gravity than the flushing liquor, to settle to the bottom. The liquor flows over a fixed weir at the opposite end of the decanter through an adjustable seal, known as a decanter valve, which can be raised or lowered. Tar quality is controlled by adjusting this seal wither upwards or downwards

Fig. 7.90 Flowsheet showing the major steps involved in the carbonization of coal by the byproduct process and the subsequent recovery of coal chemicals from the gases generated.



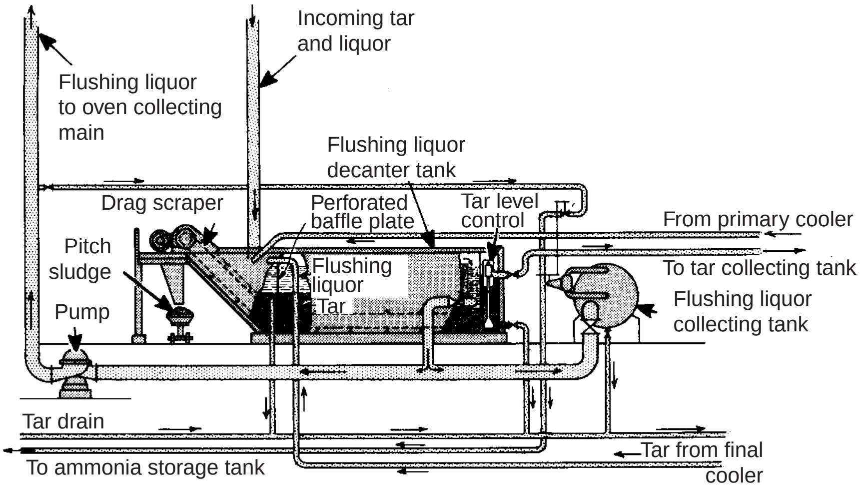


Fig. 7.91 Schematic representation of a flushing liquor decanter tank or hot tar drain tank

to regulate the retention time of the tar in the decanter. Carbonaceous deposits in the bottom of the decanter are continuously removed by scrapers dragged slowly along the bottom by two endless chains.

Normally, the tar recovered from the flushing liquor contains 2–5% water. When the water content of the tar is in excess of 5%, further decantation or blending may be required to reduce the water content. This is usually accomplished by placing tar receiving tanks and separating tanks in the process lineup prior to the tar storage tanks. Tar receiving tanks are simply intermediate storage tanks which receive the tar from the decanters prior to being pumped into the tar storage tanks. Depending on the water content of the tar in a receiver, the tar may be pumped directly to storage, heated to lower the water content, or be pumped back into the decanter system.

7.7.2.2 Circular Flushing Liquor Decanting Tank

In modern plants the tar and flushing liquor separation is accomplished by a combination of a so-called heavy tar box (or decanter) and a circular decanting tank, Fig. 7.92, for the separation of tar and liquor from the flushing liquor.

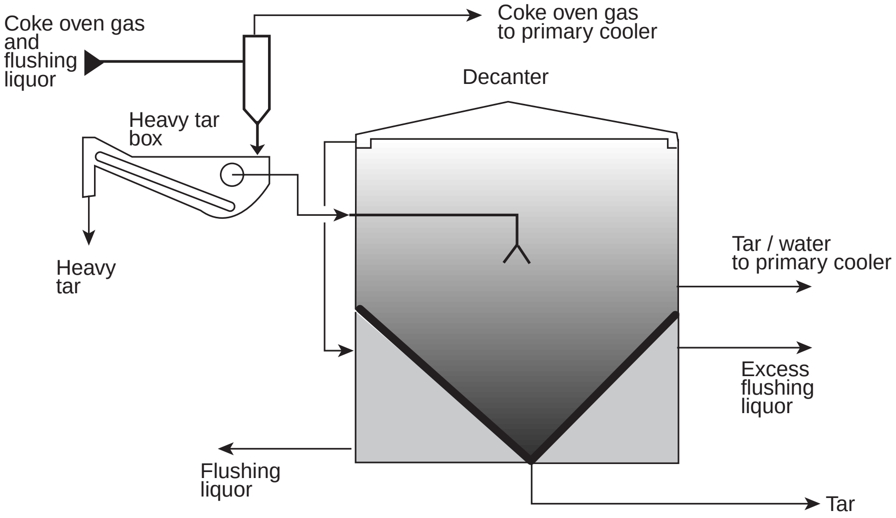


Fig. 7.92 Flushing liquor handling system with a circular decanting tank

With this arrangement, the heavy tar or sludge is separated before the actual tar decantation takes place. This separation occurs by passing the flushing liquor through the openings of a slowly rotating sleeve drum. Large size particles or agglomerations will not pass through the drum. Instead, they settle in the bottom of the tar box. A continuously moving drag conveyor carries the heavy tar out of the box into a container. To prevent plugging of the sieve drum, brushes remove deposits off of the rotating drum.

The pre-cleaned flushing liquor flows from the inside of the sleeve drum to the actual tar/water decanter (circular decanting tank). The decanting tank consists of three compartments: the tar water separating zone, the conical bottom where the tar will settle, and the outer chamber where the cleaned flushing liquor will flow into after overflowing a weir in the upper part of the decanter. This outer chamber serves as a pumping tank for the flushing liquor and, more importantly, provides the heat to the conical section that is necessary for a good tar/water separation. From this outer chamber, the excess ammonia liquor (or virgin liquor) will be withdrawn and pumped back to the gas collecting main of the coke oven battery.

This liquor/tar handling system contains all moving parts in a relatively small vessel and therefore a spare can be provided at low cost. The decanter itself is a *sophisticated* tank and therefore needs no spare. Because of the relatively high undisturbed settling time, a low-moisture tar is produced.

There is another beneficial side effect with this type of decanter. On the outer perimeter, at a certain elevation, a special tar with low viscosity and a high solubility for naphthalene can be withdrawn. This quality of tar is the ideal additive to the primary cooler circulation liquor in the case of direct primary coolers or the correct flushing medium for indirect primary coolers for the prevention of naphthalene deposits.

Certain modifications have been made, mainly to eliminate the so-called heavy tar box, from the system, Fig. 7.93. No matter what type of tar/liquor separation system is installed, a certain quantity of heavy tar (sludge) is produced. This fraction must be removed from the tar or it will plug lines and settle in the tar storage tanks.

In most plants this heavy tar is fed into a container and then carried to the coal yard and mixed onto the coal. Because the heavy tar is a hazardous and strong-smelling material, it is becoming more and more difficult to handle. As such, some plants have begun to process the heavy tar in a machine where the particles are ground down.

Because the particles produced with this machine will stay in suspension with the tar, it is no problem to feed the ground heavy tar solution to the liquor flow entering the decanter. As the

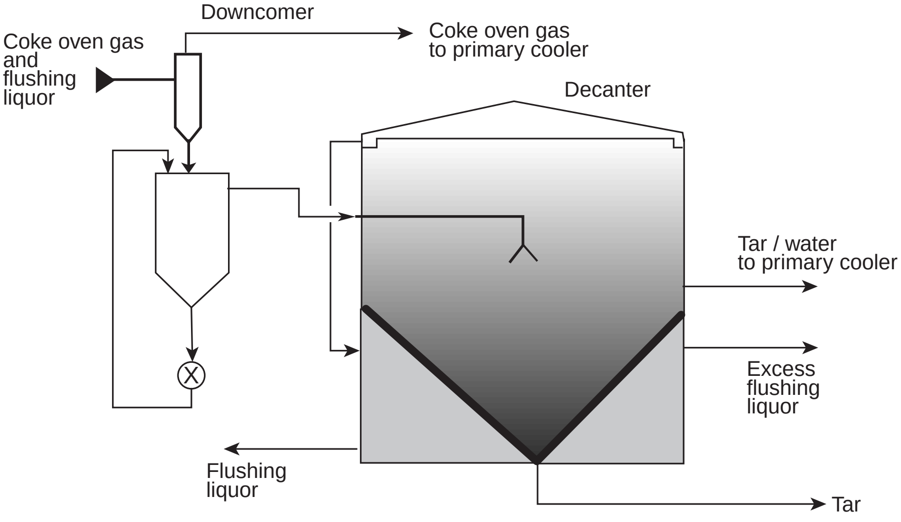


Fig. 7.93 Flushing liquor handling system without a heavy tar box.

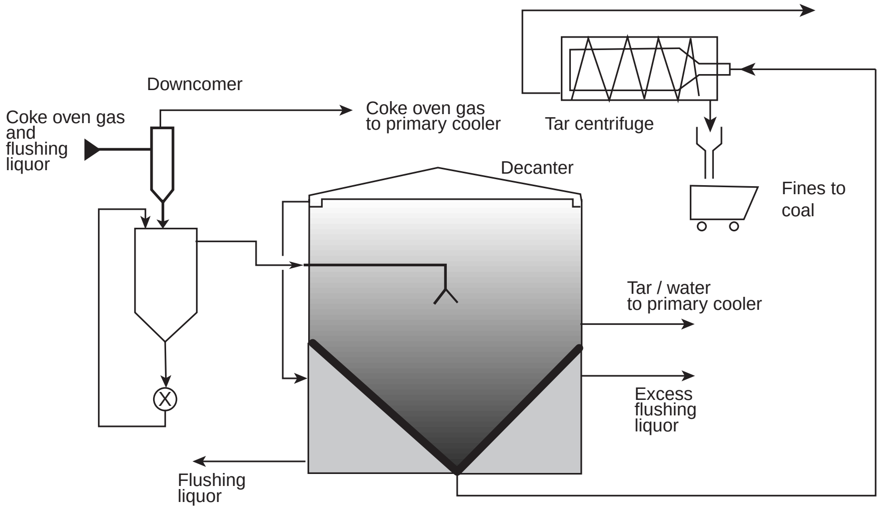


Fig. 7.94 Flushing liquor handling system with a centrifuge to reduce fines content.

quantity of heavy tar, <0.5% of all tar produced, is negligible, the increase of fines in the tar product is minimal.

With more stringent pollution control on coke oven batteries, the concentration of coal and coke fines in tar is steadily increasing. To counteract complaints from tar processors, some plants have installed centrifuges, Fig. 7.94, to free the tar from most of the fines before it is sent to the storage tanks.

In these centrifuges, nearly all particles greater than 75 μ are removed. The particles are recovered in the form of a very dry powder-like fraction, which can be easily mixed with coal.

7.7.2.3 Primary Cooler

The non-condensed gas and vapors leaving the collecting and suction mains at a temperature of 75–80°C (167–1276°F) require further cooling to 35°C (95°F) to remove additional tar and a major portion of the water vapor and to reduce both volume and temperature of the gas before its admission to the exhausters. This cooling may be conducted in either direct or indirect primary coolers.

The *direct primary cooler*, Fig. 7.95, consists of a tall, cylindrical scrubbing tower fitted with hurdles or baffles usually constructed of wood. The top portion is equipped with a series of spray nozzles and the lower portion contains a chamber to collect the liquor and condensate.

The gas enters the bottom of the tower and the cooling liquor is pumped into the top of the tower through the spray system to provide a downward flow of cooling liquor into counter-current flow to the gas stream. This direct contact between the gas and liquor provides for

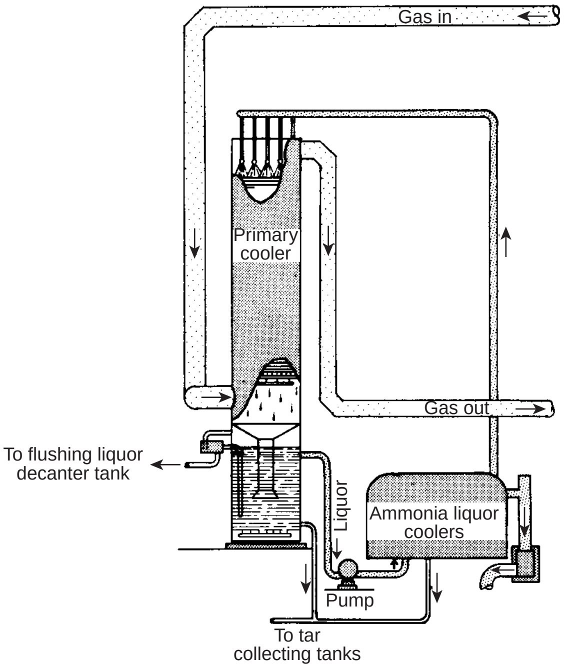


Fig. 7.95 Schematic diagram of a direct primary cooler

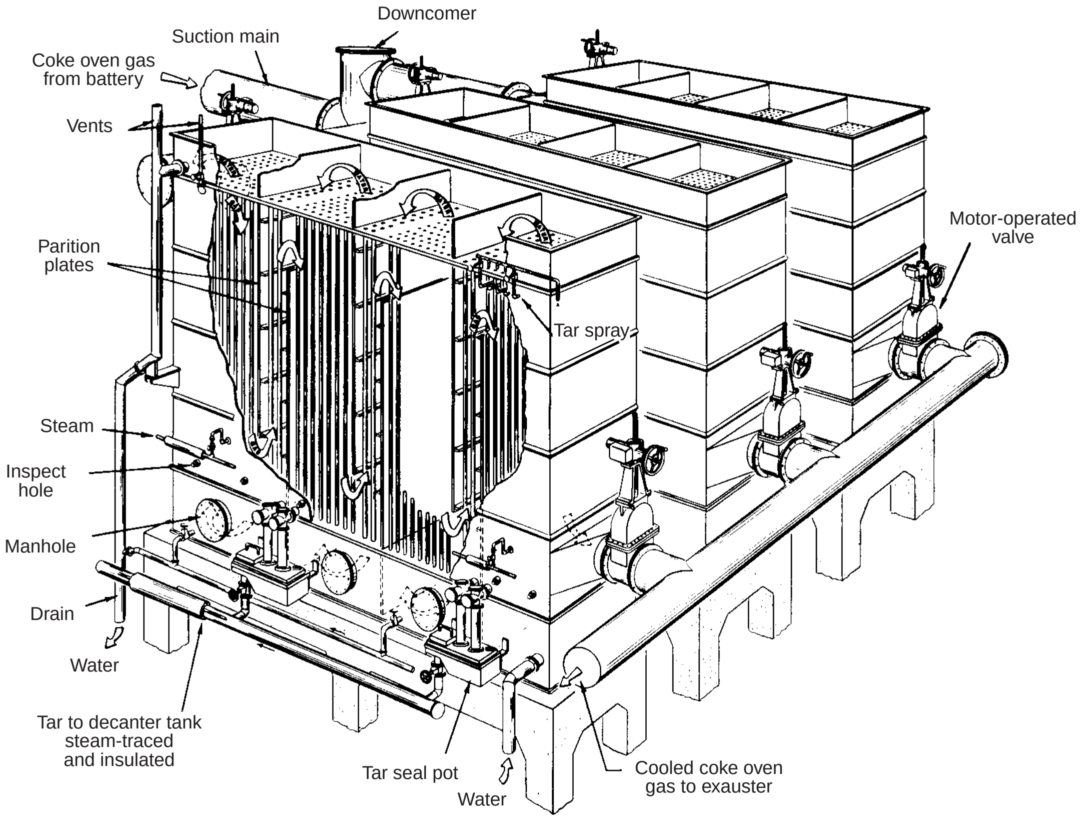


Fig. 7.96 Three indirect primary coolers of the vertical tube type.

exchange of heat which is transferred from the hot gas to the liquor. This heat is removed from the liquor by indirect heat exchange, through tubular heat exchangers, with circulating water. As a result of this cooling, 20–25% of the total tar recovered is condensed along with a considerable quantity of weak liquor containing ammonia. These condensates are processed either separately or in conjunction with the tar and liquor condensates from the collecting main.

There are two different types of indirect coolers: (1) the vertical tube type, Fig. 7.96, which preferably will be installed when only contaminated cooling water is available; and (2) the horizontal tube type, Fig. 7.97, which is preferably operated with a closed cooling water circuit. The horizontal type provides the best temperature approach between cooling water in and gas out. High efficiency is maintained by a specific continuous flushing circuit, which simultaneously effects naphthalene removal.

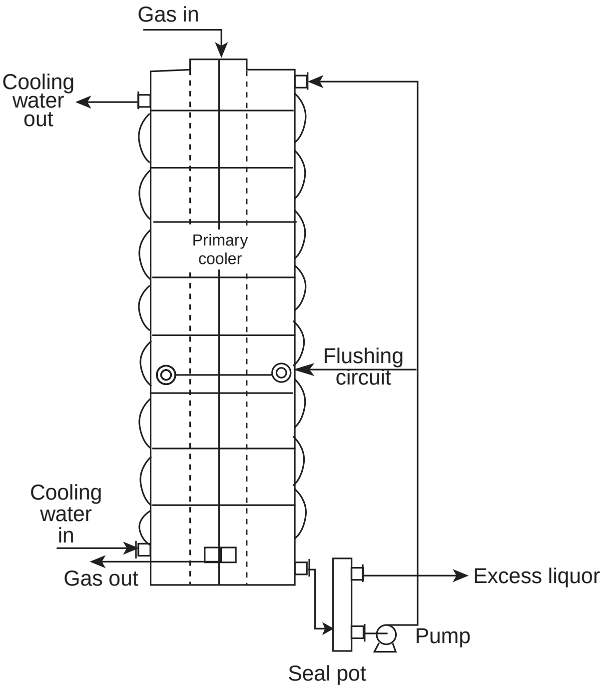


Fig. 7.97 Schematic diagram of a horizontal tube type indirect cooler.

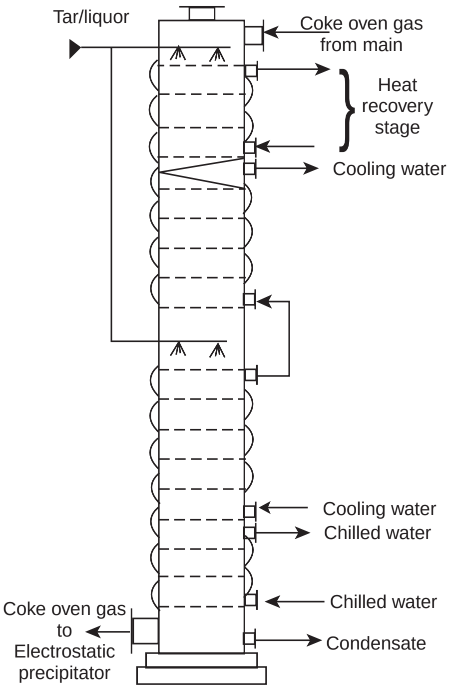


Fig. 7.98 Indirect primary cooler

7.7.2.4 Primary Gas Cooling

It is well known that a primary cooler system providing direct contact between gas and cooling liquor should not cool the gas below 30–35°C (86–95°F), otherwise the resultant plugging problem for the vessel(s) and heat exchangers becomes too severe. With the indirect primary cooler in Fig. 7.98, gas outlet temperatures of 18–24°C (64–75°F), depending on available cooling water temperature, are typical. The benefit of a gas temperature that low for the subsequent byproduct train is obvious. With a continuous spray of tar/water mixture form the tar and flushing liquor decanter onto the tubes of the primary cooler, a naphthalene absorption takes place which will lower the naphthalene dewpoint of the by 1–2°C (2–4°F) below the gas outlet temperature. This is even more important if one considers the fact that the gas leaving a direct primary cooler is supersaturated with naphthalene in the form of aerosols. Deposits in the top of these primary coolers and in the gas outlet lines are caused by this carryover of naphthalene.

In warmer climates, this indirect primary cooler may be operated with chilled water in the lower part of the cooling bundles to achieve the required low gas temperature. For heat recovery purposes, some coolers have been designed to produce hot water in the upper section. This hot water may be used for heated buildings or sanitary purposes.

7.7.2.5 Electrostatic Precipitator

The gas leaving the primary coolers still contains small amounts of tar that would cause difficulty in the operation of the subsequent units in the recovery system. The method used for removal of this entrained tar is through electrostatic precipitation. The electrostatic precipitator may be placed before or after the exhausters. The preferred location is after compression of the gas (following the exhausters) to prevent infiltration of air into the precipitator. In the electrostatic precipitator, Fig. 7.99, removal of tar fog from gas is achieved by passing the gas between electrodes having a high electrical potential. The discharge electrode is of small cross-section, such as wire or a series of points, in order to develop the high-intensity electrical field at its surface which is required for ionization of gas. The collecting electrode has a large cross-section and serves as a collector for the suspended particles which are ionized and transferred to this electrode. In this operation, the electrostatic precipitator, in addition to its function as a collecting unit for dispersoids, also serves to catalyze the formation of vapor-phase gums formed by oxides of nitrogen and unsaturated hydrocarbons.

7.7.3 Recovery of Ammonia

The ammonia formed during coking appears in both coke oven gas and the weak liquor condensed from the gas. Typically, 20–25% of the total ammonia is found in the liquor.

The recovery of this ammonia can be accomplished by two different methods: (1) the *semi-direct process* in which the ammonia in the weak liquor produced during carbonization is removed by distillation and alkali treatment and added to the gas stream, the gas containing all of the ammonia then being passed through an absorber containing an absorbing solution for the ammonia; or (2) the *indirect process* in which the ammonia is removed from the gas by scrubbing with water and then removed from the water by distillation and treatment with an alkali, after which the ammonia and steam are passed through an absorber.

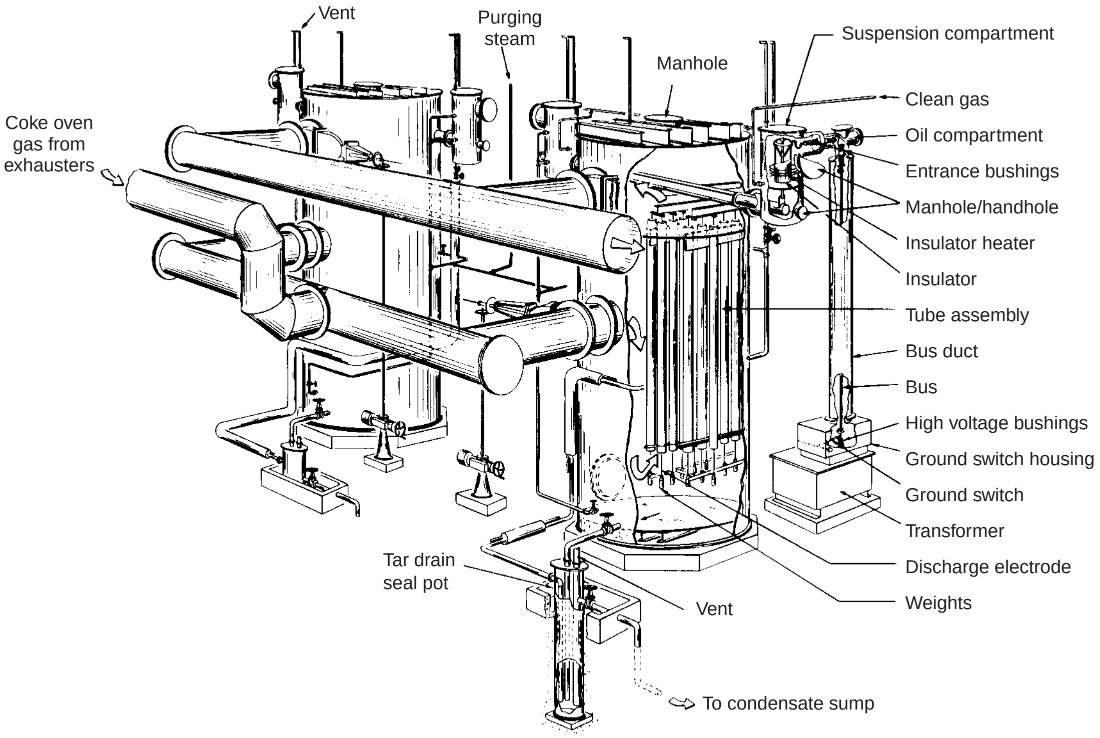


Fig. 7.99 Electrostatic precipitators of the tube type.

The ammonia present in the weak liquor is in two forms classified as *free* and *fixed*. The free ammonia is that which is readily dissociated by heat, such as the ammonium carbonate, sulfide, cyanide, and so on, while the fixed ammonia is that which requires the presence of a strong alkali to effect displacement of the ammonia from the compound in which it is present, such as ammonium chloride, thiocyanate, ferrocyanide, sulfate, and so on. The operation to recover this ammonia is carried out in an ammonia still.

7.7.3.1 Conventional Ammonia Still

In the processing of the liquor, a uniform flow of liquor is fed to the top of the *free leg* of the ammonia still, Fig. 7.100, and passes down the column over a series of trays. This liquor is contacted by an upward flow of steam which vaporizes the ammonia and acidic gases. The vapor leaves the top of the free leg at a temperature of 96–100°C (205–212°F), and passes into a dephlegmator to cool the vapor and remove excess water which is

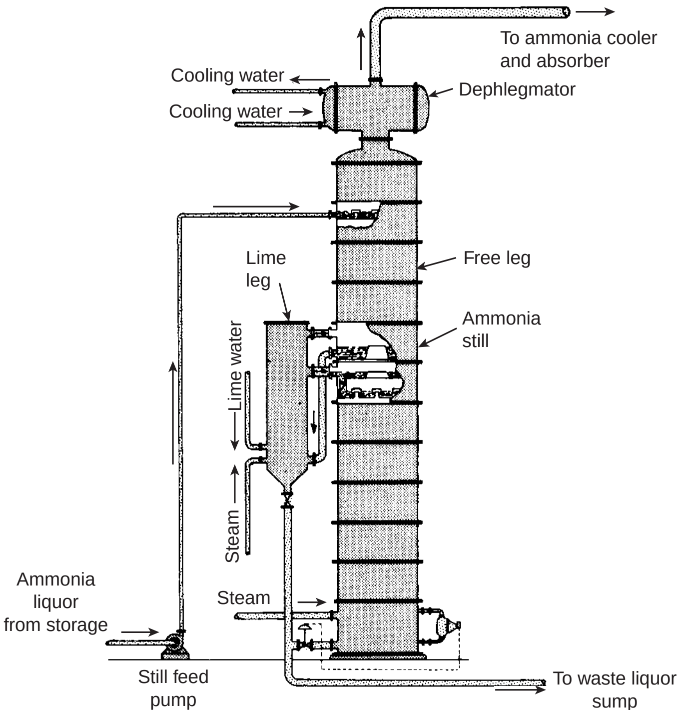


Fig. 7.100 Diagrammatic representation of the essential parts and operation of an ammonia still.

returned to the still. The vapor leaving the dephlegmator consists of ammonia which may vary between 10–25%, depending upon the vapor temperature, with the balance consisting of water and some acidic gases and neutral oils.

The liquor leaving the base of the free leg passes into the *lime leg* where it is treated with *milk of lime*. The calcium hydroxide reacts with the fixed ammonium salts of which ammonium chloride is the main constituent.

The liquor then flows into the *fixed leg* which consists of a series of trays to provide effective stripping of the ammonia by a counter-current flow of steam. The steam pressure required at the base of the still is of the order of 21–28 kPa (3–4 psi). Some ammonia stills are operated with caustic soda (NaOH) instead of lime to avoid the column fouling caused by lime salts. However, the cost of caustic soda is several times that of lime.

The vapors leaving the ammonia still are added to the gas stream so that all of the ammonia can be recovered in the ammonia absorbers.

7.7.3.2 USS CYAM System

New environmental regulations on water discharged from coke plants have prompted development of more efficient ammonia stills. The technology for meeting these standards typically consists of a highly efficient still system followed by a biological treatment plant. The USS CYAM system was developed to provide the efficient cyanide and ammonia removal to allow a biological treatment plant to function efficiently. The combination can achieve a high degree of removal of ammonia, cyanides, sulfides and organics including phenols.

In the CYAM system, the wastewater flow path is similar to that through a conventional ammonia still. However, ammonia from the fixed still is not introduced into the free still. This allows the bottom section of the free still to become neutral or slightly acidic, greatly enhancing the volatility of acid gases in the free still.

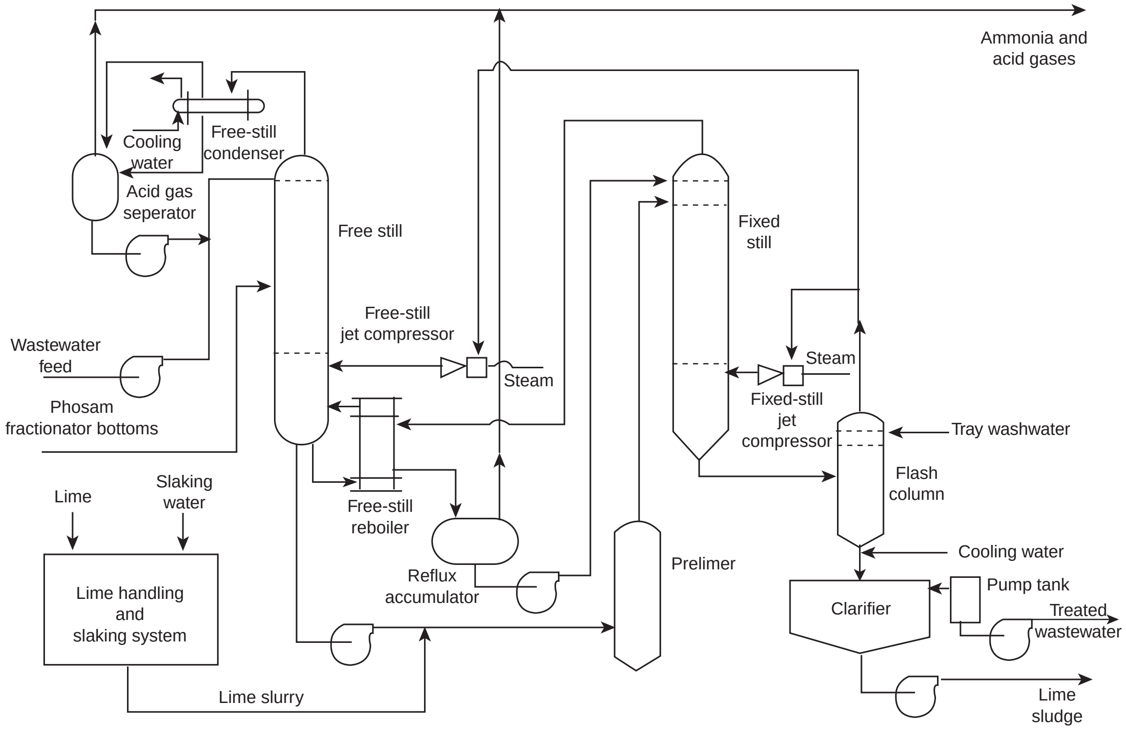


Fig. 7.101 Flow diagram of the USS CYAM system.

A second feature of the process is its relative freedom from fouling by lime salts, achieved by a combination of process design and an anti-fouling additive. The system can operate a year or more without cleaning, which negates the need for a spare still. The CYAM system can also use caustic soda (NaOH) and achieve high cyanide removal, if higher alkali cost is accepted.

The flowsheet in Fig. 7.101 shows a typical arrangement of the CYAM system in which steam jet compressors are used to recover heat (low pressure steam) from the effluent stream. Overhead vapor from the fixed still, typically 70–84 kPa (10–12 psig), flows into the free still reboiler where it is partially condensed to generate ammonia-free stripping vapors for the free still. Overhead vapor from the free still, normally at 28–42 kPa (4–6 psig), is passed through a partial condenser to achieve the desired concentration, which is typically in the range of 12–16 wt% ammonia. Remaining vapors from the free and fixed stills are then sent to the coke oven gas upstream of the ammonia recovery equipment. Stripping-stream requirements are about 0.12–0.14 kg of steam per litre of feed (1.0–1.2 lbs of steam per gallon of feed). Lime requirement are roughly 2.2 kg of 90% CaO per kg of fixed ammonia (2.2 lbs of CaO per lb of fixed ammonia).

Ammonia nitrification and removal of carbonaceous material can be achieved in a single totally-mixed aeration basin when CYAM effluent is treated in a biological treatment plant. Ammonia concentration can be reduced from the 25–100 ml/m^3 (25–100 ppm) range normally produced by the CYAM system to about 10 ml/m^3 (10 ppm). Free cyanide concentration (CN_A) in treated water from the CYAM system is about 1–2 ml/m^3 (1–2 ppm) and is further reduced to about 0.25 ml/m^3 (0.25 ppm) in the biological treatment plant. Sulfide removal is essentially complete in the CYAM system, and effluent from the biological treatment plant is normally below 0.3 ml/m^3 (0.3 ppm).

7.7.4 Recovery of Ammonia as Ammonium Sulfate

7.7.4.1 Saturator

At coke plants built prior to about 1930, ammonia-absorbing facilities consisted mainly of devices called saturators. These were large dome-shaped, cast iron, lead-lined vessels. Gas was admitted to the saturator through a distributor called a *cracker pipe*. This arrangement provided for direct contact between the ammonia and dilute acid, which reacted according to reaction 7.7.1 to form ammonium sulfate.

$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4 \tag{7.7.1}$$

More modern processes have superceded the saturator.

7.7.4.2 Ammonia Absorber

In an Otto-type absorber, coke oven gas enters the ammonia absorber, Fig. 7.102, near the bottom and is sprayed with a dilute solution of sulfuric acid as it rises to the top of the absorber.

As the dilute sulfuric acid sprays the gas rising through the ammonia absorber, the ammonia in the gas combines with the acid to form ammonium sulfate. The resulting solution drains to a crystallizer from which it is recirculated to the absorber. A constant flow of sulfuric acid is added to the ammonia absorber to replace the acid neutralized by the ammonia in the coke oven gas. After the solution becomes supersaturated, crystals of ammonium sulfate are precipitated in the crystallizer and accumulate as a slurry in the bottom. A portion of this slurry is removed from the crystallizer and is pumped to the slurry tank where the salt settles, the liquid overflows and returns to the ammonia absorber. The concentrated slurry is withdrawn from the bottom of the slurry tank and is fed continuously or in batches to the centrifugal dryers. These dryers are arranged to perform the following sequence of operations automatically:

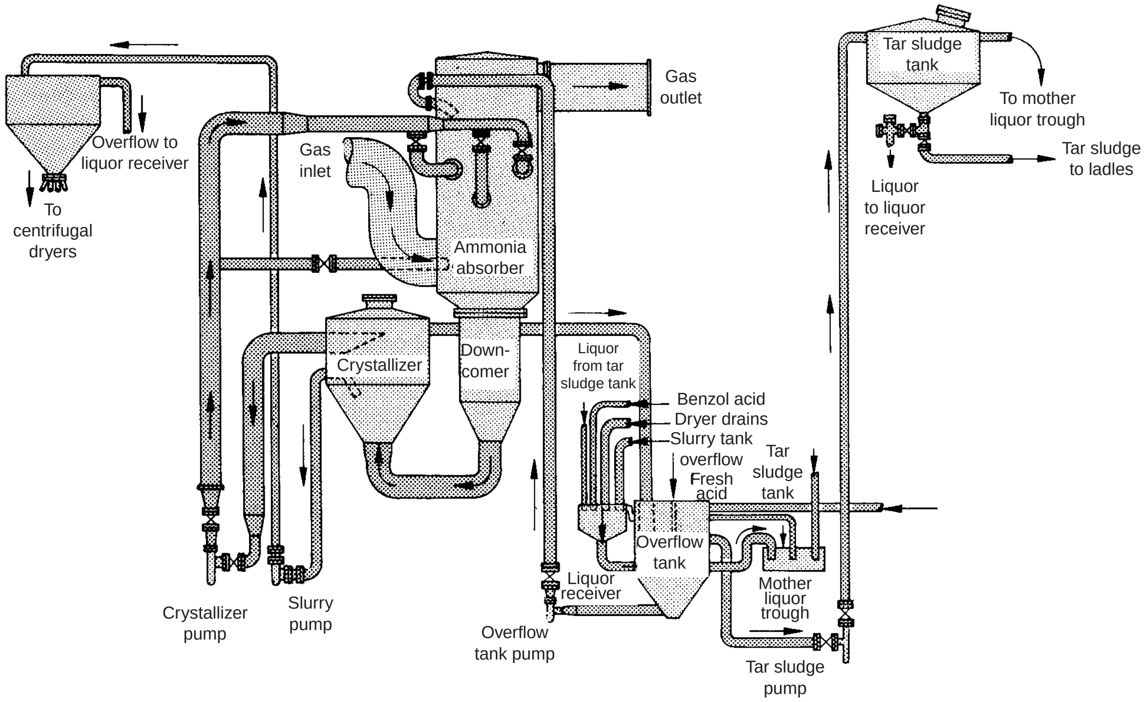


Fig. 7.102 Schematic flowsheet of the operation of an Otto spray-type absorber for the recovery of ammonia as ammonium sulfate.

(1) rinse the dryer basket screen with water;

(2) feed the slurry into the basket;

(3) neutralize the acid remaining in the salt with a dilute solution of aqueous ammonia;

(4) rinse the salt with water to remove excess ammonia;

(5) centrifuge the water from the salt in the basket;

(6) remove the dried salt from the basket;

(7) and discharge it onto a conveyor belt.

The liquid portion of the slurry is recovered and returned to the ammonia absorbers. The partially-dried ammonium sulfate is conveyed to heated rotary drum dryers for final drying to a water content of approximately 0.1%. All equipment is made of stainless steel.

Another process used for the recovery of ammonia is the Wilputte low-differential controlled-crystallization process for producing ammonium sulfate, the equipment for which is constructed of stainless steel throughout, Fig. 7.103. In this process, the gas is passed through a spray-type absorber over which is circulated a 6% solution of sulfuric acid nearly saturated with ammonium sulfate. The acid-entrainment arrestor is an integral part of the absorber. Leaving the absorber, the solution is delivered to the solution circulating system of a crystallizer in which crystallization takes place by the combined cooling and concentrating effects of vacuum evaporation.

By the variation of circulating rate and the degree of concentration, the size range of the product can be controlled closely within narrow limits. As the crystals grow in size, they settle or gravitate to the bottom of the suspension tank from which they are delivered to a slurry feed tank and from there to a continuous centrifuge or filter, followed in either case by a dryer. The accumulation of deposits of hard salt within the equipment is minimized and *killing* for removal of such deposits is very infrequent. The product can be made with a size consist favorable to almost any type of application.

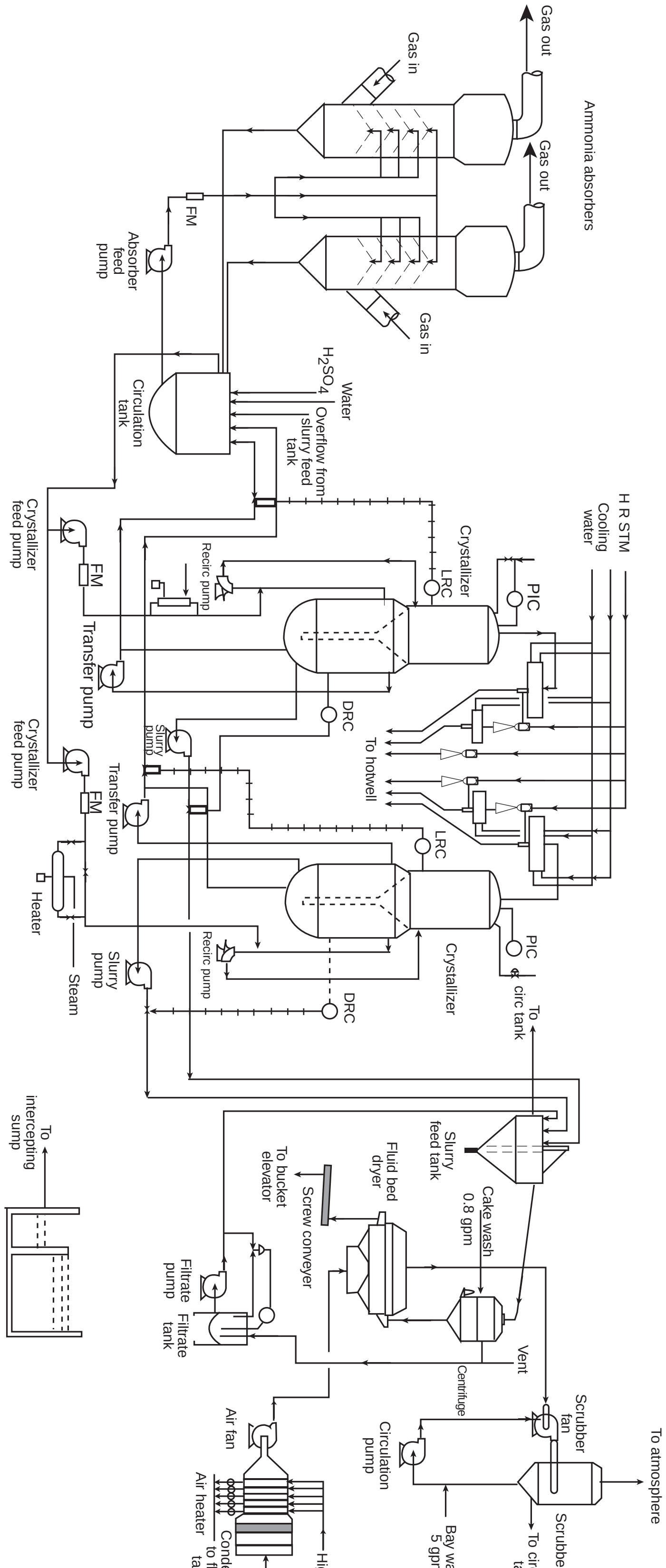


Fig. 7.103 Flow diagram of the Wilputte low-differential controlled-crystallization process for producing ammonium sulfate.

7.7.5 Recovery of Ammonia as Anhydrous Ammonia

The USS PHOSAM process was developed by U.S. Steel Corporation for recovery of the ammonia in coke oven gas and gas liquor as high-quality anhydrous ammonia. This process is applicable to the recovery of ammonia from any gas or vapor stream and is especially advantageous when H_2S, CO_2 or other acidic gases are present. A sharp separation of ammonia from these contaminants is obtained by using a highly selective absorbent solution.

Fig. 7.104 shows the essential features of the process, as applied to the direct recovery of ammonia from coke oven gas. Coke oven gas, from primary coolers, exhausters, and conventional gas cleaning equipment is passed through a two-stage spray-type absorber. Ammonia is scrubbed from the gas by counter-current contact with ammonia-lean phosphate solution, which enters the top of the absorber. The gas leaves the absorber with 98–99% of its ammonia removed, and is suitable as such for further processing. The absorbing solution is stable and non-volatile, and does not require periodic replacement or purification. It is highly selective for ammonia, rejecting acidic gases such as hydrogen sulfide and organic compounds that are present in the feed gas.

Absorber pressure drop is low, normally 980–1470 Pa (100–150 mm of water), and the operating pressure is that imposed by downstream equipment. Depending on the temperature and humidity of the inlet gas, the gas may be heated slightly or cooled in passing through the absorber, where ammonia is absorbed and water is evaporated.

It should be noted that the placement of the PHOSAM absorber just downstream from exhausters and tar precipitators is conventional, but not the only possible location. The absorption of ammonia is carried out at relatively high temperatures of 40–60°C (104–140°F), always above the naphthalene dewpoint established in the primary coolers. Therefore, there is no need for naphthalene scrubbers, H_2S scrubbers, nor secondary coolers ahead of the PHOSAM ammonia absorber. When ammonia liquor stills are operated, the vapor from the still is added to the absorber feed gas.

The ammonia-rich solution from the absorber is pumped through heat exchangers into the stripper, recovering heat from the stripper bottoms and overhead vapor. In the stripper, the solution is counter-currently contacted with steam at elevated pressure, stripping out the absorbed ammonia and regenerating the lean solution. The lean solution is cooled and returned to the absorber. Automatic controls make it easy to operate the plant efficiently, despite variations in the feed gas, and to control the water content of the solution.

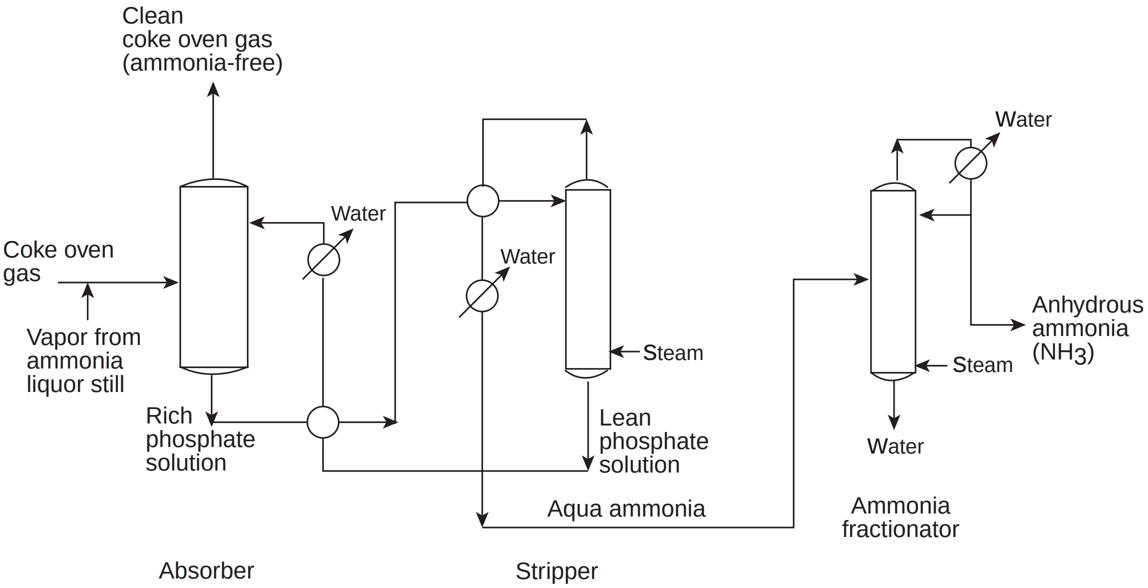


Fig. 7.104 USS PHOSAM process for producing anhydrous ammonia.

The overhead vapor from the stripper is condensed to form an aqueous ammonia feed to the fractionator where anhydrous ammonia is produced by pressure fractionation, again by using direct steam. The overhead product is liquid anhydrous ammonia, of high purity, ready for shipment.

Both of the distillation operations are conducted under pressure for reasons of economy. The optimum pressures depend somewhat on the cooling water temperature, but are generally in the range 124–1515 kPa (180–220 psig). This means, in turn, that steam at a gage pressure of 1380–1725 kPa (200–250 psi) is required.

Stripper and fractionator towers in the PHOSAM process are quite small in diameter, and, together with the associated heat exchangers and vessels can be accommodated in an area of about 9.1 × 21.3 m (30 × 70 ft).

When indirect processes for ammonia removal from coke oven gas are used (water wash or liquors associated with desulfurization processes), ammonia-rich vapors generated in these systems can be passed through a *hot PHOSAM absorber* to recover the ammonia. The *hot absorber* would operate in the range of 80–100°C (176–212°F). The absorbing solution (ammonia-lean phosphate solution) from the hot absorber would be processed in a conventional PHOSAM stripper and fractionator to produce liquid anhydrous ammonia.

7.7.6 Recovery of Phenol

The water, i.e. weak ammonia liquor, recovered with the volatile products of coal carbonization contains 0.5–3.0 g/dm^3 (about 0.031–0.187 lb/ft^3 or 0.004–0.025 lb/gal) of phenol, sometimes called carbolic acid, and its homologues. In order to recover this phenol, a solvent extraction process is used.

The *solvent extraction process* is based on the principle that phenols are more soluble in benzene or light oil than in water and that the phenols can be extracted from benzene or light oil with caustic soda.

In the operation of a solvent extraction process for the removal of phenols from weak ammonia liquor, Fig. 7.105, the liquor is pumped into the distributor header located near the top of the ammonia liquor scrubber. This scrubber has wooden grids to ensure good contact between the counterflowing liquids.

The liquor passes downward through the scrubber and comes in contact with a counter-current flow of benzene or light oil. The benzene or light oil is immiscible with and has a lower specific gravity than the liquor; therefore, it rises to the top of the scrubber as it absorbs the phenol from the liquor.. When the ammonia liquor reaches the base of the scrubber, the phenol extraction is complete, and the liquor flows to a storage tank for further processing.

The benzene or light oil reaching the top of the scrubber is phenolized. This solvent then flows to the caustic washer through an overflow line connecting the ammonia liquor scrubber and the light oil caustic treatment tower.

The light oil caustic treatment tower is divided into three compartments. The bottom compartment is the benzene or light oil circulation tank which is the pumping chamber for the dephenolized benzene or light oil. The upper two sections are the caustic washing compartments, packed with ceramic tile. In these two compartments, the phenolized benzene or light oil passes through the caustic (NaOH) to remove the phenols by the chemical reaction between the caustic (base) and the phenols (acid).

The phenolized benzene or light oil passes from the ammonia scrubber to the distributor header on No. 1 washer, through No. 1 washer to a distributor header on No. 2 washer, and through No. 2 washer to the overflow line, where the benzene or light oil, now dephenolized, is returned to the recirculation tank.

After a week or two, the caustic in No. 1 washer is saturated with phenols. When this happens, the recovery operation is shut down so that the plant can be recharged with fresh caustic soda solution.

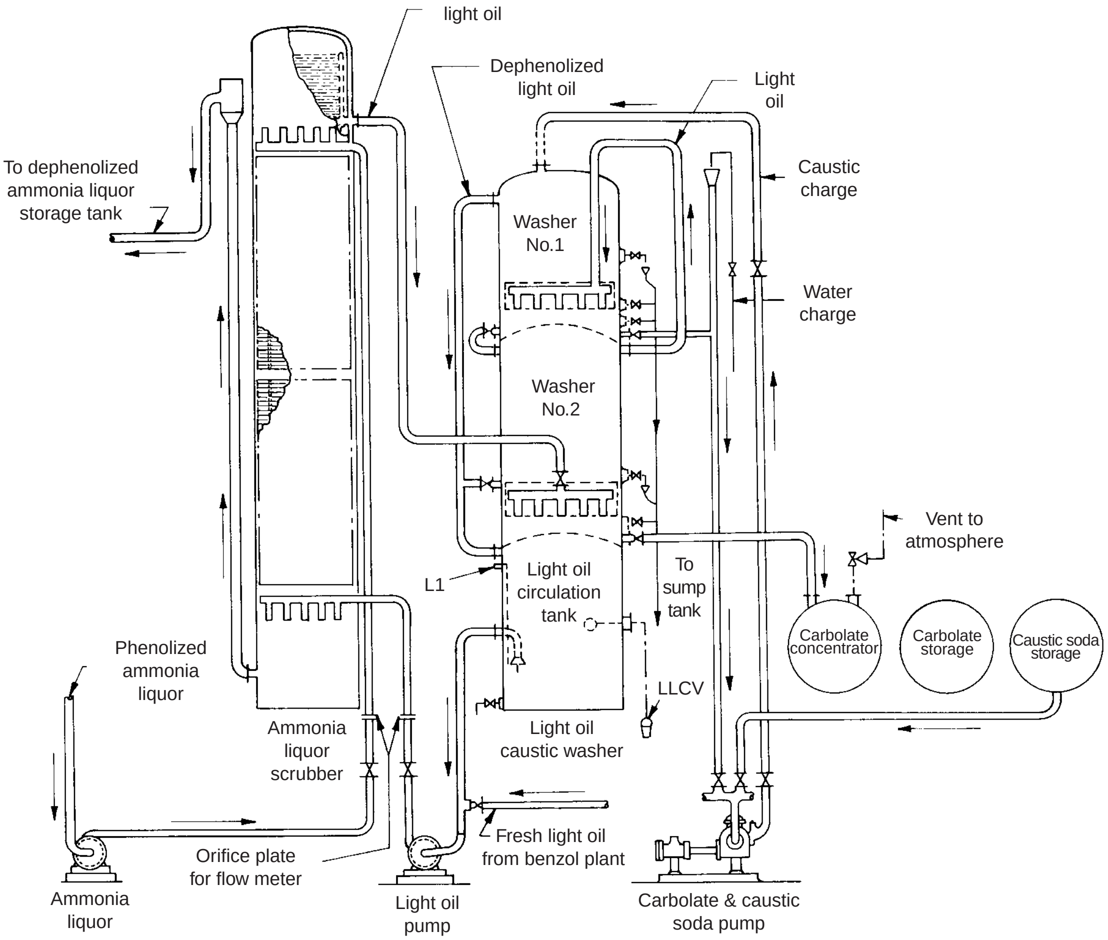


Fig. 7.105 Diagrammatic representation of the equipment for recovery of phenol by the solvent extraction process.

The sodium phenolate in No. 1 washer is drained into the carbolate concentrator. When this is complete, the partially phenolized caustic in No. 2 washer is drained to No. 1 washer, leaving No. 2 washer empty to receive a fresh supply of caustic soda solution. The plant is then ready to resume operation.

The sodium carbolate in the concentrator is boiled to remove entrained solvent and moisture. It is then neutralized with carbon dioxide to liberate crude phenols and phenol homologues.

7.7.7 Recovery of Coke Oven Light Oil

7.7.7.1 Light Oil

The gas leaving the ammonia absorbers contains light oil. This oil is a clear yellow-brown oil with a specific gravity of about 0.880. It is a mixture of all those products of coal gas with boiling points mostly ranging from 0–200°C (32–390°F), containing well over a hundred constituents, some of which are identified in Table 7.6. Most of these are present in such low concentrations that their recovery is seldom practicable. Many of the constituents, such as olefin and diolefin hydrocarbons, some straight chain and cyclic paraffins, and sulfur, nitrogen and oxygen compounds are present in small quantities. The principal usable constituents are benzene (60–85%), toluene (6–17%), xylene (1–7%), and solvent naphtha (0.5–3%). Light oil constitutes approximately 1% of the coal carbonized.

Table 7.6 Fractions of Coke Oven Gas Light Oil and Boiling Points of Some of Their Constituents

Constituent Group	Forerunnings (2% Light Oil)			Crude Benzene (60% of Light Oil)			Crude Toluene (18% of Light Oil)		
Aromatics	Traces of Benzene			Benzene	C_6H_6	80.1°C	Toluene	$C_6H_5CH_3$	110.6°C
Paraffins	n-Pentane	C_5H_{12}	36.1°C	n-Hexene	C_6H_{14}	68.8°C			
				2-Methylhexane	C_7H_{16}	90.3°C	n-Heptane	C_7H_{16}	98.4°C
				n-Heptane		98.4°C	n-Octane	C_8H_{18}	125.6°C
Cycloparaffins Naphthenes	Cyclopentane	C_5H_{10}	51.0°C	Cyclohexane	C_6H_{12}	80.8°C	Methylcyclohexane Cycloheptane	$C_6H_{11}CH_3$ 100.3°C	C_7H_{14} 120.3°C
Unsaturated (Olefins and Diolefins and Aromatic Hydrocarbons with Unsaturated Side Chains)	Butene-1	C_4H_8	–6.5°C	Hexene-2					
	Pentene-1	C_5H_{10}	30.1°C	Hexadiene-1,3					
	Amylenes		20 to 40.1°C	N-Heptylene	C_7H_{14}	99.0°C			
	n-Hexylene	C_6H_{12}	64.0°C	Cyclohexene			Unidentified Compounds		
	Cyclopentadiene-1,3	C_5H_6	42.0°C						
	Butadiene-1,3	C_4H_6	–5.0°C	Unidentified Compounds					
Sulfur Compounds	Carbon disulfide	CS_2	46.3°C						
	Hydrogen sulfide	H_2S	–59.6°C						
	Hydrogen cyanide	HCN	26.0°C						
	Carbonyl sulfide	COS	–50.2°C	Thiophene	C_4H_4S	85.0°C	Methylthiophene	C_5H_6S	112 to 115°C
	Methyl mercaptan	CH_3SH	7.6°C	Diethyl sulfide	$(C_2H_5)_2S$	91.6°C			
	Ethyl mercaptan	C_2H_5SH	34.7°C						
	Dimethyl sulfide	$(CH_3)_2S$	36.2°C						
Nitrogen and Oxygen Compounds							Pyridine	C_5H_5N	115.3°C

(continued)

Table 7.6 (continued)

Constituent Group	**Crude No. 1 Solvent** (8% of Light Oil)			**Crude No. 2 Solvent** (6% of Light Oil)			**Crude Residue** (6% of Light Oil)	
Aromatics				n-Propyl Benzene		158.6°C		
	o-Xylene		144.0°C	Ethyl Toluenes	C_9H_{12}	161.2 to 164.9°C		
	m-Xylene	$C_6H_4(CH_3)_2$	139.1°C	Mesitylene		164.6°C		
	p-Xylene		138.4°C	Pseudocumene	$C_6H_3(CH_3)_3$	169.2°C		
	Ethyl Benzene	$C_6H_5C_2H_5$	136.2°C	Memimellitene		176.2°C		
				Cymenes	C10H14	175.5 to 177.3°C		
				Durenes	$C_6H_2(CH_3)_4$	196.0 to 198.0°C		
Paraffins	n-Octane	C_8H_{18}	125.6°C	n-Decane	$C_{10}H_{22}$	174.0°C		
	n-Nonane	C_9H_{20}	150.7°C					
Cycloparaffins Naphthenes	Cyclo-octane	C_8H_{16}	150.0°C	Cyclononame	C_9H_{18}	172.0°C		
Unsaturated (Olefins-Diolefins and Aromatic Hydrocarbons with Unsaturated Side Chains)							Wash Oil	275 to 360°C
							Naphthalene	218°C
	Octylene	C_8H_{16}	126.0°C	Coumarone	C_8H_6O	175.0°C	Solvents	Above 200°C
	Styrene	C_8H_8	146.0°C	Dicyclopentadiene		170.0°C	Pitch residue	
				Indene	C_9H_8	182.0°C		
	Unidentified Compounds							
Sulfur Compounds				Trimethylthiophene		160 to 163.0°C		
	Thioxenes	C_6H_8S	137 to 146.0°C	Thiophenol		169.5°C		
				Tetramethylthiophene		182 to 184.0°C		
Nitrogen and Oxygen Compounds				Cresols	C_7H_8O	190 to 203.0°C		
	Picolines	C_5H_7N	131 to 143.0°C	Dimethyl Pyridines	C_7H_9N	143 to 164.0°C		
				Phenol	C6H6O	182.0°C		

7.7.7.2 Light Oil Recovery Processes

The removal of light oil from coal gas is generally the last step in the coal chemical recovery process.

There are three general methods used for the recovery of light oil: (1) refrigeration and compression, involving temperatures below –70°C (–94°F) and pressures of 10 atm (7600 mm Hg); (2) adsorption by sold adsorbents, involving the removal of light oil from the gas by passing it through a bed of activated carbon and recovering the light oil from the carbon by heating with direct or indirect steam; and (3) absorption by solvents involving washing the coal gas with a petroleum wash oil, a coal tar fraction, or other absorbent, followed by steam distillation of the enriched absorbent to recover the light oil. Processes employing petroleum wash oil and coal tar fraction will be discussed further below.

7.7.7.2.1 Process using Petroleum Wash Oil The practice of using petroleum wash oil, Fig. 7.106, is the one almost universally followed in the United States due to the availability and low cost of petroleum wash oil. The efficiency of recovery varies widely with the seasons in that one of the major considerations is the temperature of the coal gas and wash oil entering the absorbing process. Another consideration is the ratio of wash oil to gas. The absorption equipment should be of reasonable design as to size and contact time. The oil-to-gas ratio varies depending on the equipment design and the light oil content of the gas prior to light oil removal.

Typical operating conditions are as follows: the temperature of the coke oven gas entering the absorption process is 15–30°C (59–86°F); the temperature of the wash oil entering the process is 17–32°C (60–90°F); and the wash oil circulated per tonne of coal carbonized is 525–825 dm^3 (150–200 gal/net ton).

The boiling point of the wash oil should be well above 200°C (390°F) so as to permit an effective separation of light oil from wash oil in debenzolization. The oil should not thicken and should have

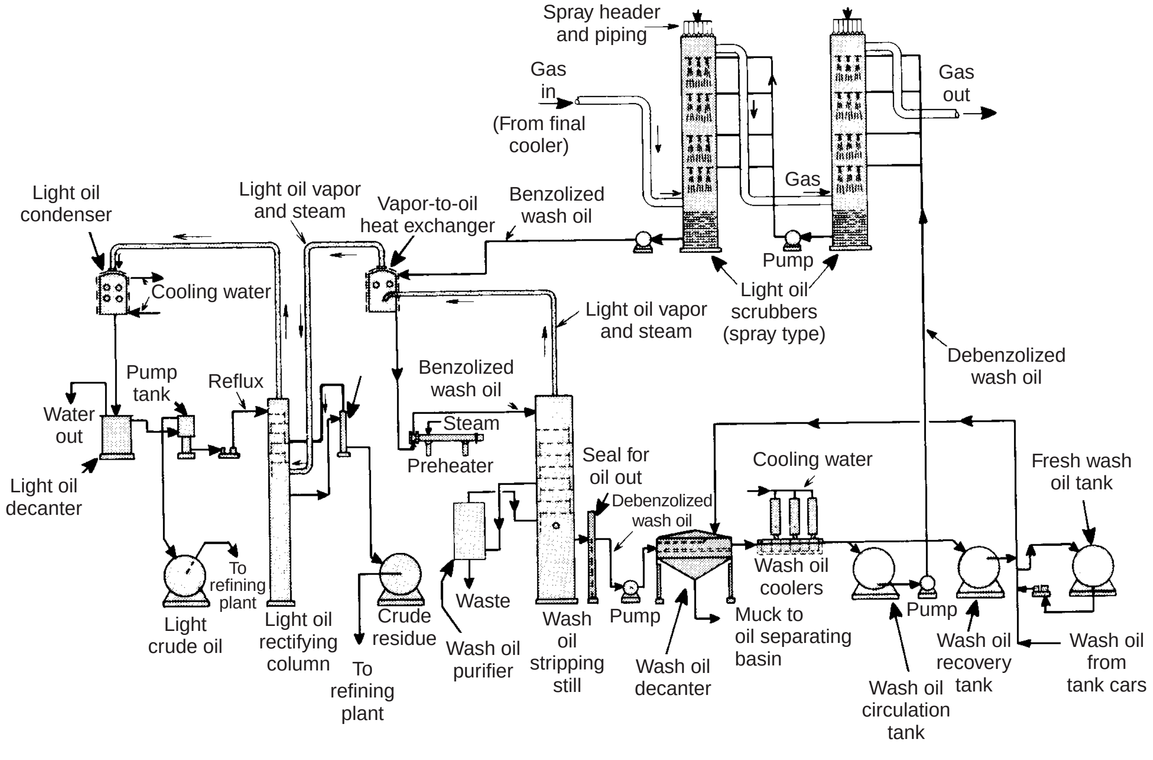


Fig. 7.106 Flowsheet of a light oil recovery system.

a low viscosity to permit its distribution in the scrubbing towers. It should not deteriorate readily but maintain its initial properties as long as possible to keep makeup oil at a minimum. It must be especially stable with respect to the repeated heating which takes place in the recycling of the oil in the process. Its absorptive capacity should be very high and it should not react with or contaminate the coke oven gas. The specific gravity should be low enough to permit effective separation of wash oil and water in the processing and keep emulsification of the two to a minimum. The specific heat should be low because the oil is subjected to repeated heating and cooling as it is recycled in the process.

The petroleum wash oil normally used for this absorption process has a boiling range of 270–350°C (518–622°F). Other specifications which are general for petroleum was oil include a specific gravity of about 0.830, a viscosity of 45 Saybolt seconds at 38°C (100°F), a pour point of 2°C (35°F), an emulsification of 95% separation in 50 seconds, a flash point of 150°C (300°F), a fire point of 168°C (335°F), and a low residue under 0.10% when heated for a period of five days at approximately 150°C (300°F).

7.7.7.2.2 Process using Coal Tar Coal tar wash oil, having a boiling range of 230–300°C (446–572°F), is used for light oil removal in a packed-type absorptive tower. The benzolized oil, which has a perfect heat stability, is preheated by the regenerated oil and finally heated to 185°C (365°F) in a tubular furnace before being flashed into the wash oil still for regeneration. Through oil-to-oil heat exchange and because of the use of a tubular furnace, steam consumption is minimized. There are two processing sections in the still: (1) the top one for light oil rectification, including top reflux and side-stream draw-off for the naphthalene oil fraction; and (2) the bottom one for wash oil debenzolization. A split stream of wash oil is passed through a purifier where by direct steam injection volatile components are returned into the bottom section of the still and heavier components, such as pitch at 70°C (158°F) solidification point, are withdrawn from the purifier bottom. The activated wash oil is reused for light oil absorption after heat exchange and cooling. A typical flowsheet of a light oil recovery system is shown in Fig. 7.107.

7.7.7.2.3 Final Cooler The first step in the recovery of light oil by absorption in a liquid medium is that of cooling the gas leaving the ammonia absorbers at a temperature of 50–60°C (112–140°F) by direct contact with water in a tower scrubber called a final cooler. The facilities are so named

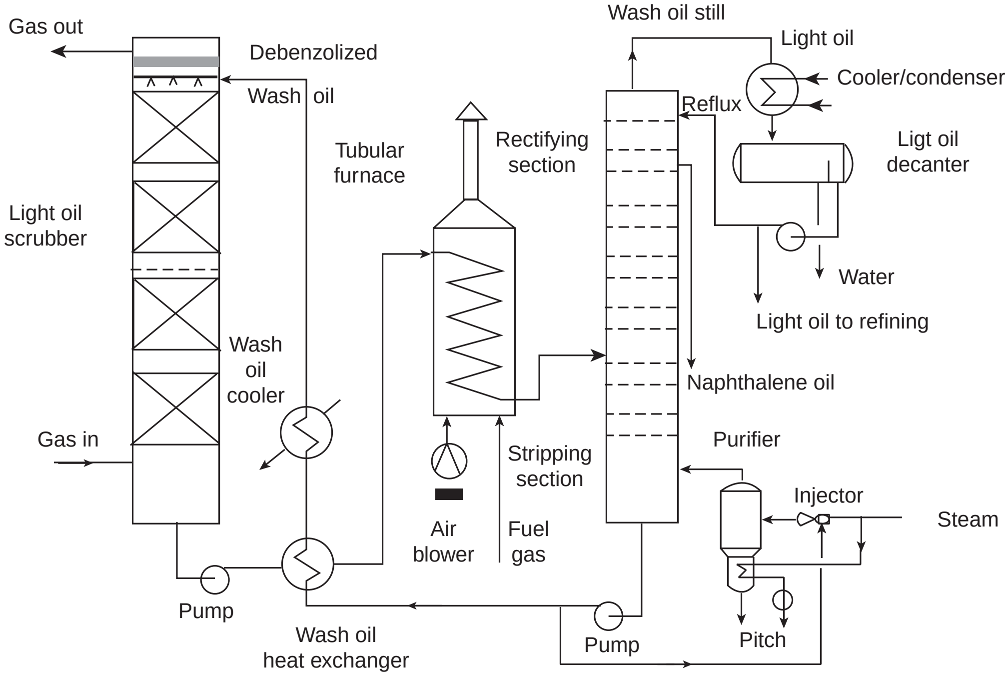


Fig. 7.107 Typical flowsheet of a light oil recovery system with coal tar wash oil.

as the gas is here given its final cooling during coal chemical processing. This is necessary to remove naphthalene from the gas and also to cool the gas prior to its admission to the wash oil scrubbers.

The tower consists of a tall cylindrical shell of steel approximately 3–4.5m (10–15 ft) in diameter and 15–23 m (50–75 ft) in height, filled with a suitable packing material that is either wooden or metallic. The gas enters near the bottom of the tower and passes up through the tower and out near the top. The cooling water enters the top of the tower through a spray system and the water passes down through a tower, coming in direct contact with the gas in a counter-current manner. The water leaves the tower at the bottom through a sealed outlet pipe to prevent escape of any gas. The heat from the gas is transferred to the water, which in turn is cooled in an induced-draft water cooling tower with air or in an atmospheric water spray cooling operation. Cooling of the water depends upon air circulation and the vaporization of a part of the water in circulation, the latent heat of vaporization of the water being responsible for additional cooling. Operating practice is to cool the water, and in turn cool the gas, to as low a temperature as practicable, depending upon atmospheric temperature, as most effective absorption of light oil is obtained at low temperatures. Cooling is not carried out below 15°C (60°F), because below that temperature petroleum absorbing oil becomes too viscous to flow freely.

This direct cooling operation causes the condensation of a major portion of the naphthalene and any entrained tar and vapor-phase gums. The naphthalene is recovered in a sump operation and is either added to the tar or refined directly to provide a salable product.

In some of the more modern facilities, the lower part of the final cooler tower is redesigned to permit the outlet water to come in direct contact with tar in order to dissolve the naphthalene as it is being removed from the gas.

This cooling operation may also be carried out using petroleum wash oil instead of water. A small bleed stream of debenzolized wash oil from the light oil stripper may be used for this purpose. In this case, the wash oil will absorb most of the naphthalene so that the gas leaves with less than about 460–685 g/m3 (2–3 gr./scf) of naphthalene in the gas. However, the quantity of wash oil used is small enough so that the light oils are not absorbed to any great extent in the final cooler.

A typical final cooler is divided into two spray compartments, Fig. 7.108. Each compartment is provided with its own set of recirculation pumps in order to recirculate wash oil from the top-section drains to the bottom section. The wash oil which is recirculated in the bottom section is cooled in a series of wash oil coolers. An oil-water separator is provided at the bottom of the column to decant condensed water from the wash oil.

The naphthalene which is absorbed in the wash oil may be stripped out by feeding the wash oil into the top of the wash oil scrubber at a point which is about 16 trays above where the benzolized wash oil is introduced. Otherwise, the naphthalene may be stripped out in a separate still.

Depending on the byproduct plant system, semi-direct or indirect, there are different technologies to cool the pre-cleaned coke oven gas down to the temperature necessary for further processing.

In the so-called semi-direct byproduct plants, it is necessary to install a final gas cooler downstream of ammonium saturators to cool the water-vapor saturated coke oven gas to an optimum temperature for the naphthalene and light oil removal.

As the ammonia absorption with sulfuric acid is a strongly exothermic reaction, an intensive final gas cooling is needed before the gas enters the benzol/naphthalene scrubbing.

One intensive final cooling method is the so-called *three stage tower*, developed and built by Dr. C. Otto and Company. This tower consists of a primary cooling stage in the lower part, a naphthalene washing stage in the middle part, and a low temperature cooling stage in the upper part, Fig. 7.109. The significance of this arrangement is that mixing of gas condensate and wash oil is avoided. In the primary cooling stage, the gas is cooled down to a temperature just above the naphthalene dewpoint of the gas. Therefore, there is no fouling of the cooler due to naphthalene deposition.

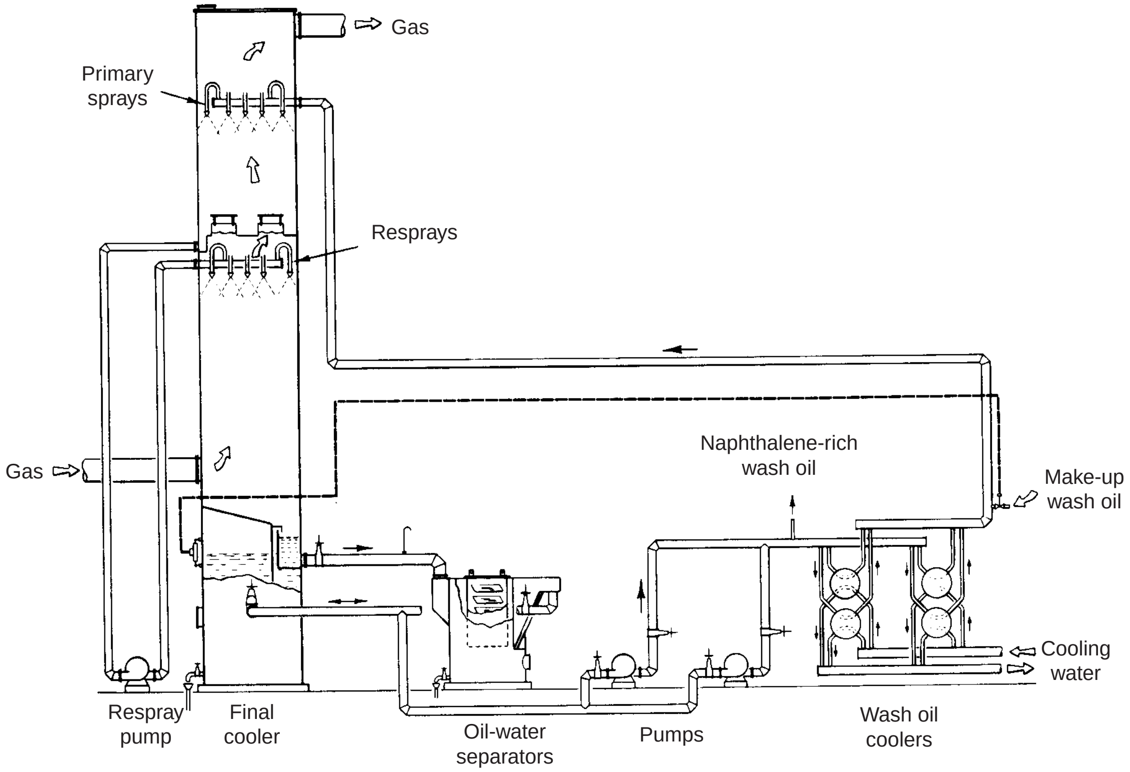


Fig. 7.108 Final cooler of the wash oil spray type

To increase the washing efficiency of the naphthalene washing stage, it is filled with ceramic rings. Wash oil corresponding to the necessary wetting rate, is recirculated through this stage. Part of the wash oil is continuously blown down to the oil regeneration plant. A corresponding amount of lean (fresh) oil is pumped as makeup to the wash oil recirculation. Enriched naphthalene oil leaves the sump of the washing stage via seal pot and passes to the regeneration plant.

The gas leaving the naphthalene removal stage will receive its final cooling per section, using recirculated liquor, which in turn is cooled in indirect heat exchangers using cooling water.

The first cooling stage, as well as the low temperature cooling stage, are designed without internals. Several spraying systems provide adequate spraying of the cooling liquor in both cooling stages.

In the gas mains connecting the three stages, and the main leaving the final cooler, demisters are installed to prevent carryover of oil and water droplets to the next stages.

7.7.7.2.4 Wash Oil Scrubber The second step in the recovery of light oil is its absorption in the liquid petroleum wash oil. The gas comes in direct contact with the wash oil in one or more tall scrubbing towers. The gas passes from the first tower to the last in series and the wash oil travels from the last tower to the first in reverse series. The flow of gas and wash oil is counter-current in each tower. The steel towers are approximately 4.5–6.7 m (15–22 ft) in diameter and 30.5 m (100 ft) in height.

The wash oil is introduced through a number of sprays in the top of the tower and comes into direct contact with the gas, which flows from the bottom to the top. An oil storage tank is provided in the base of the tower to receive the oil and maintain a surge capacity for pumping the oil away. The oil passes from the gas compartment to oil storage through a sealed pipe. It is pumped from the base of one tower to the spray system in the top of the next tower in series. From the last tower the oil is pumped at a controlled rate to the stripping stills for separation of light oil from wash oil. Wash oil prior to light oil absorption is called debenzolized and after absorption it is called benzolized.

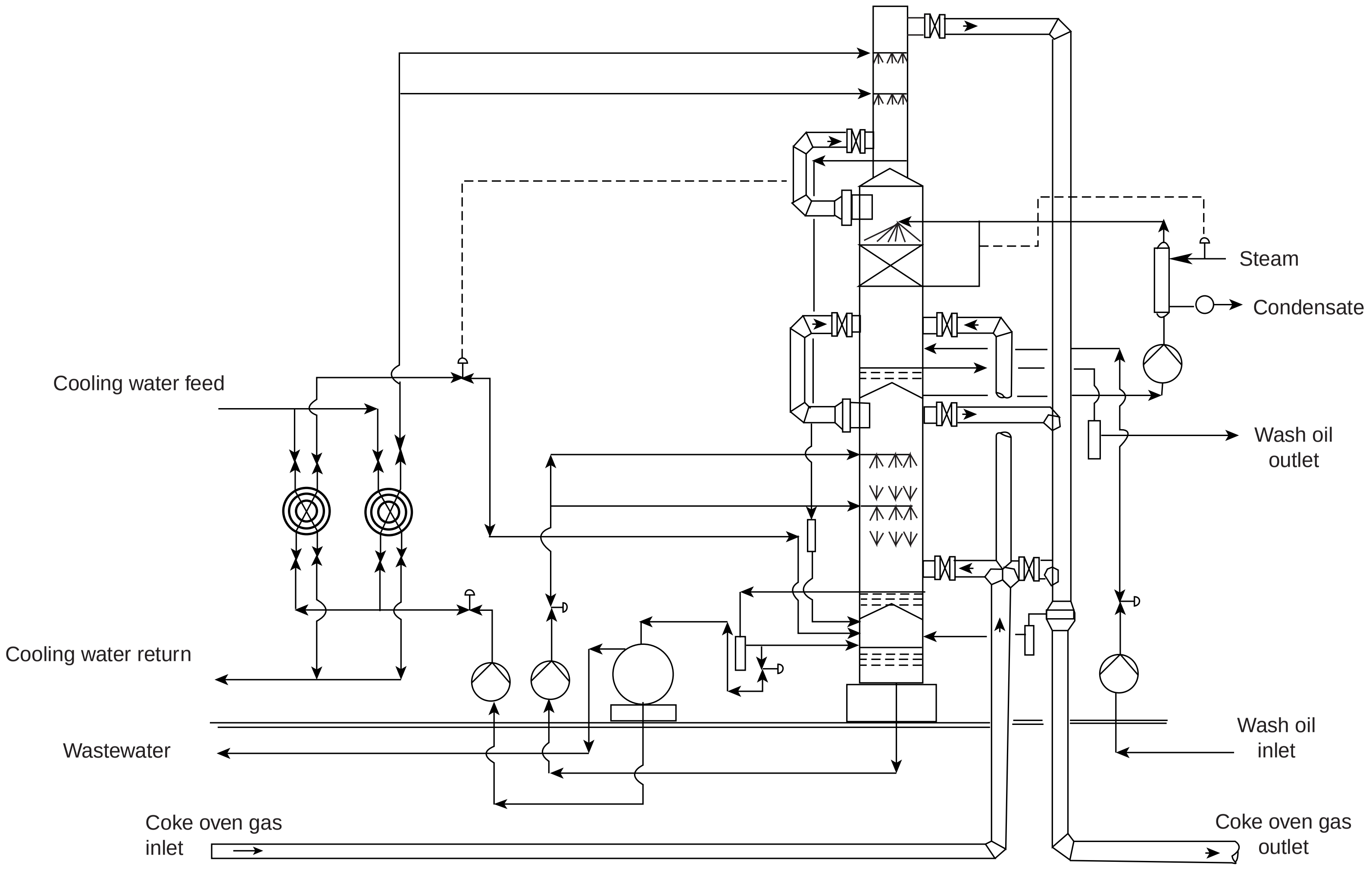


Fig. 7.109 Direct final gas cooling in a three stage tower with a naphthalene washing stage.

The benzolized wash oil contains 2–3% light oil. The debenzolized wash oil is cooled in indirect coolers to a temperature several degrees higher than that of the gas entering the scrubbers, which is 15–25°C (60–75°F). This is to prevent condensation of water from the gas, which would form an emulsion with the oil, causing clogging of the free space in the packing of the tower. The rate requirement for the circulation of oil through the scrubbers is a function of the vapor pressure distribution between the light oil dissolved in the absorbent oil and that remaining in the gas at temperature of operation. From 90–95% of the light oil content is recovered in this operation. The wash oil, after being cooled, passes through a large decanting tank which acts as a settling compartment for the emulsified and resinous materials present in the wash oil. This material accumulates in the bottom of the tank, and the wash oil decants off at a higher level to a small receiving tank, from which it is pumped to the top of the first scrubbing tower in the series. Generally, two decanting and two receiving tanks are provided to permit cleaning the residue from the tanks periodically.

Recent designs of wash oil scrubbers are not fitted with hurdles and packing used in the previous types. Contact between the gas and absorption oil is accomplished by the use of single conical sprays placed at three or four different elevations within the tower, as shown in Fig. 7.110.

Each of the sets of sprays is provided with its own set of recirculation pumps. The wash oil is recirculated in each set to obtain adequate contact between the gas and liquid in the scrubber. The wash oil is collected and recirculated by chimney trays at the bottom of each spray chamber, except at the bottom where the oil is pumped from the scrubber sump.

7.7.7.2.5 Debenzolization of Wash Oil In the debenzolization step, light oil (2–3%) in the benzolized wash oil is separated by steam distillation. The carryover of absorbing oil into the light oil is kept to about 5% and the debenzolized absorbing oil contains 0.2% light oil.

In the straight steam distillation process at atmospheric pressure, the benzolized was oil is preheated to approximately 100°C (212°F) with a vapor-to-oil and an oil-to-oil heat exchanger. Heating is continued to 145°C (295°F) with an indirect preheater of the shell-and-tube type, with the oil flowing through the tubes, using steam as the heating medium on the shell side. The preheated

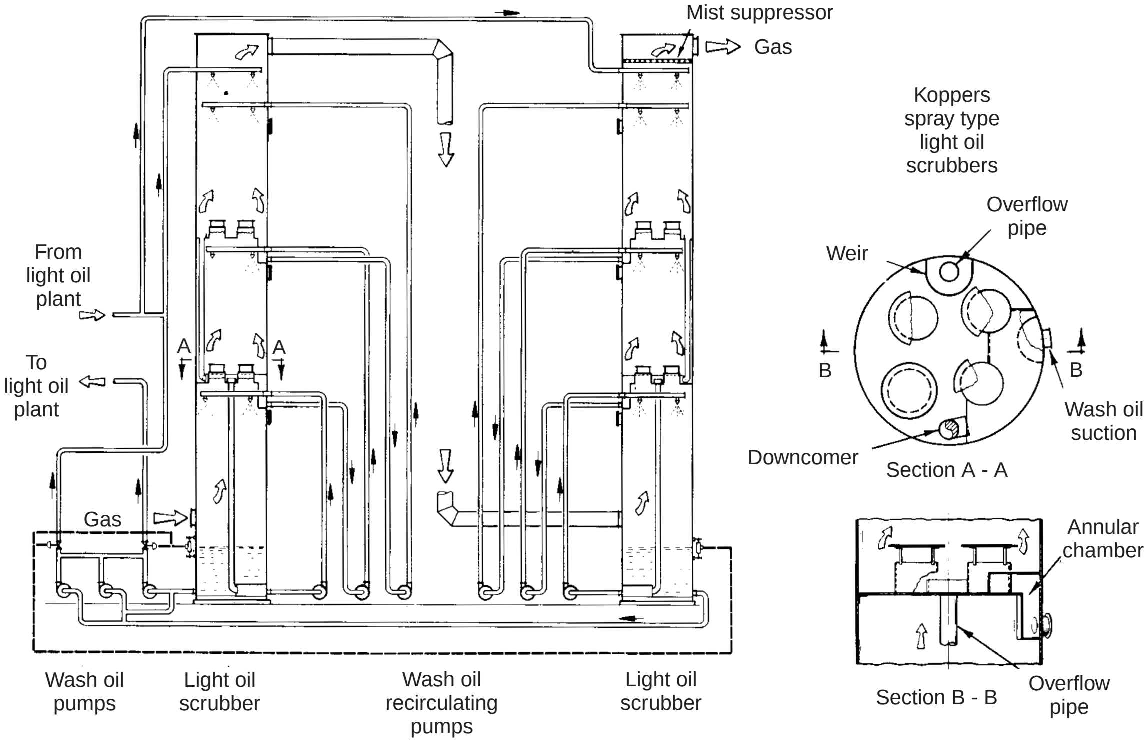


Fig. 7.110 Flow diagram of spray-type light oil scrubbers.

oil is introduced near the top into a multi-plate bubble-cap fractionating column leaving several plates above the feed to keep entrainment of wash oil to a minimum. The benzolized wash oil flows down the column counter-current to upward flow of live steam, which is introduced in the base of the still column. The debenzolized wash oil leaving the base of the column through a sealed outlet at a temperature of 145–150°C (290–300°F) passes through the oil-to-oil exchanger in which it is cooled to 100°C (212°F), giving up its heat to the incoming benzolized wash oil. Water separates out at this point and is drained off. The wash oil passes through a pumping tank and is pumped at 100°C (212°F) to cooling coils for cooling prior to being used again as an absorbent for the light oil in the scrubber towers.

The mixture of steam and light oil vapors leaving the top of the column flows through the tubular vapor-to-oil heat exchanger which recovers heat and also acts as a partial condenser. Sufficient heat is imparted to the incoming benzolized oil to raise its temperature 25°C (45°F) and, at the same time, the vapors are cooled to cause a portion of the steam and high-boiling constituents of light oil to condense (the condensate of which carries along some of the wash oil which was carried over the top of the column as entrainment). The mixture of oil and water is separated in a gravity in a gravity separator tank, the water flowing to the sump system and the oil being returned to the debenzolized oil streams. The mixture of steam and light oil vapors leaving the vapor-to-oil heat exchanger passes to a water-cooled condenser, which is of a multi-pass design, with the vapor and water flowing counter-current to each other. The condensate flows to a gravity separator effecting a separation of the light oil and water, the light oil flowing to storage and the water to the sump system.

In some designs, an additional fractionating column is added to the debenzolization process for rectifying the light oil vapors from the vapor-to-oil heat exchanger. In this case, the condensate of the vapor-to-oil heat exchanger, after separation of the water, is also introduced into the rectifying column. The mixture of steam and light oil vapors enters the multi-plate bubble-cap rectifying column near the middle section. The light oil is separated into two fractions: (1) the distillate containing forerunnings, benzene, toluene, xylene and low-boiling solvent, and (2) a residual fraction containing an admixture of high-boiling solvents, naphthalene and wash oil. A portion of the distillate is returned to the top of the column as reflux, the control point being the vapor temperature at the top of the column.

In the more modern debenzolization processes, the benzolized wash oil is processed at a temperature of 90–120°C (195–250°F) and this eliminates the need for an oil-to-oil heat exchanger in the process lineup.

7.7.8 Hydrogen Sulfide Removal

The first successful liquid purification process for removal of hydrogen sulfide from coke oven gas was the Seaboard process introduced in 1921 by Koppers Company. In this process, the coke oven gas is washed with a sodium carbonate solution in an absorber to remove the hydrogen sulfide from the gas. The solution is revivified by spraying it into an actifier where it is blown with air which transfers the hydrogen sulfide to the air.

The Seaboard process was replaced by the Koppers vacuum carbonate process, Fig. 7.111, which removes hydrogen sulfide from coke oven gas and recovers it in the form of a concentrated acid gas stream from which the hydrogen sulfide can readily be converted to either elemental sulfur or sulfuric acid.

Although coke oven gas technology has been practiced for a number of years, modern sulfur emission specifications require improvement of the old processes or development of new technology to meet regulatory requirements.

Commercial coke oven gas desulfurization processes can be divided into two categories: (1) those processes which use wet oxidation to produce sulfur, and (2) those which absorb and strip hydrogen sulfide for subsequent conversion into sulfur or sulfuric acid.

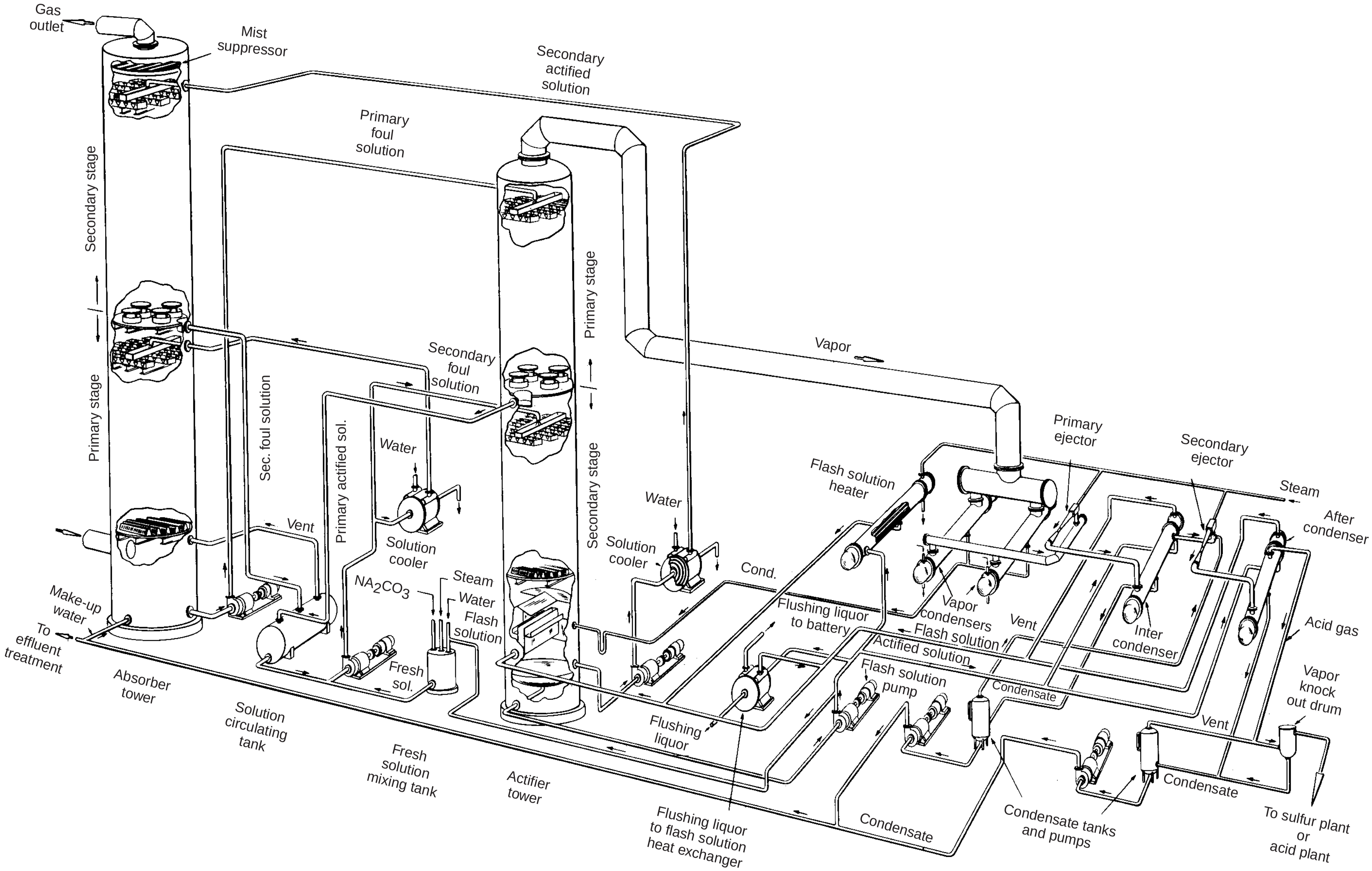


Fig. 7.111 Flow diagram of a two-stage vacuum carbonate process for removal of hydrogen sulfide from coke oven gas.

Table 7.7 Major Wet Oxidation Desulfurization Processes and Their Catalysts

Process	Catalyst
Takahax Process	Naphthoquinone-sulfonic acid
Holmes-Stretford Process	Anthraquinone-disulfonic acid and sodium ammonium vanadate
Fumaks Process	Picric acid
Thylox and Giammarco Vetrocoke	Sodium thioarsenate

7.7.8.1 Wet Oxidation Processes

All wet oxidation processes utilize a reduction-oxidation catalyst to facilitate the wet oxidation of hydrogen sulfide to elemental sulfur or sulfate. All of these processes are characterized by a very efficient removal of sulfur, but have the disadvantage of producing highly contaminated waste products which require elaborate waste treatment facilities as a part of the process. For example, all the hydrogen cyanide that is absorbed is converted into thiocyanates and a portion of the sulfur is converted into thiosulfate requiring treatment in the waste treatment facility. In addition, the solution is relatively sensitive to contamination and must be controlled to a uniform composition.

The major commercial wet oxidation processes which are used in the world today, along with their reduction-oxidation catalysts, are listed in Table 7.7.

The Takahax process, Fig. 7.112, can be designed in four different ways, depending upon the alkaline solution used in the absorber for the end product desired. In the desulfurization process, crude coke oven gas is counter-currently contacted with the alkaline solution in the absorber. Hydrogen sulfide removal up to 90–99% and hydrogen cyanide removal of 85–95% can be obtained. Solution from the bottom of the absorber is sent to a regenerator where it is air-blown to regenerate the catalyst. In order to maintain the absorbability of the solution, part of the solution is split from the system and treated by the waste solution treatment process. The desulfurization process is similar in all four types, except that Type A and B use ammonia and Type C and D use sodium carbonate as the alkaline solution. The main difference in the four types of processes is in the waste treatment systems.

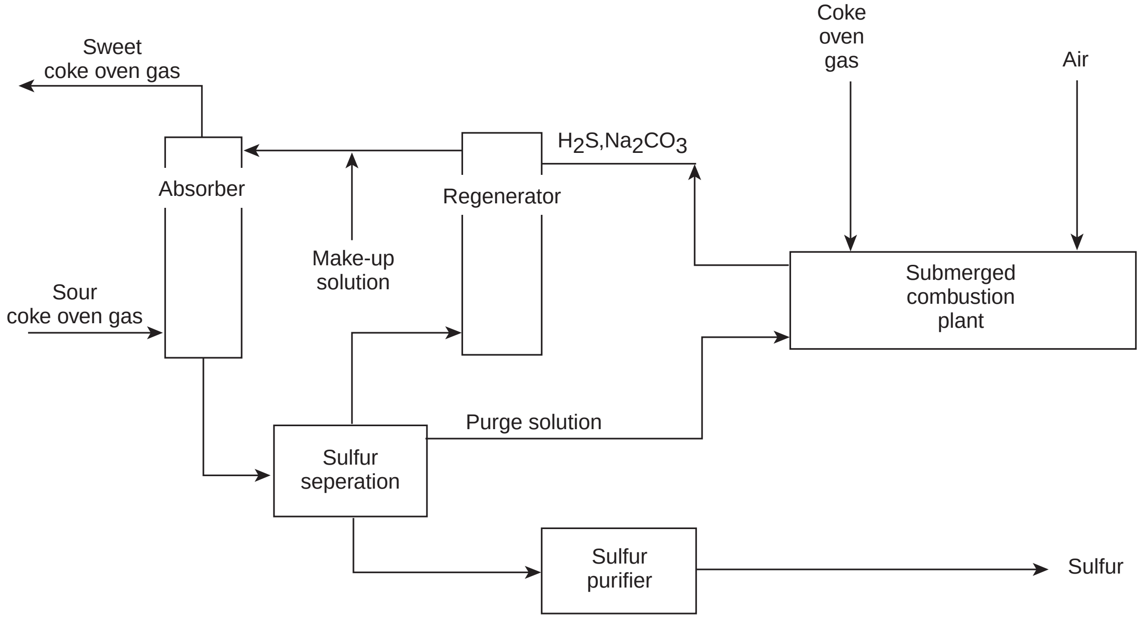


Fig. 7.112 Flow diagram of the Takahax process for desulfurization of coke oven gas.

Type A Takahax oxidizes the waste solution with compressed air to form ammonium sulfate. Ammonium sulfate crystals are recovered in a conventional crystallizer. Type B Takahax incinerates the entire waste solution, along with the sulfur cake produced in the absorber, to produce sulfur dioxide gas that is converted to sulfuric acid. Type C Takahax produces sulfur cake from the absorber and a portion of the sulfur is bled off and sent to a combustion furnace along with the waste solution. In the submerged combustion furnace, fuel is burned in a reducing atmosphere to convert the sulfur compounds to hydrogen sulfide. The hydrogen sulfide gas and the remaining sulfur are sent to the sulfuric acid plant. Type D Takahax produces sulfur cake, and a portion of the sulfur cake and waste solution is sent to the submerged combustion furnace as in Type C. Hydrogen sulfide produced in the combustion furnace is re-absorbed in the Takahax absorber, so that the entire discharge of sulfur from the process is elemental sulfur. Sulfur cake is melted in an autoclave to purify the product, producing a sulfur with a purity of 98–99%.

All of the wet oxidation processes produce a low-grade sulfur and a highly contaminated waste stream requiring elaborate waste treatment facilities. Operation of these processes requires a more sophisticated chemical control than the absorption stripping processes.

The Holmes-Stretford process is used to economically remove hydrogen sulfide from coke oven gas. In addition to the basic hydrogen sulfide absorption plant, an effluent treatment plant is included to convert the plant waste streams for recycling through the plant. This process will remove all but a trace of hydrogen cyanide, reduce the hydrogen sulfide content to substantially less than 0.23 g/m^3 (10 gr./100 ft^3) of gas, and produce a very saleable grade of liquid sulfur. An elementary flow diagram of the process is presented in Fig. 7.113.

The Holmes-Stretford process provides for scrubbing of coke oven gas with an alkaline solution of sodium ammonium vanadate which oxidizes the hydrogen sulfide in the gas to form free sulfur. Sulfur is collected as a froth which is washed, concentrated and purified to a final molten product. The reduced vanadate solution is re-oxidized with anthraquinone disulfonic acid and air to its original state and is recycled to the hydrogen sulfide scrubber.

The basic plant utilizes the Holmes-Stretford process parts which are available under license from the British Gas Corporation. The complete plant consists of: (1) basic hydrogen sulfide removal system, (2) sulfur recovery and purification system, and (3) spent liquor reprocessing system. The combines systems result in a plant with economical operating costs, a saleable grade of sulfur product, and no effluent waste streams.

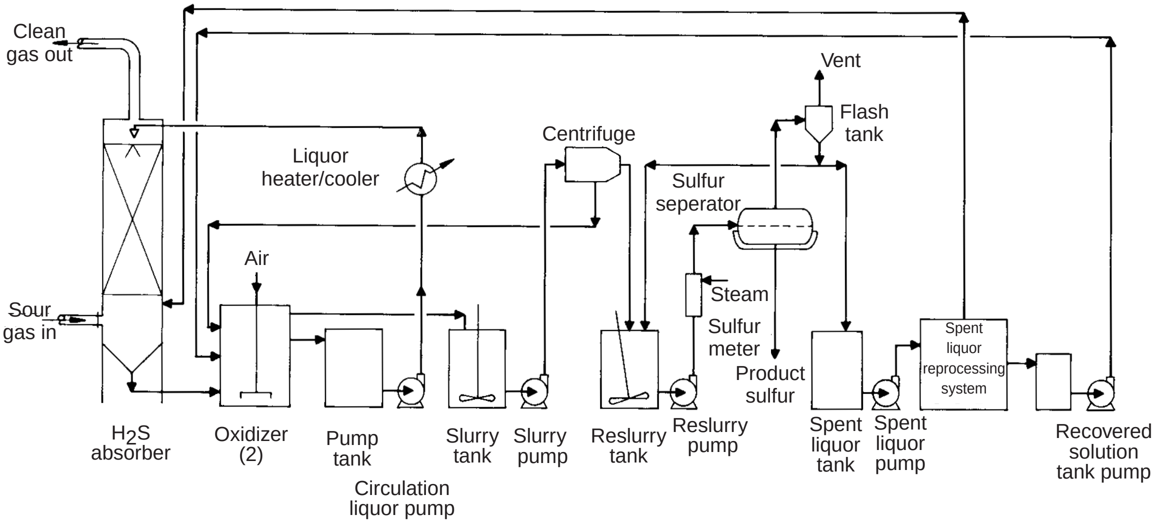


Fig. 7.113 Flow diagram of the Holmes-Stretford process for desulfurization of coke oven gas..

7.7.8.2 Absorption Stripping Processes The absorption stripping processes are characterized by generally lower hydrogen sulfide removal, but, since air is not included in the regenerating system, contaminated waste products are minimized or eliminated. The processes can be operated to produce sulfuric acid or a very high purity elemental sulfur.

7.7.8.2.1 Vacuum Carbonate Process In this process, the gas is contacted with a solution of sodium carbonate in an absorber tower to remove the hydrogen sulfide and other impurities such as hydrogen cyanide. The foul solution from the base of the absorber is circulated over the actifier where the hydrogen sulfide is removed by counter-current stripping with water vapor under vacuum. The actified solution is pumped from the base of the actifier through a cooler back to the absorber.

The actifier is maintained under a relatively high vacuum to reduce the quantity of heat required to generate the water vapor for actifying the solution. The mixture of hydrogen sulfide and water vapor leaving the top of the actifier is passed through a condenser where most of the water vapor is condensed. The vacuum in the actifier and condenser is maintained by a two-stage steam ejector. After the ejector system the concentrated acid gas stream is further cooled and processed in a Claus plant to produce elemental sulfur, or in a sulfuric acid converter.

The heat requirements to generate the water vapor to strip the hydrogen sulfide from the foul solution in the actifier can be obtained almost completely from indirect heat exchange of the solution in the base of the actifier with the vapors at the discharge of the steam-jet vacuum pumps, and supplemental indirect heat exchange with the flushing liquor from the coke oven batteries or from other waste heat sources.

The single-stage vacuum carbonate process is economical for removal of approximately 90% of the hydrogen sulfide from typical coke oven gas. In order to meet more stringent requirements in some locations, the Koppers two-stage vacuum carbonate process was developed to remove approximately 98% of the hydrogen sulfide, producing a clean gas with no more than 0.23 g/m3 (10 gr./100 ft3).

In the two-stage process, the coke oven gas flows upward through two sections of a packed absorber. In the lower section the gas is contacted with sodium carbonate solution from the upper stage of a two-stage vacuum actifier tower, and about 90% of the hydrogen sulfide is removed. The gas then flows to the upper stage of the absorber where it is contacted with a smaller stream of sodium carbonate solution from the lower stage of the actifier. This solution has been very highly actified, and removes 80–90% of the remaining hydrogen sulfide, for an overall removal of 98%.

The same stripping steam is used in both sections of the two-stage actifier, resulting in high removal efficiency and low operating cost. The condensing system, vacuum system, and heat exchange system are substantially the same as those used for the single-stage process.

The choice between the Koppers single-stage and two-stage vacuum carbonate processes depends upon the stringency of the regulatory requirements which must be met.

7.7.8.2.2 Hydrogen Sulfide and Ammonia Removal The ammonia/hydrogen sulfide circulation scrubbing process (AS circulation scrubbing), developed and patented by Carl Still in 1971, lends itself ideally to the removal of ammonia, hydrogen sulfide and hydrogen cyanide (partially) from the coke oven gas.

This process works according to the neutralization principle and utilizes as its basic component the ammonia present in the gas. With the help of an inherently generated ammonia liquor mixture and without making use of external chemicals the acidic components hydrogen sulfide and hydrogen cyanide are eliminated by scrubbing.

As shown in Fig. 7.114, the system mainly consists of four columns: a hydrogen sulfide scrubber, an ammonia scrubber, a hydrogen sulfide desorber (deacifier), and an ammonia desorber (still).

The two absorbers (scrubbers) are normally turbulent-flow expanded metal stage scrubbers, while the desorbers are normally tray-type columns. The coke oven gas passes first through the hydrogen

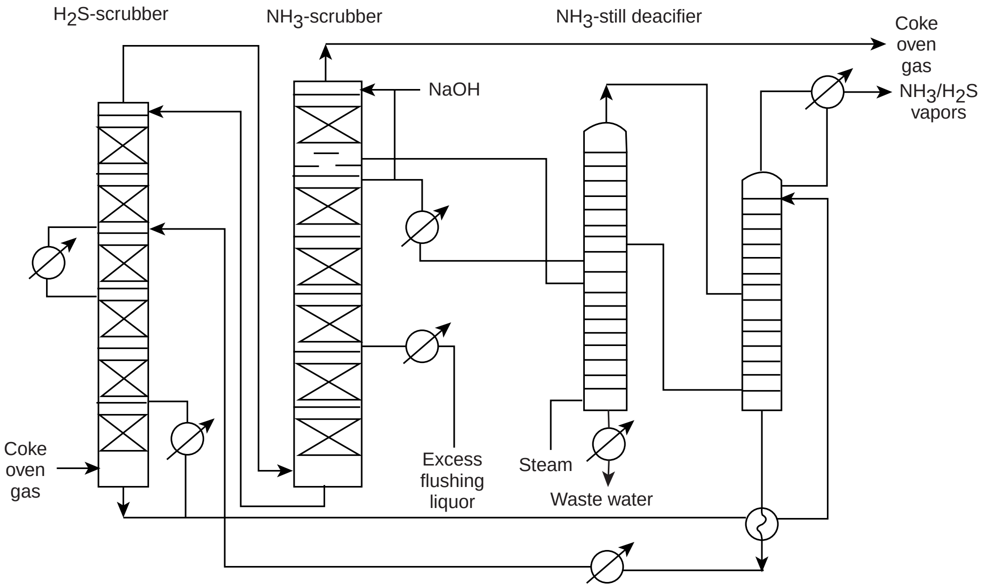


Fig. 7.114 Schematic of the ammonia/hydrogen sulfide circulation scrubbing process.

sulfide absorber and through the ammonia absorber. The scrubbing solution used the in hydrogen sulfide scrubber is the liquor drained from the ammonia scrubber as well as an ammonia-rich liquor from the desorption process. The heat released during the absorption process is eliminated by pumping the scrubbing solution through intermediate cooling stages. In this manner, the favorable absorption isotherm is maintained and the spraying density increased.

Stripped liquor coming from the desorption stage is fed to the top of the ammonia scrubber. On its way to the sump of the tower, this solution is enriched with ammonia and from the sump it is withdrawn and passed as scrubbing solution to the hydrogen sulfide absorber.

The enriched scrubbing liquor is passed from the sump of the hydrogen sulfide scrubber to the regeneration unit (desorption). In the regeneration system, which consists mainly of a still and a deacifier, components such as ammonia, hydrogen sulfide, carbon dioxide and hydrogen cyanide absorbed from the gas are stripped off by means of steam. As a result of the special mode of regeneration column operation, a deacified liquor rich in ammonia but having a low acid gas content is produced along with a stripped steam of wastewater quality.

This process arrangement enables the thermal energy contained in the ammonia still overheads to be utilized in the deacifier. Further savings in steam can be realized by making use of steam ejectors.

Part of the liquor flows from the sump of the deacifier to the hydrogen sulfide scrubber as scrubbing solution and another stream is passed to the top of the ammonia still. The virgin liquor (excess ammonia liquor) can also be fed in at this location. Part of the stripped liquor is used as ammonia washing solution while the excess quantity will be sent to the wastewater treatment plant for further processing.

If necessary, the so-called fixed-ammonia compounds can also be split up by mean of alkaline, such as sodium hydroxide, and the fixed ammonia can be driven off.

The amount of wastewater branched off corresponds with the virgin liquor quantity fed into the system plus stripping steam condensate.

The deacifier overheads contain all of the substances absorbed from the gas and stripped from the virgin liquor, e.g. ammonia and hydrogen sulfide. These components are converted in downstream process steps to obtain products such as liquid sulfur or sulfuric acid form the hydrogen sulfide and ammonium sulfate, or the ammonia may be cracked.

With the system described above, a hydrogen sulfide removal efficiency of 0.4 g/Nm^3 can be achieved. Innovations introduced to the process by Thyssen Still Otto enable even lower hydrogen sulfide levels to be reached. As may be needed for the individual application, a final purity of 0.2 g/Nm^3 of hydrogen sulfide per Nm^3 of coke oven gas can be realized by modification of the AS circulation scrubbing system. This modification may be beneficially applied in cases where ammonium compounds that cannot be cracked thermally, e.g. chlorides and SO_4, must be eliminated from the excess ammonia liquor. Up to 90% of the sodium hydroxide needed for this purpose can be used first for the cleaning of the coke oven gas.

7.7.8.2.3 Ammonia Cracking and Liquid Sulfur Production In conformity with the trend in recent years, a modified Claus plant has been provided for the processing of the hydrogen sulfide where, simultaneously, the total amount of ammonia is cracked.

Apart from the nitrogen-laden compounds such as ammonia and hydrogen cyanide, vapors containing hydrogen sulfide produced in a coke plant also carry organic products such as naphthalene and phenols. A processing of these vapors in a conventional Claus plant has not been feasible as evidenced by all of the experience to date. Complete conversion of ammonia and hydrogen cyanide to nitrogen gas, carbon dioxide gas and water vapor and conversion of hydrocarbon compounds by means of water steam to carbon monoxide and hydrogen gas are both sensibly not feasible with the given process parameters of a Claus process.

It is well known that incompletely converted ammonia in a Claus system entails a formation of salt in the waste heat boiler downstream of the Claus furnace that will plug it. Moreover, it is a well-known fact that the soot formation in a Claus furnace blocks the catalyst beds, causing substantial interferences in operation and thus inevitably some unacceptable environmental performance.

These facts and the many years of operational experience gained by Thyssen Still Otto in the field of catalytic cracking of ammonia from still vapors gave birth to a process combination illustrated in Fig. 7.115. In this process the conventional Claus furnace was replaced by a cracking reactor, which is equipped with a special catalyst.

The most significant benefits of this modified Claus principle are listed here:

1. Processing of hydrogen sulfide vapors from deacifiers/desorbers with ammonia and hydrogen cyanide constituents as well as organic products such as naphthalene, phenols, etc. is possible to obtain Claus sulfur.
2. It is feasible to process the hydrogen sulfide vapors with the entire ammonia volume from the coke plant.

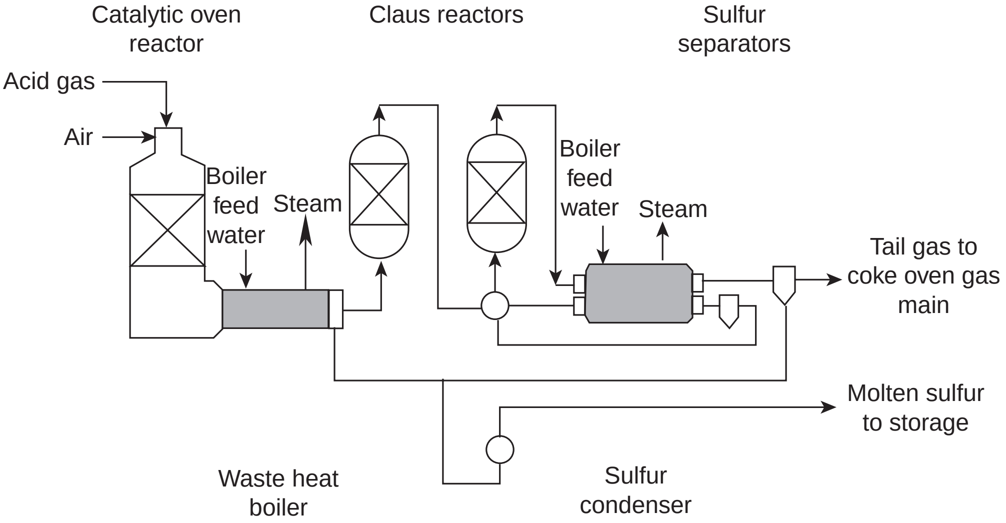


Fig. 7.115 Schematic of an ammonia cracking process with a cracking reactor in the place of the conventional Claus furnace.

3. Return of the Claus residual gas (tail gas) into the coke oven gas at a reduced sulfur dioxide content is possible.
4. Recycling of Claus residual gas into the pre-cracking stage by addition of oxygen is possible.

The process can be planned to run on one or more catalytical Claus reactor. If a return of Claus residual gas upstream to the hydrogen sulfide scrubbing of coke oven gas is applied, then the hydrogen sulfide conversion in the Claus stage bears no significance, such that one catalytic Claus stage or possibly two should be adequate for an economic operation. A reduction in the residual sulfur dioxide content towards zero should be targeted in order to avoid any additional load on effluents with salts.

7.7.8.2.4 Sulfiban Process The Sulfiban process was developed jointly by Bethlehem Steel Corp. and Applied Technology Corp. The process utilizes monoethanalamine (MEA) as the absorbing solution. In the Sulfiban process, coke oven gas is contacted counter-currently with an aqueous solution containing 13–18% MEA. The process is reported to remove organic sulfur as well as hydrogen sulfide, and sulfur content in the treated gas is guaranteed less than 0.23 g/Nm^3 (10 gr./100 scf).

Rich solution from the absorbers is pumped to the still, where hydrogen sulfide and hydrogen cyanide are steam-stripped and the regenerating solution from the bottom of the still is cooled and recycled to the absorber. The steam for the stripping operation is produced in a steam-heated reboiler connected to the still. A small amount of insoluble compounds, mainly ferrocyanide, are formed and must be removed from the system. About 3% of the circulating stream is sent to a reclaimer which is heated with high pressure steam to totally evaporate the water and MEA. Vapors from the reclaimer are sent to the still and solids are periodically removed for disposal.

Acid gases from the top of the still, containing both hydrogen sulfide and hydrogen cyanide, are sent to a cyanide reactor where the cyanide is catalytically converted to ammonia so that it will not interfere with the operation of the sulfur plant. This ammonia could be recovered with a USS PHOSAM absorber. Where a USS PHOSAM plant already exists, the integration of this small absorber into the system would be inexpensive and advantageous.

Gas from the cyanide reactor passes to a plant for conversion to high purity sulfur.

7.7.8.2.5 Carl Still or Diamox Processes Both the Carl Still and Diamox processes utilize aqueous ammonia as the absorbing solution to desulfurize coke oven gas. The difference in the two processes is primarily in materials of construction and in some operating refinements. Either process can be synergistically combined with a USS PHOSAM process to recover both ammonia and high-grade elemental sulfur.

Coke oven gas following the naphthalene scrubber passes through the hydrogen sulfide scrubber, where it is counter-currently contacted with ammonia solution. The ammonia-absorbing solution is made up of ammonia liquor from the free leg of the coke plant ammonia still, recycled solution from the deacidifier, and ammonia from the top of the PHOSAM stripper. If the hydrogen sulfide absorber is operated with no recycled ammonia from the USS PHOSAM stripper, it will remove hydrogen sulfide to a level of 0.92–1.14 g/Nm3 (40–50 gr./100 scf). If about 15% of the ammonia from the PHOSAM stripper is recycled to the hydrogen sulfide absorber, the hydrogen sulfide concentration will be reduced to about 0.23 g/Nm3 (10 gr./100 scf). The only penalty for the improved hydrogen sulfide removal is 15% additional capacity in the PHOSAM stripper. Absorbing solution from the bottom of the hydrogen sulfide absorber is pumped to the deacidifier, where it is contacted with steam from the coke plant ammonia still, augmented by additional low pressure steam.

Stripping solution from the bottom of the deacidifier is cooled and recycled to the hydrogen sulfide absorber. Acid gases from the top of the deacidifier, containing hydrogen sulfide, ammonia, hydrogen cyanide and carbon dioxide, are sent to a small PHOSAM absorber, where the ammonia is selectively removed. Acid gases from the PHOSAM absorber pass to a hydrogen cyanide reactor, where the hydrogen cyanide is catalytically decomposed. Gases from the hydrogen cyanide reactor then pass to a plant for production of high purity sulfur.

The integration of the Carl Still process with the USS PHOSAM process permits reduction of hydrogen sulfide in the coke oven gas from about 1.03 to 0.26 g/Nm3 (about 45 to 10 gr./100 scf). In addition, removal of ammonia from the acid gases is advantageous to the operation of the sulfur plant. The successful combination of these two processes offers a new technology in coke oven gas desulfurization.

The Diamox process is similar to the Carl Still process, except that it operates with lower ammonia concentrations so that ammonia recycle from the PHOSAM stripper and the acid gas PHOSAM absorber can be eliminated.

7.7.8.2.6 DESULF Process The dominating coke oven gas liquid desulfurization process in Europe, which started in the 1940s, uses ammonia water. This process, in fact, combines hydrogen sulfide removal with ammonia removal. The basic process has been updated recently to achieve lower hydrogen sulfide figures in the purified gas and to adjust to the climatic conditions (higher ambient temperatures) of other countries.

In the DESULF process, Fig. 7.116, the gas is contacted counter-currently by the liquor in three absorptive towers operated in series where the liquor's ammonia content decreases in the direction of the gas flow. The first washer provides for hydrogen sulfide bulk removal; in the second washer, ammonia and hydrogen sulfide are absorbed; while the third washer effects final removal of ammonia (0.02 g/Nm3 or 0.82 gr./100 scf) and hydrogen sulfide (0.2 g/Nm3 or 8.2 gr./100 scf). The absorption liquor streams are as follows: fresh water is used in the third tower and pumped from the tower bottom up to the top of the second washer, where activated ammonia liquor is also added; the liquor is pumped to the middle section of the first washer, while weak ammonia liquor and liquid ammonia enter its top section.

The loaded ammonia liquor is preheated and activated in the deacidifier which is equipped with bubble-cap trays. Activated ammonia liquor is pumped out of the bottom section and, after heat exchange and cooling, reused in the second washer. Surplus liquor is pumped from the deacidifier into the ammonia still, where the ammonia is removed by direct low pressure steam injection. After

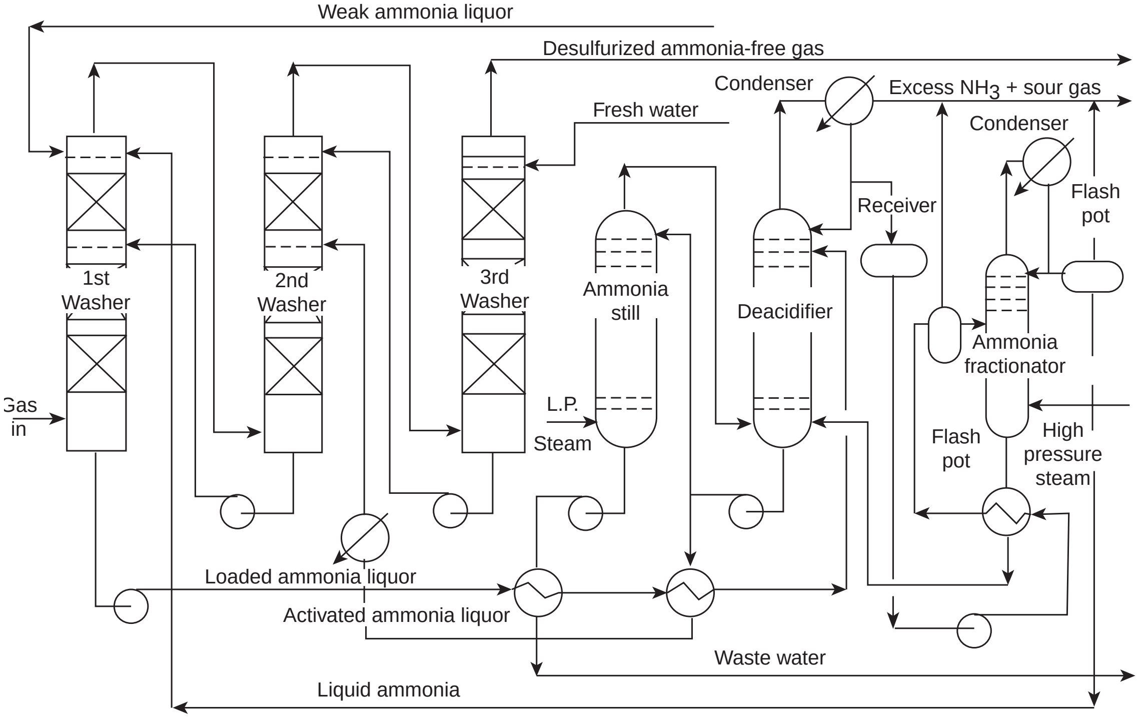


Fig. 7.116 Flowsheet of the DESULF process.

heat exchange, the liquor is discharged into the wastewater system. The vapors from the ammonia still are directed into the bottom section of the deacidifier. Top vapors from the deacidifier partially condense, so that hydrogen sulfide and the like remain as sour gas, while steam and ammonia mostly condense. A controlled proportion of the condensate is refluxed; most of the flow is pumped into the ammonia fractionator after heating and flashing off any still-entrained sour gases. The fractionator is operated at increased pressure. The concentrated ammonia liquor is fractionated by direct steam injection into lean liquor, which is returned to the deacidifier bottom, and into ammonia vapor, which is liquefied in the condenser and then directed into the first washer.

This process can be easily adjusted to changed operating conditions by modifying the ratio of activated ammonia liquor to liquid ammonia.

7.7.9 Coke Plant Wastewater

Public law has mandated that wastewaters must be treated to remove certain contaminants before these waters can be discharged to public waterways. The U.S. Environmental Protection Agency (EPA) was given the responsibility of controlling and regulating these discharges, and of developing uniform guidelines for required treatment of municipal and industrial point sources. Discharges from coke plants are one of the many areas in the steel industry that come under these Federal guidelines; refer to Section 6.6.5.

Coke plant wastewater is made up of blowdown from the flushing liquor system, discharges from the primary and final coolers, decanted water from the light oil decanters, discharges from the tar recovery and the chemicals recovery operations, and finally from other small miscellaneous sources throughout the coke plant. Because the carbonaceous and nitrogenous compounds in coke plant wastewater are amenable to biological treatment, this method has been widely used to reduce or remove these contaminants from the water before discharge to public waterways. A simplified block diagram of this process is presented in Fig. 7.117. Heavy solids or grit are removed from the wastewaters by use of bar screens or other similar devices, followed by oil and tar removal in set-

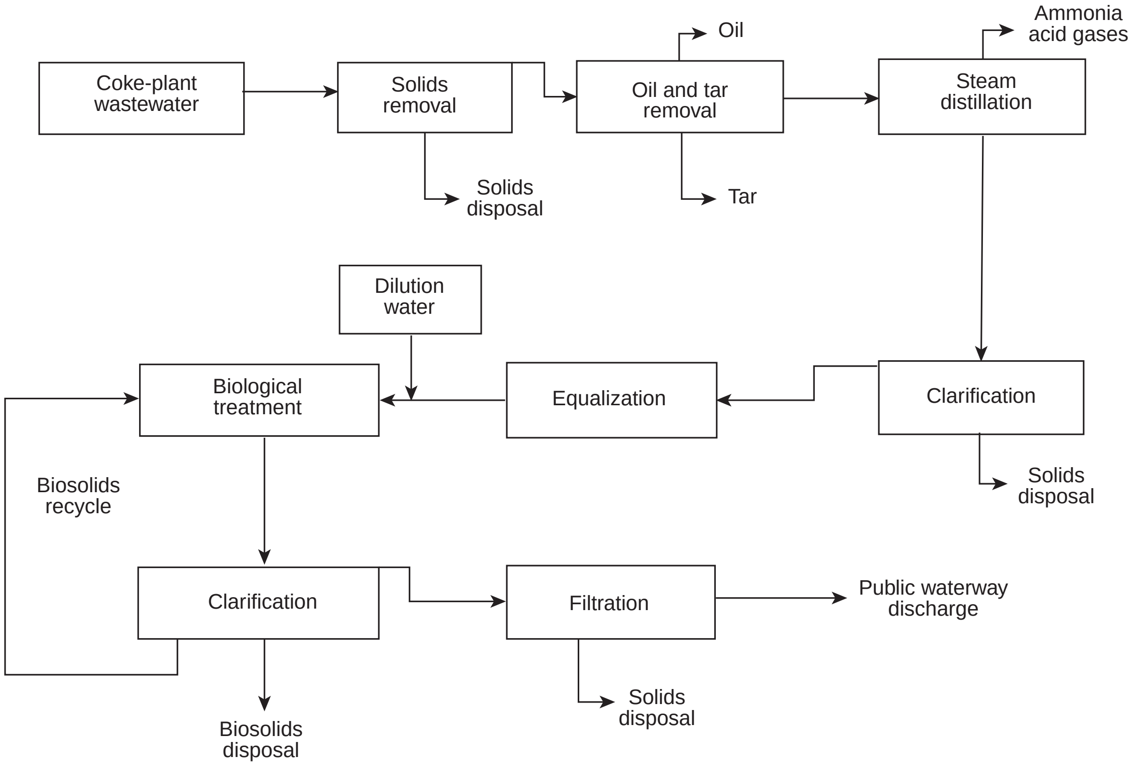


Fig. 7.117 Simplified diagram of a system for biological treatment of coke plant wastewaters.

tling tanks. Oil is skimmed from the top and tar is recovered from the bottom of these tanks. From the settling tanks, the wastewater is normally steam-stripped to reduce ammonia and acid gases, primarily hydrogen cyanide and hydrogen sulfide, prior to biological treatment. The CYAM process, discussed in Section 7.7.3.2, is a particularly efficient steam-stripping system. It is composed of a free-ammonia still. The free ammonia and the acid gases are removed in the fixed still after addition of lime. The wastewater stream from the stills is clarified and then flow and concentration equalized before undergoing biological treatment.

In most instances, biological treatment or activated sludge treatment of coke plant wastewater is an aerobic process, or one that requires oxygen. Oxygen is normally obtained from the air by mechanical mixing of the water and air or sparging with air from air blowers. Some processes that use pure oxygen gas have also been developed. The biological process is one where active bacteria, in the form of solids, are suspended in a containment vessel commonly referred to as an aeration basin. The raw wastewater, sometimes diluted with relatively clean process water to reduce the wastewater toxicity, enters the aeration basin where it contacts the suspended bacteria, which absorb the contaminants from the water and biologically oxidize them to ultimately carbon dioxide and water in the case of carbonaceous compounds and to nitrate in the case of ammonia and other nitrogenous compounds. Generation of biological solids, which must be periodically removed from the system to maintain control, is a direct result of this process. Typically, wastewater is held in the aeration basin about two days to complete the biological process, while the biological solids are kept in the system about fifty days. The former is referred to as the hydraulic retention time of the biological system, and the latter is referred to as the solids retention time or sludge age of the system. These two parameters are very important control points which need to be maintained if a quality discharge is to be realized.

Following biological treatment, the wastewater is clarified and usually filtered through dual media filters or other filtering devices, or routed through large settling or polishing ponds to reduce the suspended solids content before finally discharging into a public waterway. Refer to Table 6.30 for expected effluent quality.

7.7.10 Uses of Coke, Coke Oven Gas and Coal Chemicals

7.7.10.1 Metallurgical Coke

Coke is used for production of iron in blast furnaces and coke breeze is used as a fuel for sintering plants and for steam generation in boiler houses.

7.7.10.2 Fuel Gas

After the recovery of coal chemicals, coke oven gas provides fuel for heating the coke ovens, and the excess gas is used as a fuel in various steelmaking operations. When practicable, other gas of lower calorific value may profitably replace coke oven gas for firing coke ovens.

7.7.10.3 Ammonium Sulfate

The ammonium sulfate recovered from coke oven gas is used for admixture with phosphate and potash constituents to provide balanced agricultural fertilizers for the various requirements, or it may be used for direct application where nitrogen is the only requirement at the time of use.

7.7.10.4 Anhydrous Ammonia

The ammonia recovered from the coke oven gas and waste liquor as anhydrous ammonia liquor is a main source of nitrogen in making fertilizer. Ammonia is a major fertilizer in its own right, being introduced directly into soils. Special high purity ammonia is used in chemical synthesis, in refrigeration and in steel plants for generating reducing atmospheres.

7.7.10.5 Phenol

Phenol (C6H5OH), sometimes called carbolic acid, is recovered from both coal tar and ammonia liquor. Its most important use is in the manufacture of resinous condensation products by reaction with formaldehyde, for example Bakelite. As a chemical intermediate it is used in the preparation of synthetic tannins, dye intermediates, perfumes, plasticizers, picric acid, salicylic acid, and in the refining of lubricating oils.

7.7.10.6 Ortho Cresol

Ortho cresol (CH3C6H4OH) is also used in the production of synthetic resins to control the plasticity of the resin. It is nitrated to produce insecticides and week killers. It is used in various organic syntheses and in the production of artificial flavors and perfumes.

7.7.10.7 Meta-Para Cresol

Meta-para cresol ($CH_3C_6H_4OH$) is used chiefly in the production of synthetic resins and the plasticizer tricresyl phosphate. It is also used in organic synthesis and in the production of insecticides, dyestuffs, pharmaceuticals and photographic compounds.

7.7.10.8 Naphthalene

A large percentage of the naphthalene produced from coal is converted to phthalic anhydride. The principal use of the anhydride is in plasticizers, such as dioctyl phthalate and disoctyl phthalate, for use in synthetic resins. Nearly as much phthalic anhydride is used, however, in the alkyd resins, the important outlet for which is in coatings. In addition, polyester resins, dyes, agricultural chemicals, pharmaceuticals, insect repellents, beta-naphthol, surface active agents, tanning agents, and insecticides consume large volumes of phthalic anhydride.

7.7.10.9 Creosote

Creosote (from coal tar) constitutes a large part of the distillate from tar, and is a blend of different fractions to meet specifications established by the American Wood Preservers Association. Practically all of it goes into the pressure impregnation of wood such as piling, utility poles and railroad ties.

7.7.10.10 Pitch

Pitch is employed as a binder in making carbon electrodes, as roofing pitch, fiber pitch, road tars, and in pipeline enamels.

7.7.10.11 Benzene

Recovered from refining light oil, benzene is industrially the most important member of the aromatic family. The principal use is for the manufacture of styrene, which goes into polystyrene resins and important grades of snythetic rubber. Other important uses of benzene are for manufacture of phenol, nylon, synthetic detergents, aniline, and a host of other important organic chemicals, including DDT, maleic anhydride, benzene hexachloride, mono- and dichlorobenzene and nitrobenzene. The uses for some these benzene derivatives are evident, but others are intermediates, in turn, for additional chemicals, plastics, dyes, fungicides, and the like.

7.7.10.12 Toluene

The principal uses for toluene are in the manufacture of synthetic organic chemicals, detergents, resins, plasticizers, explosives, solvents, dye intermediates, and pharmaceuticals, and for conversion to benzene.

Toluene is converted through synthesis to phenol, benzoic acid, benzoyl chloride, benzoates, paracresol, dye intermediates, toluene sulfonates, di-isocynates and trinitrotoluene. Considerable quantities of toluene are also used as a diluent in various types of coatings.

7.7.10.13 Sulfur

Approximately 90% of the sulfur produced in the Western World is utilized for the production of sulfuric acid. Sulfur is also burnt to produce sulfur dioxide needed as bleaching agents for wool, silk, gelatin, straw, and other materials.

Roughly 10% of the sulfur is consumed as elementary sulfur to produce vulcanizing agents, is used as an additive for forming sand in the aluminum industry, or is used to produce sulfuric putty, black powder and fireworks, sulfur dyes and carbon disulfide. In agriculture sulfur is utilized to jacket fertilizers, as an important fungicide, and moreover as an additive to animal feed.

In pharmaceuticals sulfur is exploited for production of ointments or colloidal sulfur preparations against scabies, acne, seborrhea, and other skin diseases, and moreover to produce sulfurated baths against rheumatism.

More recently, sulfur has also found new fields of application in the production of sulfuric concrete. Substantial portions of asphalt contained in road pavement are already substituted by sulfur without any adverse effects.

7.7.10.14 Sulfuric Acid

Sulfuric acid is utilized in many branches of industry. The biggest consumer of sulfuric acid worldwide is the fertilizer industry, using it for the production of phosphoric acid or triple-superphosphate, mono- and diammonium phosphate, as well as superphosphate and ammonium sulfate. In the Western World, nearly 60% of the sulfuric acid production output is utilized in fertilizer production.

Another major consumer of sulfuric acid are the organic-chemical and petrochemical industries. Sulfuric acid is employed as auxiliary means in many syntheses, such as: nitrification; sulfonating; the production of both organic semi-finished products and dyes as well as plastic materials; and for refining, alkylating, and cleaning of oil distillates. In the inorganic-chemical industry, sulfuric acid is utilized in the production of titanium dioxide pigments and hydrochloric acid and also explosives, detergents, and foodstuffs. Sulfuric acid is used by the leather, chemical fiber, paper and cellulose industries. In the metal processing industry, sulfuric acid is employed for leaching of copper, uranium and vanadium ores as well as for the production of electrolytic zinc baths. A fraction of sulfuric acid is utilized as accumulator acid.

7.8 Recent Developments in Cokemaking

7.8.1 Introduction

The aging of cokemaking facilities around the world, and particularly in North America, coupled with high capital replacement costs and more stringent environmental regulations have resulted in the development of *new* cokemaking technologies which promise the production of high quality coke in an environmentally sound manner. This section has been added to provide a brief review of a variety of these technologies. Most have been tested on a prototype scale or larger. The modern non-recovery process has been in commercial operation for a number of years, but the coupling of non-recovery cokemaking facility to an energy recovery/power generation facility is a recent development.

7.8.2 Jewell Thompson Non-Recovery Cokemaking with Heat Recovery and Power Generation[29]

Jewell Coal & Coke Company, a subsidiary of Sun Coke Company has developed a non-recovery coke oven to produce a high quality blast furnace coke without the generation of hazardous or toxic emissions usually associated with a byproduct recovery coke oven. In a non-recovery oven, all of the coke oven gas generated is burned in the process.

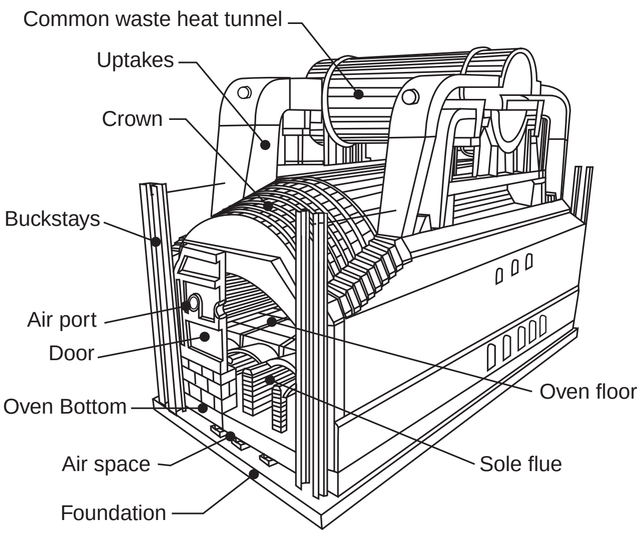


Fig. 7.118 Schematic view of Jewell-Thompson coke oven.

The ovens, known as Jewell-Thompson ovens, have a unique sole flue heating design to equalize the coking rate from the top and bottom to produce a uniform product. Because the ovens operate under negative pressure with a horizontal design, a wide variety of coals can be used which will still comply with the requirements of the existing and proposed emission regulations.

A perspective representation of a single Jewell-Thompson coke oven is shown in Fig. 7.118. The floor area of the oven chamber measures 3.6 m × 13.7 m (12 ft × 45 ft) which translates to over one ton of coal charge per inch of depth in the oven. Because the volume of charge is not constrained by the oven chamber volume, it is possible to vary charge weights with appropriate changes in coking times. The charging machine is adjustable which permits changing charge weights as desired.

Primary air for combustion is introduced into the oven chamber above the charge through ports located in the doors. These ports are fitted with adjustable dampers to control the amount of air to maintain the desired oven crown temperature. The partially combusted coke oven (offgas) gas exits the oven chamber though downcomer passages in the oven wall to the sole flues.

The sole flue arrangement, shown in Fig. 7.119, is divided into two sections, each with four passes for combustion of the offgas prior to exiting the heating system. Thus, the coke side and the pusher side can be controlled independently for uniform heating. An inlet air damper is installed at the turn from the first pass to the second pass of the sole flue. This additional damper permits the introduction of air to complete combustion of the offgas while still in the sole flue. Usually additional air is required in the sole flue only during the first hour or two after charging when gas evolution rate is the greatest. Waste gas is conducted to a common collecting tunnel through uptake passages in the oven wall. As a further means for controlling oven temperatures, a specially designed uptake damper is used to control the flow of gas exiting the oven to the exhaust system.

The common waste heat tunnel is located atop the centerline of the battery and extends the entire length of the battery. The number of ovens per exhaust stack can be varied by changing the diameter of the common tunnel. Each stack has a pneumatically-operated lid which permits closing off the battery should it be necessary for operating reasons or when co-generation is employed.

Because the coke ovens operate under negative pressure at all times, there is a minimum of fugitive emissions to the atmosphere. Pushing and quenching emissions are controlled with state-of-the-art equipment similar to that used in a byproduct plant.

Heating of the Jewell-Thompson oven begins with the coking chamber crown by allowing a limited amount of air to enter the chamber, thus burning some of the volatile matter driven off from the coal. The partially burned gas is directed from the crown through passages in the walls leading to the sole flue where further combustion is carried out. Heat released in the sole flue heats the charge from below by heat conduction through the refractory floor. The gases from the sole flue exit through uptake ducts leading to a common collecting tunnel atop the battery. All unburned volatile matter remaining after exiting the sole flue is burned in the common tunnel afterburner. The temperature in each oven is controlled individually by adjusting the amount of combustion air entering the oven through dampers located in the doors on each end of the oven. The aim maximum temperatures are 1370°C (2500°F) in the crown and 1480°C (2700°F) in the sole flues.

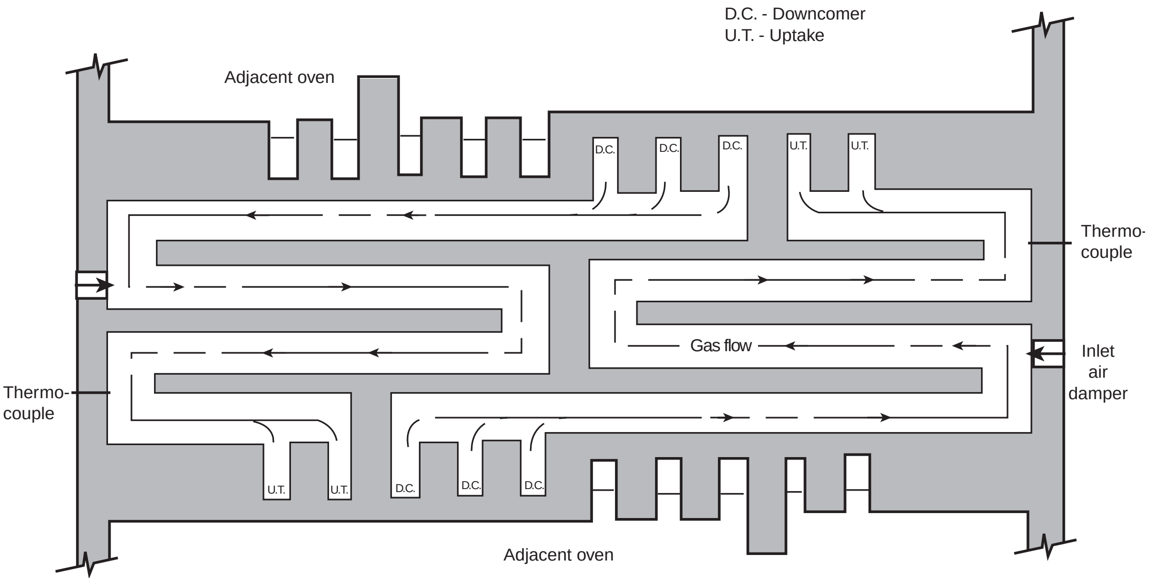


Fig. 7.119 Sole flue arrangement.

Charging is done through an open door using a conveyor-charging machine. Coal is discharged onto the oven floor by a drag conveyor which can be adjusted to accommodate various coal depths. Charging starts at the pusher side door and progresses into the oven to the coke side door.

Oven pushing and quenching is basically the same as the byproduct coke ovens except that the pushing machine is an integral part of the charging machine. When operating on a 48-hour cycle, odd numbered ovens are pushed and charged on one day and the even numbered ovens the next. Thus, there are fewer pushing and charging operations or cycles on the machine for the same production of coke.

In general, blast furnace operators require minimum 60 A.S.T.M. stability coke, particularly for the large blast furnaces. Coke produced has averaged 62 stability with a standard deviation of 0.4. The amount of a +75 mm (+3 in.) coke averages over 40% of the run-of-oven coke primarily due to the deep coal bed charge.

One of the greatest environmental concerns that affects the cokemaking industry today is the emission of hazardous chemicals. A test of emissions using a blend of high, medium and low volatile coals showed stack emissions to be below the maximum levels allowable in the U.S.

In that all of the volatile products are combusted within the system, there is a large quantity of thermal energy available which can be recovered in the form of steam used to drive electric generators. The products of combustion would be cooled sufficiently to permit sulfur dioxide and particulate scrubbers to lower the emissions to acceptable levels. Provisions have been made for the inclusion of heat recovery for steam production and power generation.

In 1998, utilizing the Jewell Technology, the Indiana Harbor Coke Company[30] commissioned the first non-recovery coke plant in North America coupled to a co-generation facility for conversion of the waster heat into electrical power. The plant consists of four 67-oven batteries designed to produce 1.21 million tonnes (1.33 million tons) of coke per year. At peak production, the co-generation facility can produce 87 MW of electricity.

7.8.3 The Single Chamber System (SCS)

The European Cokemaking Technology Center completed the work on the single chamber coking system, which was developed by Ruhrkohle AG in cooperation with the German coke oven engineering companies and Bergbau-Forshung, the coal mining research institute.

The SCS was developed recognizing coke required for the blast furnace process would have to be produced at low cost, with high quality, using a wide range of coals, with high thermal efficiency and in an environmentally benign manner.

An essential characteristic of the new coking system is the process-controlled single chamber reactor in combination with coal preheating. This means that the conventional multi-chamber system with heating walls and coking chambers arranged alternately has been converted to a single chamber system, abbreviated SCS, while maintaining the chamber principle. In terms of modular technology, the single chamber is a structurally and operationally independent component in a coke plant.

This arrangement offers a range of advantages: greatly increased static load-bearing capacity by means of side-anchoring of the heating walls; an increase of approximately 100% throughput or more, due in particular to coal preheating and productivity and as a result of this; a ≥ 50% reduction in the number of coking units; an increase in production flexibility due to individual computer control of the coking process; more flexibility in the coal basis and/or improved coke quality; a reduction in the specific energy consumption; increased freedom when determining the dimensions of the coking chamber and the heating walls; and a decrease in harmful emissions from the underfiring.

The emphasis in development work was focused on: proving the operability of the single reactor design (SCS); determining the SCS potential for improving coke quality and for a greater usage of poorly coking coal components in coal charging blends; proving high thermal efficiency in coke production; and proving the operability of all of the integrated process techniques to improve environmental performance.

7.8.3.1 Description of Test Installations

The SCS demonstration plant was erected on the RAG coke plant Prosper in Bottrop, Germany in 1992. For operational testing on the SCS, two construction alternatives with half-chamber length were evaluated.

Construction alternative I with the standardized construction principle for chamber, heating flue and regenerator arranged below, named SCS-B in Fig. 7.120, was evaluated with steel sidewalls made of 1000 mm (39.4 in.) I-supports.

Construction alternative II with neighboring regenerator, named SCS-S in Fig. 7.121, was evaluated with 1200 mm (47.2 in.) thick sidewalls made of concrete.

The most substantial characteristic data of the SCS units are: dimensions of 0.85 m (33.4 in.) width, 10.0 m (32.8 ft) height, and 10.0 m (32.8 ft) length; liner brick thickness of 60 mm (2.4 in.); zero oven chamber taper; program-controlled heating as per CODECO-process; lean gas heating (exclusively); and omission of the top anchoring.

The main components of the SCS demonstration plant included: the two SCS units; the Pre-carbon coal preheating process with a permanently connected drag chain conveyor as the charging installation; the conventional coke pusher machine; and the coke cassettes which were planned primarily as the hot coke transport system. In the experimental plant, however, these cassettes were also used for coke cooling.

A mixing station generated lean gas by mixing the coke oven gas and waste flue gas.

7.8.3.2 Plant Operation

Heating up of the reactors began in January, 1993. The reactor incorporating the classical regenerator arrangement was heated up without any problem to an initial operating temperature of 1200°C (2190°F). However, the SCS-S reactor incurred damage due to an improper side anchoring and the unit was shut down permanently. First coke was pushed in April, 1993.

During the 3.5 years of operation, phase coking times as run ranged between 36 and 24 hours, carbonizing both German and international coals. Special attention was paid to product quality and

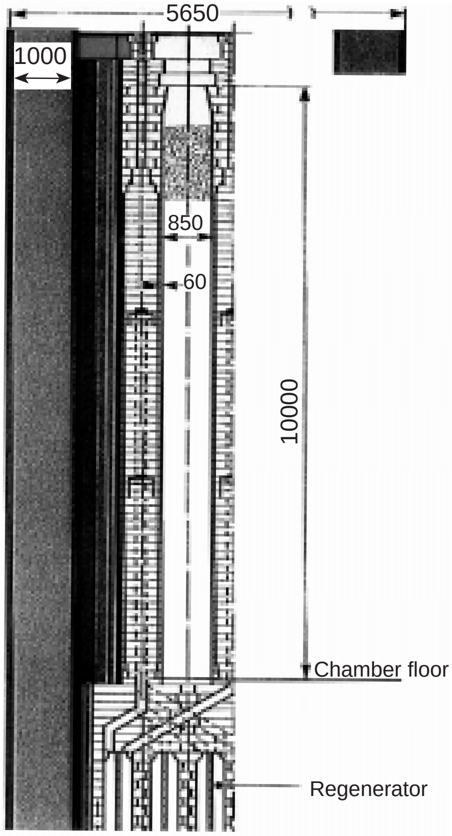


Fig. 7.120 Construction alternative I, SCS-B.

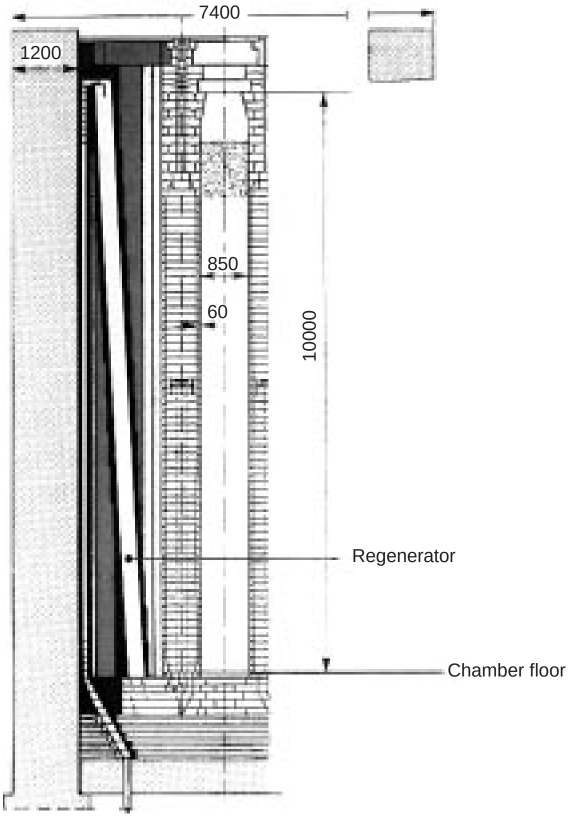


Fig. 7.121 Construction alternative II, SCS-S.

imbalanced coking pressure impacts on structural mechanics. Heat engineering investigations and measurements on environmental protection were made.

7.8.3.3 Results

The test using various charging coal blends demonstrated that significant improvements were achieved in the CSR values, providing more flexibility in the coal basis and improved blast furnace coke quality. The main causes for this are coal preheating and higher bulk density. Consequently, it is possible to achieve the required coke quality necessary for high rates of oil or coal injection into the furnace and/or to use a greater proportion of cheaper, poor coking coals in the charging coal blend.

The process of combining coal preheating with program-controlled heating reduced heat consumption for the underfiring by a total of approximately 8%, improving thermal efficiency. By incorporating coke dry quenching in addition to coal preheating, thermal efficiency can be increased from its present level of 38% to over 60%.

The coking technique of the future must offer an economical solution regarding environment protection and safety at the workplace. The single chamber system fulfills an important technological need for the environmentally friendly process of the future. First of all, there is a reduction of emission sources by the use of low-emission or emission-free components in the process. There is a reduction in coking units utilized. The charging system is a completely sealed transportation method; there is no need for leveling because of preheating of the coal charge. Coke pushing is carried out into a cassette which is coupled to the reactor chamber by a perfect sealing system. The result in total is a reduction in emissions by approximately one-half.

An economic evaluation of capital and operating costs for a large-scale plant indicates that cost savings may be realized compared to conventional cokemaking.

7.8.4 Calderon Cokemaking

Calderon Energy Company has developed an integrated, continuous cokemaking process comprised of sealed coking reactors discharging coke to a sealed quenching system and cleaning of the foul coke oven gas in a sealed hot gas cleanup (HGC). Only two raw materials are required for the process, metallurgical coal and limestone. The only products are coke, coke breeze, desulfurized syngas and elemental sulfur.

Being completely sealed, the process requires no doors, chuck doors, offtakes, lids, pushing emission control, charging emission control, quenching station, wastewater treatment plant, byproducts plant or gas blanketing. Syngas desulfurization is accomplished in the (HGC) and does not require a separate unit such as Stretford, Sulfiban or Still. No Claus or acid plant is necessary. A condenser condenses the sulfur from the tail gas leaving the HGC. The chemistry is summarized in Table 7.8 by the following reactions.

The entire system is designed to operate at elevated pressure with no gas exhausters or boosters required. Depending on the final use of the syngas, the operating pressure will be no lower than 0.97 bar (14 psig) and may be designed to operate as high as required for the consuming process. A prototype unit was designed to operate at 24 bars (350 psig) and was operated as high as 12.5 bar (180 psig).

In previous test work, Calderon produced coke with quality equal to or greater than coke produced from the same coal blend in conventional slot ovens. Based on this work Calderon has designed a modular, full-sized commercial coking reactor to demonstrate continuous cokemaking. Included in the demonstration is an HGC module designed with all the operating parameters (temperatures, pressures, flows, etc.) of a commercial plant. After demonstration, the coking reactor will be replicated and installed side-by-side in batteries. Space required for the process is less than half that of conventional ovens.

Current design data indicate that sixteen reactors are required to produce 0.9 million tonnes per year or 1.0 million tons per year at a 90% operating rate. Annual production at a 100% operating rate would be 1.0 million tonnes (1.1 million tons).

7.8.5 Antaeus Energy Cokemaking Process

Converting coal to coke involves devolatilization over a wide temperature range under controlled heating conditions. The average time to convert coal to coke varies from 18–24 hours in conventional processes. However, if the devolatilization patterns for most coals are examined, it can be seen that there are two distinct zones in the coal devolatilization process. One is at relatively low temperatures (300–600°C or 570–1110°F) and the other is at higher temperatures (800–1100°C or 1470–2010°F). These two zones are separated by a non–reactive region, as shown in Fig. 7.122. Coke quality is mostly controlled by the second phase of the devolatilization zones.

Table 7.8 Chemical Reactions in Calderon Cokemaking

Cracking	$2CxHy+1100°C \rightarrow yH_2 + 2xC$
Desulfurization	$CaO + H_2S \rightarrow CaS + 2H_2O$
Regeneration	$2\ CaS + 3O_2 \rightarrow 2CaO + 2SO_2$
	$2\ C + O_2 \rightarrow 2CO$
	$2\ CO + SO_2 \rightarrow 2CO_2 + S$
Water Gas	$H2O + C + 760°C \rightarrow H_2 + CO$

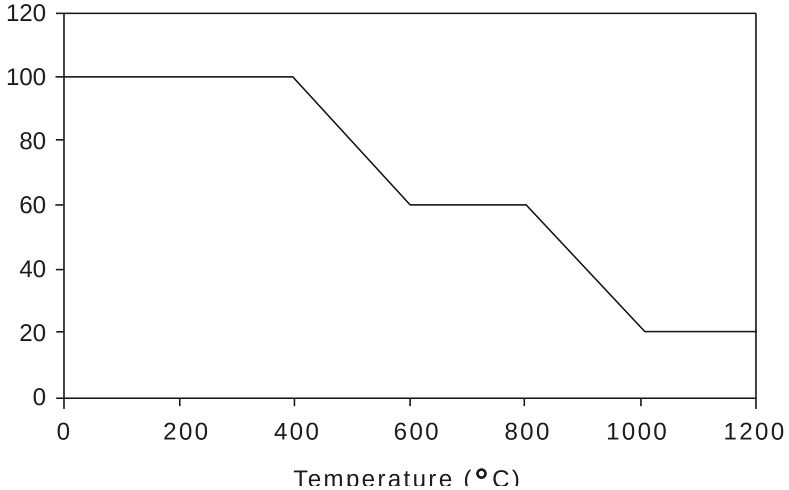


Fig. 7.122 Throughput for coal devolatization process.

Antaeus Energy has developed the Antaeus Continuous Coke^{SM} process, which uses a two-stage pyrolysis-based process to produce high quality coke for both foundries and blast furnaces. The process takes advantage of the split in the devolatilization process by minimizing the reaction residence time and managing the coke quality by adding suitable binders before the secondary pyrolysis zone. The process can produce coke in five hours. For these reasons, it is estimated that the Antaeus Continuous CokeK process operating and capital costs can be significantly reduced. In addition, a wide variety of coal feeds can be used to produce acceptable quality coke for foundry and furnace use. Moreover, the process can produce other premium carbon products made from waste materials such as spent automobile tires and coal tar. Another positive feature of the two-stage pyrolysis coke production process is that it can produce marketable byproducts. The char produced is a marketable intermediary product used in ferroalloys production.

An important feature of this two-stage cokemaking process is that it is environmentally advantageous. Not only can the process significantly reduce the air emissions problems associated with traditional cokemaking; it will actually benefit the environment by the reclamation of coal waste sites into safe and attractive properties for future use.

7.8.5.1 Overview of the Technology

A schematic of Antaeus Energy's patented Continuous Coke^{SM} process is shown in Fig. 7.123. This process can use either coal fines or coal as its feedstock. Coal-fine wastes can be recovered from tailings ponds or other waste piles and processed to remove impurities. The processed coal fines then undergo a two-stage pyrolysis process that converts them first into char and then into coke.

During the first stage of pyrolysis, the coal fines undergo carbonization in a twin-screw pyrolyzing reactor vessel, as shown in Fig. 7.124. Coal fines enter the reactor from the feed port with the help of the screw feed. During stage one, coal or coal fines are subjected to low-temperature pyrolysis in a twin-screw reactor vessel at moderate to low heating rates with a reaction residence time of less than one hour to produce the intermediate carbon product, char. The hollow screw reactor consists of two hollow screws with flights that overlap one another at the center of the reactor. The screws are enclosed within the reactor shell wall to provide the bed for the coal fine feed. The reactor is heated indirectly in the outer shell and within the hollow screws. The heating of the outer shell is divided into zones, each of which heats different areas of the reactor.

Volatile gases produced during the devolatilization process are allowed to escape from the reactor through a gas outlet pipe. In that the process is a non-recovery process, the condensable and non-condensable gases are not separated, but instead all of the volatile gases evolved are used to provide energy for the pyrolysis process.

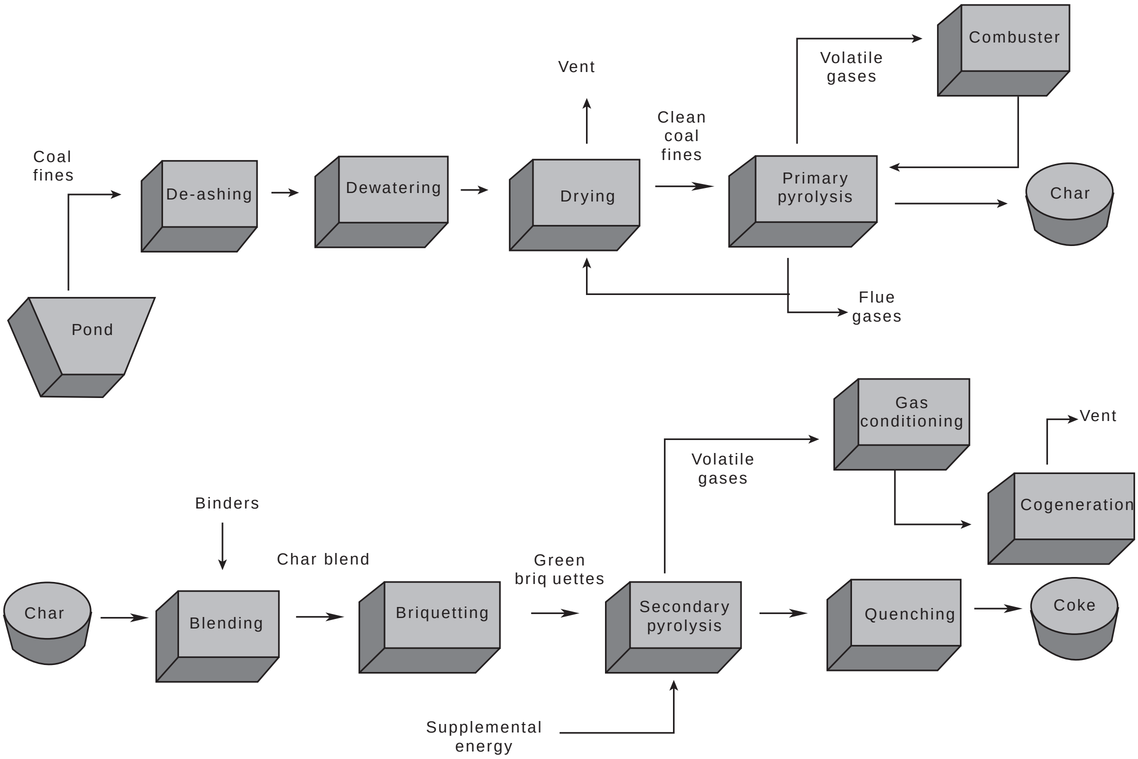


Fig. 7.123 Schematic of the Antaeus Continuous Coke^{SM} process.

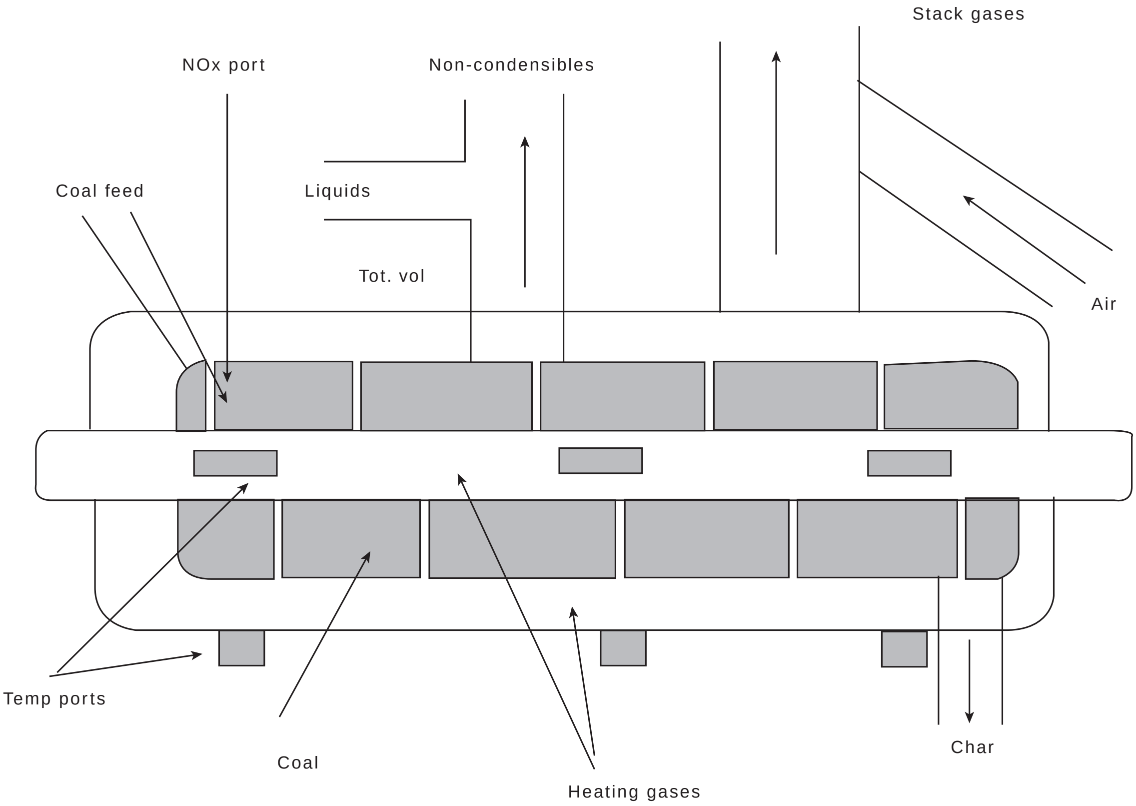


Fig. 7.124 Antaeus pyrolyzing reactor vessel.

During carbonization, the coal fines undergo thermal breakdown of their hydrocarbon bonds that attempt to escape the coal matrix. This process leads to a buildup of gas pressure, forming a pseudo-plastic regime. The result is coal swelling and liberation of hydrocarbons. The pyrolyzing reactor vessel, which is heated at atmospheric pressure, removes part of the hydrocarbons, resulting in a carbon known as char. The char undergoes particle agglomeration and subsequently exits the reactor after being cooled.

During stage two of the pyrolyzing process, the char is ground into fine particulate and blended with suitable binders under a unique formulation to produce stable green briquettes with a uniform distribution of porosity and strength. These green briquettes are pyrolized at high temperatures for calcination in a rotary kiln/tunnel furnace to produce uniformly shaped and sized, high-quality coke briquettes. The process has been optimized to reduce the residence in the high-temperature kiln to two to five hours followed by the gradual coking process. The size of the coke briquettes can be customized to meet the requirements of the coke consumer.

The volatile matter from the devolatilization process are combusted in a reducing atmosphere to provide supplemental energy sources for the coking process. The flue gases are conditioned and cleaned before being vented to the atmosphere.

The sensible heat from flue gases can be utilized to generate power through a co-generation system. It is estimated that for 500,000 tons per year of coke production, a total of 30 MW of electric power can be produced through the Antaeus process.

7.8.5.2 Scale-up of the Antaeus Energy Technology

Studies have shown that a large-scale (500,000 tons per year) Continuous Coke^{SM} process is both technically feasible and economically viable. A coal recovery plant has been built in West Virginia to recover about 0.5 million tons per year of clean, high-quality coal from tailing ponds and convert it into char as the first stage of the pyrolysis process. The second stage, converting char to coke, is expected to be implemented at another site in Pennsylvania.

7.8.6 TSOA/PACTI Non-Recovery Cokemaking[31]

In the TSOA/PACTI non-recovery oven system, two coking chambers with a gas collecting chamber in between form an oven unit, Fig. 7.125. The coking chambers have a tunnel-like shape with a rectangular floor area and a roof designed as an arch. The oven chamber is 13.7 m (45 ft) long, 4.0 m (13 ft) wide and has a height of approximately 2.4 m (8 ft) from the oven floor to the crown of the roof arch. Silica refractory is the basic material used for the ovens. Only 36 individual brick shapes are required for the entire silica brickwork structure. Similar to conventional horizontal chamber ovens, the ovens are charged from the top through charging holes. Typical coal charging levels in the oven range between 700–1000 mm (27–40 in.), corresponding to approximately 30–40 tonnes (33–48 tons) of wet coal per oven charge. As a result of the relatively large free space above the coal mass in the oven and the correspondingly low gas velocity in the range of 2–3 m/s (6.5–10 ft/s), carryover of coal fines into the sole flues during charging is avoided.

A number of vertical gas ducts (downcomers) are arranged in the side walls of the oven chamber connecting the chamber free space with the sole flues underneath the oven floor. Through these downcomers the partly combusted raw gas is transferred to the sole flues where combustion is completed. In each downcomer, a slide brick is installed to allow for adjustment during commissioning of the gas pressure distribution in a predetermined pattern between the chamber and the sole flues. The slide bricks can be adjusted from the oven top through inspection holes very similar to the conventional slot-type coke oven.

In the longitudinal direction of the chamber, the ovens are supported by a buckstay bracing system including top and bottom cross tie rods and spring plungers resembling the bracing components used for the conventional horizontal chamber oven. Rigid pinion walls are arranged to maintain the stability of the oven banks in a longitudinal direction.

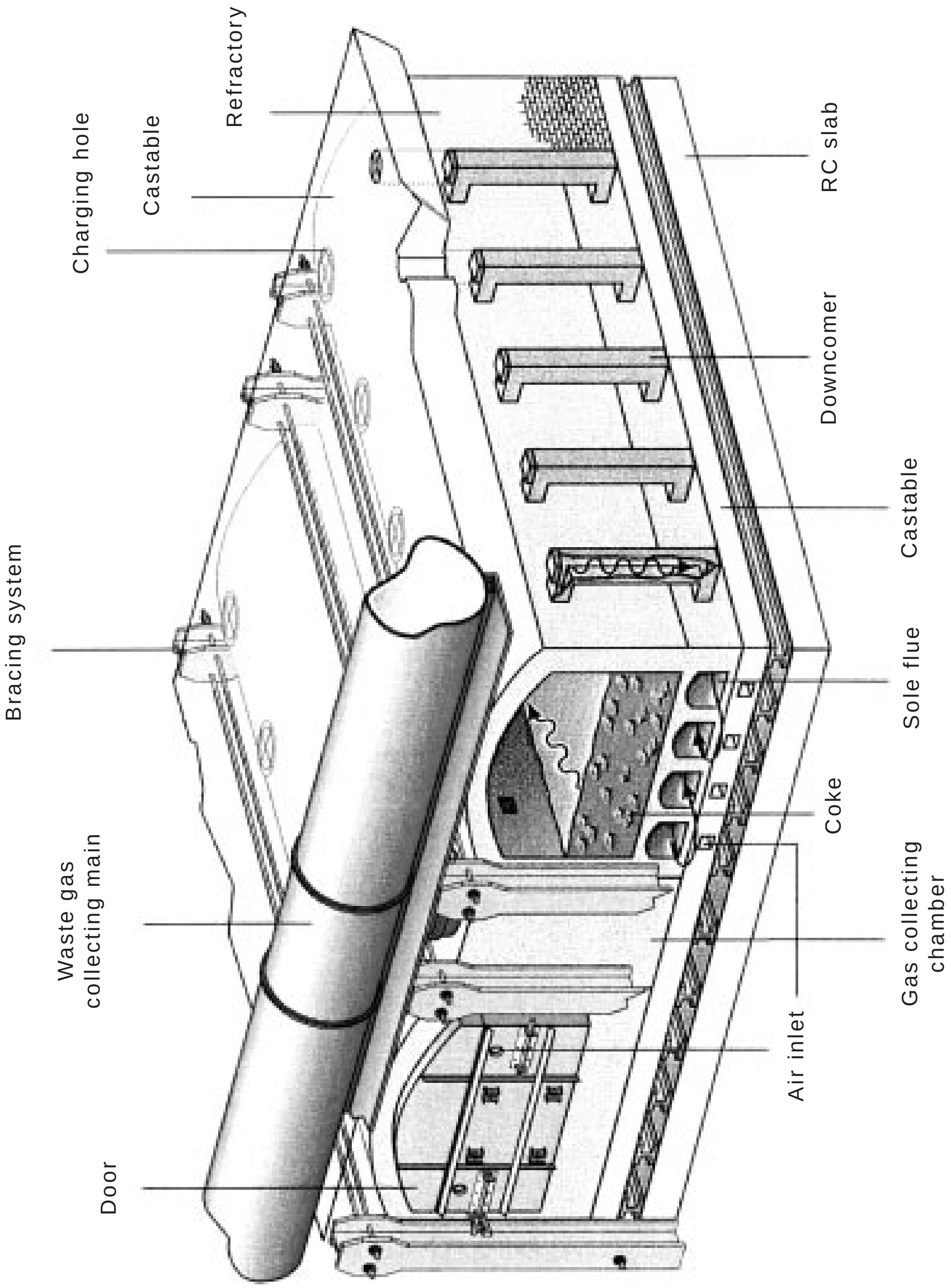


Fig. 7.125 TSOA/PACTI non-recovery cokemaking oven unit.

The oven doors are made of steel equipped with a refractory door liner. Door jambs are made of cast iron. Because the pressure in the oven chamber is negative, there is no need for technically sophisticated sealing systems.

The charge car rails are located above the oven roof, arranged such that no load is introduced into the brick crown. Charging holes with frames and lids are arranged in the roof and are located on the centerline of the chamber.

The oven substructure below the sole flues is made of refractory castable and the entire bank rests on steel beams. The free space between the I-beams running in the longitudinal direction of the chamber allows air cooling to protect the base plates and the foundation against overheating.

The non-recovery ovens are arranged in such a way that two ovens with one intermediate gas collecting chamber form a unit, Fig. 7.125. Six such units form one bank which is approximately 61 m long and 20 m wide (200 ft 3 × 85 ft).

The oven machinery needed to operate a non-recovery cokemaking plant consists of one set of each of the following: the charging car, the pusher machine, the quench car and locomotive, and the stationary coke pushing device. Charging a single oven takes approximately 90 seconds for a 44 tonne (48 ton) coal charge with a leveled coal bed height of 1000 mm (40 in.). Charging emissions will not occur because the ovens are operated under negative pressure and both the pusher side and coke side doors are closed.

In order to achieve a uniform coke quality in the wide chamber non-recovery oven, it is important to provide for a constant coal bed height. It is therefore required that the coal mass in the chamber is properly leveled after charging. Leveling through a partially opened pusher side door has been successfully demonstrated in Australia.

As soon as the coal is charged and comes into contact with the hot oven chamber and radiation heat from the oven cavity, coke oven gas begins to evolve. The raw gas produced is subsequently burned in two stages and provides the heat required for carbonization.

In the first stage, i.e. in the oven cavity above the coal mass, the raw gas burns in the presence of a sub-stoichiometric air volume at temperatures around 1200–1300°C (2200–2370°F). The heat transfer into the coal bed takes place mainly by radiation. In this way, the coal is progressively carbonized from the surface of the coal mass down towards the oven sole. The required primary air flow enters through the oven doors and is controlled with the help of manually-operated air dampers. The control variable in this case is the cavity temperature.

Combustion of the residual raw gas volume is completed in the sole flues which are arranged horizontally underneath the oven sole and connected with the oven cavity via downcomers. Combustion in the presence of excess air in the range of 6–8% of oxygen in the waste gas leads to a complete incineration of the raw gas at temperatures of 1300–1400°C (2370–2550°F).

From the front face of the ovens, the supply of air to the sole flues can be adjusted by means of slide bricks located below the sole flues. Air flow is induced and maintained by the negative pressure inside flue chambers, similar to the primary air supply. In the event that the coke plant is operated without energy recovery facilities, a suitable waste gas stack will produce the required negative pressure by natural draft.

In plants with energy recovery systems, the required additional negative pressure is created through fans located downstream of the waste heat boiler. In addition, an emergency stack will be provided to ensure the required suction in case of a power failure.

As a result of the transfer of heat from the sole flues through the oven sole, carbonization progresses from the oven sole towards the surface of the coal mass. Identical carbonization rates from the top and bottom surfaces can be achieved by appropriately adjusting the primary and secondary air flows. Uniform coking velocities from top and bottom will result in a coke seam located in the middle of the coke mass.

To accomplish as uniform heating as possible of the coal mass via the oven floor, the sole heating flues are designed in a double serpentine configuration. The raw gas-waste gas mixture from the oven cavity passes to the outer sole flues via downcomers. The required combustion air is induced to the sole flues in stages via ducts arranged below the sole flues.

With this unique heating system with nine downcomers per oven and staged combustion air supply, a uniform temperature profile is achieved, comparable to that in the proven heating system of the horizontal chamber oven.

In addition, the multi-staged heating system with air introduced at different levels leads to the formation of lower NOx levels in the waste gas. From the sole flues, the waste gas enters into the gas collecting chamber.

From the gas collecting chamber, the hot waste gas enters a collecting main supported upon the coke side buckstays. Twelve individual ovens each are connected via six collecting chambers to a single collecting main. For control reasons and due to thermal expansion of the hot collecting mains, the number of ovens connected to a single main has to be limited. Due to high waste gas temperatures, the entire collecting main up to the waste heat boiler has to be refractory lined.

The collecting mains of two banks of twelve ovens each connect into one suction main through which the hot waste gas enters the waste heat boiler. As a rule and depending on the sulfur content of the coal feedstock, a flue gas desulfurization unit is provided to meet the environmental regulations.

The coke pushing operation starts with unlatching and extracting the oven doors on the pusher and coke side. Following this, the pusher machine and the quench care are exactly spotted in front of the oven to be pushed.

The electro-mechanically driven pusher ram pushes the undisturbed coke cake into the quench box.

A most significant characteristic of the pushing operation is that the coke is not dumped, but is pushed horizontally into the quench box. The shape that the coke cake had inside the chamber is maintained. Emissions normally encountered when coke is dumped are therefore avoided.

This concept of pushing the coke cake onto a flat-bed quench car has been in practice for over 80 years in Australia. In a modern plant, the quench box is provided with a moveable cover to eliminate windblown ash. This cover slides sideways when the quench car enters the quench tower.

The coke is quenched in a tower similar to the system being used in a conventional coke oven plant. Quenching commences after the cover over the coke bed is removed. After the quenching process has been completed, the quench train moves onto a stationary coke pushing station. This station mainly comprises of two pusher rams, one for each bay of the wharf, including a common drive, that engages either ram alternately.

The quench train operator aligns the loaded quench box with the pusher ram of the stationary unit and the coke wharf. At this point, the coke is pushed out of the quench box onto the coke wharf.

Some typical characteristics of the TSOA/PACTI coke produced from blends of Queensland, Australia coals are presented in Table 7.9.

Table 7.9 Typical Characteristics of TSOA/PACTI Coke Produced from Blends of Queensland, Australia Coals

Ash	12.6%
Volatile Matter	1.4–1.5%
ASTM Stability	60–61
Hardness	60–64
CSR	60–62.6
CRI	24.6–24.7

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