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# The Making, Shaping and Treating of Steel

Edited by Harold E. McGannon

United States Steel

Ninth Edition

Table 3—XIII. Classification of Coals by Rank.[a,f]

| Class | Group | Fixed Carbon Limits, per cent (Dry, Mineral-Matter-Free Basis) | | Volatile Matter Limits, per cent (Dry, Mineral-Matter-Free Basis) | | Calorific Value Limits, Btu per pound (Moist,[b] Mineral-Matter-Free Basis) | | Agglomerating Character |
|---|---|---|---|---|---|---|---|---|
| | | Equal or Greater Than | Less Than | Greater Than | Equal or Less Than | Equal or Greater Than | Less Than | |
| I. Anthracitic | 1. Meta-anthracite | 98 | ... | ... | 2 | ... | ... | ... |
| | 2. Anthracite | 92 | 98 | 2 | 8 | ... | ... | ... |
| | 3. Semianthracite[c] | 86 | 92 | 8 | 14 | ... | ... | Nonagglomerating |
| II. Bituminous | 1. Low volatile bituminous coal | 78 | 86 | 14 | 22 | ... | ... | ... |
| | 2. Medium volatile bituminous coal | 69 | 78 | 22 | 31 | ... | ... | ... |
| | 3. High volatile *A* bituminous coal | ... | 69 | 31 | ... | 14 000[d] | ... | Commonly agglomerating[e] |
| | 4. High volatile *B* bituminous coal | ... | ... | ... | | 13 000[d] | 14 000 | |
| | 5. High volatile *C* bituminous coal | ... | ... | | | 11 500<br>10 500 | 13 000<br>11 500 | Agglomerating |
| III. Subbituminous | 1. Subbituminous *A* coal | ... | ... | ... | ... | 10 500 | 11 500 | Nonagglomerating |
| | 2. Subbituminous *B* coal | ... | ... | ... | ... | 9 500 | 10 500 | |
| | 3. Subbituminous *C* coal | ... | ... | ... | ... | 8 300 | 9 500 | |
| IV. Lignitic | 1. Lignite *A* | ... | ... | ... | ... | 6 300 | 8 300 | |
| | 2. Lignite *B* | ... | ... | ... | ... | ... | 6 300 | |

[a] This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48 per cent dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free British thermal units per pound.

[b] Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[c] If agglomerating, classify in low-volatile group of the bituminous class.

[d] Coals having 69 per cent or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[e] It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in high volatile *C* bituminous group.

[f] From ASTM Designation D-388-66 in "ASTM Standards 1968," Part 19, page 74, to which reference may be made for method of calculation to mineral-matter-free basis and other information. Reproduced by permission of the American Society for Testing and Materials. The complete specification is obtainable from the society.

The mining of coal is performed by either one of two methods: (1) **Open work** or **stripping,** also called **contour mining,** or (2) **underground** or **deep mine**. The first method involves removing the formation (over-burden) above the seam by stripping with scrapers, bull-dozers, or mechanically operated shovels, followed by removing the exposed coal. Stripping is applied to coal seams which are relatively close to the surface, particularly to thick seams underlying overburden 80 to 150 feet deep, although the development of larger equipment and improved techniques in recent years has justified removal of thicker layers of overburden than this. Auger mining is being used extensively to recover coal where the overburden is too great for strip-mining practices to be employed. A large-diameter auger or drill with cutting bits on its end is propelled into the exposed edge of a coal seam. As the auger progresses into and along the seam, the broken coal is conveyed away from the face through the tube to the outside for transport away from the auger. Production by strip mining has increased greatly since World War I due to reduced labor and material costs and a quicker return on capital investment compared to underground mining. In the United States, strip mining accounted for slightly over 25 per cent of the coal produced in 1957. In 1968, strip and auger mining combined produced 36.7 per cent of the total coal mined.

Underground mining is performed by either the **room-and-pillar** or the **longwall** method. The room-and-pillar method is in more common use in the United States, accounting for approximately 90 per cent of present underground mining. The longwall method is particularly adaptable to mining seams up to about 4¼ feet thick under conditions where the roof may be permitted to settle. It is used more extensively in the mines of the Middle West than in the East. There are a number of modifications applicable to each method. The room-and-pillar system consists essentially of working out rooms, chambers, or breasts in the coal seam from passages

**Table 3—XVI. Composition and Properties of Typical Liquid Fuels**

| Fuel | Ultimate Analysis—Fuel (%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $H_2O$ | C | H | N | O | S | Ash | Undetermined |
| Pitch-Tar (Dry) | | 90.78 | 5.35 | 1.39 | 1.65 | 0.61 | 0.22 | ... |
| Pitch-Tar (Natural Basis) | 1.33 | 89.57 | 5.28 | 1.37 | 1.63 | 0.60 | 0.22 | ... |
| Bunker "C" Fuel Oil (Dry)° | | 88.60 | 10.50 | 0.30 | 0.00 | 0.55 | 0.05 | ... |

| Fuel | Specific Gravity at 60° F. | Weight (Lbs./Gal.) | Calorific Value (Btu/Lb.) | | Dry Air Required for Combustion (Cu. Ft./Lb.) | Theoretical Flame Temp. (°F) |
|---|---|---|---|---|---|---|
| | | | Gross | Net | | |
| Pitch-Tar (Dry) | ... | | ... | ... | ... | ...... |
| Pitch-Tar (Natural Basis) | 1.199 | 9.9855 | 16,155 | 15,674 | 158.13 | 3495 |
| Bunker "C" Fuel Oil (Dry)° | 0.9529 | 7.935 | 18,890 | 17,820 | 180 | 3800 |

°Courtesy of Sun Oil Co.—(Typical Analysis).

| | |
|---|---|
| Gravity—API (60° F) | 13.0 to 16.0 |
| Flash point (closed cup) | 150° F minimum |
| Btu per gallon | 150,000 minimum |
| Sulphur (%) | 0.6 maximum |
| Viscosity at 122° F | 100 secs. Saybolt Furol |
| Water and sediment (% by vol.) | 1% maximum |

The yield of tar produced in by-product coke ovens by high-temperature distillation between 1832 and 2012° F (1000 to 1100° C) differs within very wide limits according to the kind of bituminous coal coked, and to the temperature, coking time, and design of oven employed in the process. Virgin tar as produced in the by-product ovens consists essentially of tar acids, neutral oils which are principally aromatic hydrocarbons, and a residue pitch.

The residue pitch from the distillation of tar is highly viscous or brittle. Pitch contains a substantial percentage of free carbon and some high-boiling and complex organic chemicals. The composition and properties of a typical pitch-tar mix and Bunker "C" fuel oil are shown in Table 3—XVI.

The viscosity of liquid fuels such as virgin tar, pitch-tar mixtures and topped tar decreases with temperature increase as shown in Table 3—XVII.

**Combustion of Liquid Fuels**—The combustion of liquid fuel usually is obtained by atomizing the fuel. Atomization breaks up the fuel into fine, mist-like globules, thus permitting an increased area for intimate contact between the air supplied for combustion and the fuel. The chemistry of combustion of liquid fuels is complex. The small particles of fuel either vaporize to form gaseous hydrocarbons which burn to $CO_2$ and $H_2O$ through a chain of reactions, or the fuel cracks to form carbon (soot) and hydrogen which also burn with complete combustion to $CO_2$ and $H_2O$. Both of these conditions normally occur in the combustion of liquid fuels. The first condition predominates with good atomization and proper mixing with sufficient air. A deficiency of air or poor atomization will cause smoke. For large furnaces, such as open hearths and heating furnaces, the atomizing agent is usually steam at a pressure anywhere between 60 and 125 pounds per square inch gage. The steam consumed in atomization varies from 0.3 to 0.7 pounds per pound of fuel. When liquid fuels are used in smaller furnaces, atomization usually is procured by compressed air or by mechanical action. The character of a liquid-fuel flame, that is, its shape, size and luminosity, may be altered with a fixed burner design by changing the degree of atomization which is controlled by the steam pressure. Liquid fuels normally are burned in steel plants to produce a highly luminous flame at an intensity of flame propagation intermediate between that generally secured with coke-oven gas and that with natural gas.

Liquid fuels usually are preferred above all other fuels for use in open-hearth furnaces because they permit better control of flame direction and, because of their high calorific value, control of flame temperature and luminosity.

The amount of air required to burn liquid fuels de-

**Table 3—XVII. Effect of Temperature on Viscosity of Various Tars and Tar Mixtures.**

| Fuel | Test Temp. (°F) | Viscosity in Sec., Saybolt Universal |
|---|---|---|
| Virgin Tar | 175 | 189.4 max.<br>73.3 min.<br>109.4 avg. |
| Pitch-Tar Mix | 175 | 1940 max.<br>181 min.<br>946.1 avg. |
| Pitch-Tar Mix | 210 | 687 max.<br>97 min.<br>561.7 avg. |
| Topped Tar | 200 | 700 max.<br>550 min.<br>600 avg. |

that the burning of blast-furnace gas was not successful until 1857. It is probable that progress in the utilization of blast-furnace gas was delayed by its dust content, the problems of cleaning and handling, and the low cost of solid fuel. Increasing cost of other fuels and competition forced its use, and by the turn of this century, blast-furnace gas had become one of the major fuels of the iron and steel industry. In 1968, the steel industry used 4,454 billion cu. ft. of blast-furnace gas (based on 95 Btu per cu. ft.) for blast-furnace stove heating and other uses including the firing of melting, heating and annealing furnaces and coke-oven underfiring; this quantity of blast-furnace gas represents 15.7 million tons of coal equivalent.

The initial use of by-product **coke-oven gas** in the iron and steel industry was at the Cambria Steel Company, Johnstown, Pa., in 1894. This installation was followed by only a few by-product coke-plant additions until shortage of transportation facilities and the rising price of coal and natural gas during the first World War accelerated installations throughout the steel industry. The utilization of coke-oven gas has been very profitable as it reduced the purchase of outside fuels. It is estimated that plants operating steelmaking furnaces used 881,074 million cubic feet of coke-oven gas as fuel in 1968 (based on 500 Btu per cu. ft.).

## NATURAL GAS

Natural gas and petroleum are related closely to each other in their chemical composition and in geographical distribution. Both are made up predominantly of hydrocarbons. Petroleum rarely is free of natural gas, and the same fields usually produce both fuels. When natural gas exists indigenous to an oil stratum and its production is incidental to that of oil, it is called **casinghead gas.** Gas found in a field is usually under pressure which diminishes with extended use or, sometimes, from the presence of too many other wells. The life of a well varies from a few months to twenty years. Rocks bearing gas are sandstones, limestones, conglomerates, and shales—never igneous rocks. Natural gas is derived from the remains of marine animal and plant life—in theory, the same as described previously for petroleum.

Natural gas as found is usually of singular purity and is composed principally of the lower gaseous hydrocarbons of the paraffin series, methane and ethane, some of the heavier liquefiable hydrocarbons (which are recovered as **casinghead gasoline** or sold in bottled form as butane, propane, pentane, etc.) and a small amount of nitrogen or carbon dioxide. Some natural gases contain small quantities of helium. Occasionally, wells are found in which the gas contains hydrogen sulphide and organic sulphur vapors. **Sour gas** is defined as a natural gas which contains in excess of 1½ grains of hydrogen sulphide or 30 grains of total sulphur per 100 cu. ft. It is fortunate, however, that by far the greater part of natural gas available in this country is practically sulphur-free.

There are a number of great gas fields in the United States and Canada. Major fields, based on remaining reserves, are: Panhandle-Hugoton in Kansas, Oklahoma and Texas; San Juan in New Mexico and Colorado; Puckett and Chocolate Bayou in West Texas; Katy and Old Ocean on the Texas Coast; Jalmat-Eumont in New Mexico; Big Piney in Wyoming; and Peace River in British Columbia. Gas from the extensive Texas oil fields, which previously had been allowed to escape on account of lack of pipe lines to carry the excess to more distant consuming centers, now is being utilized.

The principal constituent of natural gas is methane, $CH_4$. Since natural gas contains from 60 to 100 per cent of $CH_4$ by volume, the characteristics of methane gas, which were shown in Section 1, largely dominate the parent gas. Comparing methane with the other principal combustible gases, it will be noted that it has a low rate of flame propagation, a high ignition temperature, and a narrow explosive range. Methane, as well as all other hydrocarbons (of which it is the lowest member), burns with a luminous flame. Typical compositions of natural gas are presented in Table 3—XVIII.

The iron and steel industry consumed a total of 586,850 million cubic feet of natural gas in 1968 in blast furnaces and other uses in the blast-furnace area, steel-melting furnaces, heating and annealing furnaces, heating ovens for wire rods, and other uses; heating and annealing furnaces consumed 51 per cent of the total gas used.

### Table 3—XVIII. Typical Composition of Natural Gas in Various Districts (Based on American Gas Association Survey, Fall of 1962).**

| Constituents (Per Cent by Volume) | Districts | | | |
|---|---|---|---|---|
| | Birmingham | Pittsburgh | Los Angeles | Kansas City |
| Carbon Dioxide | 1.06 | 0.80 | 0.50 | 0.22 |
| Oxygen | | 0.01 | ...... | ...... |
| Nitrogen | 2.14 | 0.40 | 2.60 | 17.10 |
| Butanes and Higher Hydrocarbons | 0.49 | 0.39 | 0.50 | 0.56 |
| Propane | 0.67 | 0.74 | 1.90 | 2.91 |
| Methane | 93.14 | 94.03 | 86.50 | 72.79 |
| Ethane | 2.50 | 3.58 | 8.00 | 6.42 |
| Specific Gravity | 0.599 | 0.595 | 0.638 | 0.695 |
| Gross Heating Value Btu per Cu. Ft.* | 1024 | 1051 | 1084 | 945 |

* At 30 in. Hg, 60 °F, dry.

** Source: "Gas Engineers Handbook" (see Segeler listing at end of chapter). Additional information is available in "Analyses of Natural Gas, 1966" by B. J. Moore and R. D. Shrewsbury in U. S. Bureau of Mines Information Circular 8356 (1967).

which were used in heating and annealing furnaces. A steel cylinder of propane as sold for domestic purposes contains approximately 21,640 Btu per pound of liquid gas.

**Special Gas Processes**—Studies and investigations in the art of gasification of solid fuels have been under way for many years. In addition to the processes already discussed, other methods have been developed that cannot be described here. Reference can be made to the following sources for information on these latter processes: the contribution by C. G. von Fredersdorff and M. A. Elliott entitled "Coal Gasification" in "Chemistry of Coal Utilization (Supplementary Volume)" edited by H. H. Lowry and published by John Wiley and Sons, New York (1963); and the article by C. G. von Fredersdorff and F. E. Vandaveer on "Substitute Natural Gas from Coal" in the "Gas Engineers Handbook" edited by C. George Segeler (see bibliography at end of chapter).

## BY-PRODUCT GASEOUS FUELS

The two major by-product gaseous fuels are blast-furnace and coke-oven gases. A number of other unavoidable gaseous fuels are created by regular manufacturing processes. Some of these are of minor economic consequence, but the majority are useful and generally utilized at the plant where they are produced. An exception is oil-refinery gas which is sometimes piped and marketed to industries adjacent to refineries. The calorific value and flame characteristics of by-product gases have wide ranges. Blast-furnace gas has probably the lowest heat content of any, and oil refinery gas the highest, respectively 90 and 1850 Btu per cubic foot, although both vary from these values.

**Blast-furnace gas** is a by-product of the iron blast furnace. The paramount objective in blast-furnace operation is to produce iron of a specified quality, economically; the fact that usable gas issues from the top of the furnace is merely a fortunate attendant circumstance. When air enters the tuyeres (see Chapter 15 on "The Manufacture of Pig Iron") its oxygen reacts with the coke. The resulting gas passes up through the shaft of the furnace which has been charged with coke, ore, and limestone, and after a number of chemical reactions and a travel of some 80 feet, issues as a heated, dust-laden, lean, combustible gas. The annual volume production of this gas is greater than that of any other gaseous fuel. Two and one-half to three and one-half tons of blast-furnace gas are generated per ton of pig iron produced. While the purpose of the gases generated by the partial combustion of carbon is to reduce iron ore, the value of a blast furnace as a gas producer is evident from the relation just noted. The essential reactions by which blast-furnace gas is produced are shown in Chapter 15.

The percentage of CO and $CO_2$ in blast-furnace gas is directly related to the amount of carbon in the coke and the amount of $CO_2$ in the limestone charged per ton of iron produced. The rate of carbon consumption depends principally upon the kind of iron to be made, the physical and chemical characteristics of the charged material, the distribution of the material in the furnace stack, the furnace lines, and the temperature of the hot blast. The total $CO + CO_2$ content of the top gas is about 40 per cent by volume, and when producing ordinary grades of iron the ratio of CO to $CO_2$ will vary from 1.7 to 2.5, to 1. The hydrogen content of the gas varies from 3 to 4 per cent. The remaining percentage is made up of nitrogen, except for about 0.2 per cent $CH_4$. The efficiency of the blast furnace as a gas producer on a cold basis is a little less than 70 per cent; on a hot basis, about 90 per cent.

Blast furnace gas leaves the furnace at a temperature of 250° to 700° F, and at a pressure of 15 to 60 inches w.g., carrying with it 10 to 50 grains of water vapor and 8 to 15 grains of dust per cubic foot. The particles of dust vary from $\frac{1}{4}$ to 0.00001 inch in diameter. In early days of blast furnace operation, the gas was used as it came from the furnace without cleaning, causing a great deal of trouble with flues, combustion chambers, and stoves due to clogging. The gas now is cleaned almost universally, the degree depending upon the use.

The outstanding characteristics of blast-furnace gas as a fuel are: (1) very low calorific value—75 to 90 Btu depending on blast-furnace coke rate, (2) low theoretical flame temperature—approximately 2650° F, (3) low rate of flame propagation—relatively lower than any other common gaseous fuel, (4) high specific gravity—highest of all common gaseous fuels, and (5) burns with a non-luminous flame.

**Coke-Oven Gas**—The steel industry, which uses nearly 90 per cent of the total coke-oven gas generated in the United States, generally classifies coke-oven gas as a by-product of coke manufacture. This undoubtedly is due to the former waste of coke-oven gas and other coal products for so many years in the beehive-coke process. Actually, the production of coke-oven gas and other coal chemicals is a part of an important manufacturing process in which large sums have been expended for their recovery, as they have a value almost equal to that of the coke. Coke-oven gas is produced during the carbonization or destructive distillation of bituminous coal in the absence of air, as described in Chapter 4. Approximately 11,000 cu. ft. of 535-Btu coke-oven gas are produced per ton of coal coked in conventional high-temperature coking processes.

The composition of coke-oven gas varies in accordance with grade and density of coal and operating practices. Typical ranges for the constituents of dry coke-oven gas by volume are as follows:

| | |
|---|---|
| $CO_2$° | 1.3 - 2.4 |
| $O_2$ | 0.2 - 0.9 |
| $N_2$ | 2.0 - 9.6 |
| CO | 4.5 - 6.9 |
| $H_2$ | 46.5 -57.9 |
| $CH_4$ | 26.7 -32.1 |
| Illuminants | 3.1 - 4.0 |
| Specific Gravity | 0.36-0.44 |
| Heating Value, Btu per cu. ft. (gross) | 537-580 |
| Heating Value, Btu per cu. ft. (net) | 480-523 |

°Includes $H_2S$

Coke-oven gas contains hydrogen sulphide, $H_2S$. About 40 per cent of the sulphur in coal, not removed in the washing process, is evolved with the distillation products. Much of this remains in the gas. Carbonization of coals containing 1.20 per cent sulphur evolves a gas containing about 424 grains of sulphur per 100 cu. ft., and those containing 1.60 per cent sulphur about 600 grains per 100 cu. ft. Commercial coals in the eastern part of the United States usually run from 0.5 to 1.5 per cent sulphur. Gases high in sulphur content are very undesirable for metallurgical purposes.

Coke-oven gas normally is saturated with water vapor. In distribution systems, means must be provided for draining off the condensation due to any temperature change.

Coke-oven gas burns with a non-luminous to semi-luminous flame, depending upon the degree of mixing air and gas. Its rate of flame propagation is high—considerably higher than natural, producer, or blast-furnace gas. It has a low specific gravity—lowest of any of the gaseous fuels commonly utilized by the steel industry. It has a high theoretical flame temperature—about 3600° F, a little higher than that of natural gas. The explosive range is about twice that of natural gas.

Based upon a heating value of 500 Btu per cu. ft., the steel industry used 881,074 millions of cubic feet of coke-oven gas in 1968, of this total, 40.8 per cent was used in heating and annealing furnaces, 26.3 per cent in coke-oven underfiring, 10.4 per cent in steel-melting furnaces, blast furnaces, other uses in the blast-furnace area and in heating ovens for wire rods, and the remainder (22.5 per cent) in all other uses, according to 1968 Annual Statistics of the American Iron and Steel Institute.

## USES FOR VARIOUS GASEOUS FUELS IN THE STEEL INDUSTRY

Gaseous fuels are ideal for many steel-plant applications. Below are the more important applications where gaseous fuels either must be used on account of the nature of the work or facility, or where they are preferred over liquid or solid fuel:

Coke-Oven Heating
Blast-Furnace Stoves
Gas Turbines for Power Generation
Gas Engines for Blowing or Power Generation
Soaking Pits
Reheating Furnaces
Forge and Blacksmith Furnaces
Normalizing and Annealing Furnaces
Controlled-Cooling Pits
Foundry Core Ovens
Blast Furnace and Steel Ladle Drying
Drying of Blast-Furnace Runners and
  Open-Hearth Tapping Spouts
Hot-Top Drying

The choice of the most desirable fuel for each of the many facilities in a steel plant is not always possible, but by judicious planning the most efficient fuel or combination can be selected from those available. The general characteristics of each gas govern, wherever possible, its selection for a specific purpose in a steel plant. An outline of the important applications of the major gaseous fuels follows.

**Uses for Blast-Furnace Gas**—For many years, the use of blast-furnace gas for purposes other than for the firing of stoves and boilers was not economical. A number of factors have contributed, however, to the enlarged use of blast-furnace gas, the more important of which are: (1) rising cost of purchased fuel; (2) technical progress in gas cleaning, in the use of regeneration and recuperation, and in the mixing of gaseous fuels; (3) the economic advantage of using pulverized coal in boiler houses to substitute for blast-furnace gas, thereby permitting its substitution elsewhere for the more expensive liquid and gaseous fuels; and (4) seasonal shortages in the availability of purchased liquid and gaseous fuels.

In certain applications, in addition to preheating the air, the gas itself may be preheated to provide higher temperature potential. For the facilities listed below, blast-furnace gas may be utilized successfully without preheat:

Blast Furnace Stoves
Soaking Pits
Normalizing and Annealing Furnaces
Foundry Core Ovens
Gas Engines for Blowing or Power Generation
Gas Turbines for Power Generation
Boilers

The thermal advantage of using blast-furnace gas in gas engines for blowing and for electric-power generation must overcome the heavy investment and maintenance expense of this equipment. The modern boiler house utilizing high steam pressure and temperature with efficient turboblowers and generators has sufficiently reduced the thermal advantage of gas engines so that their use is difficult to justify. A relatively recent successful development has been the use of direct-connected gas turbines for driving generators, and jet engines for driving compressors.

Preheated blast-furnace gas burned with preheated air has been used successfully in the following:

Coke-Oven Heating
Soaking Pits
Reheating Furnaces

When blast-furnace gas is preheated, it should have a minimum cleanliness of 0.01 grains per cu. ft.; and in all cases where this gas is used, extra precautions must be taken to prevent the escape of fuel or unburned gas into attendable surroundings since it contains a large percentage of toxic CO gas. Blast-furnace gas is used for many applications in the steel plant and, in addition, is used frequently for heating coke ovens and sometimes is mixed with other gases as an open-hearth fuel.

**Use of Coke-Oven Gas**—Coke-oven gas has had a more extended use than blast-furnace gas because of: (1) relatively low distribution costs due to its low specific gravity, high calorific value, and cleanliness; (2) its ability to develop extremely high temperatures by combustion; and (3) the high rate at which it can release heat, thereby eliminating excessively large combustion chambers. Important applications for coke-oven gas include open-hearth furnaces in addition to those previously listed for gaseous fuels. The low specific gravity of coke-oven gas is a disadvantage in the open hearth, and for this reason, it is supplemented wherever possible with a driven liquid fuel in this service. In addition, the sulphur (in the form of $H_2S$) present in raw (not desulphurized) coke-oven gas is a distinct disadvantage, particularly when used in making low-sulphur heats in the open hearth and in heating certain grades of alloy steel for rolling. Its presence also requires the use of materials resistant to sulphur attack in pipe lines, valves, and burners.

There are a number of fuel applications in a steel plant where neither blast-furnace gas nor coke-oven gas, when

## Table 3—XX. Properties of Typical Gaseous Fuels (60° F, 30 in. Hg, dry)(1)

| Fuel Gas | Constituents of Fuel Gas Per Cent by Volume (Dry Basis) | | | | | | | | | Specific Gravity | Cu. Ft. of Air Required for Combustion of Cu. Ft. of Gas | Heating Value Btu per Cu. Ft. of Gas | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $CO_2$ | $O_2$ | $N_2$ | CO | $H_2$ | $CH_4$ | $C_2H_6$ | Illuminants | | | | Gross | Net |
| | | | | | | | | $C_2H_4$ | $C_6H_6$ | | | | |
| Natural Gas (Pittsburgh) | .... | ... | 0.8 | | ... | 83.4 | 15.8 | | ... | 0.61 | 10.58 | 1129 | 1021 |
| Reformed Natural Gas | 1.4 | 0.2 | 2.9 | 9.7 | 46.6 | 37.1 | .... | 1.3 | $C_3H_6$<br>0.8 | 0.41 | 5.22 | 599 | 536 |
| Coke-Oven Gas | 2.2 | 0.8 | 8.1 | 6.3 | 46.5 | 32.1 | .... | 3.5 | 0.5 | 0.44 | 4.99 | 574 | 514 |
| Water Gas (Coke) | 5.4 | 0.7 | 8.3 | 37.0 | 47.3 | 1.3 | .... | .. | ... | 0.57 | 2.10 | 287 | 262 |
| Carburetted Water Gas | 3.0 | 0.5 | 2.9 | 34.0 | 40.5 | 10.2 | .... | 6.1 | 2.8 | 0.63 | 4.60 | 550 | 508 |
| Oil Gas (Pacific Coast) | 4.7 | 0.3 | 3.6 | 12.7 | 48.6 | 26.3 | ... | 2.7 | 1.1 | 0.47 | 4.73 | 551 | 496 |
| Producer Gas (Bituminous Coal) | 4.5 | 0.6 | 50.9 | 27.0 | 14.0 | 3.0 | ... | .. | ... | 0.86 | 1.23 | 163 | 153 |
| Blast Furnace Gas | 11.5 | ... | 60.0 | 27.5 | 1.0 | .... | .... | . | . | 1.02 | 0.68 | 92 | 92 |
| Butane (Commercial) | .... | ... | .. | $(C_4H_{10} = 93.0)$ $(C_3H_8 = 7.0)$ | | | | | | 1.95 | 30.47 | 3225 | 2977 |
| Propane (Commercial) | .... | ... | .. | $(C_3H_8 = 100.0)$ | | | | | ... | 1.52 | 23.82 | 2572 | 2371 |

## Table 3—XX. (Continued)

| Fuel Gas | Products of Combustion in Cu. Ft. per Cu. Ft. of Fuel | | | | Ultimate % $CO_2$ | Net Btu per Cu. Ft. of Products of Combustion | Theor. Flame Temp. No Excess Air °F |
|---|---|---|---|---|---|---|---|
| | $H_2O$ | $CO_2$ | $N_2$ | Total | | | |
| Natural Gas (Pittsburgh) | 2.22 | 1.15 | 8.37 | 11.73 | 12.1 | 87.0 | 3562 |
| Reformed Natural Gas | 1.30 | 0.53 | 4.16 | 5.99 | 11.3 | 89.6 | 3615 |
| Coke-Oven Gas | 1.25 | 0.51 | 4.02 | 5.78 | 11.2 | 87.0 | 3610 |
| Water Gas (Coke) | 0.53 | 0.44 | 1.74 | 2.71 | 20.1 | 96.6 | 3670 |
| Carburetted Water Gas | 0.87 | 0.76 | 3.66 | 5.29 | 17.2 | 96.2 | 3700 |
| Oil Gas (Pacific Coast) | 1.15 | 0.56 | 3.77 | 5.48 | 12.9 | 90.5 | 3630 |
| Producer Gas (Bituminous Coal) | 0.23 | 0.35 | 1.48 | 2.06 | 18.9 | 74.6 | 3175 |
| Blast Furnace Gas | 0.02 | 0.39 | 1.11 | 1.54 | 25.5 | 59.5 | 2650 |
| Butane (Commercial) | 4.93 | 3.93 | 24.07 | 32.93 | 14.0 | 90.5 | 3640 |
| Propane (Commercial) | 4.0 | 3.0 | 18.82 | 25.82 | 13.75 | 91.2 | 3573 |

(1) From: "Combustion," American Gas Association (Third Edition); "Gaseous Fuels," American Gas Association (1948); and "Gas Engineers Handbook" (see bibliography at end of chapter).

# The Making, Shaping and Treating of Steel

Edited by Harold E. McGannon

USS United States Steel

Ninth Edition

the dust is more easily and economically handled in the dry state as it comes from the dustcatcher. The dustcatcher is from 35 to 40 feet in diameter, usually lined with brick to prevent cooling and the attendant precipitation of water from the gas. It is a cylindrical structure fitted with a 60-degree inverted cone on the bottom and a cone-shaped top.

The single downcomer from the top of the furnace carries the gas to the top of the dustcatcher, where it enters a vertical pipe that is centrally located inside the dustcatcher and extends nearly to the bottom. This vertical pipe flares outward about 8 degrees and is thus larger in diameter at the bottom than at the top. As the gas passes downward through this pipe, its velocity (and therefore its ability to carry dust) is lowered, causing some of the dust to drop out of the gas stream and be deposited at the bottom of the dustcatcher. When the gas emerges from this pipe, it must change direction of flow suddenly and rise to the top of the dustcatcher, since the gas is removed from a convenient location at the top. The sudden change in flow direction causes more dust to be dropped from the gas stream. Efficiency of the dustcatcher is approximately 60 to 75 per cent, depending upon the type of ores used and the blast volume. The accumulating dust usually is removed from the dustcatcher by a double-shaft pug mill which is rigidly fastened to the cone bottom. Water is added to the pug mill until the dust is slightly mositened, which prevents the dust from blowing around the vicinity as it drops into a railroad car. An auxiliary hand-operated gate also is provided which permits dust to be removed in case the pug mill is down for repairs. The exit gas passes from the dustcatcher into the bottom of the primary washer.

**Gas-Cleaning Plants**—Neglecting the larger lumps blown out occasionally when the furnace "slips," the dust particles in blast-furnace gas vary in size from ¼ inch to a few microns (1 micron = 0.00003937 inch) with practically all of the dust passing the dustcatcher being minus No. 20-mesh sieve size. The difficulty of cleaning increases as the particle size decreases, the removal of the very fine particles being comparable to the removal of smoke from air. On this account, plants generally are planned to clean the gas in two stages, a **primary stage** to remove the coarser particles, which form the larger proportion of the dust, and a **secondary** or **final stage** to remove as much of the remaining dust as possible. The approximate removal of incoming dust by the usual gas-cleaning system is 60 to 75 per cent in the dustcatcher, 90 to 95 per cent of the remainder in the primary cleaning unit, and 90 to 95 per cent of the dust still in the gas leaving the primary unit is eliminated in the secondary cleaner. The gas entering the dustcatcher contains from 7 to 30 grains per cubic foot, an average dust content being about 16 grains per cubic foot. In some cases, a centrifugal cleaner is installed between the dustcatcher and the primary cleaning unit.

Either of two methods is used to clean the gas after it has passed through the dustcatcher, wet cleaning or dry cleaning. In **wet cleaning**, the aim is to wet the dust particles and wash them out of the gas with water. Incidentally, the gas is cooled to about the temperature of the wash water, and any moisture in excess of saturation at this temperature is precipitated. In **dry cleaning**, one of the aims is to remove the dust without cooling, thus conserving the sensible heat. In many cases, the temperature of the gas leaving the furnace is under 300° F (150° C) as contrasted with 500° to 600° F (260 to 315° C) in former practice. The elimination of the water, which exists in the gas as superheated steam, and which is reduced to its dew point concentration at the cleaning-water temperature, more than balances the loss in sensible heat in wet cleaning. For these reasons, dry cleaning presently is not used to any great extent.

**Primary wet cleaners** include venturi washers, stationary spray towers, revolving spray towers, Feld washers as described later, baffle towers, spray fans and water separators. The venturi washer and the stationary-spray tower are most used, although many Feld washers remain in use, and sometimes a washer consists of a combination of one or two Feld washer revolving cones in the bottom, above which are several banks of stationary sprays. In almost all cases, a water separator is an integral part of the washer.

The **venturi washer** is a vertical-type unit that is installed adjacent to the dustcatcher (see Figure **15**—2). Gas from the main enters the top of the unit and passes downward (see Figure **15**—15). As the gas passes through the narrow "throat" of the unit, it is sprayed with water. There are two sets of water sprays, one operating at low pressure and entering the unit at right angles to the gas flow, and the other operating at high pressure and directed upward at an angle of 110° to the gas flow. The washer is lined with a suitable abrasion-resistant material to withstand the erosive effect of dust-laden gas. The

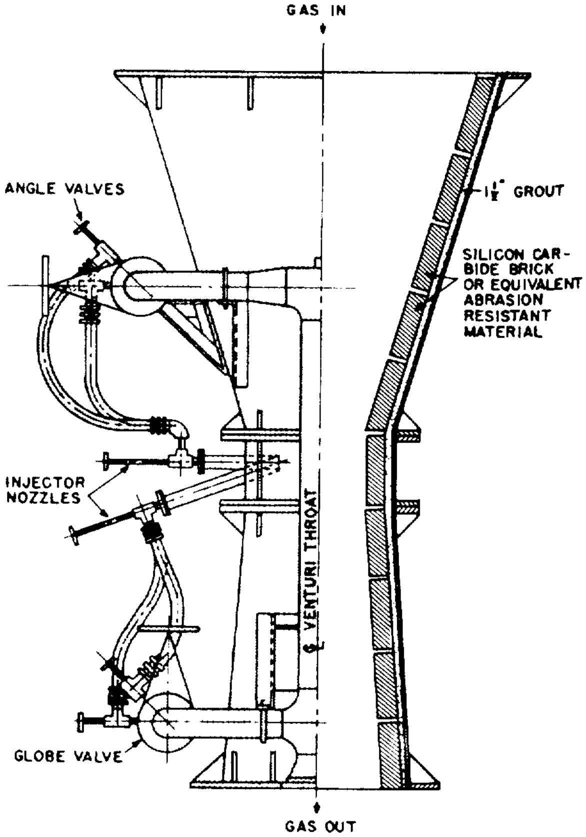

FIG. **15**—15. Schematic arrangement of a venturi-type unit for washing blast-furnace gas, right side cut away to show lining.

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venturi-type washer can clean gas to an average dust content of 0.05 grain per cu. ft.

The gas passes from the venturi washer into a water separator directly beneath it, and thence to a cooling tower where its temperature is lowered by passing through water sprays. The cooled gas then passes through a moisture eliminator before going to the secondary cleaning system.

The **stationary-spray tower** consists of a supported steel cylinder with conical bottom and conical top with the gas entering at a point near the bottom of the cylinder and leaving through a centrally located outlet on top of the top cone. Inside the cylinder are three or four banks of ceramic tile (with about 5-inch diameter round holes in them) which split up the rising gas and tend to prevent channeling. Above each bank are water sprays which uniformly cover the cross section of the washer with a falling "rain." A U-shaped seal pipe at the outlet of the bottom cone carries the dirty water away to a Dorr thickener or settling basin and prevents the gas from blowing to the atmosphere. A centrifugal-type water separator above the topmost bank eliminates any entrained water in the outgoing gas.

The **Feld washer** is a cylindrical shell with a flat bottom and a conical top in which there is a series of from 5 to 7 inverted frustums of cones which rotate on the same centrally-located vertical shaft, driven by a motor and reduction gear on top of the washer. The lower edge of each cone is immersed in a separate water tray. The centrifugal action of the rotating cones picks up water from each tray and throws it outward toward the shell as a spray through which the rising gas must pass. Baffles guide the water back into the trays for reuse, excess water spilling into the next tray below. A water separator similar to that on the stationary-spray tower is located above the topmost rotating cone.

**Primary dry cleaners** include various modifications of cyclone separators, centrifugal machines, metallic-wool-pad filters, and electrical or Cottrell precipitators. The dry-type Cottrell precipitator may also be classed as a secondary dry cleaner and will be discussed under that heading. The cyclone and centrifugal types present the problems of excessive wear and difficulty in handling the fine dust removed. The filters have a tendency to clog shortly after being placed in operation.

**Secondary wet cleaners** have consisted of wet-type Cottrell precipitators, high-speed distintegrators, and Theissen disintegrators. Formerly, Theissen disintegrators were used almost exclusively, but on later installations have been replaced by high-speed disintegrators or by the wet-type Cottrell precipitators, with preference being given to the latter type. The **Theissen disintegrator** is a type of fan that dashes water, introduced through small jets, into a spray which is forced to travel in one direction while the gas is forced through the same channels in an opposite direction.

The **high-speed** or **rotary disintegrator** is a smaller diameter machine than the Theissen but rotates faster (500 to 700 rpm) and consists of a casing in which is mounted a rotating "squirrel cage." This cage is made up of two heads fastened to the shaft with a series of bars parallel to the axis fastened to the heads. Vanes mounted on the heads reduce the pressure-drop through the machine and force the incoming gas through the rotating bars, upon which water is sprayed, to the center of the cage where it is taken off to the clean-gas main. These machines are built up to 40,000 cu. ft. per min. rated capacity, require from 400 to 500 horsepower to drive them, and will clean the gas to under 0.02 grains per cubic foot.

In the **Cottrell wet method** of cleaning, the primary-cleaned gas is forced to pass through narrow channels or ducts across which an electrostatic field is maintained. The dust particles are "precipitated" or separated from the gas through the action of electrostatic charges. The molecules of gas are ionized and, in turn, induce electrostatic charges upon the surfaces of the small dust particles. Under these conditions, the dust particles are attracted toward the electrode of opposite polarity. There is also an "electrical wind" or corona effect. Current is supplied from an alternating-current source, stepped up in voltage by a transformer, and made unidirectional by a mechanical rectifier or by vacuum tubes. In most precipitators cleaning cool gases, the unit collecting electrode is a vertical tube, 8 to 12 inches in diameter, or it may be of parallel steel plates through which the gas is forced upward, or sideways. In the former type the discharge electrode is a wire suspended coincident with the long axis of the tube and, in the latter, multiple wires midway between the plates. A thin film of water flows over the inside edge of each tube or plate which washes it free of dust that has been deposited thereon, the dirty water being conducted to a Dorr thickener or settling basin. The precipitator usually is divided into two units with valving so arranged that one unit may be shut down for inspection or repairs while the other unit is operating. In some installations, the precipitator is mounted directly above the primary washer. The rotary disintegrator has the advantage of lower first cost but has higher power cost than the wet-type Cottrell precipitator. The cleanliness of the gas may be slightly in favor of the precipitator.

**Secondary dry cleaners** have included bag filters and Cottrell precipitators. The bag-type filters, sometimes called the Halberger-Beth type, consist of a number of fabric "socks" made of cloth, glass threads, asbestos threads, or very fine Monel metal screen (or a combination), supported at the top and closed on the bottom, into which the gas passes from the outside forming a film of dust on the sock which acts as the filtering medium. When the film of dust becomes too thick, the exit end of the sock is closed thereby shutting off the gas flow and the sock is shaken or vibrated to drop the excess dust into a collecting hopper. The socks are stiffened both circumferentially and longitudinally to prevent their collapse. It has been difficult to find a fabric which does not break down under the temperature encountered with hot blast-furnace gas. Also, if the temperature of the gas should reach its dew point, moisture would deposit in the fabric thereby forming a deposit of dust on the sock which cannot be dislodged.

The dry-type Cottrell operates upon the same principle as the wet type but is constructed somewhat differently. The modification consists in using slabs of reinforced concrete as collecting electrodes to form channels for the passage of the gas, with the discharge wires suspended along the center lines of the channels. Periodically, each unit is taken out of circuit to permit the dust on the collecting electrode to fall into a hopper below. In