KBW: IMPROVEMENTS ON A WELL-KNOWN PROCESS

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1. Introduction

The vulnerability of the United States' energy supply to world political events has become widely recognized in the past several years. However, the United States is also blessed with abundant resources which, if properly applied, could assure our energy supply far into the future. These resources include coal, oil, gas, and uranium lying within the political boundaries of the United States and, in the long-term, geothermal, geo-pressure, solar, wind, biomass, and nuclear fusion.

In order to cope with our extremely large energy requirements now and in the future, we must pursue in parallel the development and commercial application of several of the above alternate energy sources. The one with the greatest potential for large scale, immediate commercial application is coal. Coal can be burned directly as a fuel or converted to a host of other products to fill various energy needs. This paper will concentrate on one type of coal gasification process to produce a synthesis gas which can be purified and burned as a clean fuel or treated by several chemical processes to yield a variety of valuable products.

2. KBW Coal Gasification Process

In October 1980, the Koppers Company, Inc., and the Babcock & Wilcox Company (an operating unit of McDermott, Inc.) formed a joint venture, KBW Gasification Systems, Inc., to serve the expanding synthetic fuels market (Figure 1). The objective of KBW is to engineer, design, market, fabricate, construct, and service coal gasification systems worldwide. KBW is offering commercially an atmospheric pressure, oxygen blown, slagging, entrained flow gasification system.

2.1 Historical Perspective

As contrasted to the fixed bed and fluidized bed gasification processes the entrained flow gasification process has the following advantages:

- It can gasify any rank of coal.
  The coking properties of bituminous coals do not affect the gasification process.

- It can treat 100% of the mine output.
  All of the coal including the fines are pulverized.

- It has a high capacity.
  The higher throughput velocity of an entrained flow gasifier provides greater gasification capacity.

- It has major environmental advantages.
  Tars, phenols or other hydrocarbons which must be removed from the product gas are not produced in an entrained flow gasifier because of the high gasification temperature.

- It does not produce methane.
  There is no need for methane reforming.

The entrained flow gasification process was first demonstrated in the United States about 30 years ago. In 1948, Koppers built a demonstration plant for the U. S. Bureau of Mines at Louisiana, Missouri. In 1951, The Babcock & Wilcox Company supplied an entrained flow gasifier to the U. S. Bureau of Mines at Morgantown, West Virginia. Based upon the successful operation of this installation, a larger pilot scale gasifier was designed and operated for the Bureau in the early 1950s. In 1955, Babcock & Wilcox built a large scale (17 tons/hr of coal) entrained flow gasifier for DuPont at Belle, West Virginia. Coincidentally, the vast discoveries of oil and gas in this country spelled a temporary demise for the economic practicality of coal gasification in the United States. However, in Europe the need for expansion and modernization of agriculture required the use of coal to produce ammonia. In 1952, the first commercial size entrained flow gasification plant was installed in Finland. Since then, 16 commercial size entrained flow gasification plants have been installed by others in the Eastern Hemisphere.

By today's standards, these initial plants were small in size and inherently simple in design; lacking in the areas of overall thermal efficiency and coal throughput capacity. They employed long residence times and small internal volumes, had limited flexibility to operate efficiently with a wide variety of coals, and experienced refractory erosion problems. During the 1960s and 1970s, several design and hardware modifications were implemented to improve the earlier gasification systems. As a result, several commercial, entrained flow gasifiers utilizing steam generating cooling jackets, shorter residence times, larger internal volumes, and improved refractories were designed and installed.

2.2 Features of the KBW Coal Gasification Process

In its formative days, KBW recognized the fact that despite the improvements mentioned above, the existing commercial entrained flow gasification systems could not economically meet the high synthesis gas production requirements of the currently proposed synthetic fuel plants. Therefore, the KBW commercial coal gasification system was designed to offer the synthetic fuels industry an efficient, reliable and advanced system that utilizes modern and proven technology. More specifically, the KBW gasification system has the following important features:

- It is based on a wealth of design data, knowledge and experience possessed by Koppers and Babcock & Wilcox in the areas of coal preparation and handling, entrained flow coal gasification, slag handling, mass transfer, heat transfer, equipment fabrication, and plant construction.

- Both the gasifier and heat recovery boiler utilize components that have been proven through years of fabrication and service.

- Membrane walls constructed of vertical, water cooled tubes which have been widely used in boilers are utilized in the KBW gasifier. This feature enables the gasifier to produce high pressure steam. The water cooled tubes can withstand much higher heat fluxes than the jacket type cooling system while assuring nucleate boiling. With the water cooled tubes, the fluid circulation is well defined and the differential stresses are minimized.

- Thinner refractories are used in the gasification zone instead of thick refractories which have been proven to be unworkable in slagging gasifiers (i.e., they are easily eroded).

- The KBW gasifier has approximately twice the internal volume of the largest commercial entrained flow gasifier in existence. This results in approximately twice the throughput rate for the KBW gasifier for the same residence time.

- The KBW gasifier does not require a water spray quench and hence has a higher thermal efficiency.

- The KBW gasifier offers a high degree of flexibility to operate with a wide variety of coals since it can accommodate high heat fluxes.

2.3 Description of the KBW Coal Gasification Process

The KBW gasification process can be described in terms of three major stages (Figure 2):

2.3.1 Coal Preparation and Feeding

2.3.2 Coal Gasification and Heat Recovery

2.3.3 Gas Cooling and Cleaning

<u>2.3.1 Coal Preparation and Feeding</u> The KBW system begins at the coal storage yard. Coal crushed to 1-1/4 in. x 0 in. (32 mm. x 0 mm.), is conveyed to a bunker which feeds the pulverizer. The pulverizer is air-swept to provide drying and transport of the coal. With Eastern bituminous coal, the typical product has a fineness of 70-85% through 200 mesh (74 microns) and a moisture content of approximately 2%.

From the pulverizer, the pulverized coal passes to a storage bin with a cyclone separator at the inlet. The cyclone separator removes the pulverized coal from the conveying air and discharges it into the bin. The moisture laden air is vented to the atmosphere through a bag filter which removes traces of pulverized coal from the vented air.

From the storage bin, the dried pulverized coal is transported with nitrogen to the service bins located adjacent to each gasifier. Each service bin is equipped with a cyclone separator and a bag filter to remove the pulverized coal from the conveying nitrogen. The nitrogen is vented to the atmosphere, and the pulverized coal is stored under an inert atmosphere in each service bin.

From each service bin, the pulverized coal passes through two parallel weigh feeders to two smaller feed bins where it is stored under an inert atmosphere. The feed bins maintain a constant supply of coal at the inlet of variable speed screw feeders which regulate the flow of pulverized coal to each burner of the gasifier. There is one feed bin and one screw feeder for each of the eight burners in the KBW gasifier. At the exit of the screw feeder, the pulverized coal is picked up by a stream of oxygen and steam, and transported a short distance to the burner in the gasifier wall. The velocity of the coal, oxygen, steam mixture is maintained above the flame propagation velocity at all times and the screw feeder is designed to maintain a gas-tight plug of pulverized coal to prevent back-flow of oxygen into the coal feed system.

2.3.2 Coal Gasification and Heat Recovery The KBW gasifier (Figure 3) is a square column nominally 15 feet (4.6 m.) on a side and 61 feet (18.6 m.) high. The premixed reactants enter the gasifier through eight burners located two each toward the bottom of each side wall. The burners are arranged vertically, one over the other, and are offset from the center of the wall so that the gases form a vortex in the gasifier to promote good mixing. The gasification reactions take place as the pulverized coal entrained in the hot gas passes upward through the gasifier. The temperature in the "gasification zone" is above the ash fluid temperature so that the ash in the coal is melted, finds its way to the gasifier walls and runs down as a molten slag to the sloping hearth floor. It then drains continuously through a slag drain opening in the floor. Below this opening is a water filled slag quench vessel where cold water shatters the molten slag into a solid granular material resembling black gravel. This material is removed continuously from the slag quench vessel by a conveyor for disposal.

The gasifier shell consists of water-cooled membrane tube walls continuously welded to form a gas tight enclosure (Figure 4). Experience over approximately 40 years on commercial combustion furnaces including slag tap furnaces has proven this wall construction to provide long periods of continuous on-stream operations with low maintenance. The individual tubes are continuous from bottom to top. All the tubes begin at headers at the bottom of the gasifier and are arranged to form the floor or hearth and the slag outlet. They are then bent to form the vertical gasifier walls. And finally, they are bent in to form the top of the gasifier and the gas outlet before being terminated in headers at the top of the gasifier.

Water enters the individual tubes through the lower headers. As the water flows upward through the tubes, it boils and a portion of the water turns to steam. The steam water mixture is collected in the upper headers and flows to the steam drum where steam is separated from the water and sent to a superheater located in the heat recovery boiler. The saturated water is returned through downcomers to recirculating pumps where it is pumped to the lower headers to make another pass up through the gasifier tubes. Boiler feed water make-up is supplied to the steam drum through an economizer section in the heat recovery boiler.

The tubes are typically 2-1/2 in. (64 mm.) O.D. on 3 in. (76 mm.) centerline to centerline spacing with steel bars continuously welded between adjacent tubes. Groups of tubes and bars are welded together in the fabrication shop to form complete wall panels of "membrane welded" tubes. These shop assembled panels are shipped to the job site for field assembly into gas tight furnace enclosure walls.

The tubes (Figure 5) in the lower portion or "gasification zone" of the gasifier have many small steel studs, 3/8 in. (10 mm.) diameter x 1/2 in. (13 mm.) long, welded to them. A dense, slag resistant refractory is applied around the studs over the tubes to a thickness approximately equal to the length of the studs. The studs lock the refractory in place and provide cooling for it. The temperature of the furnace face of the refractory is kept below the ash fusion temperature and a layer of frozen slag forms on the refractory. The molten slag flows down over this layer of frozen slag. The frozen slag offers protection to the refractory and tubes while minimizing the heat loss from the gasification zone.

The gasification reactions are essentially completed at an elevation approximately 15 ft. (4.6 m.) above the upper row of burners where the gas temperature is 200°F (93°C) above the ash softening temperature. Above this elevation, the studs and refractory are discontinued and the remainder of the gasifier walls are bare membrane welded tubular walls. The gas is cooled by radiation to the walls in this "cooling zone" as the gas temperature passes from where the ash is clearly molten to approximately 1800°F (982°C) where it is dry particulate fly ash. At intermediate temperatures, the ash is plastic and can form deposits. In this temperature range, it is handled best with cold bare steel where the ash tends to shed off spontaneously. In addition, retractable wall sootblowers are located throughout the upper portion of the gasifier to assist in dislodging any deposits that may build up. These deposits fall to the floor of the gasifier where they melt and flow out through the slag drain opening with the rest of the molten ash from the coal.

The gas with some unreacted char and fly ash at approximately 1800°F (982°C) leaves the gasifier and passes through the crossover flue to enter the top of the waste heat recovery boiler. It flows downward over the banks of horizontal convection surface comprising the superheater and economizer. The gas leaves the heat recovery boiler at the bottom at approximately 450°F (232°C) and flows to the gas cooling and cleaning equipment downstream.

The walls of the heat recovery boiler are bare membraned welded construction identical with the upper portion of the walls of the gasifier. The horizontal convection surface is supported from castings welded to the wall tubes in the same way that horizontal convection surface is supported in commercial boilers. Water flows upward through the wall tubes where a portion of the water turns to steam. The steam water mixture is collected in headers at the top of the heat recovery boiler and flows to the steam drum where the steam is separated from the water, the water is recirculated and the saturated steam flows to the primary superheater counterflow to the gas flowing over the tubes. The steam flows from the primary superheater outlet header to an exterior spray attemperator and on to the secondary superheater. Feedwater is sprayed into the steam in the attemperator to control the steam temperature at the exit from the secondary superheater. The steam flows through the tubes of the secondary superheater and flows on to the various mechanical drive turbines throughout the plant.

Feedwater from the feedwater pump flows through the tubes of the economizer counter-flow to the gas flow and then flows to the steam drum. This water picks up heat from the gas being cooled and saves the heat in the gas below the saturation temperature corresponding to the steam side operating pressure.

2.3.3 Gas Cooling and Cleaning Each gasifier is equipped with a gas cooling and cleaning train. Gas from the heat recovery boiler enters a multicyclone dust collector which removes about 90% of the entrained particulates.

Gas leaving the cyclone dust collector flows through a saturator cooler where the gas is adiabatically cooled and saturated with water. Discharge water from the saturator coolers flows to a clarifier and then to disposal.

Gas leaving the saturator cooler enters two disintegrators in series where the entrained particulate in the gas is reduced to about 0.01 grains per standard cubic foot (24 mg. per normal cubic meter). The gas then enters a spray type final cooler where it is cooled to about 105°F (41°C) by direct contact with water.

From the final cooler, gas flows to a gas blower which maintains the pressure in the system. From the blower, the gas passes through an electrostatic precipitator. The precipitator reduces the entrained particulate loading to about 0.0001 grains per standard cubic foot (0.24 mg. per normal cubic meter). A gas holder is provided to absorb system surges. Gas from the precipitator flows to the plant battery limits.

2.4 KBW System Performance Characteristics

One of the advantages of the KBW gasifier is its versatility in accepting a wide range of feedstocks. Feeds as diverse as peat through all ranks of coal to petroleum coke can be gasified.

The gasifier is standardized with a square internal cross section 14' - 3" (4.3 m.) on a side. Gasifier operating conditions are dictated by the characteristics of the coal being gasified, but typical ranges are as follows:

Typical Performance

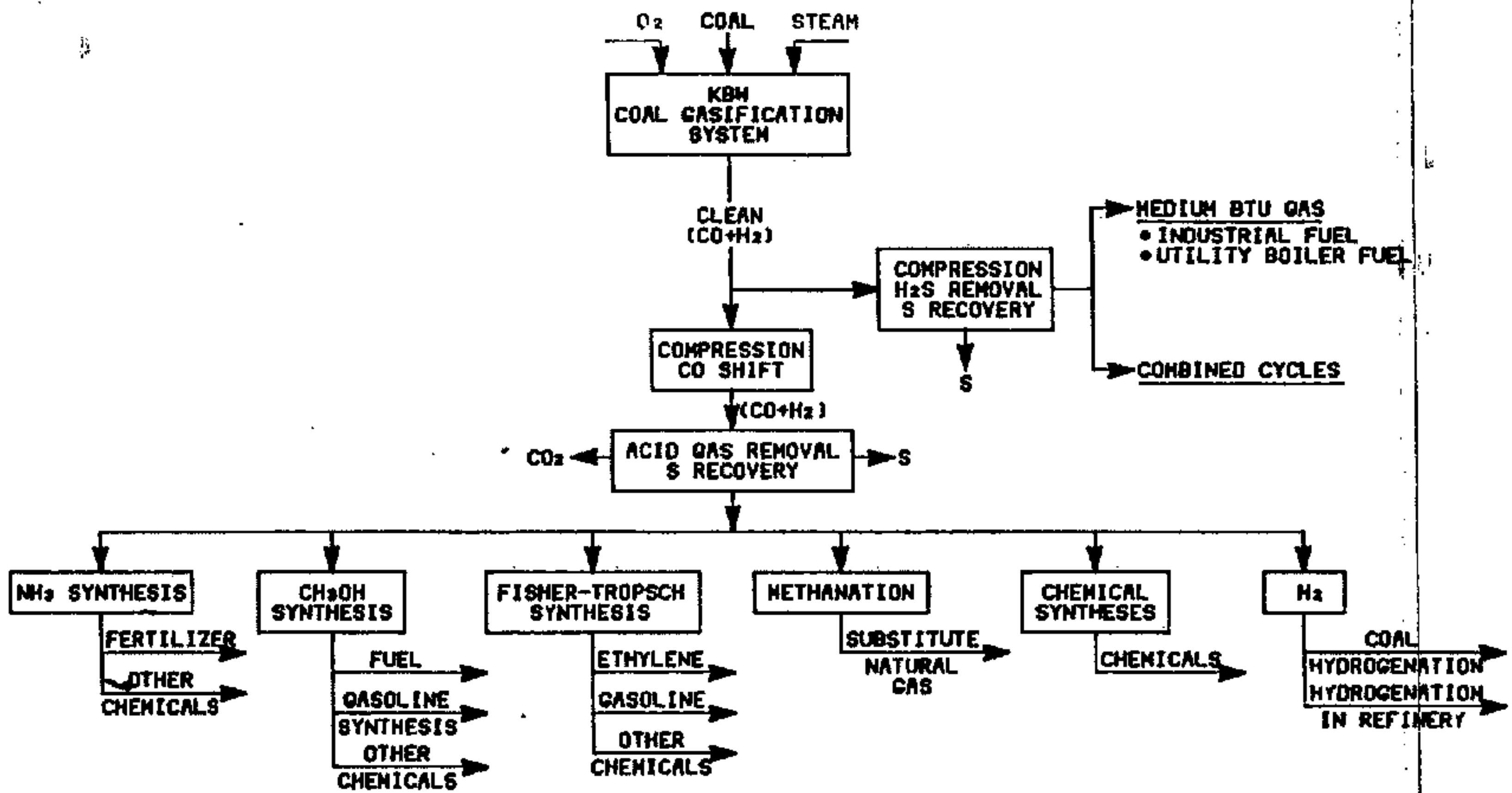
Coal Feed Rate	800-1200 Tons/Day (726-1089 MT/Day)
Gas Production	32,000-45,000 SCFM (51,440-72,340 Nm^3/Hr
Gas Composition:	% by Volume (dry)
CO	53-65
CO_2	8-11
H_2	25-35
Trace Compounds	1-2
Higher Heating Value	290-300 Btu/SCF (dry, acid gas free) (2720-2820 K Cal./Nm^3)
Oxygen to Carbon Mass Ratio	1.15-1.32
Carbon Conversion	86%-98%
Steam Pressure	700-1200 psig (49-84 bar.)
Steam Temperature	500°F-900°F (260°C-482°C)

3. Conclusion

KBW is structured to provide single-source capability for turnkey, entrained flow coal gasification plants worldwide from initial feasibility studies through start up of the completed plant. The KBW coal gasification system is based on proven capabilities of Koppers and Babcock & Wilcox in entrained flow coal gasification and in various technologies associated with the processing and utilization of coal and its products. This combination of expertise and experience enables KBW to offer a gasification system of an efficient, reliable and advanced design that utilizes modern, proven technology.

FIGURE 1

APPLICATIONS OF KBW GASIFICATION SYSTEM



KBW

FIGURE 2

KBW GASIFICATION PROCESS

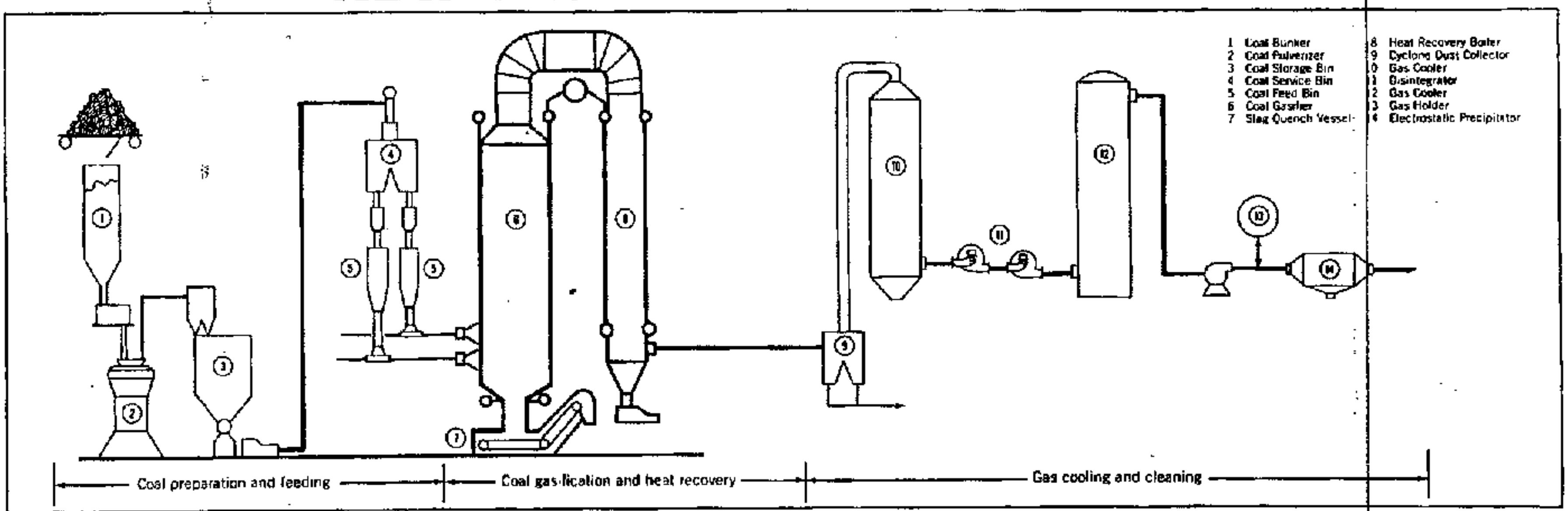


FIGURE 3

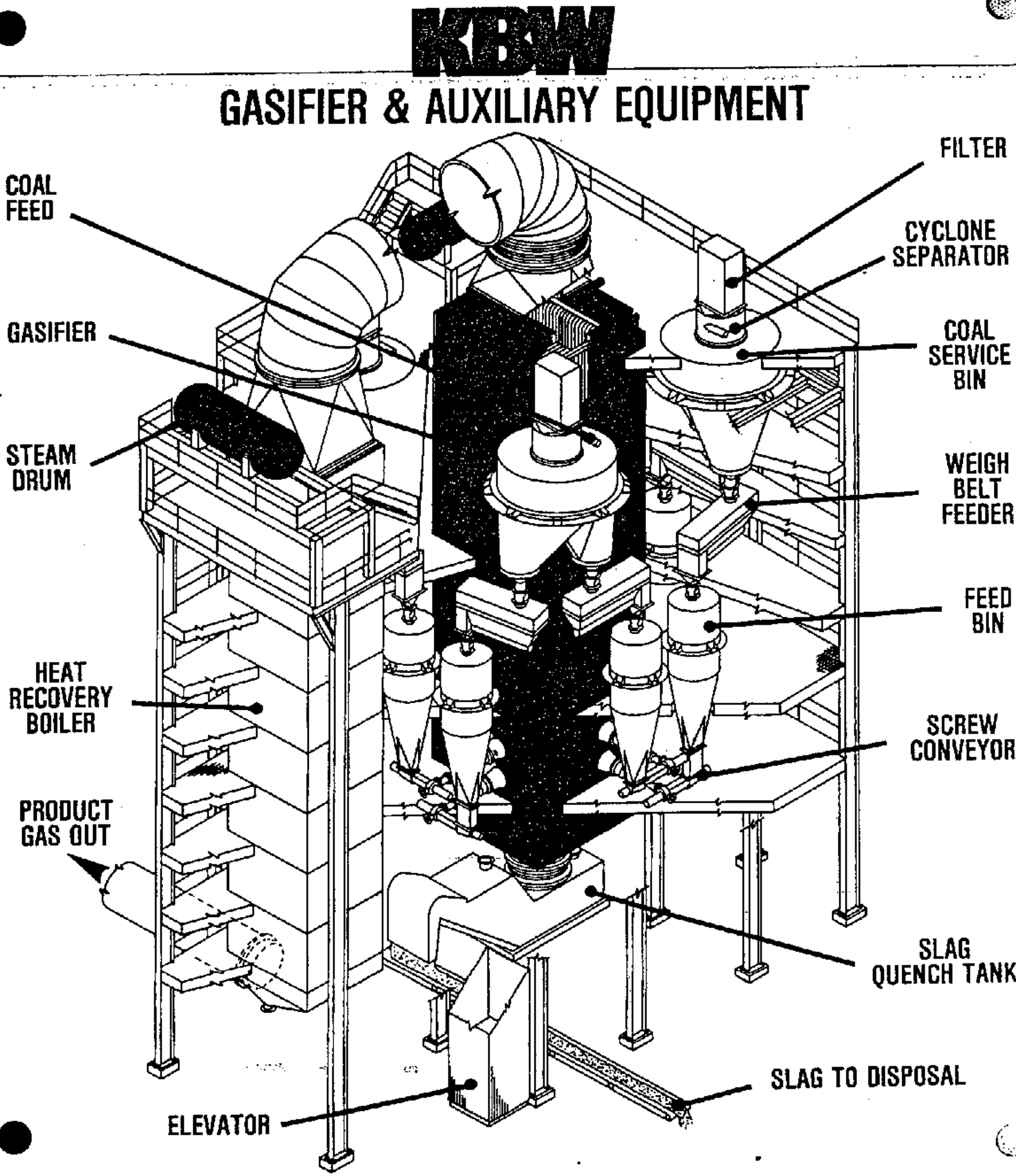

KBW
GASIFIER & AUXILIARY EQUIPMENT
COAL FEED
GASIFIER
STEAM DRUM
HEAT RECOVERY BOILER
PRODUCT GAS OUT
ELEVATOR
FILTER
CYCLONE SEPARATOR
COAL SERVICE BIN
WEIGH BELT FEEDER
FEED BIN
SCREW CONVEYOR
SLAG QUENCH TANK
SLAG TO DISPOSAL

FIGURE 4

KBW GASIFIER

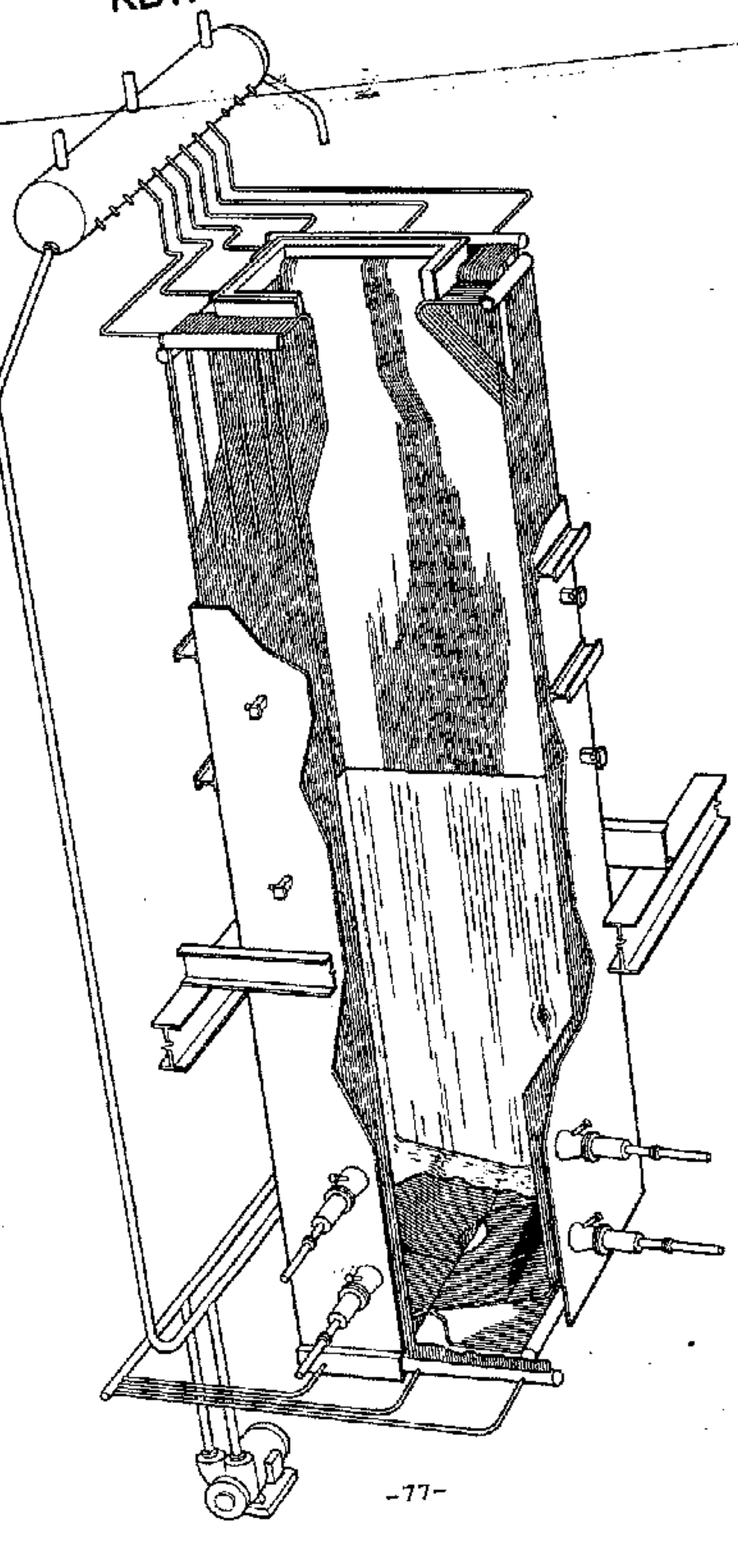


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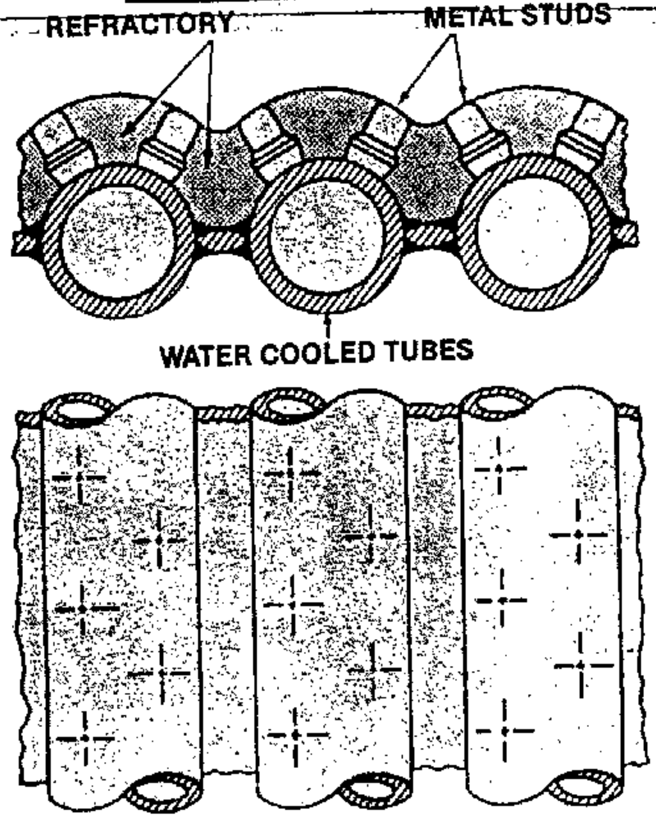
FIGURE 5

KBW GASIFIER MEMBRANE WALLS

GASIFICATION ZONE



COOLING ZONE

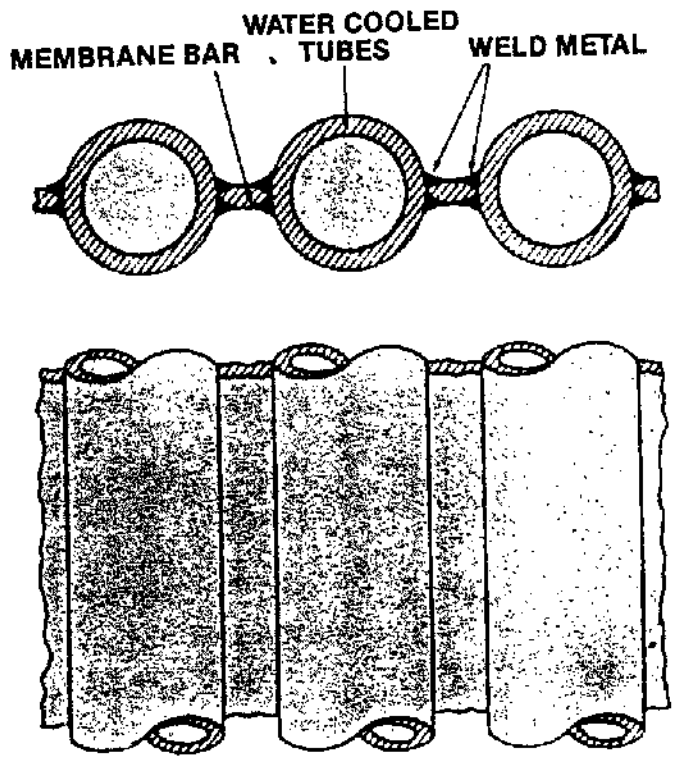


Figure 2