2.3.3 Texaco Process [T]

The Texaco Coal Gasification Process (TCGP) is based on the principle of entrained bed gasification at elevated pressure and under slagging conditions. Coal is fed in a coal/water slurry form. The gasifier can be used for hydrogen generation in direct liquefaction processes by gasifying solids residue and/or coal.

2.3.3.1 History and Status

The TCGP is being developed to gasify solid carbonaceous feedstocks. The process evolved from the Texaco Synthetic Gas Generation Process (TSGGP) which has been commercially used to produce synthesis gas from natural gas, naphtha, oil, and heavy vacuum residues. There are a total of 76 licensed plants located in 22 countries using TSGGP.[37]

Development of the TCGP first started in the early 1950's. Extensive process development work at Texaco's Montebello Research Laboratory culminated in the construction and operation of a 100 t/day coal demonstration plant at the ordnance works in Morgantown, West Virginia. Further development work was slowed with the wide availability of natural gas transported via pipelines.[35,36]

The current development work began in 1973 after the Arab oil embargo. In 1977, Ruhrchemie and Ruhrkohle jointly built the 150 t/day coal gasification plant at Oberhausen. The plant went onstream in January 1978. During the two-year period from January 1978 to January 1980 the plant had an operating time of about 4000 hours and had processed 15,000 tonnes (16,500 tons) of coal. As of September 1980 the plant had an operating time of 6500 hours and had processed 36,000 tonnes (39,600 tons) of coal. Five types of coals, including low and high volatile bituminous coal with volatile contents up to 32%, and coal sludges from coal washing with ash contents up to 30% have been tested. The amount of syngas produced totals more than 60 million cubic meters (2 billion cubic feet). Part of this gas has been used in facilities of Ruhrchemie, and some was methanated in a fluidized bed pilot plant by Thyssengas GmbH. The maximum run length has been 800 hours, but an 8000 hour refractory life is projected.[29,32,37]

The total costs for the Oberhausen demonstration plant including operation for 4 years will be about $30 million. The amount contributed by the Federal Ministry of Research & Technology is 60%, the remaining 40% being divided between Ruhrkohle and Ruhrchemie in the ratio of 2:1. Commercialization by 1983-84 is expected.[37,38]

Current plans call for the scale-up of the Texaco gasifier to 6-7 times its current capacity within the next 2-3 years. Plants having a 600 tonne/hr (660 ton/hr) capacity with reactors as large as 100-150 tonnes/hr (110-165 tons/hr) are being considered. Ruhrchemie has the rights to the coal preparation and waste-heat boiler while Texaco has retained the rights to the gasifier.[1]

2.3.3.2 Company Experience

Texaco Development Corporation has performed extensive development work on TCGP at their Montebello Research Laboratory in California. The pilot plant has been utilized to gasify the molten liquefaction residues from SRC-I, SRC-II, H-Coal and EDS pilot plants.[35] A patent application has been filed for a process (drying, treating, slurrying) which permits a 70 wt % coal/water slurry to be fed. TVA, Grace/Ebasco and Gulf (SRC-II) are also associated in developing the process through licensing.[32,25]

Ruhrchemie is owned by three different companies, each with 1/3 of the shares, and has five basic product lines. These include high density polyethylene, low density polyethylene, organic chemicals, fertilizers and heterogeneous catalysts for hydrogenation. The organic chemicals are produced by oxosynthesis. They include alcohol and amines. The amines are produced by a high pressure process using a cobalt catalyst invented by Ruhrchemie. Ruhrchemie generates their own synthesis gas from partial oxidation of oil and more recently from partial oxidation of coal via the Texaco Coal Gasification Process. Initially Ruhrchemie used the Shell Partial Oxidation Process but more recently has switched to the Texaco process for partial oxidation.[19,39]

Ruhrkohle had about 134,000 employees in 1979. One of their interests is coal gasification. They are pioneering work on a 10 MPa (1450 psi) Lurgi coal gasification process at Dorsten. They are also studying coal liquefaction using a 200 t/day plant at Bottrop in conjunction with Veba Oel AG. This plant will constitute investment of $100 million dollars and have an operating budget of $70 million over a five-year period. They have an interest in two plants generating power from coal and a small share in the Exxon Donor Solvent Process.[19,39]

2.3.3.3 Texaco Gasification Process Flow Description

The flow scheme for the 150 t/day pilot plant at Oberhausen-Holten in West Germany is shown in Figure 2.28.

Coal fines, 0-10 mm (0-0.4 in), are fed together with water to a wet mill and ground finely. During passage through the mill an intimate mixing of solids and water takes place, so that the product emerging from the discharge end of the mill is already an almost homogeneous mixture of coal and water with a high solids content. In the next-in-line slurry tank a further homogenization of the mixture is achieved by stirring. The now-ready suspension is brought up to the gasification pressure of 4.0 MPa (580 psi) by means of a pump and conveyed to the reactor. The addition of oxygen brings about the partial combustion of the fuel that supplies the energy for heating up the substances participating in the reaction to the gasification temperature of 1,300-1,500°C (2370-2730°F) as well as meeting the needs of reaction energy. The reaction proceeds very rapidly in the flame, so that the mean residence time in the reactor is only a few seconds.

At 1350-1500°C (2460-2730°F) operating temperature and 18-30 bars (270-450 psi) pressure and a 70% coal/30% water slurry, the moisture-free yield in volume percent was: CO, 52%; H_2, 35%; CO_2, 12%; CH_4, 0.1%. Operating at 4.4 tons/hr of coal and 2860 cu m/hr (101,000 ft^3/hr) oxygen input (O/C ratio = 1.01) at 19.4 bars (290 psi) the moisture-free synthesis (raw) gas has a volume percent composition of CO, 65.2%; H_2, 25.5%; CO_2, 0.8%; H_2S, 0.3%; N_2 et al., 8.2%. The gas flowed at 9500 cu m/hr (335,000 ft^3/hr).[J]

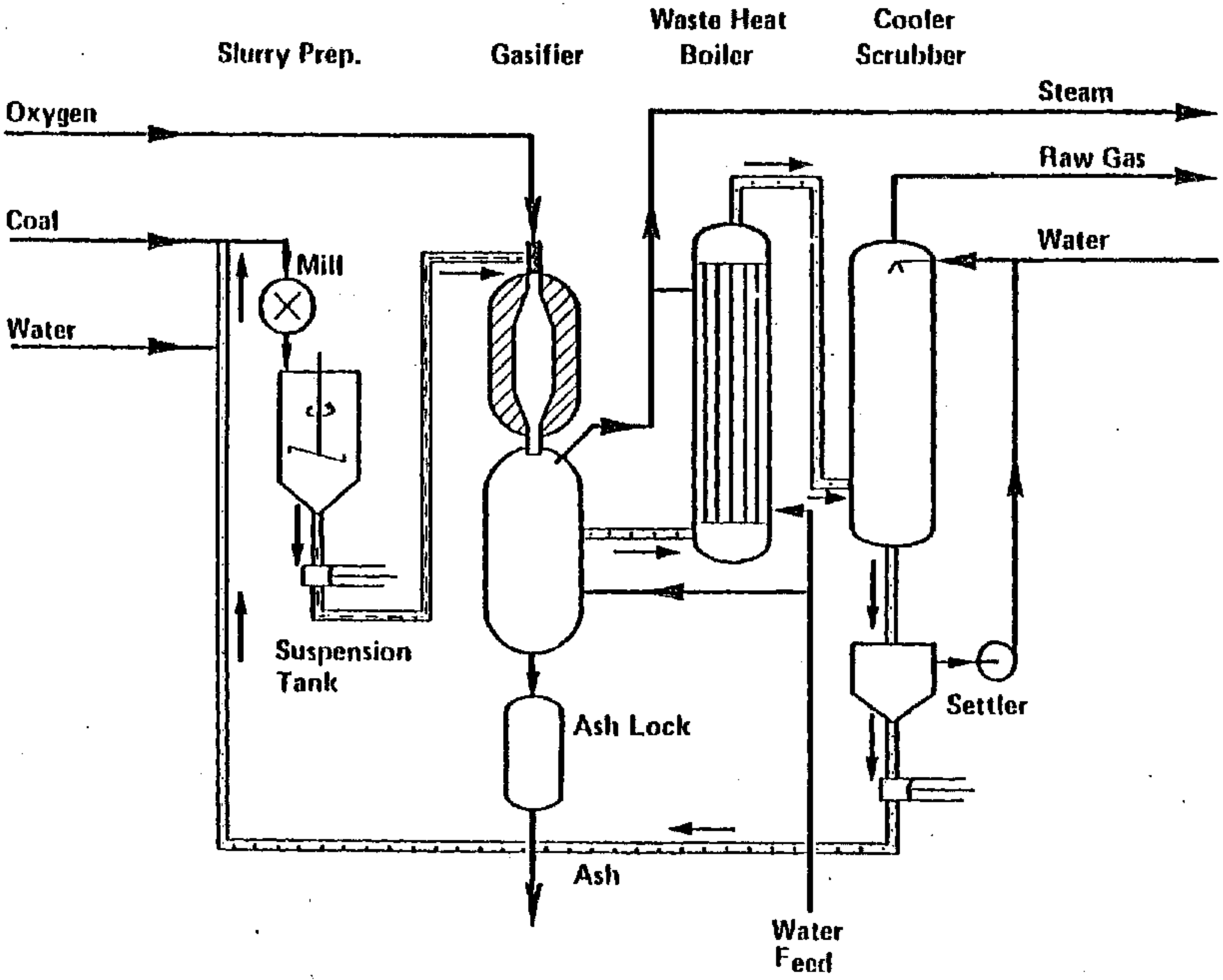

FIGURE 2.28

TEXACO GASIFICATIO. PILOT PLANT

After leaving the reactor, the gas flows first through a waste heat boiler where it is cooled to below the ash fusion point. The gas is deflected at the discharge end of this boiler and the major part of the slag is separated out, granulated in a water bath and discharged via a lock hopper. The gas is then cooled further in a second boiler, generating more steam.

The second boiler is followed by a quench cooler, which as a result of direct contact with the wash water also scrubs out the solids still carried in the gas, with cooling of the gas proceeding simultaneously. After the raw gas has passed through the quench cooler, hydrogen sulfide and carbon dioxide are removed in a conventional acid gas unit.

The wash water, laden with solids, is separated in a thickener into a settler overflow, which is re-used as wash water, and a slurry underflow. This underflow contains practically all the removed solids and is recycled, since it still contains amounts of usable combustible matter. By recycling these solids it is possible to bring the carbon conversion figure up to 98-99%.[29,37,38]

2.3.3.4 Feed Requirements

It is claimed that the gasifier has the capability of operating on virtually all types of coals, petroleum or coal cokes, residues and chars from coal liquefaction processes, solid wastes and other materials that can be slurried in water, liquid fuels, and waste liquids. It can also accept coal fines. Coal is ground to <10 mm (0.4 in) and slurried with water at concentrations up to 70%. To get a 70% slurry feed concentration, the coal must first be dried if it is high in moisture content and then mixed with water plus a chemical agent (which has not been disclosed). Coals with ash contents of 6 to 30% have been tested. Solids residue from direct liquefaction processes can also be gasified for hydrogen generation.[35,40]

2.3.3.5 Reactants

Oxygen = 1 kg/kg (1 lb/lb) maf coal

Steam = Not required

2.3.3.6 Efficiency[37]

Overall thermal efficiency = 92% (steam included)

Cold gas efficiency = 74% (no steam included)

Carbon conversion = 98%

2.3.3.7 Environmental Aspects

The raw synthesis gas leaving the TCGP battery limits contains as impurities carbon dioxide, hydrogen sulfide, and some carbonyl sulfide, all of which can be removed with conventional downstream processing. The pilot plant uses the Sulfinol process for removing H_2S and CO_2 from the synthesis gas. The Sulfinol system existed from the original Shell Oil Gasification Facility. There are no phenols, tars, or other heavy materials to remove. The water circulating in the system and which comes in contact with the synthesis gas and the slag must be purged to maintain the total dissolved solids at a reasonable level. This stream can also be taken care of using commercially available technology.

The slag is free of organic components but does contain elemental sulfur. Some metals can be leached from the slag. These include zinc, aluminum, sodium and potassium. However, the environmentally hazardous metals such as mercury and lead have not been detected.[29,35,39]

2.3.3.8 Equipment Design of Pilot Plant with Key Problems and Points of Emphasis for Development

Failure of temperature measuring devices in the high temperature gases has been a problem. Present techniques (not disclosed) have a life of about 1000 hours before replacement. Initially, longer test periods were hampered by the brief service lives of thermocouples which were a consequence of the destruction of their protective covering by slag and damage to the platinum/rhodium pilot wires by hydrogen.[29,37]

The Tennessee Valley Authority (TVA) has described its experience with temperature measuring techniques at the TVA 150 t/d Texaco coal gasification pilot plant at Muscle Shoals, Alabama. Reliable measurement of the flame temperature is crucial to achieving design carbon burnup and acceptable refractory life simultaneously. TVA has experienced thermocouple difficulties similar to those described by Ruhrchemie. Greater success has been claimed with optical pyrometers installed through the head of the TVA gasifier. Perhaps the most reliable indication of flame temperature, however, is the concentration of methane in the product gas. This can be measured and related to flame temperature.

Ruhrchemie claims that the refractory problems have been solved but they would not disclose how long they can operate before refractory replacement. Ruhrchemie claims to have achieved refractory life greater than 800 hours in the longest sustained test so far and confidently projects an 8,000 hour life in commercial operation. Five or six refractories have been tested. During initial operations of the Texaco gasifier at Ruhrchemie, a number of refractories were tested simultaneously. As expected, the duration of a test was limited by the life of the poorest refractory. As more satisfactory refractories were identified, the duration of the tests increased, but the number of refractories investigated per test decreased. A portion of the refractory test surface in the gasifier reportedly is water-cooled. It is believed that the gasifier has been relined completely at least once during the reported 6,500 hours of operation since commissioning (as of September 1980). They did admit that they are conferring with others in Germany on the development of water-cooled gasifier walls which would permit the formation of a protective slag layer over the refractory walls. Burner life has been good with no changes required.[29,37]

2.3.4 Saarberg-Otto Process[H,S,U]

The Saarberg-Otto process is a high-pressure entrained-bed slagging gasification process which can be utilized for hydrogen production in direct liquefaction processes. The unique feature of the gasifier is its rotating molten slag bath. Feed to the gasifier may consist of a mixture of fresh coal and solid residue from liquefaction processes. Oils or residues from liquefaction processes may also be gsified with or without coal.

2.3.4.1 History and status. The Saarberg-Otto process is a pressurized version of the Rummel/Otto gsification process which operated at atmospheric pressure in 1950. A pilot plant having a capacity of 3300 m^3/hr (116,500 ft^3/hr) was located at Union Kraftstoff, Wesseling, W. Germany. In 1956 a 250 t/d pilot plant was operated at the same location to produce 14,500 m^3/hr (512,000 ft^3/hr) of medium-Btu gas.

In January 1976 Saarbergwerke AG, Saarbrucken, and Dr. C. Otto and Company GmbH, Bochum, formed a partnership in order to jointly develop, test and utilize a new process for pressure gasification of coal. A 264 tonne (290 ton) per day demonstration plant operating at a pressure of 2.5 MPa (360 psi) was scheduled to be operational by mid-1979. No test work had been done at high pressure prior to construction and operation of this demonstreation plant. Test runs of the coal feeding system were started early last year. The original schedule was delayed by some bad winter weather, which apparently resulted in a number of freeze-ups and damage to some pieces of equipment. In April 1979 the plant was in the pre-start-up equipment test phase. The plant has been in operation since December 5, 1979. Plans are to operate the plant on oxygen (first phase) for the first three years. This phase will cost approximately $27 million of which 75% will be borne by the Ministry of Research and Technology of the Federal Republic of Germany. The second phase will consist of operating the plant in an air-blown mode for application to combined-cycle power generation.

Since start-up the plant has operated for approximately 3000 hours. Testing of critical equipment such as coal feeding system, gasifier with cooling system, slag removal and particulate matter removal system has been done.[32,41,42,43,44]

2.3.4.2 Company Experience

The joint venture of Saarbergwerke AG and the Dr. C. Otto & Co. GmbH has combined experience in various fields for the execution of the development project.

Saarbergwerke AG posesses extensive operational experience in coal dressing, degassing, gas purifying and desulfurization and wastewater treatment. Dr. C. Otto & Co. GmbH has extensive experience in the construction of large plants, especially in the fields of coal dressing, degassing, gas generation and treatment, air pollution control and wastewater treatment. Also, experience was gained in the 1960's in the operation of the Rummel-Otto slag bath atmospheric gasifier.[41,45]

2.3.4.3 Plant Location

The demonstration plant is located at Saar Technological Center at Völklingen adjacent to a number of other plants either owned by Saarbergwerke or one of their joint ventures, including the Fürstenhausen coke plant and a power plant. Gases produced in the gasifier will flow to the coke plant for desulfurization and then will blended with the fuel gas produced by the coke ovens. The oxygen and nitrogen used in the pilot plant are produced in an oxygen plant at the coke plant. High pressure superheated steam from the pilot plant is at the same pressure as the steam used in the power plant and excess steam produced when the unit is in operation goes into the power plant steam system.[32,41,42]

2.3.4.4 Saarberg-Otto Gasification Process Flow Description

The demonstration plant in Fürstenhausen is designed for a coal throughput of 11 t/hr and a gasification pressure of 2.5 MPa (360 psi). The quantity of gas generated is 22,800 m^3/hr (805,000 ft^3/hr). Figure 2.29 shows a flow diagram of the Saarberg-Otto process including coal preparation, gasification, particulate removal, gas cooling, waste heat utilization and waste water purification.

The gasifier installed in the demonstration plant is a vertical cylindrical vessel 16 m (52.5 ft) high and 1.5 m (5 ft) internal diameter. Figure 2.30 gives a more detailed view of the gasifier.

In the lower portion, the gasification zone (Stage I) and the post gasification zone (Stage II), have water-cooled walls, because there are no economically available refractory materials capable of withstanding the erosion of the circulating slag in both oxidizing (Stage I) and reducing (Stage II) conditions at the high temperature levels [1650-2400°C (3000-4350°F)]. Therefore, the gasification and the post-gasification zones in the gasification chamber are protected on the inside by water-cooled finned tubes. This is part of a forced circulation cooling system which ultimately generates low pressure steam for use elsewhere in the process.

The upper portion of the gasifier (Stage III), the cooling zone, is refractory lined since the gas in this zone is cooled by recycled product gas to a lower temperature. Coal, oxygen and steam are fed to the gasifier through four inclined, downward directed, co-axial, tangential nozzles. The oxygen and steam are mixed externally in a ring main before flowing through the annular portion of the nozzle

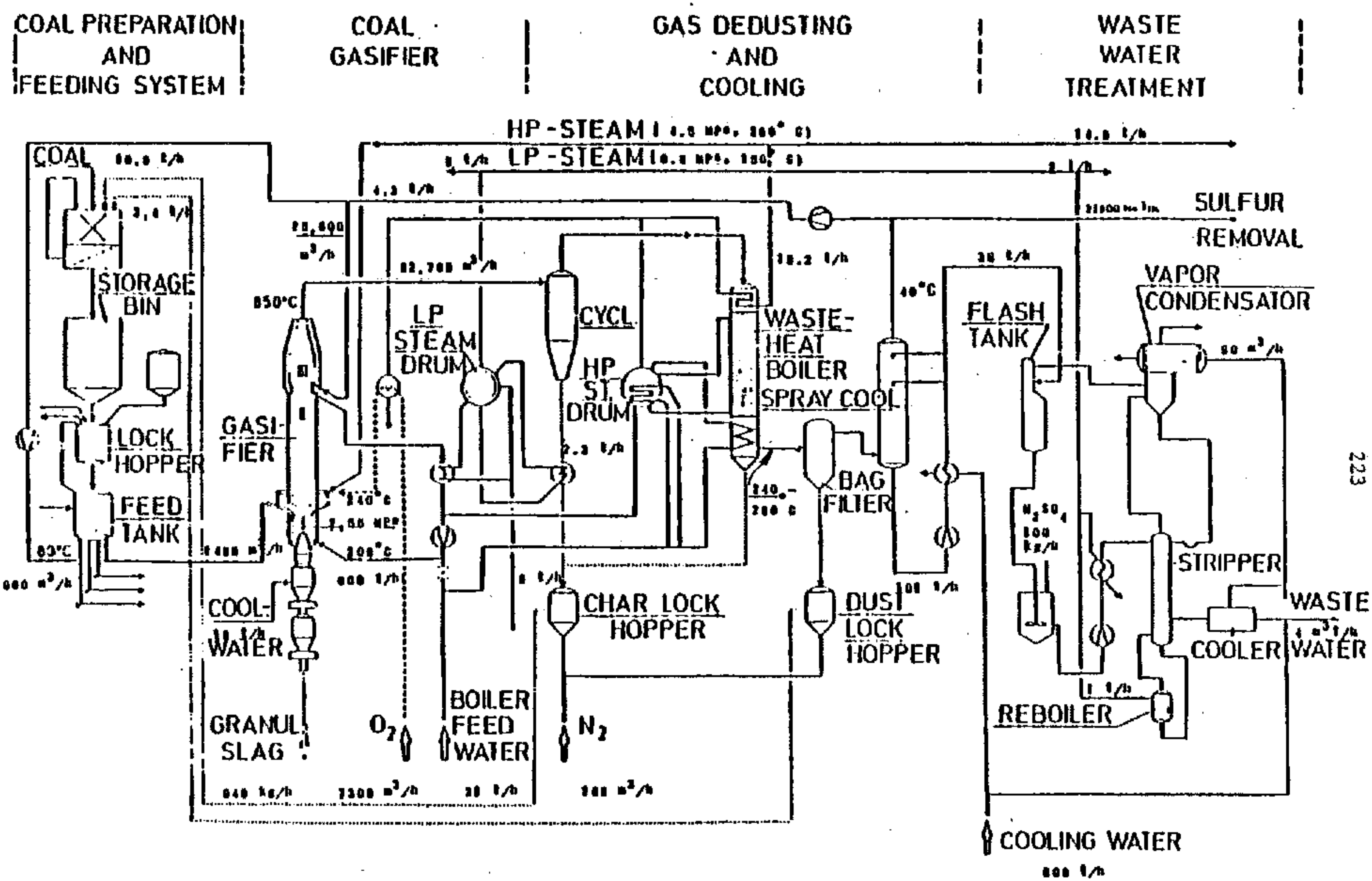

Figure 2.29

SAARBERG/OTTO COAL GASIFICATION PROCESS

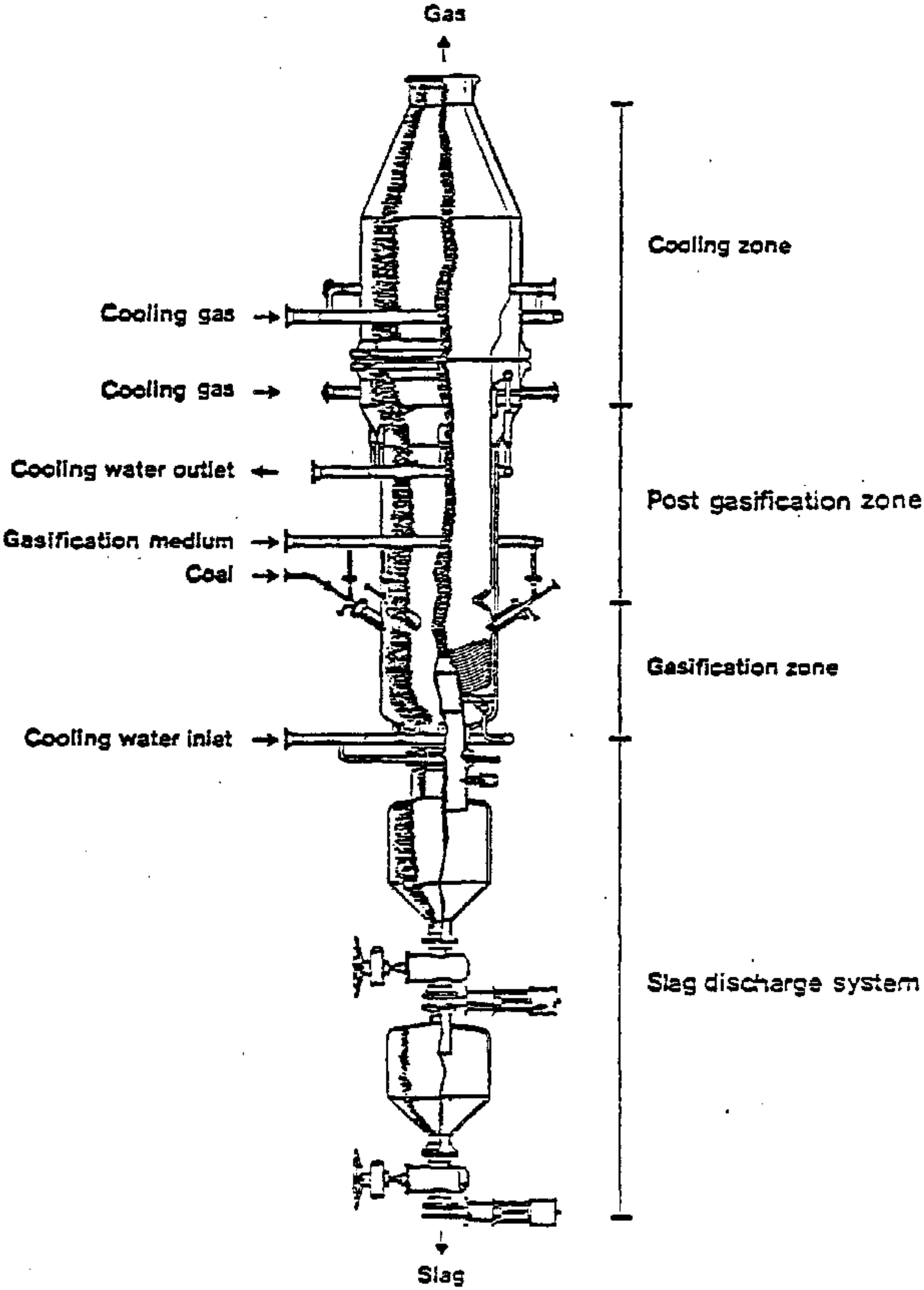

Figure 2.30 SAARBERG-OTTO GASIFIER

to the reaction zone. The coal is pneumatically conveyed by recycled gas through the inner portion of the nozzle.

The coal and steam/oxygen streams exiting the four tangential nozzles impinge upon the molten slag, imparting a rotational motion to the slag bath. As the slag inventory in the gasifier builds up due to the ash content of the coal, the excess slag overflows through a central, raised taphole at the base of the gasifier. This molten slag is quenched in a water bath into granules and removed from the gasifier through a slag discharge lockhopper system. The carbon content in the slag is less than 1%.

In the grinding and drying section shown in Figure 2.17, the coal is pulverized to a particle size of less than 3 mm (0.12 in) and dried to a moisture content of approximately 2% (for brown coal it is approximately 12%). It is then transferred to the storage bin. From the storage bin, which is at atmospheric pressure and under nitrogen, the coal dust is passed via a lock hopper to the pressurized feed tank. Recycled product gas carries controlled quantities of coal dust through four feed pipes to the gasifier. The means of achieving this control is not known.

The feedstock and the gasification media (steam and oxygen, oxygen-enriched air, or air) are injected into the gasifier through the system of tangential nozzles. The feedstock reacts with the gasification medium at temperatures between 1,650 and 2,400°C (3,000 and 4,350°F). The oxygen, or the mixture of oxygen and air, is preheated by saturated steam from the waste heat system. Superheated steam from the high-pressure steam system serves as process steam.

The gas generated in the gasification zone rises with a rotational motion imparted by the tangential feed system. This gas carries entrained particles of coke (fly-coke) and slag. The rotational velocity is accelerated by a throat in the gasifier between the gasification and the post gasification zones. This acceleration of the rotational velocity causes the fly-coke and slag particles to be thrown against the wall of the gasifier so that they drop back into the gasification zone. The finer particles remain in the gas and flow to the post-gasification zone. The gas enters this zone at about 1650 to 1750°C (3000 to 3180°F). The additional retention time at high temperature provides for the further gasification of the fine coal particles. About 10% of the carbon reacts in Stage II. There is a commensurate drop in temperature with the conversion of sensible heat in the gas to chemical energy through additional gasification. The gas continues to flow upwards into the cooling zone at 1200–1500°C (2190–2730°F). This zone has an enlarged cross-sectional area which reduces the velocity of the gas thus allowing disengagement of char and slag particles from the gas stream. Recycled gas is introduced into this portion of the gasifier to reduce the temperature of the outlet gas stream below the melting point of the slag. The volume of recycled gas is about equal to the volume of gas entering from Stage II. The height of State III is such that a cooling of the gas to 850°C (1560°F) is achieved.

From the gasifier, the raw gas passes to a cyclone, where most of the entrained solids are removed. The heat of the raw gas is recovered in the waste heat boiler by generating superheated high-pressure steam. By this time the gas has been cooled to 240–280°C (460–540°F). The gas then passes through a high temperature, fibrous filter where most of the dust, which is still present in the gas chiefly in the form of finer particles, is removed. The particulate matter (char and slag) separated in the cyclone, waste heat boiler, and the fibrous filter is recycled in order to gasify any remaining unconverted carbon.

The raw gas is cooled to 40°C (104°F) in the spray cooler and passed to the desulfurization plant. Some of it is recycled to Stage III to provide the necessary cooling in the gasifier.

The cooling water from the spray cooler is circulated via a heat exchanger. Part of this water is blown down and treated in a conventional waste water system to meet permissible emissions standards.[41,43,44,46]

2.3.4.5 Feed Requirements

The gasifier is suitable for all types of coal having an ash content up to 40%, irrespective of caking and crushing properties. The coal must be pulverized to 100% through 16 mesh. Hard coal must be dried to approximately 2% moisture (brown coal to approximately 12% moisture)in order to maintain free flowing of the feedstock.[41,42] Because of the unique rotating slag bath and the rotation of the gasifying medium itself, carbonaceous solids tend to move to the outer wall where they are carried back down into the reaction zone by the downflowing molten slag. This results in a significantly longer effective residence time for the carbonaceous solids in the reaction zone. As a consequence of this feature the Saarberg-Otto gasifier can accept substantially larger feed particles than other pressurized entrained-flow gasifiers.

2.3.4.6 Reactants[41,42]

Oxygen (99.5%) = 1 t O_2/t coal
Steam = 0.15 t steam/t coal

2.3.4.7 Gas Composition

Typical raw gas composition for bituminous coal from the Ensdorf colliery for O_2-blown operation is shown below in Table 2.22.[41] Also shown in this table are the compositions from the first set of test runs where bituminous coal was used.[42]

Table 2.22 Saarberg/Otto raw gas composition

Component	Typical Vol %	Test Results Vol %
CO	54.0%	56-59
H_2	31.4%	31-34
CO_2	13.2%	6-10
N_2 & Ar	0.8%	-
H_2S + COS	0.4%	<0.2
CH_4	0.2%	<0.1
Higher heating value, MJ/m^3	11.0	11.5-11.9
Btu/ft^3	295	310-320

The crude gas is free of tar and oil. It is produced at the rate of 2100 m^3 per tonne (67,400 ft^3 per ton) of coal. The steam generated amounts to 1.4 tonnes (1.5 tons) of high pressure steam at 4.5 MPa (650 psi) and 300°C (570°F) per tonne of coal.

2.3.4.8 Efficiency[41,42,44]

Overall thermal efficiency = 88 - 94%
(calorific value of gas plus high pressure steam/calorific value of coal feed)
Cold gas efficiency = 70-73%
(calorific value of gas/clorific value of coal feed)
Carbon conversion = 99.0-99.5%

2.3.4.9 Environmental Aspects[41,42]

The primary goal of the demonstration project is to demonstrate the environmental compatibility of the Saarberg-Otto process:

- By using very high gasification temperatures, the gas generated contains no higher hydrocarbons such as tars, phenols, resin formers, etc.
- The total quantity of ash carried in with the coal is rejected as granulated slag which represents the only solid byproduct of the process. The glassy granulate can be considered as environmentally neutral. Disposal problems are not anticipated if the slag is properly handled in the gasifier.

- The amount of waste water that must be discharged is small. A quantity of 0.4 m^3 (14 ft^3 = 105 gal) per ton of coal with very low contents of ammonia and cyanides is anticipated.

2.3.4.10 Equipment Design of Demonstration Plant with Key Problems and Points of Emphasis for Development

The rotating slag bath and rotating gasification mixture in the Saarberg-Otto gasifier are the keys to its performance, particularly in the areas of carbon burnup and reduction of fines carryover. These features present particular challenges to scaling up the gasifier in that tangential velocities, particulate radial velocities, heat transfer, slag temperature control, carbon burnup, and fines removal are all interrelated in a complex fashion. Critical design features (which have not been disclosed) involve the basis for specifying the internal diameter of the throat between the gasifier and quench areas, and the basis for and possible limitations on the diameters of the slag bath and slag tap.

The characteristic parts of the demonstration plant, some of which represent new developments (first designs); special points of emphasis in development in pressure gasification of the coal by the flight-stream principle are:[41,42,43]

- the coal intake system,
- the integrated cooling system,
- the slag discharge systems, and
- removal of dust from product gas.

For controlled, unperturbed gasification, it is important to feed precisely metered quantities of fuel evenly into the gasifier. The continuous intake of dry, finely divided and dusty coal into a system under pressure was expected to present problems in the following areas.

1. Pneumatically conveying the fuel mixture at high pressure.
2. Precise dosing of the fuel mixture into the different delivery lines.
3. Monitoring this dosing so as to allow adequate control.
4. Minimizing the abrasion of material, especially the delivery pipes.

The tests have shown that the demands for high accuracy of dosing the coal to the four nozzles is not as critical as had been expected. The gasification process is not adversely influenced by small fluctuations in the coal feed. Up to October 1980, no abrasion has been found because of the relatively low velocity of carrier gas and coal dust in the feed pipes.

Problems have not been encountered with the gasifier cooling system, where a flux of 8.4 GJ/m^2-hr (740,000 Btu/hr-ft^2) is maintained, or with refractory erosion.

The gasifier is a cylindrical pressure vessel with approximate internal and external diameters of 1.48 and 1.90 m (4.85 and 6.23 ft) in Stages I and II, and 1.6 and 2.4 m (5.3 and 7.9 ft) in Stage III (Figure 2.17). It is about 16 m (52 ft) in height.

The coal gasification agent and the carrier gas are blown into the reactor through four nozzles. The nozzle head extending into the gasifier is water-cooled. The lance (inner pipe of the nozzle) consists of a carborundum pipe through which coal dust and carrier gas are introduced. There is a second pipe co-axial to the lance with oxygen and steam flowing through the annulus. The axial movement of the lance makes it possible to vary the velocity of the gasification agent when it meets the fuel. Thus, this adjustability of the annular gap in the conical region between lance and outer pipe allows the same velocities of the gas/solid mixture to be maintained at different pressure levels and for different throughputs.

The high gasification temperature must be dealt with by especially intensive cooling. At temperatures up to 2400°C (4350°F), local heat flux densities of up to 8 GJ/m^2h·r (700,000 Btu/hr-ft^2) can occur in the reaction flame for the case when the slag skin adhering to the inner wall of the reaction chamber peels off and the reaction flame is directed against the cooling wall. The Saarberg-Otto slag bath gasifier is therefore equipped with a specially developed combined boiling/condensing cooling system by which heat is carried out of the gasifier through heat exchange with a low pressure steam system.

It is believed that such a cooling system assures positive control of extremely high heat flux densities. It is so designed that at lower heat flux densities [≤ 4 GJ/m^2h) (350,000 Btu/hr-ft^2)] it operates as a pure pressurized water cooling system, and at higher heat flux densities [≥ 4 GJ/m^2h (350,000 Btu/hr-ft^2)] as a boiling/condensation cooling system in the range of sub-cooled boiling. The rest of the so-called film boiling regime (formation of a heat-insulating layer of vapor on the inner wall of the cooling pipe) is avoided by a high cooling water throughput.

The cooling system is designed so that it can be modified for pure boiling water cooling, which is more economical to operate, if sufficient operating experience has assured that heat flux densities > 3 GJ/m^2h (264,000 Btu/hr-ft^2) will not occur.

Measures have been taken against erosion-corrosion processes inside the gasifying-cooling system. The prepared feed water is adjusted to a pH of about 9.5. Since an operating temperature of about 200°C (392°F) is unfavorable for the formation of a magnetite protective layer, an initial passivation is undertaken by incorporating a several-day-long start up process at about 250°C (482°F). Recent (1980) material tests did not show any fatigue of the cooling tube material.

About 5% of the thermal energy is lost from Stage I of the gasifier. Therefore, the adjustment of the thickness of the slag skin has particular significance.

The correct transportation of the slag is also important for problem-free reactor operation. The viscosity of the slag can be adjusted by flux addition or reactor temperature change in such a way that it is sufficiently liquid and can be drawn off. Studies along this line will show the viscosity spectrum within which problem-free removal and discharging of the slag are possible.

To protect the reactor and the cooling system, an extensive temperature measuring system has been installed. These devices are to provide information on the temperature distribution and the maximum heat flux densities in the reactor. The data obtained are important in determining the later use of the cooling system in the boiling cooling mode.

The ignition of the gasifier is divided into two steps:

1. Heating the reaction chamber with gas, and

2. Switching from gas to coal dust, followed by a constant rise in the supply coal and gasification agent until the optimum operating conditions for gasification are reached.

In the Saarberg-Otto process, the four multi-substance nozzles perform the heating of the reaction chamber, using coke oven gas that is available from a nearby source. The gas is ignited by a special device which does not have to be removed from the reactor after the switch from gas to coal is made.

In the operating position, the ignition device extends through the slag runoff tap into the reaction chamber. The flame from the ignition burner ignites the gas-air mixture emerging from the four main burners into the reaction chamber.

When the ignition burner is no longer necessary--at a slag surface temperature of 600°C (1110°F)-then it can be retracted by means of a mechanical pressure-type actuator from outside the reactor. In its rest position, it is shielded from liquid slag and high heat radiation.

The waste heat boiler installed in the demonstration plant has been designed to handle the raw gas stream coming from the hot gas cyclone. As this gas is still laden with fly ash, provision has been made for cleaning the heat exchanger surfaces.

The removal of particulates from the raw gas required special designs to operate under the present system conditions [2.5 MPa, 850°C (360 psi, 1560°F)].

Mechanical cleaning of the hot raw gas to remove entrained slag and fly coke is performed by means of a hot gas cyclone. The cyclone operates at the system pressure and is lined with special high-grade abrasion resistant bricks. The use of a replaceable guard plate made of heat- and stress-resistant composite metal material instead of firebrick lining is a possibility. Up to 80% of the larger sized fly coke particles are removed in the cyclone where only 40% of the slag dust particles are removed. It has been found that about 55% of the dust removed by the cyclone has particle sizes between 30 and 80 μm (microns) while 15% of the dust is smaller than 5 μm (microns).

The material deposited in the hot gas cyclone at 850°C (1560°F) must be cooled to below 240°C (464°F) in order to avoid damage to the pumps of the sluice system. For this purpose a radiation cooler is used.

For fine dust removal from the raw gas, a high-pressure filter assembly is used which consists of two parallel hose filters. The filter hoses used are designed for a peak temperature of 320°C (610°F). Of the particles removed by the filter, 90% are smaller than 3 μm (microns) and 40% are smaller than 1 μm (microns).

The test program that was proposed for the Saarberg-Otto gasifier envisioned:

- o Extensive testing of the plant components separately and as integrated systems. This was performed from 1978 onwards.
- o Testing a solids pump as an alternative to the sluice system of the pneumatic coal and fly coke conveyor. Such a solids pump avoids the problem of handling the expansion gases from the sluice containers.
- o The ability of the combined boiling-condensation cooling to be modified into the more economical boiling cooling.
- o Determination of the most favorable muzzle velocities for the nozzles.
- o Replacing recycled gas by water injection to achieve cooling of the product gas in Stage III.
- o Two years of oxygen-blown operation followed by a year of air-blown operation.

Other components of the test program are:

- The determination of the flexibility of the gasifier in the presence of power variations (reactor load following).
- The determination of the minimum and maximum power of the gasifier at which reliable operation is guaranteed. When this is done the plant will also have to be run at different pressure levels (reactor turndown).
- The study of the temperature profiles and flow requirements in the reactor.

The following parametric tests are contemplated:

- The variation of the gasification agent mixture of oxygen and steam in order to study the possibility of influencing the gas composition,
- The production of a reducing gas at low gasification pressure and in the dry-ash operating mode,
- Gasification of different types of coal, coals with higher ash contents and variable clinkering properties, and the gasification of lignite,
- The simultaneous gasification of coal and hydrogenation residues,
- The variation of the particle size by grinding to determine the most favorable size of the fuel for gasification, and
- The variation of the fly coke/coal ratio.

Another important constituent of the test program is the use of additives for the desulfurization of the raw gas in the reactor.

During the entire test program, material studies will be performed with regard to strength and corrosion resistance. Other measurements will determine the environmental compatibility of the process.

During the first 100 hours of operation the following observations were made:[43]

The coal feeding system is one of the most critical parts of the plant. Both a mechanical and a pneumatic system were tested. Gasification was started using the pneumatic system while work with the mechanical version was continued in parallel.

Because of the very high gasification temperatures of 2400°C (4350°F) a sophisticated cooling system is necessary to control the great heat fluxes of about 8.38 GJ/m^2hr (737,900 $Btu/hr\text{-}ft^2$). No difficulties were encountered with the cooling water system. The initial protection of the tube wall construction by castable refractory was continuously exchanged by molten slag freezing on the cooled tube wall.

Process conditions for proper slag flow in the gasifier and discharge from the gasifier were determined. The influence of fluxing agents on slag viscosity was studied.

As mentioned above, particulate matter is separated by a cyclone, a waste heat boiler and fibrous filters. The fibrous filters remove the dust to less than 10 mg/m^3 (0.004 $grain/ft^3$) (standard). In the cyclone the dust content of the raw gas is decreased to less than 4 g/m^3 (1.75 $grains/ft^3$) (standard).

Table 2.23 shows the distribution of the particle sizes in the dust recovered in these three pieces of equipment.