3. SPECIFIC PROCESS UNIT DEVELOPMENT EFFORTS

Certain process units have been found to be critical with regard to operation of direct coal liquefaction systems because of the hostile environments encountered in these processes. This chapter of the report identifies some of these critical units.

From reports on foreign coal liquefaction projects, information has been gathered for each section. Most of the critical areas are related to coal constituents such as abrasive mineral matter and corrosive sulfur, chlorine and other compounds which impose stresses on mechanical components. Another limit that is being pushed back is size. In order to handle the volumes of raw materials and products that are potentially possible with the coming of a large synfuels industry, the size of some items of equipment is outside the range of cumulative experience of the industry.

3.1 Pumps for Coal Liquefaction Plants

Pump applications for a typical coal liquefaction plant are as shown in Figure 3.1. They are:

Slurry feed

Slurry recycle

Solvent recycle

Filter feed

Filtrate transfer

Filter bottoms

Fractionator bottoms

Char slurry

Operating temperatures for these pumps are expected to range from 115° to 380°C (240 to 720°F), and vary from less than 2 wt% to 50 wt %. Table 3.1 shows typical slurry pump services sized for a 25,000 t/day liquefaction plant.[1]

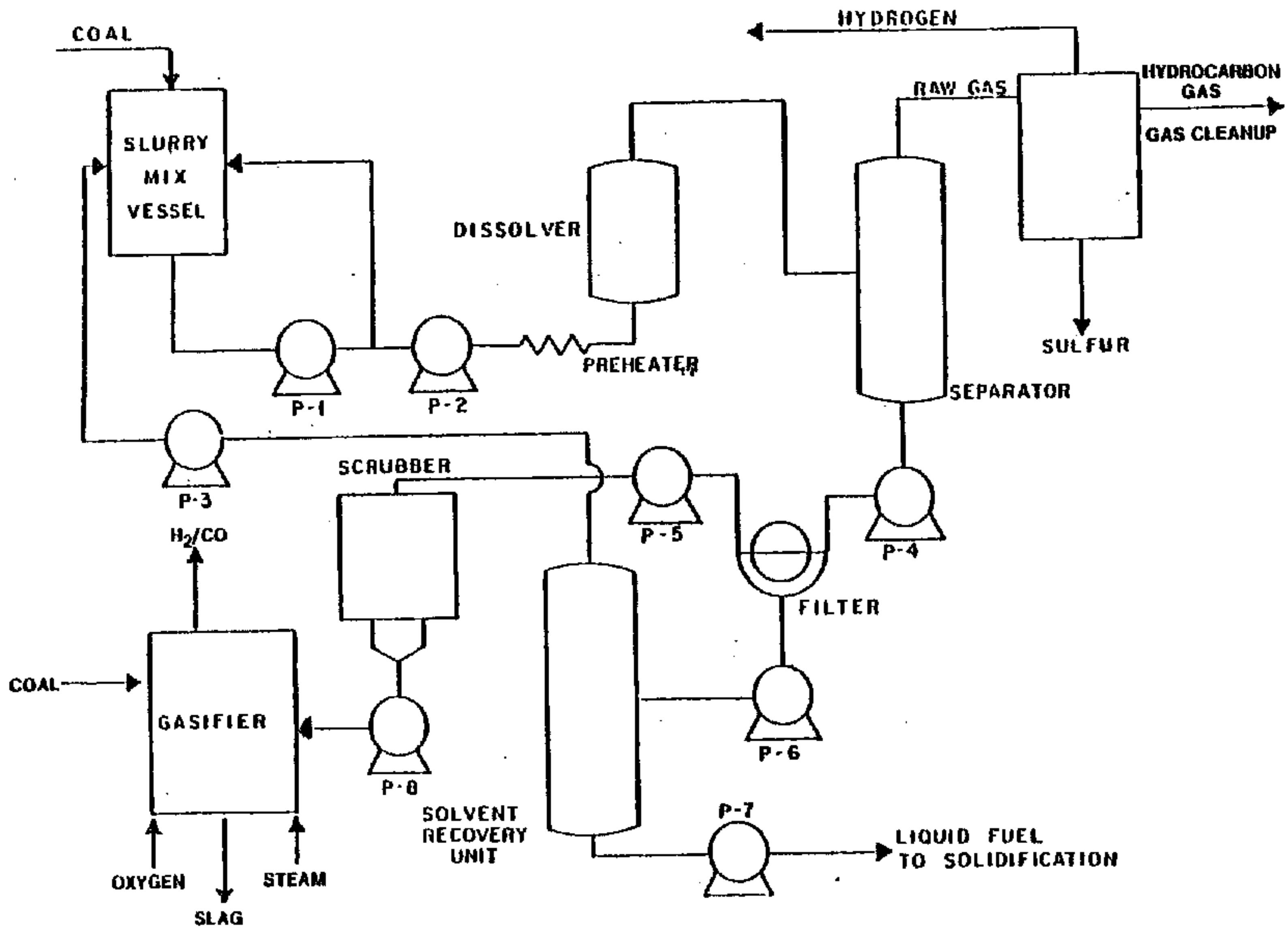

FIGURE 3.1
COAL LIQUEFACTION PLANT PUMP APPLICATIONS

Table 3.1. Typical slurry pump services for a 25,000 t/day coal liquefaction plant

Service	Total flow liter minute (gpm)	Disch. press. kPa (psi)	Suct. press. kPa (psi)	S.G. @ 15° temp.	°C (°F)	Head m(ft)	wt % solids
P-1 Slurry recycle	85,000 (22,500)	240 (35)	10 (2)	1.24/1.17	230 (450)	20 (65)	50
P-2 Slurry feed	47,000 (12,500)	15,200 (2,200)	200 (30)	1.24/1.17	230 (450)	1300 (4,264)	50
P-3 Solvent recycle	35,000 (9,250)	690 (100)	35 (5)	1.18/1.07	290 (550)	60 to 120 (200 to 400)	1-3
P-4 Filter feed	12,500 (3,300)	1,240 (180)	1,050 (150)	1.17/1.06	290 (550)	20 (65)	1-3
P-5 Filtrate pump	4,300 (1,140)	1,310 (190)	800 (116)	1.18/1.07	290 (550)	50 (164)	0-[illegible]
P-6 Filter bottoms	3,400 (900)	1,620 (235)	1,050 (150)	1.22/1.15	290 (550)	52 (170)	40-50
P-7 Fractionator bottoms	3,300 (870)	790 (115)	140 (20)	1.22/1.00	380 (720)	67 (220)	0-3
P-8 Char slurry	850 (225)	1,620 (235)	1,360 (200)	1.24/1.20	115 (240)	25 to 60 (82 to 200)	50

High-pressure slurry feed pumps in pilot plants are reciprocating-plunger type pumps. Discharge pressures required for processes currently under development are in the range of 11.0-21.0 MPa (1600 to 3050 psi). These pumps have operated successfully in pilot plants and reliability does not appear to be a problem. However, there is a size limitation — available pumps have a rating of 2250 kW (3000 hp) with maximum pumping rates of 3800 liters/minute (1000 gpm). For a 25,000 t/day coal liquefaction plant, slurry feed service would require 10 to 15 pumps.

Another approach is a multi-stage centrifugal slurry pump. It is judged that a proper multi-stage centrifugal pump may have a capacity of 15,000 liters/minute (4000 gpm), requiring only 3 to 4 pumps.[1] This could reduce pump costs significantly but extensive research and development will be required. There is no international proven pilot plant or industrial experience yet defined. The potential technology sources and candidate pump suppliers in West Germany are:[2,3]

Sources	Suppliers
VDMA Frankfurt, FRG	KHD Industrie Anlagen AG Cologne, FRG
	Sulzer Weise GmbH Bruchsal, FRG
	Weller Pumpen GmbH Kamen, FRG
	Deutsche Worthington GmbH Hamburg, FRG

Centrifugal pumps transferring coal and coal residue slurries have suffered severe erosion from entrained particulates and surface fatigue due to cavitation resulting from flashing gases. Slurry pumps are different from process pumps. They are run at low speeds to reduce erosion. As a result they are much larger in size, and produce a lower head/stage, with a normal head of approximately 45 m (150 ft) to 60 m (200 ft) and a maximum of 90 m (300 ft). (The practical limit according to U.S. experience is about 200 ft/stage.) Centrifugal slurry pumps could have a steel shell for pressure containment, but inside, the pumps would have a hard, chrome-iron lining and impeller. When worn, the parts could be easily replaced by taking the pump apart at the flanges. An average time between maintenance in current pilot plant operations is about 30 days. An alternative approach could be use of special impellers and linings of tungsten carbide, increasing the time between overhauls. Potential international technology sources are:[1,2,3]

Warman International, Ltd.
Sydney, Australia

Weller Pumpen GmbH
Kamen, FRG

Saarbergwerke of FRG has been working on a centrifugal slurry feed pump. Plans are to pump a 60 wt% solids slurry before diluting it with recycled solvent in two steps to 50 wt% and 38 wt%, respectively.[4]

Deutsche Worthington has designed a high temperature coal-oil slurry feed pump for the Ruhrkohle A.G. 200 t/day liquefaction plant. This pump is a 178 mm (7 in) minimum stroke vertical triplex pump designed for 280°C (540°F) slurry temperature and 32 MPa (4640 psi) discharge pressure.[3]

3.2 Heat Recovery Systems

Conceptual designs of direct coal liquefaction plants indicate thermal efficiencies in the range of 50 to 60 percent depending on effectiveness of heat and energy recovery systems. Pilot and demonstration plants could employ innovative approaches for higher thermal efficiencies. The Saarbergwerke 6 t/day pilot plant incorporates a vacuum flash step and recycling of a portion of the hot flashed gas stream, which contains a large proportion of solvent.[2,5] This is condensed in a slurry preheater exchanger to raise the temperature of the reactor feed slurry. Condensed solvent is also recycled forward and mixed with slurry. With these two recycle streams it is possible to preheat the feed slurry to at least 380°C (720°F). Claimed advantages of this arrangement are as follows:

- A fired furnace for preheating slurry is not required for normal operation. (Assessments by designers of U.S. demonstration plants indicate that preheat is likely to be required above 720°F. Preheating to 750-850°F may be needed.)
- A fired preheater furnace is provided for start-up, but operates only with solvent, not slurry, being heated.
- Lower operating pressures [about 25 to 28.5 MPa (3625 to 4133 psi) vs about 65 to 70 MPa (9430 to 10,150 psi)] are possible because asphaltenes are not recycled.

It is also possible that these developments will result in an increase of about two percentage points in thermal efficiency, a lowering of investment costs, and an improvement in process operation and safety.

3.3 Solid-Liquid Separation

All direct liquefaction processes share in common a need to separate the solid residue of ash and unconverted coal from the liquid product. However, the solid-liquid separation step does not have equal importance in all liquefaction schemes. For example, SRC-I produces solid boiler fuel and requires a thorough separation job whereas SRC-II and EDS processes yield lighter products and can make do with a less-complete separation step as a precursor to vacuum distillation. H-coal, depending on the mode of operation - solid boiler fuel or liquid fuel - will need either complete or less-complete separation.

Several techniques have been tested and/or are currently being tested at pilot plant levels in the U.S. and abroad.[6]

The SRC-I process at one time was based on the use of filtration methods. Development efforts were geared for better mechanical reliability, higher throughput rates and longer component life. Experimental work performed during recent years at SRC pilot plants in the U.S. already has eliminated rotary-drum and horizontal-leaf filters, either because these did not work well or would be too costly to scale up. The likely choice could be a vertical-leaf pressure filter developed by U.S. Filter Fluid System Corp., Whittier, California.[6]

A summary of foreign development efforts in filtration is presented in Table 3.2. The BBK candle filter will be tested at the 6 t/day SRC-I plant in Wilsonville.[4] The BBK filter is a joint development of the West German coal-mining industry's research center - Bergbau Forschung GmbH (Essen) -and the private firm of Boll & Kirch GmbH (Sindorf). It features a bottom discharge, and requires no sluicing. Commercial units have a filtration area of up to 10 m^2 (100 ft^2) but scale-up work to 400 m^2 (4000 ft^2) is underway. A simple design is said to allow operation at temperatures up to 350°C (660°F) and pressures of 0.6–1.0 MPa (87-145 psi). Filtration rates up to 600 $l/(m^2)$ (hr) (15 gal/ft^2-hr) help in holding down the size and number of units needed for a given throughput.[7]

The National Coal Board of the United Kingdom has also done considerable work in filtration and plans to use filtration for the 25 t/day Liquid Solvent Extraction process pilot plant. They have done fundamental and pilot plant investigations on rotary drum filters since 1976 and have been able to optimize digestion conditions and obtain fast filtration rates. The NCB is now testing prototype designs of continuous filters in their 30 kg/hr (66 lb/hr) pilot plant.[2]

Table 3.2 Solid /Liquid Separation Techniques

Country process	Separation technique	Comments
United Kingdom		
1) Liquid Solvent Extraction (LSE)	Filtration	o Rotary drum filters are being used at the 30 kg/hr (66 lb/hr) coal pilot plant. Investigation since 1976 has enabled NCB to optimize digestion conditions to give fast filtration rates.
		o Recent developments have led to hot filtration specifically designed for coal liquefaction application.
2) Supercritical Gas Extraction (SGE)	Pressure reduction	o Separation of extracted liquid is obtained simply by pressure reduction in a separate vessel whereby the extract is vaporized leaving behind the unconverted coal.
West Germany		
1) Bergbau-Forschung Hydrogenation Plant	High vacuum fractionation	o The system has been operating in 0.25 t/day pilot plant at Essen; the data have been used in the design of 200 t/day Bottrop pilot plant.
		o B-F has described use of a wiped-film vacuum evaporator for fractionation of the heavy coal liquids. They also have experience with other modes of vacuum fractionation of coal liquids.
	Filtration	o B-F and Boll & Kirch GmbH (Sindorf) have jointly developed a candle filter and it is to be tested at the SRC-I Wilsonville pilot plant.
		o B-F has also operated a small leaf filter.
Japan	Filtration	o Mitsui is operating a 10 m^2 (100 ft^2) Funda leaf at their Ohmuta, Japan pilot plant.

Mitsui of Tokyo, Japan is also operating a 10 m^2 (100 ft^2) Funda leaf filter at their Ohmuta, Japan pilot plant.[2]

Distillation avoids the direct mechanical process of solid-liquid separation. For processes like SRC-II, EDS, and H-Coal (fuel oil mode) which consume more hydrogen (to produce lighter fuels) than SRC-I, vacuum distillation is an attractive possibility for the required solids separation. Bergbau-Forschung of West Germany is using vacuum fractionation at its 0.25 t/day hydrogenation plant. Bergbau-Forschung has also described the use of a wiped-film vacuum evaporator for fractionation of heavy coal liquids.[2,5]

Deashing processes (critical solvent deashing and anti-solvent deashing) are under development by U.S. companies with no known foreign company involvement.

3.4 Pressure Letdown Valves

Coal liquefaction involves reactions of coal slurry and hydrogen at elevated temperatures and pressures. After the reaction is complete, the pressure is reduced to essentially atmospheric pressure by a pressure letdown valve (PLV) in preparation for product recovery and refining. The letdown valves must handle liquids with contained particulates and cope with the flashing of gases as pressure is reduced. Erosion and surface fatigue occur due to the high velocity of particles and the flashing of gases. The presence of hydrogen results in embrittlement of metal. Sizing of the valves is difficult because of the three-phase flow. Life expectancy of these valves at U.S. pilot plants has been 20 to 60 days. In some cases valves can be destroyed in one day.[2]

Among foreign countries, West Germany is leading the effort in developing pressure letdown devices. Bergbau-Forschung has operated letdown valves made of tungsten carbide continuously for 400 hours at their 0.25 t/day pilot plant in Essen, West Germany.[2,5]

Saarbergwerke has an alternative procedure for pressure reduction under development. They have designed, constructed and tested a device called a "pressure letdown machine" (PLM) in a 10 kg/hr (22 lb/hr) bench-scale liquefaction plant and claim satisfactory performance for 3000 hours operation as of March 1979. The device utilizes a reciprocating plunger with inlet and outlet control valves; it is similar to, in a mirror image sense, operation of feed pumps which raise the pressure from essentially atmospheric to the reaction pressure. With the PLM and associated power recovery equipment a significant amount of the power required to raise the feed slurry pressure to reaction conditions can be recovered. Saarbergwerke AG intends to test a larger unit in a 6 t/day pilot plant presently under construction.[2,4,5]

3.5 Gasifier Coal Feed System

Coal can be fed to a gasifier either in a dry non-compacted form or in the form of a water or oil slurry. For the Koppers-Totzek gasifier which operates at a pressure of about 300 kPa (44 psi), dry pulverized coal is injected into the gasifier by a variable-speed screw pump. High-pressure gasification pilot plants operated in the U.S. employ lock hoppers or slurry feeders. Lock hopper systems are expensive and can be troublesome to operate, and using a water slurry feed to entrained gasifiers can reduce thermal efficiency by about 8 percent. To improve the performance and economics of commercial plants a number of coal feeders are under development in the U.S. Developers include Ingersoll Rand, Foster Miller and General Electric. Table 3.3 gives a summary of gasifier coal feed systems in Germany and The Netherlands.

Table 3.3 Gasifier coal feed systems

Country/developer	Status
West Germany	
1) Werner & Pfleiderer (W&P) Stuttgart	Has screw-type coal feeder under development in cooperation with Ruhrkohle and Veba Chemical. Reported capable of feeding at pressures to 10 MPa (1450 psi).
2) Maschinenban Louise GmbH Cologne	States "stationary discharge machine" would perform satisfactorily to 5 MPa (725 psi) and 230°C (450°F). This is a pressure cylinder with internal rotating arms forcing movement of the coal to the discharge nozzle.
3) Saarbergwerke AG Saarbrucken	Design of Saarberg-Otto entrained gasification pilot plant included a solid coal feed system incorporating feed screws in conjunction with a pneumatic system. Pilot plant was in start-up phase.
4) Ruhrgas/Ruhrkohle/Steag, Dorsten	Solid coal feeding at 10 MPa (1450 psi) will be a part of the "Ruhr 100" program to develop a modified Lurgi gasifier to operate at 10 MPa (1450 psi). This unit is being built at Dorsten, FRG and was scheduled for start-up in 1979.
5) Ruhrchemie Oberhausen/Holten	Coal/water slurry feeding at 4 MPa (580 psi) is part of the Texaco gasification process development. Slurry concentrations up to 70 wt% have been achieved.
Netherlands	
1) Shell International Petroleum Maatschappig Den Haag	Shell-Koppers entrained gasification pilot plant located near Hamburg, FRG stated to include Shell-developed pneumatic feed system and feed rate measurement at pressures at 3 MPa (435 psi) in start-up.

3.6 Compressors

Direct coal liquefaction plants require process hydrogen to be generated by gasification of solids residue in a gasifier. Depending upon the type of gasifier selected, large amounts of oxygen will be required at pressures ranging from 300 kPa (44 psi) (absolute) (for the Koppers-Totzek gasifier) to about 11.0 MPa (1595 psi) (absolute) (for the Texaco gasifier). The oxygen will be provided by large conventional air separation plants which must be equipped with compressor capacity to 1) provide the feed air, and 2) compress the oxygen output to about 11.0 MPa (1595 psi) (absolute). For a commercial air liquefaction plant the size of the air compressor for 100% capacity will be larger than ever built before. Also, no oxygen compressor has even been built for the combination of capacity and pressure required. If a Koppers-Totzek gasifier is selected for hydrogen generation, then the generated hydrogen will require compression to high pressure.

The largest oxygen compressor known to be sold has 2600 t/day capacity at 3.68 MPa (534 psi) (absolute) discharge pressure. A 1,350 t/day compressor has a discharge pressure of 10.0 MPa (1450 psi) (absolute). Large single-train oxygen plants could reduce compressor capital cost, take advantage of the high efficiencies of large steam turbine drivers, and reduce operating manpower requirements. Firms having potential technical expertise and capability for necessary checkout and start-up support are:[8]

Sulzer Brothers
Zurich, Switzerland

Demag
Duisburg, FRG

The commercial-size plant will use a single centrifugal oxygen compressor in preference to a combination compressor train which uses dual reciprocating compressors of limited size for the final stages of compression to 11.0 MPa (1595 psi) (absolute).

In either event, two-case centrifugal compressors (low and intermediate pressure) would be used to raise the oxygen pressure to the 5.0 to 6.0 MPa (725 to 870 psi) range. Both vendors have two-case centrifugal oxygen compressors in successful operation. While neither vendor has applied his three-case (high-pressure) barrel-type compressor to 11.0 MPa (1595 psi) oxygen service, both have compressed other gases to much higher pressures in similar machines. Furthermore, Sulzer has at least five reciprocating machines compressing oxygen to 11.0 MPa (1595 psi) with a high degree of success. Therefore, oxygen compression requirements are a matter of applying proven centrifugal machines to a task which has heretofore been handled by limited-capacity reciprocating machines. Certain material changes (based on reciprocating experience) must be made in the centrifugal compressors.

The safety requirements and potential for oxygen fires will be essentially the same regardless of the type of final stage compressor used; however, during the last ten years oxygen compression has not proven to be unduly hazardous if proper precautions are applied. The best available guide for oxygen compressor safety is the European Working Panel Code of Practice. Should oxygen fires occur, they can cause extensive machine damage, hence, a generous sparing policy is indicated.

Operating and maintenance expertise gained in the operation of low- and intermediate-pressure centrifugal compressors can be directly applied to three-case compressors as well.

For air compressors (for oxygen plants), both DEMAG and Sulzer have proposed very impressive combination axial-radial compressors.[8]

Machines for 1500 tonnes/day (1650 tons/day) (based on oxygen production) are operating successfully. DEMAG has an axial compressor running which handles sufficient air for a 3000 tonne/day (3300 ton/day) oxygen plant and they also have proven radial compressors for that capacity which when added to the axial section would provide the required pressure. They have not actually built a machine using both of these sections on one shaft but the necessary design is complete and they are awaiting an application. Sulzer has a similar machine completely designed. It is one step larger than they have built [90 cm (3 ft) dia vs 80 cm (2.6 ft) dia]. The 80 cm (2.6 ft) dia units are the largest they have in operation. The larger unit has not been built only because there are no applications for it. Sulzer and DEMAG believe 3000 t/day air separation (oxygen) plants are "just around the corner".

Both vendors are capable of providing a single axial-radial combination machine to handle an air separation plant up to 3000 t/day plants. Sulzer also has a machine in service at 450 psi on a 2200 t/day plant in Burns Harbor, Michigan. The large machines are capable of 60% to 65% turndown by stator blade adjustment and/or speed control.[8]

3.7 Waste Heat Boilers

The reliability of a gasification plant depends to a great extent on the successful operation of waste heat boilers with high temperature and high pressure gases containing particulate matter. Steam generators are commercial today at low pressure and high temperatures. Steam superheaters are limited in temperature by metallurgy.

The Shell-Koppers pilot plant has been operated for a total of 760 hours during 30 experimental runs. The maximum duration run, which was 240 hours, was terminated by the fouling of the waste heat boiler by non-sticking solids.[9] Thermal shock, usually done by shutting down one burner to reduce temperatures by 50°C (90°F), was not successful. Steam is produced at 6 MPa (870 psi) and 520°C (968°F) and direct production of superheated steam in the waste heat boiler is much more desirable than saturated steam. The present waste heat boiler was designed for cross flow tubes and low velocities. Consideration is being given to redesign the waste heat boiler which will use higher velocities and parallel flow tubes. The waste heat boiler in the Saarberg-Otto pilot plant is of contemporary design. Since the raw gas stream coming from the hot gas cyclone is still laden with fly ash, capability for cleaning the heat exchanger surfaces is provided. In the Texaco pilot plant the gas flows first through a waste heat boiler, where it is cooled to below the ash fusion point. By deflecting the gas at the discharge end of this boiler the major part of the slag contained in the gas is separated out, granulated in a water bath and discharged via a lockhopper. The gas is then cooled down further in a second boiler.

The following companies are said to have experience with waste heat boilers for high temperature and high pressure gases containing particulate matter:[2]

1. Ruhrchemie
   Aktiengesellschaft
   Oberhausen, FRG

2. Rheinsche
   Braunkohlenwerke AG
   Cologne, FRG

3. L&C Steinmuller GmbH
   Albstadt (Ebingen), FRG

4. Linde Aktiengessellschaft
   Hossriegelkreuth, FRG

3.8 Acid Gas Removal Systems

There are several commercially available acid gas removal systems, and the selection of the most appropriate one depends on the pressure, the levels of hydrogen sulfide and carbon dioxide in the synthesis gas before treatment, the specified levels of these impurities after treatment, and whether it is necessary to split the hydrogen sulfide and carbon dioxide streams.

No problems are expected in the application of acid gas removal processes to coal conversion processes. Raw gas from the Shell-Koppers pilot plant located at Shell's Hamburg refinery is desulfurized in the refinery's acid gas removal process. Gas from Saarberg-Otto plant is sent to a nearby power plant for desulfurization. The Texaco pilot plant uses the Sulfinol process for removing acid gas from the synthesis gas. The Sulfinol system existed from the original Shell Oil gasification facility.

Present acid gas removal processes require cooling to temperatures below 120°C (250°F) and reheating for use in combined cycle power plants with a resultant thermal efficiency loss of 1 to 2 percent. To eliminate this efficiency loss, hot acid gas removal systems are under development and the potential technology source and their status are as below:[2]

Source	Status
STEAG/Lurgi Essen, FRG	Hot potassium carbonate system stated to have been tested satisfactorily in pilot plant to 120°C (250°F). This is stated to be a Lurgi process.
Hamburg Gas Works Hamburg, FRG	Lab scale tests of iron oxide system.

3.9 References

1. Worthen, R., "Equipment Needs In Coal Gasification and Liquefaction Plants", presented at the 4th Annual International Conference on Coal Gasification, Liquefaction and Conversion to Electricity, August 4, 1977.

2. Ralph M. Parsons Company, "International Coal Conversion and Utilization Technologies and their Application to the U.S. Coal Program", Draft Report, February 1979.

3. Bonerigo, J.E., "Report of A Trip to Boll and Kirch Facilities and Deutsche Worthington Facilities in West Germany" International Coal Refinery Company, Allentown, Pennsylvania, May 1, 1980.

4. Cochran, H.D., "Trip Report - Technical Details of European Coal Technology", Oak Ridge National Laboratory, Oak Ridge, Tennessee, August 4, 1980.

5. Strobel, B., Romey, I., Kolling, G., "German Routes to Coal Hydrogenation" paper presented at IGT Symposium on Advances In Coal Utilization Technology, Louisville, Kentucky, May 14-18, 1979.

6. Deutsch, D.J., "Solid/Liquid Separation Routes Are Nearing Demonstration Stage", Chemical Engineering, August 25, 1980.

7. Bixler, A.D., Rappe, G.C., "Trip Report - Visit to Krupp-Koppers, and Bergbau Forschung Essen", International Coal Refining Company, Allentown, Pa., June 16, 1980.

8. Nagle, J.W., Samuels, L.G., and Sassetti, R.F., "Trip Report-SRC-II Demonstration Plant Oxygen and Oxygen Air Compressor Study", July 20, 1979.

9. Vogt, E.V., and Van der Burgt, M.J., "Current Status of the Shell-Koppers Coal Gasification Process", paper presented at the 72nd AIChE Annual Meeting, San Francisco, California, November 29, 1979.

4. MATERIALS OF CONSTRUCTION

The literature describing overseas coal conversion projects was reviewed for insights into materials aspects of plant engineering and for information on the performance of materials. To facilitate international comparisons, a table of alloy standards designation correlations was compiled; this table is included in this report as Appendix C. Looking at the overall picture of coal conversion technology development, some programmatic generalities appear that relate to materials. In general, the work going on is developmental, not fundamental; the objectives are commercialization of specific processes. The emphasis is on the direct use or adaptation of existing technologies, usually from earlier coal conversion efforts and from the petroleum processing industry. That is, each process is a series of unit operations and each unit operation has a significant experience base. Only the specific combinations of unit operations and the specific process conditions are new.

While the selection of a given process is predominately dictated by the product requirements of a given country or region of a country, which for economic reasons may also be strongly influenced by existing or needed infrastructures such as distribution systems or colocated industries, a strong factor in the selection process is the type of coal available. Coal characteristics, such as sulfur, ash and chloride content, also have a significant impact on materials requirements. Materials selections are largely dependent on cost and availability. In many instances overall economics may suggest a process step modification or addition to permit the use of less expensive or more readily available materials or alloys. These are, of course, the normal products of design tradeoffs common to any large scale commercial venture.

Another form of tradeoff in materials selection is involved with the design life of various components. M. J. Cooke and D. M. Lloyd of the English National Coal Board[1] scoped this feature of materials selection well:

"The financial cost of unscheduled stoppages is high. It is essential therefore that unexpected component failures are avoided. The philosophy adopted when materials are being selected for coal utilization applications can depend greatly on the role and accessibility of the various components concerned. For cheap and easily replaceable items, (e.g. instrument probes) fairly frequent replacement, say after 1000 hours of operation, may be acceptable. Other components, (e.g. gas turbines and valves) could be replaced or refurbished on an annual basis, and therefore they may only need to be designed for about 10,000 hours operation to avoid unscheduled stoppages caused by their failure. However, particularly expensive or inaccessible items (e.g. reaction vessels and heat exchangers) would normally be required to survive the life of the plant which could amount to 100,000 to 200,000 hours of operation."

The materials problems associated with coal liquefaction have been extensively reviewed by others over the past few years[2-9] and will not be repeated here. It will suffice to observe that reviewers and available information on materials performance in U.S. laboratory scale process development plants and pilot plants indicate that the materials requirements for coal liquefaction are more stringent than those found in the existing petroleum industry.

In the United States there is a broad program under DOE sponsorship which is addressing many of the generic materials problems based in large measure on a recently published needs assessment.[10] In addition to this DOE-sponsored generic materials R&D program, there are materials testing programs associated with each of the processes under development specifically addressing the process equipment materials requirements for given types of coal. In initiating this assessment it was hoped that both generic broad based programs and specific process materials programs for the non-U.S. countries could be defined and evaluated. To date the success in this area has been limited. A number of government organizations monitoring, coordinating and funding process development have been identified. However, information on specific materials programs has been difficult to obtain.

The literature and other contacts indicate that, except for two exceptional situations, there are no general materials development programs in support of coal converison technologies in foreign countries. This may be attributable to the needs for economy and imminent design freezes which mandate the use of familiar, readily available materials. One of the exceptions is the Japanese exploration of coal gasification by the molten salt lime-slurry process.[11] The requirement for materials which can withstand the corrosive molten salt environment will determine the feasibility of the process. A statement from that project's report, however has general applicability: "...this process...depends on development of inexpensive anti-corrosion materials...". For more conventional processes, the emphasis is on inexpensive materials, not development of new materials.

The second exception is the materials development program of the Federal Republic of Germany (FRG) in support of the nuclear process heat (PNP) program.[12] The high temperatures (approximately 1000°C) proposed for coal gasification together with the unique safety and licensing requirements for these prcoesses has led to a unified program investigating environmental effects on both commercial and developmental alloys. However, in most conventional coal processing development areas, projects are not supported by a general materials program for the solution of problems of common interest.[13] In fact, several visitors to the FRG have noted that there appears to be a competitive rather than cooperative aura to the coal development projects, even though most of the support is derived from the federal and state governments.

This does not mean that materials research and development is not being done. Instead it appears that access to such information is being limited probably because such information, together with the specific components design details and operating procedures, are considered proprietary information that will provide a commercial advantage. This is particularly evident in Federal Republic of Germany supported programs where, according to our understanding, patent rights to the developments will be the property of the commercial organizations doing most of the development and pilot plant operation.