

**CANADA CENTRE FOR MINERAL AND ENERGY TECHNOLOGY
(Former Mines Branch)**

**REPORT ON THE VISIT OF THE CANADIAN DELEGATION
ON SOME DEVELOPMENTS OF THE COAL TECHNOLOGY OF
SEVERAL EUROPEAN COUNTRIES
FROM SEPTEMBER 26 TO OCTOBER 12, 1974**

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INTRODUCTION

In North America and the industrialized Nations of Europe, there is a rapidly growing realization that though nuclear power may relieve some of the strain on stationary power requirements, a large amount of liquid fuel is still indispensable for the operation of transportation systems and other mobile equipment. The recent Arab oil embargo made the dependence of the United States of America and Western Europe on foreign oil imports amply clear.

Even before the oil crisis, it was obvious that the petroleum resources of North America and Europe or even the whole world could not satisfy future demands for oil to support present growth rates of the world's major industrialized nations.

As a consequence, the industrialized nations of the world are searching for a diversification of their energy resources and are developing alternate processes or combinations of processes to make better use of those energy sources located within their boundaries.

The discrepancy in the energy supply and demand and the necessity to minimize the insecurity and expenditure of foreign exchange associated with petroleum imports, induced the industrial organizations and government agencies of these nations to examine if their coal deposits could be used to augment their oil and gas supplies. Coal is the most abundant fuel in the world. The reserves of about 8.9×10^{12} tons contain about 7.8 times the energy of all crude oil and about 28 times the energy of all the natural gas reserves in the world. Conversely to this coal provides at present on a world scale only 33% or 2.38×10^9 tons of the 7.2×10^9 tons total energy equivalent, as compared to 3.25×10^9 tons for crude oil and 1.58×10^9 tons equivalent for natural gas. Based on a recovery of only 50% of the coal reserves of the world, they will, at the present level of consumption of 2.4×10^9 tons per year, last for about 1,850 years and even if the coal production would increase to 2.5 times the present consumption at an extraction rate of 67%, the coal reserves would last 1000 years.

The increasing awareness of the public of the pollution caused by large thermal power stations, burning coal, in conjunction with the relatively low price of crude oil and natural gas, lead to the conversion of a considerable number of those facilities to oil and natural gas. The growing scarcity of the petroleum and gas reserves in North America, which was predicted by geologists about 55 years ago (on this prediction the German coal liquifaction plants were built), begins to make itself felt by the steady and considerable price increase for these products in relation to coal and provides the incentives to switch back to coal.

To insure that the coal's full contribution to the national economics of the industrialized nations is realized as soon as possible, the latter are embarking into extensive research and development programs. An effort is being made to co-ordinate research in various countries and international co-operation is encouraged. International agreement on coal research co-operation between the U.S. Department of the Interior and the U.K. National Coal Board is already in force and the U.S.A. and the Federal Republic of Germany are negotiating a similar agreement.

Although Canada possesses large reserves of bitumen in the tar-sands of Alberta, this material requires several refining operations before it can be transported and used in existing equipment. The increasingly stringent constraints set by the anti-pollution legislation and especially the necessity to minimize the cost of transportation of energy from the fossil fuel reserves in the west to the distant energy consuming centres in the east, made it advisable to study the Coal Technology of the United States of America and of the industrialized nations in Europe for possible application of this technology for the benefit of the Canadian economy. For this purpose a delegation consisting of 12 members from various parts of the country and from different agencies of federal and provincial governments and industries was sent to Europe to contact industrial and government research and development institutions to gather information on the present status of their technology and possibilities of future development as well as to discuss views and strategies with respect to future energy needs and related problems.

As Canada at present has no international agreements on coal research and exchange of technological expertise, the west european tour of the Canadian delegations was made possible through bilateral agreements between Canada and the countries visited.

The information presented in this report was obtained from a multitude of sources, in some cases as written material but mostly by oral communication. In order to make this information easier to understand, it is not given in chronological order or by source but related to a specific field of interest or subject.

ENERGY POLICIES AND R & D PROGRAMS

The European Common Market countries plan to reduce their dependence on imported oil by trimming the specific energy consumption and developing alternate energy sources about as outlined in Table 1.

TABLE 1
Common Market Countries Energy Use Pattern

	1973		1985 Forecast		1985 New Objectives	
	10 ¹⁵ kcal	%	10 ¹⁵ kcal	%	10 ¹⁵ kcal	%
Solid Fuels	2.39	22.7	1.84	9.7	2.63	15.9
Oil	6.48	61.4	12.17	64.4	6.86	41.6
Natural Gas	1.22	11.5	2.77	14.7	3.94	23.9
Hydroelectric Power	0.31	2.9	0.43	2.3	0.36	2.2
Nuclear Energy	<u>0.14</u>	1.3	<u>1.67</u>	8.8	<u>2.72</u>	16.5
Total	10.54		18.88		16.51	

The consumption of energy was forecast to rise by 80% and oil consumption by 88% in 1985 but as a consequence of the oil crisis, these figures have been revised to 57% increase in total energy and only 6% in oil consumption. The difference is to be supplied by natural gas, nuclear energy and to some extent by solid fuels. The common market countries plan to increase their own output of natural gas and oil mostly from the North Sea. The new program would reduce the dependence on outside energy sources from 63 to about 40% and its objectives shall be reached by investing a total of \$300x10⁹ (in 1973 \$) over a 10 year period. Of this, about \$120x10⁹ is to be invested in nuclear plants and about \$30 to \$60x10⁹ in thermal and other

power generating stations. For the production of oil and gas, about $\$110 \times 10^9$ will be spent while the increase and especially modernization of coal production, will require about $\$6 \times 10^9$. The overall energy investment during the next 10 years will increase to 2 - 2.5% of the gross national product of the ECM countries, as compared with 1.5% during the years 1965 to 1970.

The pattern of use of energy in the Federal Republic of Germany is presented in Table 2.

TABLE 2
The Use of Energy in the Federal Republic of Germany

	1973		1985	
	10^{15} kcal	%	10^{15} kcal	%
Solid Fuels	0.79	30.8	0.81	21.4
Petroleum	1.41	55.1	1.63	42.8
Natural Gas	0.26	10.3	0.69	18.2
Hydroelectric Power	0.06	2.5	0.08	2.1
Nuclear Energy	<u>0.02</u>	0.9	<u>0.60</u>	15.7
Total	2.56		3.81	

At present Germany derives her energy supplies to over 95% from fossil fuels. Extreme dependence on oil ($\approx 55\%$ of the total energy) and natural gas ($\approx 10\%$) make the German industry very vulnerable as 97% of her oil supplies and 50% of her gas supplies must be imported.

In order to reduce the dependence on foreign oil imports, the Federal Republic of Germany has initiated a substantial energy research and development program. In the five year period from 1974 to 1978 a total of 1500×10^6 DMk (= $\$610 \times 10^6$) will be spent on non-nuclear energy and related research, of which about $\$250 \times 10^6$ is to be used for coal gasification and

liquifaction. About $\$135 \times 10^6$ is spent on coal mining research and coal preparation, while for prospecting and development of deposits, $\$71 \times 10^6$ is spent. Research on energy transportation, transformation and storage, will be funded with about $\$110 \times 10^6$. In addition, for research on rational utilization of energy (+reduction of waste and losses) about $\$23 \times 10^6$ will be spent. Concurrent to this, on nuclear research, in the same period, about 6.15×10^9 DMk ($=\$2.5 \times 10^9$) will be spent. These funds are distributed in the form of grants to various national and also external companies and institutions conducting research in the field of energy development. These grants can cover between 50 and 100% of the expenditures for a given project.

In the United Kingdom, a coal research program has been proposed which would require about $\pounds 17.55 \times 10^6$ ($=\$41.7 \times 10^6$) to be spent over a period from 1975 to 1979. The research extends mainly to mining safety and increased mechanization as well as coal combustion, coking and gasification.

The pattern of use of the various forms of energy in the U.S.A. differs considerably from that of the European countries as is shown in Table 3.

TABLE 3

Energy Use by Energy Forms in U.S.A.

	1970		1980	
	10^{15} kcal	%	10^{15} kcal	%
Solid Fuels	3.87	22.8	5.50	21.8
Petroleum	7.27	42.8	11.26	44.7
Natural Gas	5.59	32.9	6.24	24.8
Hydroelectric Power	0.22	1.3	0.31	1.2
Nuclear Energy	<u>0.05</u>	0.3	<u>1.89</u>	7.5
Total	16.99		25.19	

It is surprising that in spite of the experiences during the oil crisis, the share of petroleum on the total energy consumption does not decrease and in fact, the absolute value of energy from coal and petroleum still increases considerably more than the nuclear energy. This reflects the fact that the development of nuclear energy and new coal conversion processes, in spite of massive spending, proceeds too slowly to show any effect until 1980.

The U.S.A. have an extensive coal research and development program and in their quest for independence from overseas energy imports, will spend in their energy development, about $\$985 \times 10^9$ over the next 20 years, which is approximately 5% of the gross national product. The five year coal utilization program of the Office of Coal Research (OCR) shall provide the advanced technology for economical utilization of coal with minimal influence on the environment. This program is organized into 8 areas with funds allocated to each field as presented in Table 4.

TABLE 4

Office of Coal Research Coal Utilization R & D Program

<u>1975-1979 Funding in</u>	<u>\$ Million</u>	<u>%</u>
Coal Liquifaction	647.3	24.2
High BTU Gas	363.8	13.6
Low BTU Gas	484.2	18.1
Direct Combustion	342.4	12.8
Advanced Power Systems	200.7	7.5
Advanced Research & Supporting Technology	130.1	4.9
System Studies	30.5	1.2
Pioneer Plant Projects	417.1	15.6
Administration & Supervision	<u>53.5</u>	
Total OCR Spending	2669.6	

The objective of the Coal Utilization Research and Development Program is to develop on an accelerated and cost effective basis, technology which will permit the rapid commercialization of coal conversion and direct combustion processes, which are technically as well as economically sound and environmentally acceptable and also represent a wise utilization of natural resources. The program includes continued research on existing coal utilization processes as well as on a number of new promising projects, operation of pilot plants for the acquisition of data applicable to process-optimization and further on the operation of demonstration plants for the development of realistic technologic and economic data for full scale commercialization. The program is organized into eight areas: 1) Liquifaction 2) High Btu Gas 3) Low Btu Gas 4) Direct Combustion 5) Advanced Research and Supporting Technology 6) Systems Studies 7) Piggy-Back-Pioneer Plants and 8) Demonstration Plants.

In the coal liquifaction program the solvent refined coal process is most actively pursued. A large scale pilot plant is constructed near Fort Lewis. Five other plants for investigation on direct catalytic hydrogenation, coal pyrolysis variations and of the Fischer-Tropsch process are proposed.

The known coal deposits in the U.S.A. account for about 68% of its total energy resources and it can be expected from the results of the investigations, conducted at a multitude of public institutions and private enterprises, a well developed, improved coal technology, will emerge, hopefully without the undesirable side effects as experienced in Europe a century ago.

The Canadian energy use pattern is somewhat different from that of the U.S.A. The use of solid fuels is relatively low compared to petroleum and especially hydro-electric power. No long range program on coal research has been made public yet. A proposed five year combustion research program, mainly aimed at reduction of air pollution, requires a total spending of about $\$5 \times 10^6$, which would be financed jointly by industry, federal and

provincial governments. On coal research and development activities in 1973-74, about $\$4.6 \times 10^6$ was spent, while for development of nuclear energy and related activities, 14 times as much, i.e. $\$63.8 \times 10^6$ was allocated.

Among the private companies, Canada Pipelines is conducting a feasibility study on manufacturing SNG from coal, costing $\$8 \times 10^6$, which is to be raised by increasing the price of gas.

Table 5 presents some figures on the Canadian use of various forms of energy.

TABLE 5
Use of Various Forms of Energy in Canada

	1970		1980	
	10^{15} kcal	%	10^{15} kcal	%
Solid Fuels	0.16	8.7	0.19	5.0
Petroleum	0.82	44.6	1.59	41.7
Natural Gas	0.68	36.9	1.21	31.8
Hydroelectric Power	0.16	8.7	0.23	6.0
Nuclear Energy	<u>0.02</u>	1.1	<u>0.59</u>	15.5
Total	1.84		3.81	

Remarkable on the Canadian energy development program is that the relative contributions of the fossil fuels are not too drastically altered. Their absolute quantities increase a little less than the overall increase of energy consumption. The main share of the increase is taken up by nuclear energy, which in Canada, contributes about 90% of the total energy reserves in place.

France imports about 75% of her total energy needs and about 32% of her coal consumption and her dependence on foreign imports grows every year. The research and development of coal utilization in France is centred mainly in the Centre d'Etudes et Recherches des Charbonnages de France (Cerchar). The total expenditure on research was, in 1973, about 56×10^6 Fr. Fr. ($\$12.7 \times 10^6$) in mining and 15×10^6 Fr. Fr. ($\$3.4 \times 10^6$) on coal utilization and upgrading. Except for some research in coal carbonization (Coaltek) and anti-pollution, no work is done on coal conversion.

In Belgium, the principal areas of coal research are the mining and mining safety and increase of the productivity of the Belgian mines. Besides this, research in underground gasification, applicable to thin layers, is in progress.

The South African coal mining industry produces about 60×10^6 metric tons annually, of which 54% are used for power generation; 9.2% for metallurgical purposes and only 7.5% for gasification. Coal supplies over 3/4 of the energy needs of the country and about 4% is exported. Research activity in South Africa on coal production and utilization is co-ordinated in two main organizations: The Chamber of Mines handles, besides others, geological survey, rock mechanics, water control and mine safety. The Fuel Research Institute of South Africa is required to undertake scientific and technical research on all matters relating to fuels and as in South Africa no fuel deposits are known other than coal, the work of the FRI has been concentrated on this type of fuel. The financing is very modest; the budget for 1975 is about $\$2 \times 10^6$. Besides this, the private sector of the coal industry is actively engaged in research, especially the Sasol Research and Development Dptm., which works not only on improving the gasification of coal but is also doing research on solvent refined coal. The South African coal deposits were estimated in 1970 at 37×10^9 tons; later findings, however, double this figure.

Australian coal resources are estimated at 111.4×10^9 tons bituminous coal, 0.51×10^9 tons subbituminous coal and 86.7×10^9 tons lignite. The coal consumption was in 1972-73, about 56.8×10^6 tons bituminous coal, 2.7×10^6 tons subbituminous coal and 23.7×10^6 tons lignite or a total of 83.2×10^6 tons.

Research is carried out in the field of mining, rock mechanics, mining safety, coal beneficiation, coal processing including solvent refining, combustion and gasification. The expenditure of large sums of money is contemplated for research on processes for the production of oil and gas from coal by the Australian Fuel Research Institute.

COAL MINING

In all western industrialized nations it is expected and the reversing of the downward trend in coal production in those countries confirms this, that coal in the very near future will play an increasingly important role in the further development of the industry and the well being of the population. In order to familiarize the members of the Canadian delegation with modern coal mining technology, a deep underground mine - Fuerst Leopold in Dortmund Dorsten - and an open pit lignite mine - Garsfeld of the Rheinische Braunkohlen Werke AG, were visited.

Hard Coal Mining

The hard coal mining industry in Germany is almost completely organized in the Ruhrkohle AG which produces 95% of the German bituminous coal output. The number of operating mines has been reduced from 135 to 35. The coal output has decreased from a peak of about 150×10^6 tons in 1957 to about 97×10^6 tons in 1973. The production per operating point rose from 212 ton/day in 1957 to 1086 ton/day in 1973; the production per man-shift from 1.6 tons to 4.3 tons in the same period. This has been achieved by a high degree of mechanization of the "longwall" mining method. 95.8% of the longwall faces (average length 150 to 300 m) are fully mechanized while haulage of the coal is at present only 63.9% mechanized. The productivity per man-shift in Germany of 4.3 tons compares with 3.6 tons for Great Britain, 3.5 tons for Poland, 2.8 tons for France and 2.6 tons for Belgium. The current investments per year in the deep coal mining industry in Germany have decreased from a high of 5.49 DMk./ton in 1957 to 2.45 DMk./ton in 1973 at constant value of the DMk. The number of employees has receded from 384,300 in 1957 to 110,300 in 1973. The mechanization will still be increased mainly by replacing the haulage cars by conveyor belts and changing the hoist to skip hoisting. Improving the underground communication and automation-control of the haulage contributed greatly to a reduction of accidents which stands at present at a rate of 1 accident per 1000 man-shifts,

about the same as in the U.S.A., while in the U.K. 0.29 fatalities per 1000 man-shifts occur. There is about the same amount of coal deposited in depths below 1200 m as is above this depth. The extraction of this coal would, however, require much larger centralized cooling systems for the air pumped into the mine as used at present. The average working temperature in depths of 1200 m is, in Germany, about 28°C (82.4°F); in 1600 m depth it would be 45°C if the air were not cooled. Hydraulic mining is not practised yet in Germany. Coal deposits up to a depth of 1500 m are estimated at $21 \cdot 10^9$ tons, of which, with the present technology, about 50% can be extracted. The world price for good coking coal is at present U.S. \$80 to 100 per ton.

Lignite Open Pit Mining

The strip mining of lignite is much less labour intensive but slightly more capital intensive than deep mining; the average productivity including some less modernized mines is 81.5 tons per man shift, i.e. about 8 to 18 times as much as with deep mining. The number of accidents per 1000 man-shifts is 0.029, i.e., negligible compared to deep mining of 1 per 1000 man-shifts. The costs per unit heat in lignite is about one-third of the costs of bituminous coal. The application of large pieces of machinery, bucket wheel excavators moving 100,000 and even 240,000 metric tons/day of over-burden with an installed power of 12 and 16 MW and conveyer belts of up to 3.2 m width and moving at 6 m/sec and recently, 3.8 m width and speeds of 8 m/sec, make it economically possible to strip mine lignite with an over-burden/coal ratio of up to 6 and in depths of up to 300 m. Similar excavators but with a lesser capacity are used to break and move the coal. The conveyers are capable of overcoming grades of up to 30° and prove to be more economical than rail cars. These conveyer belts transport the over-burden from the worked side of the mine opening to the other side where it is dumped by stackers and spreaders similar to the excavators. The conveyer belts are several kilometers long and transport the coal from depths of over 150 m right to the surface. The over-burden is removed in layers to conserve the top soil, which

is stored until sufficient land is filled back. In spite of this the land requirement is relatively low; about 4 m^2 per ton of coal. After proper grading, the backfill is covered with 2 m of top soil. This reclaimed land is then farmed for 5 years by the coal company before it is sold back to the farmer from whom it is taken. This land reclamation makes the lignite mines the biggest land dealers in the country and requires large capital investments for acquiring besides the mining right, the surface rights for the mined area as well as land for temporary storing of the over-burden and top soil to "open up" the mine. The price installed of one $240,000 \text{ m}^3/\text{day}$ excavator was given at \$46,000,000; due to its size it must be assembled at the mine site, which takes about 4 years because it weighs about 16,000 tons. The conveyer belts have drivers of up to 1.5 MW each. An open pit mine of about 12 km^2 area at the top can produce about $3 \cdot 10^6$ tons coal/day but this could be increased to $6 \cdot 10^6$ tons/day. A special problem is the disposal of the mine water, which in such a large opening is about 14 m^3 per ton of coal in average. The Rheinbraun intends to build a subterranean tunnel of several 100 km length to transport this water to places where it is needed. During the years 1960 to 1970 the lignite production rose from 75 to $92 \cdot 10^6$ tons per year while the production of hard coal from deep mine decreased from about $150 \cdot 10^6$ tons to about $95 \cdot 10^6$ tons/year. The moving of the over-burden constitutes about 40% of the cost of the coal.

Mining Research

A number of research institutions, operated by the governments of the respective countries or by large groups of industries mostly with financial support by the government are working on projects related to accident prevention, mine safety, dust abatement and rock mechanics. Special fields like mine rescue, silicose prevention and other vocational diseases are explored in special institutions. In other research institutes stratigraphic and tectonic explorations of the bituminous coal deposits and development of methods for the observation, presentation and pre-reconnaissance of rock structures is carried out. New mining machinery can be tested such as

tunnelling machinery and coal planers for longwall mining of bituminous coal as well as mine rescue equipment. A significant portion of the work is devoted to air supply (Wetterfuehrung) climatization and dust abatement of the mines. The institute for Bergbau-Forschung of the Steinkohlenbergbauverein in Essen has a large test rig for rock investigations as well as testing of roof support equipment, which can generate pressures of up to 720,000 kp in continuous cycles. Also, full scale models of mine tunnels can be subjected to high pressures in various directions.

COAL CONVERSION

A. Classification and Cleaning of Coal

Besides mining research, a large portion of the work of European Coal Research Institutes is devoted to coal beneficiation and coal conversion. Work on coal beneficiation is directed towards optimization of the coal classification for the particular application of the coal, i.e. mainly steam coal or coking coal, with emphasis on the elimination of the pyrite and concentration of the vitrinite in the coking coal. 40% of the German coal production is used by the coking industry and 25% of the coal is consumed in the iron industry. The finest dry coal is separated by wind sifters and not by gravity flotation and cyclones. Due to improved coal preparation methods, smaller particle size and enrichment of vitrinite, the coke quality and the reserve basis for the coking industry has been considerably improved.

B. Coal Carbonization and Coking

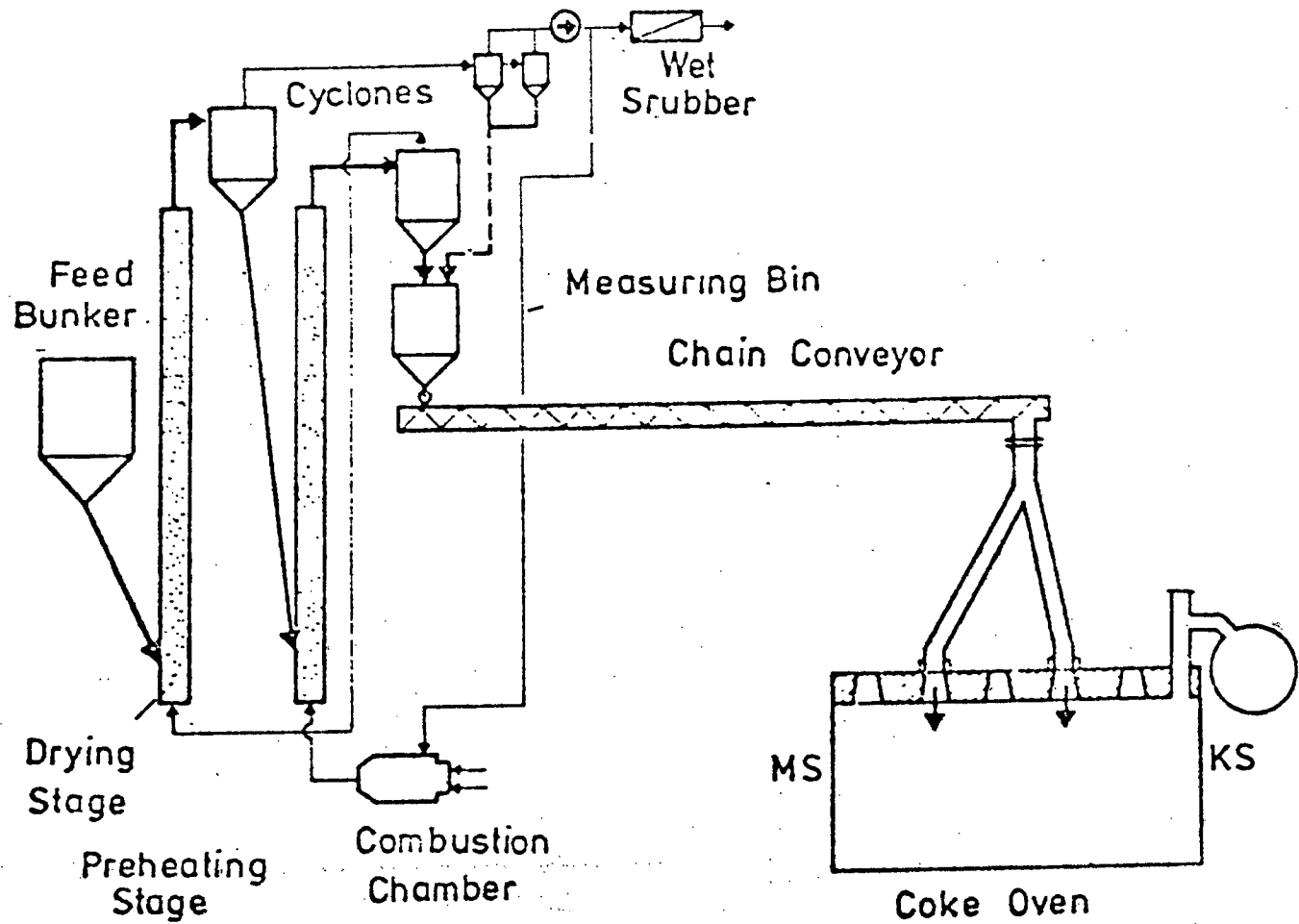
The carbonization of lignite has not appreciably changed since about 1935 when dried and briquetted lignite was carbonized in a hot gas stream to coke, hard enough to be used in low shaft blast furnaces for iron production. The iron industry in western Europe uses now about 40% of the bituminous coal produced there in 22 coking plants. Mainly 3 methods are explored to improve the quality of the coke and above all, to improve the economics of the coking operation.

1. Computer assisted investigations in commercial coke ovens are carried out for the shortening of the time required for coking one charge by the optimization of their heating cycles. At the beginning of a cycle when the coal must be heated to the coking temperature, a larger quantity of heating gas is used than at the end of a cycle, when the conversion of the hot coal to coke is completed. In conjunction with the use of

thinner bricks in the fire walls and the use of brick materials of better heat conductivity such as MgO and SiC₂, and designing the heat regenerators with a larger heat transfer surface which simultaneously permitted the use of higher flue temperatures, a considerable increase of the throughput and some improvement in the coke quality of a slot oven plant can be realized. The retention time can eventually be reduced from 30 to 15 hours.

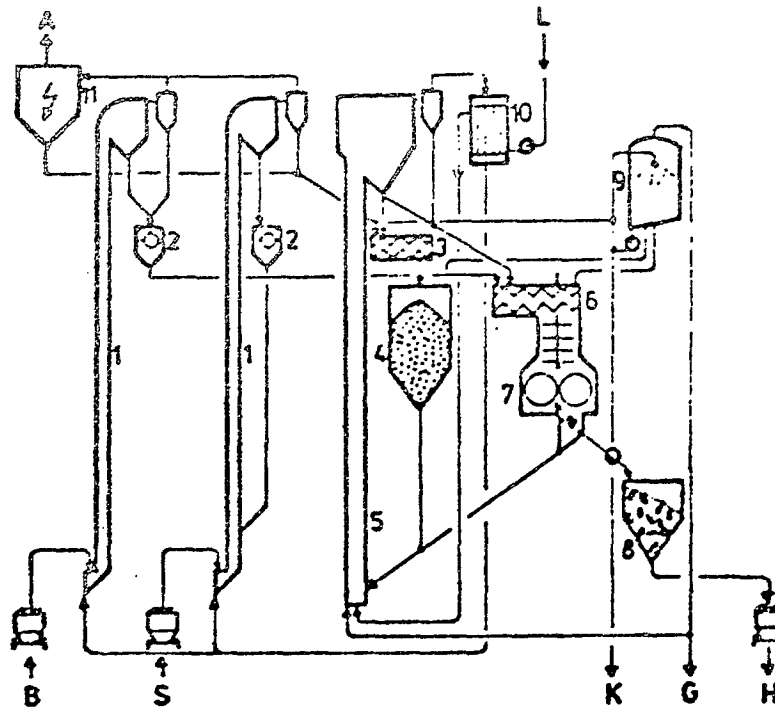
2. By supplying the heat for drying and preheating the coke charge by means other than through the heating walls of the slot ovens, retention time and investment capital can again be reduced and the lifetime of the heating walls can be extended by avoiding their cooling by the cold coal charge. In the Precarbon Process of the Bergbau-Forschung, Germany (see diagram) coal is dried and preheated in a two stage fluidized drying system to about 200°C (see Figure 1). This operation is performed continuously with hot combustion gases in separate equipment. The coal is then transported by chain conveyers to the slot ovens, which it fills more densely and evenly without planing as the hot coal flows easier. A reduction of the residence time from 20 to about 12 hours can be achieved and as the charge is heated more evenly, the coke shows a better quality and can be discharged at lower temperature. The first industrial plant of this kind is being constructed for the U.S. Steel Company near Chicago. In the Coaltek process, which is similar, the coal is transported pneumatically, therefore large amounts of dust are blown over into the first condensation stage.
3. The slot oven coking is a batch process and there are limitations on the coking characteristics of the charge coal. By using the experiences made with the carbonization and briquetting of lignite, several new methods of producing the so-called formcoke have been developed. One of them is the Bergbau-Forschung-Lurgi process (see Figure 2). In order to obtain form-stable briquettes, about 70% of the coal with no particular requirements on its characteristics except a high volatile content, is dried and carbonized to reduce its volatiles as far as possible. The

FIG. 1



Precarbon-System
(Pilot Plant Emil)

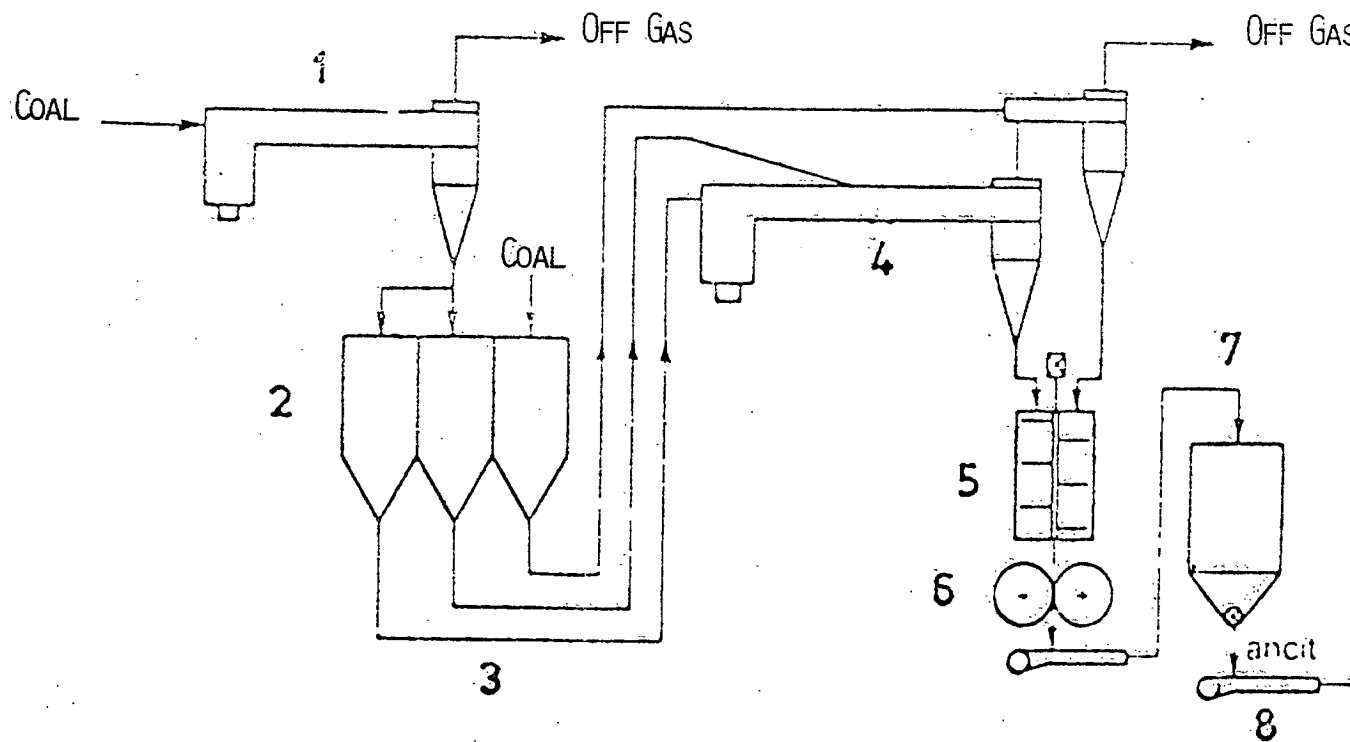
FIG. 2



FLWSHEET OF THE
BERGBAU-FORSCHUNG
LURGI FORM COKE
PROCESS

- | | | |
|-----------------------|-------------------------------|--------------------------------|
| B binder coal | 3 mixer | } Lurgi-
Ruhrgas-
system |
| S coal for charmaking | 4 hopper | |
| K oil | 5 air lift | |
| G coal gas | 6 mixer | |
| H hot briquettes | 7 press | |
| A flue gas | 8 cooler | |
| L air | 9 condensation | |
| 1 coal flash dryer | 10 air preheater | |
| 2 crusher | 11 electrostatic precipitator | |

FIG. 3



- | | |
|---------------------------------|--|
| 1. PRETREATMENT | 5. MIXING DEVOLATIZING |
| 2. STORAGE | 6. BRIQUETTING |
| 3. COLD DOSAGE | 7. COOLING |
| 4. DRYING, GRINDING, PREHEATING | 8. AFTERTREATMENT, AUTOTHERMIC CARBONIZATION |

ANCIT - HOTBRIQUETTING PROCESS
(ESCHWEILER BERGWERKS - VEREIN)

drying of the 30% binder coal is performed in the entrained state with hot air. Immediately thereafter, the dried binder coal is mixed with the carbonized coal and the hot mixture briquetted. These briquettes, which contain only 6% volatiles, may then be used directly in the blast furnace but it is technically, as well as economically advantageous, to subject them to a final continuous coking operation in which they retain their shape and size. This process is installed at the Prosper-Plant in Germany. The short retention times permit an increase of the throughput to several times that of the slot ovens.

The other important formcoking process is the one developed by the Eschweiler Bergwerksverein, the so-called Ancite process (see Figure 3). Here also, about 70% of a low volatile non-coking fine coal is blown at two locations into a horizontal entrained (Flugstrom) reactor. Due to the fast heating of the coal to 600°C, it is thermally disintegrated by water evaporation. The heated coal is separated in a cyclone and mixed with 30% of a preheated coking coal in a hot helical mixer. The coal mix emanating from it is plastic and in this state is briquetted hot. A second high temperature carbonization beneficiates the formcoke to blast furnace quality.

Both the above processes are operating in a 250 ton/day plant and plants of 700 ton/day are in the planning stage. These processes have shown better results than the Caltek or Simoncarb processes. The Bergbau-Forschungs Institute investigates also the production of plastic compounds from coal on a bench scale by admixing polymers to the coal and extruding it.

The research on coal conversion in the U.K. centers around the improvement of the coking of bituminous coals for metallurgical purposes. The research establishment of the British Carbonization Research Association in Chesterfield, which is 62% owned by the British Steel Corporation and the National Coal Board, has a customer contract relationship. Each project

is dealt with separately because now funding is available through the European Economic Community.

The establishment in Chesterfield concentrates its efforts on the heating walls by using pilot ovens which allow them to measure the temperature distribution and other variables during the coking operation. A five ton slot oven for preheated charge is being operated for studies of the influence of heating rates, heat transfer rates, production and properties of tars and other by-products, naphthalene and gas compositions as well as effluents. The by-product shortage dominates the targets.

Besides this one, there is a 4.5 m high oven for 10 tons charge and a 6.5 m high oven for 17 tons charge will be ready in the spring of 1975.

The Altech-process stipulates pipeline charging and is more complicated. A high temperature oven of 1 m x 1 m x 0.4 m, for a charge of 250 kg, with a mobile wall, equipped to measure the pressure on this wall, as well as temperature probes, is available. A formcoke plant for about 700 tons per day is being built in that area.

Other tests investigate the influence of the charge preparation and the fundamentals of the coking process, as well as the various influences on the physical and chemical properties of the coke.

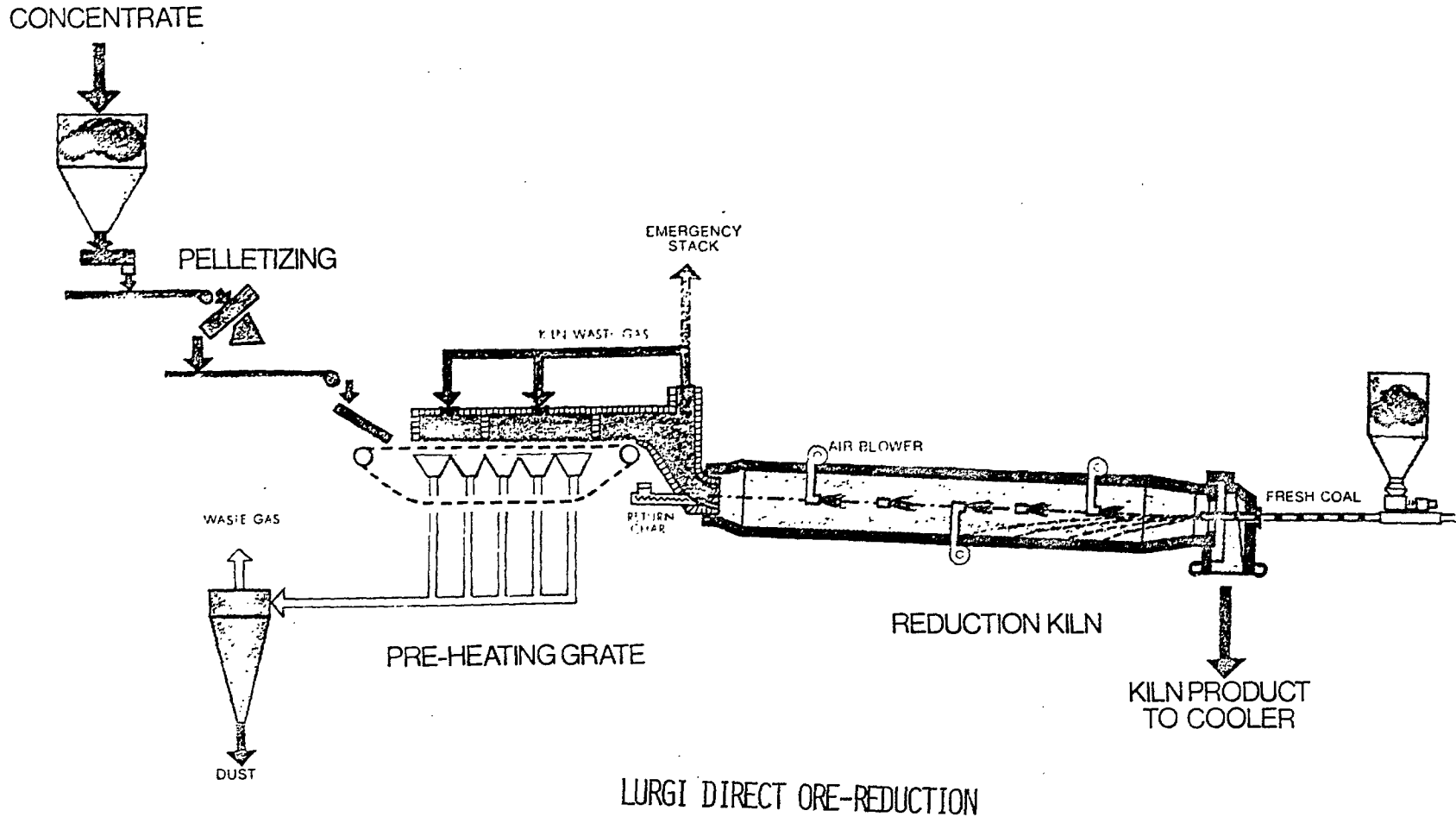
Further investigations are carried out on pitch for electrode manufacture and the effect of incorporating polymers into road tar for modification of the properties of road surfaces. The coke can be tested in a Micum drum, which can be heated up to 1900°C in order to investigate the coke behaviour at elevated temperatures.

C. Direct Reduction of Ores

The ore agglomeration and direct reduction facilities of the Lurgi Co. in Frankfurt, Germany were inspected.

The ore-and coal fines-agglomeration was carried out in rotating inclined pans and on a larger scale in rotating cylinders. Depending on the nature of the material to be agglomerated, varying amounts

FIG. 4



of binders were added. Temperatures were also varied if a semi-plastic range of the material could be reached.

The direct reduction facilities consisted of a pelletizer drum of about 2 m O.D. and 4 m length, with feeding and discharge equipment. This rotating drum could discharge the iron ore pellets directly into the upper end of the rotating kiln for direct reduction with fine coal, which was fed at the lower end of the kiln. The kiln had a length of about 20 m and an O.D. of 2 m (see Figure 4). At several distances from the lower end small blowers were attached to the outside of the kiln, rotating with it, which supplied the air for gasifying the coal and burning a sufficient quantity of it to supply the required heat. The process operates at atmospheric pressure and by varying the throughput, the ore-coal ratio and to a certain extent the temperatures, can be conducted in such a way as to obtain varying degrees of reduction of the ore ranging from 46 to 95%. The reduced pellets can be discharged into a rotating cylindrical cooler for shipping, or directly into an electric arc-furnace, for the production of high grade steel.

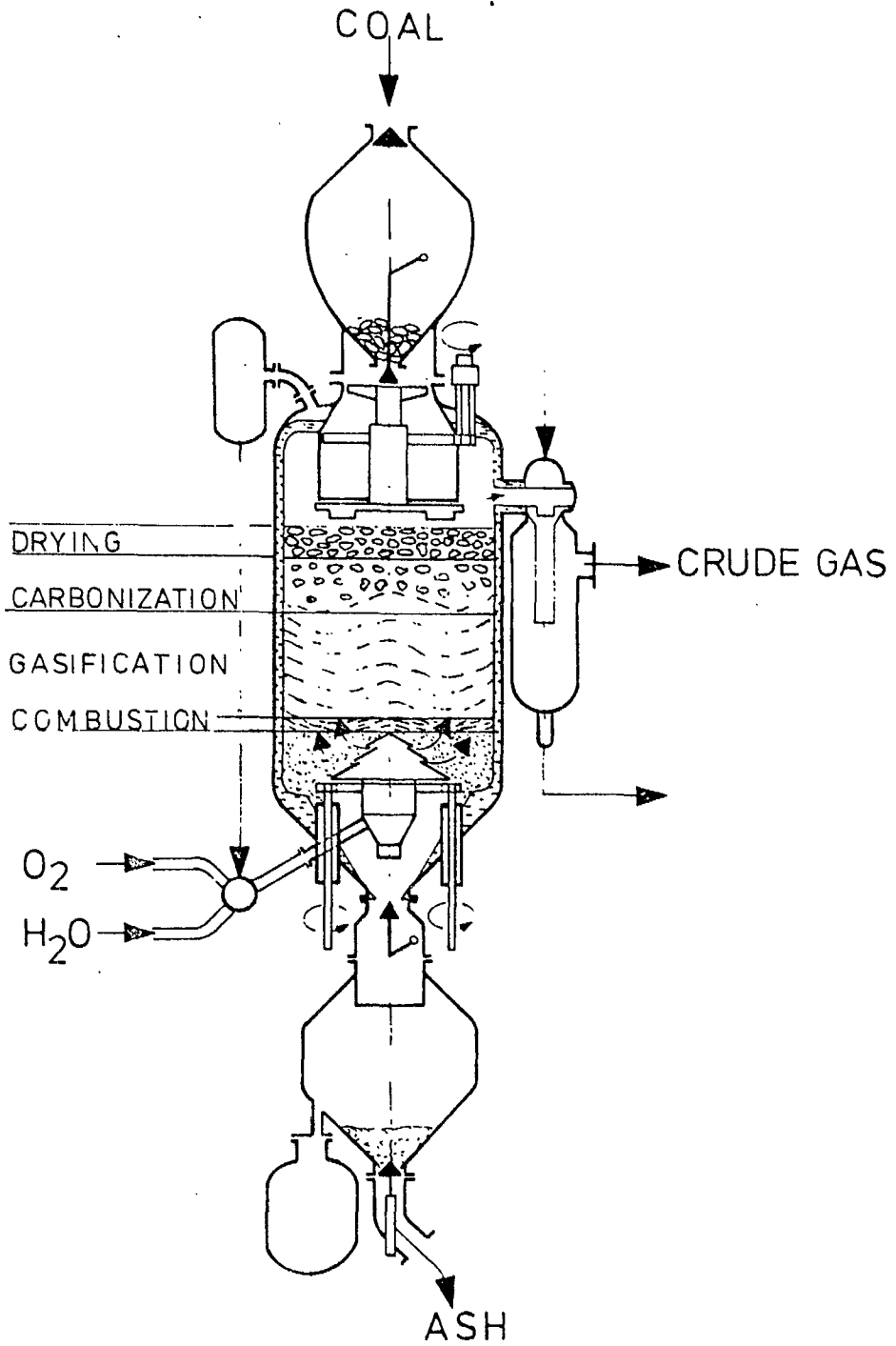
D. Coal Gasification

Lurgi Pressure Gasifier

One of the most efficient methods of converting the dirty coal to a clean fuel, which can be economically transported over larger distances and then distributed, is its gasification. Coal gasification processes have been in operation on a commercial scale since the end of the last century but have been temporarily abandoned due to the availability of ample of non-toxic and cheap natural gas.

As gas, manufactured in a centrally located plant, will, with the greatest probability, be transported in a pipeline at pressures of 68 atm or higher, any gasification process operating at elevated pressure will be at an advantage over processes operating at normal pressure.

FIG. 5



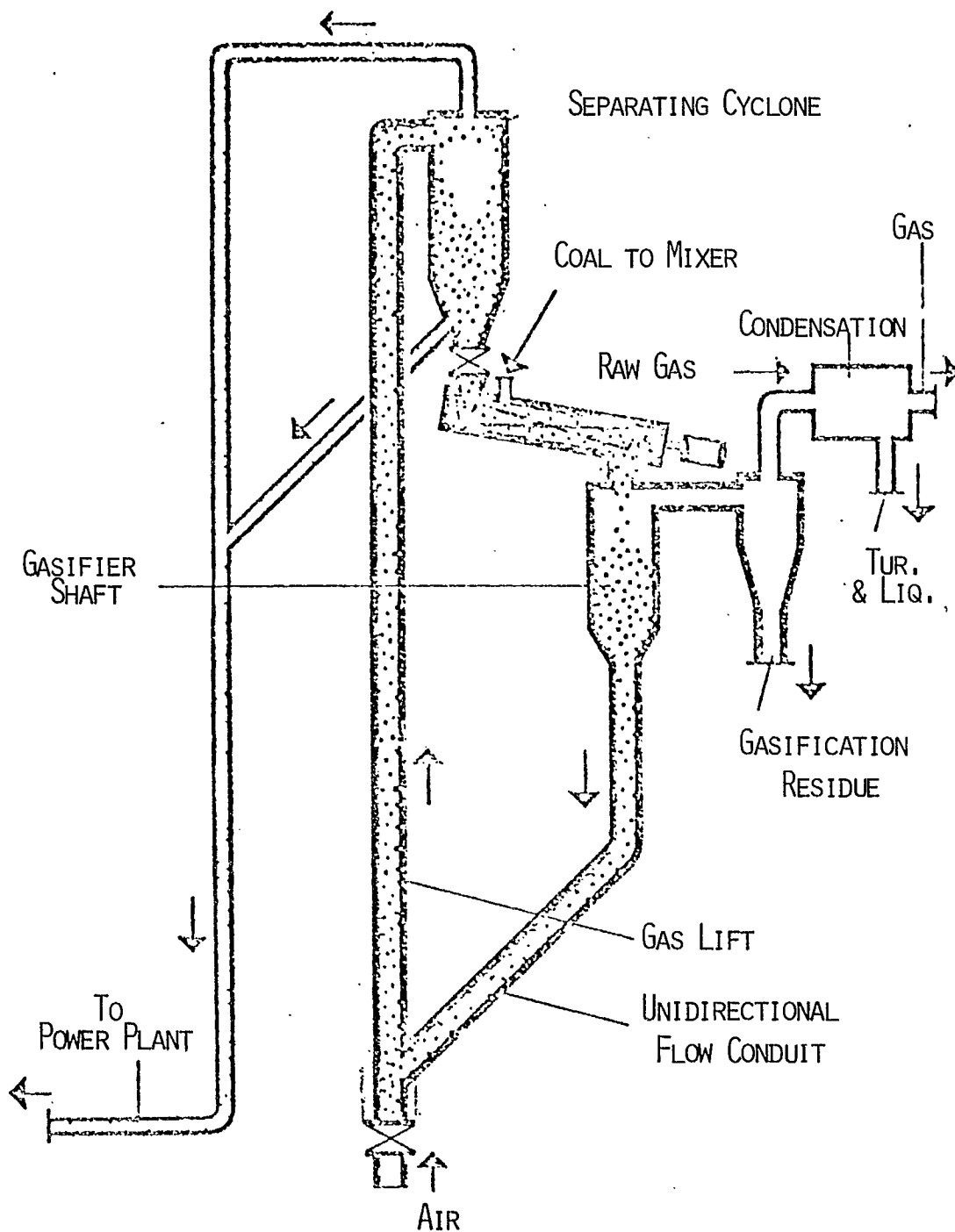
LURGI GASIFIER

At present the Lurgi gravitating bed gasifier, either as standard with rotating grate or as slagging gasifier with tuyeres, is the only process working at elevated pressures on a commercial scale in 14 plants throughout the world. It operates in a counter-current mode and therefore with the highest thermal-efficiency obtainable - up to 95%. The coal is charged and the ash is withdrawn by automated lockhoppers which work trouble-free over a long time (see Figure 5). The coal is preheated by the upstreaming gas and devolatilized. If rabble arms are installed, coals with a swelling index of 5 up to 7.5 can be gasified. The coal requires no special preparation; crushing to less than 2 inches and screening out the undersize below 3 mm is sufficient. Ash contents of up to 40% and moisture contents of up to 20%, both dependent somewhat on the heat value of the coal, can be tolerated. 30% ash in coal is most desirable. The sensible heat in the ash leaving the gasifier is utilized to augment the steam produced in the steam jacket thus supplying up to 60% of the gasification steam required. The temperatures in the combustion zone are kept at least 100°C below the ash melting point.

The slagging Lurgi gasifier operates at temperatures in the combustion zone above the melting point. Eventually, materials must be added to the coal to lower the fluidity point of the ash. The slagging gasifier requires a little more oxygen but much less steam than the standard Lurgi and therefore, the CO/H₂ ratio is slightly higher, requiring more shift conversion capacity if methane production is intended. A dominant feature of the slagging gasifier is that its throughput can be increased up to 4 times that of the standard gasifier and it requires only a small gas liquor treatment plant.

Commercial Lurgi gasifiers have an internal diameter from 3.3 to 3.6 m and a height of about 20 m overall. The height of the coal bed is varied from 2.7 m for synthesis gas production from high reactivity coals in order to have a low methane content in the raw gas to up to 5.7 m for a high methane (up to 16%) raw gas. The higher the coal layer, the lower the oxygen consumption, the cooler the raw exit gas and the higher

FIG. 6



LURGI RUHR GAS PROCESS

its methane content. Additional steam is produced by passing the exit gas through a waste heat boiler.

Pressures of 25 to 35 atm can easily be handled with the presently employed seals in the coal and ash lock valves, which now seal metal on metal. A standard gasifier of 5.2 m inner diameter, having approximately double the throughput, is being tested at present. Also, after successful runs of a 1.8 m I.D. slagging gasifier in Holten, Germany, one of the 3.3 m gasifiers in Westfield, Scotland, is being converted to slagging operation.

The Lurgi gasifier produces H_2/CO ratios in the gas ranging from 1.8 to 2.4, the highest of any known process, with the exception of gasifiers operating with outside heat sources. This ratio can be varied in certain limits by varying the oxygen-steam ratio which is normally 0.175 - 0.245 by weight. The oxygen-steam ratio which, for the standard Lurgi gasifier, is $1.427 \div 8$, changes for the slagging gasifier to $1.569 \div 2.7$, i.e., 0.58 by weight. The gasification end-temperatures and to a certain extent the oxygen requirements, vary with the reactivity of the fuel: Coke: 850°C, Semi-anthracite 800°C, Subbituminous coal 750°C and Lignite 650°C. (Figures 6 and 7).

Lurgi Ruhrgas Gasifier

Not all coals have the properties required to be processed in a gravitating bed gasifier, i.e. hard enough not to disintegrate in the fire zone and still not, or only moderately caking, like the subbituminous coals. Lignite can be processed in a gravitating bed gasifier only after briquetting it; the small pieces formed by disintegration would be carried out of the reaction space by the upstreaming gas. This difficulty is overcome by the Lurgi Ruhrgas process. The heat for the endothermic carbonization is supplied by preheating the coal with up to 5 times its quantity of hot char (see Figures 6 and 7). A portion of the char coming from the coking or carbonizing vessel is burned or gasified with air or with an oxygen-steam mixture in a lift-pipe, which transports the hot char up to a separating cyclone and storage vessel, from which it flows downward into a mixing unit. The fresh coal is combined in this mixing screw-conveyer with the hot char

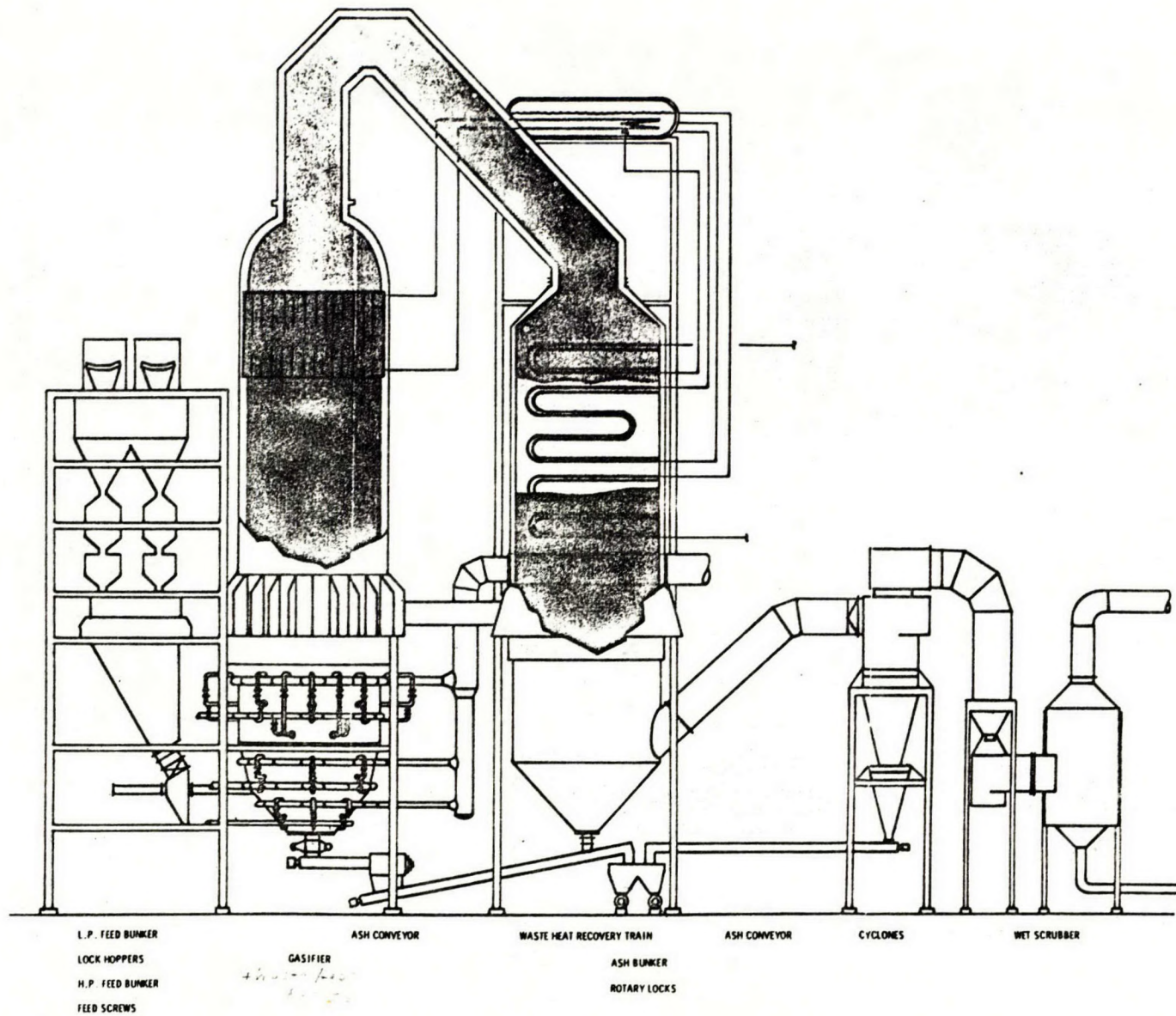
and the mixture is then discharged into the hot carbonizing vessel, in which the carbonization or coking, which is a "delayed" reaction, proceeds and from which the carbonization gas is discharged into the cooling and condensation train. The gas produced in the carbonizer is a high Btu gas, containing, however, too much carbon monoxide to be used as synthetic natural gas and would have to be methanized. The offgas from the lift-pipe, if steam-oxygen is used as a gasification agent, can be mixed with the carbonizer gas for methanation. As the offgas from the lift-pipe is discharged at a high temperature and contains a large quantity of sensible heat which can only partly be recovered, besides latent heat in the form of carbon monoxide, this process does not offer a good thermal efficiency. The heat in the offgas from the lift pipe can, however, be utilized by discharging it directly into a power plant. In this mode of operation, one other difficulty must be overcome. As this process would operate probably on low value, high ash, high sulphur coals, most of the sulphur leaves the process with the lift offgas and appears in the stack gas of the power plant, thus requiring a costly stack gas clean-up facility.

The Lurgi Ruhrgas has, however, a probable field of application in which the before mentioned disadvantages are of no importance. The extraction of the bitumen from the tar sands can be performed at a probably higher efficiency, in a single step, than with the other presently known methods, as simultaneously a reduction of molecular weight and refining is achieved, sufficient to render the product oil fluid enough to be pumped in a pipeline. The small amount of coke deposited on the surface of the sand, together with the offgases from the coking, are sufficient to provide all the heat for the process and the heat otherwise lost with the hot sand (instead of char) and the lift offgases (no carbon monoxide) can be recovered to a great extent by direct heat exchange with the combustion air. Therefore the Lurgi Ruhrgas process, if operated in this fashion, operates with a much higher thermal efficiency than if operated as a gasifier.

Winkler Gasifier

The Winkler gasifier, which employs a fluidized bed of coal particles of 1 to 10 mm size, operates in three units on a commercial scale in Kutahya-Turkey. The other 33 gasifiers of this type which have been built so far are no longer in operation including the first 5 which were installed in Leuna,

FIG. 8



WINKLER GASIFIER ARRANGEMENT

East Germany, in 1926.

The gasifier is a cylindrical refractory lined vessel of 2 to 5 m inner diameter and 18 to 22 m height (see Figure 8). The dried coal is only at the bottom part in a bed, which in the settled condition is 1.5 to 3 m high. The air (oxygen and steam, which must be mixed very thoroughly before entering the gasifier to prevent hot spots, enters at the bottom through tuyeres with an upward speed of about 5 m/sec.

The gasification is conducted by adjusting the air-oxygen-steam ratio so that the temperature in the bottom part is kept 50 to 80°C below the ash fusion point. Due to the turbulent motion of the coal particles, their attrition is very high and the dust so produced is entrained in the gas and must be burned with secondary steam and oxygen into the upper part of the gasifier to insure an acceptable gasification efficiency. This secondary combustion, however, results in relatively high gas-exit temperatures and therefore, in a lesser thermal efficiency. The retention time of the coal in the gasifier, due to its small particle size, is only 20 to 30 minutes but about 60 to 75% of the coal ash is carried out at the top of the gasifier. As this carry-over contains about 55 to 60% unreacted carbon, the thermal efficiency is very sensitive to the ash content of the coal, also, this ash is non-reactive and cannot be re-introduced into the gasifier but must be, as was practised in Leuna, completely gasified in a different type (Pintch-Hillebrand) of gasifier.

The raw gas leaving the gasifier is passed through a waste heat recovery system; part of this may even be arranged in the top part of the gasifier itself (see Figure 8). 0.3 to 0.4 kg/kg coal excess steam are produced. The fly ash is separated by cyclones, followed by wet or electrostatic precipitation. Normal operating pressure at the bottom is about 1.3 atm. The throughput varies from 600 Nm³/m² hr. with O₂/steam to 3300 Nm³/m² hr. with air steam and up to 80 tons/hr. of (highly reactive) coal can be processed. The overall thermal efficiency, including steam production, is about 85 to 90% but decreases rapidly with increasing ash content of the feed coal.

The CO/H₂ ratio is about 1.25; CO₂ content is about 16 vol.% and Methane content is about 2%. The oxygen consumption is 0.8 to 0.9 kg per kg steam, i.e., due to the high reactivity of the feed coal, relatively low.

The Winkler process is somewhat safer than the Koppers Totzek process as the probability that there is no coal in the gasifier is much less but in the upper part the oxygen may still break through into the gas main, therefore safety precautions must be taken and the instrumentation must be appropriate, though not as elaborate as with the Koppers Totzek gasifier.

The Winkler process, due to the high entrainment of carbon, results in incomplete gasification and is limited to highly reactive lignite coal and preferably lignite chars with non-coking properties and high ash fusion points.

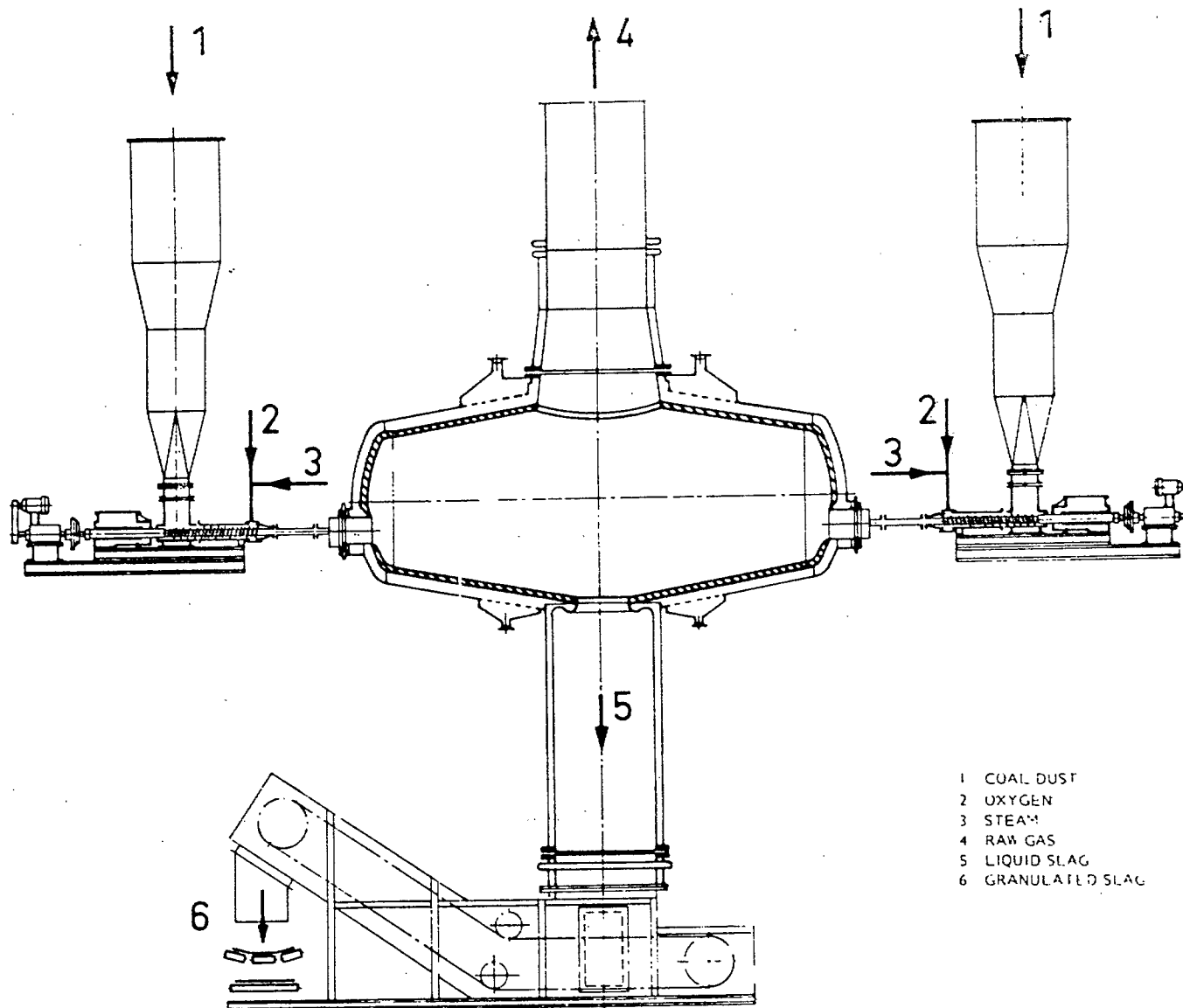
In discussion with Davy Proverges Co., it was revealed that a pressurized gasification system was being developed, parts of which were already completed and tested like ash removal system and gas scrubbing system.

Koppers Totzek Gasifier

Besides the hard coals, large deposits of lignite, especially in Canada, are available for gasification, which are too soft to be processed in a gravitating bed gasifier. If these coals shall be converted to synthesis gas then the Koppers Totzek gasifier is particularly well suited to this job. This type of gasifier operating in the so-called entrained mode, is in commercial operation in 16 plants throughout the world. (See Figure 9).

The special feature of this process is that the (lignite) coal must be dried to less than 6% H_2O , to be pulverized to less than 1/10 mm and blown by oxygen and steam into the conical ends (heads) of the gasification chamber, in which it burns like a coal dust flame but with insufficient oxygen (see Figure 9). In order to complete the reaction, the operating temperature must be held at about 1500°C. This high temperature results in retention times of less than 2 seconds (in one case 0.8 seconds) but also in a high oxygen consumption (about 6 kg O_2 per kg steam). The water-cooled walls of the gasifier are lined with 2 to 3 inch chromite, which lasts for about 5 years. Contrary to the Lurgi gasifier, which requires additional steam from an outside source and which puts certain limits on the characteristics of the coal, the Koppers Totzek gasifier produces a large quantity of (about 0.72 kg/kg coal) excess high pressure superheated steam, which for certain applications may be an asset for power generation concurrent with gas production.

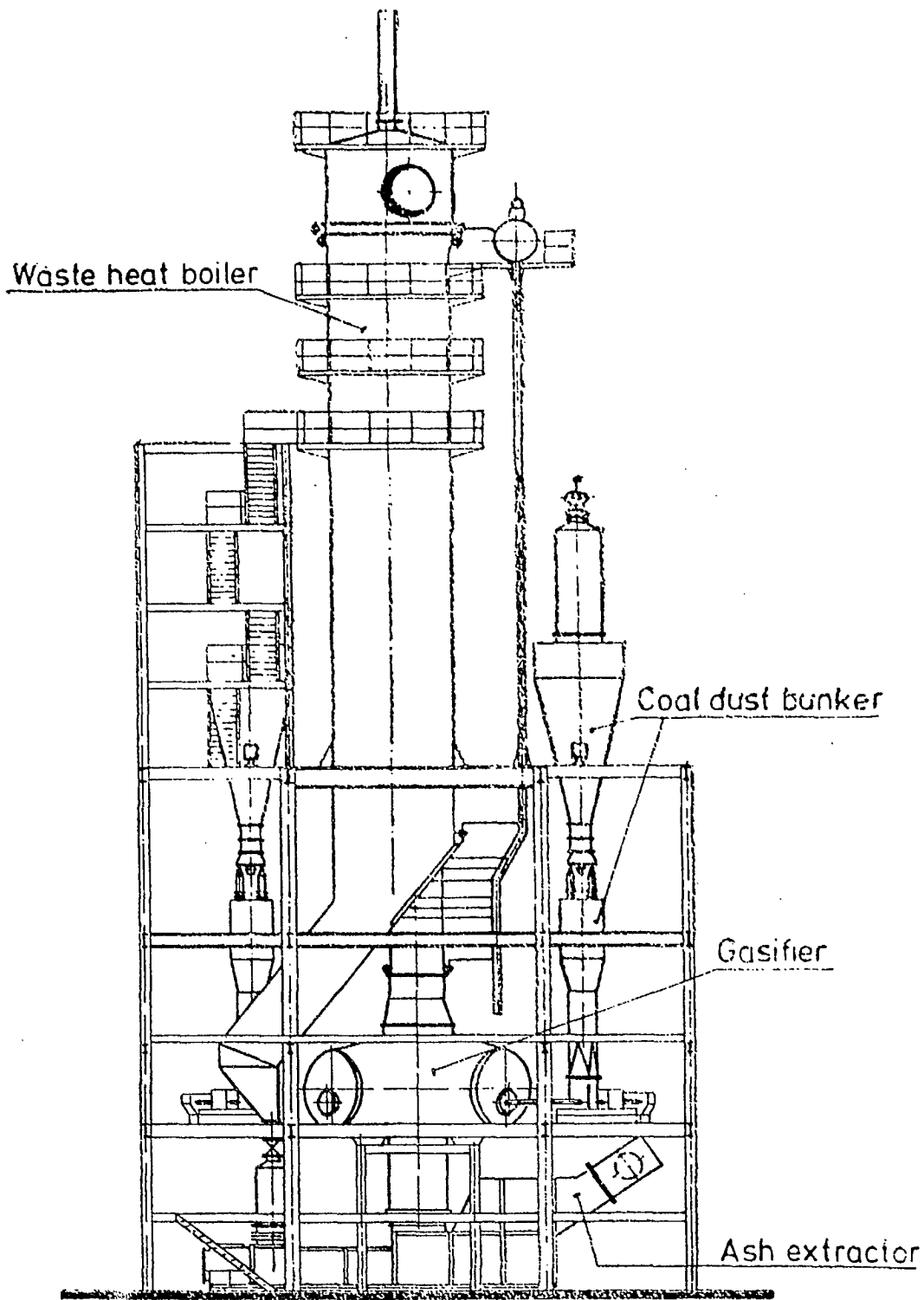
FIG. 9



- 1 COAL DUST
- 2 OXYGEN
- 3 STEAM
- 4 RAW GAS
- 5 LIQUID SLAG
- 6 GRANULATED SLAG

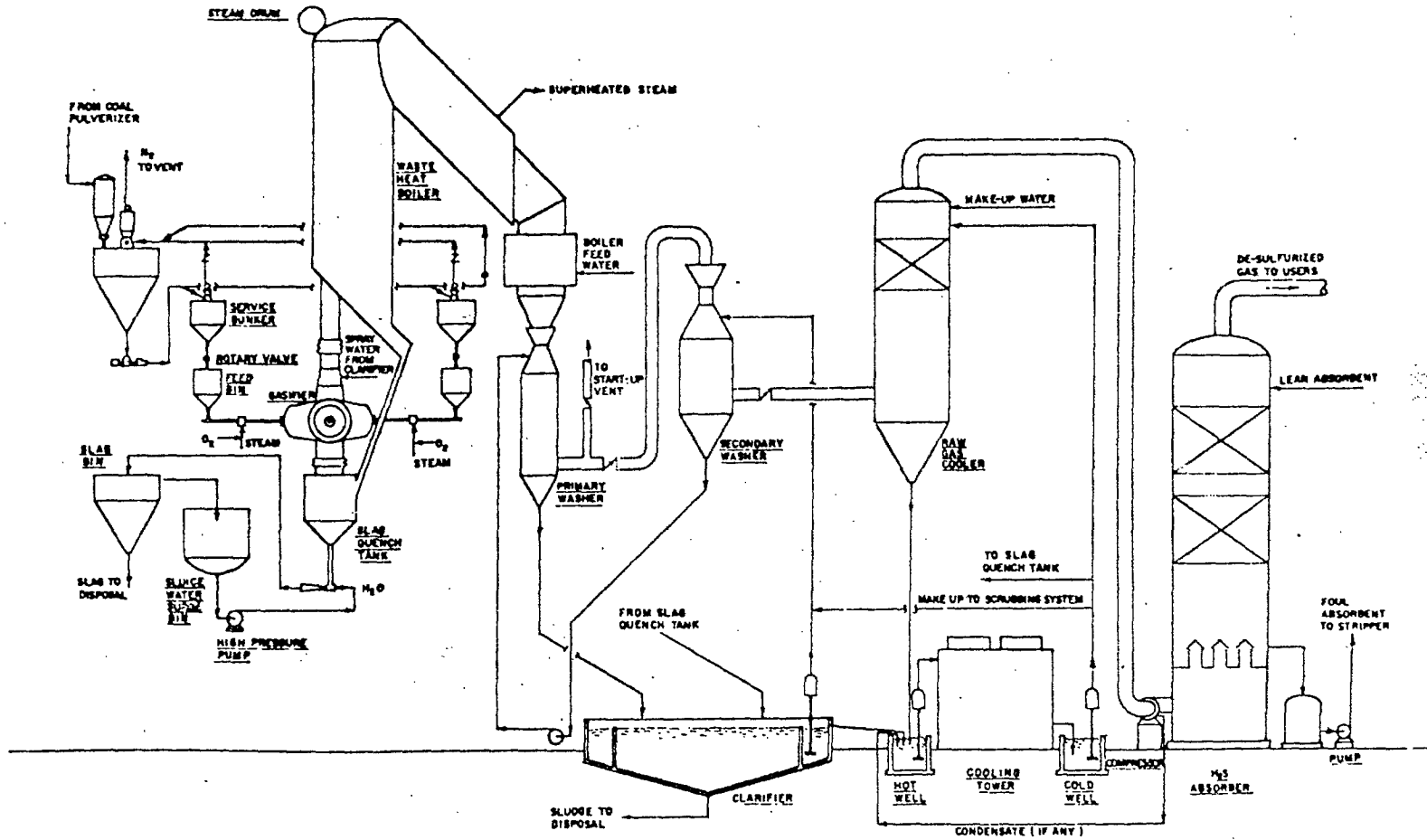
CROSSECTION OF KOPPERS-TOTZEK GASIFIER

FIG. 10



FOUR HEADED KOPPERS-TOTZEK GASIFIER

FIG. 11



K-T GASIFICATION PROCESS AND ANCILLARY EQUIPMENT

The gas composition, due to the high operating temperature, shows CO contents about 1.5 to twice as high as the H₂ content, requiring large capacities for the shift conversion. About 45% of the coal ash leaves the gasifier as molten slag and drops into a water-filled trough from which it is continuously removed. The sensible heat of the ash is thus used to supply some steam to the gasifier.

For the prevention of explosions either by cut-off of the steam or oxygen, or by blockage of the coal dust supply, an elaborate system of safety devices is necessary.

The hot gases leave the gasification chamber at about 1500°C carrying about 55% of the coal ash as entrained solids into the lower part of the waste heat boiler on top of the gasification chamber. Here the raw gas flows at a speed of about 50 m/sec. through the quench zone in which the entrained particles are cooled sufficiently to prevent sticking to the heat transfer surfaces of the boiler. (See Figure 10). From this boiler the gas is transferred to a cleaning system in which the carried-over particles are separated from the gas either by Theissen washers or by Venturi scrubbers (Koppers-Pittsburgh). (See Figure 11).

The Koppers Totzek process is very flexible in that it is not dependent on the characteristics of the feed stock, provided it has sufficient heat value to reach a temperature of 1500°C. A particular feature of this gasifier is that it can also operate on heavy liquid fuels, eventually simultaneously with coal. A four-headed gasifier can produce about 50,000 Nm²/hr raw gas. The sulphur of the coal appears to about 90% in the gas as H₂S and 5% as COS. 5% of the coal sulphur remains in the ash. It is reported that high sulphur in the ash could cause difficulties in the ash removal system.

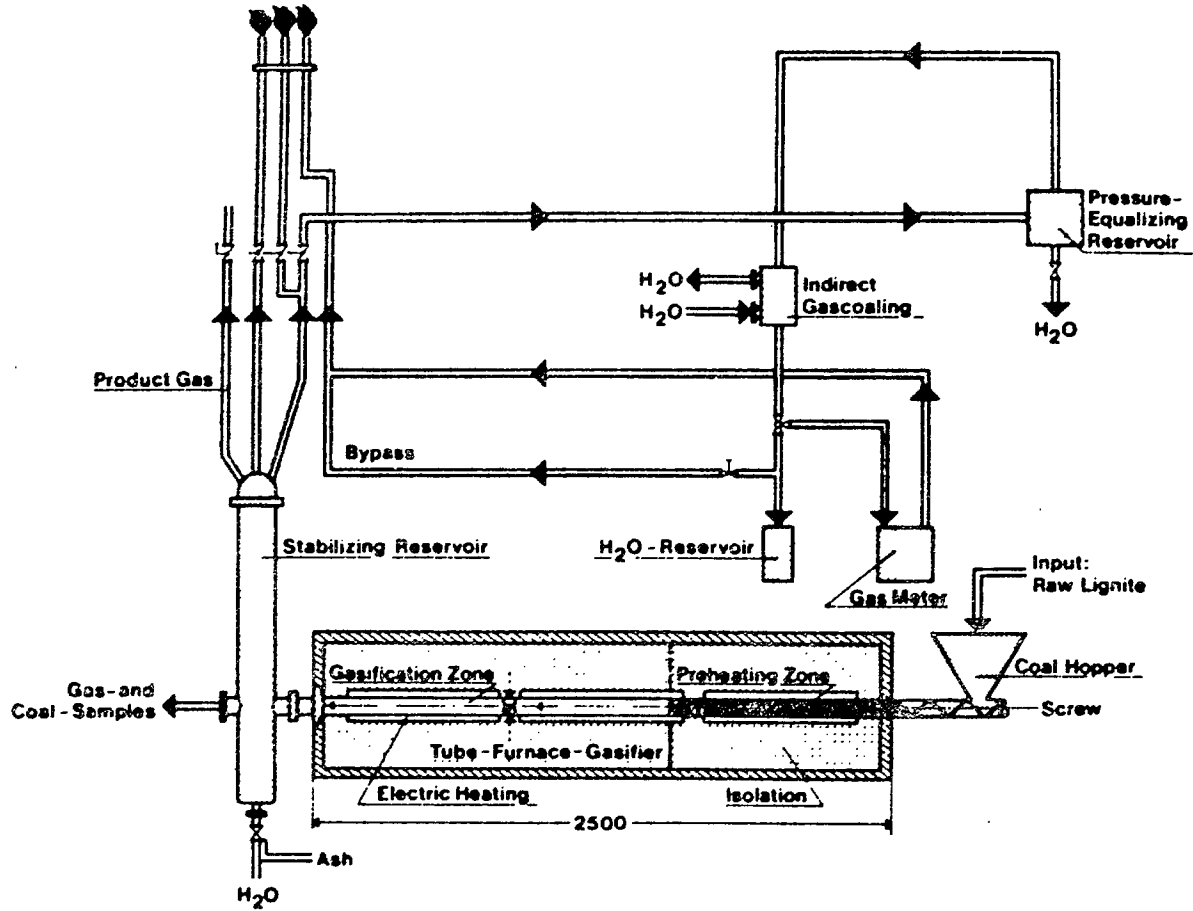
The mass balances of the four gasification processes mentioned before are compared in Table 6.

TABLE 6

MASS BALANCE OF GASIFICATION PROCESSES

	<u>Winkler</u>	<u>Koppers Totzek</u>	<u>Lurgi</u>	<u>Lurgi-Ruhrgas</u>
Input kg maf coal	1000	1000	1000	1000
kg C	700	830	780	763
kg H	60	50	50	48
kg O	22	100	150	168
kg N	10	10	10	11
kg S	10	10	10	10
kg Moisture	100	10	85	189
kg Ash	150	160	350	81
kg Coal	1250	1170	1435	1270
kg Oxygen	650	950	415	air
kg Steam	400	150	1700	-
Output Nm ³ Clean Rawgas	1900	2000	2300	354
Vol.% H ₂	35	33	38	27
Vol.% CO	42	53	23	30
Vol.% CO ₂	18	12	27	9
Vol.% CH ₄	3	0.1	12	44
kg Excess Steam	400	200	920	-
kg Tar	-	-	80	100
kg Ash	150	160	350	81
kg Carbon in Ash	170	22	14	472
Particulates in Gas mg/Nm ³				
a)after scrubbing	5000	530	150	50
b)after Theissen Washer	50	15	8	4
c)after electro- filter	5.0	2.5	1.5	1
Thermal Efficiency %	84	71	91	53

FIG. 12



RHEINBRAUN-TUBE FURNACE GASIFIER FOR LIGNITE

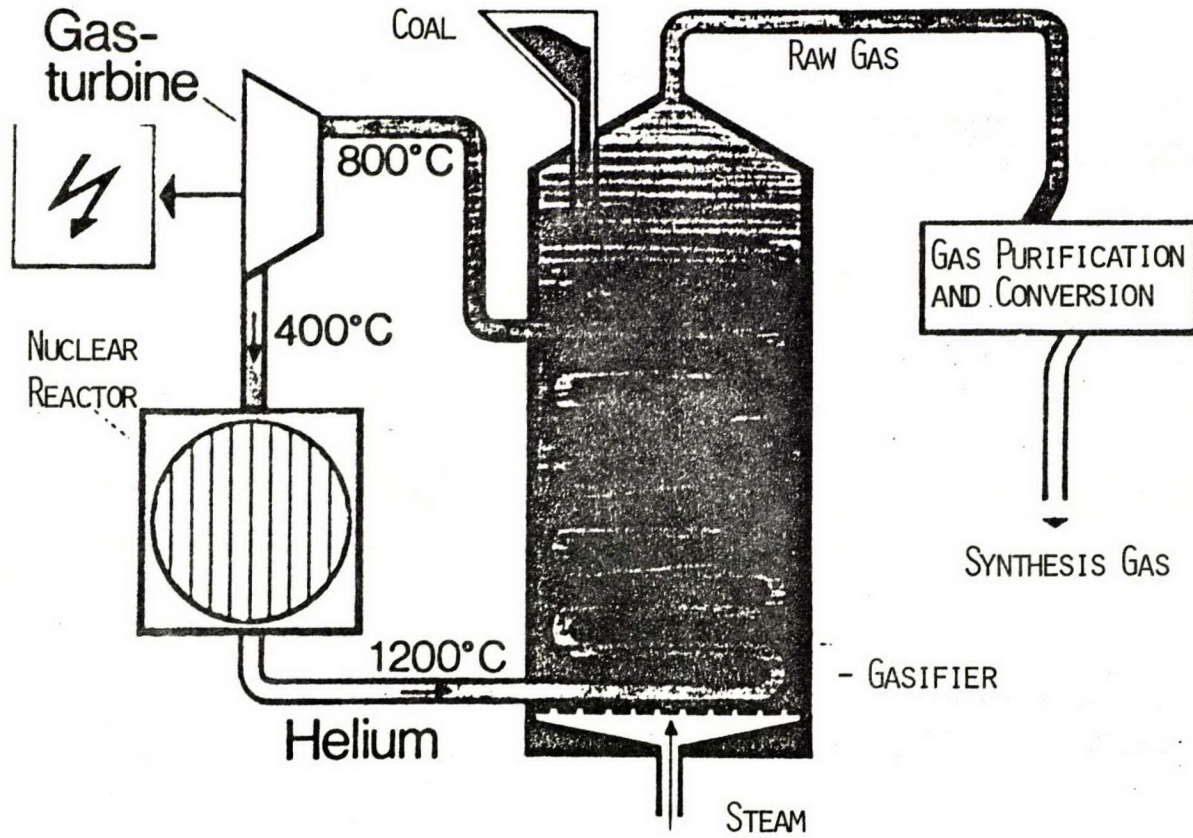
Tube Gasification Process

The tube gasification process of the Rheinbraun A.G. takes place in a zone of about 40 cm length of a horizontal tube of a total length of about 2.5 m and a diameter of 6 cm. (See Figure 12). The wet (45 to 55% H₂O) lignite, having a particle size of less than 1/4 inch, is fed at room temperature and a rate of 5 to 10 kg/hr into one end of the tube, which is heated from the outside. The moisture evaporates rapidly and the developing steam pressure together with the shrinking of the coal particles, develops a fluidized condition which facilitates the transport of the coal particles and enhances the heat transfer. When the temperature reaches 900°C, about 60 wt.% of the coal is gasified very rapidly. The moisture content of the lignite is sufficient to provide the steam required for gasification. Iron and alkali in the ash greatly enhance the gasification. The product gas, containing only small amounts of nitrogen emerges from the other end of the tube. The remaining char is separated and can be used to supply the heat for outside heating of the tube or can be sold if other heat-sources are available like waste heat from a high temperature metallurgical process or nuclear heat. In experiments conducted at the Technical University of Aachen, the optimum diameter of the gasifier tubes was found to be 6 cm; the length of the tubes for commercial installations would however, be increased from 3 to about 10 m. A pilot plant for a capacity of up to 0.2 tons/hr is being constructed at the Rheinische Brannhohlewerke near Cologne. It is not entirely excluded that sawdust as well as suitably sorted municipal refuse can be processed by this method. This gasification is conducted at pressures of up to 40 kg/cm².

Coal Gasification with Nuclear Heat

It is standard gasification practice to supply the endothermic heat for the reduction of water to hydrogen and carbon monoxide by burning part of the coal or coke to (mostly mixed) carbon oxides. This heat can, however, also be supplied by heat foreign to the process, i.e. by super

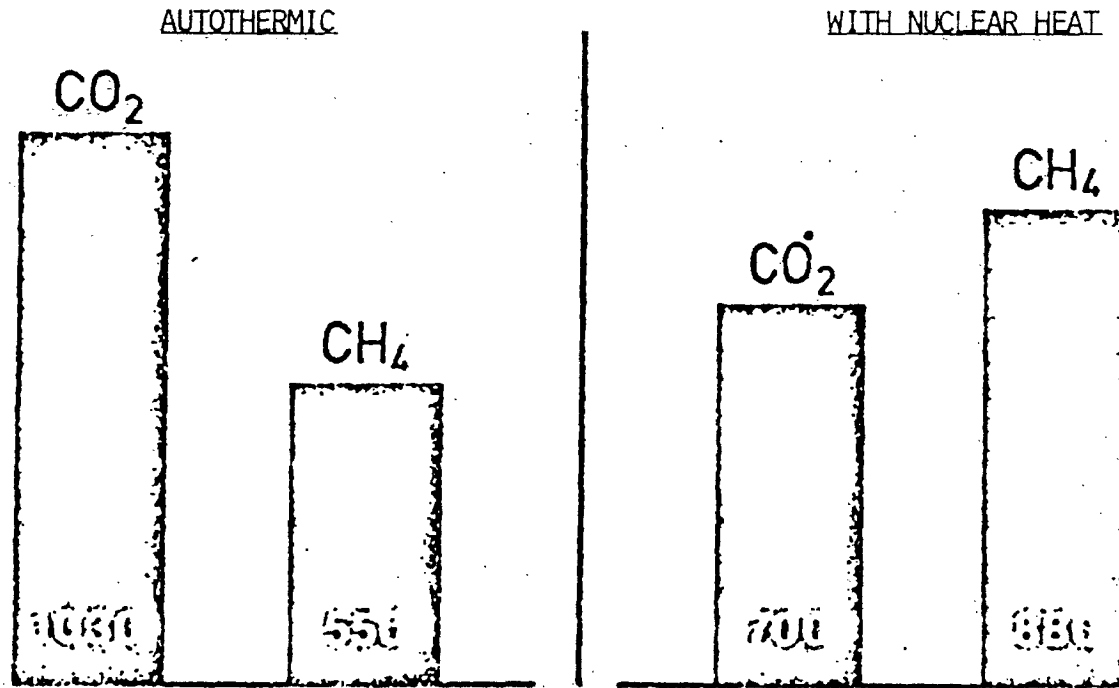
FIG. 13



STEAM GASIFICATION OF COAL AND POWER GENERATION WITH NUCLEAR HEAT

FIG. 14

1 TON COAL (MAF; HU = 7.8 GCAL) YIELD



GAS YIELD IN Nm³/TON COAL

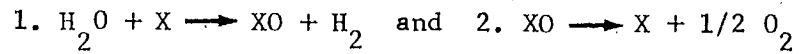
heating the steam for the gasification electrically to 1800 to 2000°C, or by heat exchange with helium heated in a HTR nuclear reactor to 950-1050°C. (See Figure 13). It was said by Dr. Schulten that the high temperature reactor has operated for a sufficiently long period (1/2 year) at 950°C and that the reactor materials, as well as the heat exchanger materials, have been tested with quite satisfactory results (at 950°C). A further development to reach 1050°C is presently proceeding. The HTR reactor produces only solid fission products, thus posing no environmental problems and alleviating the waste disposal considerably. Figure 14 shows that the coal reserves of the world for the production of methane could be extended by 60% if the process heat would be supplied by nuclear energy.

Transportation of Nuclear Energy over Longer Distances

It is economically viable to generate electricity in a large central power station and distribute the low pressure steam from extraction turbines for heating purposes over distances of up to 25 km, thus increasing the thermal efficiency of such a power plant from normally 35% up to 75%, but beyond this limit the heat losses from the steam lines are too large and for smaller cities, even one nuclear power plant may be too big or a smaller one may be uneconomical. For this field of application, a new energy transportation and distribution system may offer advantages over all other methods, the so-called Adam and Eve process. This process is said to cost over longer distances only about 1/3 of that of district heating. It consists of reforming methane with steam and nuclear heat in a big central station from which the resultant H_2CO mixture is distributed to distant smaller catalytic recombination stations which regenerate the methane (and H_2O) releasing the energy of $2198 \text{ kcal/Nm}^2 CH_4$ (49.3 kcal/mol). Eventually this methane can be burned to produce additional heat. Then from the recombination stations, electrical power as well as district-heat can be produced without environmental problems. The methane burned can be replaced with H_2CO produced from coal and steam also produced by nuclear heat. The investment costs for this mode of energy transportation are estimated at a

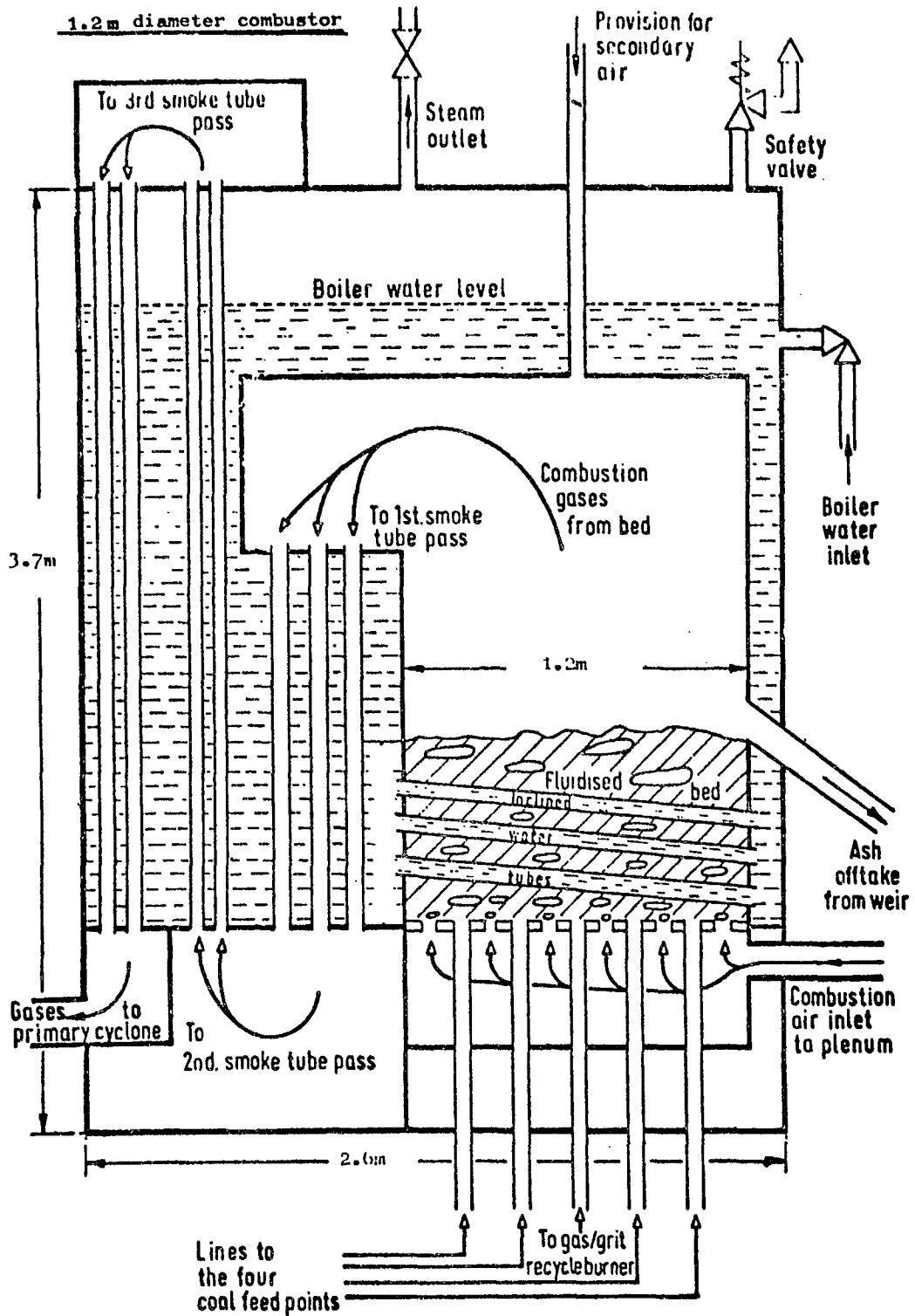
total of only \$118/kw, including the piping system.

One other system of energy transportation is investigated by the University of Aachen, the splitting of water to H₂ with heat in the presence of halogenes instead of electrolytically. The two reactions are:



The hydrogen thus formed can also be used as energy carrier over long distances as its flow resistance is the lowest of all gases (except helium).

FIG. 15



FLUIDIZED BED COMBUSTION

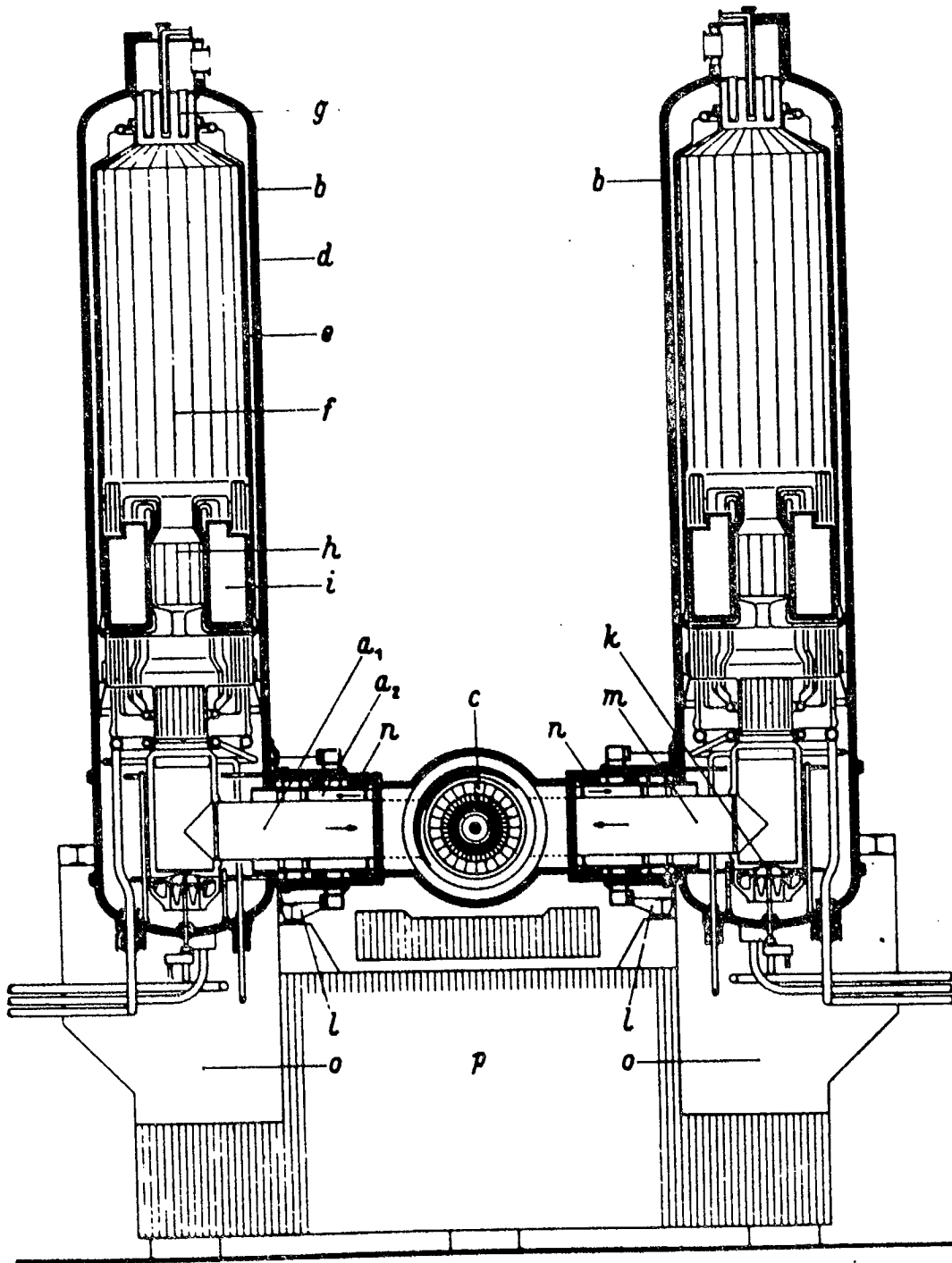
POWER GENERATION

A) Fluidized Combustion

The research establishment in Leatherhead is perfecting the fluidized combustion at atmospheric and elevated pressure with good success. Work is also being done on the Co-Gas process for low temperature carbonization of coal in conjunction with the Co-Gas Development Co. (Princeton, N.J.) and Republic Steel, with a view to coal gasification and power generation. For the evaluation of the fluidized combustion process the Combustion Systems Ltd. has been formed.

In their fluidized combustion system only 0.5% combustibles are present in the fire bed, which has a temperature of only 800 to 950°C or at least 100°C below the ash melting point. The coal is fed at the lower part of the bed and the ash is withdrawn at the upper layer. (See Figure 15). The heat transfer rate is 50 to 100 Btu/ft² ht (135-270 kcal/m²/hr). Smaller particles give a higher heat transfer rate. Such a boiler needs about 1/2 of the transfer surface of a conventional boiler. The bed height is 2 to 3 ft. at atmospheric pressure; higher pressures allow higher bed heights i.e., at 10 atm 12 ft. (3.6 m). The pressure difference in the bed is about 5 inches H₂O at atm pressure and about 24 inches H₂O at 5 atm. The SO₂ from the combustion of coal can be absorbed if sufficient lime is added. Coal with 5% sulphur and 30% ash emitted a stack gas with only 100 ppmv SO₂. The incremental cost of the S-removal is just the cost of the lime. CaSO₄ is dumped along with the ash but can also be regenerated to CaO. The particle size of the coal should be 1/8 to 1/4 inch. If the moisture content of the coal is above 20%, feeding difficulties are experienced. Usually 2% O₂ corresponding to 10% excess air is used. The cross section of the bed at present is 2 to 10 ft. of boiler combustion space. For atmospheric operation an electrostatic precipitator is required; at elevated pressure a cyclone is sufficient. The upward flow rate of the (flue) gas is between 5 to 12 ft/sec. 8 ft/sec. seems to be optimal. A large pilot plant with a capacity of 23 to 44,000 lbs. steam/hr. will be

FIG. 16



ARRANGEMENT OF COMBUSTOR-BOILER AND GAS TURBINE

operating in late 1975. A 325 MW boiler will have a diameter of 12 ft. and a height of 20 ft.; a 625 MW boiler will have a diameter of 17 ft. There will be 4 independent beds for preheating, super heating, reheating, vaporization, etc. The coal may have water contents of up to 8%. Municipal refuse can also be burned if properly prepared. The turndown ratio is not quite known yet at larger installations. Up to 1974, about 7.10^6 dollars have been spent on fluidized combustion. An experimental fluid bed boiler for 8000 lb/hr steam at 1000 psi is being constructed.

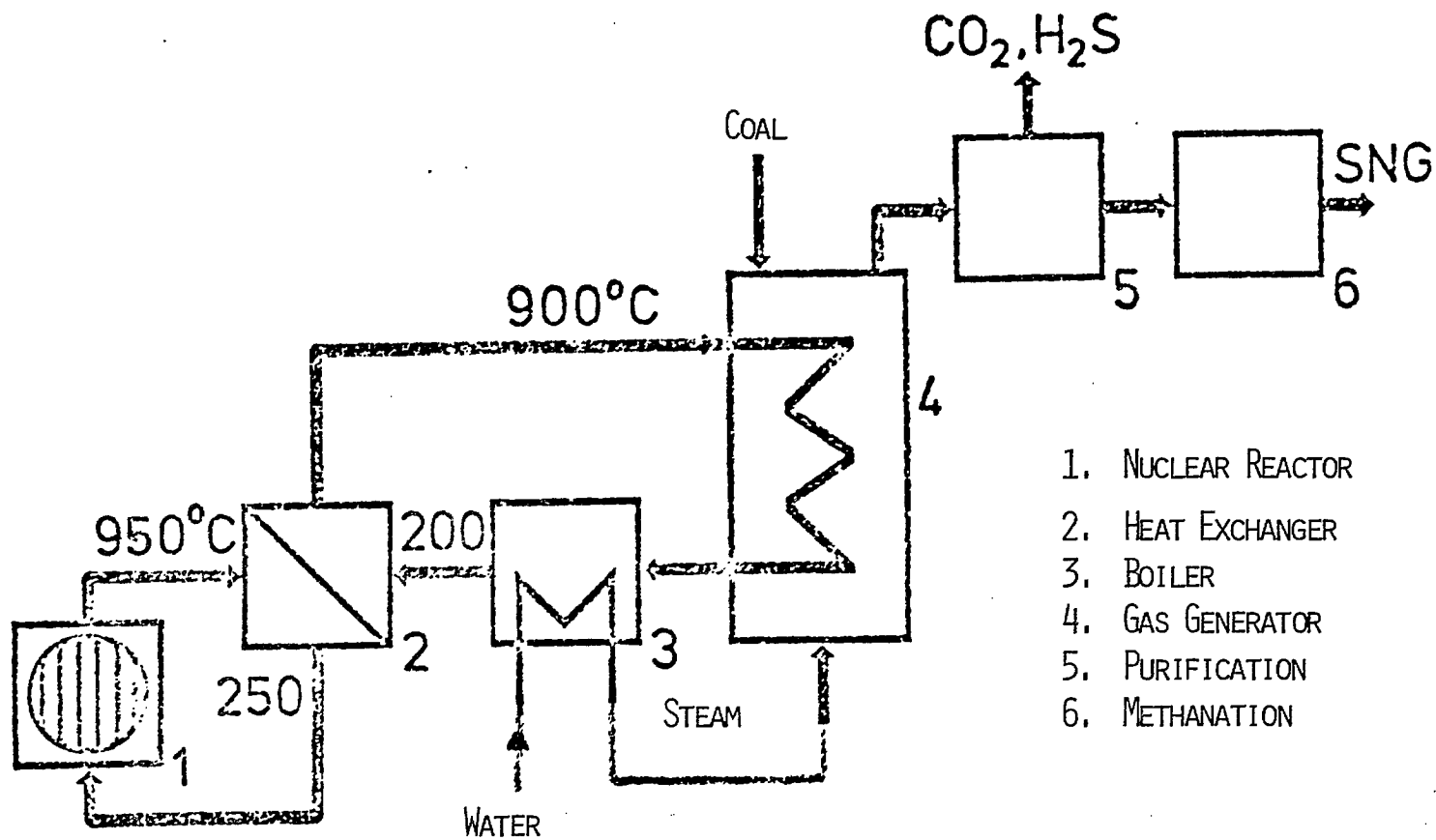
Combustion research concentrates at present on the development of the fluidized combustion, the advantages of which, compared to conventional boiler firing, are better economy and less environmental pollution.

Six pilot boilers, varying in diameter from 0.15 to 1.0 m have been operated in Cheltham England. Work on fluidized combustion is also carried out in the U.S.A. by Westinghouse and the Co-Gas Development Co. Plans for a pressure demonstration unit with a cross-section of 3 x 3 m have been completed; the installation is planned for 1975.

B. Power Generation Via Gasification (Low Btu Gas)

The Steag in Germany operates a 170 MW demonstration plant for converting bituminous coal with a lower swelling index to electricity in a combined cycle operation. The coal is gasified in 5 Lurgi generators at 26 atm pressure with air and steam. The raw gas is scrubbed at present only in the usual way so that not more than 150 mg/Nm^3 particulate matter remains. The scrubbed raw gas passes through an expansion turbine in which its pressure is lowered to 10 atm and as its volume is about 2.5 times the air required for gasification, and, besides compressed air, 30 MW power is generated. 10 atm is the entrance pressure for the gas turbine, determined by the permissible temperature of the hot blading (850°C). The two combustors of the gas turbine - about 3.6 m O.D. and 20 m high, contain also the boiler tubes for the steam turbine. (See Figure 16). Thus, instead of heating excess air, normally 4 times the stoichiometric volume of fuel gas, steam is produced and the excess air is reduced to eventually 1.1 times the

FIG. 17



STEAM GASIFICATION OF BITUMINOUS COAL
AND POWER GENERATION WITH NUCLEAR HEAT

stoichiometric amount, which is the means to reduce the heat losses of the gas turbine. The gas turbine produces 60 MW and the steam turbine 80 MW and no major difficulties have been experienced. This installation, delivering a total of 170 MW, has been in operation for several years now. A complete gas clean-up facility, not yet installed, would cost much less than a stack gas clean-up installation (about \$8.-/KW versus \$110.-/KW) as the volume of gas to be cleaned is, 1) much smaller than the corresponding stack gas volume and 2) it is at 25 atm pressure with the corresponding reduction of the volume of solvent and solvent regeneration capacity required. A full size commercial unit of 800 MW is designed and the installation is in the procurement stage. The thermal efficiency could be increased to 43%; any coal which can be gasified in a Lurgi gasifier can be used, thus allowing a wide choice of fuels.

C. Power Generation with the Aid of Nuclear Heat

The Kernforschungs Anlage in Juelich has developed systems in which heat from the so-called High Temperature Reactor can be used for the gasification of coal with considerable benefits. The consumption of coal for the production of 1000 Nm³ methane could be reduced from 1.818 tons to 1.136 tons, i.e. to 62.5%. The steam for gasification and power generation is produced simultaneously. Due to the high temperature and capacity (3000 MW) of the nuclear reactor, this system can also be operated to use only the upper temperature range from 1000°C to 500°C for chemical energy and from 500 to 200°C for steam raising. (See Figure 17). This offers the possibility of operating a chemical or metallurgical plant or a gas turbine besides a generating station with the corresponding increase in thermal efficiency (see also the Adam and Eve principle).

The HTR which is now 5 years in operation, is filled with about 675,000 fuel elements in a helium atmosphere. They are constantly recycled at the top and withdrawn at the bottom. Here they are checked for remaining activity and if the latter is no longer sufficient, they are replaced by

fresh fuel elements. These spherical fuel elements of about 6 cm O.D. have a 0.5 cm thick graphite wall and are filled with a large number of 0.5 mm thick U_3O_8 spherules, embedded densely in graphite. They are fairly solid and withstand abrasions very well. The U_3O_8 is 59% enriched, i.e. higher than the 32% enriched U_3O_8 used in the U.S. reactors. The used fuel elements which yield only solid fission products are burnt to eliminate the graphite and the resulting inorganic material is reprocessed. It is expected that ultimately, helium temperatures of 1150°C can be reached.

In order to obtain the required cooling effect in this reactor, the helium must be at elevated pressure and this makes the reactor vessel more costly than the water cooled and moderated reactors. If the cost of the pressure vessels could be reduced by about 40% then the HTR would operate as economically as the light water reactors but with a much higher energy efficiency.

GAS PURIFICATION

The first step in any gas cleaning operation is the scrubbing, to eliminate entrained dust and tar droplets. (Compare Figure 11 and Table 1). This reduces the particulate matter usually to 150 to 200 mg/Nm³ and simultaneously cools the gas far enough for further purification. However, even in the subsequent Theissen (droplet) disintegrator or Venturi scrubber, the dust content can be reduced usually only to 50 mg/Nm³, which is not good enough for catalytic operations downstream. In order to reduce the dust content further, electric precipitators must be used. The Lurgi Laboratories operate a larger number of test apparatus for the investigation of variables such as voltage, electrode shape and distances, as well as dust discharging equipment and aerodynamic influences.

At the beginning of the production of town gas, wet iron oxide was used to desulphurize the gas. For small operations, this may still be the most economical method, due to its simplicity and low investment. If only the sulphurous components shall be separated from the gas, the active carbon process is economical even in larger installations as it can produce sulphur directly. For larger operations, in which, besides sulphur, a large percentage of carbon dioxide must be separated, liquid solvents are mostly used. If the gases to be purified are at elevated pressure then the so-called physical solvents are preferred and among these, especially methanol, because at temperatures of -69°C it dissolves several times the volume of the gases to be eliminated than chemical solvents and this requires correspondingly less heat and equipment to regenerate this solvent. The methanol in the Rectisol process has a good separation coefficient between CO₂ and H₂S, which results in richer acid gas concentrations, contributing to an improved operation of the subsequent Claus process for the production of elemental sulphur. (See Figure 18). Methanol also dissolves the organic sulphur compounds and the gum-formers completely and thus eliminates many difficulties farther downstream in the catalytic conversion units.

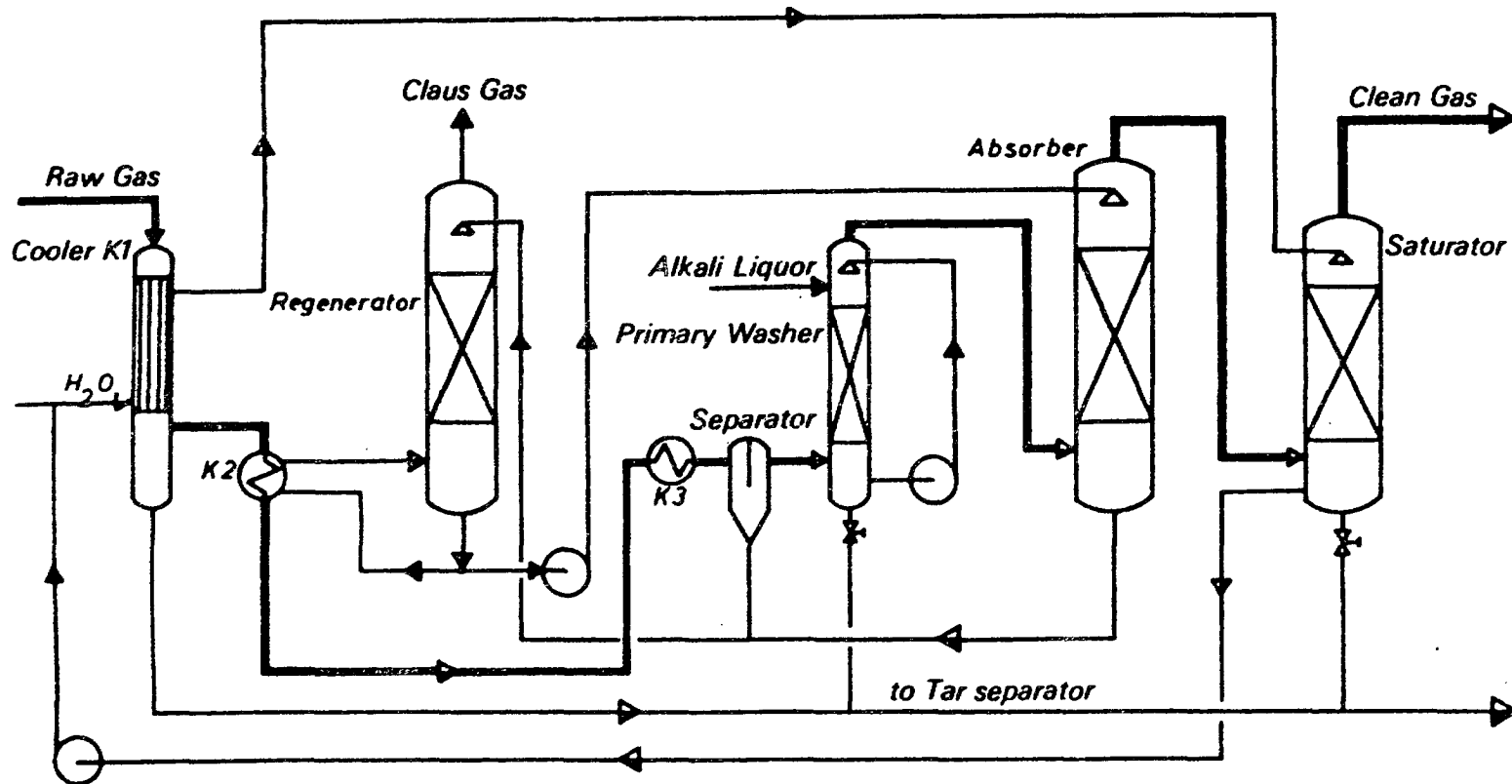
If a more precise separation of CO_2 and H_2S is required and the H_2S content of the gas to be purified is lower than usual and must be more concentrated in the Claus-feed gas, then the Purisol (N-methyl pyrrolidone) process must be considered, although its operating costs are somewhat higher than the Rectisol (methanol) process.

In the case of power generation by combined cycle and gasification of the solid fuel, the elimination only of the H_2S is required and desired. Separating the CO_2 and condensing the H_2O vapour would mean a loss of gas volume and therefore power. The Lurgi has developed a modified hot potash process which dissolves mostly the H_2S . (See Figure 19). The gas is cooled by heating the desulphurization solution to be regenerated and after purification in the adsorber, it is saturated by passing it countercurrently in a tower through hot water from the first indirect gas cooler. This process, however, works only with gases at elevated pressure.

For the clean-up of stack gases at atmospheric pressure, four processes were tested at the operations of the Steag in Luenen:

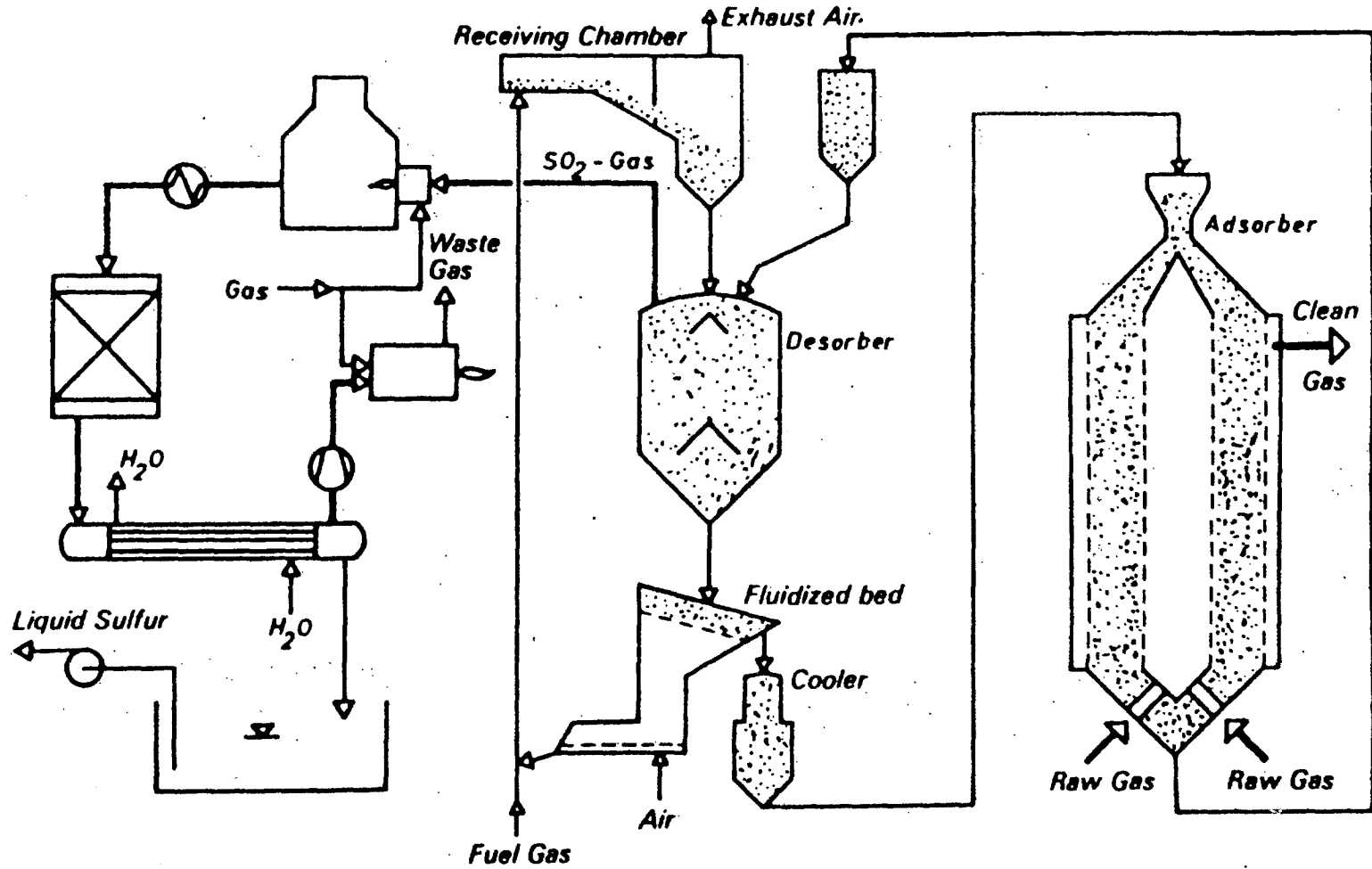
- 1) The Bergbau Forschungs process, in which activated coke or char is alternatively laden with SO_2 from the stack gas, which is then desorbed for the production of H_2SO_4 . The desorption can be carried out either as a dry process with air and partial combustion of the coke, or wet by dissolving the H_2SO_4 in water. (See Figure 20). The cost difference is in favour of the dry regeneration process because the concentration of sulfuric acid from the wet process requires too much energy.
- 2) The Bishoff process, in which the SO_2 from the stack gas is absorbed by a lime slurry in 2 stages. The saturated lime and fly ash is settled out and eventually reprocessed to H_2SO_4 . Scaling in pumps and ducts was experienced. Due to the cooling by the lime slurry, a draft fan is required to discharge the stack gases into the stack.
- 3) In the Combustion Engineering process, pulverized limestone is blown into the combustion chamber in which a large part of the sulphur of the fuel is bonded to the lime. After the air preheater, the flue gases pass through a scrubber, containing glass spheres in which the remaining sulphur is absorbed

FIG. 19



HOT POTASH GAS DESULFURIZATION

FIG. 20



BERGBAU-FORSCHUNG STACK GAS -
DESULFURIZATION PROCESS

by a lime slurry.

4) The Grillo AGS process, is in principle similar to the Bishoff process. Instead of a lime slurry, a slurry of manganese magnesium hydroxides is used. The laden slurry is regenerated by roasting it in the presence of pulverized coal or other fuels and reductants.

5) The Ugine-Kuhlmann process uses an ammonia solution to extract the sulphur from the flue gases. The ammonia is recovered by additions of lime and steam to the laden solution. The ammonia from the regenerator is recycled to the first absorption tower.

COAL LIQUIFACTION

The oil crisis in 1973-74 made it amply clear that liquid fuels are indispensable for the North American and European economies and the U.S.A. and Germany are actively engaged in developing methods of converting coal to liquid fuels. Those methods known at present would produce liquid fuels from coal at a price 3 to 5 times as much as those produced in a standard refinery from crude petroleum. Liquid fuels have been obtained in the form of coal tars as "by-products" from the coking and carbonization of coals for a long time. Some efforts are being made to increase the quantitative yield of these products by either a slow stepwise carbonization of the coal like the "COED-Process"; others try to obtain a higher yield of liquids from coal by very fast heating of the coal to temperatures of 600°C or higher, such as the Lurgi Ruhrgas or the Garrett process (very fine particles). It should be mentioned here that the Lurgi gravitating bed pressure gasifier can produce a fair amount of tar from coal, if operated with a greater layer height.

Coal contains relatively much less hydrogen than petroleum. The relative quantity and cost per unit of hydrogen required to increase the hydrogen content play a dominant role in the cost of the liquid fuels produced from coal by pressure hydrogenation. The production of aviation gasoline from coal, as practised in Germany during the war, included 4 refining steps besides coal preparation, hydrogen production, energy generation and 7 gas and liquid separation and finishing steps, besides handling of waste products. The aim of the research is to reduce the overall costs by reducing the number of steps required and by producing liquid fuels, which are less refined and therefore require less hydrogen and simultaneously produce a smaller amount of hydrocarbon offgases, which require treatment and thus increase the portion of liquid fuels produced per unit weight of coal.

Direct High Pressure Hydrogenation

As the high pressure hydrogenation of coal to liquid fuels requires too much pressurized hydrogen, most of the research is directed towards high temperature pressure extraction of coal, essentially as practised in a plant in Botrop, Germany in accordance with patents of the Friedrich Uhde Co., Dortmund. The underlying view is that much milder conditions are required to split the layers of molecules of which coal is made up and hydrogenate the valence cleavages opened between the layers rather than to split the aromatic molecules in the layers themselves for further hydrogenation. In additional steps, the extract, separated from most of the ash of the coal by hot filtration and pre-refined, can then be hydrogenated more economically in the presence of more active catalysts to usable products.

Other processes aim at reducing the number of operating steps by hydrogenating the coal by passing it in an oil slurry over a fixed bed of pelleted catalyst like the Synthoil process or by having the coal-oil slurry streaming upward in the presence of finer catalyst particles at such a velocity that the settling equilibrium of the catalyst prevents the latter from being carried out of the reaction space like the H-Coal process. So far, however, none of these processes has yet produced marketable liquid fuels at a price comparable to that of fuels from petroleum.

Fischer Tropsch Synthesis From CO-H₂

The same is true for the liquid hydrocarbons produced by reacting CO-H₂ mixtures at moderate temperatures and pressures over catalysts. The Sasol Co. is still operating this process since 1949. Two variants of this process are practised, a) the older Ruhrchemie-Lurgi (Arge) process, operating at low pressure and about 250°C with a fixed bed cobalt catalyst, producing higher molecular liquids besides waxes and b) the Kellogg process, operating at somewhat higher pressure and at 350°C, with an entrained re-circulated iron oxide catalyst of a lifetime of days only. The third process, the Koelbel process, reacting a mixture of 3 vol. CO with 1 vol. steam at about

380°C in a catalyst oil slurry also at moderately high pressure, is no longer practised in Germany. The latter process allows the production of a significant quantity of substantially straight chain olefines. Some research in this field is still being done, although, especially on a large scale, the Fischer Tropsch and related processes, due to the high energy losses in the conversion step to liquid fuels, look less attractive than the direct hydrogenation.

CONCLUSION

The purpose of the visit of the Canadian Delegation to Europe, undertaken between September 22 and October 12, 1974, was to familiarize the Canadian Governmental Agencies and industrial organizations with the development of the coal technology in Europe.

In order to minimize the risks of the dependence on foreign oil imports, the United States, as well as the industrialized European countries, have adapted and are developing strategies to broaden and to diversify their domestic energy resources. All those countries possess coal reserves which could last, at the present energy consumption level, for at least the next century.

In order to develop the use of coal as an energy resource and simultaneously make it environmentally acceptable, extensive research and development programs are initiated in those countries to improve the existing coal conversion processes as well as to find possibly new and better ones and also to make those processes compatible with the existing economic and social conditions.

Canada possesses at present, ample reserves of semi-liquid hydrocarbons in the Athabasca Oil Sands; therefore the Canadian Government felt not the same urgency to put large sums of funds into the development of a coal conversion industry, but rather to improve on the processing of the bitumen from the oil sands and black pools. It will appear, however, that even in this field, the close observation of foreign technology, as for instance the adaptation of the Lurgi-Ruhrgas process to the extraction and simultaneous refining of the bitumen from the oil sands, could lead to an improvement and simplification of the existing processing methods.

The Federal Government of Canada has therefore at present, limited any of its activities in the field of coal conversion research to the observation and critical review of the developments taking place in the other industrialized countries, in order to be able to decide eventually when the need arises, in what direction the development of a future coal conversion industry should go in Canada and how it would be integrated into the economic and social pattern of Canada.

LIST OF ORGANIZATIONS VISITED DURING THE TRIP

- Sept. 23, 1974 Lurgi GmbH, Fuel Technology Division, Frankfurt (Main). Discussion of coal refining and conversion processes.
- Sept. 24, 1974 Lurgi GmbH, Fuel Technology Division, Frankfurt (Main). Tour of the laboratories and pilot plant facilities.
- Sept. 25, 1974 Davy Powergas GmbH, Cologne. Discussion of Winkler gasification process.
- Sept. 26, 1974 Koppers GmbH, Essen. Discussion of Koppers-Totzek gasification process.
- Sept. 27, 1974 Nitrogen Works, Puentes de Garcia Rodrigues, Coruna. Tour of the Koppers-Totzek gasification plant.
- Sept. 30, 1974 Nuclear Research Center, Juelich. Discussion of nuclear process heat utilization and the systems of energy transport.
- Rheinbraun GmbH, Cologne. Visit to Poffendorf Castle Information Center and to the open cast pit at Garsdorf. Discussion of coal gasification processes.
- Oct. 1, 1974 Ruhrkohle AG, Essen. Visit to First Leopold Mine at Dorsten. Discussion of coal refining and gasification processes.
- Oct. 2, 1974 Schering AG, Berkamen. Discussion of the role of coal in the chemical processing industry and the tour of the chemical plant.
- Steag AG, Luenen. Discussion of coal gasification processes and the tour of combined gas/steam turbine generating plant with Lurgi gasification process.

- Oct. 3, 1974 Bergbau-Forschung GmbH, Essen. Discussion of coal refining and conversion process. Tour of the laboratories and pilot plant facilities.
- Oct. 4, 1974 Federal Ministry for Research and Technology, Bonn. Discussion of the German energy policies and R&D program.
- Oct. 7, 1974 BCURA, Leatherhead, England. Discussion of fluidized bed coal combustion and tour of a pilot plant facility.
- Oct. 8,9, 1974 Second International Coal Research Conference, London.
- Oct. 10, 1974 British Coke Research Center, Chesterfield. Discussion of coke production processes and tour of laboratories and test-oven plant facilities.
- Oct. 11, 1974 Scottish Gas Board, Westfield at Kinross. Discussion of Slagging Lurgi coal gasification process. Tour of the test gasification plant.