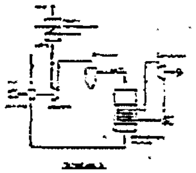
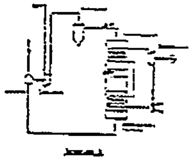
power generation costs can be achieved by comparison with a coal dust-fired power station with waste gas desulphirisation.

Thereby the circuit shown in Fig.22 is used as a basis.



The flue gases coming from the fluidised bed firing system are fed, after cleaning, to the gas turbine at 800 °C. This generates power and the necessary compressor output. The waste gases from the gas turbine are brought by heat exchanger up to an economical waste gas temperature.

The circuit depicted in Fig.23 shows concepts based on a study by VK with which the problems of flue gas cleaning and the gas turbine arise in a considerably lower temperature range.



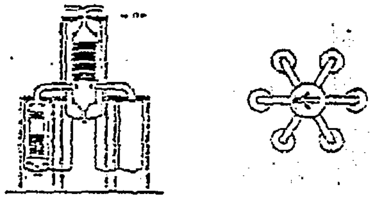
The flue gases leaving the fluidised bed cool in a following heat exchanger to a point where the following gas turbine, during expansion,

ers only the compressor output without additional power generation.

steam generation heating surfaces are in the supercharged section and e kept extremely small owing to the high heat flow densities attaribu-le to the supercharging. Dust extraction then takes place within a rature range which can already be mastered. The gas turbine can also nstructed with adequate resistance to erosive and corrosive wear in temperature range.

The loss in process efficiency as compared with the circuit in Fig.22 be offset by lower investment overheads and improved availability.

Fig.24 shows a concept of a 600 MW_{el} unit in which six separate and pendent fluidised bed firing systems operate on a following common et exchanger.



The load can be regulated by bringing in or shutting off individual ng systems.

The pressurised or supercharged fluidised bed firing system still s considerable development effort, so that commercial deployment of s technology is not be anticipated for about 6 to 8 years.

Concluding Observations

Knowledge and experience acquired with fluidised bed firing systems has been accumulated for the greater part from laboratory tests, semi-technical installations and a few pilot plants.

It is therefore understandable that immediate deployment of the environmentally acceptable fluidised bed firing process on power station scale represents a certain risk at present.

This relates not only to actual use of the fluidised bed firing syst but also to the difficulties which can arise in conjunction with individ components which, in isolation, have proved quite satisfactory.

It must also be borne in mind that in some cases considerable time may be required to bring a plant up to reliable, smooth operation.

However, the encouraging experience gained in operation of the Flingern plant gives reason to hope that the fluidised bed firing system will enable much better solutions to be found to many outstanding problems, including the constant growth in energy requirements, the limited resources of low-sulphur fuels, the increasing dependency on fuel imports and particularly the needs for environmental acceptability.

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COAL FIRED POWER PLANTS - CONVENTIONAL AND ADVANCED CONCEPTS, TECHNICAL, ECONOMICAL AND ECOLOGICAL CONSIDERATIONS

Contents

Introduction

Forecasts of the world coal production predict an increase from . 10^9 TCE today to about 5 . 10^9 TCE in the year 2000. Most of the produced hardcoal and lignite will be burned in power plants. According to Indonesian forecasts, about 12.000 MW new coal fired power plants will be in operation in the year 2000.

Coal fired power plant units for burning low-grade bituminus coal and lignite with high ash content and undesirable ash properties are a very high standard in Germany today. An important reason for this is the very good cooperation between utilities, manufactures and R & D-institutes. To meet the high requirements on economical and ecological operation it is necessary to undertake intensive efforts in devěloping new power plant concepts.

The ministry for Research and Technology is supporting numerous R & D projects, pilotplants and demonstration plants for national and international projects.

Requirements on coal fired power plants

The modern power plant comprises of a multitude of components that are produced in a number of different factories. Inevitably, each piece of equipment has an influence on the reliability, the availability and the hence on profitability of the plant. In order to prevent plant break down due to unforeseeable direct or indirect damages, reliability of each component is imperative. Preventive maintenance and investigation of damage, as well as operation under load conditions and conscientions servicing are of prime importance to the national economy. The operating staff will have to fulfill exacting requirements which necessitates a good professional education and continued advanced training. In the past few years, the requirements imposed upon power plants have steadily increased. The most important points are depicted in Fig. 2.-1.

3. Conventional coal fired power plants

3.1 Economical considerations

Thermal cycle efficiency, availability, reliability and high load change and startup capabilities are the most importing factors for influencing the economical operation of a power plant.
Since 20 years, most German utility power plants are equipped with once through BENSON-steam-generators. They meet the above mentioned characteristics in an excellent way.

3.1.1 Possible method of improving thermal cycle efficiency

The primary measures to improve thermal cycle efficiency are:

- Increasing the main steam pressure
- Increasing the main steam temperature
- Increasing the reheater temperature
- Providing double reheat

These measures are discussed in relation to a 720 MW reheat unit that utilizes the steam conditions of 185 bar/530 °C/530 °C (2670 psig/985 °F/985 °F) that are typically employed in West Germany at present. Fig.3.-1 depicts the following possible efficiency increments:

- Raising the main steam pressure to 250 bar (3610 psig) brings about an approximate 2 % net improvement in efficiency. A further increase to 300 bar (4335 psig) yields only an additional improvement of 0.75 %.

- Raising the main steam temperature from 530 °C to 540 °C (985 °F to 1005 °F) results in a 0.25 % improvement. No further appreciable increase in temperature was covered by the study in order to allow the well-proven currently used materials to be employed in the boiler and for the steam pipes.

- Similarly, raising the reheater temperature from 530 °C to 540 °C (985 °F to 1005 °F) increases the efficiency by 0.25 %. A further increase to 560 °C (1040 °F) yields a 0.75 % efficiency improvement. Here again, any higher temperature requires the adoption of other then presently standard materials.

- Providing two stages of reheat allows the efficiency to be increased by 1,5 % to 2 %. Of course, this greatly complicates the plant, thus rendering double reheat economically justifiable only in special cases.

This study shows that the most effective way of improving thermal cycle efficiency is to increase the design main steam pressure. The same investigations reveal that adopting supercritical steam conditions makes economic sense even for medium-sized power plants.

It is essential that an increase in efficiency should not lead to a lowering of operating availability. Since in the case of Benson boilers, the adoption of supercritical steam conditions does not involve any change in the basic design, system arrangement and controls, the possibility of a reduction in availability can be discounted.

Fig.3.-2 shows the influence of fuel prices, steam-pressure on the attainable profit of a 720 MW hardcoal fired power plant.

3.2 Environmental protection problems

In Germany, very similar than in the USA or Japan. New power plants have to meet very high environmental protection standards.

Fig.3.-3 shows the permissible dusty and gaseous emissions for conventional power plants in Germany.
The most important pollutants are SO_2 and NO_x.

Fig.3.-4 shows a comparison for 3 different cases. The remarkable reduction of SO_2 and NO_x for a combined cycle with coal gasification and low BTU-purification is obviously.
The gas desulfurization is necessary for all new power plants in Germany.

3.3 Utility power plants

Steam power plants will assume the most important role in the generation of electricity in Indonesia for many years to come. They shall be fueled by lignite or subbituminous coal.

For this reason we will describe 3 typical plants, which could be of interest to the Indonesian power plant experts.

3.3.1 Wilhelmshaven 720 MW-hard coal fired power plant

This power plant is owned by the NWK and located at the sea not far of the city of Wilhelmshaven in North Germany.

The site offers open-cycle cooling with seawater and fuel delivery by sea-going ships. Due to the low bearing capacity of the soil the plant had to be founded on piles.

KWU's activities in the construction of the power station included the consulting services for the total plant as well as the supply of sizable parts of the electrical equipment and the turbine generator.

The power station was planned to cover the varying load demand between morning hours and midnight.

The annual power generation was equivalent to 4000 full-load hours. The unit was therefore designed for shutdowns of each night and over the weekends. Short start-up and shutdown times as well as rapid load changes were required for the envisaged schedule of operation.

The power plant was to be designed for coal and heavy oil firing. As the coal was to be bought from all over the world the characteristic values of the coal were assumed within the following ranges:

low heating value	25 000 - 34 000 kJ/kg
ash-content	7 - 15 %
hard grove no.	45 - 65

All these conditions have led to the selection of the following design data:

- at the boiler outlet 191/530 bar/°C
- reheat 530 °C
- final feed-water temperature 247 °C
- no. of extractions:6
- condenser pressure 0.06 bar

Remarks: for a base load unit the design parameters would have been 240 bar, 545/545 °C) with 8 extractions and 0.03 bar)

The mode of operation was decided to be sliding pressures as usual in Germany.

There was a strong opposition from the population against this coal fired station and the permission to built it was finally obtained from the government under the following conditions:

- stack height must be 275 m,
- flue gas must not contain more dust than 75 mg/m³ at 0 °C, 1.013 bar,
- provision of a desulphurization plant for 20 % of the flue gas flow,
- limitation of the SO_2-emission to 5 t/h,
- limitation of the noise level to 30 db (A) at a distance of 2 km from the power station fence.

Let me now explain in sequence the essential features of the power station which was commissioned in 1976 after 3 years of construction time.

Boiler

The steam generator (Fig. 3.-5) is a Benson boiler of the two-passes design with a rated steam flow of 603 kg/s supplied by Babcock AG. The wall heating surfaces of the furnace, of the horizontal gas pass as well as of the second gas pass consist of welded tube walls (membrane walls) which are flue gas-tight. The furnace up to the horizontal pass has tubes arranged in the shape of a spiral. At the top of the first pass (radiation space) there are vertically anged tubes.

teel tubes are also in the side walls of the horizontal pass
of the second pass. The convection heating surfaces are
modated in the second pass and not as usual in the horizontal
. The entire boiler body is suspended from the transversal
on the top of the boiler which rest on the steel columns.

all thicknesses of headers and separators in the pressure
of the boiler which could reduce its flexibility have been
d. This was achieved by a higher number of parts arranged
allel and by the use of better material. Mixing headers
have rather thick walls and which are often used for tempe-
equalization within the individual streets of the super-
are completely eliminated in this boiler. Temperature
ences in the flue gas are compensated by crossed arran-
of the four superheater streets (strands).

ntrol of the main steam temperature is achieved by two spray
arranged in sequence in each system.

suring and control circuit as well as the sprays are
nt to avoid temperature changes, in case of a failure in

mensions of the furnace are:

ght from the upper end of the hopper to the
ling of the furnace: 61.7 m
th 23.66 m
th 15.77 m
flue gas inlet temperature of the convection
ating surfaces is 1190 °C
he maximum gas velocity in the passes is limited
o 14 m/s.

e combustion is done in 32 combined coal dust / oil burners
hich are arranged at 4 levels in the front and back-wall of the

perational Experience

Figure 3.-6 shows typical load characteristics of the power station. The oad curve on top of this figure is a typical base load characteristic. The curve below is also for base load operation but in addition with load changes required by the grid system to control the frequency. Load changing rates of up to 50 MW/min. have been performed with sliding pressure control.

During the first year of operation the 3rd curve at the bottom of this figure was typical for daily shut-downs and shut-downs over the weekend.

The results of load changing tests are shown on figure

In case of large and fast load changes (in the medium load range 10 % of nominal rating/min are possible) there is no change of main steam temperature. The reheat temperature is only varying with the load in accordance with the natural reheat steam temperature characteristic.

Even with load changes of 10 %/min the permissible limits for thermal stresses are nowhere reached. The load changing rates are therefore limited by the response of actuator and the capability of auxiliary equipment only.

With cold starts only the wall stress evaluator is limiting the rates of speed or load increases. The cold start is done with gradually increasing steam pressure and temperature to achieve short starting times.

The unit can be started up and shut down automatically from any condition with dry superheater surfaces. Cold start of the unit is accomplished in the variable pressure operating mode.

Fig.3.-7 shows the automatic starting performance with a cold steam-generator.The unit supplied 300 MW to the power system only [illegible] minutes after the boiler was ignited.

A warm start (after 8 hours shut down) needs about 30 minutes from boiler ignition to full load.

3.3.2 Lignite fired power plant

About 70 % of the brown coal mined all over the world is fired in power plants in Europe.
Nearly 35 % of our electrical energy in Germany is produced by approximately 15.000 MW lignite fired power plant. Due to the relatively low fuel costs they are operating as base load units. Therefore, the most important factor is a high availability.
All lignite fired units are designed with a pressure in the range of 160 - 190 bar, single reheat stage, 530°C.

Fig. 3. -8 shows a typical steam cycle flow diagram.
A longitudinal cross section of the 325 MW power station is shown in Fig. 3. -9.
The biggest component of the plant is the boiler which is of the BENSON- type.

RWE, the German biggest utility has about 13.000 MW lignite fired power plants in operation. In 1970/71 six 600/630 MW-units had been ordered, they went into operation between 1973 and 1974.

Fig. 3. -10 shows the longitudinal cross section of the 600 MW power plant unit Niederaußem G.

The single pass steam-generator is appr. 128 m high: the combustion chamber has a volume of about 20.000 m³. The most important problems influenced by the typical characteristics of ash from lignite are:
- ash-fouling of radiation and convection heating surfaces.
- erosion of heating surfaces and other flue gas passing components.

Longterm experiences have shown that a single pass boiler is the best solution for a high availability.

In table 3. -1 some development highlights of lignite fired steam generators in RWE- power plants are shown. The first generator (100/150/300 MW) has about 13 remarkable design characteristics. In contrast to that, all 600 MW-boilers are of uniform design.

Advanced power plant concepts

bined gas and steam turbine power plants (combined cycle units) natural gas or oil firing have won rapid acceptance in the few years as a result of their economic adantages. This deve- ment has been made possible as a result of advances in gas turbine gn and through the increased availability of low ash content ls such as natural gas and oil.

to the fact that the availability of fuels fluctuates, it is necessary to make provision for employment of coal for pro- tion of electrical power. New combined cycle units must there- be suitable for coal firing. A further requirement is that the ecologically favourable coal processing technologies such as gasification and fluidized bed combustion must be integrated combined cycle systems if these technologies are to be econo- cally employed in large capacity power plants.

shall now consider three different types of combined cycle units, are either in operation, under construction or in the planning in the Federal Republic of Germany, and shall describe the it, the efficiency and the potential for further development. three combined cycle units are designed for coal firing. The types of combined cycle units are (Figure 4. -1).

bined cycle with coal fired steam generator in series:
e exhaust of the natural gas fired gas turbine, which contains a high percentage of oxygen, is employed by the coal red steam generator as combustion air. Planning for this plant been completed and construction began in 1979.

bined cycle with supercharged steam generator.
e steam generator is installed in the gas turbine combustion mber. Either natural gas or coal gas, produced by a coal ification plant, is employed as fuel. A plant of this type been in operation for a number of years. In Kellermann power nt the coal gas is generated in a Lurgi pressurized coal ification plant.

- Combined cycle with atmospheric fluidized bed combustion. The thermal energy produced by fluidized bed combustion is [illegible] to a gas turbine in Volklinger Prototype power plant. The gas turbine exhaust is employed as combustion air for th following steam generator.

4.1 Activities in Germany and in other countries

Table 4. -1 shows a classification of the most important R & D - projects for advanced power plant concepts. The activities in this field are so numerous that it is not possible to list up all projects.

A comparison of different fluidized bed-combustion- and coal gasification-systems is made, concerning the main interesting characteristics:

- Cost reduction of the plants
- Rising efficiency
- Minimal air pollution and
- Operational advantages.

Our government, R & D institute and several relevant companies are very interested in successful cooperations with other countries.

. Power plant concepts with combined cy[illegible] and coal fired steam generator in series

The detailed circuit of this combined cycle is depicted in Figure 5.-1. The gas turbine exhaust is fed to the coal fired steam generator as combustion air. Since an air preheater heated by flue gas is not employed, the final stage of cooling of the flue gases is effected by the feedwater heaters, which are connected in parallel with the steam heated heaters. A higher thermodynamic efficiency is obtained as a result of the parallel connection. The heating surface costs and the fuel costs are taken into account for optimization of the feedwater partial flows among the heaters connected in parallel. Generally, between 40 and [illegible] % of the feedwater flows through the flue gas heated heaters.

The temperature of 450 - 500 °C of the flue gas leaving the gas turbine is too high for coal drying, for which reason a certain quantity of cold air must be mixed with the gas turbine exhaust. In contrast to natural gas or oil fired power plants a fan must be continually in operation. On failure of the gas turbine the combustion air provided by the forced draft fan is heated to approximately 200 °C in a steam air preheater in order to ensure adequate drying of the coal.

The following combinations shown in Table 5.-1 employing gas turbines from the range at present manufactured by KWU are practible in order to achieve a unit rating of the order of 700 MW:

Number of gas turbines		1	2
Gas turbine exhaust flow	%	65	94
Additional air flow	%	35	6
Gas turbine rating	MW	108	2 x 74
Steam turbine rating	MW	640	646
Total power output	MW	748	794

Table 5.-1 Combined cycle unit with one or two gas turbines

The circuit employing one gas turbine only results in a somewhat simpler layout as compared with the other solution, however, the FD-fans must be rated for 100 % output. The use of two gas turbines results in a higher efficiency over the whole load range and offers operating advantages: the FD-fans, which are continuous operating, are dimensioned for 60 % of th total combustion air flow. On failure of a gas turbine a singl FD-fan can supply the combustion air required.

The net efficiency (fuel-low-voltage terminals of transformer) obtained with this circuit is shwon in Figure 5.-2. Calculation was based on a gas turbine inlet temperature of 930 °C, an air temperature of 10 °C and conventional steam conditions. The efficiency can naturally vary to a certain extent dependent fo example on the cold end of the turbine (choice of the low press turbine, cooling mode). The improvement in efficiency is 5 % a full load.

The net efficiency of combined cycle units starts to fall rapid in the lower portion of the partial load range, since the consta thermal energy of the gas turbine exhaust leads to heat transfer in the leading section of the steam generator. as a result of which premature evaporation may occur in the economizer. The partial load characteristic depicted in Fig.5.-2 applies for stea generators of conventional design. It is however possible to alter the design of the heating surface and their arrangement an the overall design of the steam generator in order to shift th range of low efficiency to even lower partial load ranges.

Figure5.-3 depicts a BENSON steam generator for a combined cycl plant. The steam generator is characterized by cooling of the flue gases down to a temperature of 155 °C by means of an economizer and partial flow preheaters. An air preheater is not employed. Part of the gas turbine exhaust is injected above the 2nd draft in the lower partial load range. Adequate mixing of the exhaust gases with the flue gases from the firing is ensured by means of 16 inlet openings. Short flow paths are ensured by means of vertical secondary air channels into which

gas turbine exhaust gases or fresh air - fed.

asic steam generator design combines the advantages of draft design with those of dual draft design. Water upwards through the water bearing heater surfaces of cond draft and the heating surface are arranged in an led steel duct.

bined cycle unit with coal fired steam generator requires 30 % of the thermal energy in the form of high quality (gas or light oil) in the gasturbine. Furthermore the flue s of large units must be desulphurized for ecological reasons. e two requirements can be avoided when the coal gasification ology, type Vereintigte Elektrizitätswerde Westfalen/Stein- er, is integrated in the combined cycle. The coal will be degase partially gasified in this process resulting in the generation ar and coke. Ash and sulphur are removed from the gas which is d in the gas turbine. The coke is fired in the following steam rator. On the basis of the results obtained in prototype plants, is anticipated that, as a result of removal of sulphur from the produced, the presently obtaining ecological requirements for al power plant can be satisfied. It is thus possible to a combined cycle plant based solely on the use of coal as a . The net efficiency would, however, be lower than that of a al gas/coal combined cycle power plant due to the losses in al conversion process.

wer plant concept with coal gasification

present state of combined cycle technology with coal gasifi- n gives the possibility to realize a commercial power plant. of the most important preconditions is an available gasturbine a gas-inlet-temperature in the order of 1200-1300°C. expected that, at the end of the 80_th., the development of cooking systems may assure that goal.

. Coal gasification processes

ted coal gasification processes in a commercial size are

also available within the next decade.
The following pressurized processes are now operating in a pilot plant size

processes	Reactor-type
-Lurgi-Ruhr 100- process	Moving bed
-High temperature Winkler process (HTW)	Fluidized bed
-RAG/RCH-Texaco process	Entrained bed
-Shell-Koppers process	Entrained bed

6.2 Combined cycle with differnt pressurized processes

Generally all the above mentioned gasification processes are suitable for combined cycle power plants.
Fig. 6. -1 shows the flow scheme of a Steag process-combined cycle with a Moving bed Lurgi gasifier for a max. output of 135MW + 665MW = 800 MW based on a project-study.

Fig. 6. -2 is a very simplified scheme of a combined cycle for the HTW-fluidized gasification process, developed byRheinische Braunkohlewerke A.G.
Two differnt proposals for combined cycle power plants based on the Shell-Koppers entrained bed gasifier are shown in Fig.6. -3 an Fig. 6.-4.

Fig.6. -3: Coal gasifiers can be built together with the power plants, matching them in size and sharing the same location. An essential feature of this option is the integration of gasifier and power plant.

Fig. 6. -4: Gas can be produced in large coal gasification complexes ("coalplex") and piped for instance to power plants of the combined cycle-type. No integration between gasifier and power plant would be considered, the only link being a trunk line gas grid.

. Power Plant Concepts Using Fluidized -bed Combustion

les using atmospheric fluidized-bed combustion (AFBC)

spheric fluidized-bed combustion affords many advantages. particular in respect of adding the fuel which, if necessary, y be injected from above into the fluidized bed without the d for pre-drying. Furthermore, ash removal presents less blems than is the case with pressurized systems. In addition. e-gas dust separation is possible at low temperatures.Naturally, sign difficulties may due to the low specific cross-sectional ting with plants of high rating. Thus, for instance, a 350 MW eam generator would require a floor space of over 25 m x 25 m r the combustion chamber alone (a conventional steam generator th this rating would only require 12,5 m x 12,5 m).

ever, with a conventional reheat steam cycle both the evaporator ating surfaces and some of the superheater heating surfaces may accommodated in the fluidized-bed zone itself. This substantially duces the overall height when compared with a comparable conven- nal plant.

is also possible to incorporate atmospheric fluidized-bed bined gas turbine-steam turbine cycle (Fig.7.-1).However, the ve-mentioned design disadvantage remains. The compressor air heated in the immersion heating surfaces in the fluidized bed. idual heating up to the required gas turbine inlet temperature accomplished by means of gas in the gas turbine combustion mber. The exhaust gases from the gas turbine flow into the idized-bed combustion zone, thus serving as carrier and combus- n air. The resultant stack gases at a temperature of approximately [illegible] °C are then cooled in the tailing steam generator. For the steam e we may assume, as a basis, that the steam exiting at the rheater outlet will be at a pressure of 95 bar and a temperature [illegible] °C. The feedwater is preheated by means of flue gas and steam.

Of the overall heat requirement, 82 % is supplied through coal and 18 % through gas. This arrangement achieves a net efficiency of slightly less than 36 % at a gas turbine inlet temperature of 850 °C. Due to the high backpressure (gauge pressure) of 200 mbar required for fluidized-bed firing, the gas turbine has a relatively low output when used for this cycle.

Fig.7.2 illustrates one further possibility in which only part of the exhaust gas stream from the gas turbine is used as combustion air, the remainder being supplied directly to the waste heat steam generator. The exhaust gas leaves the gas turbine at a temperature of 420 °C and a backpressure (gauge pressure) of 30 mbar, matching the fireside resistance produced by the waste heat steam generator. A blower transfers a bypass flow of the exhaust gas to the fluidized-bed combustion zone. The resultant flue gases are first cooled by heating surfaces from a temperature of 850 °C to 420 °C and, after mixing with the remaining exhaust gases from the gas turbine, are then used again for steam generation. The steam conditions at the superheater outlet are 50 bar/530 °C.

This arrangement produces an increase in net efficiency to a good 37 %. However, only 67 % of the fuel heat input to the cycle results from coal and 33 % from gas.

When compared with a straight steam cycle incorporating fluidized-bed firing, both these combined cycles entail the disadvantage that an appreciable proportion of the heat needs to be supplied by gas.

In contrast, due to the high efficiency, the arrangement shown in Fig.7.3 represents one interesting alternative to a conventional steam cycle. A pulverized-coal-fired steam generator incorporating high-grade steam-generating parameters and a reheater is arranged after the gas turbine and the fluidized-bed combustion zone. A proportion of the gas turbine exhaust gases serves as combustion air for the steam generator and the hot flue gases from the fluidized-bed combustion zone are passed, at a temperature of 850 °C, to the steam generator. Using this arrangement, a net efficiency of 39 % may be achieved depending on the ratio of steam turbine to gas turbine output.

Combined cycle incorporating pressurized fluidized-bed combustion and water/steam cooling

In the case of a pressurized fluidized-bed combustion system, we may assume that the fluidized-bed surface area will decrease approximately inversely proportional to the pressure of the flue gas. Pressurized operation enables smaller, more units to be employed, which may be shop-assembled depending upon the rating. Furthermore, increasing pressure has a favourable effect on the retention of sulfur dioxide and reduces the formation of nitric oxides.

By combining a gas turbine cycle with a high-grade steam turbine cycle, we may achieve maximum plant efficiency (Fig.7.-4. The combustion air for fluidized-bed combustion is supplied by the gas turbine compressor. Sufficient heat is transferred to the water/steam cycle in the fluidized-bed immersion heating surfaces so that the temperature of the fluidized bed does not exceed 850 °C. The dust is separated from the flue gas and the pressure is reduced in the gas turbine from an absolute pressure of approximately 10 bar and a temperature of 850 °C to ambient pressure and a temperature of approximately 420 °C. The residual heat from the gas turbine exhaust gases is largely dissipated in the feedwater heaters. The net efficiency is approximately 39 %.

Increasing the temperature of the fluidized bed to a value of [illegible] °C would increase the efficiency to approximately 40 %. However, further efficiency improvements are not possible since, in the case of specific grades of coal at temperatures above 900 °C, there is the risk of fusion of ash particles deteriorating the fluidization process. Furthermore, the sulfur absorption rate will decrease at these high temperatures.

Combined cycle incorporating pressurized fluidized-bed combustion and air cooling

The advantages of pressurized fluidized-bed combustion may also be applied to air cooling (Fig.7.-5).The compressor air is thus split into two partial streams: one partial stream serves as cooling air and the other as the combustion air for the fluidized bed. The flue gas, at 850 °C, resulting from the combustion process is separated from the dust which it contains and is then mixed with the cooling air (hot air) before entering the gas turbine. In the steam cycle tailing the gas turbine, the steam parameters are selected so that maximum electric power is generated from the gas turbine exhaust heat.

This division of the compressor air into the two partial streams plus the temperature of the hot air effect the inlet temperature to the gas turbine and, thus, have a governing effect on the efficiency of the combined cycle. Maximum efficiency is achieved in the boundary-line case of using all of the compressor air for combustion purposes. and, thus, none for cooling purposes. In this case, the fluidized-bed combustion equipment is operated at high excess air the dimensions increase accordingly. With a cooling air component of 50 %, the result is a net efficiency of approximantely 34 %.

The lower net efficiency in comparison with the cycle incorporating a water and steam cooled fluidized bed results from two factors: firstly, the efficiency of the steam cycle is poorer and secondly, due to the relatively high gas turbine output, the influence of the pressure loss on the air and flue gas sides of the fluidized-bed combustion system on the efficiency is increased.

Power plant design incorporating air-cooled fluidized-bed combustion entail a large gas turbine-to-steam turbine power ratio reducing the cooling water flow required. Thus design of this nature may be used to advantage in municipal combined heating and power stations where an adequate supply of cooling water is often lacking. Furthermore, with a large cooling-air flow, the flue gas after the fluidized-bed combustion zone is diluted, thus correspondingly reducing the dust loading at the inlet to the gas turbine. In contra this system entails the disadvantages of a low efficiency and the necessity of high--grade materials for the air cooled heating surfa in the fluidized bed.

cycle using a supercharged steam generator

rized fluidized-bed combustion will not become generally pted until the degree of dust separation of the hot flue from the fluidized-bed furnace achieves the values per- sible for gas turbines. Naturally, the problem may be alleviated appreciably cooling the flue gases between the fluidized-bed ustion zone outlet and the hot-gas dust separator by means of ection heating surface. The lower flue gas temperature also a favourable effect on the degree of corrosion produced by the gases in the gas turbine.

gas turbine compressor delivers the combustion air to the idized-bed furnace of a steam generator. Firstly, the high- ssure and reheater heating surface cool the fluidized bed and n, in a convection section, cool the flue gas from a tempe- ture of 850 °C to approximately 440 °C (Fig.7.-6).These heating rfaces are subject to a fireside absolute pressure of between 9 10 bar and are therefore relatively small as a result of the heat transfer characteristics.

fore entering the gas turbine, the dust is separated from the e gases. The inlet temperature is selected so that the gas bine produces precisely the output required for driving the pressor. A percentage of the exhaust heat from the gas turbine still used for preheating the feedwater. Dispensing with a gas-heated reheater simplifies both cooling of the fluidized- furnace and also the steam cycle arrangement.

37 % net efficiency of this cycle is ample, being in the same er of magnitude as that of a conventional steam cycle incorpo- ting flue-gas desulfurization. However, this cycle permits the of pressurized fluidized-bed combustion for the steam cycle ther with all its advantages and reduces the problem of rating dust from the hot gas which, at present, has not yet solved at an industrial scale.

Main development objectives

Before gas turbine-steam turbine systems incorporating pressurized, fluidized-bed combustion are used on an industrial scale, it is still necessary to carry out comprehensive development work in respect of the gas turbine. The steam turbine cycle may be considered to have been largely perfected. Comprehensive development programs are already underway for the three components: fluidized-bed combustion system, dust separation from hot gas and gas turbine.

Comprehensive findings are already available in respect of fluidized-bed combustion, yet a whole series of process engineering problems are still to be solved before this systems can be utilized in industrial-scale plants. For pressurized plants, problems of solid-fuel feeding and hot-ash extraction arise in addition. Furthermore, for airswept cooling surfaces, a material still needs to be found which remains sufficiently strong and corrosion-resistant at temperatures above 800 °C.

The use of pressurized fluidized-bed combustion systems also depends greatly on finding a satisfactory solution to the problem of dust separation. The prospects of success in the field of separator development are, at present, difficult to assess since, on the one hand is no dust separator available on the market which is suitable for high temperatures, high pressures and high separation capacity and, on the other hand, experience is lacking as regards fluidized-bed ash.

The gas turbine forms the third focus of development since when used after a fluidized-bed combustor, it is subject to both corrosive and erosive influences.

Kraftwerk Union is carrying out research into problems of fluidized-bed combustion, separation of dust from hot gas, and gas turbines for dust-laden gases within the framework of its development program

8. Völklingen a Prototype Power Station of Saarbergwerke AG.

Fig.8.1 shows how the new unit will be integrated into the existing large power station. Fig.8.2 shows a simplified diagrammatic arrangement of the power station system and Fig.8.3 the layout of the various buildings.

The design and environmental compatibility of the prototype station, exhibit a number of important features.

Design of the station

The design of the station is illustrated in Figs.8.-4 and 8.-5. The compressor of the gas turbine draws in atmospheric air and compresses it to the working pressure necessary for the gas turbine. The compressed air is passed through heat exchangers immersed in the fluidized-bed and its temperature is raised to approximately 700 °C. In the turbine combustion chamber the final turbine inlet temperature of approximately 820 °C is attained when coke-oven gas is being burned. The inlet and outlet air ducting between the gas turbine and the heat exchangers is coaxial. In the gas turbine, expansion is carried down to 1.04 bar (absolute) and 436 °C. When the ambient temperature is 15 °C, and when operating with fluidized-bed combustion, the electrical output of the gas turbine generator is 32 MW.

The fluidized-bed and steam-generator firing systems are designed so that in normal operation the oxygen contained in the gas turbine exhaust is sufficient for complete combustion.

The fluidized-bed combustion units burn hard coal containing a high proportion of incombustible matter at an average combustion temperature of approximately 850 °C, with intensive heat transfer to the air flowing through the heat exchangers.

Part of the exhaust from the gas turbine is used as primary and secondary air for the pulverized-coal burners of the steam generator and for pulverized fuel drying.

The combustion gases from the fluidized-bed combustion units and the steam generator combine within the steam generator combustion chamber and flow together through the convection heating section. The flue gas temperature after the steam generator is approximately 150 °C.

It is intended that further heat will be extracted from the flue gases in a fluidized-bed heat exchanger for the Saar district heating system so that finally the flue gases can be admitted to the flue-gas desulphurizing plant,incorporated in the cooling tower at a temperature of approximately 90 °C. After the wet scrubbing, the cleaned flue gases mix with the cooling tower air and are discharged together with it (the outlet temperature of the desulphurizing plant will not exceed 60 °C under any conditions).

The steam produced by the steam generator (532 °C, 147 kg/s, 190 bar) is admitted to the single-flow high-pressure cylinder of the steam turbine, reheated to 532 °C in the boiler reheater and then admitted to the double-flow i. p. and l. p. cylinders of the turbine before being exhausted to condenser. The turbine generator produces an electrical output of 195 MW. There are h. p. and l. p. bypass valves to permit dumping of the main steam in the condenser for bypass operation.

The main condensate is circulated by the main condensate pumps (reentry pumps) through a demineralizing plant, two coolers and three l. p. feed heaters (a duplex immersion-type heater is used for the first two feed heating stages) to the spray-type deaerator of the feed tank. The boiler feed pumps draw from the tank and circulate the feedwater through three h. p. regenerative feed heaters and through the parallel-connected partial-flow economizer. When the two feed flows come together, i. e. at the inlet to the full-flow economizer, the feed temperature is approximately 250 °C. The drains are discharged in a cascade arrangement to the feedwater tank and, in the l. p. range, to the condenser.

A steam/water heat exchanger of conventional design is used for supplying the district heating system from the steam turbine. The steam is extracted from the crossover between the i. p. and l. p.

linders. Pumps circulate the hot water throug he system (the ping station is outside the power station buildings).

am-generator and fluidized-bed combustion units

e plant will have atmospheric fluidized-bed combustion units th fuel feeding from above) with the steam generator placed tween them (Fig. E-5)The area of each fluidized bed is approximately 100 m^2, which is considerably larger than any others in rvice or under construction. The depth of the fluidized bed is pproximately 2.3 m. The combustion gases from the fluidized-bed mbustion units are fed into the furnace of the steam generator rough ducts below the burner levels. The supply air (oxygen arrier and fluidizing medium) is the gas turbine exhaust which s forced into the beds through nozzle plates with the aid of high-ressure blowers. This plant is the first to have air circulating rough heat exchangers immersed in fluidized beds. This air is ken from the compressor of the gas turbine. The preheated air s fed to the combustion chamber of the gas turbine through the ner duct of the coaxial ducting. Due to the relatively poor ternal heat transfer of the air, wall temperatures of approximately °C must be anticipated at the heat exchanger tubes. Such high mperatures make severe demands on the materials and structural sign despite an absolute pressure of only about 7 bar.

th this heat cycle it is the first time that coal heat will be ansferred directly to a gas turbine, i. e. without prior conversion to a combustible gas.

fluidized-bed combustion test rig for conducting various experiments is already under construction on the Fenne power station site. s test rig will also provide information on material selection d arrangement of the heat exchanger tubes.

e Benson-type, once-through boiler (147 kg/s) is of conventional sign except for the introduction of the heat from the fluidized-d combustion units below the burner levels in the boiler furnace.

In order to obtain a uniform temperature profile and to ensure post-combustion of the incompletely burned particles in the combustion gases from the fluidized-bed combustion units, considerable emphasis has been placed on providing thorough mixing of the fluidized-bed combustion gases with those of the steam generator. Tests will show whether the offset, horizontally-opposed system of firing chosen will satisfy this requirement completely.

Cold end

The natural-draught cooling tower (100 m high), which employs the crossflow principle, will be the first to incorporate a flue-gas desulphurizing plant (Saarberg-Hölter method). The scrubbed flue gas is mixed with the cooling tower air to be discharged. The design makes stringent demands on thorough mixing of the gases, the composition of the concrete and the protective coating for the concrete structure.

This station has no chimney !

Other parts of the installation

It is not the intention in this paper to deal with other parts of the installation, although they are of great interest, especially the instrumentation and control (which poses some complex problems in this station), the gas turbine combustion chamber, the burners as such (here again tests are being conducted in order to optimize the design) and the coaxial ducting.

Environmental compatibility

The Völklingen prototype power station has been designed to use the local, high-sulphur coal and other coal with such a high proportion of incombustible matter that it would normally be rejected as waste. But at the same time contamination of the environment must be kept to a minimum and less than any other coal-burning power station yet built.

This performance will be due, in the main, to the following measures and equipment:

Fluidized-bed combustion is ideal for burning coal containing a high proportion of sulphur and incombustible matter. (The production of nitrogen oxides is reduced due to the long residence time and the low combustion temperatures in the fluidized bed. The proportion of sulphur dioxide in the combustion gases is considerably reduced by primary binding in the ash due to the lime already contained in the ash or introduced by adding carbonate of lime).

Through the use of air-cooled heat exchanger tubes the compressor air of the gas turbine is preheated in the fluidized-bed combustion units to such an extent that only a small amount of heat energy has to be added to the hot air in the gas turbine combustion chamber.

The burners used in the steam generator produce only small quantities of nitrogen oxides.

The design of the electrostatic flue gas precipitator ensures that the legal levels of dust in the flue gases are not exceeded despite the high dust content originating from fluidized-bed combustion units.

After leaving the electrostatic precipitator, flue gas is passed through a desulphurizing plant where it is scrubbed; the scrubbing not only removes more than 80 % of the sulphur dioxide but also a further proportion of the dust.

The flue-gas desulphurizing plant is incorporated in the cooling tower. (This means that any remaining harmful substances in the flue gas are exposed to the considerably better distribution conditions in the cooling tower discharge. Reheating of the flue gas, which would be necessary if a chimney terminated the system, is thereby eliminated, which also improves the overall efficiency of the station).

The combination of a gas turbine with a steam generator and fluidized-bed combustion, together with the mixing of the cold flue gas with the cooling tower discharge described previously, gives a better efficiency than conventional reheat cycles for coal.

Low-grade heat or waste heat from the steam circuit and from the flue gas is utilized for district heating.

The use of a closed cooling with a naturaldraught cooling tower avoids any undesirable heating of the River Saar.

In addition, use in also made of the waste products from the flue-gas desulphurizing plant (gypsum for the building industry) and the furnaces (ash, e. g. for road construction).

Noise levels will be kept within the values set by the local authoritis, despite a higher ambient noise level.

Construction schedule

Initial work on the site and the installation of the site power and lighting systems began in October 1979. Excavation work on the foundations for the power station buildings commended in February 1980.

The shell of the cooling tower will be completed by the end of 1980 and work on the steel structures for the steam generator and boiler house will begin in October 1980.

Commissioning is expected to begin in late 1981 and bypass operation in April 1982 (closed-circuit operation with the turbine shut down).

The whole plant will operate for about three years on an experimental basis. By 1985 it is expected that adequate reliability will have been achieved so that normal on-line operation can be commenced.

9. Power plant efficiency.Comparison of different concepts

An important element in comparing the various systems is the generating efficiency.
The clean, full-load efficiencies require correction to allow for a number of factors viz :

- efficiency loss due to part-load
- efficiency/load relation for coal gasification
- start-up/shutdown losses
- aging and fouling losses

Fig. 9. -1 shows a typical load efficiency for a combined cycle based SHELL/KOPPERS coal gasification (published by Shell/Koppers EC 1980)
A comparison between conventional and advanced power plants is shown in Fig. 9. -2.

10. Conclusions

In conclusion, it can be stated that coal fired power plants burning low-grade bituminous coal and lignite have a very high technical standard in Germany.
Due to meet high requirements on economical and ecological operation, new on coal based power plant concepts are under development in Germany and some other countries.
During the next years, a number of pilotplants and demostration plants will be taken into operation.
The Völklingen prototype power station is the most interesting one.
The most important characteristics of this plant are:
- the large scale fluidized bed combustion chambers and
- the environmental compatibility.

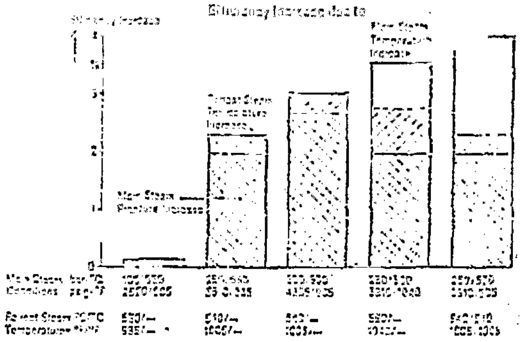
The German "Ministery for Research and Technology, which is sponsoring nearly all new projects, is very interested in international cooperation in the field of new power plant concepts.

Modern coal fired power plants have to meet the following main requirements :

- Economic production of electric power
- High environmental production standards
- High availability
- Burning a wide range of different kinds of coal in the combustion chamber of the boiler
- Flexible operational behaviour
  - High load change rates
  - short start - up capability
  - restart conditions after a black out
  - High degree of automatization
- *Maximum* standardization of main components
- *Long running* times, short timespans for inspection, short overhaul time, good maintenance conditions

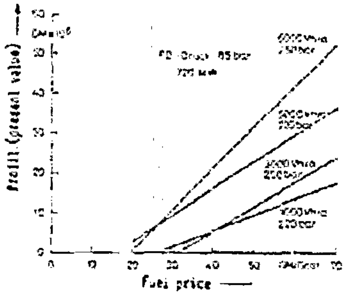
Requirements on coal fired power plants

Fig.: 1



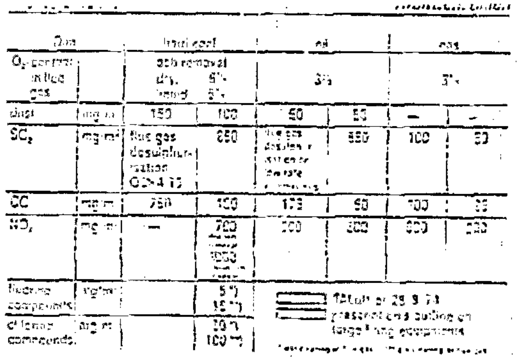
Improvement of efficiency by increasing steam pressure and temperature and by providing a second stage of reheat

Fig.: 3-1



Profit by increasing life steam pressure

Fig.: 3-2



[illegible]		hard coal		oil		gas	
O_2-content in flue gas		ash removal dry 6% liquid 5%		3%		3%	
dust	mg/m³	150	100	50	50	—	—
SO_2	mg/m³	flue gas desulphurisation [illegible]	650	flue gas desulphurisation [illegible]	850	100	50
CO	mg/m³	250	100	175	50	100	50
NO_x	mg/m³	—	700 [illegible] 1000 [illegible]	500	300	500	200
fluorine compounds	mg/m³		5 [illegible] 15 [illegible]				
chlorine compounds	mg/m³		30 [illegible] 100 [illegible]				

TA Luft of 28.9.74
present ones putting on large firing equipments

Conventional steam plants
Permissible dusty- and gaseous emissions in Germany (Nov 1978)

Fig. 2-2

Syngas from Coal on the Basis
of the Development of
Texaco/Ruhrkohle/Ruhrchemie

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presented by: DR. RAINER DORRFELD
Oktober 1990

Abstract

Ruhrkohle AG und Ruhrchemie AG (West-Germany) operate a coal gasification plant, which is a modified Texaco principle. Over an operationtime of 6000 h a syngas has been generated with the composition of 54 % CO, 34 % H_2, 11 % CO_2, 0.3 % H_2S, 0,6 % N_2 and less than 0,1 % CH_4 from about 30.000 t of coal. Gas for chemical or heating purposes from coal is thus available through a process of the "second generation". Typical features of this process are high pressure, high gasification temperature and utilization of finely-devided coals in form of a slurry.

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I. Introduction

The necessity of assigning coal a fortress between energy carriers in our time, is a precaution for the future. This is valid in the field of raw material supplying chemical industry.

Attempts to obtain this goal are numerous. They go back even to the year 1837. There are very few technological developments having produced a similar variety of ideas as coal utilization did. Nevertheless, only very few technologies have burst through:

- coke-burning for the production of
  - . coke for reduction of iron-ore
  - . fluid hydrocarbons as raw material for chemical industry
  - . Syngas as a building block for the synthesis for organic compounds
  - . gas for heating purposes.
- gasification of coal, which is thought to convert coal completly in opposition to coke-burning.

The older of the above technologies is coke-burning. Is has already reached a standard, which makes it almost impossible to find further improvements. The fact, that coke-burning implies the coproduction of coke, tars, oils and gas, originated the development of coal gasification as a mode of diminishing the negative influence on price yield for the products. Their commercial access was reached by

. Lurgi 1936
. Koppers-Totzek 1952
. Winkler 1954

Due to the fact, that these coal gasification processes stand at the very beginning, they are called "processes of the first generation".

1.1 Gasification Processes of the first Generation

The established gasification technics have proved their however, their application is limited by their own princ The following parameters are typical for them:

- Lurgi pressurized gasification is a fixed bed proces for coal pieces in the range of 10 - 50 mm of non- low-caking coals.

- Winkler-process is a fluidized bed gasification at atmospheric pressure for non-or low-caking coals wit a particle size less than 5 mm.

- Koppers-Totzek-process is an entrained gasification at atmospheric pressure for the feed of all coal types. pendant on caking properties of coals, with particle less than 80 µm.

Each of the mentioned process has advantages as well as dis tages, which have to be balanced. The following criteria be applied:

- Coal basis

  The applicability of a gasification process is given

  - caking properties
  - particle size distribution
  - ash melting temperature

By this the established process can be classified:

	Gasification fixed bed	fluidized bed	entrained
caking properties SI	< 3	< 3	all
particle size mm	10-50	< 5	$< 0,1$
$\frac{\text{gasification temp.}}{\text{Ash melting temp.}}$	< 1	< 1	> 1

Table 1: Effect of coal properties on choise of process

- Utilization of the coal gas

  As a consequence of different process performance the produced gases differ from each other. A comparatively high heat value of the gas can be achieved utilizing the fixed bed process. Because of its low operation temperature a high methane content of 8 - 12 % can be reached.

  If the H_2/CO fraction is important, one should consider the concerned ratio to be typical for the process performance.

  The yield of hydrocarbons is due to the nature of the fixed bed gasification in the order of 13 % of input coal. This is a coproduct which is to be considered valuable if it is saleable besides the gas.

A comparsion shows the following table:

		Gasification		
		fixed bed	fluidized bed	entraine
CH_4-content	%	8-10	0-1,4	< 0,01
H_2/CO	-	2-2,4	0,7-1	0,67
Cn Hm	%	0,5	0,5-1,5	-
Tars,oils	%	4-13	-	-
Hu	$\frac{kcal}{Nm^3}$	3800	2600-2900	2600-2

Table 2: Typical gas data of different technologies

Only the Lurgi-gasification is operated under pressure. Con-cerning the process steps downstreams this is of special tage with respect to the investment costs of the gas

Applying atmosphericgasification process costs for of the gas must be afforded

- weather for subsequent chemical reactions or for utilization, e.g. by means of "combined cycles". For reason pressurized processes are more profitable pheric ones.

- Environmental demands

  At least in highly industrialized countries considerations tend to become decisive criteria. Com-pounds as H_2S, COS, NO_x, heavy metals, smelling or hydrocarbons can be removed from the produced with more or less expenditure, but, however if it sible, to suppress the formation environmental compounds it can be evaluated as a positive effect. this respect high temperature processes benifit sion of hydrocarbons formation. This reduces costs

  fication of waste water, which is a remarkable fraction of total costs.

1.2 Processes of the "Second Generation"

A summery in between leads to the result, that the gasification technologies at present available shows important restrictions which shall be put aside by the development of modern technologies. Processes of the socalled "second generation" are supposed to satisfy modern requirements with respect to feedstock, process technology, gas utilisation and economic aspects.
This includes:

- operation at high pressure, which guarantees a high specific performance and reduces the investment costs and costs for compression of the gas for further utilization Pressures between 20 and 100 bar are envisaged.

- operation at high gasification temperature in order to realize high yields and to suppress formation for hyd carbons, which otherwise burdens the water purification. The ash removal is simplified as it is granulated by solidification in a water bath.

- possibility of utilization of pulverized coal, which ope the gasification to all carbonaceous material independ on its character and its origin. In particular modern gasification technologies must take in account, that high automized mining technics produce fines at remarkable extend.

- preparation of coal as a slurry for the advantage of an extreme simple handling. There is no need for special saf precautions, predrying of run of mine coal or other dem of special specification of coals. It should be mentione that coal feed as a slurry makes the control of an invariant C/O-ratio possible in favour of a constant gasification temperature.

2. Texaco Coal-Gasification Process

The above mentioned requirements to a modern gasificat process recognized the consortium Ruhrkohle AG/Ruhrche (RAG/RCH) to be combined in a process, which has been in a laboratory scale by Texaco Development Co. in the 1950 years. RAG/RCH gained a license for this process cided to build a demonstration plant for a capacity of coal feed. This plant war completed in Febr. 1978. It inaugurated by the Minister of Research and Development the Federal Republic of Germany, who has supported the (Fig. 1).

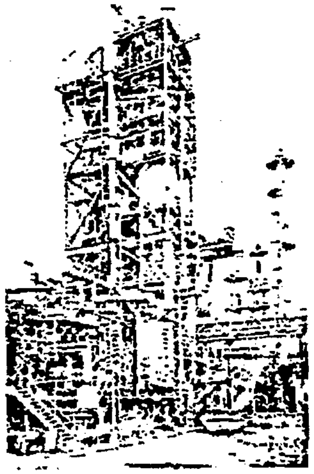

Fig. 1 RAG/RCH coal gasification demonstration plant at Oberhausen-Holten

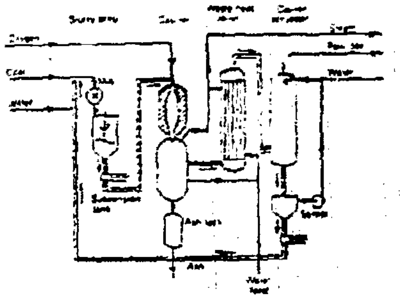

Fig. 2 Flow-diagram of the Ruhrchemie/Ruhrkohle adaption of the Texaco coal-gasification plant

2.1 Discription of the Process

Fig. 2 shows the flow diagram fo the process.
Precrushed coal as it is delivered form the mine is fed to ball mill. Depending on the primary water content, additional water and additives are introduced to the mill. The suspension is prepared in that way, that solid content will reach about 70 % still remaining pumpable. The slurry is pumped into a storage vessel, where it is homogenized by stirring.
From there the slurry is delivered through a special pump to the burner on the top of the reactor, which sprays the slurry together with oxygen into the reactor.
The gasification is operated at a pressure of about 40 bar and a temperature of about 1500 °C. The slurry-oxygen-mixture is ignited by spraying it into the reactor. The gas generated passes through the throat of the ceramic-lined reactor to the subsequent heat recovery system, which consists of two stages.

- a radiation cooler, to cool the gas below the sintering temperature, and

- a convection cooler, to cool the gas down close to the dewpoint.

Afterpassing the heat recovery, which is used for stea ration, the gas is washed with water in a gas scrubber moval of fly ash down to 1 - 3 mg solids/Nm³.
The further upgrading can be done in a conventional fir cleaning step.

The ash is removed from the process at the bottom of the tion cooler as a water suspension via a lockhopper syste works automatically, and from the bottom of the scrubber water either. Water and solids are separated in a settler, makes a recycle of the fly ash possible, if it is reason As no hydrocarbons are formed, the wash-water clean up need further explanations.

2.2 Operating Experiences

Up to now the plant has been operated more than 5000 h. The sed coal throughput is about 28.000 t being converted to 54 million Nm³ syngas. Without technical difficulties ferent coal typs with volatiles between 15 % und 32 % and content between 8 and 30 % have been gasified. By this the flexibility of the process could be demonstratet.

The practical behaviour of the plant proved to be very s to the predicted. The comparison between design data and performance shows Table 3.

		Design	Achieved
Temperature	(°C)	1,500	1,350-1,500
Pressure	(bar)	40	25
Coal throughput	(t/h)	6.0	2.5-6.0
Gas quantity	(Nm³/h)	10,000	11,500
Slurry concentration	(%)	55-60	70
Grain-size distribution	(%-<90µ)	—	14-40
Gas composition	(Vol-%)		
CO		45-55	52
H_2		30-40	35
CO_2		15-20	12
CH_4		<1	<0.1
H_2S/COS		—	0.2
N_2		—	0.6
Conversion	(%)	95	>99
Efficiency (cold gas)	(%)	70	74
(thermal)	(%)		92

Tabl. 3 Design data and achieved performance of the RAG/RCH coal-gasification-plant (Stat: 30.09.1980)

The good-natured behaviour results to a high extend from the trouble-free transport of the coal-water suspension. Due to this the temperature of the gasification can be kept in line by simple means. Thus the plant is calm and can be operated over a wide load range.
Besides these general remarks a few results shall be discussed:

- Different grinding facilities lead to different results. After one years work the first mill was replaced by a ball mill. The advantages of this grinder lie in low investment costs and a good control of wear. The changed particle size distribution opened the capability of preparing a slurry with solid content up to 70 %. Even carbon conversion rose. Additionally the grinder is insensitive against foreign bodies.

- Particular attention was spent on the refractory material used for lining the reactor. High demands on the material result from the reducing gasificati atmosphere as well as from the chemical attack of the liquid slag, which happens preferably at high temperatures. Systematical investigations with testmater in several test fields inside the reactor have brig the corrosion mechanism. New materials have been co succesfully. Today it looks possible to run a gas over one year.

- The temperature measurement inside the reactor prove to the especially difficult. All thermocouples faile after a short running time as a consequence of slag In the near past a pyrometer has been testet success after several month of discouraging attempts.

- The two-stage-heat-recovery system has proved itse satisfactory. The radiation cooler solidifies the slag without beiing seriously affected. Fly ash, wh deposes on the heat exchangers can be removed easily operation. Since some technical modifications in the radiation cooler and the convection cooler have been no operation restriction could be found.

- Initial problems of slag removal from the radiation have been solved by increasing the water flow, since factory sedimentation of the slag in the transportat water due to a low particle density has been observed.

- The recycle of unreacted carbon has so far not prove be necessary. The conversion of carbon was high en estimate the recycle rather costly. Thus the convers Table 3 refer to tests without carbon recycle.

- The effluentwater is characterized by table 4. The analysis is determined without water recycle for slurry preparation. It should be mentioned, that no organics are contained. All other impurities are necessarily brought in by the coal, so far this water must be comparable with water coming from other high temperature processes.

pH	–	7
Hardness	°dH	5
p-Value	mval/l	0
m-Value	mval/l	9
Electr. conductivity	µS/cm	3,000
Evaporation residues	mg/l	600
Total sulfur	mg/l	90
Chloride	mg/l	500
NH_3-NH_4^+-ions	mg/l	400
CN^-	mg/l	5
COD	mg O_2/l	60
$KMnO_4$ consumption	mg/l	90
Arsenic	mg/l	0.1
Cadmium	mg/l	<0.002
Nickel	mg/l	0.2
Phosphorus	mg/l	0.03

Table 4 Data for effluent water quality (valid for Ruhr coa

- As expected the slag can be deposed without risk.

- Air pollution is governed by the fact, that the gasificat is a pressurized process. The gaseous emissions are controlled by proper operation of gas-washing and sour gas treatment.

Since February 1980 a fraction of the syngas produced in the Texaco/Ruhrkohle/Ruhrchemie process has been fed to the Ruhrchemie Oxo-Synthesis. No changes have been noticed. Therefore it can be stated, that the replacement of syngas from oil by syngas from coal is feasible.

3. Prospects

Since the process of Ruhrkohle and Ruhrchemie has been proved feasible, it can be offered for further applicati as e.g. supplier of heating gas, reductiongas or syngas.

Nevertheless there are still some investigations to be c for the reduction of technical risks:

1. Optimization of the burner, which permits a further increase of solids content in the slurry and a reduct of oxygen consumption.
2. Increase in the thermal efficiency by reducing heat losses.
3. Tests of refractories and metal materials for higher lifetime.
4. Gasification of residues from coal liquifaction aiming the process to become an integrated part of coal liquifaction plants.

Considering, that syngas from coal is about 20 % more expen than syngas form oil, the "second generation"-process of [illegible] ist rather close to its commercialisation.

The Federal German Minister of Economy has commissioned the RAG/RCH-consortium, to work out a preengineering study for a gas-plant, called SAR, for the production of 50.000 Nm³/h s The costs for that plant will be in the order of 250 mill It is expected that this plant will be erected in 1983.

Additionally it should be mentioned, that several potential companies in the USA are very much interested in our process

The RAG/RCH-process has already been licenced once. Several gasification tests over 4 weeks each with American coals will be performed within this and the next year. So it is possible to say, that coal is under way to become again an important energy carrier in our time.

GAS FROM COAL

based on Saarberg/Otto Gasification Technology

status of its development and its further applications

D: 8210041070

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Djakarta, Oktober 1980

Medium term energy and raw material supply of the industrial nations is characterized by the following facts:

- An important disproportion is apparent between the existing resources and the consumption of fossil energies and raw materials like coal, mineral oil and natural gas (figure 1).
- More than 90 % of the energy consumption is covered by coal, mineral oil and natural gas. The comparison of the consumption with the economically exploitable resources results in different availability times:
  Mineral oil will be exhausted in about 30 years, natural gas in about 50 years whereas coal will still be available for about 300 years.
- The energy and raw material consumption will continue to increase, although in a more moderate manner.
- The disproportion between resources and consumption will probably increase too, since the requirement for gaseous and liquid hydrocarbons, up to now exclusively covered by natural gas and mineral oil, cannot be met by coal, unless coal can be converted in a commercial scale by gasification and liquefaction into substitute products which can be offered in a consumer friendly way.
- The role of nuclear energy is still discussed; therefore for the present the portion of nuclear energy in energy production certainly cannot be increased.

The above mentioned facts result in the necessity of further development of the known coal gasification and liquefaction processes in order to meet the customers demands for economy and environmental impact, so that commercial scaled plants can be put into operation in a measurable space of time.

The special objects of the current development of coal gasification processes, which started again in the FRG in 1974, are:

- to improve the economy of the known processes
- to make possible that all kinds of coal can be gasified and
- to ensure a low environmental impact.

In order to obtain these objects, the gasification mainly has to run at higher temperatures and higher pressures. Especially the entrained bed gasification can satisfy these conditions and thus reach high specific gasification efficiencies and produce gases free of higher hydrocarbons, without regard to different coal feedstock.

The companies Saarbergwerke AG and Dr. C. Otto & Comp. GmbH have developed a process for the entrained gasification of coal under pressure. The design for a demonstration plant was started in 1976. In December 1979 the plant was put into operation at Völklingen-Fürstenhausen. It is designed for a coal throughput of 264 tons per day (290 short tons per day) and an operation pressure of 25 bar (365 psi). In the oxygen-blown operation, the gasification produces approximately 550,000 m^3 (standard) of gas per day (20.6 MM SCFD).

The figures 2 and 3 show the Saarberg-Otto coal gasification demonstration plant.

The project is part of the Energy Research and Development program of the Federal Republic of Germany. The costs for design and construction amounted to approximately DM 54 MM, for initial operation to DM 6 MM. The operation costs amount to DM 12 MM per year. The total costs of this development project are sponsored by the Western German Ministry of Research and Technology with 75 %.

The Saarberg/Otto process, a high temperature pressure gasification process, is well suited to meet the P. R. requirements.

High pressure and high operating temperature [illegible]erate the coal conversion reactions and enable the plant [illegible]e sized favourably.

This process is suitable for the gasification of all types of coal with an ash content up to 40 % without any regard of caking property, grain size and ash melting behaviour, and for the gasification of residues from coal hydrogenation plants.

As a result of the high gasification temperature, liquid slag collects in the lower part of the gasifier and acts as a heat shield, which enables high flame temperatures. Thus high energy density and high coal conversion rate are obtained. The molten slag enables the gasification of relatively large particles, thus the costs for coal preparation are reduced. Discharged granulated slag contains less than 1 % of unconverted carbon.

The operation of the Saarberg/Otto plant and its special features result in a mild environmental impact. The gas produced is free of such hydrocarbons as oils, tars and phenols wich, if present, could be removed only at considerable expense. Granulated slag is the only solid material produced. This slag can be dumped and used in road construction. The amount of waste water is small relative to the amount of gas produced. Impurities of the waste water as well as the sulphur compounds in the raw gas can be removed by conventional methods.

Figure 4 shows the Saarberg/Otto gasifier.

The gasifier installed in the demonstration plant is a vertical cylindrical vessel of 16 m (52.5 ft) height and 1.5 m (4,9 ft) inner diameter.

The lower portion, the gasification zone and the post gasification zone in the gasfication chamber, are protected on the inside by water cooled finned tubes. The upper portion, the cooling zone, is refractory lined since the gas in this zone is cooled by recycled product gas to a lower temperature. Four two-channel nozzles are installed in the gasification zone to inject the feedstock and the gasification media (oxygen/steam mixtures or oxygen enriched air or air). The reactants are mixed after leaving the nozzles, oxygen and steam are mixed externally in a ring main before flowing to the reaction zone. The excess slag overflows through a central raised taphole at the base of the gasifier, is granulated in a water tank beneath the gasifier and then discharged through a lock hopper.

Figure 5 shows the flow diagram of the process arrangement realized in the demonstration plant.

In the grinding and drying facility (1) the coal is pulverized to a grain size of less than 3 mm (0.1 inches) and dried to a moisture content of approximately 2 % (brown coal approximately 12 %). It is then transferred to the storage bin (2). From the storage bin, which is at atmospheric pressure and under nitrogen, the coal dust is passed via a lock hopper (3) to the pressurized feed tank (4). The coal feeding system continuously supplies the four feed pipes to the gasifier (5) with the required quantities of coal dust. Recycled product gas is used as carrier.

The feedstock and the gasification media are injected into the gasifier through the system of nozzles, which are directed tangentially towards the surface of the molten slag. The feedstock reacts with the gasification medium at temperatures between 1,650 and 2,400 °C (3,000 and 4,350 °F). The oxygen is preheated by saturated steam from the waste heat system (7). Superheated steam from the high-pressure steam system serves as process steam.

The gases generated in the gasification zone rise with a rotational motion imparted by the tangential feed system. These gases carry entrained particles of char and slag. The rotational velocity is accelerated by a throat in the gasifier between the gasification and the post gasification zone. Due to this, slag droplets and char particles are separated and flow down the wall.

Fine particles are carried with the gas stream to the post gasification zone which provides additional retention time at high temperatures for the further gasification of coal particles.

The ascending gas stream is cooled in the refractory lined zone by cold recycle gas to a temperature of 800 to 900 °C (1470 to 1650 °F) in order to solidify the entrained slag droplets. Surplus slag is discharged through the lock hopper (6).

From the gasifier, the raw gas passes to the cyclone (8), where the majority of the entrained solids are removed. The heat of the raw gas is used in the waste heat boiler (11) to generate superheated high pressure steam. The gas then passes through a high temperature fibrous filter (12) where most of the dust, which is still present in the gas chiefly in the form of finer particles, is removed. The particulate matter (char and slag) separated in the cyclone, waste heat boiler, and the fibrous filter is then recycled (10) in order to gasify any remaining unconverted carbon. The raw gas is cooled in the spray cooler (13) to 40 °C (104 °F) and passed to the desulphurization plant

The cooling water of the spray cooler is circulated via a heat exchanger. Part of this water is blown down and treated in a conventional waste water system to meet permissible emissions standards.

The primary emphasis of our research and development program are "coal feeding and distribution", "cooling of the gasifier", "slag discharge" and "dust removal from the syn-gas".

The test program includes running of the plant at various pressures to determine characteristic process data as well as maximum plant throughput and conversion efficiencies. These test runs also serve for the optimization of the economy of the conversion process for different coals. The knowledge gained will be the basis for design, construction and operation of prototype and commercial scale gasification plants as energy and raw material suppliers of the future.

Results of the test runs

From December 1979 up to now test runs were made for about 300 hours. The longest run was 48 hours. The plant was operated varying the inputs of coal and of the gasification media oxygen and steam.

Till now a subbituminous coal was gasified.

Figure 6 shows the average composition of this coal with an ash content of 8 - 10 %, a sulphur content of about 1 %, a chlorine content of about 0.5 % and with a relatively high fluid temperature of the ash of about 1500 °C (i. e. 2732 °F).

In Figure 7 some of the test results are shown.

The designed pressure of 25 bar and a coal throughput of 6.5 t were realized. The average oxygen consumption was 650 - 700 m³ (standard) and the steam consumption 0.15 t per ton of coal. About 2000 m³ (standard) of raw synthesis gas per ton of coal were produced and carbon contents of less than 1 % in the slag were reached. A cold gas efficiency of 72 % could be realized.

The carbon monoxide and hydrogen content of the product gas was about 90 %, the carbon dioxide content was less than 10 %; except traces of methane the gas was free of hydrocarbons.

The cooling system of the gasifier has to meet - especially at full load operation - high and intensive heat fluxes. Recent material tests did not show fatigues of the cooling tubes material.

As shown by tests under certain processing conditions more than 80 % of the ash content of the coal can be drawn off as liquid slag. The carry over in the raw gas - slag and fly coke - did not amount 5 % of the input. Up to 80 % of the larger sized fly coke particles are separated in the cyclone, whereas up to 60 % of the mineral dust pass the cyclone. These particles and the not separated fly coke have very small grain sizes and are to be removed by the fibrous filters.

About 55 % of the dust separated by the cyclone has grain sizes between 30 an 80 µm, 15 % are smaller than 5 µm. More than 90 % of the particles separated by the fibrous filters are smaller than 3 µm and more than 40 % are still smaller than 1 µm.

Possible applications of the Saarberg/Otto process

Figure 8 shows the possible applications of the Saarberg/Otto process.

Coal gas, produced by gasification with oxygen/steam, is suitable for application in the chemical and energy industry as well as in the steel industry.

For example it can be used for the production of hydrogen, ammonia, methanol and other oxo products. Via the Fischer-Tropsch synthesis or from methanol liquid hydrocarbons can be produced.

The gas is further suited for the direct reduction of iron ore or for the production of SNG or town gas.

By gasification with air or oxygen enriched air a low btu gas is produced which can be used for industrial heating or for electricity generation in a combined gas/steam turbine process with minimal environmental impact.

Figure 9 shows one possibility to integrate coal gasification with combined cycle power generation.

The pressurized clean gas is combusted with air to drive a gas turbine at maximum allowable inlet temperature. The expanded gas passes through a waste heat boiler.

The produced steam and the steam from the gasifier waste heat system are superheated by hot gas and drive a steam turbine/generator set.

The Saarberg/Otto gasifier is well suited for the integration with a combined cycle power plant, because all kinds of coal can be gasified and the produced raw gas is free of higher hydrocarbons as oils, tars and phenols.

Coal gasification integrated with a combined cycle power plant has the potential to improve the efficiency of electricity generation and to decrease environmental pollution.

Station efficiencies of 40 % and more are expected in commercialized plants. The efficiency rises with the gas turbine inlet temperature.

Figure 10 shows the synthesis gas production based on Saarberg-Otto coal gasification process.

Due to a high hydrogen and carbon monoxide content, the produced gas can be used, following conventional treatment such as desulphurization, carbon monoxide shift conversion, carbon dioxide wash, carbon monoxide and dioxide methanation, for a series of chemical synthesis, e. g., for ammonia, methanol and oxo synthesis. It can also be used for the synthetic production of liquid hydrocarbons and as the hydrogen supply in coal hydrogenation plants.

Figure 11 shows the Saarberg/Otto gasification integrated with Korf-Midrex direct reduction process.

Since the gas has a low content of moisture and carbon dioxide it is well suited for the direct reduction of iron ore.

If you compare the direct reduction of iron ore to iron sponge with conventional steel production processes, than the direct reduction - using gas made of coal - offers the essential economic advantage, that there are no limitations in coal quality.

Figure 12 shows the production of town gas based on Saarberg-Otto gasification process.

Gas treatment consists of scrubbing, desulphurization, methanation (the gas should have a methane content of 25 %), conversion of carbon monoxide and CO_2 washing.

The production of SNG requires the complete conversion of the synthesis gas into methane. The other treatment steps are similar to town gas production.

Economics

At present synthesis gas made from Western European hard coal is more expensive by factor 1.8 than synthesis gas made from natural gas. The factor amounts to 1.3 if the gas is produced from heavy fuel oil.

Synthesis gas made from German lignite coal is nearly as expensive as synthesis gas made from natural gas and about 20 % cheaper than synthesis gas produced by gasification of heavy fuel oil.

Methanol made from Western European hard coal costs about 1.4 times more than methanol made from mineral oil.

The price difference between natural gas and SNG from coal is still higher. The factor amounts to 3 if the feedstock is hard coal and to 2 if lignite coal is used.

Further Developments

In order to reach high efficiencies of the combined cycle power generation and the direct reduction of iron ore by integrating the Saarberg-Otto gasifier with these processes, equipment for hot gas cleaning shall be developed.

For instance in the combined cycle power generation the dust content of the gas should not exceed 5 mg/m³ (standard).

Beside high temperature resistant fibrous filters especially electric filters will be tested. Laboratory results shall be proven in pilot plant scale. High temperature desulfurization by addition of lime will be investigated too.

Subsequent to a two-years demonstration period with oxygen
operation in 1982 one year of air-blown operation is antic

For commercial plants, the diameter of the gasifier would be
stepwise increased. With a diameter of 2.1 m the gasifier wi
have double the capacity (gas production of 1,100,000 m³ (sta
dard) per day (i. e. 41,6 MM SCFD), hard coal throughput of [illegible]
t/h). Our final aim is a gasifier having a diameter of 3 m ([illegible]
ft). A gasifier of this size would produce about 2,200,000 m³
(standard) of gas per day (i. e. 83.4 MM SCFD) from hard co

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to the paper "Gas from Coal, based on Saarberg/Otto Gasi-
tion Technology, status of its development and its further
lications"

graphies of the authors

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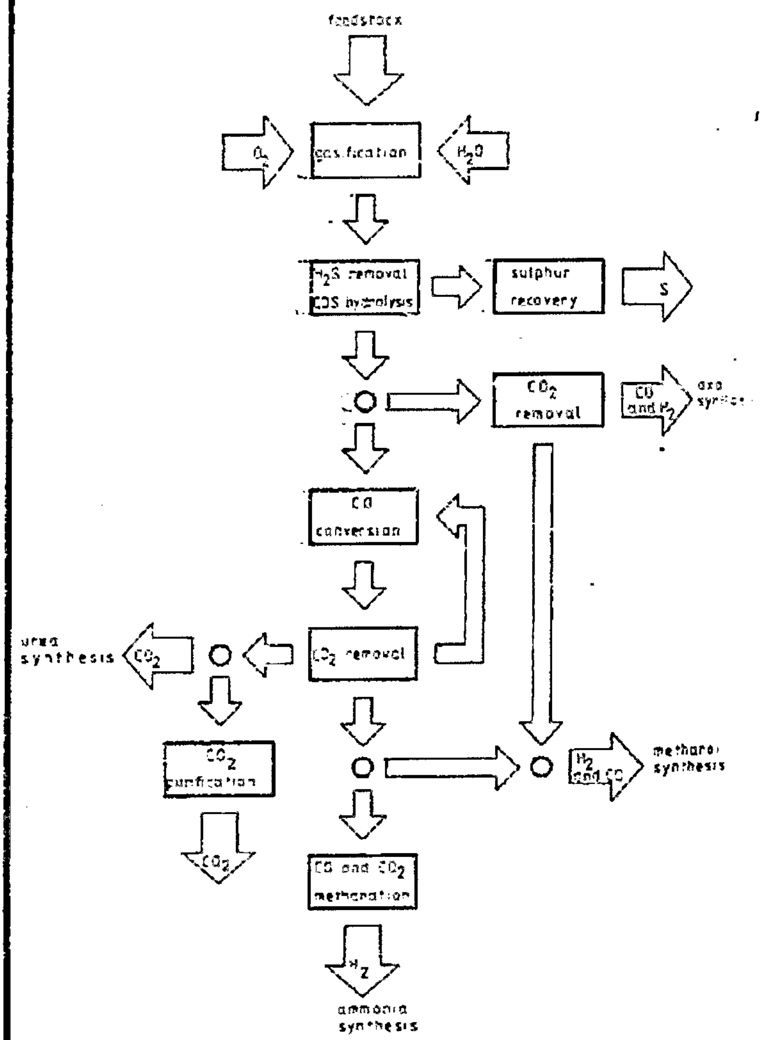
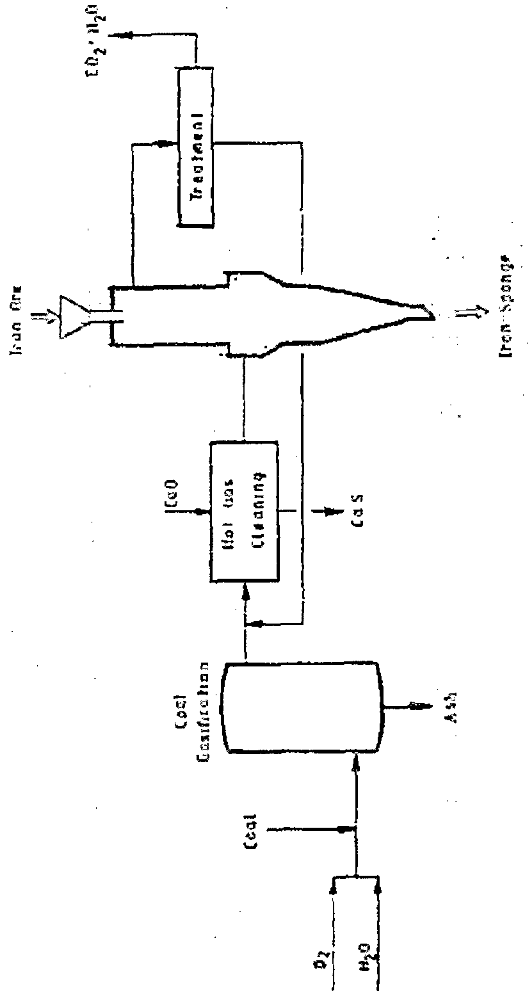


Saarberg + Dr. C. Otto

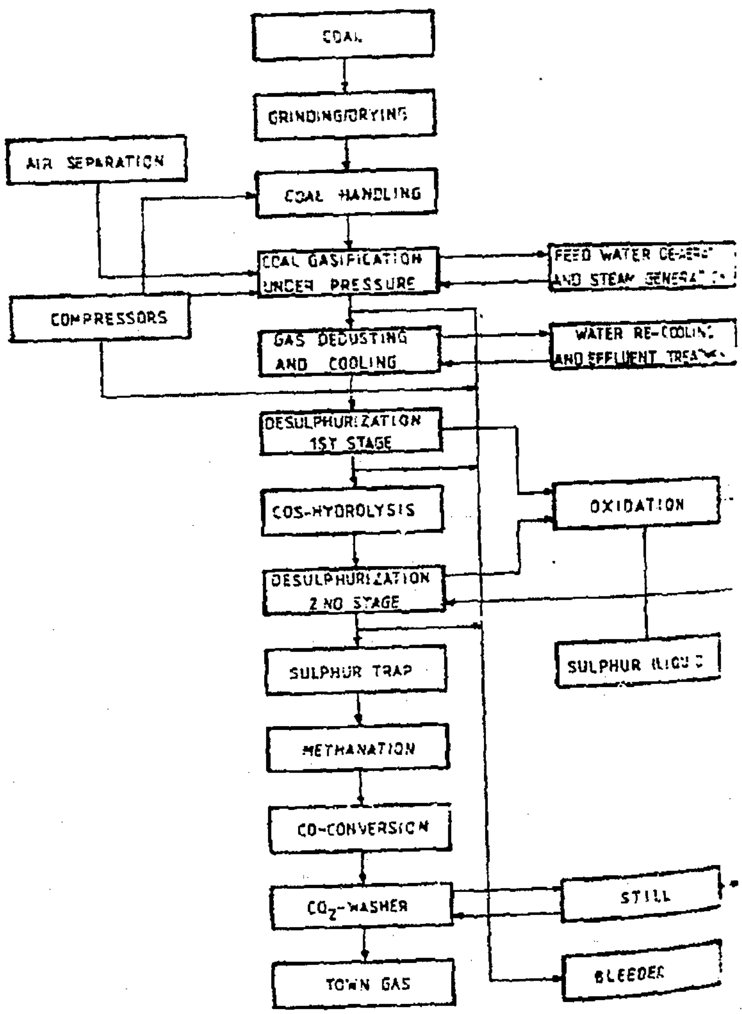
SYNTHESIS GAS PRODUCTION BASED ON
SAARBERG-OTTO COAL GASIFICATION PROCES

Figure 10



SAARBERG-OTTO GASIFICATION INTEGRATED WITH
KORF-MIDREX DIRECT REDUCTION PROCESS

Saarberg + Dr. C. Otto



Saarberg + Dr. C. Otto

PRODUCTION OF TOWN GAS BASED
SAARBERG-OTTO COAL GASIFICATIO
PROCESS

Figure 12

D: 8210041088

MOTOR FUELS FROM COAL

by

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LURGI KOHLE UND MINERALÖLTECHNIK GMBH
Frankfurt/Main

Coal Symposium in Jakarta, Indonesia, October 1980

Status of Technology 1980

Available to us to convert coal into motor fuels - gasoline, diesel oil and liquified propane and butane - is

the FISCHER-TROPSCH SYNTHESIS.

In the latter half of the thirties it gained great importance. Nine Fischer-Tropsch plants were operated in Germany. At that time further plants were built in France, Japan and Manchuria producing a total of 1 million tons per year. The Fischer-Tropsch plants were based on bituminous coal, lignite and coke-oven gas. Only a few plants continued operating after 1945. In view of the ample, low price supply of crude oil, coal liquefaction became uneconomic in the mid-fifties and thus, without importance.

However, the Republic of South Africa was an exception and decided to construct a coal liquefaction plant at the beginning of the fifties. A high ash, cheap bituminous coal in ample quantities was available as feedstock. The only process suitable for handling this coal was the Fischer-Tropsch Process as de-ashing of the coal was uneconomic. The plant is in operation since 1955 and produces gasoline, diesel oil and raw materials for the domestic chemical industry and export. Fig. 1. In the meantime, the complex has been expanded several times. The experience gained during 25 years of operation and research forms the basis for the construction of a new plant ten times the size which was recently put on stream. A duplication of this complex has been contracted and is already under erection. Thus, an annual production of 4.5 to 5 million tons of motor fuel from domestic coal will be available to the Republic of South Africa in the mid-eighties.

The Fischer-Tropsch Synthesis supplies intermediate products which are then converted to motor fuels. In addition to hydrocarbons, methanol blended with gasoline or also alone as motor fuel are today to be considered as well. A promising variation for the utilization of methanol as motor fuel was developed by Mobil Oil. The conversion of methanol into gasoline with a high octane number and a high efficiency succeeded.

2. Fischer-Tropsch Synthesis, Low-pressure Methanol Synthesis and Mobil Process

2.1 Coal Gasification

The process concept is shown in Fig. 2. Initially, synthesis gas is produced from the coal primarily comprising carbon oxide and hydrogen. This gas must be purified and, if necessary, compressed before being converted to hydrocarbons or methanol on catalyst. In a separate stage, methanol can then be converted to gasoline using the Mobil Process.

Over the years quite a number of coal gasification systems have been proposed and realized also. Each system attempts to best exploit the chemistry and thermodynamics of coal gasification. Common to all systems are the gasification agents - air or oxygen and steam - being applied to the coal at high temperatures, at least 700 °C and converted into a raw gas comprising carbon monoxide, hydrogen, carbon dioxide, methane, hydrogen sulfide, nitrogen and certain impurities. The quality and quantity of raw gas are mainly influenced by the type of coal and the composition of the gasification agent. For classification purposes we may differentiate between three main reaction groups: moving bed, fluidized bed and entrained suspended bed. As shown in Fig. 3, they differ in respect of the following: size of feed coal, flow of reactants and products, residence time of coal particles and temperatures.

The three following systems are technically proven:

- - Lurgi Pressure Gasification in the moving bed
  - the Winkler Process of gasification in the fluidized bed
  - the Koppers-Totzek Process of gasification in entrained suspension.

The gasification of coals or char with oxygen and steam in the fluidized bed under normal pressure is a proven technology termed Winkler Gasification. [illegible] transfer of this technology to gasification under pressure up to 10 bar is currently being studied in a large pilot plant.

In coal gasification in entrained suspension transition from atmospheric pressure to pressure will also have positive effects. Two processes using this principle are currently being developed. In the Shell-Koppers Process coal dust is periodically charged into a pressure chamber and proportioned continuously from there into the reactor whereas Texaco mixes the coal dust with water and pumps the mixture continuously into the gasification reactor.

The development of the Lurgi Process of gasifying coal in the moving bed stretches back to the thirties. [illegible] then it was recognized that it is more economic to gasify coal under pressure with oxygen and steam as only a small quantity of oxygen has to be compressed instead of a much greater volume of raw gas. In the pressure gasifier, Fig. 4, coal is continually and completely gasified in a downward moving bed at a pressure up to 30 bar. The coal is charged into the gasifier using a lock hopper system and is from there uniformly distributed across the cross-section by a coal distributor. The ash is continuously withdrawn via a rotating grate and discharged through a second lock hopper system. The reactor itself is a pressure vessel with water jacket. The first plants were built from 1936 for the gasification of lignite. From 1949 Ruhrgas and Lurgi extended the feedstock range to bituminous coals in joint development work, this applying in particular to weakly caking high volatile bituminous coal, semi-bituminous coal, semi-anthracite, peat and anthracite, coals with extremely high ash contents also being included. Plants were constructed in Germany, England, Pakistan, Korea, Australia and South Africa.

The development stages of the Lurgi gasifier are compared in Fig. 5. The first generation, 1936 to 1954, was designed for the gasification of lignite. The second generation was laid out for high throughputs and for the gasification of weakly caking bituminous coals. This generation includes the plants at Sasolburg, Dorsten, Westfield and Coleshill (1954-1965). From 1969 a third generation was developed with the target of increased capacity and simplified components parts taking into account modern fabrication methods. This type is suitable for gasifying all sorts of coal and has a diameter of 4 m.

Fig.6 shows the Secunda plant in the Republic of South Africa with 36 gasifiers of 4 m diameter producing 1.8 million m^3 gas/h. A further 36 gasifiers are under construction. Each gasifier has a capacity of 1000 t coal per day.

Strongly swelling and caking American coals of the type Illinois 5 and 6 as well as Pittsburgh 8 were gasified during large scale tests. The fourth generation is a gasifier with a diameter of 5 m which is also suitable for all types of coals. A prototype is currently being tested in Sasolburg. In this connection the development of a slagger and a high-pressure gasifier must be mentioned.

2.2 Fischer-Tropsch Synthesis

A simplified block diagram, Fig. 7, shows the layout of a synthesis unit. By-products, tar and naphtha, which are refined to motor fuels and, thus, increase the yield are obtained on gasifying bituminous coal or lignite under pressure with oxygen and steam using the Lurgi Process. The raw synthesis gas is purified by washing with methanol at low temperatures. Downstream of this Rectisol wash, Fig. 8, the synthesis gas primarily comprises carbon oxide, hydrogen and the methane formed in the gasification step. The carbon oxide and hydrogen are then converted to hydrocarbons on an iron catalyst, Fig. 7. This reaction is exothermal. For removing the reaction heat and controlling the reaction temperature, two reactor types have proven themselves:

- the fixed-bed reactor, termed ARGE reactor, developed jointly by Lurgi and Ruhrchemie, and
- the entrained suspension reactor from Sasol, Synthol reactor.

In the ARGE reactor the precipitated granular catalyst, Fig. 9, is arranged in tubes 12 m long which are surrounded by boiling pressure water for intensive cooling. The operating temperature is in the range 210 to 250 °C. Today's reactors have diameters from 5 to 6 m and are equipped with 6600 and 9500 tubes respectively. They produce about 85,000 and 125,000 t of primary products C_3^+ per year respectively. The Synthol System, Fig. 10, comprises the reactor furnished with cooling elements and the catalyst settling chamber. The reactor is about 40 m high. Contrary to the ARGE synthesis, the catalyst is a fine powder. Its basis is mill scale from steel works. The powdery catalyst is proportioned using a special valve into the stream of hot make-up and circulating gas and carried into the reactor by the gas stream. Here, the gas velocity drops so far that the heavy catalyst is just carried by the gas stream. Conversion takes place in the range 300 to 340 °C at a pressure of about 23 bar. The gas stream and catalyst leave the reactor and are separated in the catalyst settling chamber. The hot catalyst is recycled through the stand pipe to the reactor. Fig. 11 shows the three Sasol Synthol plants in which about 80,000 t of primary products are produced per reactor. The capacity of the new reactors at Secunda is considerably higher with 200 - 300,000 t of primary products. In both systems the reaction heat is used for generating steam. The gas leaving the reactor is cooled in heat exchangers, the hydrocarbons formed and the reaction liquor being condensed out in part. A portion of the cooled gas is mixed with make-up synthesis gas and after heating by heat exchange recycled to the reactor. The other portion of the gas is cooled in several steps to lower temperatures to recover the low molecular reaction products.

In the Synthol Process a high carbon oxide and hydrogen conversion rate is attained in one stage whereas the ARGE Synthesis is of multi-stage design. Here, about 65 to 70 % are converted in the first stage, cooling is then effected by heat exchange to separate water and hydrocarbons and in the second reactor stage a further 65 to 70 % of the carbon oxide and hydrogen is converted. Thus, a total conversion of 90 % is attained which practically increases to 100 % by the recycling of carbon monoxide and hydrogen derived from the low temperature separation of the tailgas. Methane, formed during gasification and synthesis, is recovered as a separate fraction and can be reformed to carbon monoxide and hydrogen as done in Secunda, Fig. 12.

The composition of the primary products from the ARGE and Synthol Processes is influenced by the differing catalysts and operating temperatures. TABLE 1 shows the composition of the primary products. In ARGE Synthesis primarily paraffins and olefins with low branching are formed. As opposed to this, the Synthol Process principally produces low boiling aliphatic hydrocarbons, olefins and aromatics too, the aliphatics and olefins no longer being straight chain but also branched.

In both cases only about one third of the primary products are in the motor fuel boiling range, TABLE 1. Therefore, the low and high boiling proportions of the synthesis products are to be brought into the gasoline/diesel oil range by suitable measures. The processing scheme of synthesis products is flexible and can be adapted to the market situation. The "refinery" encompasses in both cases a number of processes, all proven commercially.

TABLE 1

Composition of the Primary Products

	ARGE Synthesis			SYNTHOL Process		
Reaction temperature, °C	230			330		
Reaction pressure, bar	24			22		
CO + H_2 conversion %	88			85		
H_2 : CO in synthesis gas	1.7			2.8		
Composition of the reaction product, wt.%						
Methane	5.0			10.0		
Ethylene	0.2			4.0		
Ethane	2.4			6.0		
Propylene	2.0			12.0		
Propane	2.8			2.0		
Butylene	3.0			8.0		
Butane	2.2			1.0		
Petane, pentene	3.5			8.0		
Gasoline fraction	19.0	)		31.0	)	
Diesel fraction	15.0	)	75.5	5.0	)	42.0
Above 320 °C	41.0	)		6.0	)	
Oxygen compounds	3.5			6.0		
Acids	0.4			1.0		
	100.0			100.0		

The results of the up-grading of the primary products of the ARGE Synthesis and the by-products of the Lurgi Pressure Gasification are shown in TABLE 2 in which the characteristic features of motor fuels are given.

TABLE 2

Characteristic Data of Gasoline and Diesel Oil

	ARGE Synthesis with Tar Processing
Gasoline	
Density	0.68 - 0.71
Aromatics, wt.%	15 - 20
Research octane number 0.15 ml TEL/l	90
Diesel Oil	
Density	0.79 - 0.81
Aromatics, wt.%	less than 10
Naphthene, wt.%	less than 5
Cetane number	70

Dependent upon the tar content of the coal, the density octane number of the gasoline and cetane number of the diesel oil alter slightly. The diesel oil basis is primarily paraffinic/olefinic with about 15 % aromatics and naphthenes. The gasoline largely comprises isoparaffins together with aromatics stemming from the tar naphtha. The cetane number of the diesel oil is excellent whereas the octane number of the gasoline meets the current standard for a regular gasoline. Due to the low aromatic and naphthene contents of the gasoline, its blendability with methanol is problematic. In comparison with this, the octane number of the Synthol gasoline is higher but the cetane number of the diesel oil is lower.

It is to be seen from the structure of the primary products from Synthol and ARGE Synthesis units that the Synthol Process is predestined for the maximum production of gasoline. Contrary to this, the strength of the ARGE Synthesis lies in diesel oil. Due to newer developments of the pressure gasification it is possible to operate the synthesis in the pressure range from 40 to 50 bar. Thus, the reaction temperature can be reduced. Due to this, the life of the catalyst is extended and the "wax selectivity" improved. Under this term one understands a moderate withdrawal of the proportion of the primary product boiling above 320 °C in favour of the proportion boiling below 200 °C over the cycle time of the catalyst. It is possible to supply up to 80 % of the primary product as kerosine and diesel oil of the best quality by the combination of oligomerization of the olefins boiling below 140 °C and hydrocracking the waxes boiling above 320 °C. Therefore, the ARGE and Synthol Processes supplement one another in a practical fashion.

2.3 Low-pressure Methanol Synthesis

Todate the application of methanol was limited exclusively to the chemical industry. About 10 years ago Lurgi succeeded in making a basic improvement and reducing the methanol production costs by the development of a low-pressure process which superseded the previous high-pressure process operating at 300 bar. Due to this and the improvements in coal gasification and gas purification, the production of methanol has become less expensive and its application as an energy carrier interesting. All the equipment required for this technology has already been operated in large-scale units producing 1 million t of pure methanol per year and more. Fig. 13.

Carbon oxide and hydrogen is converted in the temperature range of 230 °C and at pressures of 50 to 80 bar on a granular catalyst arranged in a tubular reactor. In comparison with the Fischer-Tropsch Synthesis, the reaction is selective and practically without by-products forming. Methanol and small quantities of water are separated from the gas stream by cooling. Plants for producing methanol are indeed comparable with Fischer-Tropsch plants in their layout as regards gas production and gas purification but the processing of the reaction product is considerably simpler as it only comprises distillation. The application of methanol as motor fuel blended with gasoline or as a component in two-component injection for diesel engines is known. It is not intended to go into the problems connected with this at this point.

2.3.1 Conversion of Methanol into Hydrocarbons

Mobil Research and Development Corporation has succeeded in converting methanol into hydrocarbons on zeolites separating water at the same time. The exothermal reaction proceeds selectively in the temperature range between 360 and 430 °C under pressure and supplies a mixture of olefins, isoparaffins, naphthenes and aromatics, primarily in the gasoline boiling range. The exothermic process can take three routes:

- in the multi-stage fixed bed reactor
- in the fluidized bed analogous to fluid catalytic cracking or
- in the tubular reactor analogous to the Fischer-Tropsch Synthesis, generating steam.

The latter system being preferred by Lurgi.

The Process is shown diagrammatically in Fig. 14. Methanol, e.g. aqueous raw methanol, is evaporated in the recycle gas which occurs as reaction by-product. The gas mixture enters the reactor where the methanol conversion takes place. The product leaving the reactor has its heat removed by heat exchange and is then cooled. To maintain the reaction pressure, which lies between 10 and 20 bar, constant, tailgas is withdrawn from the system. C_3 and C_4 hydrocarbons recovered by cooling the tailgas are converted into gasoline by alkylation. The hydrocarbon yield is very close to the theory. The composition and the characteristic data of the gasoline are shown in TABLE 3:

TABLE 3

Yield and Composition of Gasoline (Mobil Process)

Mobil Process		
1.	Yield	Related to 1000 kg Methanol
	Gasoline incl. alkylate	390.6
	Liquified gas	23.4
	Fuel gas	20.0
	Water	566.0
		1000.0 kg
2.	Analysis of the Gasoline	
	Density, g/ml	0.730
	Boiling range 10-90 vol.%/°C	47 - 169
	RON without lead addition	97
3.	Composition, wt. %	
	Paraffins (largely i-P)	56
	Olefins	7
	Naphthenes	4
	Aromatics	33

Of the reaction product 95.4 wt.% or 414 kg can be utilized in the form of gasoline and liquified gas. The rest is used in the process as fuel gas. The technology of converting methanol is today mastered to the extent that commercial plants can be built. The methanol synthesis and its combination with the Mobil Process thus represent real alternatives to Fischer-Tropsch Synthesis. It ought to be remarked that todate it has not been possible to produce diesel oil using the methanol route.

3. Thermal Efficiency

The thermal efficiency is calculated on the basis of the net calorific values. The efficiency is to find as the calorific value of the production - gasoline, diesel oil and liquified gas - related to the calorific value of the coal used for conversion and utilities production. The consumption of the off-sites is taken into account in the balance. Contrary to this, the caloric credits for sulphur and ammonia are not taken into consideration. The values for the processes described are assembled in TABLE 4.

TABLE 4

Thermal Efficiency

Process	Thermal efficiency % related to NCV	Gcal coal per Gcal product
1. Fischer-Tropsch Synthesis	40	2.50
2. Methanol Synthesis	49	2.04
3. Mobil Process	45	2.22

In case the by-product methane is used as SNG and not reformed to synthesis gas, the overall efficiency of the three routes is improved by approx. 10-12 points.

Due to drying the coal the efficiency is a few percent lower on lignite being used. The coal costs for the individual processes related to 1 metric tonne as function of the coal price as shown in Fig. 15. The highest raw material costs are for the Fischer-Tropsch Synthesis with the methanol synthesis having the lowest. The Mobil Process lies between these two lines. In this Figure, methanol is shown in particularly favourable light due to its low calorific value related to the weight.

Production Costs

They are the sum of

- the fixed costs and
- the variable costs.

The fixed costs are determined on the basis of the capital investment for a turn-key plant including the off-sites erected on a bituminous coal basis. The investment costs contain neither financing nor costs for preliminaries, costs for the site and its development, interest on the capital during the construction period and the startup, infrastructure and the costs for mining or landing coal.

The fixed costs cover depreciation and interest, personnel costs and overheads, repairs and maintenance, insurance as well as interest on the working capital.

The variable costs comprise largely the coal costs. The make-up water requirement is considerable in all cases and, total water cooling being presumed, is up to 35 m^3/t product. The consumption of chemicals and catalysts also represent further variable costs. The latter are low and can be neglected.

Not taken into account were the sales costs, profit and taxes.

The following conclusions can be drawn from the production cost related to 10 Gcal or 1 metric tonne product as function of the coal costs, Fig. 16.

The only commercial motor fuel synthesis in application currently is the Fischer-Tropsch Process. The process is suitable for covering the market requirement for gasoline, diesel oil and liquified gas. As this synthesis can handle ash-rich coals, which in regard to the supply of feedstock is to be viewed as a particular advantage, coal costs can be expected in this case which are especially low per calorific unit.

Methanol assessed calorifically as motor fuel lies in the region of the Fischer-Tropsch product. The specific investment related to Gcal/year is also not far distant from Fischer-Tropsch Synthesis. However, methanol is then especially interesting when it can be used to substitute gasoline in motor fuel. This is the case in the order up to about 15 %.

The conversion of methanol to gasoline is technically solved. The production costs for gasoline using the Mobil Oil Process are less than the costs of Fischer-Tropsch Synthesis due to a better selectivity. Regrettably, todate diesel oil cannot be produced using this route.

Fig. 17, Secunda

CONCLUSION

The oil price situation at the end of 1980 is confusing but the trend would appear to be that crude oil at less than 20 US$/barrel is a thing of the past. If one counts on higher figures in the future and considers the transport and conversion costs, the profitability threshold for coal conversion will be reached in a relatively short time in countries having large deposits of easily mined coal available.

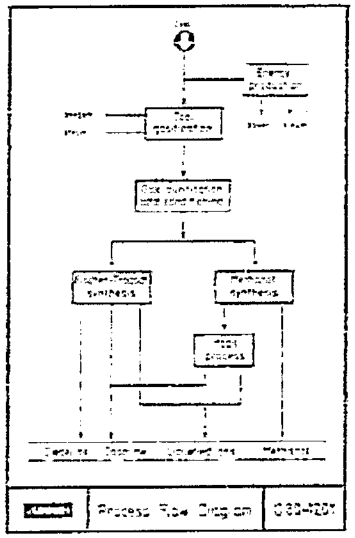

Coal
Energy production
Oxygen
Steam
Coal gasification
Gas purification and conditioning
Fischer-Tropsch synthesis
Methanol synthesis
process
Process Flow Diagram

Fig. 2

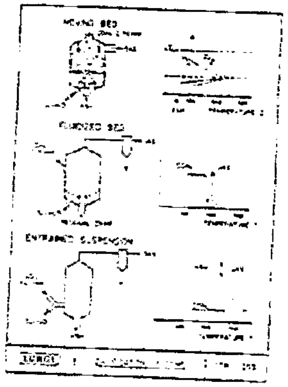

MOVING BED
FLUIDIZED BED
ENTRAINED SUSPENSION

Fig. 3

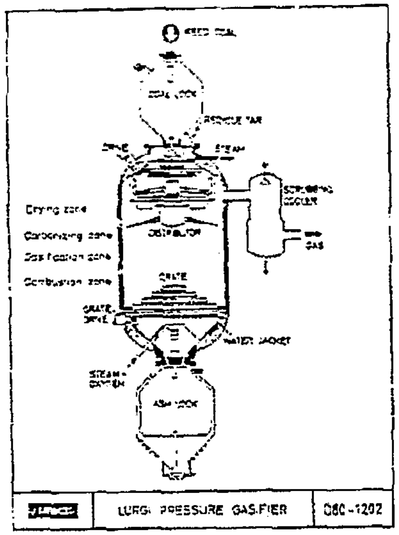

FEED COAL
COAL LOCK
RESIDUE TAR
DRIVE
STEAM
SCRUBBING COOLER
Drying zone
Carbonizing zone
Gasification zone
Combustion zone
DISTRIBUTOR
GAS
GRATE
GRATE DRIVE
WATER JACKET
STEAM + OXYGEN
ASH LOCK
LURGI PRESSURE GASIFIER
080-1202

Fig. 4

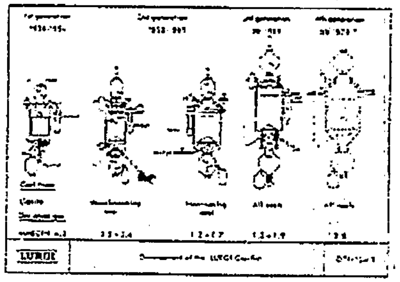

All coals
LURGI

Fig. 5

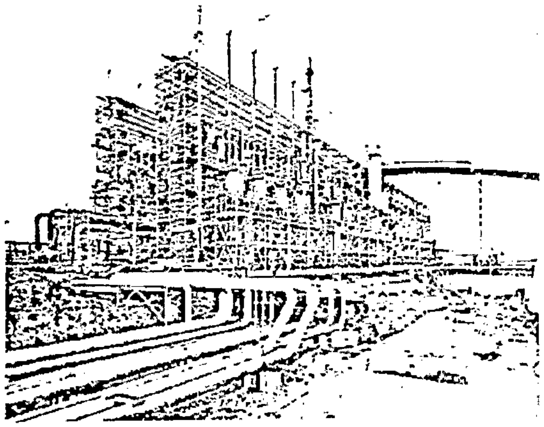


Fig. 6

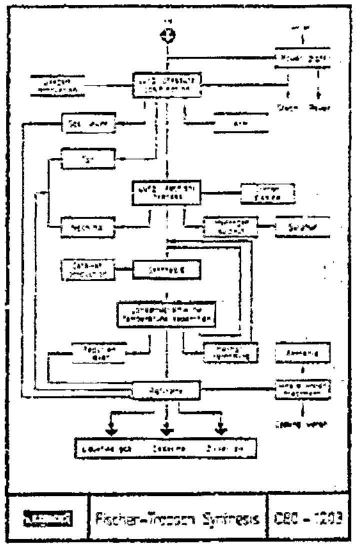

Power plant
Steam
Power
Fischer-Tropsch Synthesis
CBC - 1203

Fig. 7

D: 8210041096

Synthesis gas made from coal by High-Temperature-Winkler-Process.

by K.-J. Mundo, Uhde GmbH, Dortmund, FRG

The role of synthesis gas and hydrogen

Synthesis gas is the key to chemical commodities manufactured and traded in large tonnages and it may by predicted to play an ever increasing role in future schemes, when petro-fuels have to be replaced by coal-based fuels. The bulk of synthesis gas so far has been utilized in the production of ammonia, methanol, and oxo-products, but in future much more will be needed to substitute petrofuels.

In general terms synthesis gas is defined as a gas containing a mixture of carbonmonoxide and hydrogen as its essential components. Depending upon the use of syngas the ratio of $H_2 : CO$ may vary in an infinite range f.i.

$H_2 : CO = \infty$: ammonia, hydrogen
$H_2 : CO = 2$: methanol
$H_2 : CO = 1$: oxo synthesis
$H_2 : CO \approx 1$: iron ore reducing gas
$H_2 : CO = 0$: phosgene

Special emphasis should be given to hydrogen, which is at the upper end of the scale of H_2/CO-ratios. The main consumer of hydrogen so far is the ammonia synthesis. We now look back to an ammonia production of almost 70 years. During this time its growth rate has been in the order of 50 % per decade within the first 3 decades, but after the second worldwar it climbed to 100 % per decade, lately jumped to 250 % per decade and it now has surpassed the 100 mio tons per annum-mark of nitrogen fixation. In the course of this rapid development the places of production have shifted from industrialized areas to developing areas, and raw materials have shifted from coal to natural gas and liquid hydrocarbons.

Anticipated use of hydrogen in substitution of crude-oil-products

In these years of our confrontation with diminishing natural oil resources we are faced with the problem of substituting petroleum derived products by coal-based fuels. All of the processes which can be considered for this purpose are hydrogen consumers to a large extent. If for instance we undertanke to predict the hydrogen consumption in Germany during 2 decades of continuous reduction of oil throughput at a rate of 5 % per annum, we arrive at a forecast of hydrogen requirement as shown in figure 1. This figure should demonstrate that hydrogen requirements in Germany will be a multiple of what is used nowadays in an already highly developed chemical industry. Methanol and its further conversion to liquid hydrocarbons are expected to contribute heavily to the overall consumption, and will share the market with hydrogenation products and possibly Fischer Tropsch-Products as the sources of transportation fuel. Synthetic natural gas (SNG) will also have a considerable share in the hydrogen market, particularly as a well distributable domestic fuel. This scenario indicates the grand nature of hydrogen; - and thus hydrogen will generally have to come from coal.

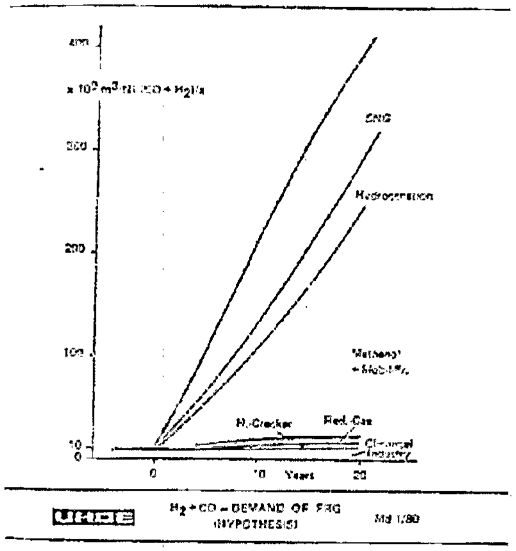
Although the predicted hydrogen consumption shown in figure 1 is the result of an assumed reduction of oil throughput, it would certainly be misleading to consider hydrogen as a substitute of mineral oil. Whereas petroleum and its fractions are primary energy carriers donated by nature as the result of a long lasting accumulating process, hydrogen can only be considered as a secondary energy carrier. If hydrogen is not produced as a decomposition product of hydrocarbons, we ultimately have to generate it through the decomposition of water, where it is available in large abundance, however in its most oxydized and therefore most stabile from. This means, that we have to apply at least the decomposition energy of water. Whatever process we might consider will have to be measured by the efficiency of applying the energy of water decomposition. This means that the process which has lowest energy input for water decomposition should be favoured.

The present technology

If we look at the various processes for the generation of synthesis gas we may briefly touch the steam reforming of natural gas for a number of reasons. Natural gas used to be a cheap feedstock. It can be treated in a simple and cheap installation, but still at high thermal efficiency and at a low degree of pollution. So there are good reasons for this process to be the predominant one in producing synthesis gas and it will certainly continue to maintain an important role during the years to come. The thermal efficiency of the steam reforming process is in the order of 65 % and there are ways to improve that efficiency further. This high energy conversion efficiency is due to the fact, that only one third of the total hydrogen yield is to be produced by water decomposition, whereas the majority is being generated from the hydrocarbon.

Figure 2 shows a steam reformer which is typical for present technology, operated at approx. 880 °C and 20 bar. For the production of 1 billion m³ per anno of hydrogen such reformer would need approx. 630 reforming tubes. The entire reformer is of a modular design and therefore the mentioned capacity is not a limitation. (Fig. 2 not included in print)

Another process is the partial oxydation of heavy hydrocarbons which are available from refineries. Stringent legislation for the abatement of air pollution restrict the use of heavy oil fractions as a fuel in power stations, but partial oxydation is a suitable process to concentrate and remove sulphur and metals contained in the heavy fuel oil. The thermal efficiency of this process is at approx. 62 %. Present development is directed towards recycling of combustible by-products as well as towards improved heat recovery, whereby the thermal efficiency will be further improved.



$H_2 + CO$ – DEMAND OF FRG (HYPOTHESIS)

Fig. 1

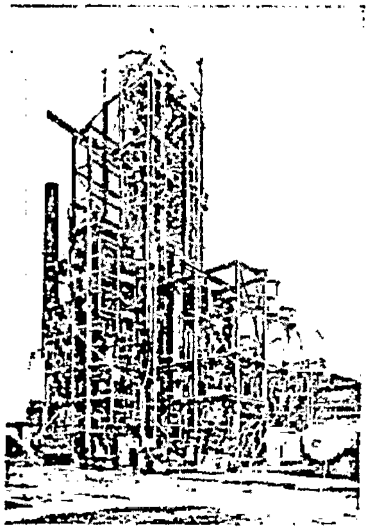


Fig. 3

The HTW-Pilot-Plant at Wachtberg/Cologne

Coal based synthesis gas generation

In these years of diminishing oil resources we have to look back at coal as the prospective candidate to fill the widening gap between demand for synthesis gas and its possible supply from hydrocarbons. But not only do we have to look at the expertise gained 30 to 50 years ago especially in Germany, we also must look forward to modern technology providing improved economics. There are some basic principles to describe and to classify the technology of coal gasification. These are for instance

- the fixed bed gasification, where coal and gasification agent are in countercurrance,
- the fluid bed gasification, where a thorough mixing of coal particles in the fluidized bed is achieved, and
- the flame-typ gasification, providing co-currance of coal and gasification agent.

Typical representatives of these gasifier types are the Lurgi process, the Winkler gasifier and the Koppers-Totzek gasifier.

Today the Koppers-Totzek gasification as well the Lurgi gasification are in commercial service in a number of units. These processes have reached technological achievement, when cheaply available oil and gas have forced the coal out of nearly all applications in chemical process plants. However in those few cases, when special economic premisses justified the use of coal, these two processes could be operated successfully and are also being advanced in technology. It should be mentioned, that there are also some installations according to the classic Winkler process in operation.[1]

A number of further processes have been developed in past and came close to technological satisfaction. In most cases these have been process concepts known for many years, which have been adopted to the requirements of large throughput figures. Process principles are generally governed by the properties of coal-feed, may it be a highly-reactive or less reactive coal, may it be hard or soft or even in fine grain form, or may its ash melting point be high or low. These are the most essential parameters to define the most suitable gasification process. High throughput figures make the application of increased gasification pressure almost imperative to all processes from a energy saving point as well as from an equipment size point of view.

Since the operating parameters of coal gasification have to be responsive to the nature of respective coal, there cannot be a common answer to the request for the most suitable process. The answer can only be, that for a given coal quality gasification processes may be more or less suited. This statement will likewise apply to the fluidized bed gasification, on which this presentation will focus, since other processes have been or will be described during this symposium by more competent contributors.

The classic Winkler gasification process

The classic Winkler process was developed in Germany in the twenties. Since then, a number of plants using this process have been constructed, some of which are still in use. The basic principle of this process is gasificaion in a fluidized bed. The coal is conveyed into the gasifier by a screw feeder, the gasification agent is admitted through nozzles arranged at the circumference of the fluidized bed. In order to maintain the bed in fluidized state, the gasification temperature must remain below the melting point of ash.

The characteristic features of the Winkler process may be summarized as follows.

- Low consumption of gasification agents, i.e. oxygen and steam.
- Simple coal preparation process, because a relatively broad grain size spectrum can be used, the maximum grain size being several millimeters in diameter. This means that crushing of the coal will be sufficient without further grinding.
- High gas quality, because the gasification process takes place at a uniform temperature and because final gasification in the upper part of the reactor achieves complete conversion of the higher hydrocarbons.
- High ash content in the coal feed is permissible.
- Due to the large quantity of coal in the reactor, the reactor can continue to operate even in case of a temporary stoppage of the coal feed.
- No considerable reduction in efficiency when operating at partial loads.

The disadvantages of the conventional Winkler process are the relatively low coal conversion rate due to the fact that minute coal particles are entrained by the gas leaving the reactor, and operation at atmospheric pressure and moderate temperature.

The Rheinbraun HTW-Process

The disadvantages mentioned here have been the starting point of the development work of Rheinische Braunkohlenwerke with the aim of performing the gasification under pressure and at an elevated temperature. Hence the name was derived: HTW = High-Temperature Winkler Process

Operation under pressure and at elevated temperature offers the following advantages:

The gasification rate is increased and the effective gas velocity in the gasifier is reduced. This makes it possible to construct high-capacity gasification reactors of comparatively small physical size.

The gas leaves the reactor under pressure, thus obviating a compression step prior to further processing. The expense involved in compressing the gasification agent is more than compensated.

The higher temperature accelerates gasification and, consequently, coal types with a lower reactivity can be processed, also the carbon conversion rate can be increased.

However, just as any fluidized bed operation, the Winkler process is dependent upon solid particles to exist in its reaction zone. Therefore the higher temperature creates the risk of getting molten or agglomerated ash. Preliminary tests have shown that the addition of limestone increases the ash melting point of the investigated coal types. Simultaneously the limestone reacts with the sulphur released from the coal and retains it in the ash.

A pilot plant has been built by Rheinbraun and is in operation since two years to test the process. The development is being sponsored by the Federal Ministry of Technology, BMFT, in Germany. Engineering services in design, construction and operation have been provided by Uhde. Figure 3 shows this installation which is located in a place near Cologne.

Fig. 4 and 5 [2] give a flow-diagram of this plant, and it may be described briefly. The heart of the process is the fluidized bed and the entrainment reaction chamber above the fluidized bed with essentially two levels of gasification agent admission, the first one being underneath the fluidized bed an the second one being above that bed in the postreaction zone. Solid particles still carried with the gas at the outlet of this zone are separated in a cyclone - type separator and are returned to the fluidized bed via a dip - leg pipe.

The high-temperature Winkler gasification plant is fed with dry coal from conventional tubular lignite driers. For reasons of flexibility, provision has been made in the pilot plant for further drying the coal. The coal is pressurized in a lock hopper system to reaction pressure and fed into the fluidized-bed reactor by a screw feeder. Controlled quantities of limestone, lime or dolomite can be fed to the reactor simultaneously with the coal through the lock hopper system shown on the left. In the reactor, the coal reacts with the pre-heated gasification agent which can be oxygen and steam or air and steam. The fluidized reaction zone is operated in the upper range of permissible gas velocities. So we have a certain degree of particle entrainment with the product gas, which is intended.

The dust-laden product gas leaves the reactor at the top. The coarse dust particles are removed in the first separator, which is of cyclone-type, and returned to the fluidized bed through a dip-leg. Further dust separation takes place in the second separator, the dust being discharged through a lock hopper system. The purified gas is cooled and presently is burnt in a power plant.

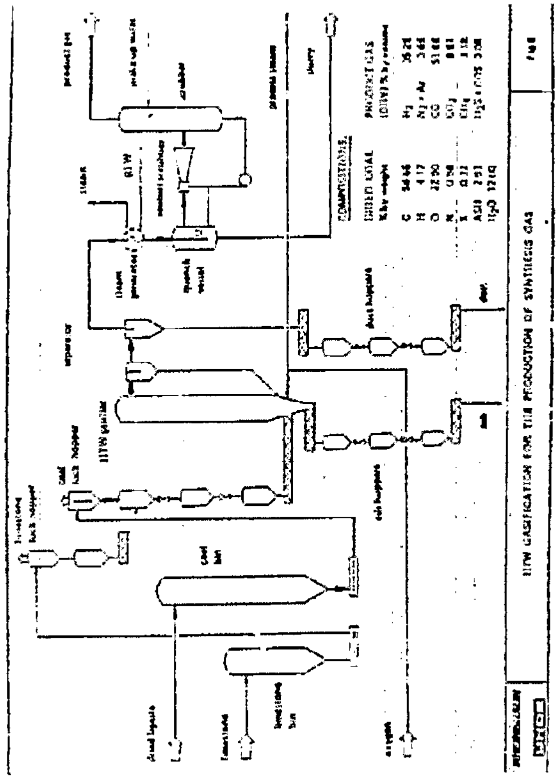


Fig. 5

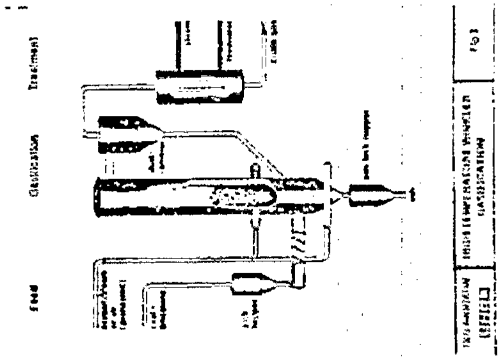


Fig. 4

...in ash removal is effected via a lock hopper system underneath the reactor. In commercial installations the two ash discharges may be combined.

The plant design permits not only lignite but also less reactive carbon carriers to be gasified. The Rheinbraun HTW process is particularly suitable for reactive coal types with low clinkering tendency, especially lignite.

The characteristic design data for the HTW pilot plan are as follows:
coal throughput: 1 t/h of dry lignite
gas production: 1500 m3 (stp)/h
gasification pressure: 10 bar
gasification temperature: 1100 oC
gasification agent: oxygen - steam

The pressure chosen for this pilot plant does not present a limitation to the process, but can be raised in future installations. A diagram of compression energy requirement, however, demonstrates, that the highest incentive to increase the gasification pressure is in the low pressure range.

The purpose of the tests is not only to examine the possibilities of producing synthesis gas but also to investigate the fundamentals for other applications, such as the production of reducing gas, substitute natural gas or fuel gas for a combined cycle process with steam- and gas turbine.

The pilot plant went on stream in summer 1978 (figure 6). The results obtained so far have confirmed the expectations placed upon the Rheinbraun HTW process. It is planned to subject the process to further tests in a larger plant. Uhde is currently performing the engineering for a demonstration plant for the production of methanol synthesis gas with a capacity roughly equivalent to a 1200 tpd methanol plant in a modular way.

It should be mentioned at this point that the HTW process is also suitable for the gasification of wood, as was shown by appropriate preliminary tests. Uhde is at present under contract to Swedish and Brazilian companies for the design of large-scale pilot plants for wood gasification.

The HTW-demonstration plant

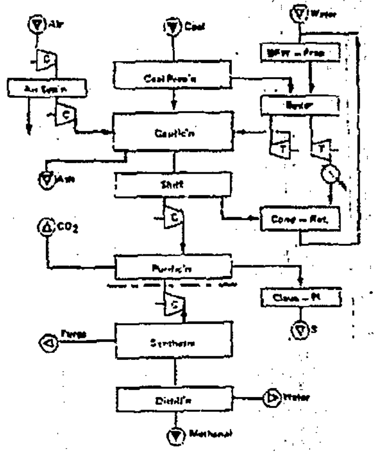
Following the success of the pilot plant operations the decision was made to build a commercial-scale gas generation plant to feed a 1200 tpd methanol unit. Four mudules will provide the synthesis gas, each of these gasifiers being of about the diameter of formerly operated Winkler generators but operated at elevated pressure.

In chosing the geometric dimension of formerly operated fluidized beds we expect to have a fairly good control of the behaviour of the reactor, particularly with respect to the even distribution of gasification agent in the coal.

PARAMETER		HTW PROCESS (TARGET)	CONVENTIONAL WINKLER PROCESS AT UREK (ACTUAL)
Pressure	bar	up to 10	1.5
Temperature	°C	up to 1100	800 – 900
C conversion rate	%	up to 96	91
(CO + H₂) Content in raw gas	% by vol.	up to 90	85
CH_4 Content in raw gas	% by vol.	3	1 – 2
By products in raw gas (e.g. tars, phenols, oils)		none	none

RHEINBRAUN UHDE — COAL GASIFICATION PROCESS PARAMETERS — Tab. 3

Fig. 6



UHDE — COAL BASED METHANOL PLANT — VC 10 90

Fig. 7

The gasification module will be followed by a partial shift conversion to establish the proper H2:CO-ratio for methanol-formation. This shift conversion will be effected in contact with a sulphur-tolerant catalyst now available from BASF, Topsoe etc. After shift reaction carbondioxide and sulphur compounds have to be removed. A physical scrubbing process will serve this purpose, and it will release the sulphur compounds in a concentration suitable for further treatment to produce elemental sulphur in a Claus-Plant. Synthesis gas will finally be piped to an existing methanol synthesis. The gas preparation step will be carried out at the lignite mine to reduce solids transport to the bare minimum, whereas further processing will take place in a product-oriented processing plant. The syngas pipeline in between is considered to be the most economic way to carry the product from the coal mine to an appropriate offtake position. Fig. 7 shows the process arrangement and its intersection.

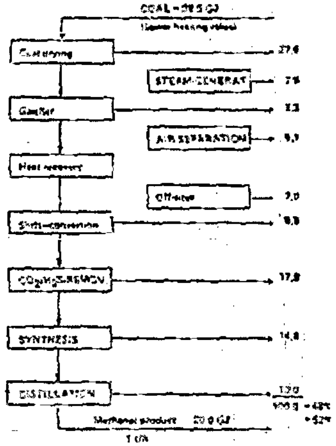
The demonstration plant is expected to come on stream in the early 80's. Uhde provides the engineering services for this plant. After this unit has shown its operating reliability we shall be ready to build HTW-plants for our clients. Already now there is a fairly high degree of confidence in the design of this unit and investigations of feasibility may be carried out soon after we have tested other coal-types in the pilot plant.

The energy conversion scheme of a coal to methanol plant using the HTW-technology

In any energy conversion scheme the degree of energy conversion is of prime concern. Even if this concern would not be dictated by the cost of primary energy, the principle would still holds true due to the amount of energy to be dissipated to the environment from plants of substantial capacity.

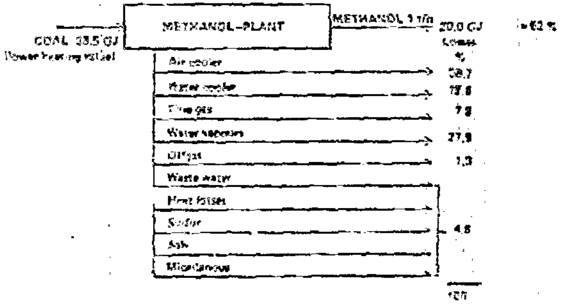
Therefore engineering efforts have to be continuously directed towards improving energy conversion efficiency. If we show data of energy dissipation now, like in fig. 8.[3] tomorrow's figures may be better. The overall energy efficiency of the entire process from as mined lignite to methanol is approx. 52 %. An analysis of energy dissipation identifies the process areas where most of the heat losses concentrate on. These are: the coal drying section, the sour gas removal section and the synthesis. High energy losses of the coal drying section are to be attributed to the fact, that raw lignite investigated here contains almost 60 % of moisture. It should, however, be mentioned, that the value of energy needed in coal drying is low and hence, if grade of energy is also taken into amount (like in exergy analysis) the overall picture will drastically change.

Attention should be attracted to the fact, that energy losses of the gasifier are very low. On the other hand, if grade of energy is taken into account as well, the gasifier contributes to the overall losses at a higher rate. Fig. 9 analyses the various measures of removing the heat losses from the process. It shows, that the major portion is removed by cooling air and cooling water, which means, that the working potential of this energy amount is nil, since this energy already is in equilibrium with



UHDE | METHANOL FROM COAL Energy dissipation | Fig. 11.

Fig. 8



UHDE | METHANOL FROM COAL Distribution of Energy Losses | Fig. 10

Fig. 9

the environment. The figures show, that in dealing with the potential of improving the process we have to concentrate on heat losses of low energy content, but high energy grade.

Hydrogen from coal compared to other raw materials

With our knowledge of the energy conversion efficiency of coal based methanol it might be of interest to compare coal based processes to processes based upon other raw materials. As an example of this we may use the large-scale hydrogen production. It has been mentioned earlier, that hyydrogen is to be considered as a secondary energy carrier just as the methanol. Energywise its value is represented by its heat of combustion and processes to produce hydrogen can be measured by using its heat of combustion as a yardstick. Fig. 10 shows such comparison for a number of raw materials, respectively energy sources, from natural gas as a hydrogen donator to mere forms of energy such as nuclear power. We can see the energy input to increase step by step and we can see it becoming extremely high for thermochemical cycles, which together with electrolysis shall be exempted from the present considerations.[4]

Unfortunately we notice an increase of investment simultaneously with the increase of energy input as we go along this sequence of processes. This means, that energy should be considerably cheaper than in the form of natural gas the more we more downwards in this tabulation, if the other raw materials have to be competitive to natural gas. A diagram may demonstrate this interdependance at figures established for the FRG, fig.11[5]. Since investment - related costs and feedstock - related costs dominate the entire production costs, in its ordinate this diagram roughly represents the ratio of investment for the various plants, depending upon feedstock. We can see, that coal should be available at no more than 40 % of the natural gas cost. if there is an option to use either of the feedstocks and hence these feedstocks are to compete. In a place like our country this competitive situation may be given for strip-mined coal. But if natural gas cost is low, the situation may differ and I certainly do not feel competent to judge the situation in this country. On the other hand all of us are aware of the exhausting resources of petrofuels, whereas coal will still be available, when the gas wells cutt off. Time to prepare the transient state may be soon, but the sooner we start working on this transition, the smoother will it occur.

The cost of producing methanol from coal compared to other raw materials

Bulk chemicals such as methanol can even nowadays be produced from coal competitively, if we use coal-types which are easy to mine and therefore can be supplied at low energy-cost. Based upon certain information we have collected from various places over the world and which may not be correct in any given case, we have computed the methanol production cost from the main raw materials and in a number of locations all over the world. An extract of this shown in figure 12, where the cost of methanol-production is plotted against cost of energy contained in the feed.

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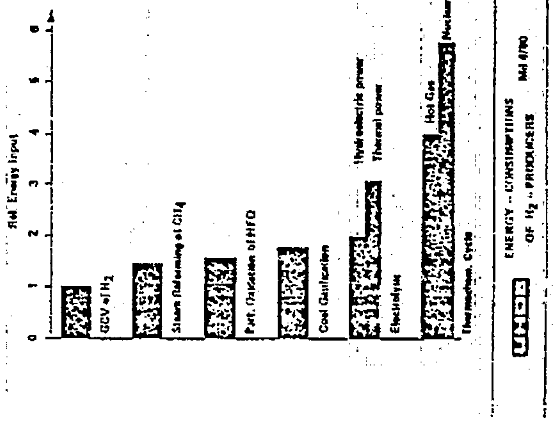


Fig. 10

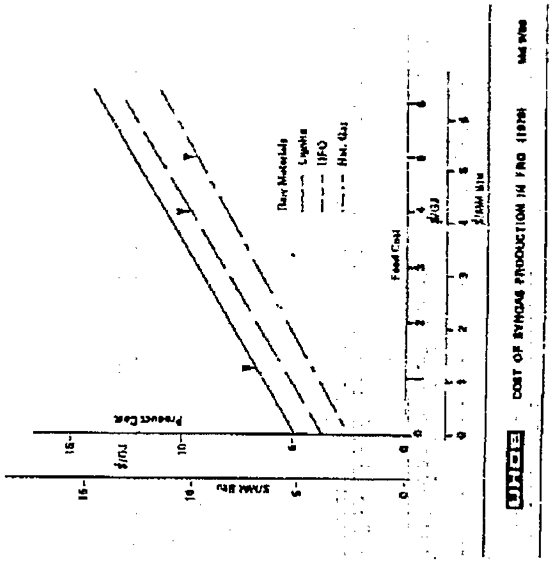


Fig. 11

capital charges have been taken even for all cases, but we have allowed for different plant investment in the individual locations by using established location factors. [6]

Here I should not detail the calculations and all its premisses, but refer to its results in a short way. For all raw materials except lignite the production costs of methanol in Germany are well above 200 $ per ton, and above 180 $ in the US, but lignite yields a production cost of only 165 $ per ton in Germany and below 150 $ per ton in the US. In Australia we could produce methanol at essentually the same cost as in Germany, although lignite runs at about half of its price in Germany. This is due to the higher plant investment. The distance between the two lines referring to a single feedstock reflect the capital charges of incremental investment. Methanol made from lignite could even compete Arabian Gulf-material and even more so if we take cost of transport into consideration as well, which we have to consider.

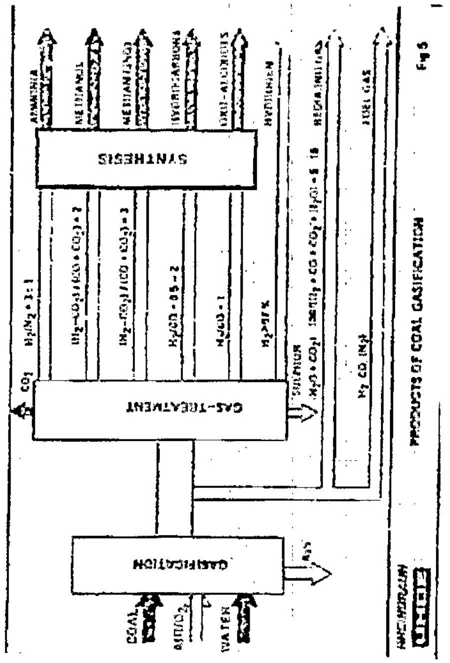
For the cost of shipping we may have to add another 3 to 4 $ / 1000 sm x t, but the entire chain of transports from the producing plant to a centralized distribution point in a consumers area may afford considerably more. Our estimate of production cost should not be made on a fob-plant site basis, but has better compared methanol cost at consumer-oriented distribution points, which has been done in an earlier stage [7].

Here we have omitted the considerations of transport to make the process comparison more transparent.

Products to be made through coal gasification

If we look back to the introductory remarks on the application of synthesis gas, we may now refer this to gas made from coal gasification. Fig. 13 represents the spectrum of products to be gained at the respective H2:CO-ratios. Ammonia will certainly be a large tonnage commodity and so will methanol be, both based upon coal. Together with SNG they represent the most compact form of energy and therefore may be the most prospective carriers of energy from remote coal mines. Next to this are the other products which mostly require combination with other processing plants, like oxo alcohols and reducing gas. Their demand will most probably be much smaller than for the first mentioned products. Hydrogen again may play a very important role in future energy schemes, however it is not easy to be shipped. In a country like this the predominant products may be methanol and ammonia.

Our challenge of these years is to prepare the change over from the few years of cheap petrofuels to the post-oil age when coal will again be the most important feedstock for our industry. We should be ready for this age in due time. A key to the coal-based future of chemical industry is the adequate and advanced gasification technology. We deem the High-Temperatur-Winkler process to be a highly valuable tool to achieve this goal.



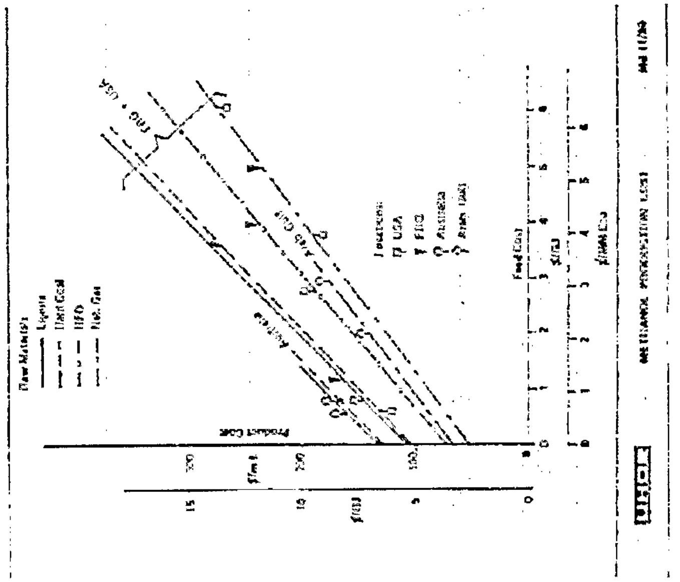


Fig. 12

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THE PRODUCTION OF LIQUID HYDROCARBONS BY COAL HYDROGENATION

The further Development of a proven process by RAG/VEBA

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Contents

Introduction

Liquid fuels are of prime necessity in the modern world. They can be more easily and efficiently transported, stored and used than other energy sources. Such ideal properties have contributed to continually increasing demand. At the current consumption rate of about 55 - 60 million b/d, the world's proven petroleum reserves represent about a 30-year supply. The infrastructure to supply, distribute and consume these products is available. So it is obvious that the major oil consumers will require an alternative energy source with the same or similar characteristic as fuels derived from crude oil.

The coal hydrogenation followed by upgrading the coal oil can be a major step in order to secure the further supply of liquid fuels.

There are two main ways to liquefy coal: the indirect liquefaction and the direct liquefaction.

Indirect liquefaction of coal first involves the conversion of coal and steam to a mixture of CO and H_2 (synthesis gas) and then the reaction of the syntheses gas to form hydrocarbons.

The direct conversion of coal to hydrocarbons seems to be the most simple procedure for a large-scale production of both fuels and chemical feedstocks; we call it hydrogenation.

To show you the principle of this direct conversion let us have a look at figure 1. As you know coal has a very high molecular weight. The liquefaction process requires the breaking of the reactive linkages in the large coal molecules. At these breaking positions hydrogen molecules have to be added to form liquid hydrocarbons with lower molecular weight.

These reactions are enhanced by the action of catalysts. Furthermore the hydrogenation of coal occurs at different conditions of temperature and pressure depending upon the sort of product desired. But always the hydrogenation results in a change of the carbon/hydrogen ratio.

Figure 2 demonstrates the different contents of hydrogen of coal, crude oil, diesel fuel, gasoline and gases. The gap of hydrogen must be added when hydrogenating coal.

Some of these processes were already commerciall available in Germany in the 1930's, especially the Bergius-Pier- and the Pott-Broch-process.

In the Pott-Broch-process the bituminous coal is disolved in a process-derived solvent, which is used as a H-Donor-Solvent. Products consist of oil, tar and electrode grade carbon for the aluminium industry.

In the Bergius-Pier-process the coal is mixed with process derived oil and catalyst to a paste-like consistency, and hydrogenated

with gaseous hydrogen. Primary products are fuel gas, light oil and medium boiling point oils which are upgraded to diesel oil and gasoline.

The products of the Bergius-Pier-process have lower boiling points compared to the products of the Pott-Broch-process. Therefore in our days the Bergius-Pier-process is prefered due to market and economical reasons.

2. The Bergius-Pier-Process

2.1 Historical Review

The first investigations on this hydrogenation process were done by F. Bergius in the year 1913 using heavy fractions of mineral oil. Lateron the hydrogenation of hard coal, lignite and tar pitches was examined. In 1925 M. Pier started to carry out the design of a commercial scale plant on the basis of catalytic high pressure hydrogenation, today known as the I.-G. Process. In 1927 the first commercial plant was brought on stream at Leuna with a capacity of 100 000 tons per year using bituminous lignite. (Figure 3 gives an overview of formerly used hydrogenation plants.)

In 1936 the tradition of VEBA OEL begann with the building of the first plant in the world using hard coal as feedstock at Gelsenkirchen operating at a pressure of 300 bars 230 000 tons of gasoline per year were produced. Lateron up to 1945 more hydrogenation plants were build in Germany processing hard coal, bituminous lignite, pitch and tars.

After 1945 the hydrogenation process was not resumed in the Federal Republic of Germany. In 1953 VEBA OEL's coal hydrogenation plants at Gelsenkirchen-Scholven and Gelsenkirchen-[illegible] were converted with a view to hydrogenating mineral oil residues. Production continued until 1964 when it was stopped for economic reasons.

This historical review already shows one of the typical characteristics of the process. It is the high flexibility, in respect to a broad range of hydrogenation applications. So process was originally developed for the hydrogenation of mineral oil residues. Because of the short supply of these residues the process was also used for coal such as hard coal, lignite, pitch and tars. Lateron it was no problem to convert the old coal hydrogenation plants in order to process mineral oil residues.

2.2 Process Basis of the German Technology

In 1974 RUHRKOHLE AG as well as VEBA OEL began again working on the coal liquefaction process of former times. The main target was the further developing and optimizing of the proven process. During this work the technology was modified in the following way:

- The feed coal is slurried with a mixture of middle and heavy distillates obtained from the process instead of the formerly used overflow of centrifuges.
- The residue which contains solids is used as feedstock in pressure gasification units for hydrogen generation.
- The processed solid-oil-mixture is separated by distillation instead of mechanical treatment by centrifuges.

This modified process - we call it the german technology - is expected to result in the following improvements:

- A drop in operating pressure from 700 to 300 bars while retaining product quality and using the same iron catalyst.
- An increase in coal throughput by 50 %.
- Improvement of heat recovery due to alteration of solid and asphaltene content.
- A decrease in the specific conversion costs.

Furthermore as mentioned above the process is extremely flexible in order to use different kinds of feedstocks, such as hard coal, bituminous lignite, pitch and tars and also vacuum residues from conventional crude oils. This is in contrast to US-technologies which are limited to very particular kind of hard coal.

3. The Project "Pilot Plant Bottrop"

In order to prove the German Technology in 1977 RUHRKOHLE AG und VEBA OEL (RAG 60 %, VEBA OEL 40 %) decided to build and operate a pilot plant.

3.1 Description of the process

In figure 4 a flow sheet of the process is shown.
The coal is ground to a size smaller than 1 mm and dried to a moisture content below 1 wt.-%. Then the coal is slurried in a mixtank with a middle and heavy oil in a 40 : 60 ratio. This slurried coal is ground to less than 0,2 mm and the catalyst is added. The final slurry contains approximately 40 wt.-% of solids.

The slurry is pumped via high pressure plunger pumps to 300 bars. Now hydrogen and recycle gas is added and the slurry is heated in a preheater to 420°C. The suspension enters the reactor from the bottom. Here only one reactor is shown but in reality three in series connected reactors will be used.

The exothermal hydrogenation reaction occurs in the reactor and is controlled by feeding quenching hydrogen into the reactor in a way that the temperatur does not exceed 475 °C. The product leaves the reactor at the top.

Following the reactor a phase separation takes place in the hot separator, where gases and vapours are removed from the top while liquid products and solids are discharged from the bottom. The hot separator operates at 300 bars and 450 °C.

The gases and vapours are cooled. The condensates are reduced in pressure and pumped to the atomspheric distillation. The remaining gas is led to an absorber tower where the hydrocarbons are washed out and the concentration of hydrogen is increased. The absorber tower is also operating at 300 bar and the leaving recycle gas returns to the process in front of the preheater.

The condensed liquids are the products of the process. They are treated by atmospheric distillation and separated into light oil, middle oil and heavy oil.

The bottom products of the hot separator are expanded by vacuum distillation and separated into distillate oil and residue. The distillate returns to the process for slurrying the coal. The residue containing minerals, unreacted coal and catalyst as solids, are cooled on a steel belt and further processed to granulate which is given to a coking plant which is situated nearby.

In order to meet with the target of solid's enrichment up to approximately 50 wt.-% several different processes of treating the residue are planned. These are different combinations of pressurizing, preheating and flash evaporating.

Furthermore a testprogramm will be established in the pilot plant. In order to test newly developed equiment designs of slurry feed pumps and preheaters are installed.

3.2 Description of the plant

The location selected for the pilot plant is Bottrop close to refineries and directly adjacent to a coking plant and a coal mine.

Figure 5 shows some characteristic details of the pilot plant which has an input of 200 t of coal per day and produces 100 t of liquid hydrocarbons.

A plot plan of the pilot plant is shown in figure 6. With a length of 273 m and a width of 215 m the plant covers an area of 58 700 m^2. The main process units including measuring and control station are located in four sections which are connected to each other by pipe bridges. These units require an area to talling 13 000 m^2 (100 m x 130 m).

In order to facilitate the supply of the feed coal and the evacuating of residue the plant is connected with the above mentioned coking plant via a belt conveying system. A flare and blow-down system is installed and tanks are provided for storage of the coal oil fractions. Furthermore however office buildings, staff facilities, workshop and store rooms are provided.

Upgrading of Coal Oil

A further aspect of the project "Pilot Plant Bottrop" is the upgrading of coal derived oil which will be done in bench scale and process development units in laboratories situated in Gelsenk.-Scholven. The properties of coal oil which are in some parts quite different from those of minerals oils require special handling. Figure 7 shows a comparison of characteristic data of oil from coal and arabian light.

Among the different properties can be mentioned especially the high amounts of nitrogen and oxygen. A lot of the latter being bound in phenolic compounds as well as the high concentration of aromatics in all fractions, which are responsible for the high specific gravity of the coal oil.

These upgrading tests have the goal to look under technical and economical point of view for methods of producing fuel oils such as heating fuel, gasoline, Diesel-fuel or jet-fuel as well as raw materials for chemicals, which may substitude or supplement the corresponding products of mineral origin in the future. The test program includes the utilization of the specific properties of the coal derived distillate oils for example by extraction of the phenols or by isolation of special aromatic substances.

The main targets for the upgrading of coal oil are shown in figure 8.

The data obtained by analysing measurments will enable RAG and VEBA OEL to project and construct a commercial plant to manufacture and process coal derived distillates.

The following fractions of distillation will be treated separately:

light oil	IBP - 200 °C
middle oil	200 - 325 °C
heavy oil	325 °C

The different ways of treatment to be persued during the tests are shown in figure 9.

In case of the light oil the main purpose of the treatment lies in the isolation of phenols and pyridine bases and in the production of gasoline and BTX-aromatics. A great importance has the hydrotreating step because of the high concentrations of sulfur and nitrogen, which are bound in cyclic compounds to a great extent, special reaction conditions and catalysts must be chosen to meet the requirements of the following process.

The main products of middle oil upgrading should be heating fuel. By severe hydrogenation Diesel fuel and jet fuel can be produced. Furthermore hydrocracking to gasoline is studied. Interesting byproducts are naphthalene and tetraline.

The main upgrading route for the heavy fractions of coal oil is the production of light hydrocarbons by catalytic cracking and hydrocracking as well as the recovery of chemicals and special oils.

The hydrotreating tests are performed in a bench scale unit one of them is shown in figure 10. Commercially available catalysts in bed size of 1 l are used after presulfurizing. In order to reach the quality of reformer feed very severe hydrotreating conditions are to be chosen compared to those for conventional naphtha refining.

5. Outlook

Now let me say some words of the further development of the process.

In July 1979 the government of the Federal Republic of Germany decided to promote without delay the commercial production of middle oil, gasoline and gas from coal.

In accordance with the government's plans the two companies RAG and VEBA OEL submitted similar proposals to the Federal government to plan, build and operate commercial plants for coal hydrogenations based on the German Technology. These proposals only differ in the fact that the plant proposed by VEBA OEL shall provide the possibility to hydrogenate extreme heavy oils and oil residues besides or instead of hydrogenation of coal.
The preliminary concept of both companies is based on an input of six million tons of coal p. a. including the plant's own consumption for the production of energy and hydrogen. The plant will produce two million tons of gasoline and middle distillates. Figure 11 shows some characteristic details of such commercial plant.

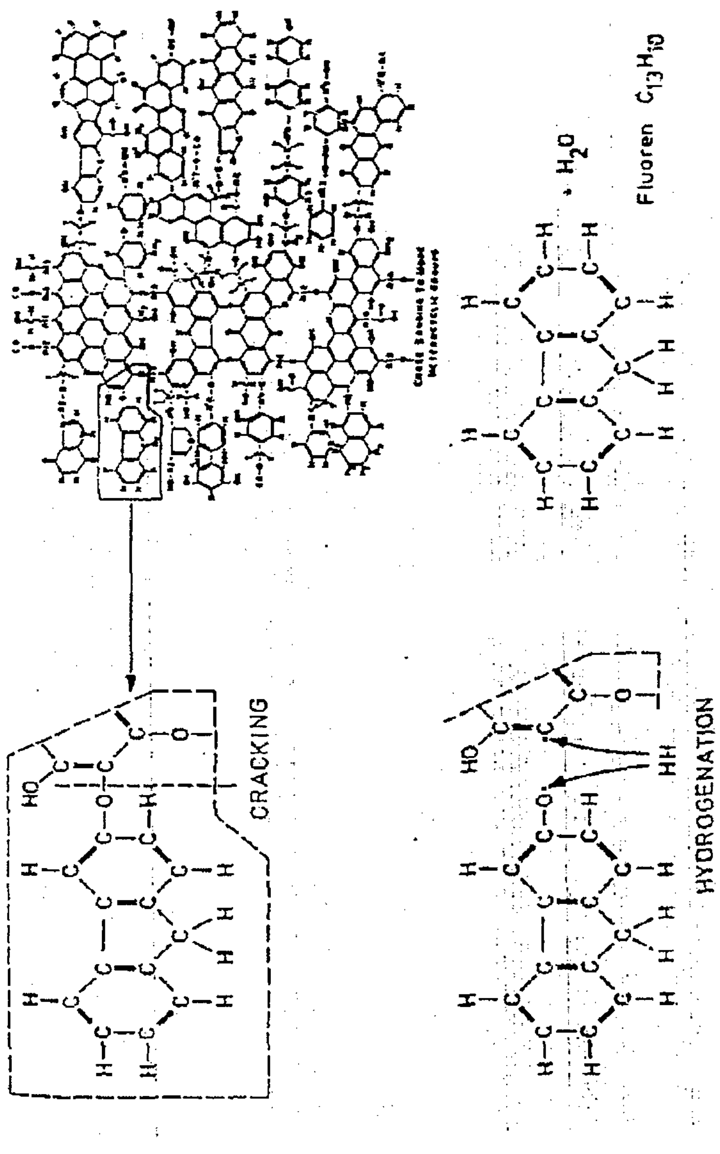
Figure 12 gives a view of the production lines of a technical size hydrogenation plant. If the electrical energy and the hydrogen required for the process could be supplied by other sources, the coal input - regarding hydrogenation only - would be four million tons per year. This concept is only an example for a technical size hydrogenation plant. It has to be adapted to the special conditions of the different projects.

The most optimistic time schedule for realizing one of these projects in Germany is a follow:

1980/81	feasibility study
1982/83	detail engineering
1984/86	construction
1987	start up

This time schedule requires that the approval of permits will not delay the project.

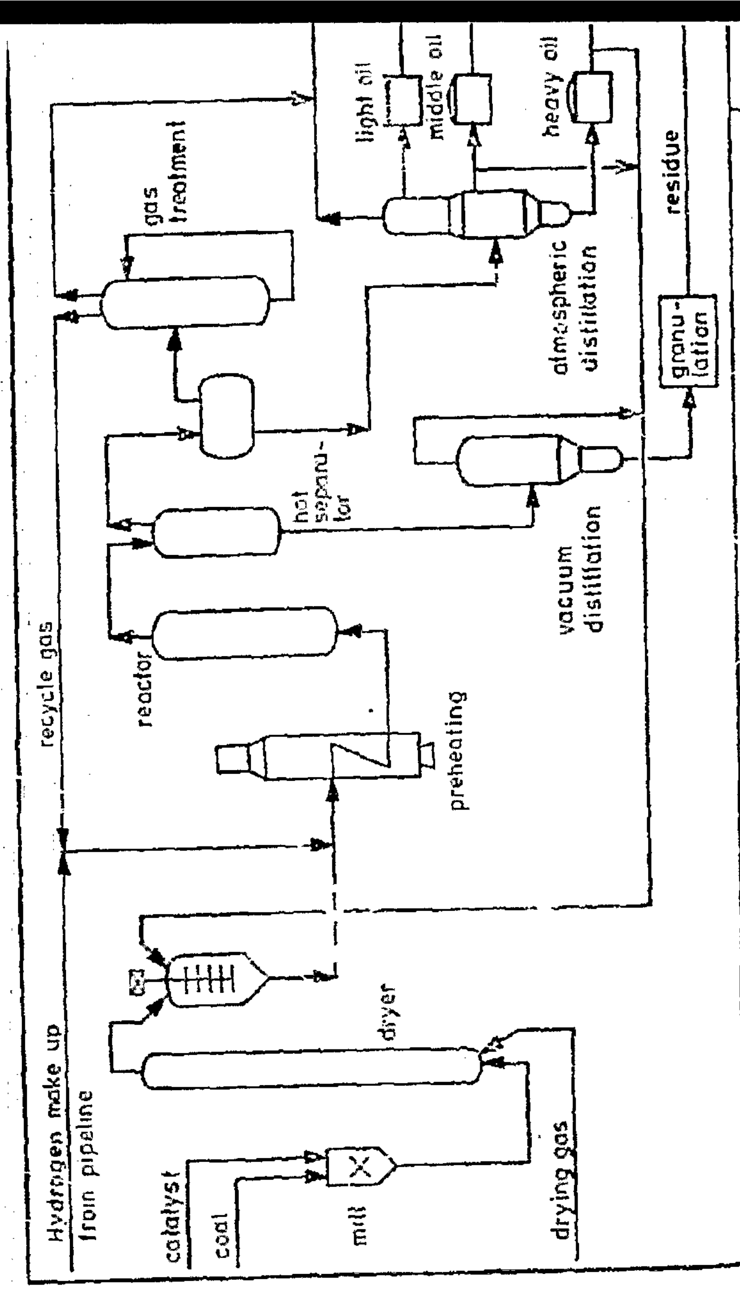
Now at the end let me say some words about economics.
The costs of coal oil are shown in figure 13. They are based on present investment and operating costs. The figure shows that costs of a barrel of coal oil range from 55 - 60 $/bbl. if using German hard coal at a price of 95 - 100 $/t. Using coal at a price of 25 $/t the equivalent price for oil devired from coal is approx. 35 $/bbl., a price already paid on the market today.



VEBA OEL
Entwicklungsges. mbH

CRACKING AND HYDROGENATION OF COAL

Fig. 1
553/60-1



FLOW SHEET OF THE PILOT PLANT BOTTROP

RUHRKOHLE AG
VEBA OEL AG

COAL LIQUEFACTION PLANT BOTTROP

FEEDSTOCK:

COAL (maf)	200 t/d

RAWPRODUCTS:

GASOLINE (<200 °C)	30 t/d
MIDDLEOIL (200-325 °C)	70 t/d

VARIATION IN PRODUCT SPECIFICATION IS POSSIBLE

FURTHER TREATMENT IN LABORATORIES

INVESTMENT	135 MIO. DM
SUBSIDY	BY STATE OF NRW
PARTNERS	RAG / VEBA OEL
START UP DATE	BEGINNING 1981
PLANT OPERATION	3 YEARS

RUHRKOHLE AG
VEBA OEL AG

PILOT PLANT BOT.
CHARACTERISTIC DATA

Fig. 5

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Possibilities of Utilising Indonesian Coal by Carbonisation and Gasification

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October 1980

Possibilities of Utilising Indonesian Coal by Carbonisation and Gasification

Since the Fifties and Sixties, mineral oil and natural gas have superseded coal as energy carrier and raw material throughout the world. However, in the meantime it has generally become obvious that the reserves of mineral oil and natural gas are rather limited, whereas coal is sufficiently available, although a great deal of it is of inferior quality. To ensure the future supply of energy, fuel and raw materials, the use of coal will become absolutely necessary.

The measures for the substitution by coal can only be carried out on a long term and must, therefore, be taken at an early time, under consideration of specific local conditions.

The basis of such considerations for Indonesia is that certain coal resources are available, but due to its poor quality, the coal cannot be evenly employed for any coal utilisation technology known at present.

As an experienced engineering company dealing with processes for the beneficiation of coal we now see a possibility of utilising Indonesian coal for both carbonisation and gasification. I am going to explain this briefly in the following.

.../2

1. Carbonisation

Let me start with the classical method of coal beneficiation: the carbonisation.

When bituminous coal is heated up under exclusion of air, to approximately 1.000°C, a thermal conversion takes place which can be described as coking, carbonisation or dry distillation. During this process, the volatile constituents of the coal are expelled and coke and gas are obtained as final products. The by-products contained in the gas, particularly tar, sulphur compounds, ammonia, and benzole, are subsequently removed.

If no lean gas is available for heating the coke ovens, approximately 35 - 40% of the gas output must be used instead. The remaining surplus gas volume can be processed for further use.

The figures stated hereunder apply to a coke oven plant with an output of 1.5 million tons of coke per year, which produces about 80,000 Nm^3 gas per hour. 50,000 Nm^3 per hour remain after deducting the underfiring consumption.

If the gas is intended to be used for heating purposes in steelworks or power stations, purity requirements are similar to those of gas used for underfiring the ovens. More extensive cleaning is required, if the gas is to be utilized for distribution in towns or transportation over long distances.

.../3

Another method of using coke oven gas is the production of hydrogen by catalytic steam reforming. From 50,000 m^3 coke oven gas, about 55,000 m^3 hydrogen of 96% purity can be produced. By application of molecular sieves, the degree of purity may be increased to 99.9%.

If catalytic steam reforming with the addition of air takes place in a secondary reactor, ammonia synthesis gas is obtained. When 50,000 m^3 coke oven gas are processed per hour, synthesis gas for approximately 700 t ammonia per day is yielded.

Also, the manufacture of gas for reduction purposes is possible. 50,000 m^3 coke oven gas per hour supply the necessary volume for direct reduction at a capacity of 700,000 t sponge iron per year.

The coke yielded by carbonisation can be used for firing in power stations or households or for metallurgical purposes, depending on its quality.

For the production of certain coke qualities, corresponding coal blends have to be prepared. Blast furnace coke, for instance, which must meet stringent requirements of strength, lump-size and retarded reaction can, in conventional carbonisation processes, only be produced from coal with good coking characteristics.

Now, what does this mean for Indonesia? Will it at all be practicable to utilize indigenous coal resources for carbonisation? The types of coal which we have tested in recent years involved various Ombilin-coals which petrographically ranged between lignite and bituminous coal with low degree of coalification. These high volatile bituminous and sub-bituminous coals have very poor coking qualities. If such a coal is conventionally carbonized, coke breeze is obtained, i.e. no solid sintered pieces. This coke substance is unsuitable for further use. However, today supplementary technologies are available, permitting the inclusion of non-coking coal in the carbonisation process. With these technologies, the feed coal is pretreated in such a way that the poor coking characteristics of the coal blend are improved during carbonisation.

Three processes have now proven their applicability on an industrial scale:

Stamping,
Partial briquetting, and
Preheating.

All of the three processes have in common that carbonisation can take place in conventional coke ovens.

With each of these supplementary technologies, only a certain portion of the poor coking coals can be utilized.

Stamping is the oldest of these processes and has been known for 100 years. From the complete coal charge of an oven, a coal cake of high density is made, which is then pushed into the carbonisation chamber as a whole. This process has up to now been limited to low chamber heights and, due to complicated operations, has not permitted large throughputs.

In the last few years, however, Saarbergwerke AG, West-Germany, have succeeded, by intensive research and development work, to prove that the process is also applicable for ovens 6 m high. Furthermore, stamping operations were modified in such a way that in spite of shortening the stamping period, the density of a coal cake could be increased and homogenized.

Numerous types and blends of coal have been carbonised in the Saar area. Some of the coals showed characteristics similar to those of Indonesian coals as far as the content of volatile matter and the Swelling Index are concerned. When these coals were stamped and carbonized unblended, stem-like coke was yielded which, however, possesses sufficient quality for use in electric furnaces.

For the manufacture of blast furnace coke with sufficient quality, 50% non-coking coal was mixed with 50% coking coal and stamped. By adding pitch and coke breeze, the portion of non-coking coal may be increased up to 60%.

If the coke produced is intended to be fired in a power station, i.e. if coke quality requirements are lower, the portion of non-coking coal may be raised to 70% or even 75%.

The second mentioned process concerns the partial briquetting of the feed blend. This technology was developed in Japan in the last few years. Today, nearly one half of the Japanese coke production is obtained from partially briquetted feed coal.

A comparison of Indonesian coals with coal types used for partial briquetting permits - with all provisos - the assumption that 25 - 30% of the local coal can be used for the production of metallurgical coke.

Last but not least I mentioned preheating. With this process, the complete charge is preheated outside the carbonsiation chamber to approximately 200°C.

Using the preheating system, it can also be expected that approximately 30% of the Indonesian coal can be utilized.

More exact statements on optimum blend compositions and required additives cannot be made for the three coal-pretreating processes until all coal data are available and carbonisation tests have been carried out

Summarising, I would like to make the following brief statements with regard to carbonisation:

1. Today, it is well possible to carbonize Indonesian coal blended with imported coking coal, whereby, particularly by the stamping process, an optimum portion of Indonesian coal can be utilized.
2. The produced coke can be used in fire places or, if it is of adequate quality, used as blast furnace coke
3. The coke oven gas produced will be available as energy, as raw material or as synthesis gas.

2. Coal Gasification

Another method to use Indonesian coal as raw material, is the gasification of coal where its organic constituents are completely converted into gas, with oxygen and/or steam serving as gasification agent.

Tests carried out by us with both Ombilin and Bukit Asam coals, produced good results for an economical gasification by the Koppers-Totzek process.

The gas yielded can be used wherever gas is consumed; thus, it offers a genuine alternative to the use of natural gas or gas from mineral oil derivatives.

Fig. 2.1 The first figure shows the most important fields of gas application.

Gas from coal gasification may be used directly as fuel or reduction gas. Furthermore, it is of significance as feed gas for the following types of synthesis:

Methane,
Ammonia,
Methanol,
The oxo-synthesis, and
The Fischer-Tropsch synthesis.

The hydrogen contained in the gas can also be used in hydrogenation processes.

The Gasification Processes of the Present

For gasification of coal, today, three industrially established processes are available, which were all developed in Germany:

The Koppers-Totzek entrained-bed gasification process,
The Lurgi solid-bed process, and
The Winkler fluidized-bed process.

The plants built for the application of the above processes, which have been adopted for many years, have reached a high technological level due to continuous further development.

Let me, quite briefly, illustrate this by way of the Koppers-Totzek gasification process as an example.
Fig. 2.2 In the next figure, the development stages of this gasification technique are illustrated. The gasifier output was increased from 3,000 m^3/h in the Fifties to 50,000 m^3/h as attained in modern plants today. With this development, the specific investment costs could be lowered and better economy achieved. Since the construction of the first plant in 1952,
Fig. 2.3 17 plants comprising 52 gasifiers have been built or are under construction.

The Koppers-Totzek gasification process operates in concurrent flow under atmospheric pressure and can be employed without limitation for any solid fuel.

Fig. 2.4 The next figure shows the principal mode of operation of this process.

By adjustable screw conveyors, the coal dust is fed into the gasifier. The gasification agents oxygen and steam are admixed with the coal dust immediately before its entry into the gasifier. In less than one second, the coal is gasified at temperatures of approximately 2 000°C.

The hot raw gas flows from the gasifier through waste heat boilers into the washer coolers in which the gas is cooled and any entrained gasification residues are washed out. After final purification, the gas can be further treated for the most diversified purposes.

Manufacturing Costs of Some Products

To give you an idea of the investment and the production costs, I will show you some data in the following. The costs have been determined on the basis of prices prevailing in the Federal Republic of Germany in mid-1979.

Fig. 2.5 For plants to produce ammonia, methanol and sponge iron, the following picture shows investments as curves plotted vs. output.

The investments refer to complete self-sufficient plant complexes with the necessary off-sites.

Fig. 2.6 In the next two pictures, calculation parameters
Fig. 2.7 are stated. These parameters have been used for
calculation of the manufacturing costs of the
individual products. In the next figure these
Fig. 2.8 costs are plotted vs. the thermal price of coal.

Comparing the manufacturing costs of various products made from coal, natural gas and mineral oil, it can be found out that costs are generally higher when using coal.

Concrete comparison figures are available for the
production of ammonia. This comparison is illustra-
Fig. 2.9 ted in the graph shown as the next figure. If the
thermal price of naphtha is three times, and that
of heavy fuel oil about 1.8 times the thermal
price of coal, manufacturing costs are at the same
level. This price relation applies similarly also
to the manufacture of other products such as
methanol, hydrogen and sponge iron.

New Coal Gasification Technologies

The realisation of the next gasifier generation is moved on intensively in many countries. The main aims for this development are:

- Suitability for the gasification of all solid fuels
- Reduction of environmental problems
- Lowering of specific investment costs

- Increase in the yield of useful gas
- Improvement in overall economy.

Ways to reach these goals are different with the various development projects. Which system will, in the end, lead to an optimum process combination, cannot be finally judged now. All processes of the new generation are at present at the test stage in order to obtain the basic data required for planning, constructing and operating industrial-scale production plants.

With respect to the time schedules of the projects to develop new gasification technologies. I can only give you details for the Shell-Koppers pressure gasification process. It is planned that by 1986, sufficient experience should be available by operating a plant for 1 000 t coal input per day, to offer the new gasification technique with all the guarantees as are required for present day coal gasification projects.

Summarising, I would like to say the following about coal gasification:

1. Indonesian coal is very well suited for entrained-bed gasification, without any restrictions.
2. The gas produced can be used for a variety of purposes.
3. The processes now available for the gasification of coal offer a mature and modern technology which can be verified by numerous reference plants.

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