

High Temperature Winkler (HTW) Coal Gasification

A Fully Developed Process For Methanol and Electricity Production

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1 Introduction

In the mid-70s, Rheinbraun embarked on the development of the High Temperature Winkler (HTW) coal gasification process. The HTW process constitutes a further development of the Winkler fluidised-bed gasification originally working at ambient pressure. The development work was first focused on the production of chemical synthesis gases from lignite. In the mid-80s, the requirement of utilising the process in IGCC plants for efficient and favourably priced electricity production as well constituted another important target.

For more than 20 years, Rheinbraun has intensively dealt with this task and developed, for both applications, an economically efficient and environmentally kind gasification process up to its industrial-scale maturity. The development costs amounted to nearly DM 1 bill. This contribution is to elaborate on today's development state of the HTW process, with emphasis being placed on the progress achieved in the last few years.

2 Development State of the HTW Process

After having completed the investigations in a pilot plant, Rheinbraun started in early 1986 the HTW demonstration plant at Berrenrath near Cologne (Fig. 1) in order to demonstrate the industrial-scale maturity of the process.

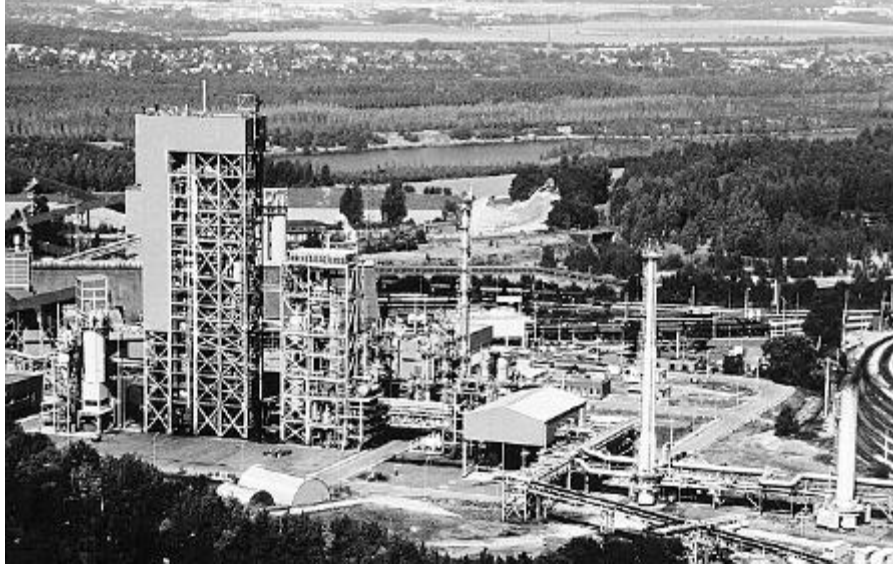
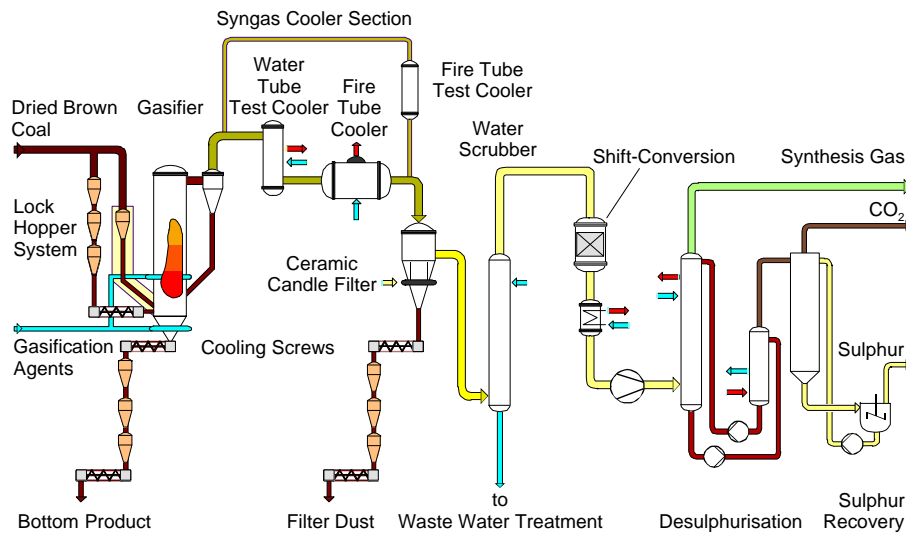


Fig. 1:
HTW demonstration plant at Berrenrath.

Fig. 2 shows the flow sheet of the plant where at a pressure of 10 bar, 25 t/h of dry lignite served to produce an hourly amount of 34,000 m³(STP) of synthesis gas, with oxygen and steam being added as gasification agents. This corresponds to a thermal capacity of 140 MW. The diameter of the fluidised-bed gasifier amounts to 2.75 m.



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Fig. 2: Flow sheet of the HTW demonstration plant

The 12 years of plant operation were accompanied by intensive measuring programmes and continuous optimising efforts. In the first few years, the focus was on attaining a high availability and optimising all components. In the last four years, funds of more than DM 100 mill. were raised to carry out--once again--an R & D programme that, with regard to the use of the process for electricity production in IGCC plants, was aimed at the following:

- improvement and simplification in order to cut the investment and operating costs, and
- increase in the electricity producing efficiency.

2.1 Availability

During the first three operating years, the HTW demonstration plant worked as a test plant. The synthesis gas produced was used in a methanol synthesis plant first also with a view to R & D criteria. Since 1989, the HTW demonstration plant had been integrated into the commercial-scale production network of DEA's methanol synthesis plant. DEA is a major German methanol producer and a company within the RWE group. The availability reached in the subsequent years (according to the criteria of the German association of large power plant operators (German abbreviation: 'VGB')) is shown in Fig. 3.

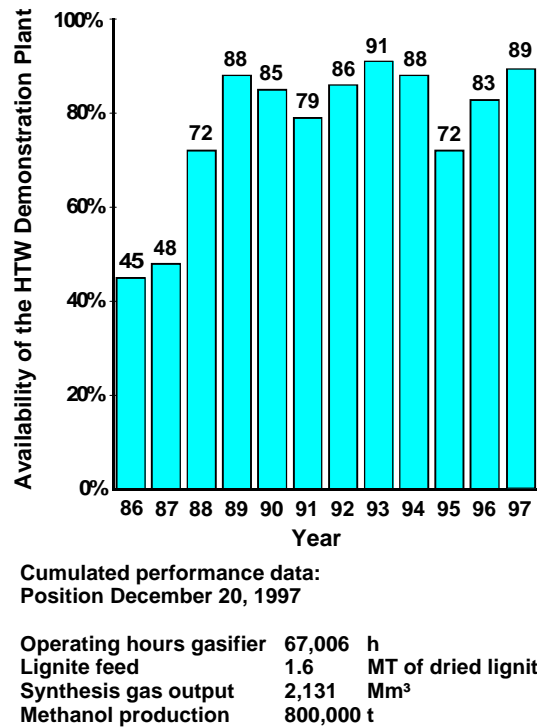


Fig. 3:

Availability of the HTW demonstration plant

The availability averaged 84 % in the last 10 operating years. This result was achieved without the otherwise usual redundancies of a production plant or a power plant. The availability of the German lignite-fired power plant units of the 600 MW class is of a comparable magnitude. In view of this result, the HTW demonstration plant succeeded in reaching its most important target in terms of operation.

2.2 Feedstock

In order to demonstrate the further application potential of the HTW process in industrial-scale operation as well, different types of feedstock, as for example plastics waste, biomasses, household refuse and sewage sludge, were used and recycled in the gasifier of the HTW demonstration plant together with dry lignite in the last few years. The maximum hourly admixing rate was 10 tonnes, that is up to 50 % of the energy input. Under these conditions, it was also possible to successfully operate solids feeding, gasification and gas cleaning. The experience gained in this field permits the design of plants that are exclusively supplied with waste materials. Thus, the HTW process is capable of efficiently converting a broad range of

feedstock into fuel or synthesis gas. The Uhde company markets the HTW process for gasification of waste materials worldwide under the name of the Uhde PreCon process.

2.3 Coal Feeding

Coal feeding by means of a lock hopper system and screw conveyors--a system that has been working very successfully for many years--has a substantial influence on the height of the gasifier structure and calls for a high-energy-requiring, pneumatic conveying system of the feedstock.

With the object of reducing the investment and operating costs thus caused, Rheinbraun had tested a new coal feeding system at the HTW demonstration plant since 1996. Fig. 4 shows a simplified diagram of this system.

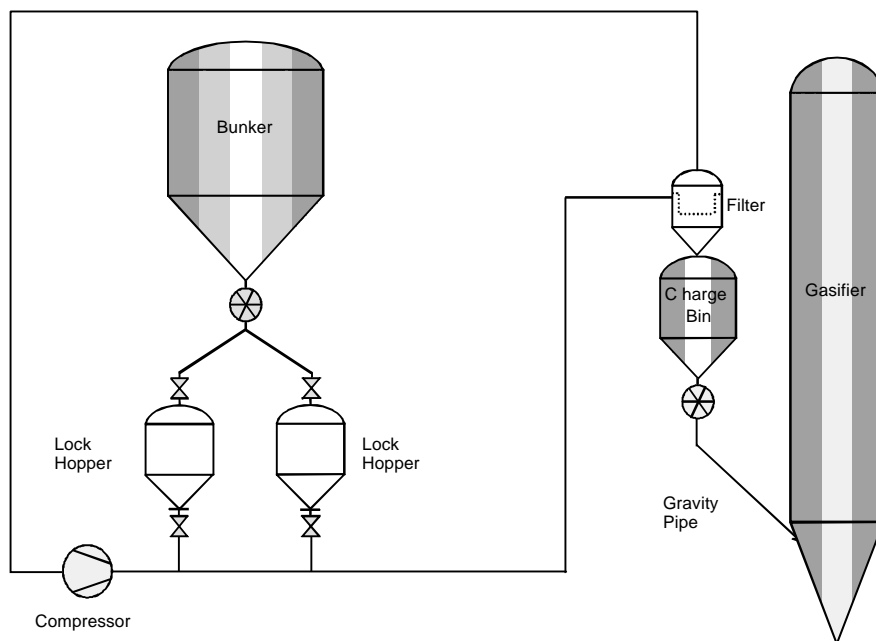


Fig. 4:
Improved coal feeding system

In this concept, the coal lock hoppers are arranged below the storage bin. After pressurising, the material is pneumatically conveyed under process pressure from the lock hoppers to the coal receiving bin installed at the gasifier. The conveying gas is filtered and returned by a

compressor for another pneumatic conveying cycle. From the receiving bin, the dosed coal quantities drop through a star feeder via a gravity pipe directly into the fluidised bed of the gasifier. This configuration has the additional advantage of doing without the originally used coal feeding screws.

The new system worked without any problems during more than 6,000 hours. The following improvements were demonstrated:

- The energy consumption and thus the operating costs for pneumatic coal conveying were reduced by more than one order of magnitude to approximately 7 %.
- Doing without the feeding screws permits an improvement in the availability of the overall plant.
- For follow-up plants, the gasifier structure can be reduced from 80 m to about 50 m.

2.4 Gasification

In the last 10 years, the development work on HTW gasification centred around the following:

- Rise in the gasification pressure to the required gas turbine inlet pressures for IGCC plants without intermediate compression,
- increase in the specific gasifier output in order to meet the fuel gas requirements of large, modern gas turbines by one line and thus at reasonable costs,
- development of a process that--depending upon its field of application--can be operated with air or oxygen/steam as gasification agent.

In addition to the operation of the Berrenrath demonstration plant, the years from 1989 to 1992 saw intensive investigations carried out in a pilot plant at Wesseling (see Fig. 5).



Fig. 5:
Pilot plant at Wesseling

During a total of 10,000 operating hours, at pressures of up to 25 bar and an hourly coal throughput of up to 7.0 tonnes, gasification was tested with both oxygen/steam and air as gasification agents.

The expected increase in the gasifier's capacity was achieved for gasification by means of O_2 /steam as well as air. Fig. 6 shows that during the development activities the specific coal throughput in the case of gasification by means of O_2 /steam was stepped up to 22 $t/m^2 \cdot h$ (related to the clear cross section of the gasifier).

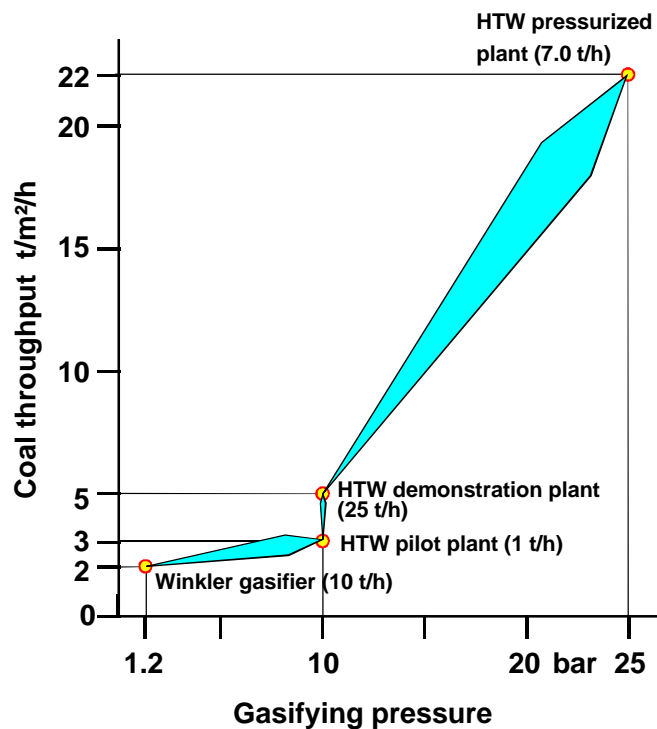


Fig. 6:

Development of the specific output of the HTW gasifier

On the basis of the performance data for the gasifier, such as residence time, superficial gas velocity and fluidised-bed volume, which were demonstrated in the test and demonstration plants, the HTW gasifiers of today are available for the following capacity units:

Electricity production in IGCC plants:

600 MW (gross) in the case of gasification by means of O_2 /steam

400 MW (gross) in the case of gasification by means of air.

Synthesis gas/methanol production:

2,400 tonnes of methanol per day from 260,000 m³ (STP)/h of synthesis gas.

2.5 Raw Gas Cooling

Raw gas cooling is a key component of all gasification processes and concepts. Together with the solids content in the raw gas and the corrosive gas components, the high inlet temperatures represent very exacting operating conditions. Therefore, the reliability of this very component is a decisive prerequisite for the availability of the overall plant.

In the HTW demonstration plant, the raw gas, before entering the gas cleaning unit, is first cooled from approximately 900 °C to approximately 300 °C in a horizontal fire tube cooler, with saturated steam being produced. Despite occasional cakings in the inlet ferrules of the cooler pipes that necessitated shutdowns of the plant, availabilities of approximately 85 % were recorded.

Since 1994, two alternative cooler concepts were tested in order to determine their potential and their suitability for being employed in the HTW process.

2.5.1 Water Tube Cooler

In 1994, Rheinbraun started testing a water tube cooler, with in particular the fouling behaviour being studied thoroughly. The water tube cooler allows superheated steam to be produced and thus to make the overall process of an IGCC plant especially efficient.

Fig. 2 shows the integration of the water tube cooler into the process of the HTW demonstration plant. The cooler is flown through by the total raw gas amount of approximately 50,000 m³(STP)/h, which is cooled in this process from 900 °C to approximately 750 °C. The dust content of the gas amounts to some 30 g/m³(STP). The heat thus generated serves to produce saturated steam with a pressure of 180 bar (360 °C) and superheated steam with a temperature of 580 °C (35 bar). The diagram of Fig. 7 shows the design of the cooler.

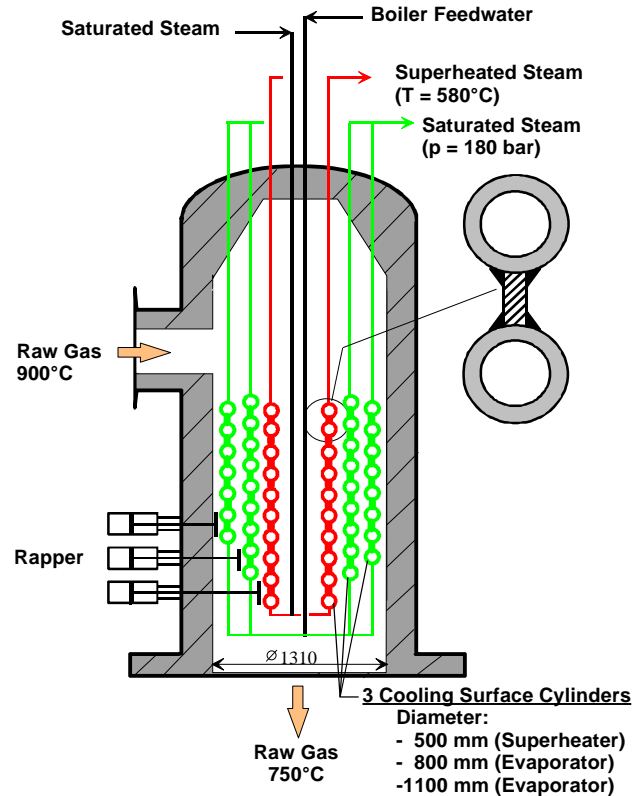


Fig. 7

Water tube cooler of the HTW demonstration plant

Until late 1997, the component was tested with several modifications for more than 23,000 h. Here, the following results were obtained:

- The water tube cooler was available without any restriction. The foulings detected did not impair operation. This also applied to very narrow lane spacings of 50 mm which were studied in respect of a compact version to reduce the investment cost.
- When the superficial velocity of the raw gas is increased from 6 m/s to 10 m/s, the dust deposits on the tubes are so small that the heat transfer is only impaired to a justifiable extent.
- The installed mechanical cleaning equipment did not cause any decrease in fouling.

- No considerable erosion was detected at the superficial gas velocities studied. As expected, the evaporator did not show any corrosion either. As early as today, operating times of more than 100,000 h can be derived from the corrosion behaviour of the superheater materials.

2.5.2 Fire Tube Cooler

In early 1997, complementary investigations into the fire-tube technology were carried out in the HTW demonstration plant. The object was to test whether the fouling of the fire tube cooler, which in cost terms is more favourable than a water tube cooler, could be reduced by means of larger tube diameters, cooled tube inlets and a stepped-up superficial gas velocity.

The different tube types were tested in a test cooler, which according to Fig. 2 was operated in a bypass of the main gas flow. The investigations at different superficial gas velocities yielded the following results:

- With sufficiently large tube diameters, caking can be avoided. This is true for both tubes with cooled tube inlet and tubes with a simple inlet ferrule.
- High superficial gas velocities aggravate fouling and erosion. Therefore, the velocity should be limited to approximately 20 m/s.

2.5.3 Summary of the Investigations into Raw Gas Cooling

Both concepts--namely, water tube cooler and fire tube cooler--allowed good results to be achieved. The technology to be employed in the future will depend on the process engineering requirements:

- High pressures and supercritical steam conditions in the field of IGCC application suggest the use of the water tube cooler. The question of whether in addition to evaporation, steam superheating in the raw gas cooler is economical as well, has to be critically examined in view of the high investment cost. For the presently available gas

turbines with high exit temperatures, steam superheating in the heat recovery steam generator is more favourable.

- In the case of steam pressures of < 150 bar and for the medium-pressure section of the raw gas cooler, the fire tube technology with sufficiently large tubes is to be recommended for cost reasons.

2.6 Hot Gas Filter

Hot gas filtration constitutes an essential element of modern and efficient gasification technologies. Hot gas filtration avoids the disadvantages of wet dedusting (solids deposits, sludge handling) and leads to a concept simplification and higher efficiencies. What is more, it is the prerequisite for dry desulphurisation at temperatures of $> 250\text{ }^{\circ}\text{C}$ which results in further efficiency advantages. Since 1988, Rheinbraun had therefore intensively been dealing with the development of the hot gas filter technology for the HTW process and developed this process stage to its industrial-scale maturity. The operation of two smaller filter units with ceramic filter candles of the Schumacher company already demonstrated a very good filtering performance. Fractures of the filter candles the cause of which was assumed to be the suspended arrangement of the components (tube-sheet design) led to a modified design with vertical filter candles, with the same filter material being used. This principle was tested in close co-operation with Lurgi Lentjes Babcock (LLB) who markets this filter principle.

According to this concept, a two-stage hot gas filter was installed in 1993 with 578 filter candles in the HTW demonstration plant to filter the total raw gas amount at a temperature of $270\text{ }^{\circ}\text{C}$ (see Fig. 2). During approximately 8,000 operating hours, this concept with vertical filter candles proved very successful.

In order to avoid the use of several parallel filters or very large filter diameters in the case of a very high gas throughput, as it is required in the IGCC plant, the filter concept was further developed once again. Thanks to internals it is possible to prevent the separated dust from depositing again in the deeper stages. This allows several stages to be arranged one on top of the other, like modules. In order to test this concept, the hot gas filter of the HTW demonstration plant was modified to include three instead of two stages and a total of 450 filter candles. Fig. 8 shows this principle which successfully completed the filter development activities.

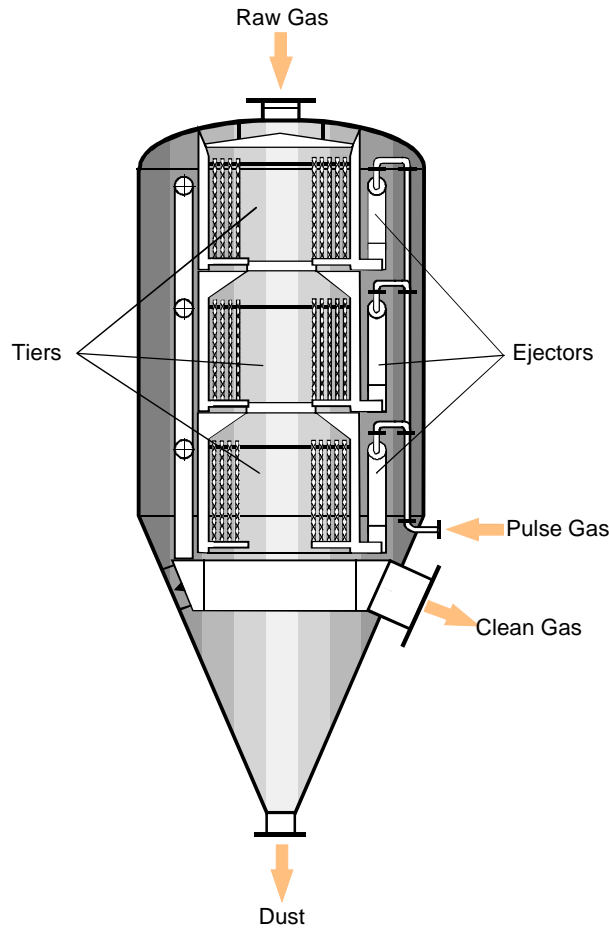


Fig. 8

Three-stage hot gas filter of the HTW demonstration plant

The three-stage filter worked for a total of approximately 7,500 h. The filter candles, which were taken from the preceding two-stage filter operating time, reached a total operating period of 15,500 h. The findings thus obtained can be summed up as follows:

- The hot gas filter technology can be employed on an industrial scale; it has proved successful in continuous operation. It permits stable and reliable operation with very small clean gas dust contents ($< 2 \text{ mg/m}^3$ (STP)) and a high availability. Even after an operating time of 15,500 h, the filter candles are in proper service without any restriction.
- Alkalis and heavy metals are almost completely adsorbed by the dust and thus separated together with the dust in the hot gas filter and discharged from the process. This

is largely true for the halogens as well. For the halogen portions that are not retained, only a simple scrubbing stage as final chloride scrubber is still required.

- During five operating years, only four filtering element failures with 41 broken candles occurred. The causes were found and virtually excluded for the future by means of technical improvements.

2.7 Desulphurisation

The different requirements to be met by the desulphurisation degree during the synthesis gas and fuel gas production led to the testing of different processes.

2.7.1 Synthesis Gas Production

The synthesis gas of the HTW demonstration plant was supplied through a 20 km-long pipeline to a methanol synthesis plant. In order to avoid deactivation of the synthesis catalyst, the H₂S content measured in the HTW demonstration plant was lowered in a physical Rectisol scrubbing unit of the Linde company to values of < 0.1 ppm (vol). In this process, most of CO₂ was also separated from the gas according to the requirements made by methanol synthesis. This process proved to be very reliable during the total operating time. No serious failures or impairments occurred in the 12 operating years.

2.7.2 Fuel Gas Production

In the case of fuel gas production to be used in an IGCC plant, the requirements to be met by the gas in terms of the sulphur content are smaller. In order to obtain a reduction in SO₂ emissions similar to that recorded by conventional power plants with flue gas desulphurisation systems, the H₂S amount in the fuel gas has to be lowered to < 10 ppm (vol). For energetic reasons, the CO₂ should remain in the fuel gas. The selection of the scrubbing processes and scrubbing liquors employed for this application has primarily to be made from the economic viewpoint, with account being surely taken of the development state of the processes as well. In the demonstration plant, both wet and dry processes were tested.

Wet Desulphurisation

In 1995, a pilot scrubbing unit started operating that consisted of a scrubbing column with regeneration section and was capable of cleaning 3,000 m³(STP)/h of gas in a bypass. Different H₂S-selective scrubbing liquors were investigated. Two chemically acting scrubbing liquors were tested in particular with regard to gasification by means of air. For gasification by means of oxygen/steam, a physical scrubbing liquor was tested. All scrubbing liquors showed a satisfactory cleaning effect. Chemical scrubbing seems to be more attractive in economical terms. For future industrial-scale applications, all necessary design data are available. The results permit application to industrial-scale plants. And the manufacturers are willing to furnish guarantees.

Dry Desulphurisation

If this process is applied in an IGCC plant, it would be advantageous for energetic reasons to employ dry cleaning of the raw gas at temperatures of > 250 °C. Aiming at this goal, Rheinbraun tested a process for partial catalytic oxidation. In this process, an oxygen-containing gas that converts the sulphides into elemental sulphur is added to the coal gas downstream of raw gas cooling and upstream of hot gas filtration, namely at a temperature of approximately 270 °C. This sulphur is separated together with the dust of the raw gas in the hot gas filter. The tests carried out in the HTW demonstration plant have shown that H₂S is completely and COS partly converted. Although the remaining COS content causes somewhat higher SO₂ emissions from the power plant than in the case of wet desulphurisation, the measured values still fall considerably below the permissible emission limit values in Germany. In the dry desulphurisation process, ammonia is not removed from the gas, as in the case of wet desulphurisation. In order to comply with the emission limit values for nitrogen oxide, NO_x removal using the SCR process in the heat recovery steam generator is therefore to be planned in Germany.

Within the scope of a study it was possible to show that dry desulphurisation results in an improved efficiency of approximately 3 percentage points and noticeable advantages with regard to the investment cost as well. Before the industrial-scale implementation of this

desulphurisation concept, however, a more detailed development and qualification programme is still to be carried out.

3 HTW Plant Concepts

On the basis of the operating results and the development work of more than 10 years, plant concepts for the optimised application of the HTW gasification process in IGCC plants and for the production of synthesis gas were elaborated. Fig. 9 shows two basic diagrams.

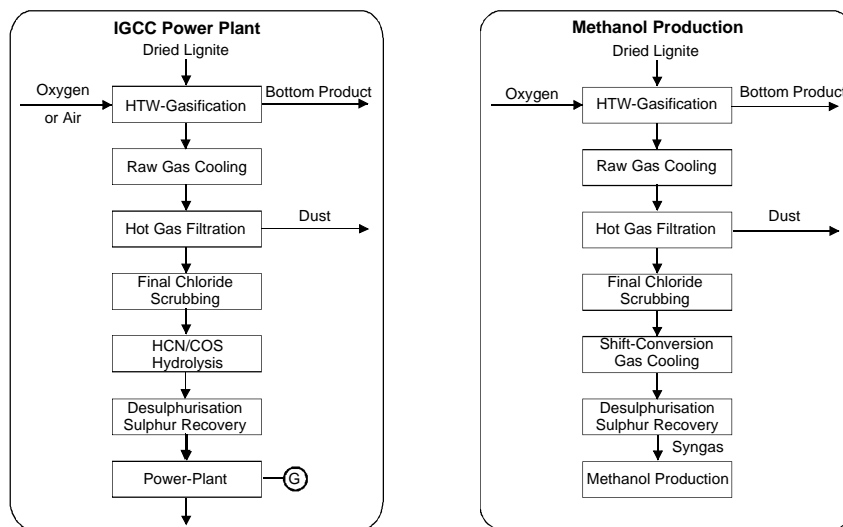


Fig. 9

Use of the HTW gasification for advanced processes

If these concepts are employed in IGCC plants, the process pressure of the gasifier amounts to 30 bar. For coal gasification, O_2 /steam or air can be used. Both variants have been subjected to comprehensive tests. The process is first based on wet desulphurisation of the coal gas before it enters the gas turbine since the partial catalytic oxidation has not yet proved its efficacy on a demonstration scale. If a modern gas turbine with an inlet temperature of 1,190 °C (ISO) is used, the efficiency of the plant will be more than 50 %.

For synthesis gas production, the process pressure in the gasifier amounts to 30 bar as well. The gasification agent employed is O_2 /steam. Apart from the higher process pressure, the process course is largely identical with that of the well-tested HTW demonstration plant. As is

the case with fuel gas production too, the availabilities and process optimisations demonstrated permit reliable production with high availabilities.

The use of the HTW process in commercial plants is determined by the future market conditions. In view of the present world market price of methanol, its production from lignite or other solid fuels is not economical. This would require a price increase of more than 30 % which is not foreseeable at present. With regard to the electricity producing costs, arising from conventional electricity producing processes the circumstances are more favourable. Today, however, there is not yet any indication that a German utility will decide to bear the costs and accept the risks that are connected with an IGCC demonstration plant. In this context, it is also the changing electricity market with the deregulation meanwhile established by law in Germany that is playing a significant role. At present, the public utilities are generally taking a wait-and-see attitude towards investment in new plant and equipment.

4 Final Remarks

After 67,000 operating hours, the HTW demonstration plant was shut down in late 1997 since all research and development activities regarding the HTW process have been completed and an economically viable operation is not possible. A total of approximately 1.6 mill. tonnes of dry lignite was processed into synthesis gas which served to produce 800,000 tonnes of methanol.

After 20 years of intensive testing, the development of the HTW process was finished. The goal aimed at, namely to offer a well-tested and environmentally kind process for fuel gas and synthesis gas production, was reached.