Section 22

COMBINED-CYCLE WITH INTEGRATED COAL GASIFICATION VEW-COAL CONVERSION PROCESS

K. Weinzierl

Vereinigte Elektrizitätswerke Westfalen AG
Rheinlanddamm 24
D-4600 Dortmund 1, Federal Republic of Germany

ABSTRACT

For current generation of hard coal the technology of a combined-cycle process with integrated coal gasification is developped. Both parts of the total process - coal gasification with gas cleaning and the combined-cycle process - are tested in parallel.

A 10 t/h - Prototype Plant characterized by a partial gasification of coal and some new methods of gas cleaning will begin its operation early in 1985. For testing the other part of the complete process a 750 MW combined-cycle plant with a natural gas-fired gas turbine and a supplementary coal-fired boiler is in operation since 1984. This technology offers a significant increase of efficiency and favourable aspects in pollution control. Construction and operation period of the prototype plant is sponsored by the Federal Minister of Research and Technology.

COMBINED CYCLE PROCESS WITH INTEGRATED COAL GASIFICATION
VEW-COAL CONVERSION PROCESS

Author K. Weinzierl

1. INTRODUCTION

The current generation from German hard coal is characterized by two points of view:

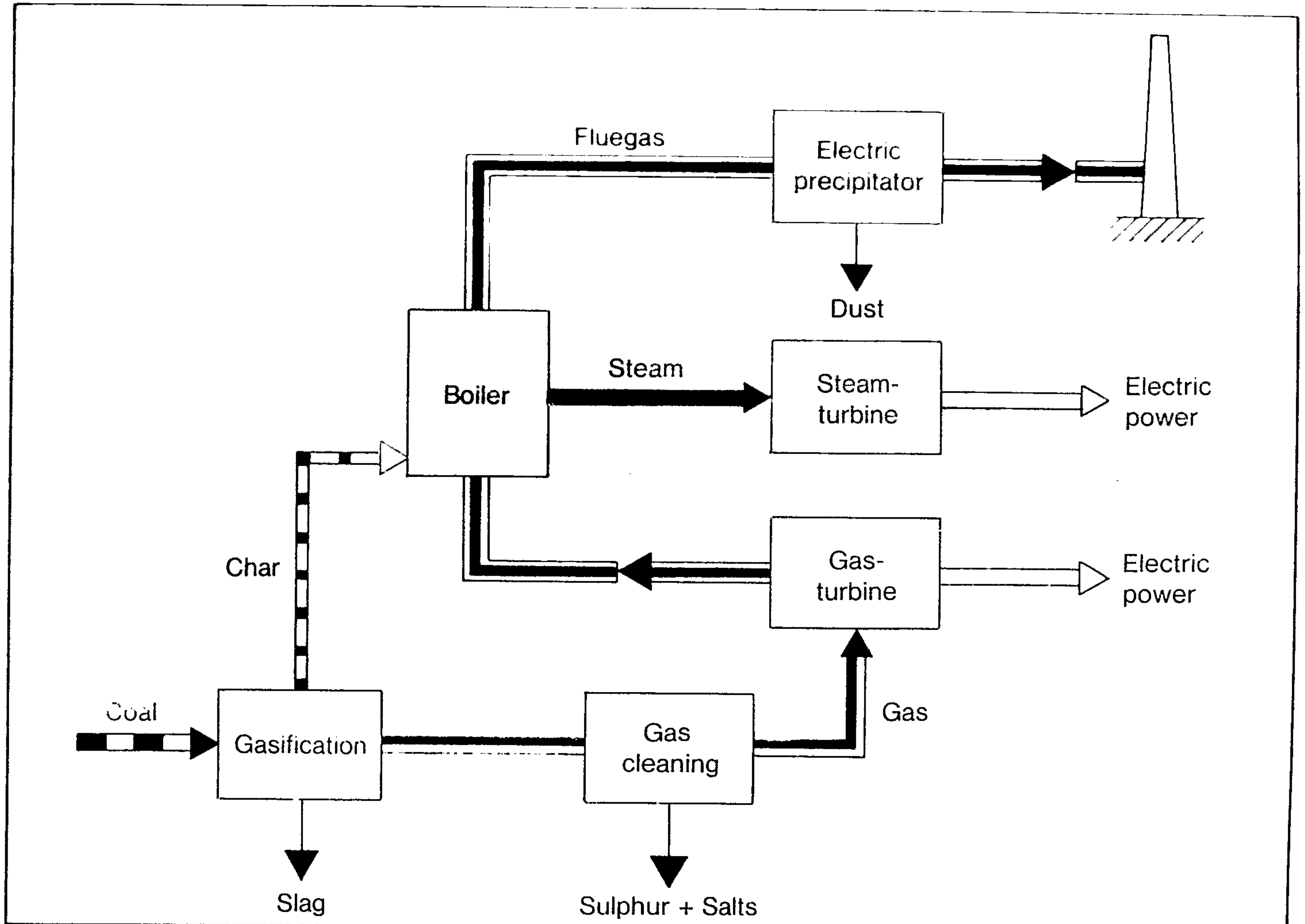
1. High costs for German hard coal due to deep cast mining;
2. conditions for pollution control.

For the electric-power production the use of large amounts of coal - approx. up to 45 Mio t/a -, which is laid down in the contract between coal mines and utilities, leads to the question how an improved efficiency can be achieved under the mentioned conditions.

2. BASIC CONSIDERATIONS

Besides pollution control the efficiency of power plants is of great interest. As we have made extensive experiences with the gas-fired combined-cycle process a design has to be developped, which offers the advantage of combined-cycle plants for the current generation from coal, too. According to the VEW-Coal Conversion Process, which is specified as follows, a partial gasification of coal is connected to a combined-cycle process. The basic principle of the coal-combined-cycle process with integrated coal gasification (Fig. 1) is planned for the use of gas in the gas turbine after a partial gasification and gas cleaning. The remaining char is fired in the furnace of the boiler. For the gas generation from coal a partial gasification is chosen because in consideration of all demands it offers some essential advantages for the application in power plants.

The **entrained gasification** shows some fundamental advantages according to the operation with a variety of coal qualities regardless of their caking qualities and their granularity, the favourable load behaviour and the production



Combined cycle process with integrated coal gasification

Figure 1

of tar- and oil-free gas. The high operating temperatures, which lead to strains on the brickwork of the gasifier, as well as the great part of waste heat are disadvantageous. The high operating temperatures can be achieved by using oxygen as well as air, but the air-blown operation leads to a large dilution of the produced gas by nitrogen and therefore also to an essential reduction of the calorific value. If a total carbon utilization is required, a poor gas is produced due to the connection of carbon utilization, residual time and operating temperature in the gasifier, which does not allow a normal combustion.

If the operation of an expensive oxygen-plant with bad load behaviour should be avoided in power plants for middle or upper load, the gasification has to be limited to a partial gasification of coal. On principle there are two ways available; on the one hand a complete carbon conversion by using oxygen, and on the other hand a partial gasification by using air. In the VEW-Coal Conversion Process the second way, that means a partial gasification in an entrained air-blown gasifier has been chosen. The process of gas production as well as the gas cleaning system has been particularly developped for the integration in power plants. The production of synthesis gas is not object to this process but only the application in power plants to improve the efficiency and to reduce the whole range of emissions.

3. PROCEDURE FOR THE INVESTIGATION

Two parts are necessary to realize the construction of power plants according to the described principle. The first part consists in the coal gasification and gas cleaning, the second part covers the combined-cycle process, in which the boiler is fired with char dust produced in the gasifier by utilizing the remaining oxygen in the exhaust gas from the gas turbine. Until the end of the 70's a prototype plant with a capacity of 1 t/h had been run to achieve extensive experiences in the range of a partial gasification. According to the results gained from this test plant the construction of the 10 t/h-Prototype Plant followed, which now starts its operation. At the same location - at the VEW-Power Plant "Gersteinwerk" - a 750 MW combined-cycle unit was constructed (named Power Plant Werne). In this power plant the boiler is fired by coal and the gas turbine is fired by natural gas. The process design as well as the technical demands correspond to the combined-cycle process, as it is required in connection with a partial coal gasification according to the VEW-Process.

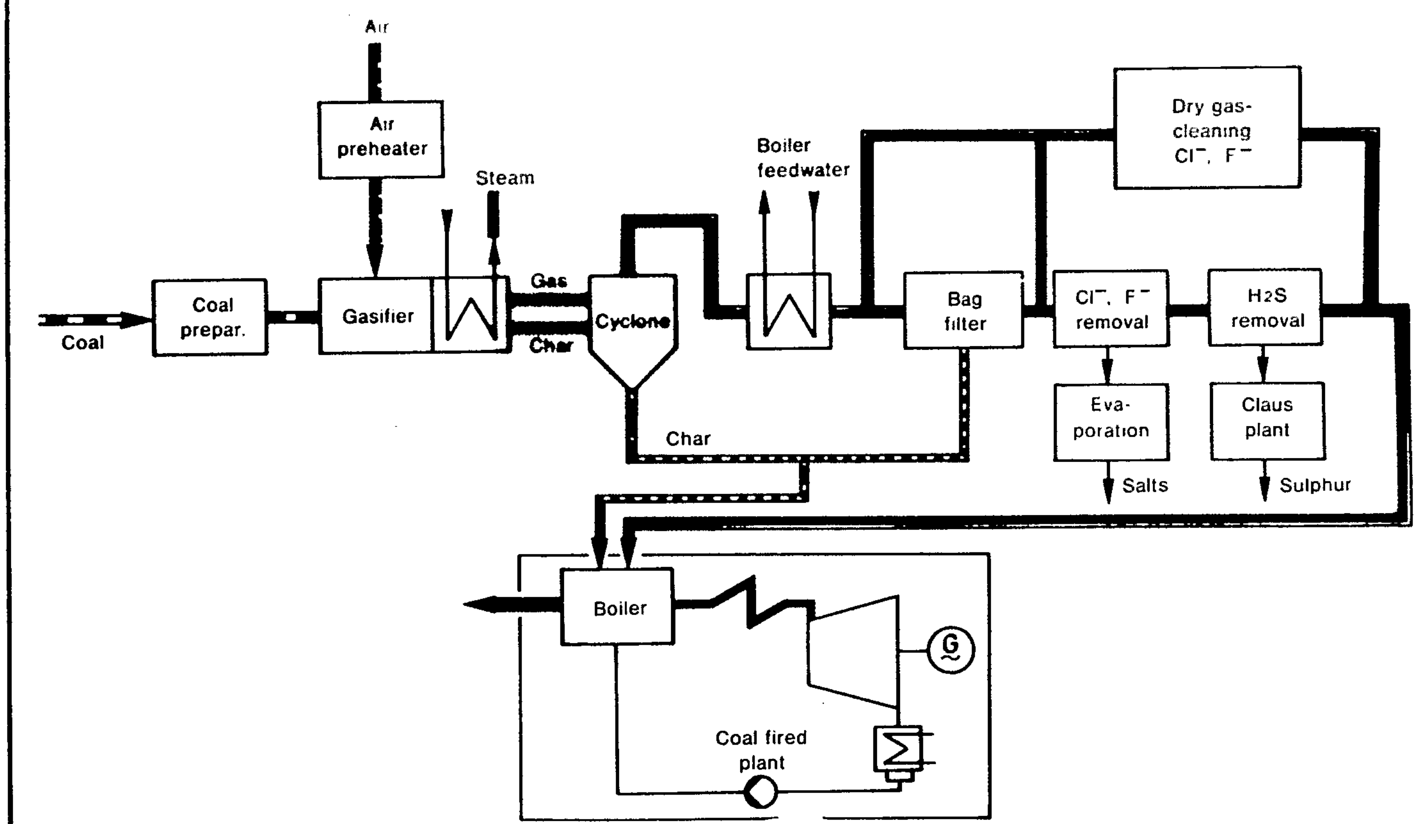
This unit started its scheduled operation at the end of 1984. So two parts of a new technology are tested in the same location.

A direct connection of both plants would not be efficient, because it is a question of different capacity. Furtheron the problems can essentially be seen in the combustion of a solid fuel by using the exhaust gas of the gas turbine as oxidizing agent, which can sufficiently be tested in this combined-cycle plant. With the next step it will be possible to connect plants of both types to a coal combined-cycle process with integrated coal gasification. This procedure allows to reduce costs as well as time of the development and the risk for scale up of this technology.

4. 10 t/h - PROTOTYPE PLANT

The basic arrangement of the prototype plant is depicted in Figure 2. First of all the coal is finely ground (smaller than 90 µm), after this it is fed into the entrained gasifier by air with a feeding system. As the produced gas/char-mixture has a temperature of appr. 1 400 °C the waste heat recovery follows to cool it down to a temperature smaller than the ash softening point. After separating most of the solid matter in a cyclone another waste heat recovery follows and subsequently the separation of the fine dust particles is carried out in a bag filter. This makes treating the gas in the gas cleaning system. At the first step - the prewashing - chlorides and fluorides are separated.

This new design of a cleaning process takes place in such a way that the produced salts are separated in a high concentrated solvent and then fed in an evaporator, which also belongs to the prototype plant. The separation of chlorides and fluorides is the basic condition for the next step of the gas cleaning, where sulphur compounds, particularly hydrogen sulphide (H_2S), but also COS and CS_2 are removed. Subsequently the produced sour gas is converted in the Claus process into elemental highly pure sulphur. This highly pure sulphur is supplied to produce sulphuric acid. As the produced gas can only be cooled down to 200 - 250 °C in the waste heat boiler because of removing and hardening of some gaseous compounds, a great part of sensible heat cannot be recovered. Based on this experience a dry gas cleaning was realized for a part of the total gas stream, to remove chlorine and fluorine in a dry manner at raised temperatures of 300 - 350 °C. Aim of this development is to burn the gas after the treatment in the dry gas cleaning in a gas turbine and to re-



VEW – Coal Conversion Process 10 t/h-plant

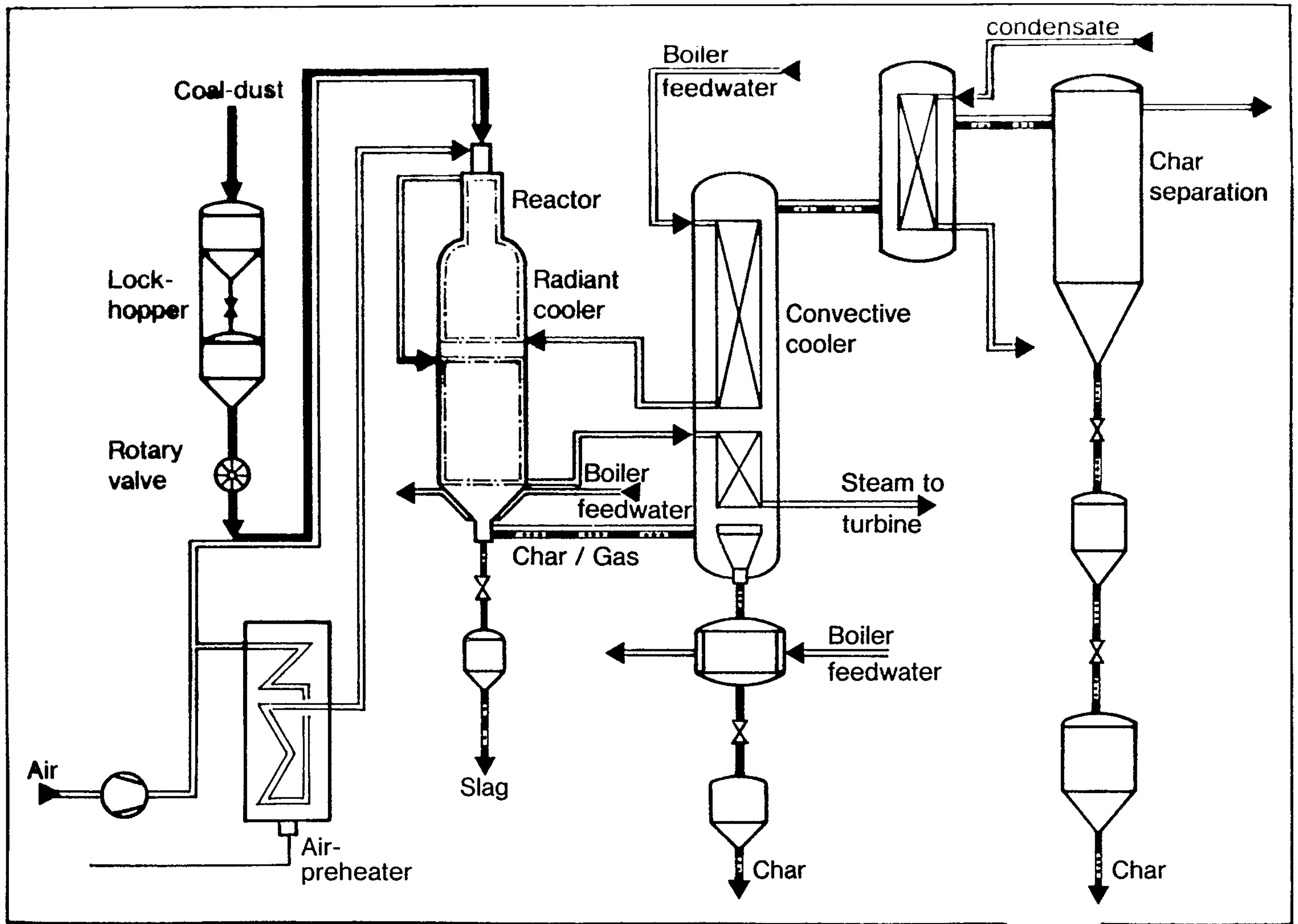
Figure 2

nounce the elimination of sulphur compounds. For sulphur removal a flue gas desulphurisation plant will be provided. The prototype plant is connected to an available coal-fired unit with an electric capacity of appr. 100 MW. The produced gas and char as well as waste heat steam are used for current generation in this coal fired plant based on a conventional steam turbine process and nearly produce 30 MW electrical power.

The fundamental principles of the construction of the gas generation plant can be seen in Figure 3. With lock hoppers and a rotary valve the coal is fed by air into the pressurized gasifier (25 bar). According to experiences gained from earlier tests it is possible to attain a high metering precision, but in this process of partial gasification it is not necessary to reach high exactness. As only a part of coal is gasified, the conversion rate may vary in a certain limit due to an inaccuracy in metering by which the results of the process are not affected. In a special burner at the head of the gasifier a partial combustion and gasification takes place by using highly preheated process air at a temperature of 600 °C. The brickwork of the gasifier is cooled a little by tubes, but its construction cannot be compared with the principle of molten ash type boilers.

The gas/char-mixture produced is cooled down in the connected radiant cooler to a temperature smaller than the ash softening point at appr. 700 °C. At the end of the radiant cooler coarse slag particles are eliminated in a stream deviation. Though the main part of ash still remains in the char, during the partial gasification of coal, the elimination of slag particles out of the reaction chamber cannot be avoided. Slag drops may fall from the walls of the gasifier and must be eliminated in a deviation at the end of the radiant cooler so that the bundles of the connected exchangers cannot be clogged.

The main part of the char is eliminated in a cyclone before the gas enters the heat exchangers, which are streamed through upwardly. At first highly superheated steam in a range of 180 bar and 535 °C is produced in the waste heat system, which is directly fed into the turbine of the power plant unit. Usually saturated steam was produced in the waste heat section of a coal gasification process. It is necessary to generate high-valued steam from the high amount of waste heat in the process to attain a favourable total efficiency for current generation. The heat exchangers, which are partly used for super-



KUV – Gasification plant

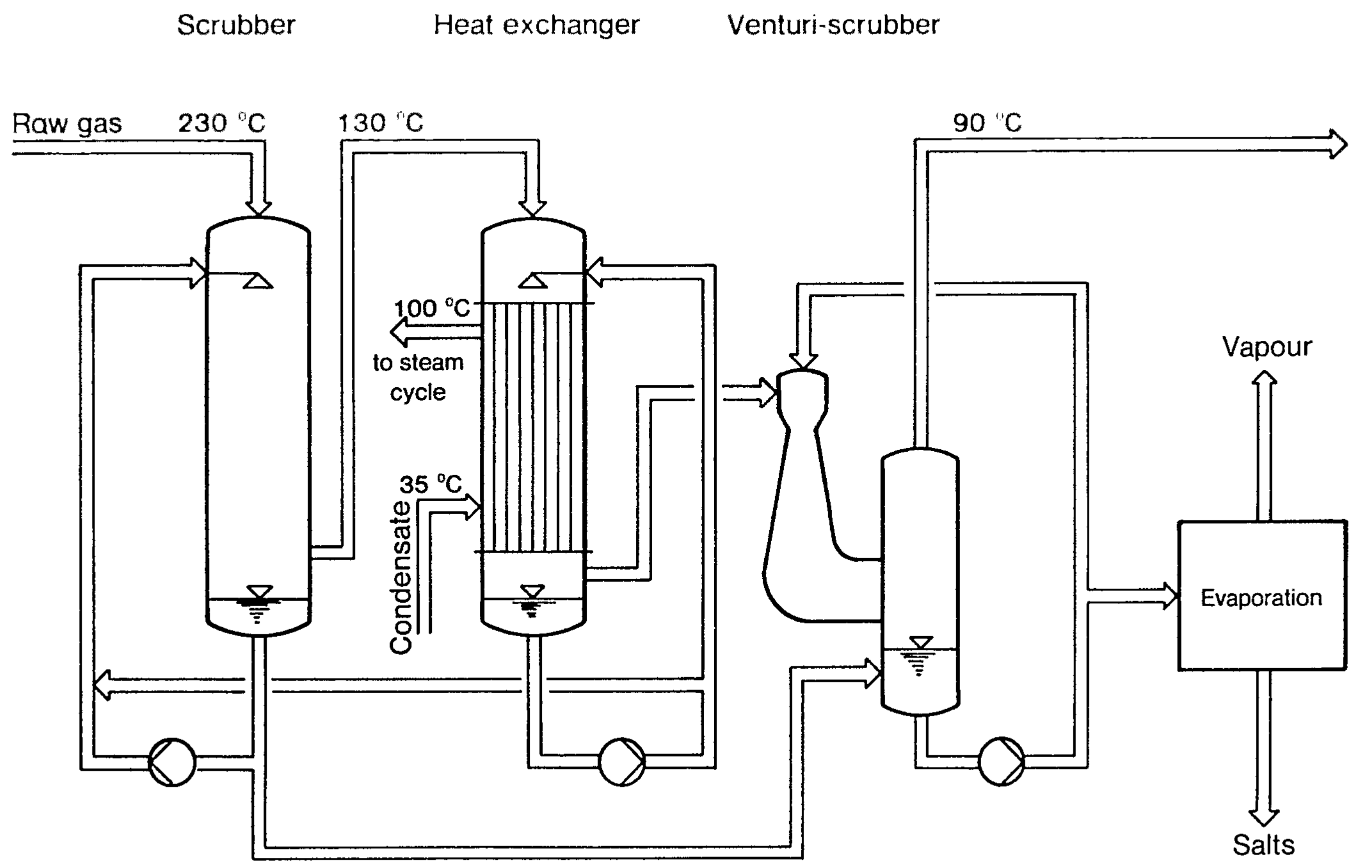
Figure 3

heating and evaporation and partly for pre-heating of boiler feed water, cool down the gas/char-mixture to temperatures of 200 to 250 °C. After removal of the fine dust by a bag filter the gas has achieved a remaining dust content of 5 mg/m^3 (s.c.).

The coal used in German power plants almost contains clorine with 0,2 to 0,3 weight %. The principle of the gas cleaning is essentially determined by the aspect of the eliminiation of chlorine und fluorine to a low degree. As the gas is usually scrubbed with a large quantitiy of water in such a way that the eliminated salts and the total sensible heat of the gas are fed into the waste water, a process has to be developped, which avoids both disadvantages. The new developped process, depicted in Fig. 4, operates with an inlet temperature into the scrubber of approx. 230 to 250 °C. By quenching with water the temperature is reduced so far that the salts produced by the aid of chlorine and fluorine can be eliminated. The gas is cooled to a temperature, which leads to a sufficient elimination of chlorides and fluorides. In a second step, similar to a heat exchanger, the sensible heat is led out of the system. The temperature level of 90 to 100 °C is sufficient for preheating condensate of the combined-cycle process. In a third step free salt particles are eliminated by a Venturi-srubber. The liquid cycle of the plant operates with such a high concentration of salt that the salts can be removed from the cycle with a small, but high-concentrated amount of water.

This saline waste water is evaporated to produce dry salts. As the produced gas contains steam, which condensates by cooling the gas, waste water cannot be avoided. These effluents appear in such a quality that an emission is harmless.

During the second step of the gas cleaning sulphur compounds, particularly H_2S, are separated in a Amisol-plant. This absorption represents an advanced development of a known process concerning the demands of the coal gasification. Particularly a high selectivity in the H_2S-absorption is reached. A high CO_2-absorption does not only lead to a corresponding dilution of Claus gas, but it also means a corresponding reduction of mass flow in the gas turbine. The composition of Claus gas is also to be seen under the aspect of operating the Claus plant not by using oxygen but air as oxydizing agent. The advantage shown for the design of the H_2S-absorption and the Claus plant consists in gas with a low amount of CO_2 produced by a partial gasification according to the entrained gasification by adding a very little rate of steam.



KUV Prewashing

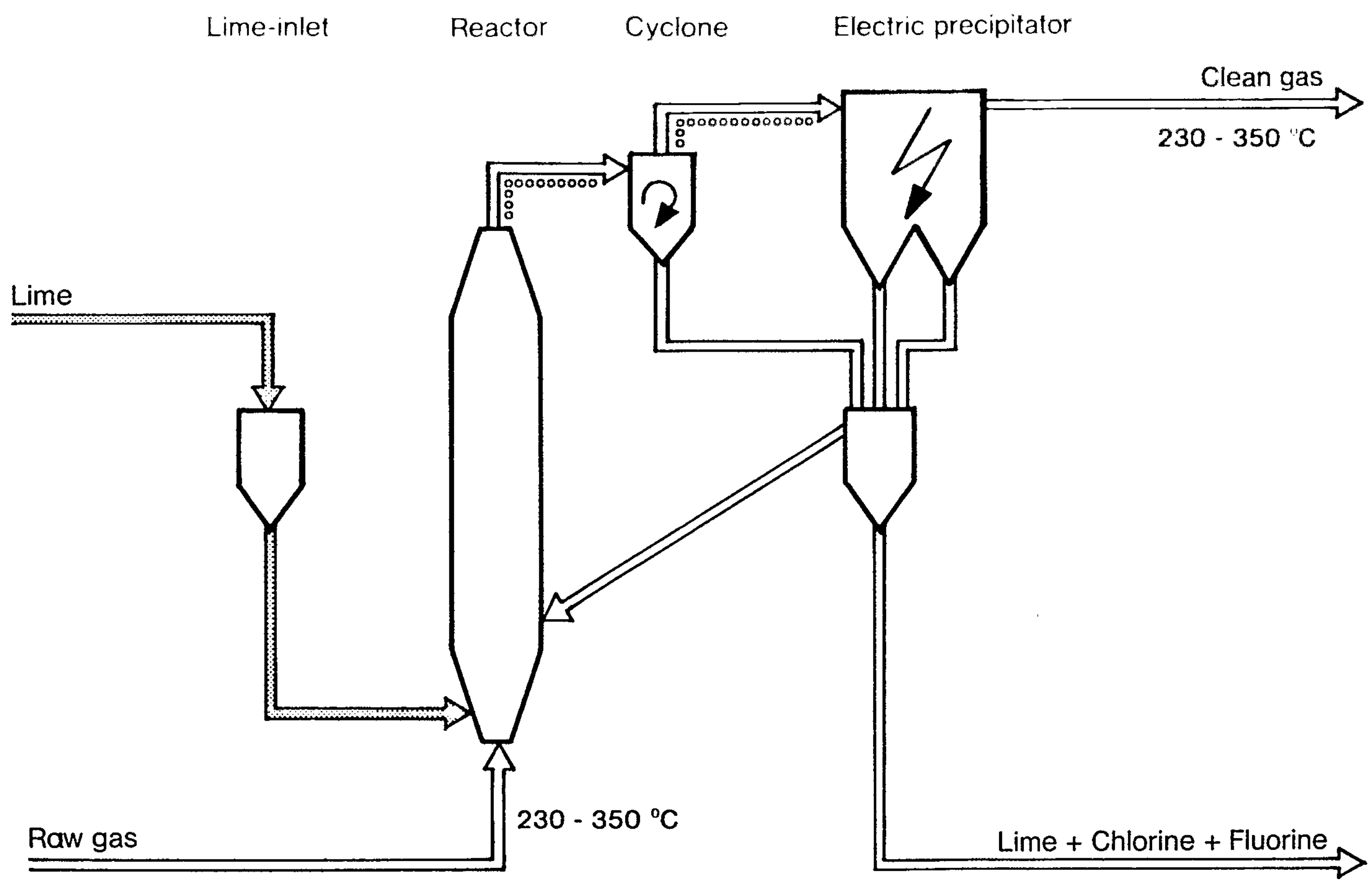
Figure 4

The dry gas cleaning with a capacity of 10.000 m^3/h (s. c.) is tested in a bypas to the wet gas cleaning. Chlorine and fluorine should be adsorbed at temperatures of 300 to 350 °C according to the principle of a circulating fluidized bed at 20 to 25 bar by using lime (Fig. 5.). With lock hoppers and a rotary valve the lime is fed into the reactor by using coal gas. After separating most of the solid matter in a cyclone it will be fed again into the reactor. Subsequently the separation of the fine dust particles is carried out in an electrostatic precipitator and the dust particles will also be fed again into the reactor. A partial stream of the loaded adsorbens leaves this system by lock hoppers and a rotary valve. Though the principle of the circulating fluidized bed is known from the coal combustion, the operating pressure shows some new demands, which consist of metering systems for the inlet and outlet of solid matter under high operating pressure as well as the recycling of solid matter into the reactor. The electrostatic precipitator working under pressure is totally new constructed. In this process the operating temperature of the system, which enables the utilization of sensible heat in the gasturbine-process - in contrast to the wet gas cleaning - without any losses, is a significant advantage.

A test facility is also set up with the prototype plant to study the corrosion behaviour of gas turbine materials depending on the gas quality from different stages of the cleaning process. These tests are important especially in respect of a reduced gas cleaning system - like in the dry gas cleaning system-, which is limited to the removal of chlorine and fluorine. The results will allow an optimization between the extent of the gas cleaning system and the characteristical dates of the gas turbine (inlet temperature) in respect to the design of the total plant.

5. CONSTRUCTION OF COMMERCIAL PLANTS

The development of the process is planned for the construction of commercial plants with a capacity of 600 to 800 MW. The coal gasification and the combined-cycle process should be totally integrated, to achieve an optimum heat recovery. For a coal capacity of 200 to 250 t/h three or four streams are necessary for gasification and gas cleaning. Due to its operating conditions the process allows a capacity of 60 to 80 t/h coal per stream.



KUV Dry gas cleaning

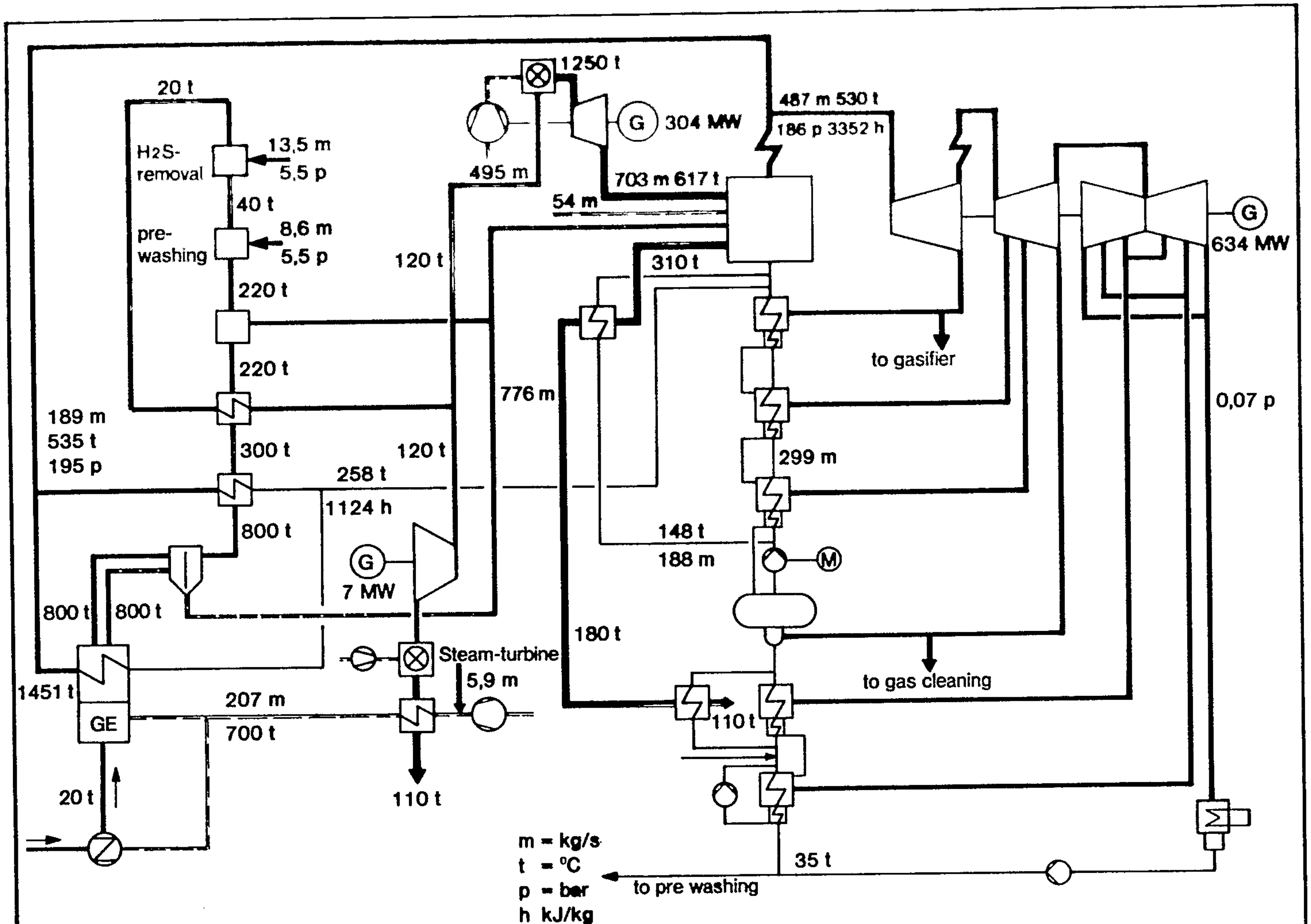
Figure 5

Especially the experiences gained from the operation of gas-fired-combined-cycle units are useful for the planning of the process design. The arrangement of the combined-cycle process with the supplementary fired boiler is similar to these units. The integration of coal gasification and gas cleaning with a combined-cycle process is to be seen in the flow sheet (Fig. 6).

The gas generator is - as described above - provided with a waste heat recovery operating with high-valued steam properties. The produced steam is immediately fed into the steam turbine. In this example a conventional design of the steam process is shown with steam properties of 180 bar and 530 °C at the turbine inlet and 530 °C for the resuperheating. The char, which is removed in a cyclone and a bag filter at low temperatures, will be fed into the boiler's furnace for combustion by utilizing the available oxygen content of the exhaust gas of the gas turbine. The sensible heat of the generated gas in the temperature range of approx. 300 °C is recovered for preheating the cleaned gas. Preheating of all boiler feed water partly takes place in regenerative preheaters and partly in heat exchangers charged with flue gas, which are connected in parallel. The recovered heat in the prewashing of gas enables to preheat condensate to temperatures of 75 to 90 °C. A wet cleaning as it is operating in the pilot plant is planned to achieve a sufficient sulphur-removal.

A certain amount of the produced gas is needed to preheat the process air, which is used as oxidizing agent in the gasifier, to temperatures up to 600 °C.

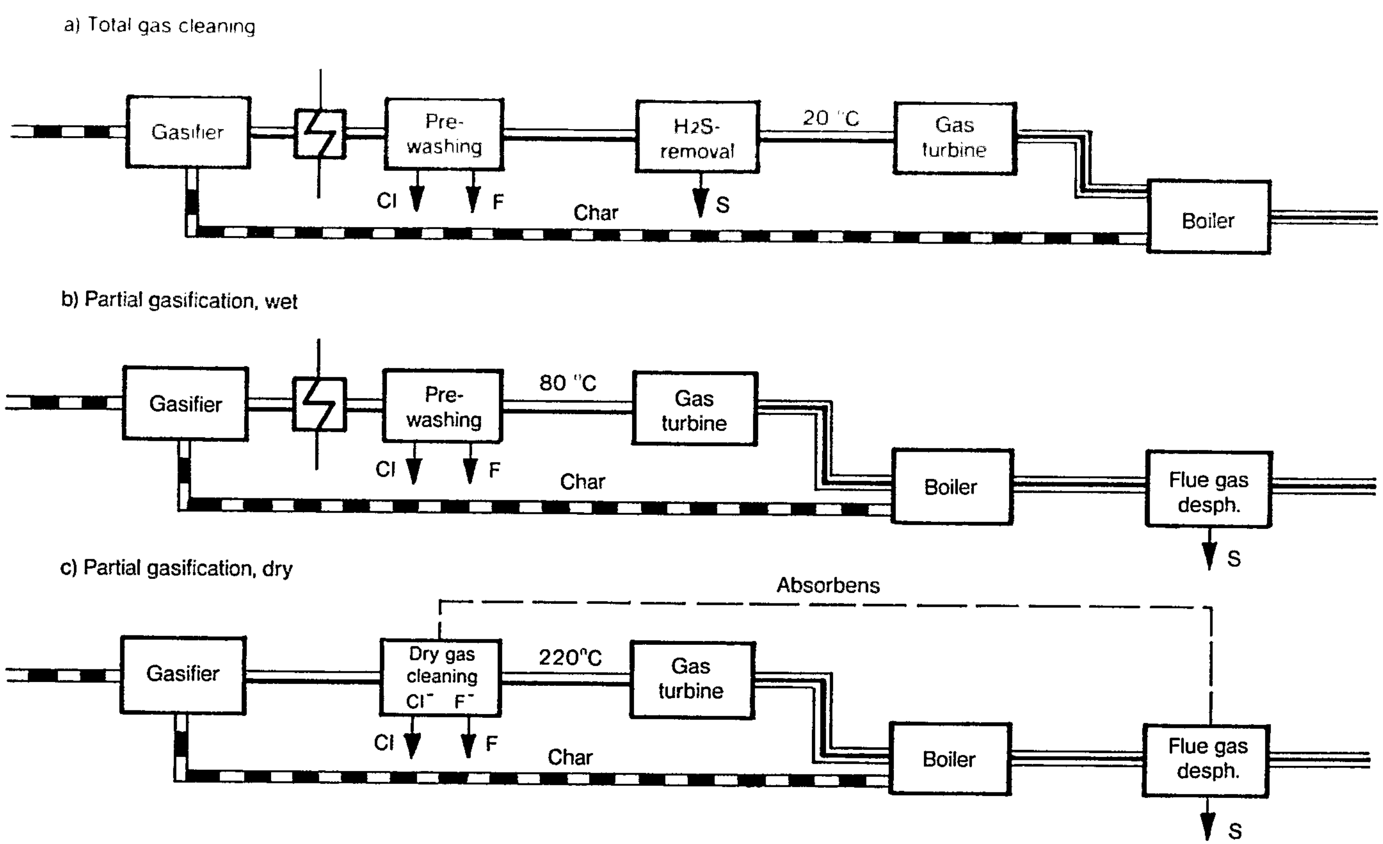
Alternatively to the described process another type of gas cleaning can be designed. The dry gas cleaning as it is tested in the 10 t/h - Pilot Plant represents an essential alternative to the named process design. Supposed that a sulphur-removal at temperatures of 300 to 350 °C is not available, the gas containing sulphur will be fired in the gas turbine. In this case the sulphur-removal would be carried out by a flue gas desulphurization plant.
(Fig. 7/Basic circuit diagram - gas cleaning)



Combined cycle process with coal gasification

VEW – Coal Conversion process

Figure 6



VEW-KUV Process modifications

Figure 7

If the dry gas cleaning cannot meet the requirements, it would be possible to eliminate chlorine and fluorine by the mentioned wet gas cleaning and to remove sulphur by a flue gas desulphurization system. The comparison of the three different process designs has shown that a flue gas desulphurization instead of H_2S-removal from fuel gas does not decrease the efficiency. Due to the inapplicable heat losses in the gas cooling system a combination of the dry gas cleaning with flue gas desulphurization offers a considerable increase of efficiency. Furtheron it has to be seen that a Claus plant connected with a H_2S-absorption hardly fits the load change behaviour of the power plant. Because of the high costs for German coal, all coal-fired power plants are preferably operated at a range of middle or upper load with often load changing or hot standby periods. These demands can be performed more favourable with a flue gas desulphurization than a Claus plant. In consideration of the efficiency of these processes the auxiliary energy is very important. All of the available processes for desulphurization of coal gas show an essential energy demand for the regeneration of the liquid absorbens.

6. CONSIDERATIONS FOR THE DESIGN OF A COMBINED-CYCLE PROCESS WITH INTEGRATED COAL GASIFICATION

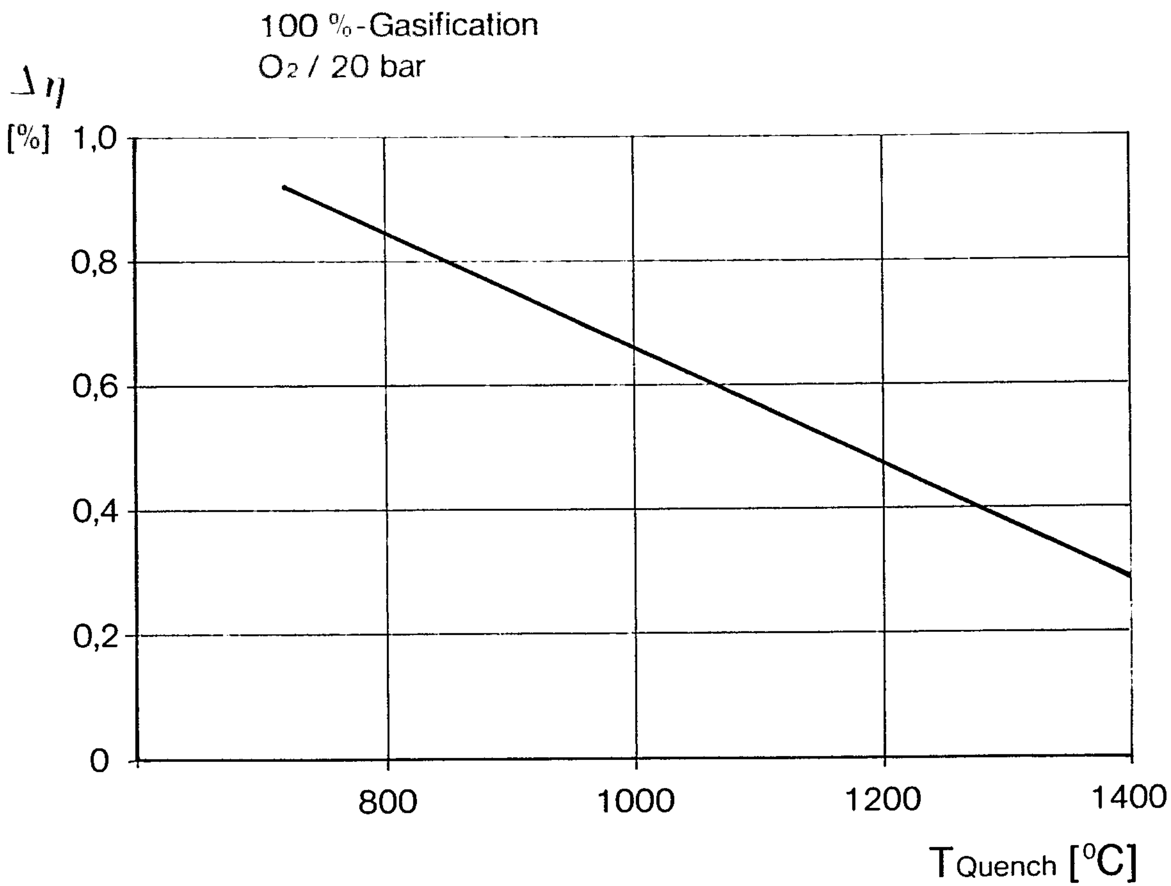
The efficiency of the various alternatives of combined-cycle processes with integrated coal gasification depends on different aspects. Besides the characterics of the gas production the waste heat recovery from the produced gas as well as from the flue gas behind the boiler and the design of the gas cleaning system are decident for the thermal quality of the whole process. Based on the principle of the entrained gasification the two described process designs - partial gasification, air blown (VEW-Coal Conversion Process) and the total gasification, oxygen blown - offer favourable operating conditions for the gasification process. In connection with a total gasification the pure waste heat process, firing produced gas totally in the gas turbine, will preferably be realized. Both methods allow a waste heat recovery in the total range of temperatures.

For complete gasification proposals are known to quench the raw gas at the gasifier outlet by cold gas to reduce the temperature for solidification of molten slag particles. So it can be avoided that sticky particles adhere to the walls of the radiant cooler. The partial gasification does not show these problems because no pure ash particles are produced, but all particles are a mixture of char and gas. Adhesion of these particles on the walls could not be seen in the various tests. By reducing the exergetic level, that means increased heat losses at low temperatures, a considerable efficiency decrease results in the use of a gas-quench by drawing-in cold gas to the end of the gasifier depending on the temperature of the quench (Fig. 8).

Another important aspect can be seen in the heat recovery in the gas cleaning system. The described Cl^-, F^--removal includes a method of heat recovery to preheat the condensate of the steam cycle. Contrary to the heat losses in the known Cl^-,F^-- removal systems an efficiency increase - depending on the temperature of the heat recovery - provides a considerable incentive for the use of this process (Fig. 9).

The gas with a low amount of CO_2 produced in a partial gasification facilitates the choice of a qualified process of sulphur- removal. The minimum CO_2-removal and subsequently a more reduced loss of the mass throughput in the gas turbine results in the lower CO_2-partial pressure regardless of the selectivity of the H_2S-srubbing system. Therefore the efficiency is hardly concerned.

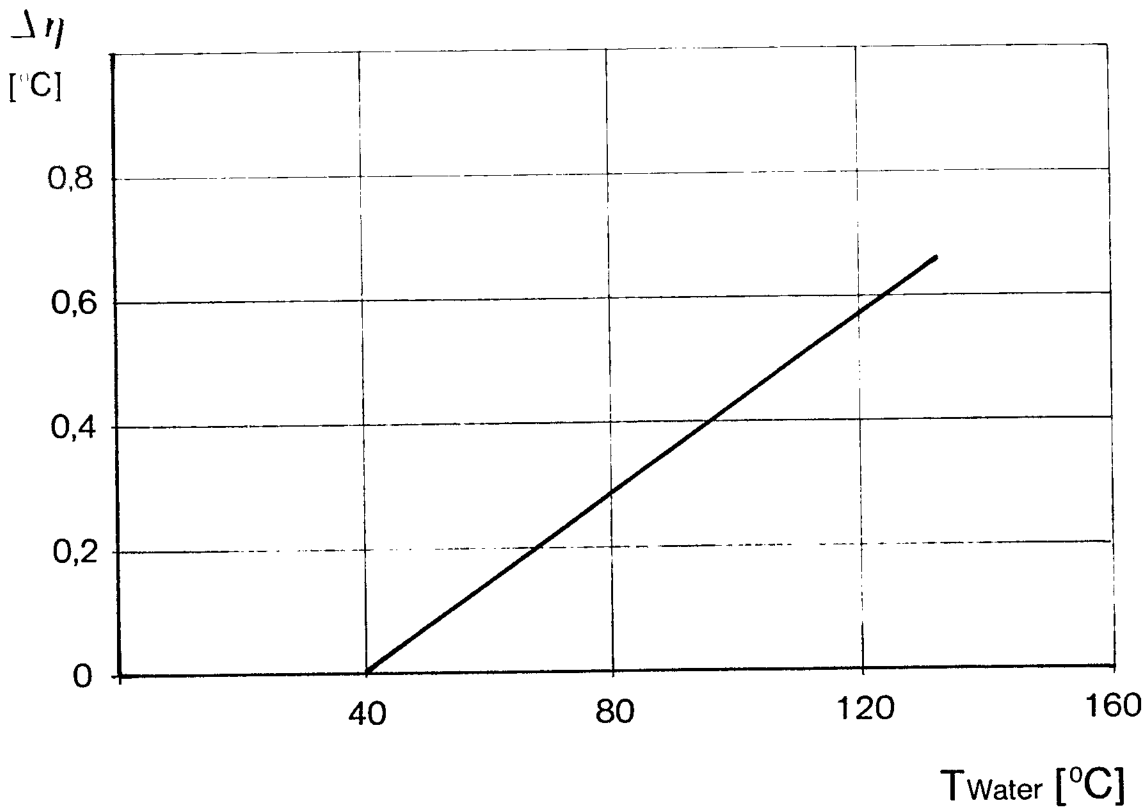
Contrary to the pure waste heat process the supplementary fired process shows an essential lower amount of flue gas. There is no problem to realize low flue gas temperatures at the boiler's outlet. Regardless to the heat recovery from flue gas a regenerative preheating can be used. In the pure waste heat process qualified conditions for the waste heat recovery can only be achieved for gas turbines with inlet temperatures of 1250 °C and a corresponding high pressure ratio. It may be necessary to provide a second steam pressure range at low temperatures to reduce the outlet temperature of the flue gas. By this method a considerable efficiency increase can be attained by low inlet temperatures of the gas turbine. Otherwise it has to be taken into consideration how far such a process design leads to difficulties in the operation of the plant.



Influence of gas-quenching to plant efficiency

Figure 8

Combined cycle with VEW-Coal Conversion Process



Influence of heat recovery in gas-prewashing to plant efficiency

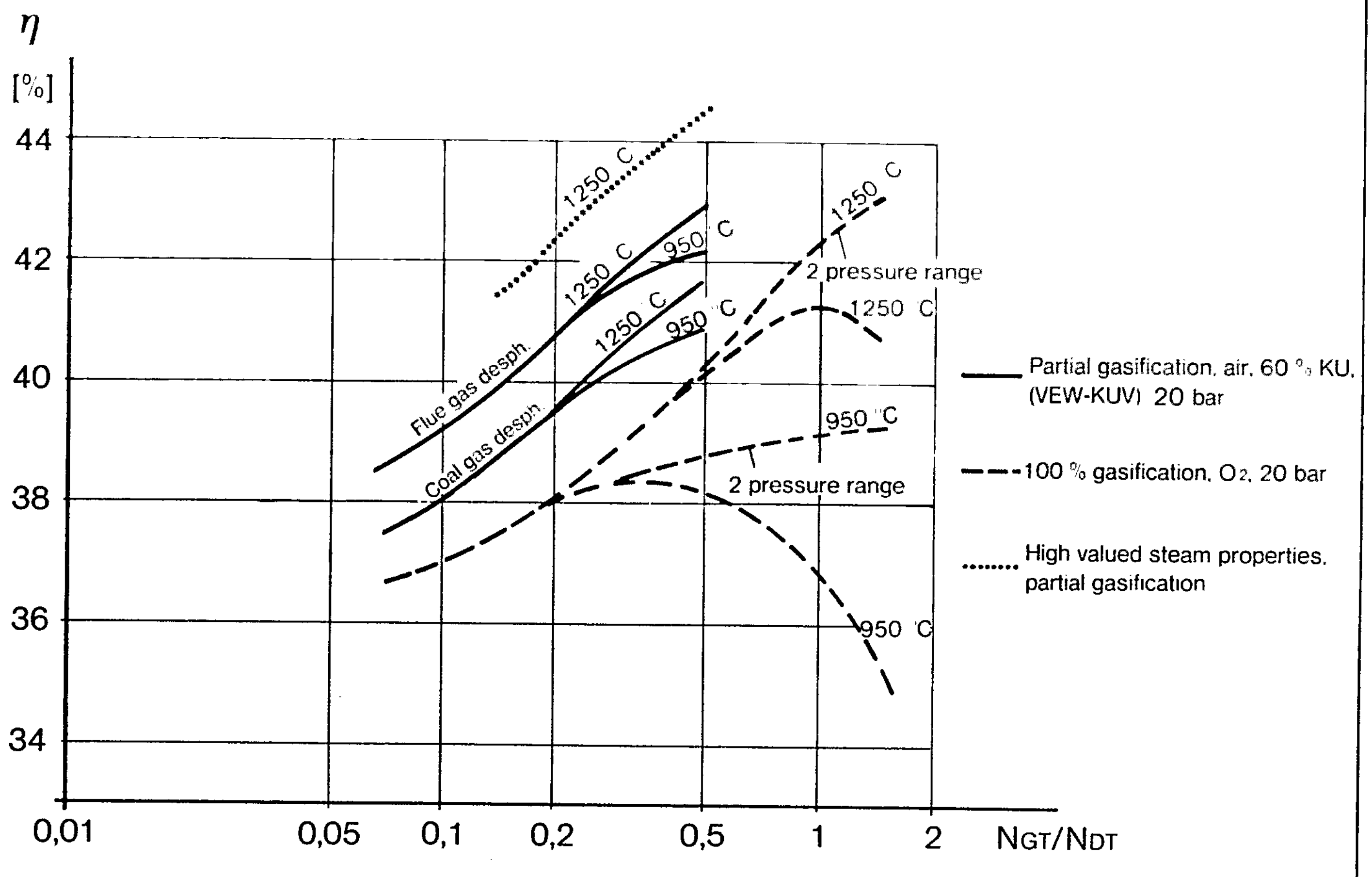
Figure 9

In dependence of the gas turbine/steam turbine ratio a variety of processes for both of the named basic designs of a partial gasification according to the VEW-Coal Conversion Process and a total gasification according to the oxygen blown entrained gasification has been calculated. (Fig. 10)

For the total gasification the waste heat system is achieved in the final point of the curve according to a high ratio of gas turbine to steam turbine. In the remaining part of the curves a supplementary fired boiler by gas is used. The significant difference of the efficiency is clearly to be seen in dependence of the inlet temperature of the gas turbine. For all inlet temperatures an essential efficiency increase can be achieved by using a second pressure range in the steam cycle. For a process with one pressure range only the optimum of efficiency is reached for a gas turbine/ steam turbine ratio below the pure waste heat process, that means with a supplementary fired boiler.

Alternatively to this design basic considerations are shown for the VEW-Coal Conversion Process. The gas turbine/steam turbine ratio ends at an essentially lower value, because - due to the production of char - this is a supplementary fired process. According to the low ratio of gas turbine to steam turbine the inlet temperature of the gas turbine is not so important for the efficiency. The shown efficiency increase is achieved by using a dry gas cleaning and a flue gas desulphurization. The considerations, as they are recognized for partial gasification, suppose steam properties of 180 bar and 530 °C with a pressure in the condensator of 0,7 bar. An increase of the steam properties is possible in the supplementary fired process without decreasing the gas turbine output. If the steam properties are increased to approx. 550 °C and supercritical pressure a further efficiency increase can be achieved. While the compared processes nearly show the same efficiency level without using the named methods, regarding the final points of curves, the improved steam properties allow an efficiency increase for combined-cycle with partial gasification, which substantially exceeds the comparative curve for total gasification processes.

The same steam properties can also be realized with a supplementary fired boiler in a process with total gasification. However, gas turbine/steam turbine ratio would be decreased and subsequently the improving influence for the steam cycle would be in contrast with a decreasing effect because of the



Efficiencies, Comparison

Figure 10

smaller amount of gas turbine capacity in the combined-cycle.

The high outlet temperatures of entrained gasifiers force to recover the waste heat on an exergetic high-valued level. In consideration of a favourable efficiency of the total process the production of steam with high valued properties, which is immediately fed into the turbine, is necessary. It has to be considered that the available materials have to resist the corrosion influences in the reducing atmosphere with high temperatures at the outside of the tubes. If the production of highly pressurized and highly superheated steam cannot be attained, saturated steam could be produced, which would be superheated in the supplementary fired boiler to reach the named properties. According to the outlet temperatures of the gas turbine and the resulting conditions of the waste heat recovery this cannot be achieved with a pure waste heat process. In this case a supplementary fired boiler would be necessary, which leads to a reduced capacity of the gas turbine and, therefore to a lower efficiency of the combined-cycle process. The process of partial gasification allows a superheating of the satured steam in the supplementary fired boiler without a reduction of gas turbine capacity, that means without a decrease of efficiency.

7. ASPECTS OF VEW-COAL CONVERSION PROCESS

The VEW-Coal Conversion Process is characterized by the partial gasification and the combined-cycle process with supplementary fired boiler. In consideration of the aspects according to the construction of coal-combined-cycle units a process design showing an improved efficiency as well as very little pollution effects has been developped:

- High carbon utilization, irrespective of the coal conversion in the gasifier. Transfer of the problems of carbon utilization from the gasification to the combustion process.

- The production of a tar- and oil-free gas permits the total waste heat recovery and avoids undesired effluents.

- Use of all coal qualities, regardless of their caking qualities, ash behaviour and granularity.

- Good load behaviour of the gasifier according to the demands of a power plant.

- The partial gasification allows a certain inaccuracy in the coal metering system.

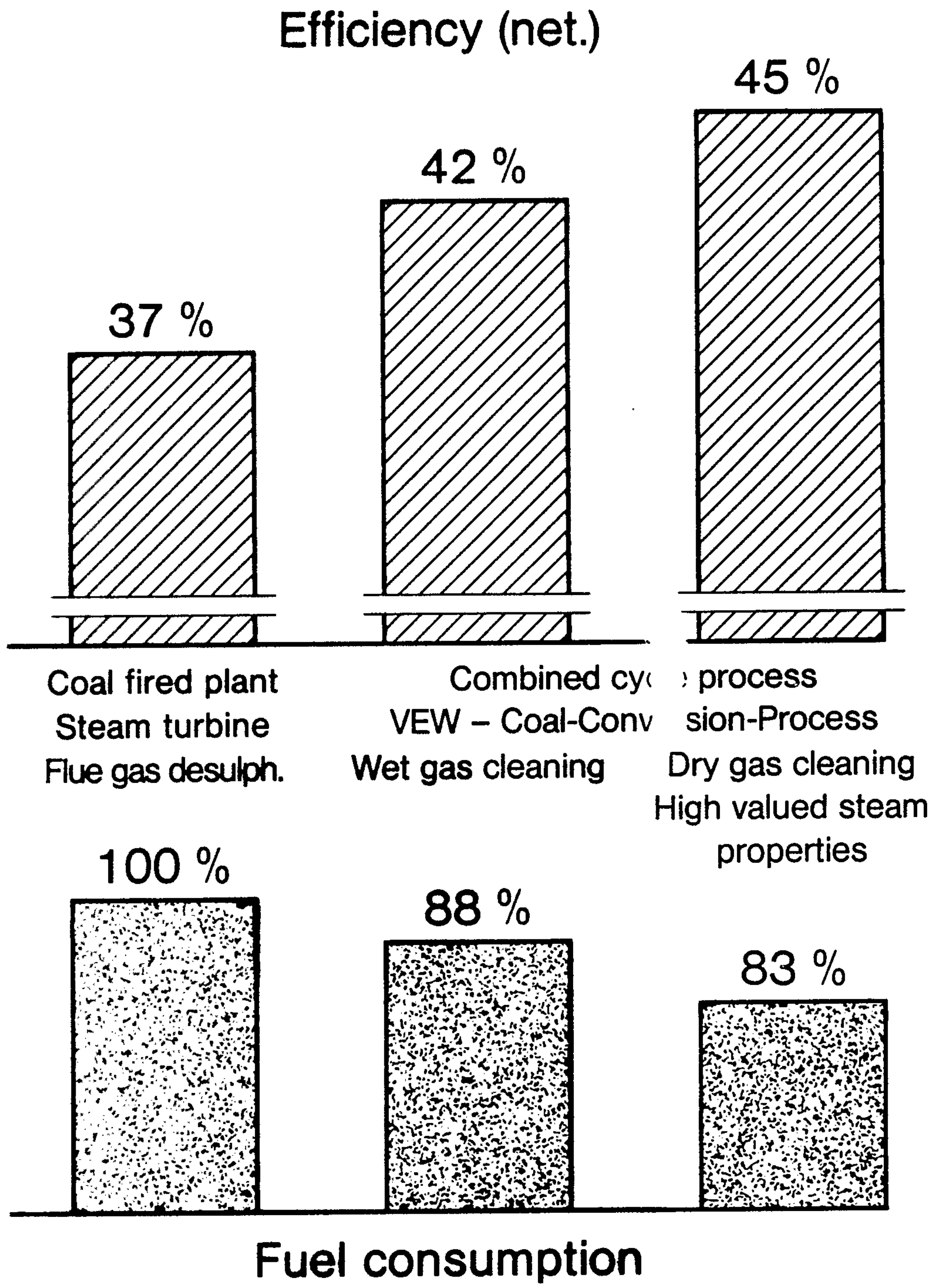
- The principle of entrained gasification enables the construction of gasifiers with throughput capacities of 60 to 80 t/h.

- The low CO_2-content of the raw gas (< 4 Vol. %) implies favourable operating conditions for the H_2S-absorption. The mass loss for the gas turbine caused by washing out the CO_2 is very small.

- It is possible to compensate arising material problems in the waste heat recovery of gasification by the production of saturated steam and a following superheating of steam in the supplementary fired boiler without decrease of efficiency.

By this process not only the legal regulations for emissions can be met, but it also shows some advantages according to the pollution effects. The requested reduction of the SO_2 is carried out by coal gas or a flue gas desulphurization preferably combined with a dry removal of chlorides. As we have learned from combustion tests with the produced char, a minimum NO_x-formation arises by firing the char with a reduced oxygen-content in the exhaust gas of the gas turbine. It is expected to reach the required limit of 200 mg/m^3 (s.c.) for nitrogen oxides only by a qualified combustion process. Purging of saline effluents can be avoided by the chosen principle of prewashing with the connected evaporation process or the dry gas cleaning.

Besides the favourable pollution effects the efficiency increase provides a considerable incentive for developping this process compared with the attainable efficiency with conventional coal- fired power plants with desulphurization process. If the operation of a cooling tower is required the VEW-Coal Conversion Process with combined-cycle and 1250 °C inlet temperature of the gas turbine achieves a minimum efficiency of 42 %. The efficiency can be increased up to 45 % by using a dry gas cleaning as well as higher-valued steam properties (240 bar, 550 °C), which can easily be realized due to the supplementary fired boiler. Compared with conventional coal-fired plants an important increase is attained corresponding to a reduced coal consumption of 12 to 17 % (Fig. 11).



– Efficiencies –

Figure 11

This fuel saving has to be seen in connection with the high costs of German coal; therefore it allows more investments compared with the conventional steam turbine process. After the extensive tests the described process design provides a significant economic advantage.

The 10 t/h - Prototype Plant, the total costs of which run up to 160 Mio DM, has been sponsored by the Federal Minister of Research und Technology. The 750 MW-coal-combined-cycle unit, which was built as a further part of the new technology, was erected without any public sponsorship. This plant - with an efficiency of more than 41 % - shows favourable operating results, especially a low NO_x-production in the supplementary fired boiler.

After the beginning of all preparations for the plant's operation it is provided to start the coal gas production in April 1985. The plant is planned to operate approx. 5 years.

The test results gained during 1985 together with the experiences of the 750 MW coal combined-cycle plant will allow to start planning a commercial plant.

The described aspects, especially the high efficiency in connection with the improved pollution conditions as well as the high costs for German hard coal provide an incentive to use this technology for electric generation from coal in a commercial scale as early as possible.