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BASIC LAY-OUT, ARRANGEMENT AND DESIGN CRITERIA OF HEAT COMPONENTS OF THE "NUCLEAR COAL GASIFICATION PROTOTYPE PLANT (PNP)"

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1. Introduction

Since 1975, the companies Bergbau-Forschung GmbH, GHT Gesellschaft für Hochtemperaturreaktor-Technik mbH, Hochtemperatur-Reaktorbau GmbH, Kernforschungsanlage Jülich GmbH und Rheinische Braunkohlenwerke AG - are working jointly on the Project "Prototype Plant Nuclear Process Heat (PNP)", with promotion of the "Bundesminister für Forschung und Technologie" [1] and of the "Minister für Wirtschaft, Mittelstand und Verkehr des Landes Nordrhein-Westfalen" [2].

The objectives of the project are the development of a high-temperature reactor, with a core outlet temperature of 950°C, suitable for various process heat applications, and the development and testing of the appropriate coal gasification technology.

In the initial stage of the project, various alternative methods were examined in respect to the gasification of lignite and hard coal for various gasifications products.

In order to restrict the number of different variants and the development effort itself, only such gasifications schemes were selected, which would allow the processing of all types

1) Federal Minister for Research and Technology

2) Minister for Economics, Small Business, and Transport of the State of North Rhine/Westfalia

of coal and the recovery of various desired products (synthesis gas, synthetic natural gas, reducing gas) through combinations of a limited number of system components. Hydrogasification and steam gasification (or a combination of both methods) were selected as reference solutions for producing methane on the basis of the coal, water and nuclear energy, with a high temperature reactor as the heat source. Hydrogasification and steam gasification, resp. combined gasification methods connected to a nuclear high temperature heat will be demonstrated in the afore mentioned Prototype Plant.

The applied gasifications methods comprise endothermal and exothermal reactions. Therefore, various heat transfer components are to be developed. In the context of this Specialists Meeting, only those components will be discussed by which heat is transfered from primary helium to secondary helium or from helium to the working or process fluid.

2. Gasification Processes

2.1 Hydrogasification

According to the hydrogasification process (figure 1), hydrogene is produced by reforming a fraction of the methane being generated in the gasifier. The heat required for splitting of the methane in the steam reformer (SR) is covered by the heat transfered from the primary circuit of the HTR. Hydrogasification is an exothermal reaction, as is also the shift reaction or conversion, where carbon monoxide and steam are reformed to yield carbon dioxide and hydrogen. The heat set free during such exothermal reactions is recovered and used in the cycle at a process stage of an appropriate temperature.

2.2 Steam Gasification

The steam gasification process (figure 2) involves the gasification of coal by steam, coupled with a conversion process and a methanation stage to produce SNG. The heat requirement for steam gasification is met by nuclear energy. The steam gasifier is installed outside of the containment in order to avoid difficulties with the integration of gasification components within the containment. An intermediate heat exchanger transfers the heat from the primary He-loop via the secondary He-loop to the gasifier. In the combined gasification process, the coal is initially subjected to hydrogasification. Then, the residual char is used for producing hydrogen via steam gasification and conversion. The heat recovered from the exothermal reactions is returned to the cycle at a point of appropriate temperature. The high temperature reactor is capable of supplying all the energy required in both the high and low temperature ranges, thus saving all the "enery coal" otherwise required for an autothermal process. However, special attention must be given to accomodate the various process stages to the thermovector of the reactor coolant, especially if the electric power produced is to be balaned to the internal consumption of the gasification plant.

2.3 State of the Gasification Technology

The above described gasification technology is presently being tested on a semi-industrial scale.
The companies Bergbau-Forschung und Rheinische Braunkohlenwerke each have operated pilot plants with a throughput of approx. 200 kg/h hard coal, resp. 400 kg/h raw lignite, for testing and further development of equipment used in the processes described above, especially the gasifiers.

Figure 3 illustrates the semi-industrial pilot plant for hydrogasification of raw lignite with a throughput of 400 kg/h; figure 4 is a photograph of a semi-industrial pilot plant for steam gasification with a throughput of approx. 200 kg/h hard coal.

3. Prototype Nuclear Process Heat Plant (500 MWth Power)

Since 1977 the project partners have concentrated on the design of a nuclear gasification plant incorporating a HTR of 500 MW thermal power output, whereby both hydrogasification and steam gasification of lignite and hard coal shall be demonstrated (figure 5). In addition, the principle of the "Long Distance Nuclear Energy Transport System" is to be demonstrated with the aid of the prototype plant.

This plant is capable of simultaneously gasifying 712.3 t/h lignite and 63.4 t/h hard coal. The total gas generation amounts to 73700 standard m³ SNG.

The reactor and the primary system are located within a prestressed concrete pressure vessel (integrated primary system). The prototype plant is equipped with two parallel cooling loops of 250 MW_{th} each, which provides an adequate scale of the loop and gasification components for future large-scale plants.

The steam reformer (SR) and the subsequent primary steam generator (SG) of the hydrogasification plant are installed in the primary loop. 50 % of the steam reformer capacity is diverted for testing the Long Distance Nuclear Energy Transport System.

The He/He-intermediate heat exchanger (IHX) is located in the primary loop associated with the steam gasification, resp. combined hydro-steam gasification plant. Other heat transfer components heated by secondary helium include: steam gasifier, secondary steam generator, and process steam superheater.

Figure 6 is a cross-section of the prestressed concrete pressure vessel showing the arrangement of the heat transfer components heated by primary helium, i.e. the He/He-IHX, the SR, and the SG. The residual heat removal coolers, which are also installed in the primary system, are not discussed within this context.
Heat Exchangers and steam reformers of the dimensions in question have not yet been operated under similar conditions in other technical fields. Apart from very stringent material requirements, there are also a number of special requirements to be fulfilled, such a compactness, in-service inspection compatibility and repairability.

4. Conditions and Design Parameters for Heat Transfer Components

4.1 He/He-IHX

There are two IHX of each 125 MW heat transfer capacity installed in parallel in the primary flow path. The helium leaves the reactor core at a temperature of 950°C. Having entered the plenum, it flows shellside upwards through two parallel IHX's, thereby cooling down to 290°C. Leaving the IHX's it returns to the core cavity via blowers. The secondary helium enters the heat exchanger tubing through the tube plate at a temperature of 290°C, where it is heated to 900°C before passing through the hot gas header and into the secondary hot gas line located above.

The system pressure in the reactor amounts to 40 bar. The pressure in the intermediate loop is always slightly higher. The pressure differential between the primary and secondary loops must be kept at a level somewhere between 0 and 3 bar during operation in order to keep the material stresses as low as possible and to ensure the realization of safety-related aspects. This subject will be discussed in more detail within the scope of the special presentation on IHX-design by W. Niemeyer, under session II.

4.2 Steam Reformer and Primary Steam Generator

The steam reformer (SR) - as compared to conventional types of heat transfer equipment - requires a different mode of heating (heat transfer by convection instead of radiation). It must meet nuclear engineering requirements and be tested under reactor conditions. The primary helium, at a temperature of 950°C, flows outside around the reformer tubes in the steam reformer and cools down to approx. 700°C. The reformer gas enters the reformer tubes from the top, subsequently emerging into an internal return tube leading through the catalyst column. The total heat transfer rate of the steam reformer amounts to 146 MW, 96 MW_{th} of which are provided by the primary helium and the remainder by the return tube and recuperation.
The helium - still at 700°C - is then used for heating the tailing primary steam generator (SG), which requires 154 MW_{th}. The steam leaves the SG at a temperature of 540°C and at a pressure of 115 bar.

4.3 Summary of Conditions and Requirements

Figure 7 lists the conditions and requirements for the heat transfer components of the primary loop (intermediate heat exchanger, steam reformer, steam generator) and secondary loop (sec. steam generator, steam gasifier). The design basis includes removability, repairability, and in-service-inspectability (accessibility) of all main primary loop components.
The design requirements in respect to strength calculations, classification, etc. present a special problem: no adequate design codes exist for such a high temperature range and the anticipated life time. An extensive material R & D program has been initiated. At present, IN 617 seems to be most suitable for the IHX, and hot gas header. Indications are that cast materials may also be used for the steam reformer.

An extensive test program is in progress for the IHX and other heat transfer components. In the case of the SG, experience gained on the THTR is of help, and some such data may be taken over. Component-integral testing on the IHX has not yet started; the necessary test loop is still in planning. Testing on single steam reformer-tubes has been conducted for improving the basic knowledge of this component. The test facility for testing of SR-tube bundles is nearly completed and preliminary testing will start soon.

Further papers within the scope of this conference will deal with aspects of design, experiments, materials and the problematics related to stress and strain analysis of the described heat transfer components of the PNP-500.

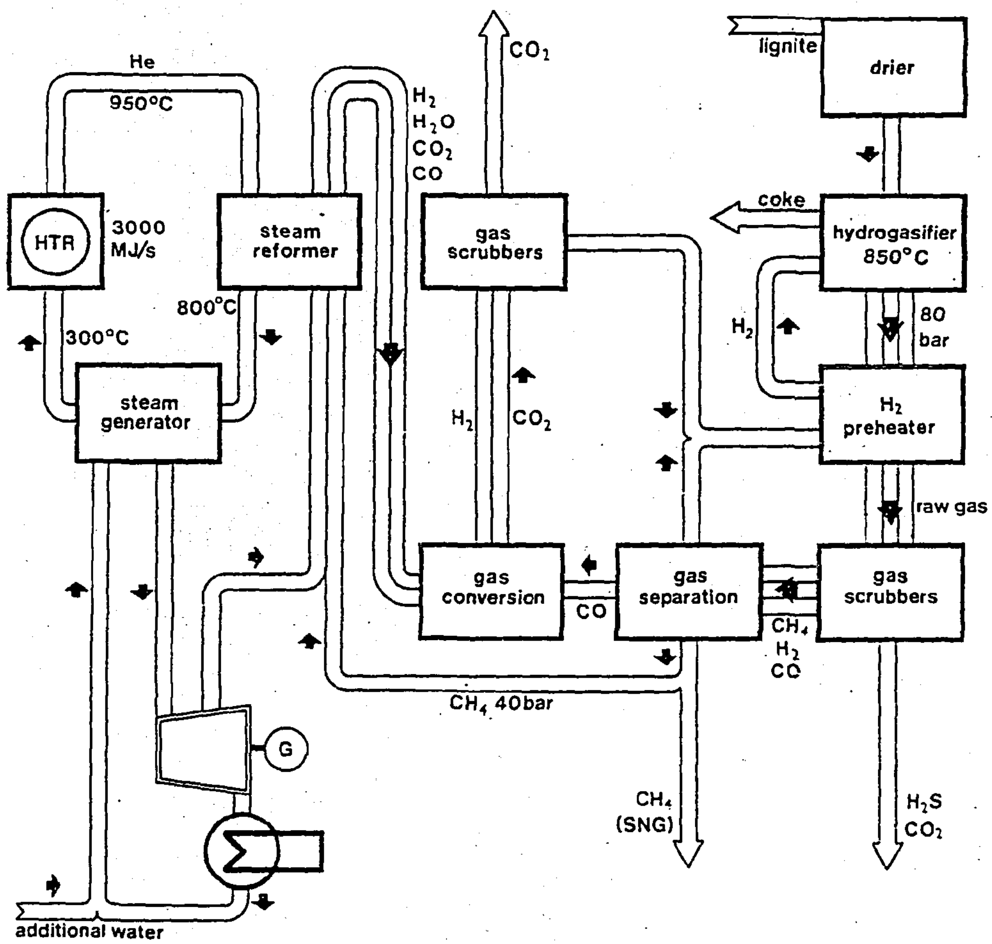

FIG.1 HYDROGASIFICATION OF LIGNITE

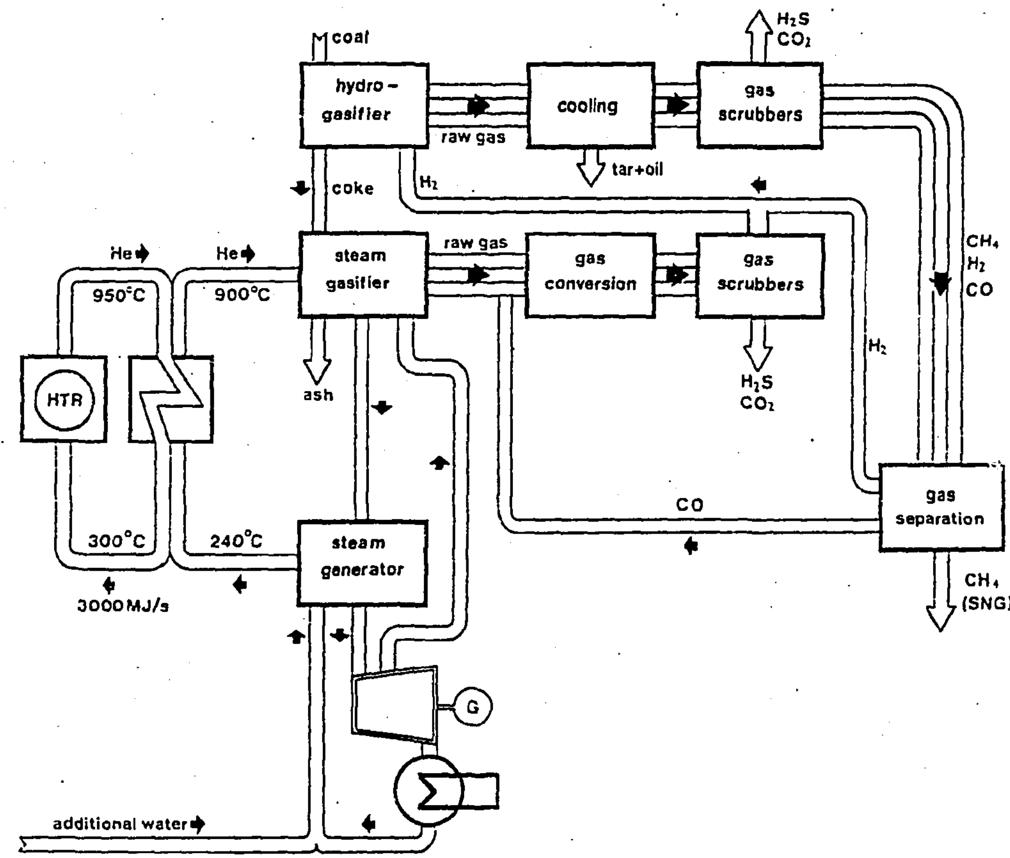

FIG. 2 COMBI-PROCESS OF HYDRO-STEAM GASIFICATION OF HARD COAL

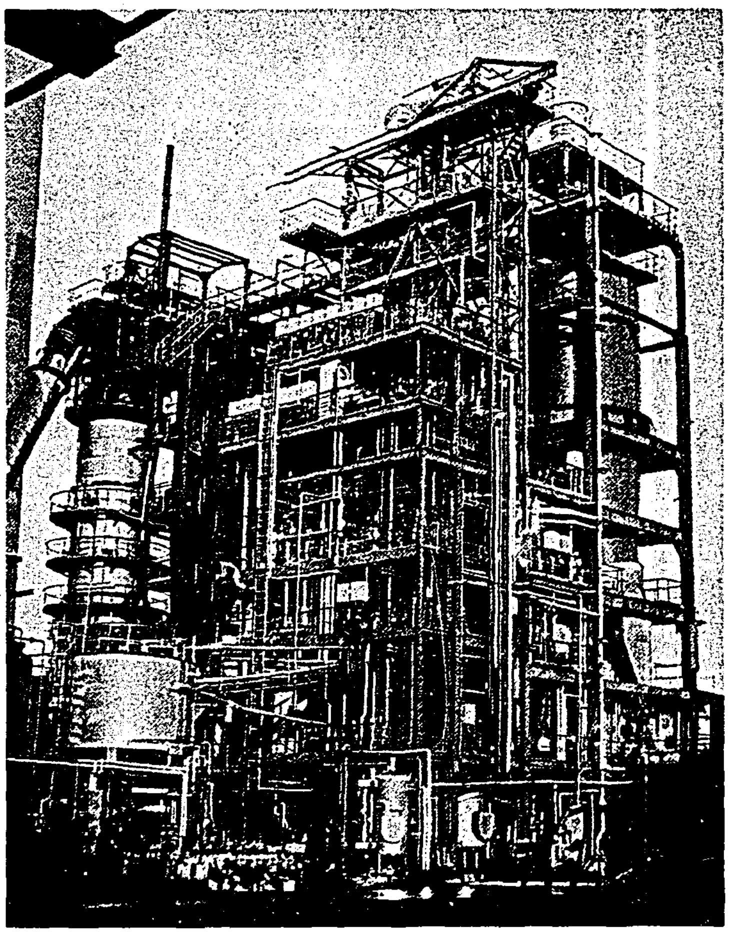

FIG. 3 SEMI- TECHNICAL PLANT FOR HYDRO-GASIFICATION OF COAL (RHEINISCHE BRAUNKOHLENWERKE AG)

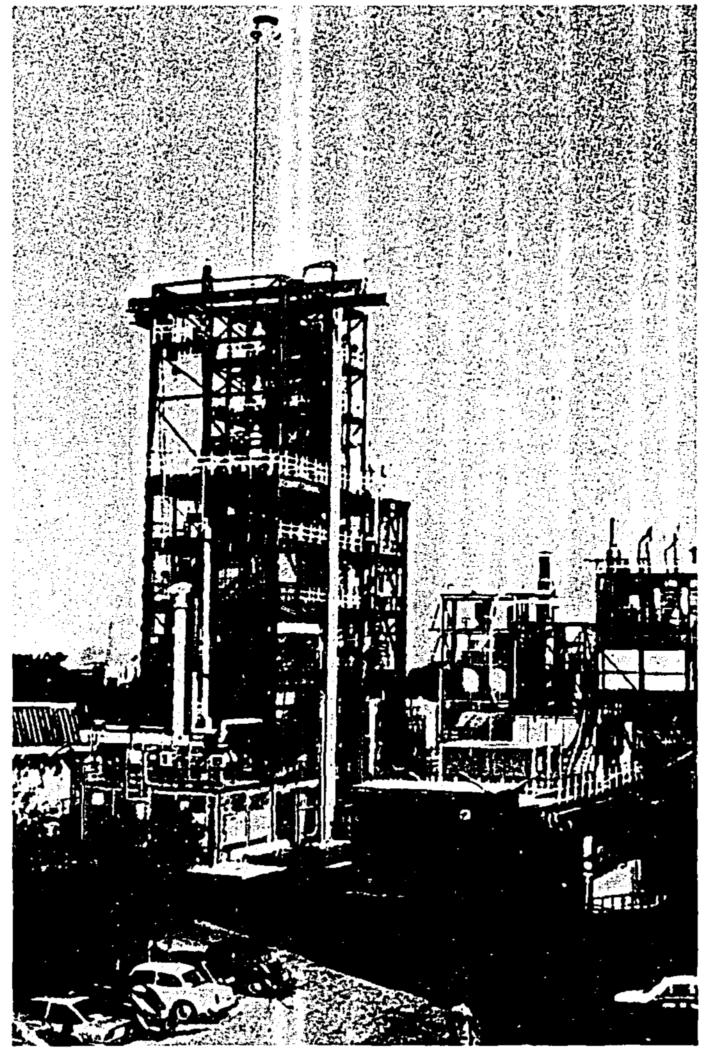

FIG. 4 SEMI - TECHNICAL PLANT FOR STEAM GASIFICATION OF COAL (BERGBAUFORSCHUNG GMBH)

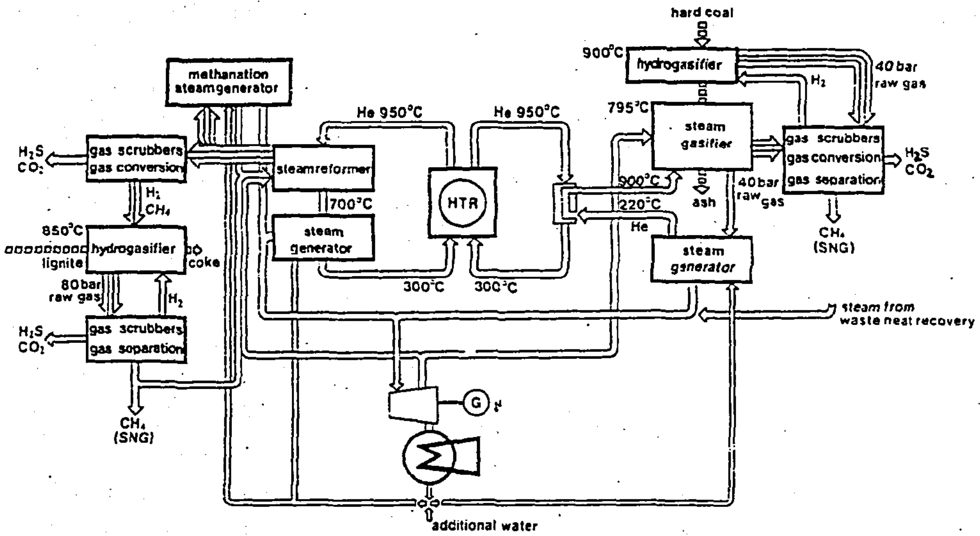

FIG. 5 FLOW SCHEME OF PNP 500 MW

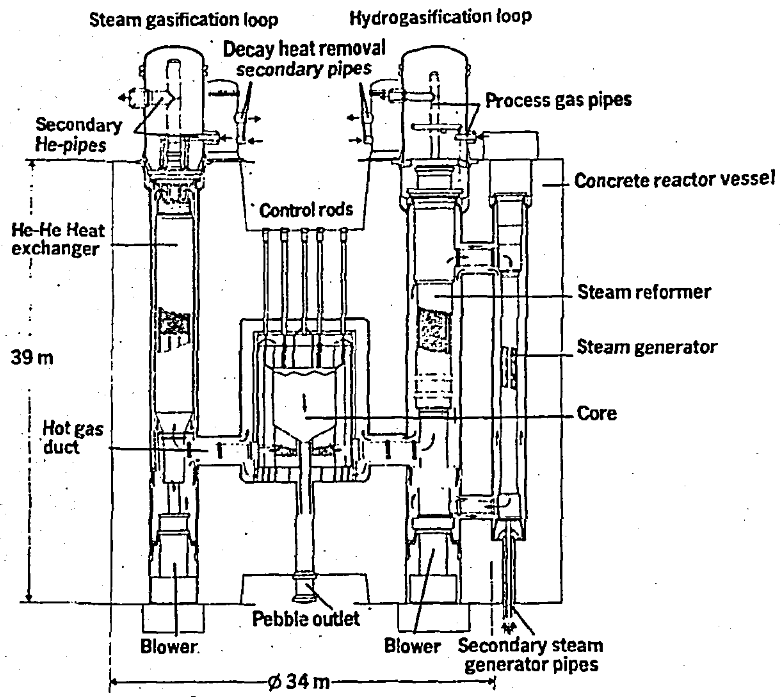

FIG. 6 HIGH TEMPERATURE REACTOR FOR THE PNP - PLANT

	Primary Circuit			Secondary Circuit	
Component	IHX	Steam Reformer	Steam Generator	Steam Generator	Steam Gasifier
Prim. Temp. In / Out	950° / 290°C (He)	950° / 700°C (He)	700° / 290°C (He)	750° / 203°C (He)	895° / 810°C
Sec. Temp. In / Out	220° / 900°C (He)	330° / 460°C (Gas)	150° / 540°C (Water/Steam)	150° / 540°C (Water/Steam)	810°C (Gasification Temp.)
Pressure Prim. / Sec.	40/42 bar	40/45 bar	39,5/115 bar (He/Steam)	42/115 bar (He/Steam)	41,6/45 bar
Thermal Power	125 MW	96 MW	154 MW	202 MW	28 MW
Life Time	15 Years	15 Years	30 Years	30 Years	10 Years
		Feed Gas $H_2O:CH_4$ 4:1			

Fig.7 Data of Heat Transfer Components