No. 31

OPERATING EXPERIENCES WITH HEAT-EXCHANGING COMPONENTS OF A SEMI-TECHNICAL PILOT PLANT FOR STEAM GASIFICATION OF COAL USING HEAT FROM HTR

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1. Concept and Operation of the Semi-Technical Pilot Plant

Within the framework of the PNP-Project Bergbau-Forschung GmbH of Essen has been operating a semi-technical plant for the development of a process of gasifying coal by means of nuclear heat /1,2,3/. Here gasification is for the first time implemented in a fluidized bed using the heat of an electrically heated helium cycle at pressures up to 40 bar and temperatures normal with a HTR /4,5,6/. The plant - a general view of which is given on Fig. 1 - serves in a first

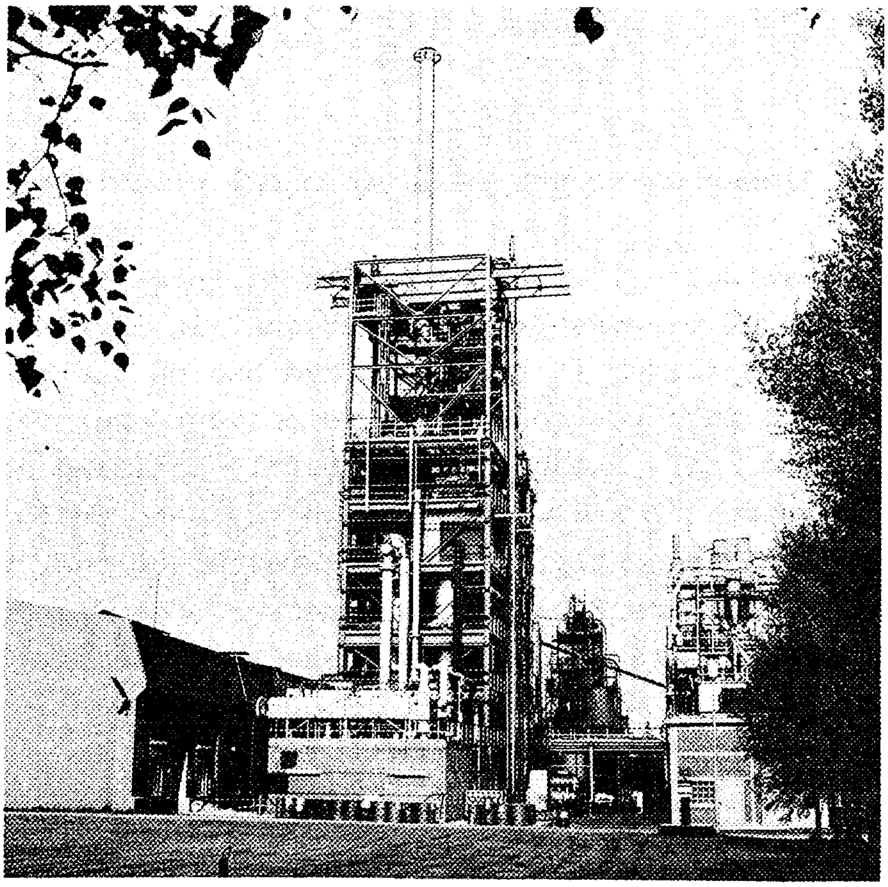


Fig. 1: General view of the semi-technical coal gasification plant on the test premises of Bergbau-Forschung in Essen

line for testing and developing various components as immersion heater, insulations, dosing devices, etc. and, secondly, for gathering sound data for further planning. The second objective can, of course, be met only if any and all plant components function in a way so as to guarantee trouble-free stationary experimental operation. Fig. 2 is a flowsheet of the experimental plant.

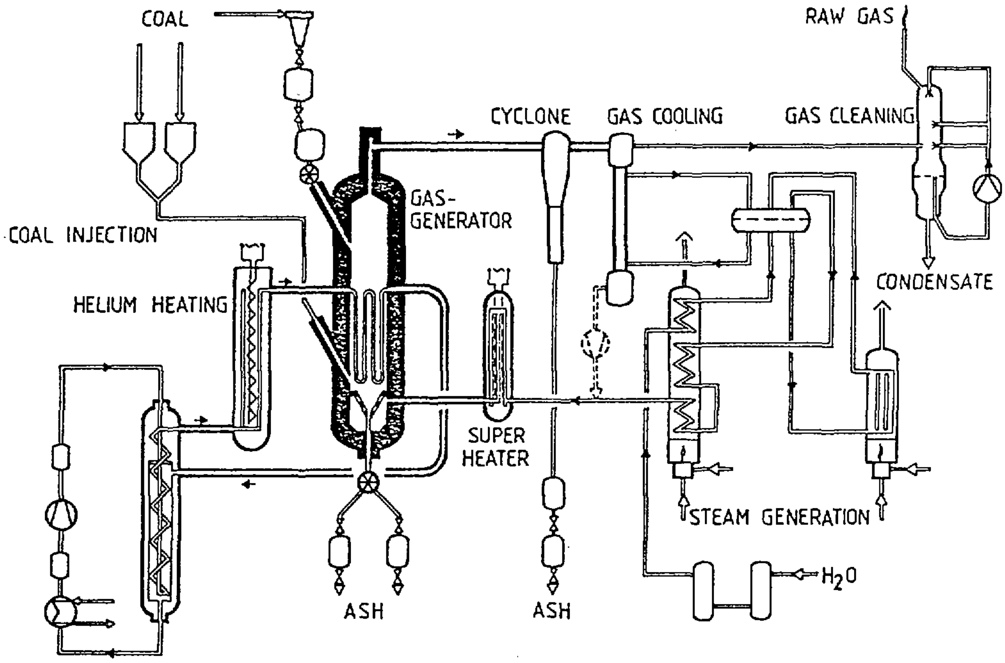


Fig. 2: Flowsheet of the semi-technical pilot plant

The non-caking coal is dose-fed via the pressure lock system to the top of the gasifier. Caking coal is introduced via an injection feeder in the fluidized bed on the gasifier bottom. The injector concept is to prevent agglomeration of the feed coal. Fresh coal and partly gasified coke shall be mixed fast and intimately enough so as to avoid any contact and, consequently, sticking together of the fresh coal particles. The gasification residues will be discharged through the gasifier bottom by means of a chamber-wheel serving a system of two parallel locks.

The helium of the heat carrier cycle is heated in an electric helium heater up to temperatures between 900 and 1000 °C; from there it flows through the heat exchanger in the fluidized bed and provides the necessary process heat.

The steam is raised in a gas-fueled steam generator as well as by heat recovery from raw gas in a pressurized gas cooler.

The product gas leaves the gasifier through the top and is then fed to a cyclone where entrained fine dust is removed at relatively high temperatures and discharged through a system of locks. Subsequently the gas will be cooled. A scrubbing system serves for cleaning the raw gas and removing the remaining, untransformed process steam by condensation. The product gas is then measured and analysed and subsequently burnt in a flare burner.

Planning of the experimental plant started from 1974. Construction work was commenced in spring of 1975, and the plant was commissioned in July 1976. Fig. 3 gives the yearly operational hours, coal throughputs and transformation rates. The overall operation including commissioning, closing down, and test operation, amounted to 24 571 hours until December 31st, 1983; 17 848 hours thereof account for hot operation and 12 611 hours for gasification.

The years 1976 and 1977 were characterized by commissioning and functional tests as well as by gasification tests for the purpose of overcoming toothing troubles with process technology. It was only after this phase that systematical gasification trials could be run on non-caking feed coals. The design figure of 4.8 t/d of carbon gasified was slightly exceeded in 1978 (4.9 t/d). The objective from 1980 onward was to establish sound data for the gasification of high volatile bituminous coal with and without addition of a catalyst.

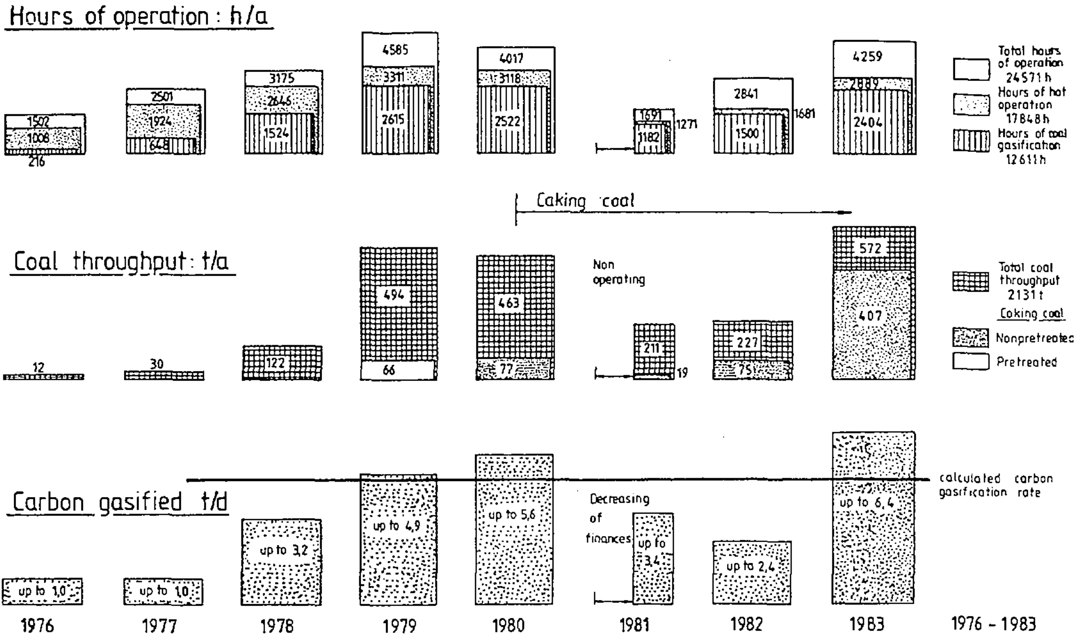


Fig. 3: Figures on test operation at the semi-technical plant

In the course of these trials and based on practical experience we were able to permanently improve the technical performance of the injector with appertaining feed hoppers, the feed bottom, the heat exchanger of the gasifier, and the ash discharge system. It was ultimately the successful technical achievement of the above components which allows to entirely control the mechanism of pyrolysis. During 1983 the carbon transformation was increased to 6.4 t/d; coal throughput was 572 t, 407 t thereof were high volatile bituminous coal /8,9/.

2. Development of several components

In the following operating experiences concerning gasifier, helium circuit and the big gas heaters installed in the plant will be reported.

2.1 Gasifier with the Immersed Heat Exchanger

The gasifier (Fig. 4) is a detail taken over from the commercial gasifier in so far as fluidized bed height and arrangement of the heat exchanger tubes are identical with the large-scale concept. The fluidized bed has a cross-section of 1 m^2 and may be up to 4 m high.

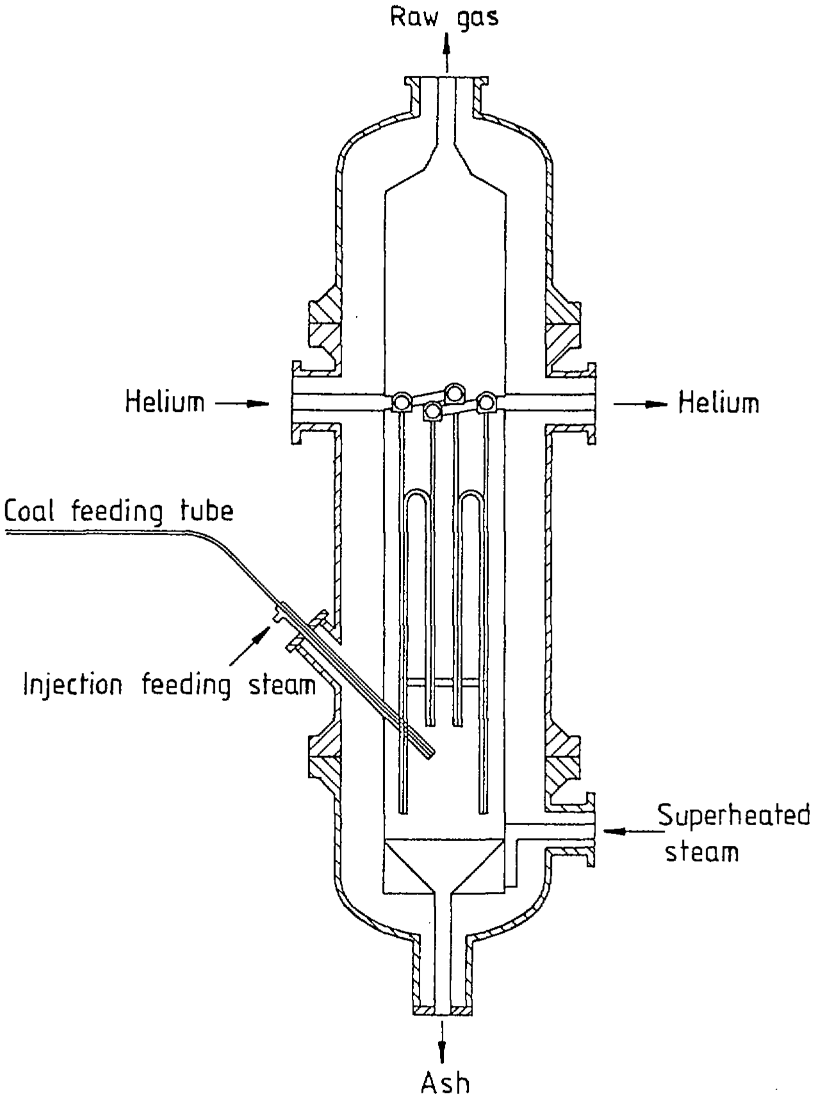


Fig. 4: Gasifier of the semi-technical coal gasification plant

It turned up already during the initial operating phases during 1976 and 1977 that the insulating properties of the gasifier brickwork lining were not sufficient. Heat transfer into the brickwork was not by conduction but rather by convection. Under gasification conditions the steam condensed in the lining, at saturated steam temperature. The heat had, consequently, to be taken down within the remaining insulating brickwork. The chemical and physical structure of the insulation became that much damaged thereby that steam by-passes through the brickwork were created. As this presented a hazard to the pressure shell and also caused substantially increasing heat losses the insulation had to be replaced by a concept, in which steam condensation was prevented.

The heat exchanger - flown through by helium - in the gasifier underwent several modifications as practical experience was broadened and for complying with the different test objectives. The first apparatus was a single-flow heat exchanger of roughly 42 m^2 effective surface; the helium flow was directed around semi-circular tube arches through the rising descending tubes. Fig. 5 shows the tube bundle prior to installation.

From October 1977 until June 1979 the device had operated for 4900 hours, 4350 hours thereof under gasification conditions and with a coal/coke throughput of 470 t. The temperature range was between 800 and 900 °C. After this period the tubes were in perfect condition. In the summer of 1979 the heat exchanger was replaced by a shorter version. This was done because subsequently to the trials on non-caking feed coal it was planned to dose-feed high volatile bituminous coal through the injector. The tubes had to be shorter to provide the necessary free space in the coal feed section. During 1980 the heat exchanger was re-modified since, due

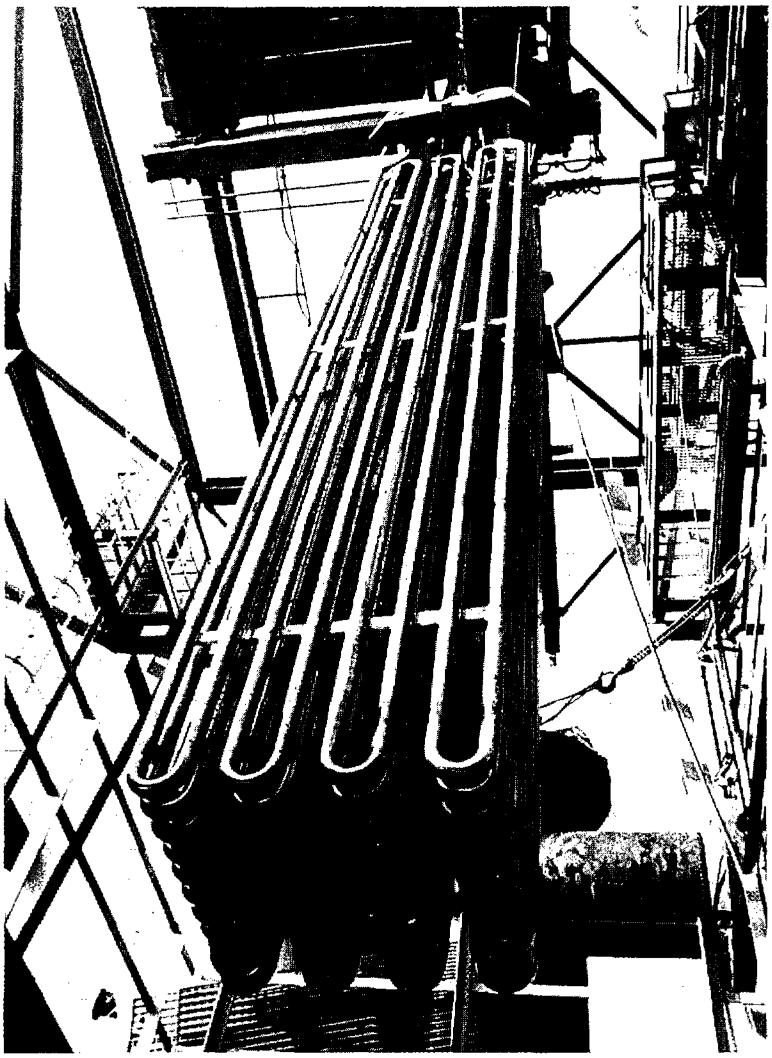


Fig. 5: Single-flow heat exchanger including semi-circular tube arches

to the good heat transfer conditions, the relative temperatures of helium and fluidized bed had become so close to each other after just about 50 % of the heat exchange surface that no further heat reduction was brought about on the remaining surface. So, to make better use of the heat, the entering helium flow was distributed over the two halves of the surface. The helium circulation volume was increased at the same time. Fig. 6 is a view of the apparatus installed early in 1982 and which differs from the previous concept mainly by hair pin tube curves instead of semi-circular tube arches, leaving no space between the rising and descending immersion-type tubes. This avoids reduction of the process space in the hair pin area. Such concept enlarged at the same time the absolute distance between tube pairs from 62 mm to 142 mm which provides more vertical freedom of movement to the fluidized bed.

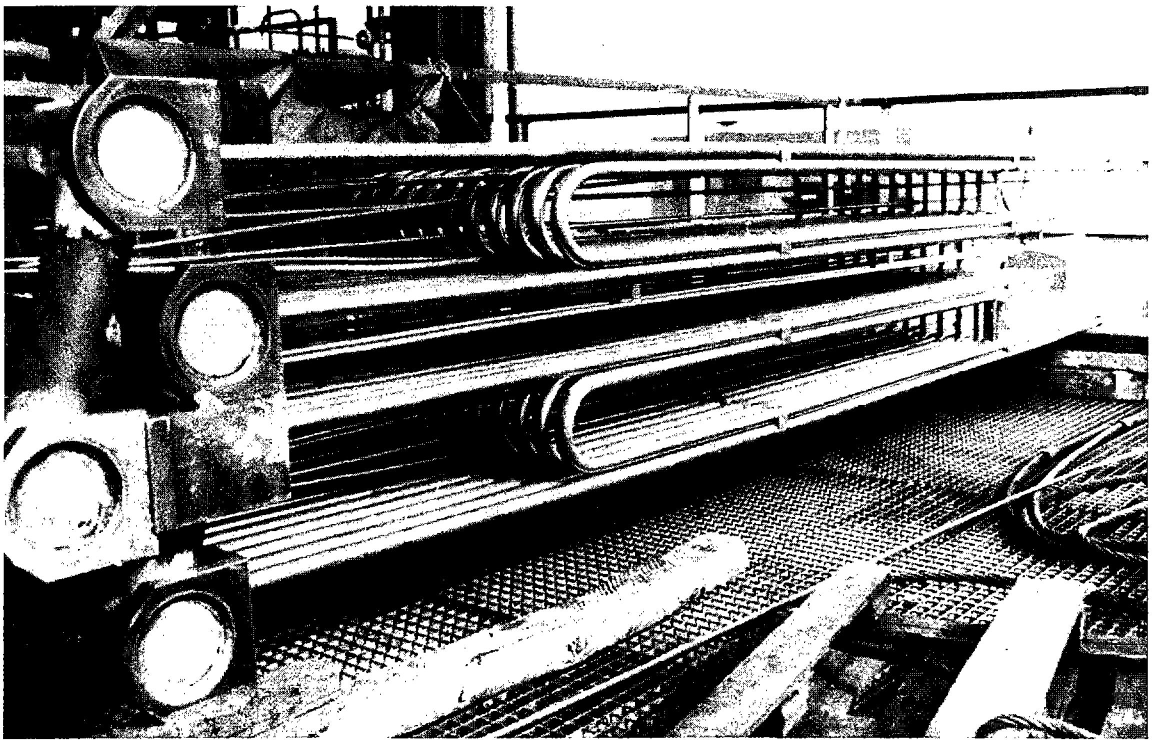


Fig. 6: Heat exchanger in gasifier, hair pin tube arrangement

2.2 Helium circuit

Another innovation is the helium cycle whose components operate at 40 bar and up to 1000 °C. Fig. 7 is a drawing of the different units operating within the high temperature range with appertaining pipelines conveying hot helium. The heart of the system is the helium heater consisting of one vertical pressure vessel of about 9 m height and an outer diameter of 1.5 m. The helium is heated with electricity. The resistance heater is a pitch coke fixed bed.

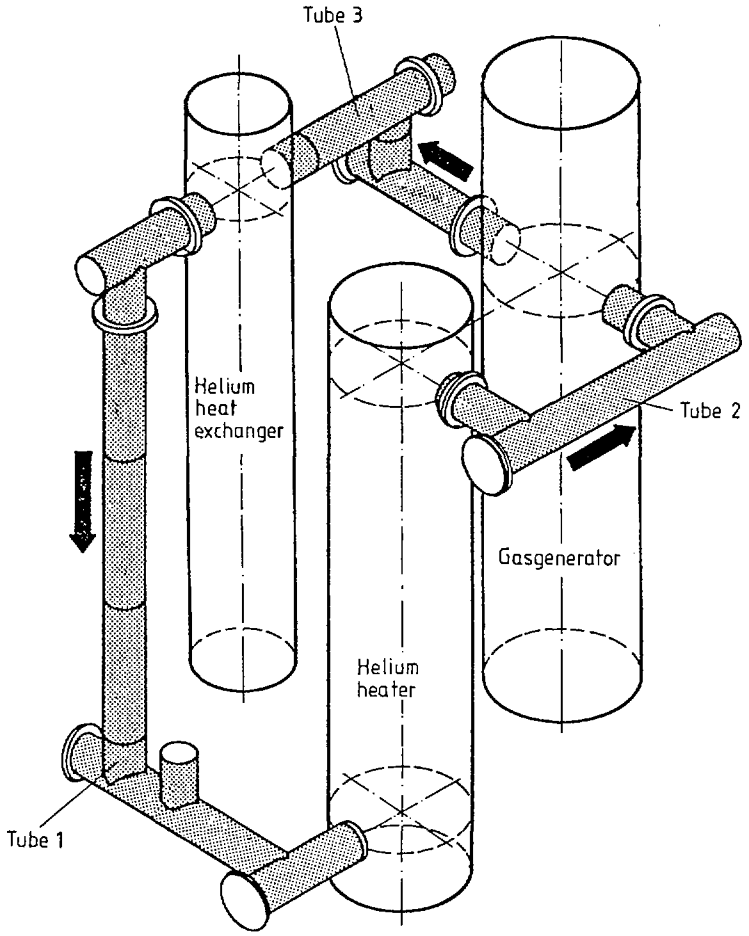


Fig. 7: Arrangement of the pipelines for hot helium within the semi-technical coal gasification plant

Early in 1976 were carried out initial functional tests (pressure test, test runs), followed by a two months' trial run. During this period the circuit was operated both as open cycle on air and as closed cycle at 3 bar operational pressure and nitrogen as heat carrier. The hot gas lines with interior insulating brickwork were pre-dried simultaneously. During this period the plant was operated on nitrogen under a pressure of 15 bar. The unexpectedly high humidity of the inner bricklining led, during the subsequent trial phases, to heat carrier losses and some damages at the inner lining of the helium heater, this due to gas formation by the reaction of coke with steam. As soon as the lining brickwork was dry enough helium was used as heat carrier, and operational pressure was increased to 40 bar. Mid-1978 the helium heater was scaled up to 0.9 MW. Given the optimized conditions for use of high volatile bituminous coal, a second up-scaling of the electric capacity of the helium heater to 1.7 MW was implemented during the third quarter of 1980. At the same time a new helium circulating compressor of 21 000 m^3/h (i.N.) capacity was installed (the capacity of the previous compressor had been 10 360 m^3/h (i.N.)). The above modifications proved their usefulness in the course of the further test operation.

During all of the trial phase thermal investigations were carried out concerning the helium/helium heat exchanger since practical experience on this apparatus is significant for the planning of bigger plants under the PNP project. Table no. 1 compares design and operational data.

Table no. 1: Design and operational data of the helium/helium heat exchanger

		Design data	Operational data
Surface	m^2	103	103
Helium volume flow	m^3/h (i.N.)	22 000	20 116
Operating pressure	bar	40	39.3
Heat transfer	W/m^2K	234	217.1
δ_{ln}		57.9	74.7
Heat withdrawn	kW	1 396	1 671
Efficiency	%	91.5	91.6

2.3 Gas heaters

Aside from the electric helium heater there are two other gas heaters installed at the semi-technical gasification plant. They are one gas-fueled and one electric steam heater. The operational data of these apparatuses can be seen, further to the data of the electric helium heater, on Fig. 8.

The gas-fueled superheater brings the steam raised in the steam boiler to 900 °C. During this the tubes of the heat exchanger - Fig. 9 - have to resist to the full pressure gradient of 40 bar between fueling section and steam section. This heater went defective in February 1978.

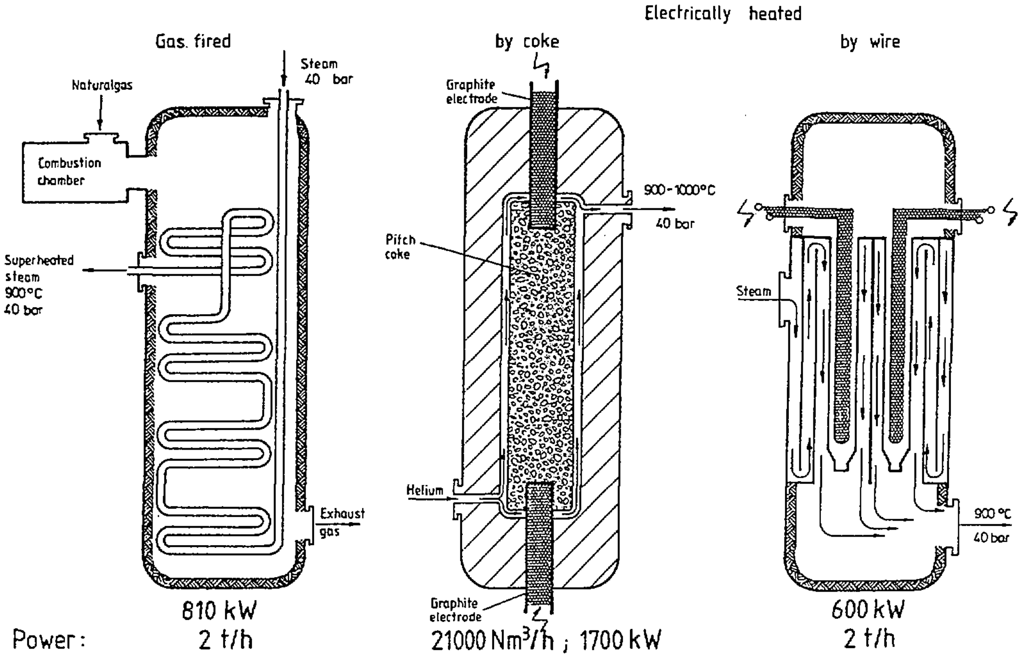
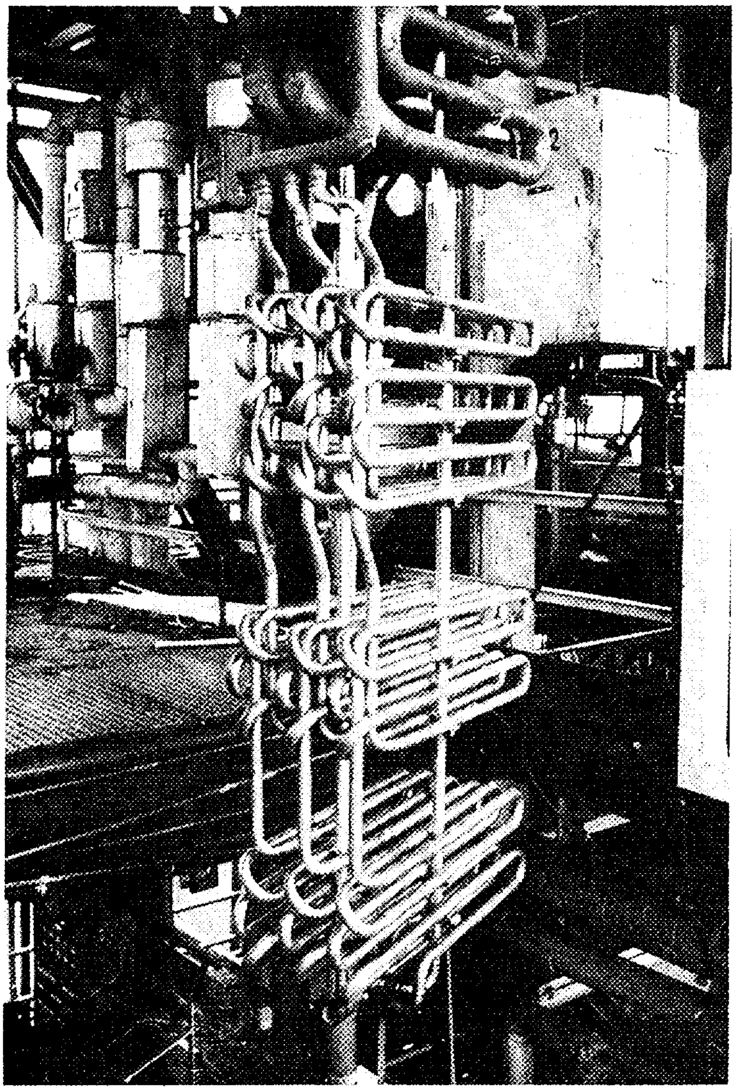


Fig. 8: Big gas heaters at the semi-technical coal gasification plant

The cause of this were three cracks in the supporting tubes. The complete heat exchanger system had to be dismantled and checked. It was found out that, aside from the cracks in the supporting tubes made of 15 Mo 3, tube bundles no. 3 and 4, of 13 Cr Mo 44, showed considerable scaling and were badly distorted. Tube bundle no. 2, of Incoloy 800, was free of scaling and hardly distorted. Bundle no. 1, of HK 40, was in perfect condition. Upon this the supporting tubes as well as bundles 3 and 4 were manufactured out of Incoloy 800. The new tube bundle - Fig. 9 - has resisted to test operation without any damages so far.



<u>Fig. 9:</u> Heat exchanger tube bundle of the gas-fueled steam superheater

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The electric steam superheater consists of a vertical insulated pressure vessel into which process steam is entered and passed evenly distributed through 36 annular tube gaps arranged in parallel whereby it is heated up to maximum 900 °C discharge temperature. In the center of the double tube construction is the electric heat conductor, mounted on ceramic material, including tmeperature controls at two different levels in order to protect the heat conductor from overheating by a cut-out system. In Fig. 10 is represented the top section of the electric steam superheater including the heat conductor arrangement. Certain problems were encountered with the electric steam superheater during the past. During the spring of 1979 - like in previous years - the heating wires of the conductor repeatedly went defective due to inadequate welding connections and excessive material deposits.

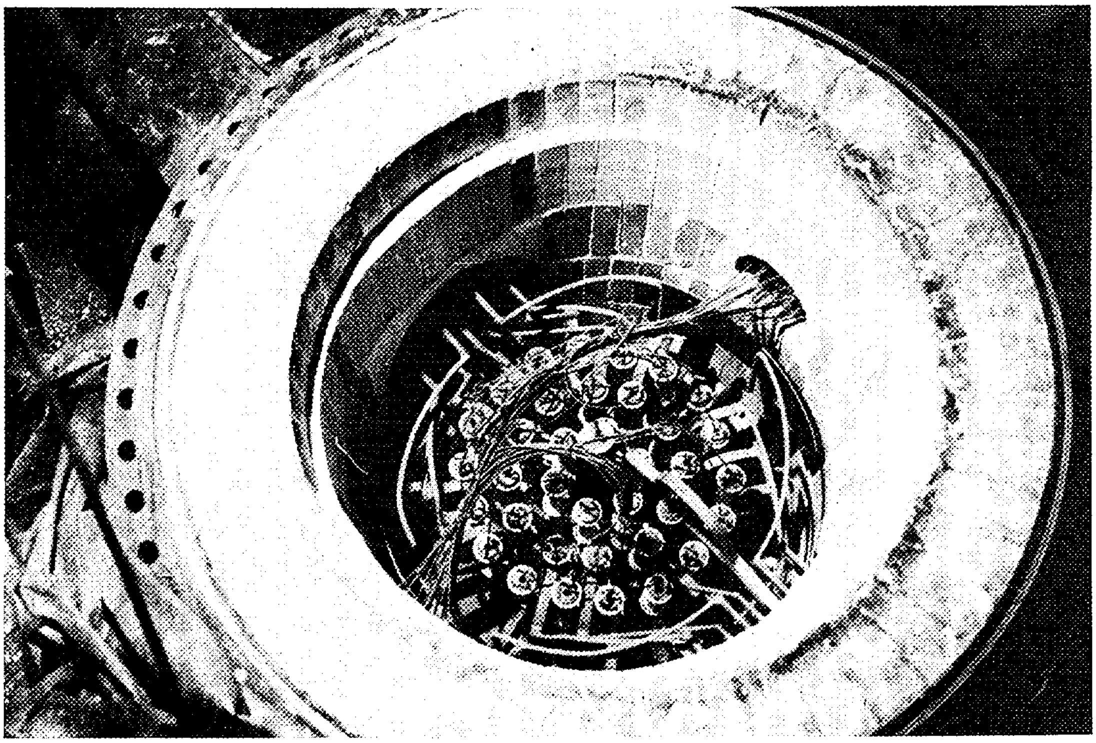

Fig. 10: Heating arrangement in the electric steam superheater

Damages of the above kind can be seen on Fig. 11. One of the causes was found out to be the excessive nickel content so that in April 1979 the heating cartridges were replaced by items of different quality. Further improvements were possible by using heat conductors of Incoloy 800 whose varying cross-sections were obtained by hammering.

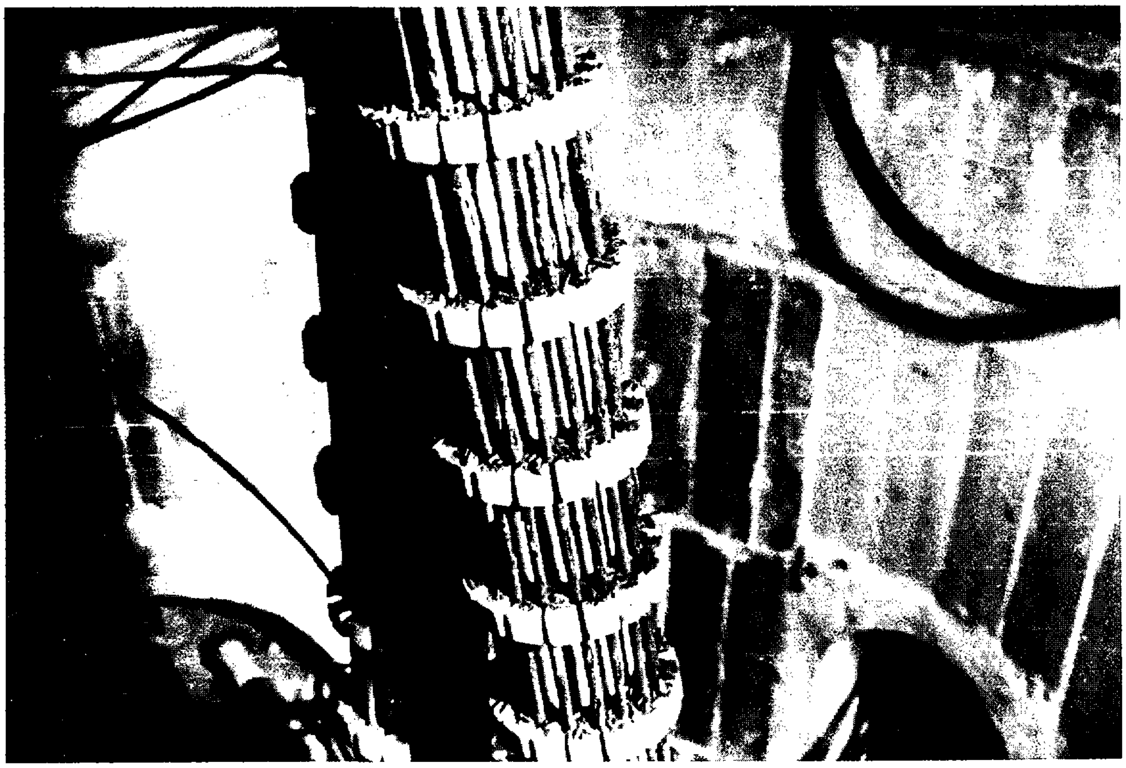

Fig. 11: Damaged heat conductor

The new heating arrangement was equipped additionally with an inner shell preventing major heat differences thanks to its aluminium oxide fibre lining. Major heat differences entraining varying elongations had, indeed, contributed to the damages and, along with unfavourable mounting arrangements, led to distortions of the heat cartridges and thus, to ruptures of the heating wires.

Based on practical experience the installation has been optimized so that the basical problems are overcome by now. And there is a sufficient amount of sound data available to back up the erection of a plant scaled-up in size.

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