Section 17

RECENT OPERATIONAL RESULTS OF HIGH-TEMPERATURE WINKLER AND HYDROGASIFICATION PROCESS

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ABSTRACT

In the Federal Republic of Germany the Rheinische Braunkohlenwerke AG, Cologne, owner of large brown coal reserves, has developed two fluidized-bed gasification processes under pressure on the basis of knowledge gained with the successful operation of atmospheric Winkler gasifiers. These processes are the High-Temperature Winkler (HTW) process for the production of synthesis gas rich in $CO+H_2$, and the Hydrogasification (HKV) process for the production of substitute natural gas (SNG).

Due to the good results obtained with test plants for both processes, pilot plants were built which have been operating to satisfaction. At present, a commercial-size demonstration plant is under construction to scale up the HTW process.

In the following paper, both lines of development, the results obtained so far as well as the present state are reported.

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SECTION 1

INTRODUCTION

Due to its widespread availability, coal is one of the primary energy sources that in future will play a decisive part in reducing the present dependence of a great number of industrialized countries on crude oil and natural gas. In particular, this will apply to the Federal Republic of Germany where coal is available in large quantities.

In coal utilization, gasification can be an important factor. Entrained-phase gasification, fluidized-bed as well as solid-bed gasification are basic processes the Rheinische Braunkohlenwerke AG (Rheinbraun) has gained experience with over the years.

At the Union Rheinische Braunkohlen Kraftstoff AG (Union Kraftstoff) at Wesseling, a Rheinbraun subsidiary, two Winkler gasifiers with a capacity of 17,000 m^3(STP) per hour of raw gas each were operated during the 1950s and 60s.

At that time, the advantages of using the fluidized-bed process for gasifying brown coal from the Rhine area were already known. But also experience with other processes was gathered at Union Kraftstoff, e.g. by operating solid-bed gasifiers according to the Pintsch-Hillebrand process and entrained-phase gasifiers according to the Otto-Rummel process.

Due to its low hardness, Rhenish brown coal after being mined and pretreated shows a rather fine grain structure which prior to its use in solid-bed gasifiers necessitates an additional briquetting step. On the other hand, due to the high reactivity of the relatively recent brown coal, neither additional pulverizing nor high gasification temperatures are required as is the case for entrained-phase gasification.

During the 1960s, gasification of Rhenish brown coal was completely replaced by the use of crude oil and natural gas. Towards the late 60s, however, a revival of interest in resuming and speeding up further development of conventional gasification technology took place, e.g. by increasing the gasification pressure and enlarging the variety of products by the use of different gasification agents, such as hydrogen, in order to improve the competitive capacity of fluidized-bed gasification. During the said period, two routes of development were started simultaneously:

- development of the Winkler process to the High- Temperature Winkler (HTW) process for synthesis gas production by increasing both gasification pressure and temperature;

- modification of the Winkler process by using hydrogen instead of oxygen/steam mixtures as gasification agents to produce substitute natural gas (SNG), i.e. development of the coal hydrogasification (HKV) process.

In the following, details on the development of these two processes to their present state are given.

SECTION 2

PRODUCTION OF SYNTHESIS GAS BY THE HIGH-TEMPERATURE WINKLER (HTW) PROCESS

This process closely follows the well-known atmospheric Winkler process which already showed the following advantages:

- low oxygen consumption
- simple coal preparation
- good partial load behaviour over a wide range of performance
- simple start-up and shut-down conditions of the gasifier
- high operational reliability
- no by-products in the raw gas, such as tars and liquid hydrocarbons.

DEVELOPMENT OF THE HTW PROCESS

Further development to the Rheinbraun HTW process added three major characteristics to the said advantages of the atmospheric Winkler gasifier:

- By increasing the pressure to 10 bar the reaction rate and thus the specific performance per gasifier cross-section unit was increased while the compressive energy required for the subsequent chemical syntheses was reduced.

- By recirculating the dust fines entrained from the fluidized bed it was possible to essentially increase the C-conversion rate.

- By increasing the temperature the methane content in the raw gas was reduced and the carbon conversion rate and thus the gas yield increased. As a result favourable preconditions were obtained in regard of gas quality and specific gas yield for the production of synthesis gas.

In addition to synthesis gas production for the chemical sector, the Rheinbraun HTW process is also well suited for producing reducing gas, hydrogen as well als low- BTU gas for use in combined gas/steam-turbine power stations.

DESCRIPTION OF THE HTW PILOT PLANT

Rheinbraun worked out the fundamentals of the HTW pilot plant and its operation with a process development unit (PDU) run at the Institute of Metallurgy of the Aachen Technical University. This plant (with a throughput of about 50 kg/h) is still operated to test a wide range of carbon carriers, such as wood, peat, lignite, sub-bituminous coal and coke for use in the HTW process.

In 1978, a Rheinbraun HTW pilot plant went on stream at the site of the Rheinbraun brown coal preparation plant at Frechen near Cologne. Rheinbraun's engineering partner for pilot plant planning and construction was Uhde GmbH, Dortmund. Fig. 1 shows a flow sheet including the plant's major design data. As feedstock dried brown coal with an 18% moisture content is used as is usually taken for briquetting.

In the brick-lined gasifier the coal first reacts at about 700 to 800°C in a fluidized bed with oxygen/steam mixtures or air injected at different gasification levels. In this stage, in addition to partial coal and gas combustion for heating energy generation, the endothermal degassing reactions take place during which, among others, CO_2 and CH_4 are produced from the brown coal while a semi-coke is formed. Part of this semi-coke reacts endothermally with steam and to a smaller degree with CO_2.

When escaping from the fluidized-bed surface, in the entrained-phase zone where a much lower solids density is given, coke dust and gas are reconverted with oxygen and steam. In this way, carbon conversion is completed at an elevated temperature in the 1,000 to 1,100°C range and the desired gas composition obtained, i.e. high CO and H_2 contents and the lowest possible CO_2 and, in particular, CH_4 contents.

In order to test part of the gas retreatment required for synthesis gas production, a partial raw gas flow is branched off to a wet scrubber where the residual fine dust is washed out while in a downstream converter various sulphur-resistant catalysts are tested for their efficiency. Fig. 2 shows a view of this plant.

TEST RESULTS OF THE HTW PILOT PLANT

By the end of 1984 the pilot plant had been in operation for about 34,500 hours including about 24,600 hours of operation under gasification conditions. About 18,300 tonnes of dried brown coal had been processed in various programs. The average availability of the unit reached from about 65 to 70% during the last years. The longest continuous operating period was seven weeks.

Tab. 1 shows a comparison between operating results of the HTW pilot plant and those of conventional Winkler gasifiers using oxygen/

steam as gasification agent. It can be seen that the carbon conversion rate increased from 91 to 96% and consequently the syngas yield per tonne of brown coal rose, too.

The synthesis gas yield of nearly 1,600 m^3(STP) per tonne of dried brown coal, calculated moisture- and ashfree (maf), corresponds to 95% of the maximum synthesis gas yield of approximately 1,650 m^3(STP) per tonne of dried brown coal, maf as theoretically calculated at a temperature of about 950°C.

Compared to the atmospheric Winkler gasifier, it was also possible to more than triple the specific synthesis gas yield to nearly 7,000 m^3(STP) $CO+H_2$ per m^2 of gasifier cross-section and hour by increasing the pressure to 10 bar.

The HTW gasifier shows a very favourable load behaviour. No trouble occurred when at a 10 bar pressure the coal throughput was varied from about 470 to 1,750 kg and about 1.5 to 6 tonnes/$m^2 \cdot h$, resp.. It should be noted that when a constant specific oxygen supply is maintained the synthesis gas yield considerably increases with a rise in coal throughput up to the maximum value of about 1,600 m^3(STP) per tonne of dried brown coal, mentioned above. It has to be proved, however, that this value can be maintained for very high throughputs of up to 1,750 kg/h and 6 tonnes/$m^2 \cdot h$, resp.. On the other hand, by raising the oxygen supply a drop in specific syngas yield caused by a reduced throughput can be compensated. Fig. 3 shows a summary of the major performance parameters as a function of coal throughput. The reduction in the specific O_2 supply with increasing throughput is traceable to the relatively high heat losses occurring at the pilot plant which with increasing throughput go down in relation to total energy conversion. It is possible to increase the coal throughput to quantities exceeding the said amounts but this would result in a higher methane content.

Progress was also made in optimizing the consumption of gasification agents. Fig. 4, for example, shows the great influence of the moisture content of the feed coal on the specific syngas yield. On the other hand, the specific oxygen requirements for a distinct rise in synthesis gas yield will be lower for feed coal dried to a lower moisture content. Coal drying could be performed by steam from the waste heat boiler used to cool the raw gas.

In late 1981, for part of the raw gas flow a water scrubbing system and a CO-shift conversion unit were commissioned in order to gather experience for a rather large HTW demonstration plant which is to be adjusted to an H_2-to-CO ratio of approximately 2.3 to 1 required for methanol synthesis. This raw gas shift conversion using a sulphur-resistant catalyst saves one gas scrubbing step and in addition improves the overall thermal efficiency.

Before feeding the raw gas into the conversion stage its dust content has to be reduced to less than 5 mg/m^3. This is carried out in a wet scrubbing system.

Apart from initial difficulties, the wet scrubber for dust separation has been working to satisfaction and reached very low dust contents of 1 to 2 mg/m^3 of raw gas. On the other hand, a concentration of solid material of up to 120 g/l in the waste water discharged from the scrubber occurred. In the CO-shift conversion unit conversion rates of 70 to 90% were obtained at 7 to 8 bar with sulphur-resistant catalysts originally developed for a pressure of about 30 bar.

DESCRIPTION OF THE HTW DEMONSTRATION PLANT

On the basis of knowledge gained with the HTW pilot plant, described in the foregoing section, Rheinbraun started work on construction and operation of a HTW demonstration plant for converting dried brown coal into synthesis gas. This demonstration plant at the site of Rheinbraun's Ville-Berrenrath brown coal preparation plant includes one HTW gasifier and all subsequent gas treatment units with a capacity of about 300 million m^3 of synthesis gas per year; it will go on stream in mid-1985.

The synthesis gas will be piped to Union Kraftstoff at Wesseling where it is to be fed into the existing synthesis gas line as a substitute for synthesis gas at present produced from residual oil.

Fig. 5 shows a simplified flow sheet of the HTW demonstration plant. The new part of the plant starts with the brown coal bunkers to be supplied with the pretreated brown coal via a conveyor belt from existing facilities. The brown coal lock-hopper and feeding system is a two-line construction designed for a maximum performance of 33 tonnes of dried brown coal per hour. Gasification itself including dust recirculation is designed according to the HTW pilot plant principles as described in Section 2.2. The hot raw gas with the solid particles having been separated is cooled to approximately 350°C in a horizontal fire tube waste heat boiler. The heat obtained is utilized to produce medium-pressure steam part of which is used as process steam in the gasifier. The residual raw gas heat is used for resaturating the raw gas in a quench vessel while at the same time further dust separation from the gas takes place. Separation of fine dust particles is then carried out by means of a venturi tube and a scrubbing tower.

In the subsequent CO-shift conversion sulphur-resistant catalysts are used to obtain the hydrogen/carbon monoxide ratio required for methanol synthesis. Following the conversion phase the converted gas is compressed to about 37 bar and then led to a one-stage H_2S/CO_2 scrubber. In this so-called Rectisol scrubber the CO_2 is washed out at temperatures below 0°C with a methanol solvent according to synthesis gas requirements while the sulphur compounds are removed as far as possible. The flash gas from the scrubber is recirculated to the sulphur recovery plant. The scrubbed carbon dioxide is partly compressed and used as a pressurizing medium for the brown coal, ash, and dust lock hoppers and partly discharged into the atmosphere. The H_2S obtained is converted into saleable elementary sulphur. The synthesis gas purified and processed to specification is piped from the CO_2/H_2S scrubber to Union Kraftstoff at Wesseling. Fig. 6 shows a view of the demonstration plant.

CHARACTERISTICS OF FEEDSTOCKS TO BE GASIFIED

In principle, the HTW process is suitable not only for Rhenish brown coal but also for several other types of coal (i.e. lignite, subbituminous and other low-caking coals) as well as other raw materials, such as peat, wood and biomass.

Considering the specific gasification conditions of a fluidized-bed gasifier, the feedstocks should have the following properties:

- Sufficiently high reactivity for gasification with oxygen/steam or air at temperatures below ash fusion.
- The ash fusion point should be higher than 1,100°C.
- Feedstocks should have low caking tendency.

In order to determine the suitability of feedstocks for HTW gasification a number of laboratory and PDU tests have been carried out by Rheinbraun in close cooperation with the Aachen Technical University. These tests and project studies have been performed for potential customers from all over the world. For example:

- wood (Brazil, Sweden, Kenya)
- peat (Finland, Sweden, USA)
- lignite (USA, Canada, Greece)
- bituminous coal (South Africa, Australia)
- coke from the hydrogasification of Rhenish brown coal.

The gasification behaviour of a special feedstock depends on its degree of coalification and its geological age, resp..

Its age pre-determines its chemical composition, in particular its contents of carbon, hydrogen and oxygen as well as the amount of volatiles and the reactivity of the coke produced from this feedstock. Therefore the volatiles content of a carbonaceous material and the reactivity of the coke are essential indicators for the gasification behaviour. The content in volatiles determines the reaction kinetics in the fluidized bed. A high volatile content causes a quick reaction of the feedstock up to the formation of coke resulting in high feed rates and low fluidized-bed temperatures. The bed temperatures can only slightly be influenced by variations in the oxygen rate. A higher oxygen rate combined with a constant coal feeding rate tends to result in a reduced bed depth since the additional heat liberated by the reactions with oxygen will immediately be used up in endothermal degassing and gasification reactions.

These relationships allow the conclusion that carbon carriers with high volatile contents as well as reactive coke can easily be gasified at low temperature and high reactor throughput rates. Consequently, the ash fusion characteristics are not decisive. As can be further observed, the ash content of these feedstocks is often quite low.

Therefore the HTW process seems to be well suited for the gasification of biomass. Tests showed, however, that also less reactive feedstocks, such as sub-bituminous coals can be gasified with high reaction rates provided the ash fusion behaviour allows the operation at the higher temperatures required. The coal throughput per cross-section unit of the reactor, of course, is lower than in the case of reactive biomass. But this effect will partly be compensated by a higher production of $CO+H_2$ per tonne of feedstock. Table 2 shows these effects as found in running the PDU for the HTW process at 1 bar under comparable conditions for wood, peat, Rhenish brown coal and lignite.

SECTION 3

PRODUCTION OF SNG BY THE HYDROGASIFICATION (HKV) PROCESS

As a fluidized-bed process, hydrogasification of Rhenish brown coal includes many characteristics of the Winkler process. Its basic difference, however, is that hydrogen is used as gasification agent in place of mixtures consisting of oxygen and steam. Oxygen can be dispensed with since part of the degassing reactions as well as gasification reactions are exothermal ones.

DEVELOPMENT OF THE HKV PROCESS

Process development up to a commercial-size gasifier will be carried out in several steps. Since the test results (Tab. 3) had been very encouraging, the construction of a pilot plant was started without delay.

For the process development unit (PDU) operated from 1975 till late September 1982 up to 0.4 tonnes/h of raw brown coal were used in a gasifier having an inner diameter of 0.2 m. The pilot plant which was built at the site of Union Kraftstoff, Wesseling, as was the case with the PDU, has been designed for the use of 23.5 tonnes /h of raw brown coal in a gasifier with an inner diameter of 1 m. While with the PDU only the gasification step was tested, the pilot plant in addition includes a complete gas treatment step.

The hydrogasification process is aimed at producing a saleable high-BTU gas. Therefore it is necessary to control the chemical reaction in the gasifier by defining the basic variables (i.e. partial pressure of hydrogen p_{H_2}, residence time of fixed material t, and the temperature of the fluidized bed t_{WS}) as well as the ash content and coal charging level in such a way that the highest possible part of the entire carbon gasified is converted preferably into methane and ethane.

Fig. 7 gives the functional relationship observed at a partial [illegible] shows for different charging levels the amount of carbon gasified into the products methane and ethane--in this case summed up as "CH_4"--as well as into carbon monoxide and carbon dioxide.

In Fig. 8 a simplified flow scheme of the HKV pilot plant is shown which comprises coal preparation, gasification, Amisol scrubbing and cryogenic separation.

Silo trucks deliver the milled coal pre-dried to a moisture content of about 12% for intermediary storage in a 600 tonne bunker. Subsequently, the coal is pneumatically conveyed via a spiral tube drier and a cyclone to a height of about 80 m.

In the spiral tube drier the coal can be redried to a minimum moisture content of 1%. This second drying step has been chosen only to test coals at different moisture contents. So far the tests were concentrated on a moisture content between 6 and 8%. Via a two-line feeding system consisting of one dosing screw, two parallel-working lock hoppers, and one feeding vessel each, the coal is dosed into the gasifier.

One of the main characteristics of hydrogasification is that no maximum C-conversion rate is aimed at since the optimum C-conversion rate of brown coal for reasons of economic efficiency is believed to range from 60 to 70%. Therefore about 25% of the coal charged is obtained as residual char. Below the charging level of the hydrogenation gas this residual char is cooled to about 250 to 300°C in a moving bed before being discharged from the bottom part of the gasifier via a lockhopper system.

The raw gas mainly consists of methane and unconverted hydrogen. It leaves the gasifier at the top, passes the dust cyclone, the hydrogenation gas heat exchanger and the waste-heat boiler where it escapes having a temperature of about 250°C. In the subsequent wet scrubber the remaining dust particles are washed out. The raw gas then enters the Amisol scrubber where the acid gas components CO_2 and H_2S as well as other impurities are separated using a DEA lye consisting of methanol and diethanolamin.

The clean gas from the Amisol scrubber is then split up into CH_4, H_2 and $CO+N_2$ fractions in a cryogenic separator at approximately -180°C.The methane obtained is piped into the natural gas system of Union Kraftstoff. The hydrogen fraction is recompressed and then, together with the hydrogen from the petrochemical plant of Union Kraftstoff used to meet most of the basic demand, preheated to about 600 to 700°C by heat exchange with the raw gas. In the downstream combustion chamber this hydrogenation gas can be adjusted to the preheating temperature required by means of partial combustion with oxygen.

In an commercial-size plant the feed hydrogen needed to balance the hydrogen requirements is produced as follows: In the hydrogasification step only 50% of the carbon is converted in order to obtain residual char sufficient for feeding a High-Temperature Winkler plant where $CO+H_2$ is produced. In a subsequent shift conversion the CO fraction is then converted into H_2 as well.

Fig. 9 gives a view of the plant, in particular showing gasification tower, Amisol scrubber and cryogenic separator.

TEST RESULTS OF THE HKV PILOT PLANT

According to cold model tests, a satisfactory fluidization both in the pilot plant and in the PDU were to be expected by adequately distributing the gasification agent. Therefore corresponding pilot plant test results were assumed. To prove these assumptions, however, detailed gasification tests had to be carried out since with scaling-up of other fluidized-bed processes extremely high losses in yield or efficiency had been observed.

On the other hand, compared to the PDU an improved efficiency was to be expected due to the pressure being elevated up to 120 bar and the fluidized bed having a greater depth.

The test program includes 18 operating phases with a total of 52 test settings. For each setting an average test period of 3 days is assumed. In order to allow evaluable test results stable operating conditions will have to be ensured.

In the program the effects of the following test parameters are to be investigated:

- coal throughput (mf) from 4 to 10 tonnes/h
- gasification pressure from 65 to 120 bar
- gasification temperature from 850 to 950°C
- fluidized-bed depth from 400 to 600 cm
- ash content of the feed coal from approx. 4 to 15%wt.

The tests are to establish the effects of the considerable increase in the size of the gasifier compared to that of the PDU. A further step is to optimize the process including the utilization of the gasifier's greater flexibility with regard to fluidized-bed depth, coal throughput and gasifier pressure. In addition, tests with auxiliary components, in particular raw gas treatment and gas separation, in combination with the gasifier are important development targets for the entire coal hydrogasification process.

Since gasification was started in May 1983, a number of successful test runs have been carried out. As Fig. 10 shows, the pilot plant was operated from July 1983 to June 1984 for more than 4,800 hours corresponding to a 55% availability; in this period about 10,500 tonnes of dried brown coal were gasified under gasification conditions during more than 2,700 hours corresponding to a 32% availability. The gasification pressure was varied from 60 to nearly 100 bar and the temperature from 800 to 930°C. With throughputs of 6,000 to about 13,000 m^3(STP)/h of hydrogenation gas the methane content in the raw gas was 22 to 36%vol.; about 6 million m^3(STP) of methane were produced.

The longest continuous run was 882 hours, 756 hours of which with coal throughput. During this time 3,924 tonnes of dried brown coal were processed corresponding to an average throughput of 5 tonnes/h. A further increase in pressure to 120 bar may result in a surplus of heat from the exothermal gasification reaction. In this case the moisture content of the feed coal could be increased to above 2%wt. to save drying costs.

The results outlined above permit an initial comparison between the data achieved with the HKV pilot plant and the comprehensive results from the PDU. On the basis of the test results obtained by operating the PDU the relations between operating conditions and efficiency data were fixed. These results were based partially on kinetic models or calculated by statistical regression models.

Two of the most important efficiency data are the carbon conversion rate and the quantity of gas suited for SNG production, i.e. methane and ethane, as a function of reaction volume and time, viz. the so-called space-time-yield.

In Figs. 11 and 12 data calculated according to the relations mentioned above are compared with test data from the pilot plant. As can be seen, both carbon conversion and space-time-yield test data and calculated data correspond well. This allows the conclusion that so far the scale-up of the gasifier has been to satisfaction.

In addition, Figs. 11 and 12 show a group of measured values distinctly below the range of the main values. A detailed investigation shows that these off-range data were measured at lower superficial velocities than those obtained with the PDU.

The reason for this reduced carbon conversion rate may be a lower mass transfer coefficient due to a lower differential velocity between grains and gasification agent or a worse fluidization in the bed. It is startling that for the space-time-yield this effect cannot be found. So far it was not possible to solve this problem.

At present, a study is being prepared on the question whether any interest exists to use hard coal in the HKV pilot plant as well. In the PDU for hydrogasification successful test operations were already performed with non-caking coal (anthracite). As the less positive results with a caking hard coal showed, a special feeding system would be required to obtain satisfactory results and, for reasons of the heat balance, a plant having at least the size of the HKV pilot plant.

When hard coal is gasified the hydrogen required can also be produced by gasifying the residual char in a steam-oxygen gasifier followed by a shift conversion step. In the case of applying sensible heat from a high-temperature nuclear reactor, the hydrogen could be obtained by steam reforming part of the methane produced.

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Teggers, H., Scharf, H.-J., Schrader, L., "Results from the Operation of a Semi-technical Test Plant for Brown Coal Hydrogasification", Nuclear Engineering and Design 78, No. 2, April (I), 1984, P. 223-231, North-Holland, Amsterdam.

		Winkler gasifier	HTW
gasifying conditions temperature pressure	 ° C bar	 950 1,2	 1000 10
gasifying agents oxygen steam	 m3 (STP)/kg*bc_{maf} kg/kg*bc_{maf}	 0,42 0,18	 0,40 0,33
spec. yield ($CO+H_2$) spec. output ($CO+H_2$)	m^3 (STP)/t*bc_{maf} m^3 (STP)/ $m^2 \cdot h$	1462 2122	max.1580 max.6850
C-conversion	%	91	max.96

*bc =brown coal

Tab. 1: Gasification with oxygen and steam

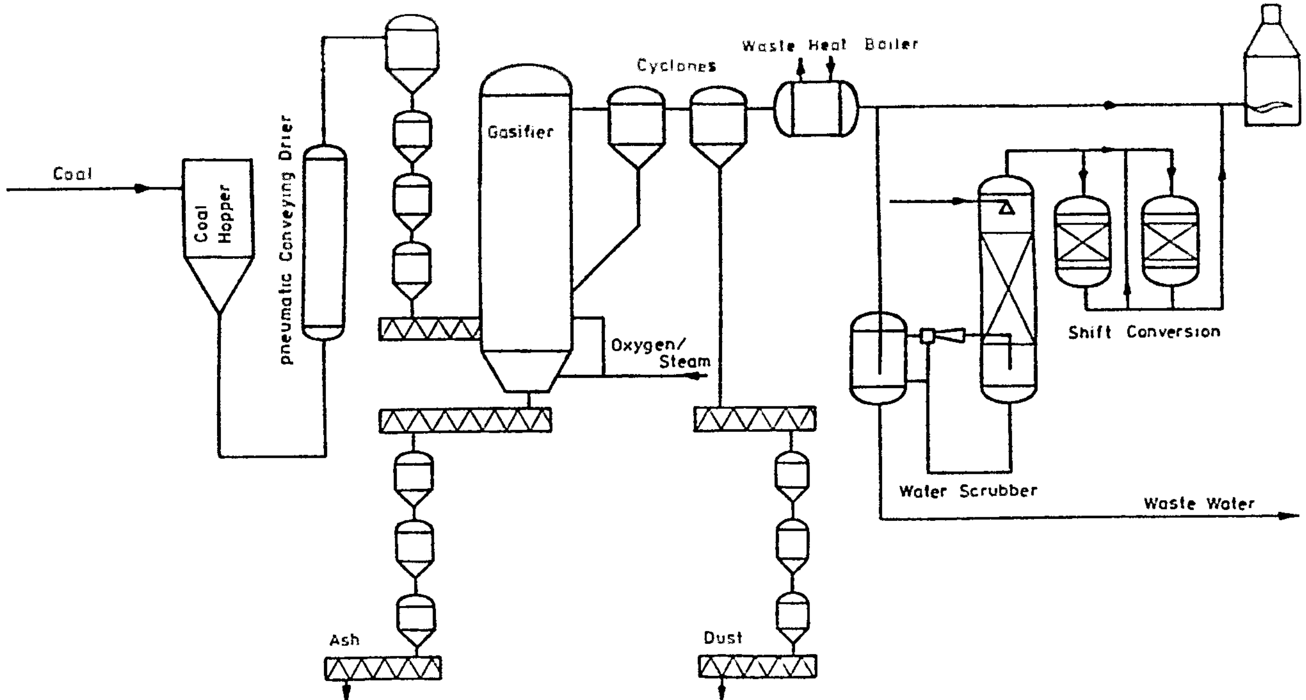
		Wood	Peat	Rhenish Brown Coal	Hard Brown Coal (Lignite)
Specific feedstock throughput	$\frac{\text{t feedstock, maf}}{m^2 \times h}$	1.12	0.89	0.73	0 52
Specific synthesis gas yield	$\frac{m^3\text{ (STP) } CO+H_2}{\text{t feedstock, maf}}$	1 020	1 170	1 370	1 590
Specific synthesis gas output	$\frac{m^3\text{ (STP) } CO+H_2}{m^2 \times h}$	1140	1 040	1 000	830

Gasification pressure: 1 bar, energy loss: 10%, C-conversion: 95%

Tab. 2: Comparison of efficiency data of different feedstocks for the HTW process development unit

	1976 - 23. Sept.1982	
	RHENISH BROWN COAL	ANTHRACITE
PLANT IN OPERATION	26987 h	
OF THAT WITH COAL THROUGH-PUT	12253 h	
COAL THROUGH-PUT (wf)	1782 t	13,6 t
SPEC. COAL THROUGH-PUT(wf)	max. 320 kg/h	max. 160 kg/h
METHANE CONTENT OF CRUDE GAS	up to 48 vol%	up to 25 vol%
DEGREE OF C-GASIFICATION	up to 82%	up to 47%
OPERATING TEMPERATURE	800-1000°C	940-960°C
OPERATING PRESSURE	55-95 bar	80-87 bar
SOLIDS RESIDENCE TIME	9-80 min	28-38 min

Tab. 3: Operating data of the semi-technical pilot plant for hydrogasification of coal



throughput (dry lignite) : up to 1800 kg/h; gasification agents : oxygen/steam or air
raw gas output : up to 4000 m^3/h, pressure up to 10 bar
temperature up to 1100 °C ,

Fig. 1: Flow sheet HTW pilot plant

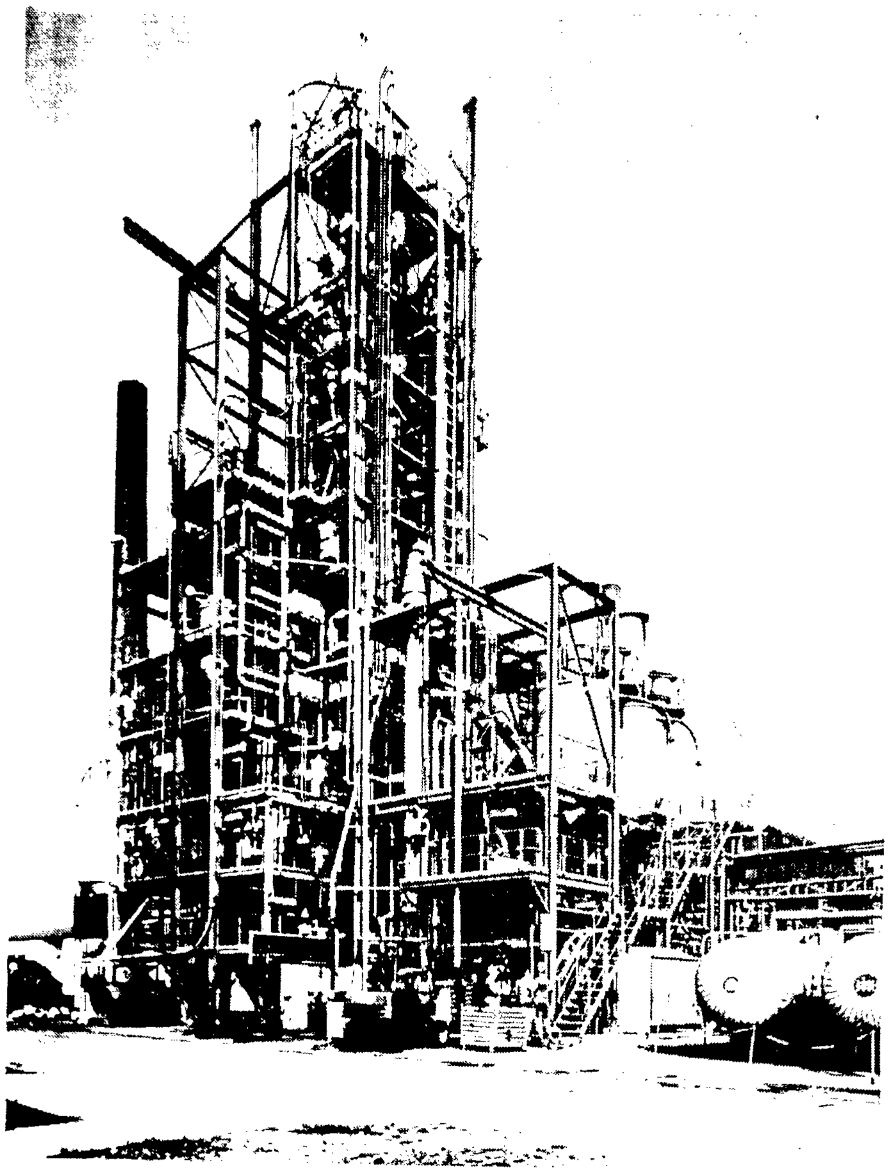


Fig. 2: View of the HTW pilot plant

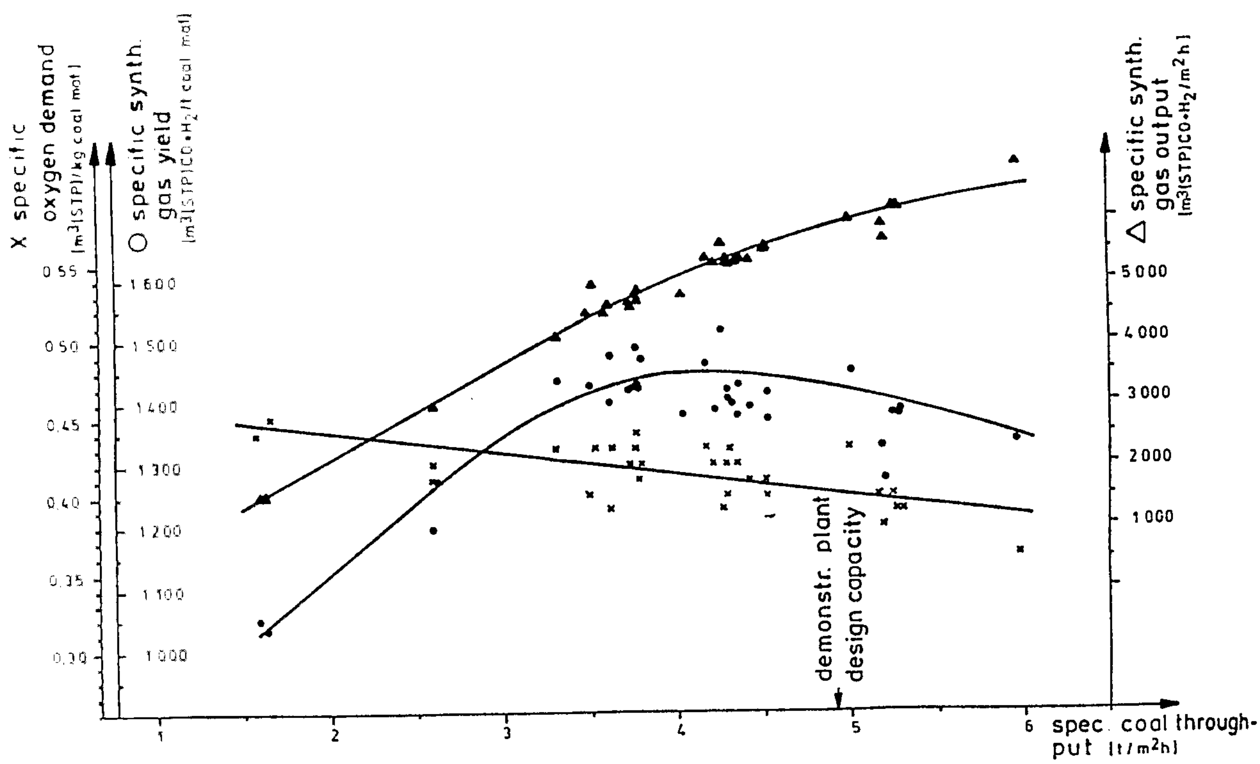
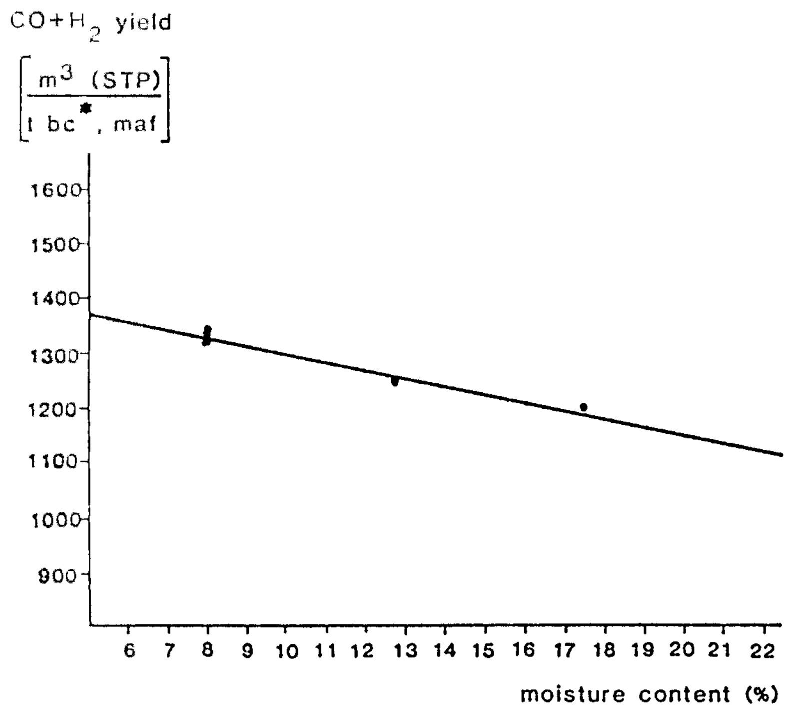


Fig. 3: HTW pilot plant
efficiency data versus specific coal throughput



*bc = rhenish brown coal

Fig. 4: Dependence of synthesis gas yield on moisture content of feed coal

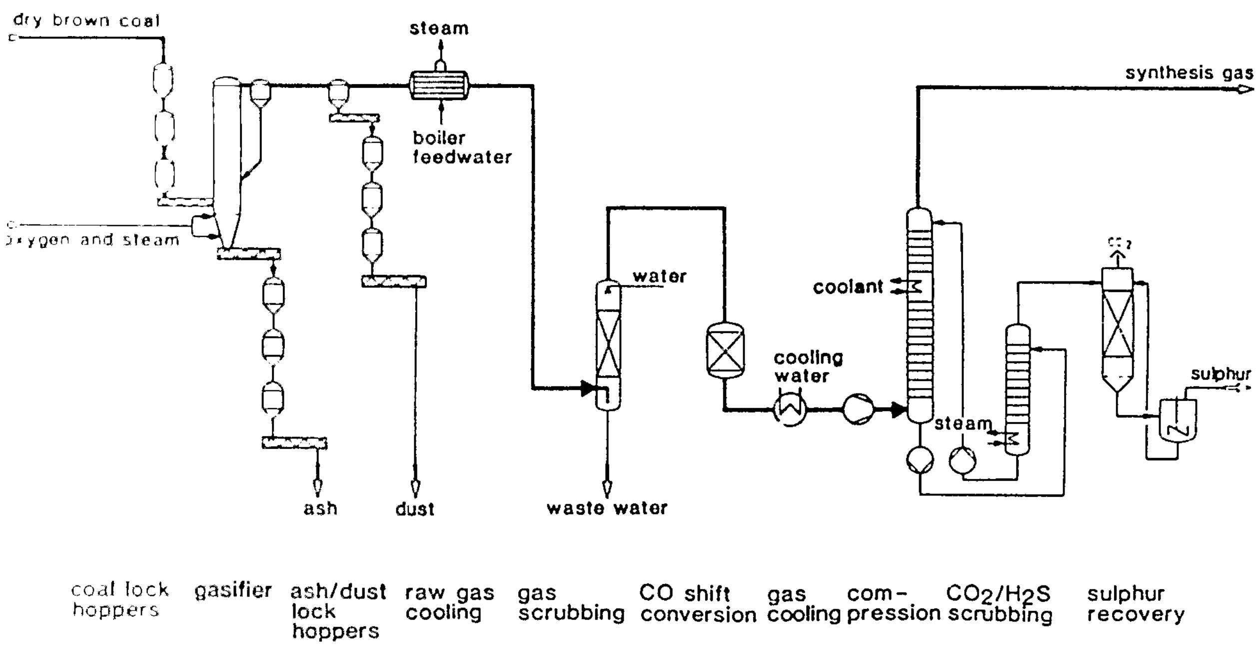


Fig. 5: Flow sheet of the HTW demonstration plant

Fig. 6: View of the HTW demonstration plant

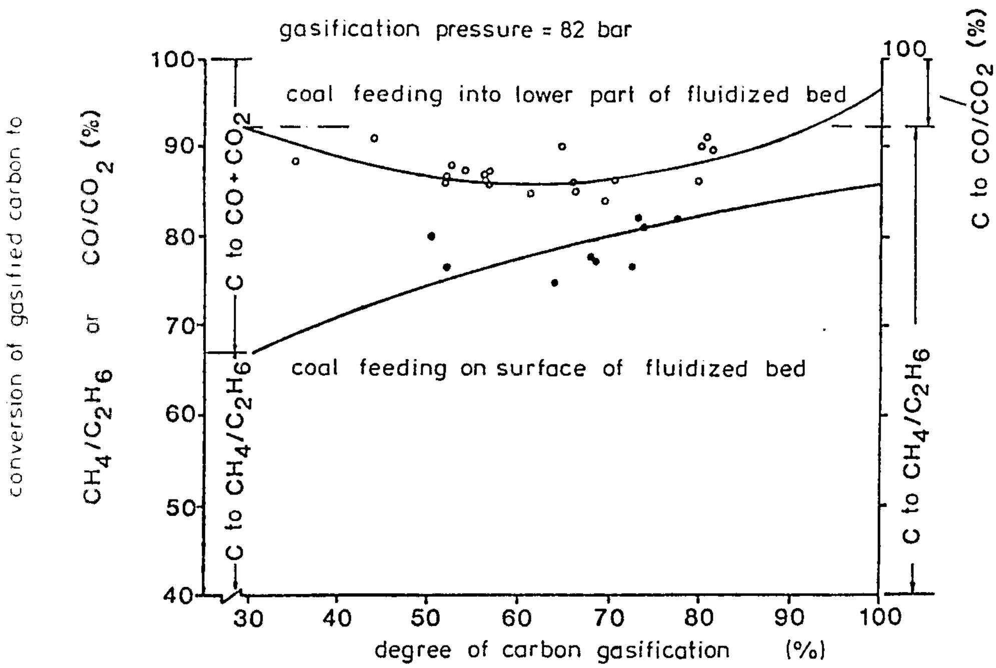
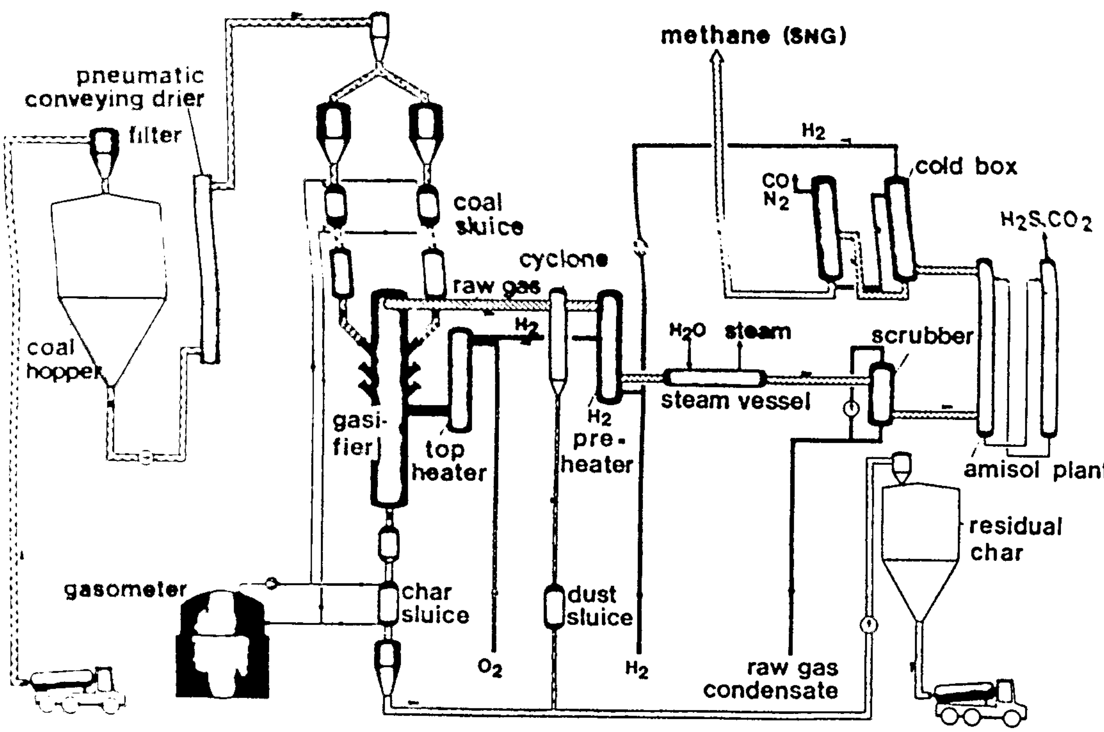


Fig. 7: Influence of coal feeding point on conversion of carbon into gases suitable for SNG



gasification pressure : up to 120 bar
gasification temperature : up to 950 °C

coal throughput : up to 9,6 t/h dried brown coal
gas production : up to 7800 m^3(i.N.)CH_4/h

Fig. 8: Pilot plant for hydrogasification of coal

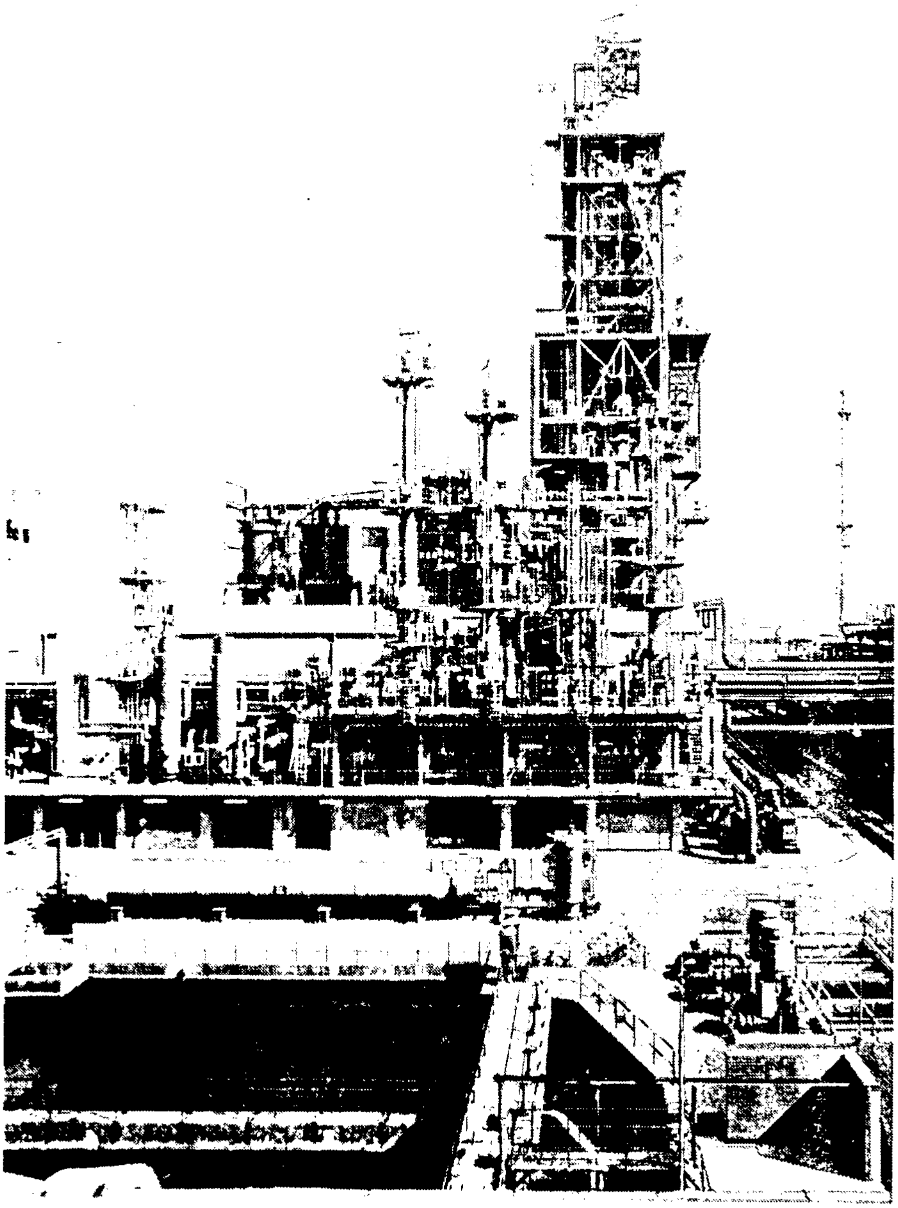


Fig. 9: View of the HKV pilot plant

Start-up of Test Operation		July 1, 1983
Status		June 30, 1984
Plant in Operation	(hours)	4819
Availability	(%)	55
Gasifying Operation	(hours)	2777
Availability	(%)	32
Dried Coal Throughput	(kg/h)	up to 7500
Carbon Conversion	(%)	50-70
Coal Input, accumulated	(t, metric)	10 574
Methane Output, accumulated	(Mill. m^3 STP)	6,3
Specific Methane Output	(m^3 STP/h)	3 650
Methane Content in Raw Gas	(% vol.)	22-36
Operational Pressure	(bar)	60-95
Gasification Temperature	(°C)	850-930
Hydrogenation Gas Throughput	(m^3 STP/h)	6000-12500

Fig. 10: Performance data of the pilot plant for hydrogasification of coal (HKV)

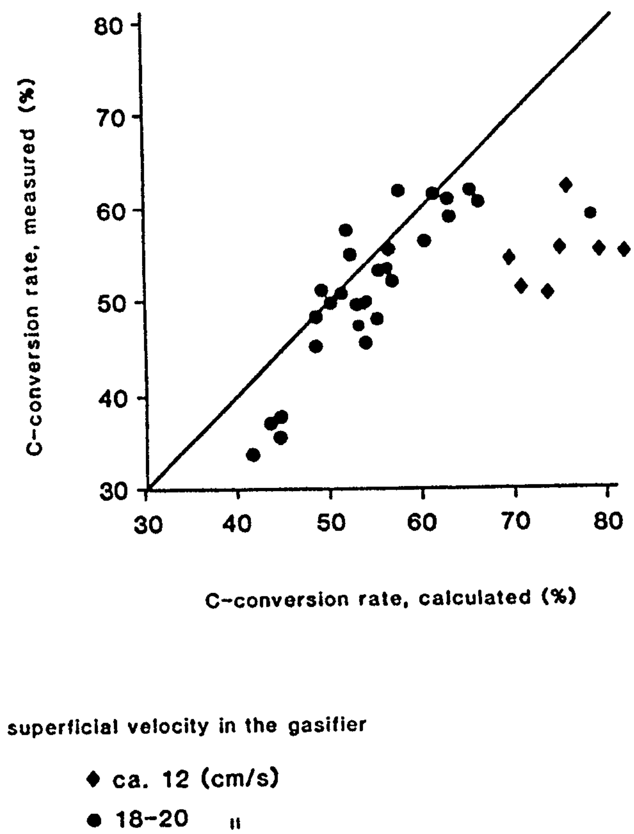


Fig. 11: Comparison of test data with calculated data of the HKV pilot plant, carbon conversion rate

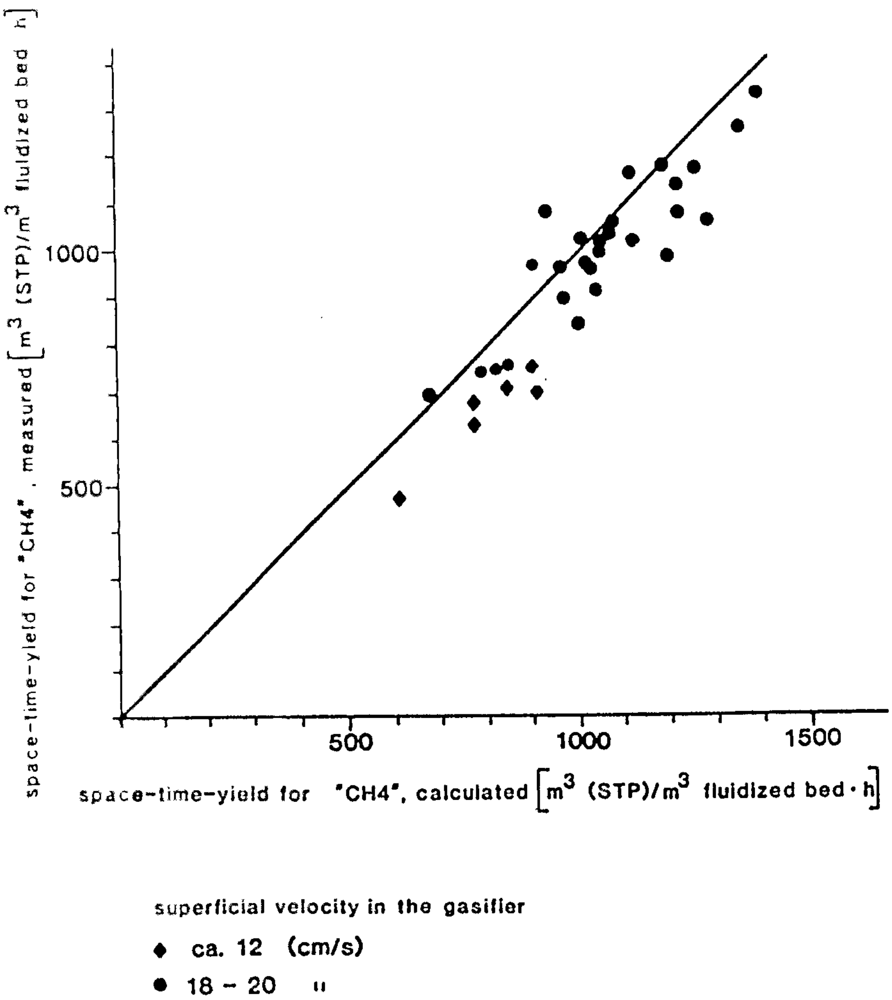


Fig. 12: Comparison of test data with calculated data of the HKV pilot plant, space-time-yield