RUHR 100 - NEW RESULTS ON THE ADVANCED DEVELOPMENT OF THE PRESSURIZED LURGI-GASIFICATION

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Introduction

After the oil crisis in 1973 coal processing in the Federal Republic of Germany acquired a considerable new measure of importance. A number of research and development projects were launched or continued with a view to devising new coal processing technologies or to updating already existing technologies and improving their economics.

One of these projects is the further development of the LURGI fixed bed pressurized gasification system in Dorsten[1] (Federal Republic of Germany). This pilot gasifier called RUHR 100 is designed for a pressure of 100 bar. In the middle of the 1970's this project was launched by the cooperation Druckvergasung (ADV), consisting of RUHRGAS AG, RUHRKOHLE AG and STEAG AG. Since then it has been sponsored by the West German Ministry of Research and Technology under the national energy research program . Early in 1977 an engineering agreement was concluded with LURGI Kohle und Mineralöltechnik GMBH for the engineering design work required for the major plant sections needed for a semi-industrial-scale pilot plant. STEAG was commissioned with the design engineering of the utility facilities.

In view of the experience gained by Ruhrgas in fixed bed gasification[2,3] from 1955 to 1967 and of a number of costlowering facilities the new pilot plant was set up on the area of Ruhrgas at Dorsten. It went on stream in September 1979.

Whereas, conventionally, fixed bed gasification is operated at a pressure of 25 - 30 bar, it was intended at RUHR 100 to raise the pressure to 100 bar in order to utilize for SNG production preferentially the additional potential afforded by this, and within the justifiable application limits of technical facilities.

The most important development targets or expectations were:

- Increasing the operating pressure to 100 bar in order to raise the methane content in the raw gas from less than 10% at 25 bar to more than 17 % at 100 bar. Concurrently, related to the shaft cross-section, the specific throughput was to be raised to double the figure and more.
- Reducing the amount of condensable hydrocarbons and changing the quality towards lighter products in consequence of the increase in the hydrogen partial pressure.
- Reduction of the quantity of dust removed due to reducing the gas velocity in the upper section of the gasifier. With this measure it was intended to produce a shift in the particle size spectrum of the gasifiable coals towards smaller diameters and/or achieve a rise in output. The measure envisaged for this was the withdrawal of a part of the gas flow in the central section of the gasifier, below the carbonization zone.
- Reduction in the carbonization products (tars, oils, phenols) in this part of the gas flow and in the gas water condensed from it.
- Adaptation of the gas quality to the respective utilization purposes with the aid of a raw gas reforming unit.. This was intended to be operated catalytically for the production of SNG at preferably low temperatures, so as to eliminate only higher hydrocarbons and to raise the methane yield. At higher temperatures both higher hydrocarbons and also methane for the purpose of synthesis gas production were to be cracked thermically to CO, CO_2 and H_2.

The total testing time amounts today after a bare three years after plant start-up to more than 4,000 operating hours. With these 4000 hours, only the test hours involving "hot" operation hours were counted. All together a total test time of 4 years is envisaged.

Description of the Process

The RUHR 100 pilot plant has already been described and introduced on several occasions[1,4,5]. Therefore, it is sufficient to deal only briefly with the gasifier and the general concept of the plant.

The plant was conceived for the gasification of oxygen; air gasification is possible and is also carried out in start-up operations.

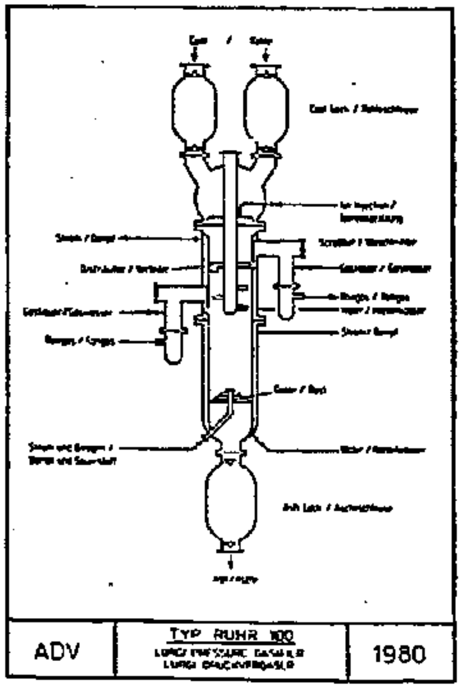


Fig. 1

Fig. 1 shows the gasifier which is operated on the countercurrent system. It is fed from above with coal from a double hopper; the gasification medium mixture of steam and oxygen enters from below via slots in the rotary grate. Ash removal is effected at the bottom via an ash lock hopper.

Fig. 2

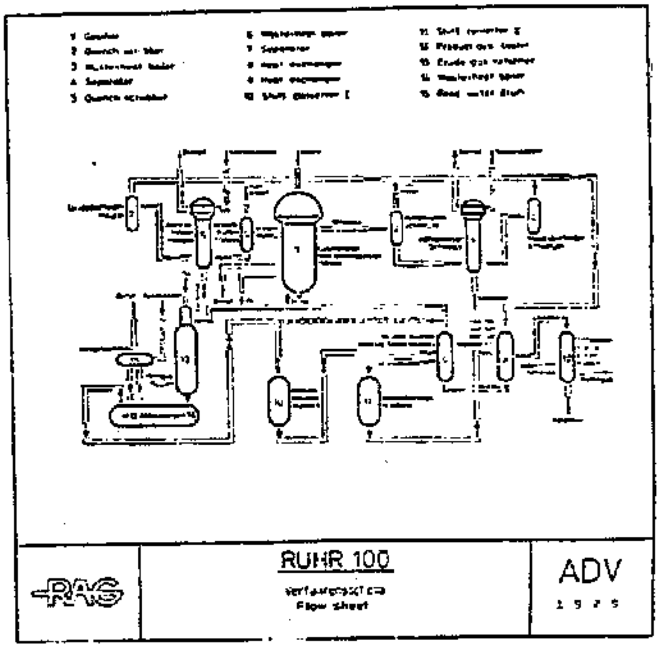


Fig. 2 shows the process flowsheet of the plant. The gasifier has two gas withdrawal outlets for the so-called clear gas, which is drawn off in the central part of the gasifier and is free from carbonization products, and the carbonization gas that is discharged together with the carbonization products from the upper section of the gasifier. Both gas streams are cooled and pre-cleaned in separate quench scrubbers by the injection of water. In the course of this process the raw gas becomes saturated with steam. For binding the dust tar or oil can be added to either the gasifier or the quench scrubber.

In the waste heat boilers the raw gases are cooled down below 200 °C with low pressure steam being generated in this units. Both these gas streams are brought together behind the dust separators in the pilot plant. With a commercial plant a separate cleaning and gas application is by all means conceivable. After stripping the crude gas of dust and tar the pressure is reduced to 25 bar in order to adapt it to the existing facilities of the pilot plant. With a commercial plant further processing would take place at a pressure above the input pressure into the distributor system in order to avoid renewed compression.

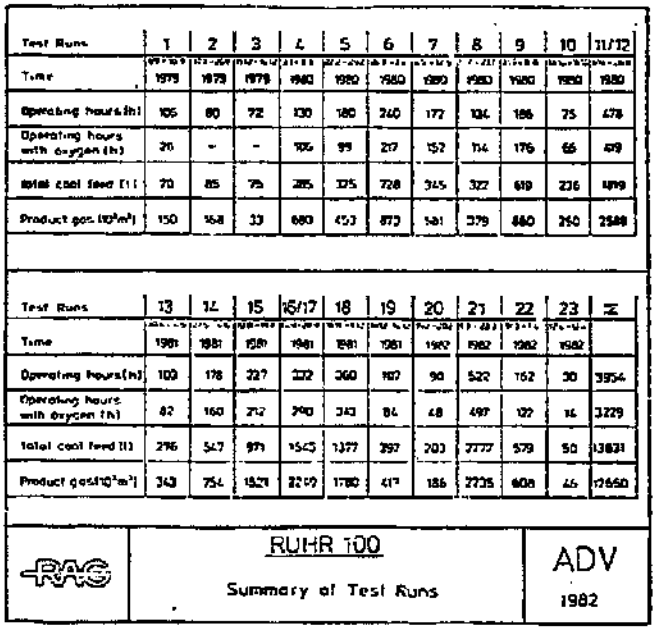
Since it is intended for the raw gas in Dorsten to be passed into the pipeline system, the CO-content must be lowered in a conventional CO-conversion process to below the statutorily prescribed maximum content for heating gases. The shift conversion process operates on a two-stage basis because of the reaction temperature limits of the catalyst:
Interposed ahead of the first reactor

is a preliminary reactor (primary) for separating dust.

A part stream of the raw gas can be passed via the raw gas reforming unit prior to the conversion process. Here, the hydrocarbons are cracked catalytically for the production of SNG or completely thermically for the production of synthesis gas.

Converted and/or cracked gas is cooled down in the final cooling stage and purified from H_2S in a gas cleaning unit. Finally the gas from the pilot plant is fed into the existing natural gas network of Ruhrgas.

Synopsis of the Test Operations



Test Runs	1	2	3	4	5	6	7	8	9	10	11/12
Time	1979	1979	1979	1980	1980	1980	1980	1980	1980	1980	1980
Operating hours (h)	105	80	72	130	180	240	177	104	186	75	478
Operating hours with oxygen (h)	20	-	-	105	99	217	152	114	176	66	419
Total coal feed (t)	70	85	75	285	325	728	345	322	619	236	1119
Product gas (10^3m^3)	150	158	33	680	453	873	581	379	880	260	2588

Test Runs	13	14	15	16/17	18	19	20	21	22	23	Σ
Time	1981	1981	1981	1981	1981	1981	1982	1982	1982	1982	
Operating hours (h)	109	178	227	332	360	107	90	522	162	30	3954
Operating hours with oxygen (h)	82	160	212	290	343	84	48	497	122	16	3229
Total coal feed (t)	296	547	971	1545	1377	397	703	2777	579	50	13831
Product gas (10^3m^3)	343	754	1521	2209	1780	417	186	2735	608	46	12650

RAG | RUHR 100 Summary of Test Runs | ADV 1982

Fig. 3

Fig. 3 provides a synopsis of the individual runs. The first six runs served to get to know and operate the plant at conventional pressure. Towards the end of the 6th run the Lurgi plant was taken over by ADV after a function test at 25 bar.

The aim of the further test periods was the raising of pressure; in the tenth run 70 bar was achieved for the first time. Simultaneously improvements were carried out, especially in the fields of gas sampling and instrumentation.

In the combined eleventh/twelfth run a change in the input coal grade was carried out for the first time while operations were running, and the load raised to 100 % of the design figure. A misoperation interrupted the continuation of the testwork for about 5 months.

After the restoration (of the plant) the plant was tried out again as a first step and a checking of the operating datas up to a pressure of 70 bar was carried out. With this measure it was intended to support or correct, as the case may be, old test results.

After this, with the fourteenth and fifteenth test run the measuring of basic and design data was started.
By reducing the steam-oxygen ratio it was possible to improve the thermal efficiency as a result of better steam decomposition. Finally, pressure was raised to over 90 bar. On account of pressure fluctuations in the steam network a steady state operation was not possible above 92 bar, the peak pressure value has been 95 bar. Since the test results, which been obtained at various pressure stages, allowed extrapolation to the designed end pressure of 100 bar, a limitation of the test operations to max. 92 bar is sufficient for the coming tests. At this pressure it was possible to raise the load to 100% of design value and above. In doing so, a specific gasification output, i.e. the hourly raw gas production, related to the unimpeded shaft cross-section, of 9,200 $m^3/(m^2 \times h)$, was achieved.

In the meantime improved appliances were installed for measuring the amounts of condensate yielded, and taking of samples for analytical purposes became possible.

Some tests were rendered difficult by large fluctuations in the coal quality, which led to difficulties in the gasifier operations due to the formation of caking crusts.

On account of the increasing proportion of fine fractions in the run-of-mine coal compacted coals were used for the first time in some runs. It was a question here of briquettes from an edge runnerpress and briquettes from a two-roll press. These tests were so short, however, that at present it can only be said that their use is possible in principle.

An extended-period test which lasted 522 hours showed that subject to a suitable mode of operation the gasifier RUHR 100 can also be operated with varying coal qualities, especially highly fluctuating ash contents, with peak values of 52% being attained. This is admittedly not a desired standard operation, since the gasifier was not designed for this, and the C-conversion rates decrease at too high ash contents.

In high load tests it was possible to show that the gasifier can be operated at far above the design data. There are admittedly technical and economic limits which are characterized above all by the utilization factor of the coal (e.g. C-conversion). However, these limits lie below the mechanical limit which is determined by clogging-up of the gasifier or its additional equipment in consequence of excessively high dust discharge.

Results

Former results see[6,8].

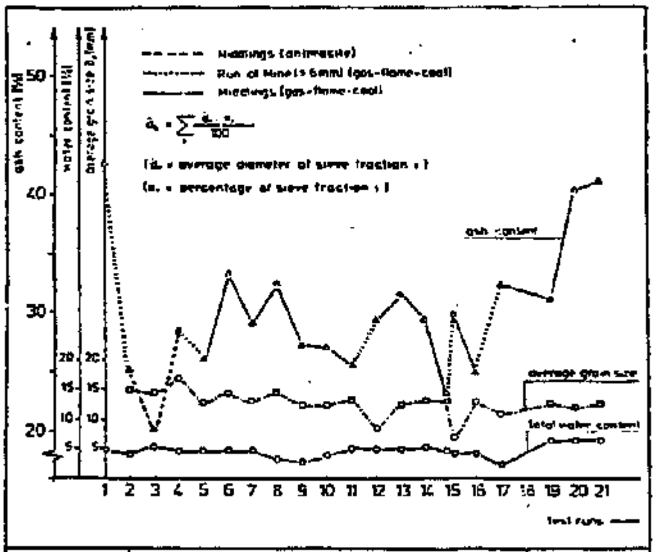
Trends in Quality of the Input Coal

A synopsis of the average coal quality is given in Fig. 4, whereas Fig. 5 shows the trends in quality occuring in the course of the test operations.

Fig. 4

Type of Coal		Gas - Flame - Coal Middlings	 Run of Mine
Screen analysis (after screening at 6 mm)			
> 30 mm	%	1,1	0,1
30 - 22 mm	%	10,0	2,5
22 - 6 mm	%	75,6	84,3
6 - 3 mm	%	7,9	8,9
< 3 mm	%	5,4	4,2
Proximate analysis			
Moisture	%	4,9	3,7
Ash (m.f.)	%	26,1	31,2
Volatile (m.f.)	%	28,5	25,9
Volatile (m.a.f.)	%	38,6	37,7
Sulfur (m.f.)	%	1,6	1,1
Swelling-Index		1 - 1 1/2	1 1/2 - 2
Ash fusibility oxyd./red.			
Softening point	°C	1270/1230	1260/1100
Hemisphere point	°C	1530/1520	1470/1420
Fusion point	°C	1560/1580	1510/1460
RAG		RUHR 100 Coal analysis	ADV 1982

Fig. 5



RAG | RUHR 100 Ash Content, Water Content and average Grain Size of the Feed Coal | ADV 1982

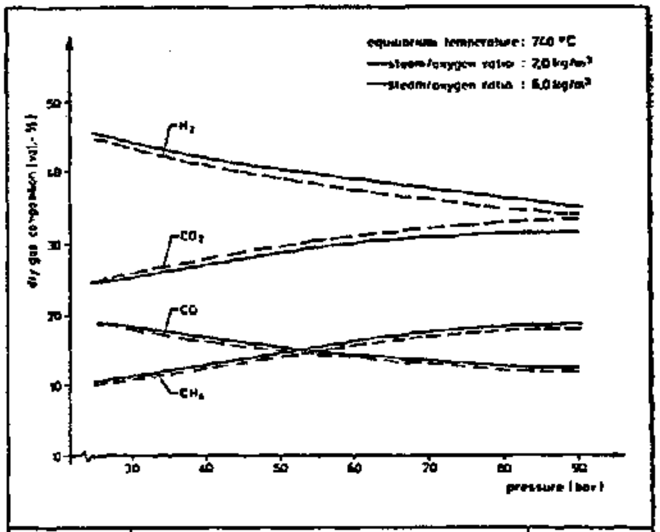
Reference is to be made here in particular to the sharp rise in the inert component content in the last runs; simultaneously there is a considerable rise in the fluctuation range. Consequently the reproducibility of specific operating states was only possible within a certain fluctuation range. Nor was it always possible to investigate the impact of all important parameters on the gasification process in the desired range; thus the steam-oxygen ratio had often to be set higher than desirable.

Pressure-Related Dependency of the Gas Composition

Represented primarily in Fig. 6 is the theoretically to be anticipated pressure-related dependency of the gas composition.[7]

[redacted]

Fig. 6



RUHR 100

Dry Gas Composition

(calculated for homogeneous simultaneous equilibrium reactions)

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These curves were calculated for homogeneous, simultaneous equilibrium reactions with respect to two different steam-oxygen ratios. They showthat increasing pressure leads to increased formation of methane with simultaneous decrease in carbon monoxide and hydrogen. This is a favorable and important pre-requisite for the production of SNG. The curves running parallel showthat the steam-oxygen ratio has only a slight impact on the composition of the raw gas. In addition to temperature the temperature of equilibrium is an essential parameter.

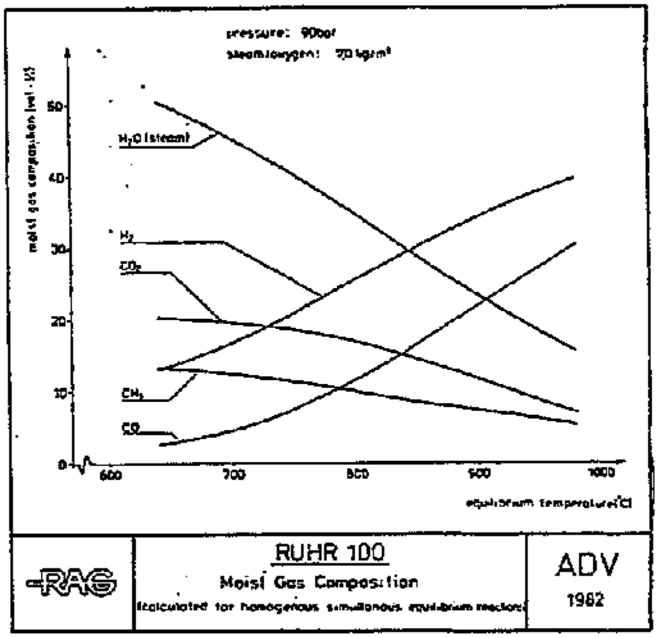
As Fig. 7 shows, the equilibrium concentrations of hydrogen and carbon monoxide increase sharply with the temperature, whereas the proportions of methane and carbon dioxide are reduced.

The following data on the gas composition apply to the entire tested range of the steam-oxygen ratio between 6.6 and 7.8 kg/m³.

Plotted in Fig. 8 is the average dry gas composition which was measured at various pressures, showing the absolute error. It will be seen that CO and CO_2 change only little with the pressure in contrast to the theoretical curve, whereas H_2 decreases decidely and CH_4 rises; this curve agrees with the theoretical calculations. The methane content rises from 10 vol.% at 25 bar to an average of 17 vol.% at 90 bar. Related to CO_2

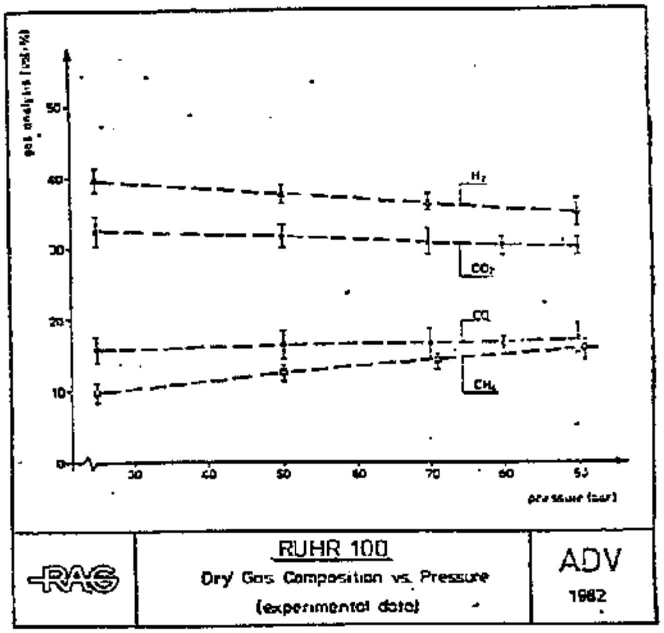
free dry gas, the methane content at 90 bar amounts to 24 %. With respect to the complete conversion of raw gas to SNG this means that approx. 48 % methane produces itself already in the gasifier at this pressure.
By comparison, pre-methanization at 25 bar amounts to only 32 %.

Fig. 7



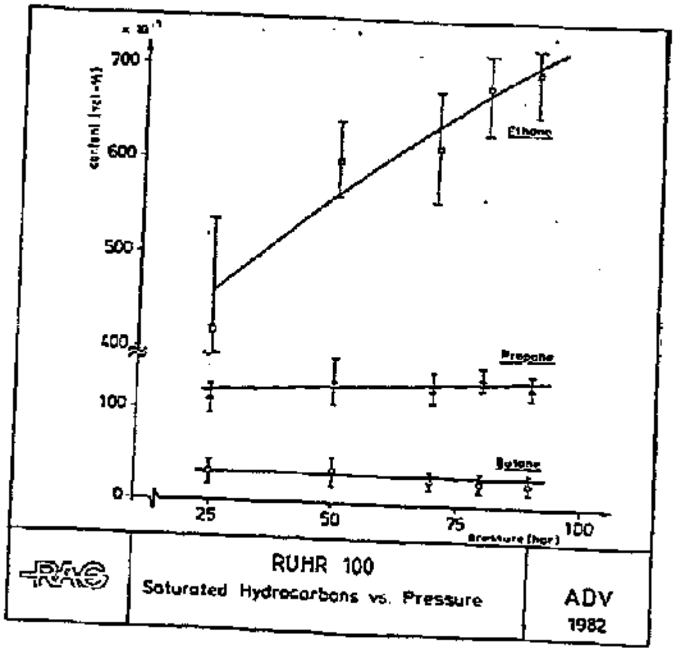
RUHR 100
Moist Gas Composition
(calculated for homogenous simultanous equilibrium reactions)

Fig. 8



RUHR 100
Dry Gas Composition vs. Pressure
(experimental data)

Fig. 9



Also the saturated hydrocarbons increase with rising operating pressure, as Fig. 9 shows[8]. Represented in Fig. 10 are the curves of the unsaturated hydrocarbons, which diminish with increasing pressure. The same manner of reaction, as Fig. 11 shows, is displayed also by the condensable tar and oil components in the raw gas.

Fig. 10

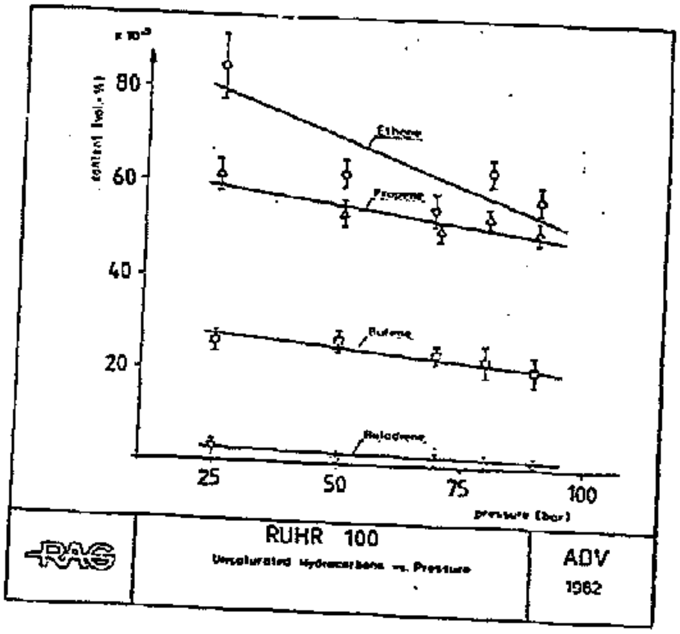
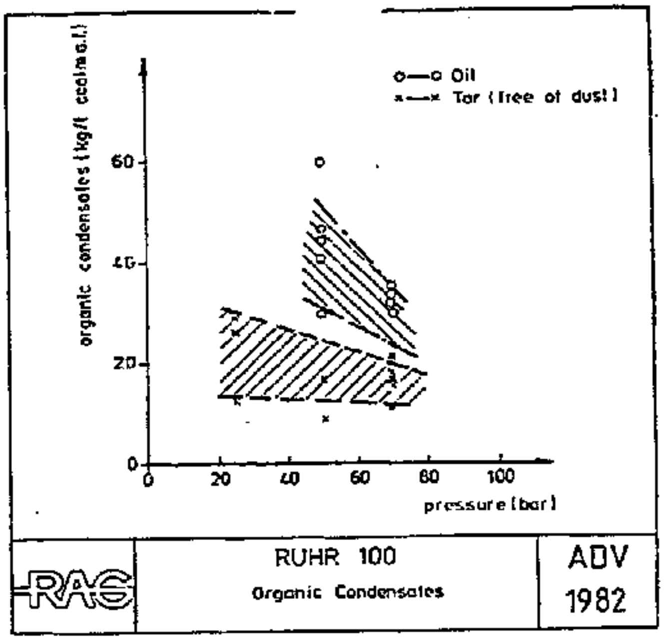


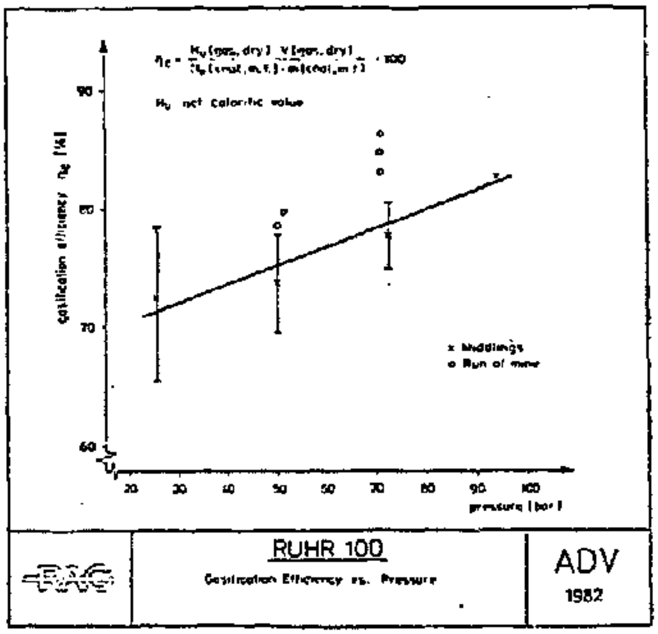
Fig. 11



Both the unsaturated hydrocarbons and the carbonization products tar and oil, are apparently hydrogenated at a higher degree with increasing pressure, and hence the yield of methane and higher saturated hydrocarbons is improved.

With the increase in the saturated hydrocarbons due to increasing the gasifier pressure there naturally follows also a rising in the raw gas heating value. Hence with increasing pressure more of the energy introduced into the process by the coal is chemically fixed in the raw gas or recovered. This is illustrated in Fig. 12.

Fig. 12



Represented here is the ratio of the chemically fixed energy - expressed here by the calorific values - of raw gas and coal in respect of various pressure stages. The plotted measuring points show that this ratio can be changed dependently of the quality of the coal employed.

Specific Data Applying to Gas Production

Just as different results can be obtained for the raw gas depending on the pressure employed, also the values for the specific data, which relate to the gasification medium or fuel are different. Thus, the specific oxygen consumption related to the coal (dab) could be lowered from 450 m³/t to 360 m³/t by increasing the operating pressure from 25 to 90 bar. That is to say by more than 20%.

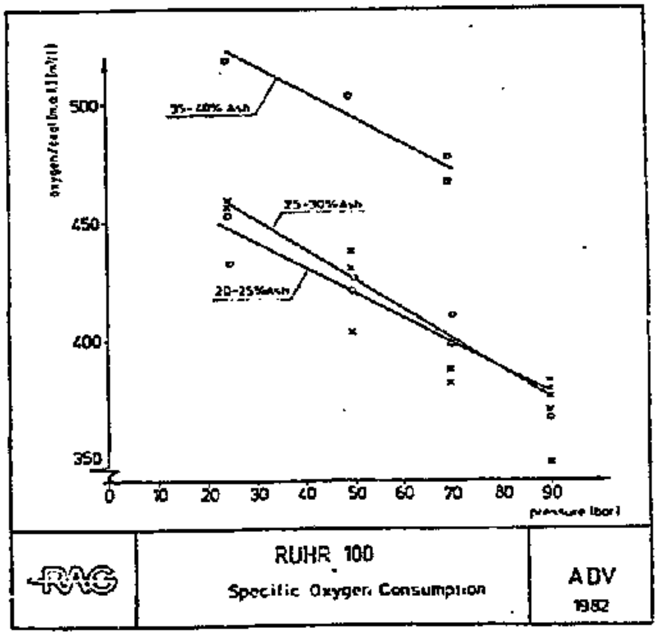


Fig. 13

RUHR 100
Specific Oxygen Consumption
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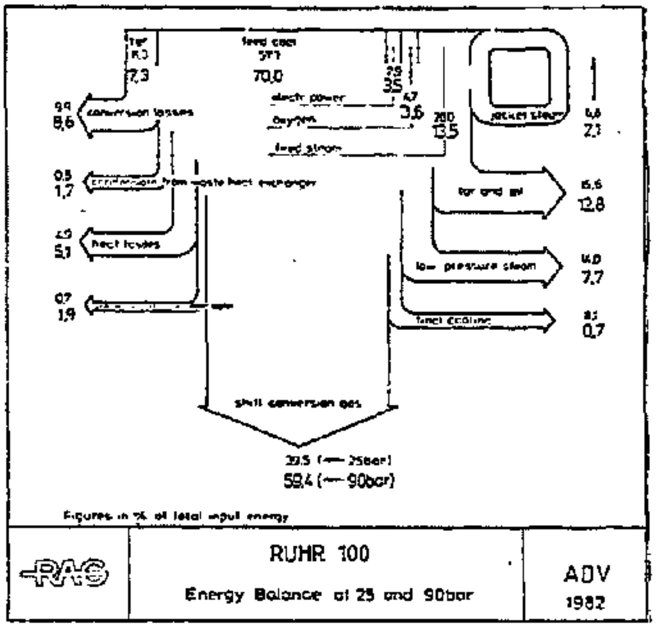
As Fig. 13 shows, the ash content of the coal influences the result. The results listed here are based on a C-conversion rate of the coal of at least 94%; the ash content was not over 40% db.

Energy Flow

The advantages of high-pressure gasification, which are apparent from the foregoing data and particulars, are reflected as correspondingly positive factors in the energy flowsheet.

Fig. 14 depicts the energy flow at 25 and 90 bar. The data refers in percentage terms to the total input of energy, which the conversion losses for power, steam and oxygen production are taken fully into account. The conversion losses are summed up in the output.

Fig. 14



The experimental results show that the conversion losses at 90 bar are lower than at 25 bar. Accordingly, with increasing pressure a more favorable gasification process in terms of energy takes place, to which primarily the increased, mainly exothermal reactions of the higher-atom hydrocarbons with hydrogen might well contribute.

Furthermore, the data obtained in the experiments show that the total losses decrease in the production of gas using increasing pressure. In other words, less energy is lost by conversion, cooling and by-products.

Of essential significance is the reduced yield of tar and oil-like condensates at higher pressures. Accordingly, it is possible to fix considerably greater amounts of the primarily introduced energy in the gas and thus appreciably raise the efficiency of gasification.

Also the portion of energy required for the low pressure steam is reduced with increasing pressure. This is all the more significant since this form of energy finds only very limited application uses today in industrial plants.

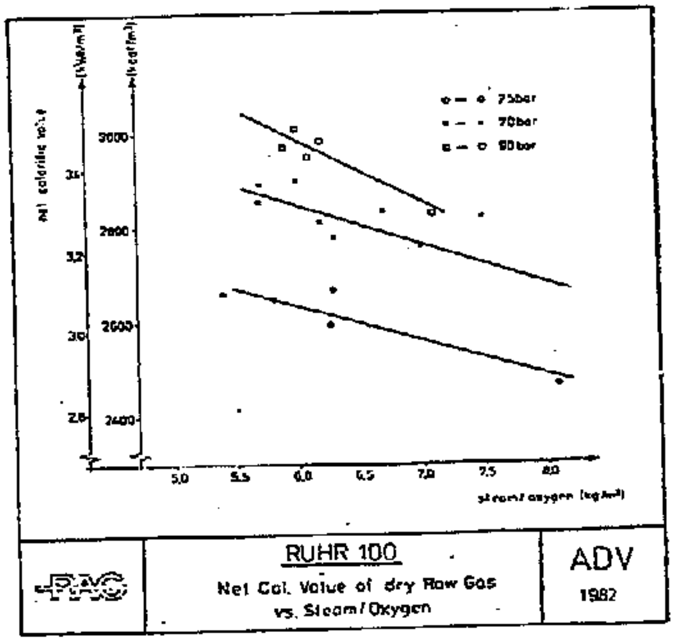
The results obtained at the pilot plant clearly reveal that in a high-capacity plant special attention attaches to the consistent utilization of waste heat under conditions that are optimal from the energy viewpoint. In this respect stricter criteria will certainly have to be applied than those applied in a pilot plant with its different priorities.

Influence of the Steam-Oxygen Ratio

An important process variable is the steam-oxygen ratio. In several tests, in which a gasflame coal/middlings blend with ash contents of between 18 and 28% was employed, a reduction in the steam-oxygen ratio was achieved in small steps down to a minimum figure of 5.5 kg/m³.

The influence of the steam-oxygen ratio, found in the experiments, to be exerted on the raw gas heating value at various pressure stages is demonstrated in Fig. 15.

Fig. 15



RUHR 100

Net Cal. Value of dry Raw Gas vs. Steam/Oxygen

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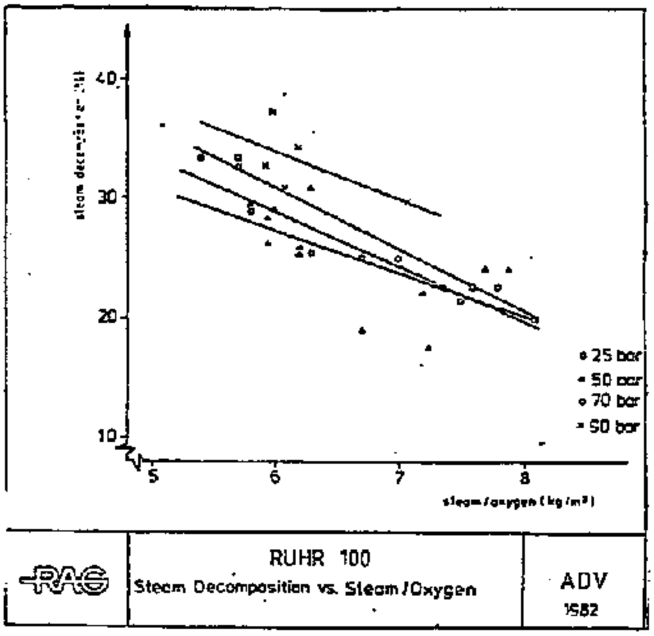

Fig. 16

Represented in Fig. 16 is the relationship between steam/oxygen and the degree of steam decomposition, which rises both with falling steam/oxygen ratio, i.e. increasingly "hotter" operation, as also with increasing pressure.

Low steam-oxygen ratio with simultaneous pressure increase leads distinctly accordingly to a better utilization of the energy input.

Influence of the Coal Quality

Limits are set to any desired lowering of the steam-oxygen ratio by the coal quality and its range of fluctuation. Since the steam-oxygen ratio influences the temperature in the combustion zone, the ash fusion behaviour of the coal has to be taken into account.

Recent investigations have shown that also high ash contents or unfavorable mineral assemblages in the dirt fractions require a "colder" mode of operation in order to avoid operational breakdowns.

Summary

In the past runs non-caking to weakly caking bituminous coals have been gasified under varying conditions at pressures of up 100 bar. The high pressure gave rise to no problems.

All the theoretically anticipated, pressure-dependent improvements regarding the production of SNG were confirmed:

- the CH_4 content in the raw gas rises from 10% at 25 bar to over 17% at 90 bar; accordingly there is also a rise in the heating value,
- the formation of tar and oil declines with growing pressure,
- the degree of efficiency in terms of the energy fixed chemically in the raw gas increases, while the overall gasification process runs more favorable in terms of energy.
- With low steam-oxygen ratio it is likewise more favorable to manage the process in terms of energy; moreover, the degree of steam decomposition increases.

The correlations between the most important parameters of the fixed bed gasification process have thus been largely dealt with.

Further tests will have to obtain results on
- the widening of the coal spectrum in the direction of using stronger higher-caking coal,
- the determination of the upper load limit
- the processing of coal fines in a compacted form.

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