REPORT FOR THE COMMITTEE ON ENERGY

Given on June 12, 1942

We were asked by you to lay the results of our research P.1
of our research in the field of complete gasification before this selected gathering. We are glad to comply with this request, because the work is practically concluded, and a workable process has evolved. We presume your agreement that those of you who are also active in complete gasification will not use the information to the detriment of our company and will consider everything confidential.

The tremendous impulse, which our economic life and especially the technic experienced in the last years, confronted the technicians with problems of the kind, that in other times had only marginal attention. The increased consumption very soon revealed the limitations in performance of traditional processes and methods. This knowledge did not lead to resignation of industry but opened the door for new methods and ways, which were considered impossible only 10 years ago.

The foundation of almost every industry is coal, which has the highest task. Either directly or indirectly, coal is the raw material for a variety of products. Aside from the P.2
known uses a new field opened up in the last few years, namely fuel generation by way of synthesis and hydrogenation.

The demand of coke and bituminous gas increased rapidly and also the consumption of illuminating gas for domestic purposes and industry came to a peak, which made deliberations necessary, how to solve the shortage of these products of bituminous coal distillation.

I am saying nothing new, because these problems were discussed here in your committee quite in detail.

The raw material for gas generation on a large scale is coal, if one disregards the water gas generation by Winkler from lignite semi-coke residue.

The production of coking coal cannot be stepped up too much and accordingly not for coke and bituminous gas. It is also to be considered that the coke coal beds are getting lower so that economy is a law for the present generation.

For these reasons it became desirable and mandatory to draw on such fuels which occurred in large workable deposits, the use of which had been practically impossible, because of lack of suitable methods and processes. The deposits in question were mainly lignite and noncoking or poor coking bituminous coal.

Dr. Heinrich Koppers offered his services with enthusiasm A survey of existing status convinced him that entirely new paths had to be taken, in order to do justice to the demands.

The first question was: in which manner can lignite be utilized for commercial gas generation by means of synthesis. After relatively brief studies of the overall problem, Mr. Kopper at his own risk undertook the construction of a lignite briquette gasification plant, designed for an hourly output of 25,000 Nm^3 standard synthesis gas for Fischer-Tropsch benzine synthesis. The plant started to operate in April 1936. The operation results were a technical success. After only 2 week operation, orders were placed for 5 more plants, with a total hourly output of 125,000 Nm^3. About a year ago the construction of a 7th unit started which after completion and full operation of all units meant 4,320,000 Nm^3 standard synthetic gas for every 24 hours. In other words, because one ton briquettes generates 1200 Nm^3 gas, which would mean a daily consumption of 3600 to lignite briquettes for gasification, these data will show you the unique pioneering done by Heinrich Koppers in this field.

The working method of the process is known. It lies in P. 4
the principle of heat utilization of wash gas-steam mixture in the temperature range of 1250 and 700°C. This method can only be used with lump or briquette lignite, which does not dis- ~~integrate in hydrogenation. The heat coverage comes thru~~ gasification of the residual coke in rotary grate generators.

The gasification possibility in these generators is only then guaranteed, when the residual fuel comes in granulated form.

It developed that the form stability of briquettes is subject to very severe fluctuations. When using unsuitable briquettes more or less of the residual fuel produced was non-gasifiable, fine size material and partly dust which could not be used in rotary grate generators.

At this point the second stage of our research began. A way had to be found to gasify even the finest grain without residue, in order to cover the heating gas supply.

As early as 1938, after preparatory laboratory tests and special ideas, a pilot plant for heating gas was constructed by "Braunkohle A.G.,"at plant Schwarzheide. Semicoke residue of partly carbonized lignite very fine grained and lignite was used.

The experiments proved the defects and inadequacies of P.5
present methods, but at the same time pointed the way which had to lead to the aspired goal. Working with lignite is comparatively simple because of its greater ability to react and a process which can be used for bituminous coal can be utilized for lignite without difficulty. Changes and redesign seemed to be necessary. We therefore decided to dismantel the

plant at Schwartzheide and to rebuild it a location where bituminous coal in pulverized form was at our disposal. It was also decided to incorporate our newly gained views and to supplement the installation so that not only heating gas but also water gas could be generated. General Manager Kost obligingly offered us the possibility to construct the unit at Colliery IV of the "Rheinpreussen" Company. We have the special deisre to thank Mr. Kost at this point for his cooperation and wish to say also that his continuous and always fresh interest had a stimulating effect on our not always easy research.

The plant started to operate in the month of January last year after searching tests on cold specimen clarified the physical reactions between the gaseous media and the coal. P.6
To the process itself and its development, the following remarks are pertinent:

In order to produce a plant which righ fully could bear the name "Universal - Gasification Method", all types of coal had to be considered and experimented with. In a series of tests coke coal, noncoking coal, lignite and lignite semi-coke residue were experimented with. The following gases were produced: synthetic gas for methane synthesis, for Fischer-Tropsch synthesis with varying ratios of $CO:H_2$; water gas for high pressure synthesis with high hydrogen content; gas for nitrogen synthesis and heating gas with a caloric valve between 1000 to 1300 heat units (w.e.). Details will follow later.

It really sounds paradoxical when I say that we chose the most difficult fuels first in order to simplify the work. These are coke-coal and lignite with a moisture content up to 15%. If it was possible to gasify correctly coking coal, the non-coking coal would offer no additional difficulties. The problem of lignite was to remove the moisture. Considering the ability to react to extremes were encountered. This had also the advantage that lignite served as indicator for correctness or effectiveness during the experiments. It developed that P.7
certain process changes made only for minor variations for bituminous coal. The same changes had 5 to 10 times the effect on lignite.

Before I turn to the gasification itself a few words should be said about ash content and ash behavior.

In a universal gasification method, the ash content and the fusion behavior of the ash should not interfere. This means that for all practical purposes run of mine or even a middle product up to 25 to 40% ash can be gasified without difficulty, if the grinding of the material is no obstacle. In passing we mention that semicoke residue with an ash content up to 45% was gasified experimentally. It means therefore to guide the gasification process so that the ash content was not injurious. This point was carefully considered and the influence of foreign mineral in the coal on the process was eliminated. This result was not a matter of course, because customary methods for slag prevention could not be used because of the ability of the carbon to react.

We have come to the point in our discussion of those characteristics which are typical for our gasification. p.8

It has been pointed out quite frequently that there is a parallel between combustion and gasification of pulverized fuels. That is true with one restriction. Pur combustion is a temperature and therefore accumulative heat process. This is an exothermic reaction while gasification, disregarding indirect heat transmission, is exothermic and endothermic alternately. The combustion is tied up with a running temperature rise and a rising reaction of the fuel grain until the carbon is completely consumed. It is presupposed that mechanical means, like turbulence, make it possible to bring the grain in contact with oxygen. Gasification is basically different if a gas of useful concentration is wanted. The following picture presents itself.

After ignition of the carbon, oxygen acts on carbon or its destilation products. After the carbon is consumed, a mixture of gaseous media is present; namely CO, CO_2, H_2 and water vapor, and N_2 if air is used. A mixture of carbon and a gas of insignificant caloric value, plus the reaction media and considerable ballast. In order to arrive at the desired reaction, the water vapor as well as the excess CO_2 has to react with the remaining carbon. This presupposes that the necessary heat is available which seems easy at first glance. I am using the term "first glance" advisedly, for on this point hinges the whole problem of dust gasification. It is not the point that the necessary heat is present in the mixture but the critera is that the carbon has reached at least the reaction temperature. We are refering to that temperature at which the carbon is eager to react. This point is 300 to 400° above the temperatures mentioned in literature, as found in previous tests. Only then has the reaction the desired rapidity for complete gasification. p.9

This requirement is not fulfilled automatically as in combustion but calls for special measures which were realized in our process.

The attempt to force heat transmission from hotter reaction media to the fuel grain by corresponding length of stay in large rooms is only a partial success. The necessary concentration of gas is only partially or not at all attained. Another way, off mentioned and used is addition of carbon or increase in carbon concentration. The excess carbon has to be separated later or used for another purpose. This cannot be termed complete gasification because of fuel and heat losses which represent 20 to 25% at least of the added carbon. Our aim was complete gasification in one work cycle. In consideration of this viewpoint, process and method evolved with the logic of natural laws. P.10

Let us consider synthetic gas. We would like to substitute this term for water gas, because of the wider use and wider requirements for synthesis gas.

The following goal was set:

1. The ideal concentration of gas must be so great that the gas can be worked in Fischer-Tropsch synthesis without washing for CO_2. The minimum synthesis value that is permissable, should be around 82%. It must be considered with a high H_2 content, the CO_2 content is automatically determined and that ~~a certain amount of H_2 from coal must be preserved.~~

2. The $CO:H_2$ ratio should be controllable in wide limits. The standards for Fischer-Tropsch method were applied. $CO:H_2$ ratio to be regulated within the following limits 1:2 to 2:1.

3. The gas should be free of resin formers and if possible free of hydrocarbons. Resin insulates the catalyst. Removal in succeeding installations is very costly.

4. Sulphur should be in such chemical compounds that removal by normal methods is possible. You will gather from the foregoing that our goal was ambitious. The problem was to reach this goal by economical means. The use of oxygen is generally not very popular, but it is a must as far as gasification of pulverized fuel for production of synthetic gas is concerned. The use of overheated wash gas as used in lignite-briquette gasification proved unsuccessful even with fast reacting pulverized lignite. This is a known fact because an industrial plant using this method ended in failure. The reasons for this were rechecked by us in experimental apparatus which Iwill show you later and the theoretical conclusion were verified. The next step was to limit the use of oxygen to a minimum. In our process, the reaction means are preheated to a high degree and the coal ground to a fineness as in coal dust furnaces. After solving numerous details, the

result could be verified in extended operation, so that a workable method exists.

I am going to show you some photos. At first one of the synthesis gas generators of Schwarzheide, Braunkohle - Benzin A.B.

Plate 1
Gasification Plant #1, Ruhland
No. 1252

Here you see the aforementioned first plant for lignite briquette gasification. The Wash gas-steam mixture is heated to 1250°. The hydrocarbons are split and the hot wash gas steam mixture goes to the generator which is under the visible fuel bin. The finished product leaves the generator at the middle of the shaft at a temperature of about 700° and travels thru the boiler, where the waste heat is used, to the wash plant. P.13
A split of the gas stream carbonizes the briquettes in the upper part. The gases thus freed are led, after detarring, to the preheaters by means of a gas exhauster.

Plate 2. No. 1197
Ruhland II.

In this picture you see the plant enlarged by 5 more generators. In the foreground is the rotary grate generator for gasification of residual fuel, then follows the preheater and the gas generator with auxiliary installations.

Plate 3. No. 1251.
Ruhland II.

This picures the same installation as seen from the south and just to complete the picture a view of a heater installation of the fuel plant Rheinpreussen. P.14

Plant 4. No. 1127.

This installation is used to transform the coke oven gas in order to make a standard synthetic, from transformed coke oven gas with standard coke oven gas. This plant has been in operation nearly 4 years.

After this brief deviation from the subject I am returning to the problem at hand by showing:

Plate #5. No. 1249.

The elevation scheme of an installation for coal dust gasification. You can see the heater pair, the generator with boiler in series for heat utilization for steam, the gas cooling and wash unit and the blowers. Further more between heaters and gas generators the coal dust storage bin. You will find a certain resemblance with the installations at Schwarzheide. That is factually so because the heaters and the installation following the generator are in principle the same units as used for lignite - briquettes. The heaters play a special part. They are equipped to heat the media to 1300°C. P.15

It might interest you that we built 16 such units during th last few years without any operational difficulties. The units which follow the generator are boilers, gas purification plant and so forth are nothing new, so I shall not give any details.

To complete the picture, I am showing here P.16

Plate 6. No. 1250

An installation for gasification of coal dust for a thruput of 400 tons coal dust in 24 hours. You may see that one pair of heaters works on 4 gas generators; that means each generator is designed for a thruput performance of 100 tons of dust in 24 hours. On waste heat boiler and on cooling washer for each gas generator, following the cooling washer, the gases are led to purification on blower plant.

The design and the working method of the gas generator is the thing that is new. It is not possible to give details in the frame of this lecture, however, we shall do so at a later date.

I mentioned the goal and it can be said now that all P.17 requirements were met also with safety. The concentration of the produced synthetic gas for CO/H_2 is according to the ratio $CO:H_2$ between 82 and 90%.

The ratio $CO:H_2$ easily contralled thru balancing of reaction media and temperature in the limits between 1:2 and 2:1. This is characteristic for our method because it is attained in the process in one work cycle. This is doubtlessly new to you.

The gas is absolutely free of resin free and also free of any trace of other hydrocarbons so that the field of application is unlimited.

The sulphur from the coal appears in form of hydrogen sulphide, which can be eliminated thru normal hydrogen sulphide purification. The amount of organic sulphur is small. The average was 18.4g/100 Nm^3 when working with bituminous coal. The purification for organix sulphur compounds is also possible in the normal known way because of the purity of the gas.

The quality of the gas was tested by the research laboratorum of the fuel plant Rhenpreussen and all given data were verified.

For the first time in the history of the technic, synthetic P.18
gas was produced from coking bituminous coal in one single work cycle. The controllable composition, its high concentration and its purity exceeds all the results obtained thus far in the field of gasification.

I am coming now to a graphic picture of the operation results of synthetic gas, generation of lignite dust and bituminous coal dust.

You shall see the heat flow sheet for generation of synthetic gas from lignite dust.

Plant 7. No. 1246.

The material used was middle German lignite dust with the following composition:

Water	13.00 %
Ash	5.95%
Volatile Matter	51.40%
Lower caloric value	5120 heat units (W.E.)

The resultinggas had the following composition:

CO_2	14%
CO	35%
H_2	50%
N_2	1%

Lower heat value 2342 W.E. per Nm^3.

Concentration of CO/H_2 is 85%.

The gas yield was found to be 1.9 m^3 per Kg raw coal, corresponding to the ideal yield of 1.62 Nm^3.

The oxygen consumption per Kg of coal was 0.304 Nm^3, corresponding to 0.16 Nm^3 per Nm^3 synthetic gas or 0.188 Nm^3 per Nm^3 ideal gas.

This will show the economical use of oxygen. It is only 50% of what is normally consumed in gasification with oxygen.

The next heat flow diagram.

Plate 8. No. 1244.

will give you the operational data of gas generation from P.20

bituminous coal dust. Coal dust of coking coal from Rhenpreussen was used. It had the following composition:

Water	1.95%
Ash	8.93%
Volatile matter	22.30%
Lower caloric value	7650 heat units (W.E.)

A gas with the following composition was generated:

CO_2	11%
CO	54%
H_2	34%
N_2	1%

with a lower heat content of 2505 heat units p. Nm^3.

concentration of $CO+H_2$ is 88%

The ratio of $CO:H_2$ was set to 1.6:1 for special reasons.

The yield was determined at 2.1 Nm^3 per Kg of coal charge, corresponding to an ideal yield of 1.85 Nm^3 per Nm^3 ideal gas.

The oxygen consumption per Kg of coal was 0.525 Nm^3, or 0.25 Nm^3 per Nm^3 of synthesis gas or 0.284 Nm^3 per Nm^3 ideal gas.

It may be noted that the oxygen consumption in gasification of bituminous coal is greater than in lignite gasification. The reason the poorer reacting ability of bituminous coal which make an 20% increase in oxygen necessary. Besides the oxygen consumption depends on the composition of the generated gas. P.21

~~It may be mentioned at this point that the gas composition can~~

be steered by introduction of CO_2 in the process in the interest of low oxygen consumption.

I am now coming to production cost of synthetic gas from lignite and bituminous coal. Even though the task was to solve the problem as such the national economics and the purely commercial viewpoints could not be neglected. The first demands a reasonable utilization of coal, the second calls for economical means. It cannot be always said that both requirements are complementary. It would be quite possible to fulfill the first demand with the help of a costly installation so that the amortization cost would make commercial economy impossible. That we succeeded in meeting both requirements is shown by our cost data per Nm^3 synthetic gas for gasification of lignite and bituminous coal. We have used the following cost figures:

1 net ton lignite dust f.o.b. dust storage	RM. 8.00
1 net ton bituminous dust " " "	Rm. 14.00
1 laborer shift	Rm. 12.00
1 KWH. electric current	Rm. 0.02
1 m^3 cooled and cleaned circulation water	Rm. 0.02
1 m^3 fresh water	Rm. 0.02
1 m^3 boiler feed water	Rm. 0.20
1 ton low pressure steam of 1.5 atoms. excess press	Rm. 1.50
1 m^3 98% oxygen	PF. 2.5
1 million heat units heating gas	Rm. 4.20

P.22

Amortization and maintenance was calculated with 15% of the investment as follows:

12% Amortization and interest
3% for repairs.

We have limited ourselves to the net-cost of the synthetic gas at the discharge point of the generator plant.

Plate 9. No. 1253

This graph shows the cost of distribution per Nm^3 synthetic gas in gasification of lignite and bituminous coal for:

1. The coal minus credit for steam generated by theplant.
2. The oxygen. P.23
3. The consumption for operation like heating gas steam, electricity, cooling water, fresh water, feed water and wages.
4. Amortization, interest and maintenance. According to this, the cost of synthetic gas from lignite is 1.32 pfennig per Nm^3. In gasification of bituminous coal and generation of a gas of the indicated composition and concentration, the cost is 1.72 pfennig per Nm^3. If the bituminous gas and the same composition as the lignite gas the cost would approximately 1.5 pfennig.

I am coming now to heating gas production. Semicoke residue from lignite was used in these tests in addition to bituminous coal and lignite. We also attempted to get by without the use of oxygen. The good reactivity of the experiments showed that lignite and its semicoke residue were especially adapted, and its good reactivity promoted the gasification. The gasification of bituminous coal however had to be conducted at higher temperatures because of poorer reactivity. It cannot be overlooked that the air nitrogen represents a considerable dilution of the coal dust / reaction media mixture, but these difficulties were overcome. P.24

I would like to call attention to the following: while the utilization of sensible heat from the synthesis gas is of minor importance, it is a factor for the economy of heating gas production for the following reason: the heating gas volume is 2 to 3 times as great as the synthesis gas made of an equal amount of bituminous coal. Furthermore, the discharge temperature of heating gas is 200°C. higher in bituminous gasification than in gasification from lignite and lignite semicoke. For this reason the waste heat must be used for high pressure steam generation. The results may be shown in the following graphs:

Plate 10. No. 1247 P.25

This heat flow chart shows the generation of heating gas from lignite dust, with the following composition:

Water	13.00%
Ash	5.95%
volatile matter	51.40%
Lower caloric value	5120 heat units

A gas of the following composition resulted:

CO_2	6%
CO	27%
H_2	20%
N_2	47%

Caloric value 1329 heat units

The commercial yield was 2.44 Nm^3/Kg feed coal.

The next heat flow chart P.26

Plate 11. No. 1248.

shows the operation results when lignite semicoke residue is used. The dust had the following composition:

Water	5.00%
Ash	21.00%
volatile matter	6.3 %
Lower caloric value	6050 heat units (W.E.)

The generated gas had the following analysis:

CO_2	6%
CO	26%
H_2	18%
N_2	50%

with a lower caloric value of 1253 heat units per Nm^3 (W.E.)

The commercial yield was determined at 2.93 Nm^3/Kg semi-coke dust.

The next heat flow sheet P.27

Plate 12. No. 1245

records the results of bituminous coal heating gas generation. The bituminous coal used had the following composition:

Water	1.95%
Ash	8.93%
Volatile matter	22.30%
Lower caloric value	7650 heat units (W.E.)

The generated gas showed the following analysis:

CO_2	7%
CO	21%
H_2	16%
N_2	56%

The lower caloric value was 1023 heat units Nm^3. The yield was determined at 3.3 Nm^3/Kg feed coal.

As you can see, 1910 heat units for each Kg of coal are recovered in form of steam, corresponding a steam generation of 2.85 Kg per Kg of Coal. Steam of 20 atmospheres excess pressure. At a steam cost of 3.00 RM. per tons, this represents a credit of 8.55 RM. per ton of feed coal or 61% of the price of coal. This unit can be rightfully called a combination gas - and steam generating plant. P.28

I am coming now to the producer cost per 1000 heat units (W.E.) of heating gas in gasification of lignite, lignite semicoke and bituminous coal. For the sake of completeness and comparison the cost are fixed in gasification of bituminous coke, 10 to 40 mm size, also nut III/IV in standard revolving grate generators. Here also it was necessary as in synthesis gas national economic as well as commercial consideration were not overlooked. For our calculations the following cost items were basic:

1 ton lignite dust f.o.b. dust bin	RM. 8.00
1 ton lignite semicoke f.o.b. dust bin	RM 8.00
1 ton bituminous coal dust f.o.b. dust bin	RM 14.00
1 ton bituminous coke 10 to 40 mmDA f.o.b. fuel bin	RM 18.00
1 Laborer shift	RM 12.00
1 KWH electric current	2 pfennig
1 m^3 cleaned and cooled circulating water	2 pfennig
1 m^3 fresh water	2 pfennig
1 m^3 boiler feed water	20 pfennig
1 ton steam 20 atü pressure	RM 3.00
1 ton low pressure steam 1.5 atü	RM 1.50

P.29

Investment charges and maintenance was taken at 15% of the total investment, consisting of

12% for amortization and interest
3% for maintenance

The production cost refer to a purified heating gas with a dust tolerance of 50 mg f.o.b. generating plant.

Plate 13 No. 1254.

This shows the charges per 1000 heat unit (W.E.) heating gas:

1. Guel minus credit for generated steam.
2. Operating consumption like steam, electricity circulating water, fresh water, feed water and wages, as well as
3. Amortization, interest and maintenance.

Now follow producer cost per 1000 heat unit (W.E.) heating gas in gasification of:

Lignite dust	0.42 pfennig	P.30
Lignite semicoke	0.42 "	
Bituminous dust	0.42 "	
Bituminous coke (20-40 mm)	0.446 "	

Even though this comparison shows that the cost of dust gasification are not much lower than bituminous coke gasification, the charges for the fuel indicate importance of dust.-gasification for the national economy. Bituminous coal and bituminous coke are directly related. In gasification of coke the charge in the gas price is more than twice what it is in gasification of bituminous dust. This is of prime importance for the political economy.

In order to round out the operational results, it may be mentioned that especially in large scale gas generating plants a partial utilization of oxygen is of value, because it not only lowers the production cost but also simplifies the working process. This point was verified by experimental test runs. Time does not permit to give details now but I hope to do so at a later date.

The operational data were obtained from the pilot plant P.31
which you will inspect later. The thruput of the plant is 5000 kg in 24 hours. Considering that the losses in such a small installation are greater than in large scale operation,

it is to be expected that commercial plants will produce much more favorable results.

I have come to the end of my discussion. We believe that we have made a new contribution to the question of energy supply, especially in view of the fact that we have adopted such fuels which should be used for gasification in the interest of the preservation of our mineral resources.