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GUMZ POWDERED COAL GASIFICATION PROCESS

BY

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ABSTRACT

Cooperative experimental work on powdered coal gasification was conducted by Demag, Bergbau-Verein and Ruhrgas in the plant of Hibernia at Herne, Germany, during 1940 - 1943. The design of the plant was based largely on theoretical considerations developed by Dr. Wilhelm Gumz but the process has been referred to occasionally as the Demag Process. The plant comprised two vertical reaction chambers each having an inside diameter of 1.2 meters and height of approximately 14 meters. The mixture of powdered coal and gasifying agent was passed upward through the first chamber and down through the second. Most runs were made with air steam mixtures as the gasifying agent. A few runs were made with air enriched with oxygen but none with air replaced by oxygen. Only moderate preheating of the gasifying agent was used (600°C. maximum) and conversion of carbon was relatively incomplete in all runs. A single unit with minor modifications was used throughout the program and trouble was always experienced due to the accumulation of slag in the first reactor. The process was not regarded as ready for commercial use and no proposals for commercial units were made. Nearly all original experimental data are available.

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I. INTRODUCTION

A. Objective

The object of the present investigation was to get all available information about a German method of gasifying powdered coal which was usually referred to in this country as the Demag process. It was discovered that Demag was one member of a group of three companies which worked cooperatively on this project during the war. The process is more properly identified as the Gumz process, after Dr. Wilhelm Gumz who was one of the most active participants in the work. The present investigation was conducted by FIAT concurrently with the investigation of the Koppers powdered coal gasification process during April and May 1947 for the purpose of determining the comparative merits of the two processes and the possible utility of both of them for coal gasification in the United States.

B. Evaluation

A very complete record of the experimental work in question was obtained from Drs. Gumz and Nistler who had been actively engaged in the conduct of the experiments and were the best possible source of information. They stated frankly that the experiments had been unsuccessful in some respects and that they did not regard the process as ready for commercial use. No operations had been conducted with pure oxygen as the gasifying agent and losses in the form of free carbon were always high, - in the vicinity of 30 per cent. Although only minor modifications of apparatus had been tried the conclusion had been reached that the reaction chamber must be designed for operation at such high temperatures that the ash can be discharged in the molten state.

The original research reports on the Gumz process are available but the data therein are less significant than they might be because of inaccurate temperature measurements. Although no claims for commercial operability are made, it is believed that the record of experience in connection with the Demag-Ruhrgas work will be useful as a basis for further development in this country.

II. BACKGROUND OF THE GUMZ POWDERED COAL GASIFICATION PROCESS

Although this process was developed as a cooperative project by Demag, Ruhrgas, and Bergbau Verein it seems to have been based largely on the ideas of Dr. Wilhelm Gumz[1] and can be properly identified by his

[1] For curriculum vitae see Appendix, page 45.

name. Since 1934 Dr. Gumz has been one of the managers of the Bergbau Verein (Union of Mining Interests) of Essen and in recent years was head of its subdepartment for fuel utilization. In 1938 Dr. Gumz published a paper on Gasification in Suspension[1] setting forth the theoretical considerations on which his process was subsequently based.

Confirmation of these theories was sought through small scale experimental work in the laboratory of the Reichskohlenrat in Berlin in 1940 under the direction of Dr Frederic Nistler[2]. Contributions to the theory of gasification have also been made by Dr. Nistler. Experimental work on a larger scale was conducted in the plant of Hibernia AG at Herne from 1941 to 1943.

Information about all of these activities was obtained by interrogation of Drs. Gumz and Nistler in April and May, 1947. Written answers to a formal questionnaire regarding the work were obtained from these men and likewise copies of all available reports. All documents thus obtained are being reproduced on Technical Oil Mission Microfilm Reel No. 238, from which copies or prints may be obtained through the Library of Congress. The original documents are being forwarded to the Office of Technical Services, U. S. Department of Commerce. Dr. Gumz stated that his only previous interrogation along these lines was by Messrs. Johnson and Bushow of Hydrocarbon Research Inc. about September 1946.

The present interrogation was conducted by Messrs. H. V. Atwell and B. M. Rosenthal of FIAT with the assistance of B. deResseguier of the French Institut du Petrole, and under the direction of Dr. W. F. Faragher, Chief of the Fuels and Lubricants Unit of FIAT. The cooperation of officials of the North German Coal Control, particularly Messrs. Shaw and Follett, in issuing necessary orders and permits, is gratefully acknowledged.

III. THEORETICAL CONSIDERATIONS

The Gumz thesis published in 1938 set forth the theoretical considerations involved in the transfer of heat and materials to particles of coal suspended in a gaseous medium. Here it was pointed out that the relative velocity between a free particle and an upwardly flowing gas steam has the largest possible value when the gas velocity is equal to the suspending velocity of the particle and that any further increase in the gas velocity merely serves to reduce the time of contact of the particle in the reaction zone. However,

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[1]Gumz, W Vergasung in der Schwebe; Feurungstechnik, vol 26 No. 12 (1938). Published in English as: Document C/691 File No. 611, British Coal Utilization Research Association, 3 July 1939.

[2]For curriculum vitae see Appendix, page 47.

to prevent accumulation of particles in the reaction zone the gas velocity must be at least as great as the suspending velocity of the coarsest particles.

The rate of heat transfer to suspended particles was calculated by Gumz by the use of principles established for heat transfer to cylinders (tubes) and by making several assumptions as to the applicability of these principles, which may or may not be justified The results of these calculations are expressed graphically by Figure 1, page 5, which indicates a very pronounced effect of particle size on rate of heating by the surrounding hot gas.

By assuming certain alalogies between the transfer of heat and the transfer of matter to the surface of suspended particles, calculations were made on the rate of conversion of coal particles to CO (gasification) by reaction with oxygen or water vapor. For these calculations a constant particle temperature was also assumed, and that the rate of material transfer rather than the rate of chemical reaction would be limiting. In this way Figure 2, page 6, was derived indicating a relatively large effect of particle size and a relatively small effect of temperature. Many other relationships are brought out in the original paper.

The conclusions reached by Gumz were admitted to be only qualitative. One of the most serious disturbing factors practically would be the progressive change in ash content of a reacting particle of coal which would modify its suspending velocity, its heat conductivity and its material diffusion characteristics. The Gumz theories were attached particularly by Totzek of Koppers during the present investigation on the ground that the assumed differential velocities do not exist in the case of very fine coal particles, whose behavior is most important if complete gasification is sought.

Nistler, in unpublished calculations[1] has attempted to predict the rate of reaction of coal particles with steam on a thermodynamic basis by estimating the rate at which the required heat of endothermic reaction will be supplied to the particles by a combination of radiation and convection from the surrounding hot gas. Assuming that a particle temperature of 800°C. is to be maintained in order to have a useful rate of reaction he concluded that the effect of the temperature of the supporting gas would be as illustrated by Figure 3, page 7, which should be regarded as only qualitative because of the many assumptions involved in its derivation. This indicates a very pronounced effect of temperature which is in sharp contrast to the conclusion reached by Gumz and which seems to be in better agreement with limited experimental data to be discussed later. A comparison of the shape

[1]F. Nistler; Notes on Gasification of Powdered Coal in Suspension 8 May 1947.

of the rate-of-gasification curves derived by the two different methods of calculation led Nistler to the conclusion that for very small particles the rate of gasification will be limited by rate of heat transfer but for larger particles it may be limited by the rate of material transfer as assumed by Gumz. In any event Nistler points out that the behavior of a small particle remaining after partial gasification will be different from that of a particle of the same size coming directly from the pulverizer since the former will have a much higher concentration of ash which may accelerate the reaction by catalysis or retard it by interfering with material transfer. Obviously the latter would predominate as the gasification approaches completion thus indicating that something less than 100% reaction of the carbon content of coal will represent the most practical solution of the problem.

IV. REICHSKOHLENRAT EXPERIMENTS

Dr. Nistler stated that all records concerning his experiments for the Reichskohlenrat in Berlin had been destroyed by bombing and fire but he prepared a summary of that work from memory. The following is a condensation of his summary.

The apparatus used for the Berlin experiments is shown diagrammatically by Figure 4, page 8. A small gas fired boiler 1, produced superheated steam at 75 p.s.i.g. which was reduced to atmospheric pressure by valve 2. The steam passed through an electric superheater, 4, the last stage of which was made of platinum wire wound through the holes of a ceramic filter to attain steam temperatures up to 1200°C. Then the steam entered the reactor 6, consisting of a vertical steel tube which was heated by low voltage current. The tube material was Sicromal which resists high temperatures and sulfur corrosion. The tube was 6 m long and when heated to 1000 °F. it grew longer by 10 cm. At such a high temperature the steel tube would sink down under its own weight and therefore it was kept in tension by two counterweights.

The steam entered the reactor tube through a filter and immediately above the filter the powdered coal entered the tube. The coal feeding apparatus, 5, consisted of a small coal bin, a feeding screw and a tube below the feeding screw in which a horizontal shaft with spikes was rotated by a motor in order to keep the dust in suspension and to maintain a continuous flow of the coal dust this way. The further transport of the coal dust into the reactor was carried out by steam at about 150°C.

Beyond the reactor the steam and the reaction products had two paths controlled by the valve, 9. Firstly the measuring equipment consisting of a dust collector with filter 10, and a condenser for the steam; secondly a by-pass with a rough separator only. The reactor tube was carefully insulated

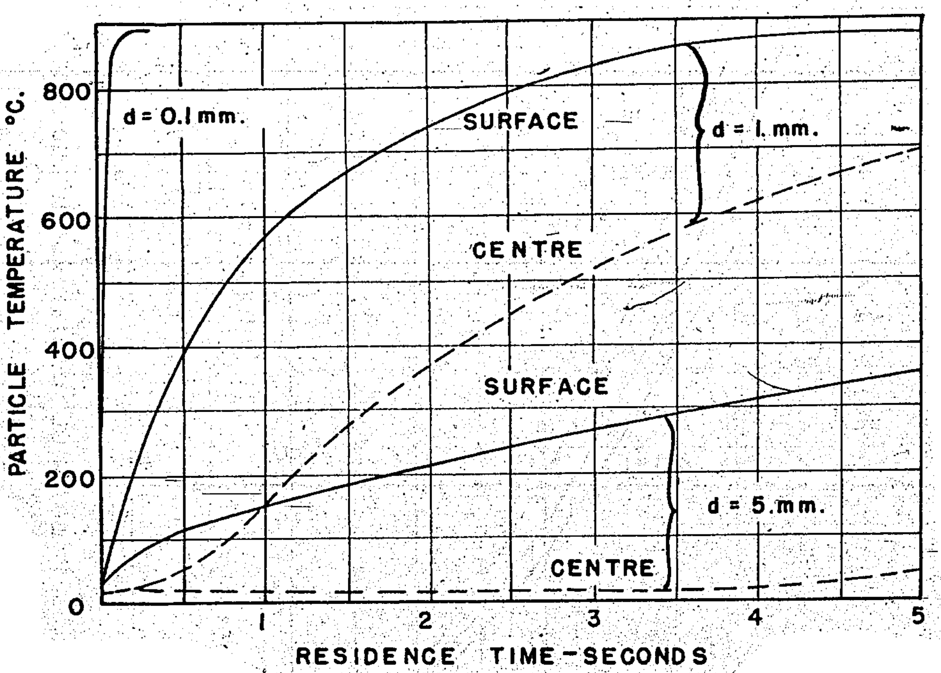


FIGURE I

HEATING OF SPHERICAL FUEL PARTICLES IN A GAS STREAM AT 900°C.

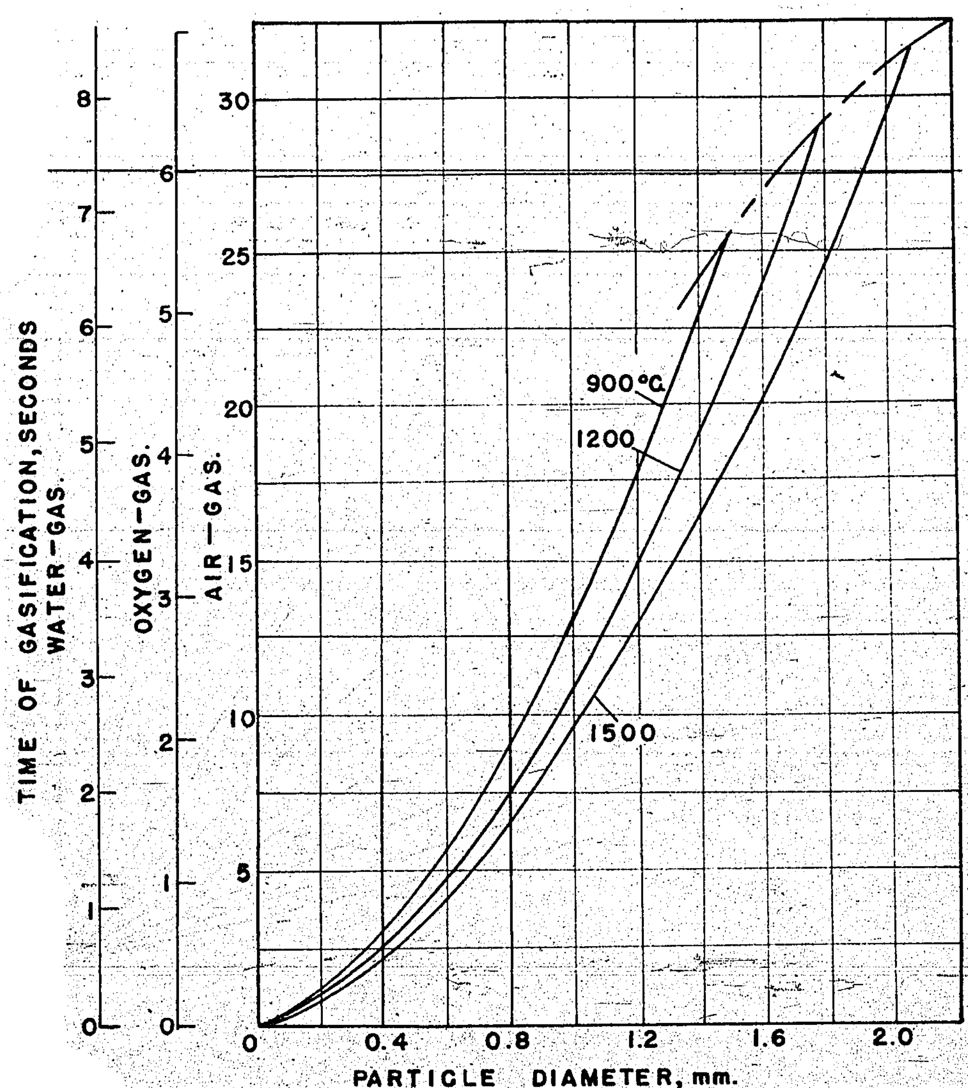


FIGURE 2

TIME OF GASIFICATION OF CARBON SPHERES OF SMALL DIAMETER

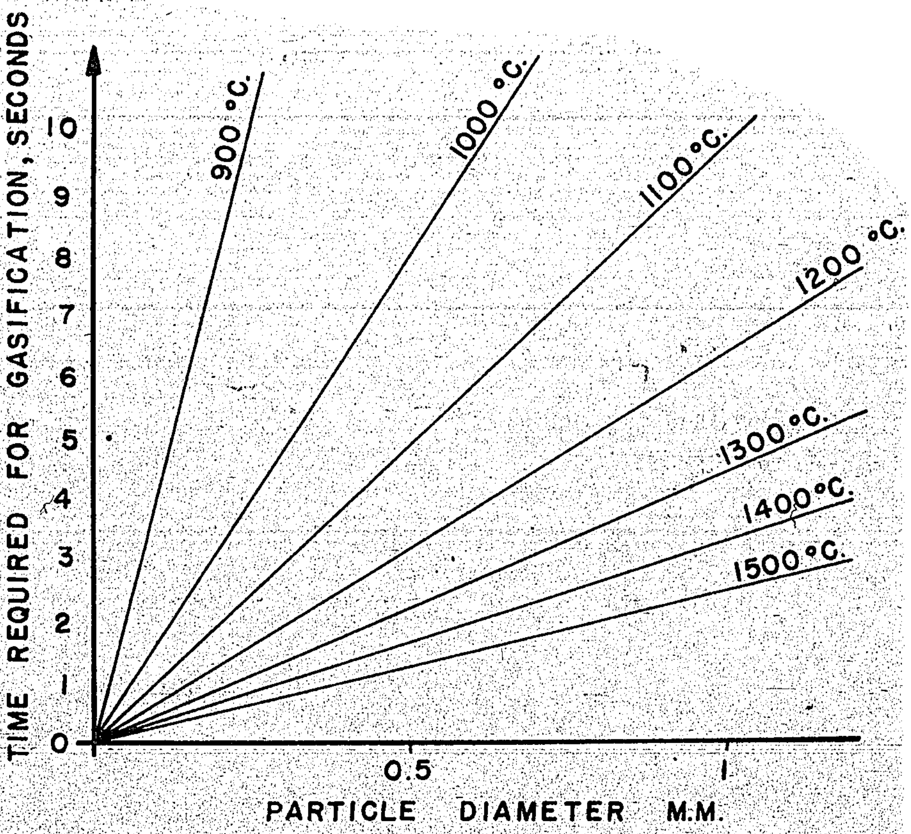


FIGURE 3

PARTICLE GASIFICATION RATES CALCULATED BY NISTLER

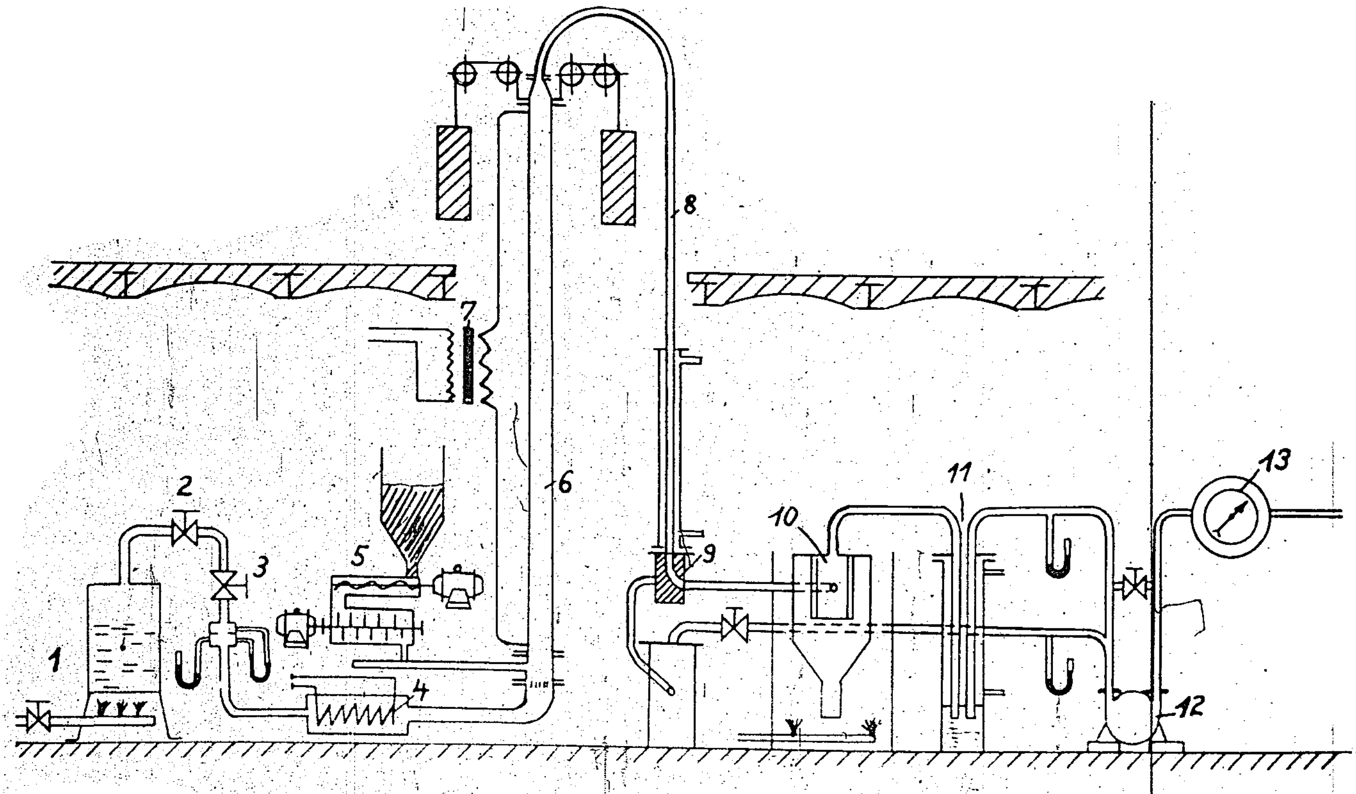


FIGURE 4

REICHSKOHLENRAT EXPERIMENTAL GASIFICATION UNIT with fire-clay, asbestos and slag wool. The whole insulated tube was covered by a sheet iron tube of 500 mm diameter.

On the evening preceeding each run the low-tension transformer 7, was switched on to heat the reactor during the night. The temperature was recorded by a six point recorder. In the morning when the temperature scheduled was nearly reached, the boiler was heated and the coal bin was filled. When the boiler gave steam the valve, 9, was set to connect the discharge pipe, 8, with the by-pass. (Different from the position shown in the figure). Then the whole equipment was brought to normal pressure and temperature conditions. Then the test was started by switching on the feeding apparatus and putting the valve, 9, into a position to connect the discharge pipe with the dust-collector as shown in the figure. The time of operation was about 30 minutes. When the coal bin was empty all electric energy was switched off and the dust discharged was removed and cooled immediately, being very reactive. Gas samples were taken before the gas had passed the filter, and sometimes after the gas meter as a control only.

The proper working of the plant was controlled by calculating the material balances. (Carbon in fuel = carbon in gas + carbon in dust recovered). The losses were found to be below 10%, generally about 5% and most likely due to the smallest particles which were difficult to recover completely.

Powdered and dried bituminous coal from middle Germany (Geiseltal near Merseburg) with about 8% ash content was used. It was ground to the same fineness as used for combustion in boiler-houses with a maximum below 0.1 mm. Operating temperatures were 800, 900 and 1000°C. The results were compared with the results of carbonizing the same coal at the same temperatures. The quantity of the steam was always very high and about double the quantity required for complete gasification of the fuel. This was done to be free from the influence of varying composition of the medium along the reactor.

When operating at 800°C. the volatile material was gasified only and nearly the same results were obtained as when the coal was heated in a china pot at 800°C. At 900 and 1000°C. the attack of the steam on the fixed carbon could be clearly observed, but the extent of conversion was not as high as would be predicted from Figure 3, page 7. The discharged dust was found to contain about 40% of its original carbon after having been suspended for about 2 seconds in pure steam at 1000°C. The procedure appears to be attractive only at temperatures which are considerably above 1000°C.

The dust recovered was screened and the fractions were examined separately in order to find out the different behavior of the particles of various size. No considerable difference could be found and the increase of the ash content was nearly equally distributed over all sizes.

The powdered bituminous coal was screened and the different sizes of particles were gasified separately. A set of screens was used with holes ranging from 0.03 to 0.15 sq. mm. The best results were obtained with the smallest particles at 1000° F. in which case the dust recovered contained about 20% of the original carbon content. The analysis of the gas samples showed no difference for the various sizes of the grain, and the composition of gas was determined by the temperature of the process only. This would indicate constancy of the surface temperature.

Dr. Nistler felt that the principle of the Reichskohlenrat experiments was sound and that more useful data could be obtained if it were possible to operate at higher temperatures. To this end he recommended the use of internal heating by burning methane with oxygen and quenching with steam to give a mixture consisting mainly of H_2O with some CO and CO_2 at such high temperatures that the temperature will still be 1000 to 1500°C. after admixing the powdered coal. The use of a ceramic reaction tube was also recommended, with external heating by the same combustion gases so that any diffusion through the walls of the tube would not appreciably change the composition of the reacting mixture. No experiments of this character were carried out.

V. RUHRGAS PILOT PLANT

A. Purpose and Plan of Work

The organizations cooperating in the pilot plant work were Demag, Bergbau Verein, and Ruhrgas. The following information about these companies was furnished by Dr. Gumz.

The Demag A.G., Duisburg, Werthauserstr. 64, founded in 1910 manufactures heavy machinery for the iron and steel industry, collieries, etc. Demag A.G. has a special department for gas producers and is, among others, licensee of the Humphrey Davis gas producer for Germany. Chief engineer of the gas producer department is Dr. Pistorius.

The Ruhrgas A.G., Essen, Herwarthstr. 60, founded in 1926, is a company for the supply of coke oven gas by means of long distance pipe lines. Among other things the Ruhrgas A.G. also developes new methods for gas technic. The managing director is Dr. Gummert.

Verein fur die bergbaulichen Interessen, Essen, (since 1945 the German Mines Supplies Organization), was founded in 1858 as a union of the collieries of the Ruhr district. Originally the Bergbau-Verein had economic interests only, but since 1938 the main object was scientific and technical research work. All the then existing research institutions were united in this association. The fuel utilization department was occupied with problems of combustion and gasification. Head of the managing committee was managing director Dr. Buskuhl (deceased), and the manager was Dr. Sogemeier. The head of the department for fuel treatment and utilization was Dr. Reerink, now in private work at Essen-Bredeney, Ruttelnskamp 2; and the head of the subdepartment for fuel utilization was Dr. Gumz.

The objective of the Demag-Ruhrgas-Bergbau work was to develop a process for making either fuel gas or synthesis gas from any kind of powdered coal and particularly from low grade coals of high ash content. The experimental unit was designed to permit the study of certain fundamental characteristics of powdered coal gasification and it was recognized that a commercial unit might involve radical changes in design.

The design of the plant was worked out jointly by Dr. Gumz of Bergbau-Verein, Dr. Pistorius and Dipl Eng. Schneemilch of Demag, and Dr. Traencker and Dipl Eng. Kukuk of Ruhrgas A.G. The plant was constructed by Demag on the property of Hibernia A.G. (synthetic ammonia) at Herne near Wanne Eichl. The site was determined by the availability of oxygen from a Linde-Frnakl unit in the adjacent Krupp Treibstoff Werke.

The operation of the plant was in charge of Ruhrgas under the immediate direction of Dr. Nistler of German Mines Supplies Organization with the assistance of Mr. Kukuk of Ruhrgas (currently with Bischoff A.G. in Essen) and Mr. Lilienfeld of Demag (currently with the Reichsbahn in Hannover.)

The unit was built during the period from October 1940 to June 1942 and the reaction chambers were dried out carefully over the next two months so that gasification experiments could begin in August 1942. Dr. Nistler stated that the experimental plant cost 750,000 marks and the cost of its operation over the two year period was 400,000 marks. The unit required 4 or 5 operators per shift.

B. Description of Apparatus

A schematic representation of the experimental plant at Herne is given by Figure 5, page 13. A scale drawing of the overall plant is shown as Figure 6, page 14, and details of the reaction chambers are given in Figure 7, page 15. Figures 8, page 16, and 9, page 17, are photographs of the unit from approximately opposite directions.

Referring to flow diagram Figure 5, page 13, raw coal was weighed into storage bunker 1 from which it was discharged to the pulverizer 2, furnished by the Kohlenscheidungs Gesellschaft of Berlin. Through the pulverizer was forced a stream of hot combustion gases from furnace 5 by blowers 4 and 6 to dry the coal as it was being pulverized and to convey it through cyclone separator 7 to one or the other of powdered coal bunkers 13. From these bunkers the coal was discharged by rotating distributor valves 15, into venturi 16 where it was picked up by a stream of air from surge tank 20 and conveyed to the desired entrance point of reaction chambers 30 and 31.

The two reaction chambers were vertical and had an overall height of approximately 14 meters and an inside diameter of 1.2 meters. They were lined with fire clay bricks containing 39-42% alumina furnished by Didierwerke. A passageway connected the two chambers near the top and in the lower part of this connection was a hopper from which it was expected to discharge ash or unconverted coal through the ejector 34. On the assumption that gasification would be accomplished below the fusion temperature of the coal ash, a centrifugal ash separator was provided at the bottom of the second reaction chamber, but actually little or no ash was collected at this point. The lower part of the first chamber was conical and a vertical pipe extended up some distance into the cone for admission of the coal and the primary air which conveyed the coal as shown by Figure 10, page 18. This primary air amounted to about 10-15% of the total air. The gasifying medium, which was mainly air, was admitted at the bottom of the first chamber through the annulus around the coal feed pipe. Connections were provided for admitting the mixture of coal dust and primary air at the top of either chamber but such operation was rarely used.

The preheating of the gasifying agent was accomplished initially by direct admixture of the products of combustion of fuel gas, and subsequently by indirect heating in a gas fired tubular heater 25. Air for gasification was supplied by a turbo blower 22. Oxygen for the same purpose was obtained from a Linde-Frankl unit of Krupp Treibstoff Werke and was introduced by a steam injector 23. Steam could be admixed with the gasifying agent or could be supplied separately to the bottom of the first reaction chamber.

The hot gases leaving the second chamber were quenched by a water spray in tower 32, which would be replaced by a waste heat boiler for commercial operation. Following this was a double washer 35, to further cool the gas and to remove all entrained ash. The water from the first or lower section of this final washer was circulated through a settling basin 38, while the water from the final scrubbing section went to cooling tower 39. The clean gas was metered and sampled, and then discharged to the air through line 36 since there was no local use for it as fuel.

1. Bunker
2. Pulverizer
3. Classifier
4. Blower
5. Hot Air Furnace
6. Furnace Blower
7. Separator
8. Filter
9. Suction Blower
10. ~~Switch Valve~~
11. Dust Seals
12. Filter Dust Seal
13. Dust Bunker
14. Level Indicator
15. Distributor
16. Venturi
17. Suction Filter
18. Gas Compressor
19. After-cooler
20. Surge Tank
21. Water Separator
22. Main Air Blower
23. Oxygen Venturi
24. Checkvalve Back Flow
25. Tubular Heat Exchanger
26. Burner
27. ~~Mixture Preheater~~
28. Burner Preheater
29. Air-line
30. Gasification Shaft I
31. Gasification Shaft II
32. Spray Tower
33. Auxiliary Chimney
34. Dust & Coal Ejector
35. Washing Tower
36. Gas Line
37. Torch
38. Clarification
39. Cooling Tower
40. Sludge Pump
41. Cooling Water Pump

FIGURE 5

SCHEMATIC DIAGRAM OF
RUHRGAS PILOT PLANT

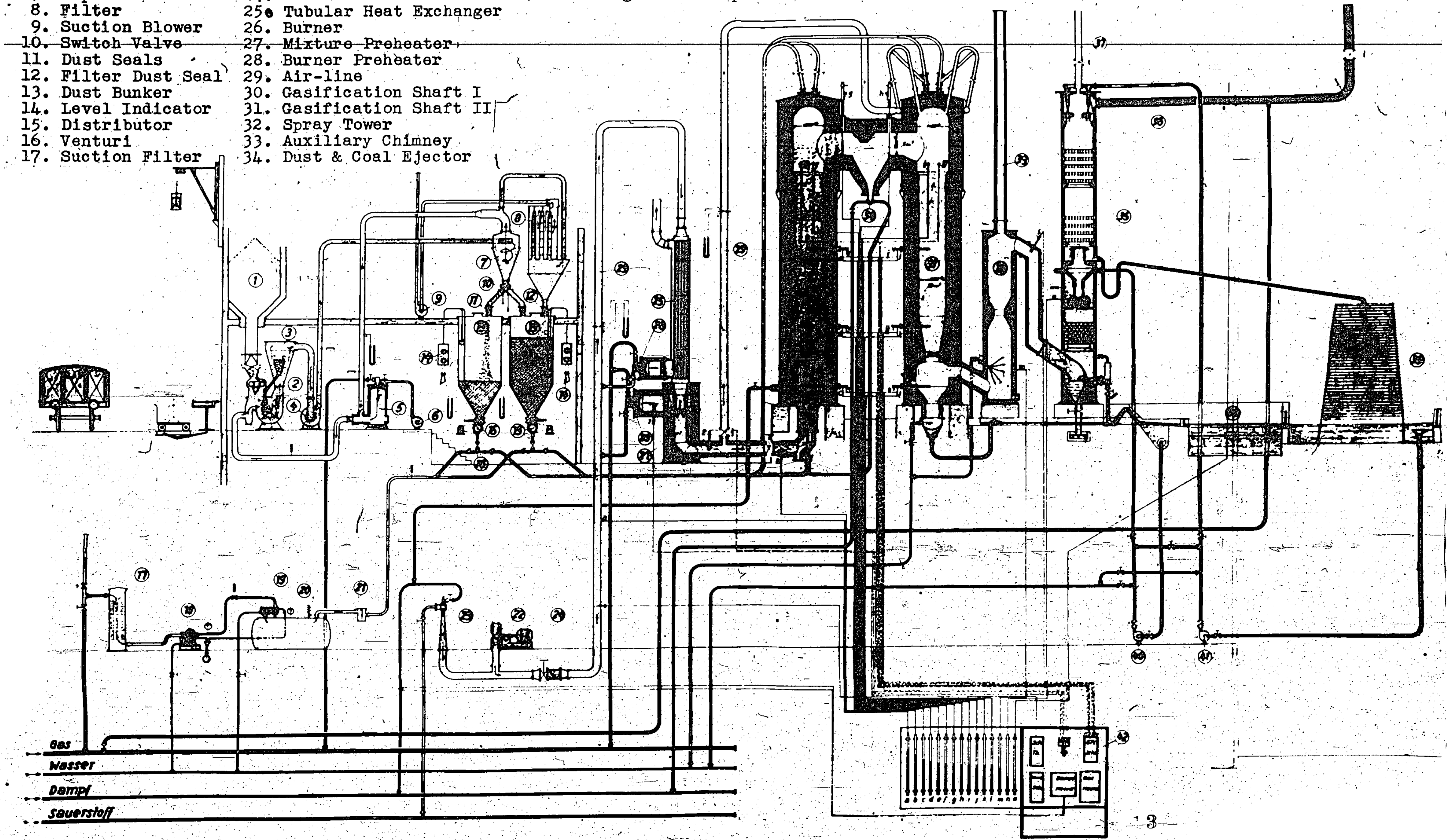
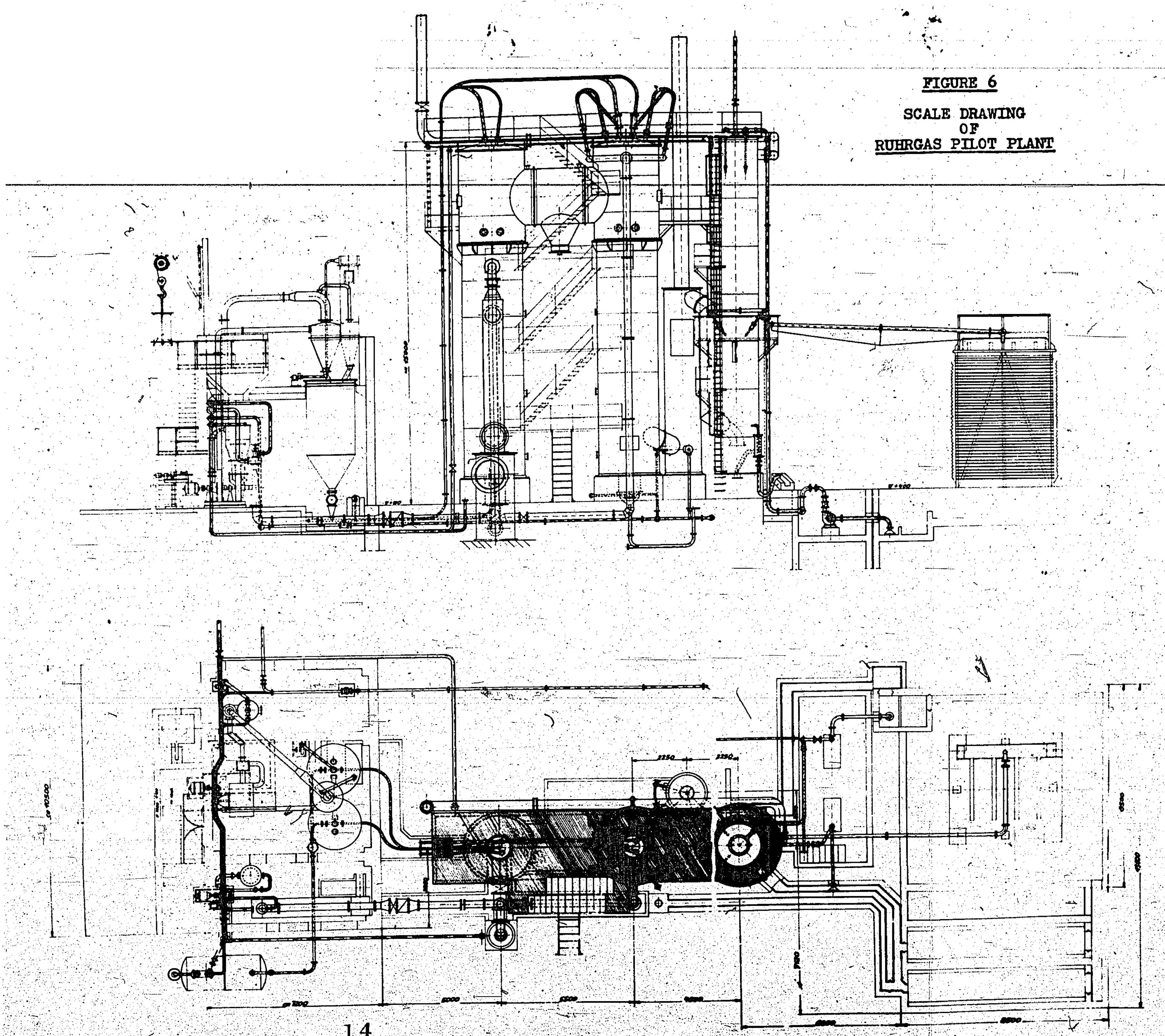


FIGURE 6

SCALE DRAWING
OF
RUHRGAS PILOT PLANT



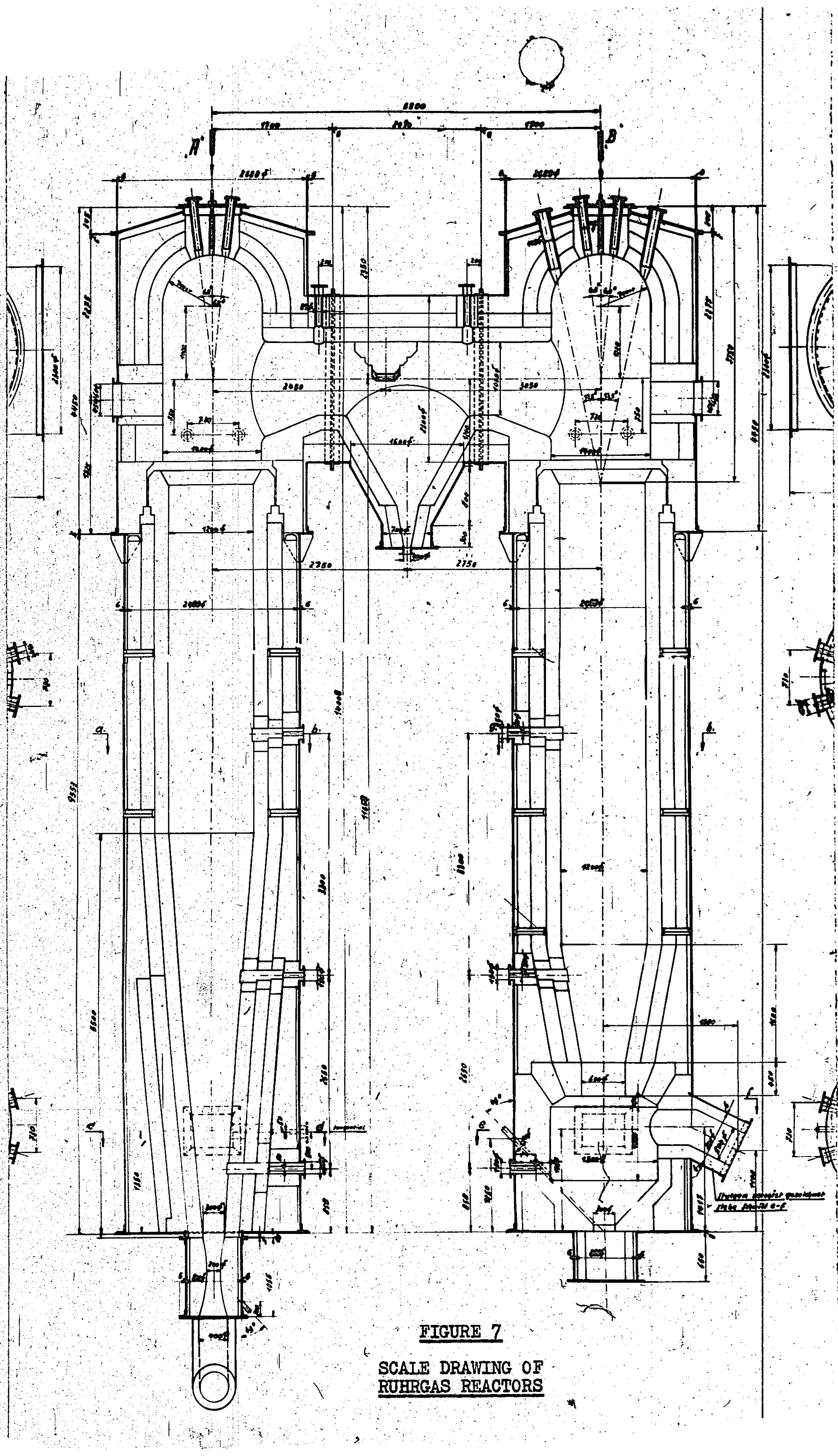


FIGURE 7

SCALE DRAWING OF
RUHRGAS REACTORS

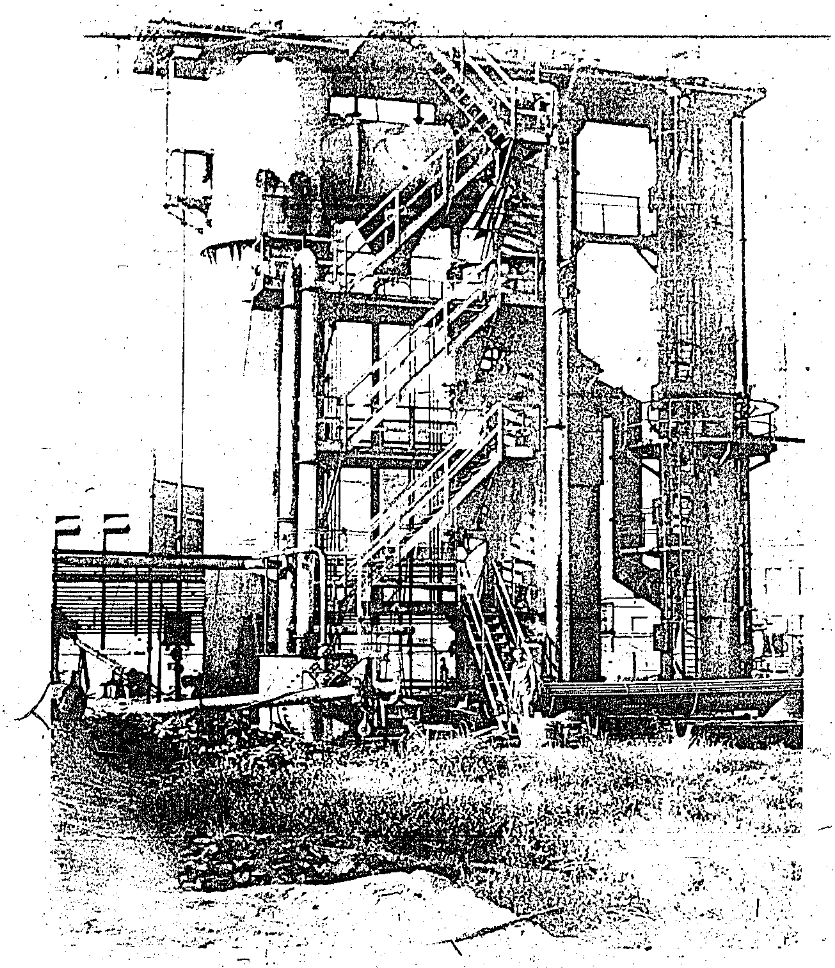


FIGURE 8

RUHRGAS PILOT PLANT

GASIFICATION CHAMBERS AND WASHER

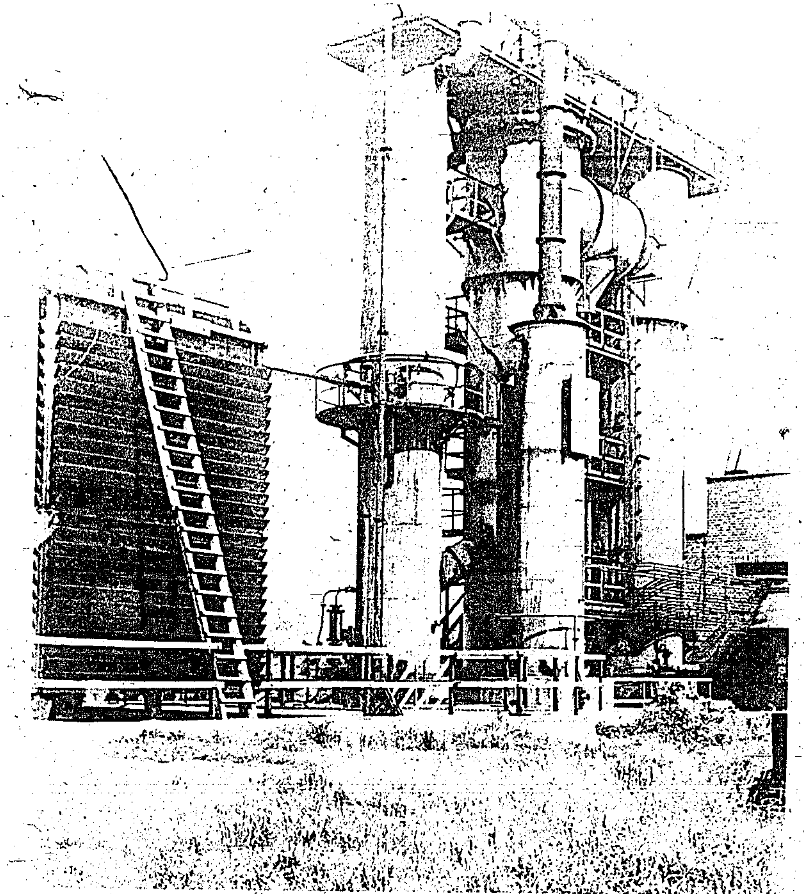


FIGURE 9

RUHRGAS PILOT PLANT

SPRAY COOLER, WASHER AND COOLING TOWER

GASIFICATION CHAMBERS IN REAR

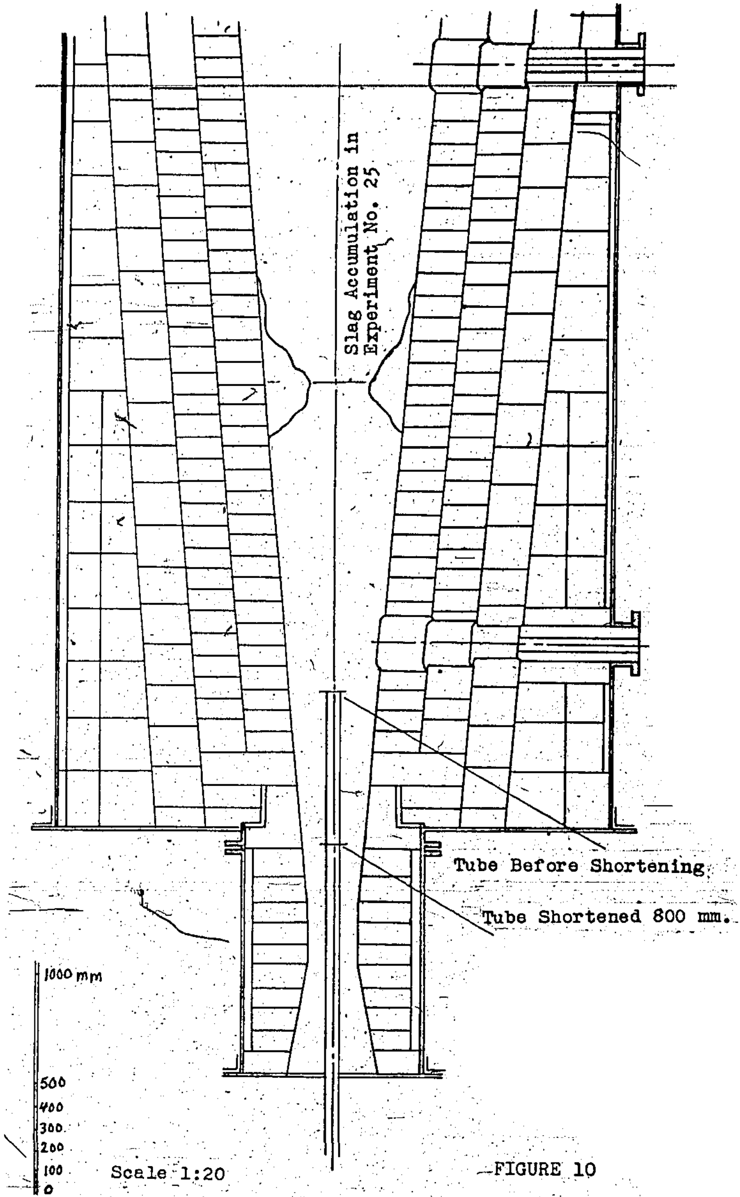


FIGURE 10

LOWER END NO. 1 REACTOR

Quantities of air, oxygen, steam, or mixtures thereof and the temperatures and compositions of these streams as well as of product gas were measured by conventional means and apparently with sufficient accuracy. The location of instruments is shown by Figure 11, page 21.

Temperatures in the reaction chambers were measured by Pt/Pt·Rh thermocouples. These were originally protected by Sicromal tubes which soon burned out and were replaced by Sillimanite tubes. For various reasons, the reaction chamber temperature measurements were never reliable, and were probably in most cases too low by several hundred degrees. At each temperature measuring point in the reactors a sample tube was provided through which gas samples could be drawn for analysis.

Quantities of raw coal consumed could be determined by direct weighing but this was impossible for the powdered coal and therefore reliance was placed on calibration of the rotary dust feed valves at different speeds which proved to be somewhat uncertain.

The powdered coal feeding device was a standard rotating valve made by Kohlenscheidungs Gesellschaft (K.S.G.) of Berlin. It might be described as a cylindrical plug cock with grooves cut lengthwise in the surface of the plug. The rotating plug was approximately 10 inches in diameter and 2 feet long, positioned horizontally. This valve received powdered coal by gravity from the superimposed bunker and discharged it into an air conveyor for delivery to the gasifying chamber. This feeder seldom gave the desired uniformity of flow and was particularly troublesome when the coal was not completely dried. This is interesting in view of the statement by Mr. Totzek of Koppers that such a feeder should be satisfactory, in contrast to the screw feeder used on the Koppers-Rheinpreussen unit. Dr. Gumz expressed the personal opinion that a Fuller-Kinyon pump would be satisfactory but there appears to be considerable doubt about the best solution of this problem, particularly if super atmospheric pressure is to be used.

C. Operating Procedure

Experiments were conducted with two bituminous coals identified at Wilhemina-Viktoria and Shamrock 1/2 and a brown coal from Neurath. The composition and screen analysis of these coals is given in Table I, page 20. Preliminary operation of the coal grinder soon demonstrated that the capacity of this mill was not greater than 200 Kg/hr compared with a rated capacity of 800 Kg/hr. Furthermore it was found impossible to adjust the mill to give the desired differences in fineness of grind, so this variable could not be investigated as intended.

TABLE I

COAL CHARACTERISTICS

Kind of Coal	Bituminous	Lignite	Bituminous
Origin	Wilhelmina-Victoria	Gew.Neurath	Shamrock 1/2
Ash, wt.%	10.41	5.22	5.92
Volatile Constituents, wt. %	29.82	54.28	21.1
Total Sulfur	1.01	0.49	1.02
Combustible Sulfur	0.87	0.44	--
Hydrogen	4.62	4.74	4.42
Carbon	76.87	64.95	83.6
Oxygen and Nitrogen	7.23	24.65	--
Higher heating value kcal/kg	7559	6111	8155
Lower heating value kcal/kg	7310	5855	7915

Because of the small capacity of the mill it was found impossible to bring the reactors to operating temperature in a reasonable time by burning coal dust alone, and therefore the practice was followed of preheating the unit by burning gas therein and switching from gas to coal dust for the final heating. After attaining the desired operating temperature the rate of coal dust feed was increased to give only partial combustion, and other gasifying agents (steam, and/or oxygen) were supplied as desired in an attempt to make gas of the desired composition.

As the criterion of gasification, as distinguished from complete combustion in the reactors, the appearance of the product gas issuing from the unlighted "torch" 37 was used. The coal dust feed rate was adjusted, with other operating variables constant, until the "torch" was slightly smoky, indicating an excess of free carbon. At the same time steam was supplied to the bottom of the first chamber at a sufficient rate to hold the average indicated temperature in the reactors at about 1300°C. However, there is evidence that reactor temperature measurements were quite unreliable and therefore the steam supply probably seldom served the intended purpose.

In reporting data the efficiency of the operation was calculated as the upper heating value of the gas from a kilogram of coal divided by the upper

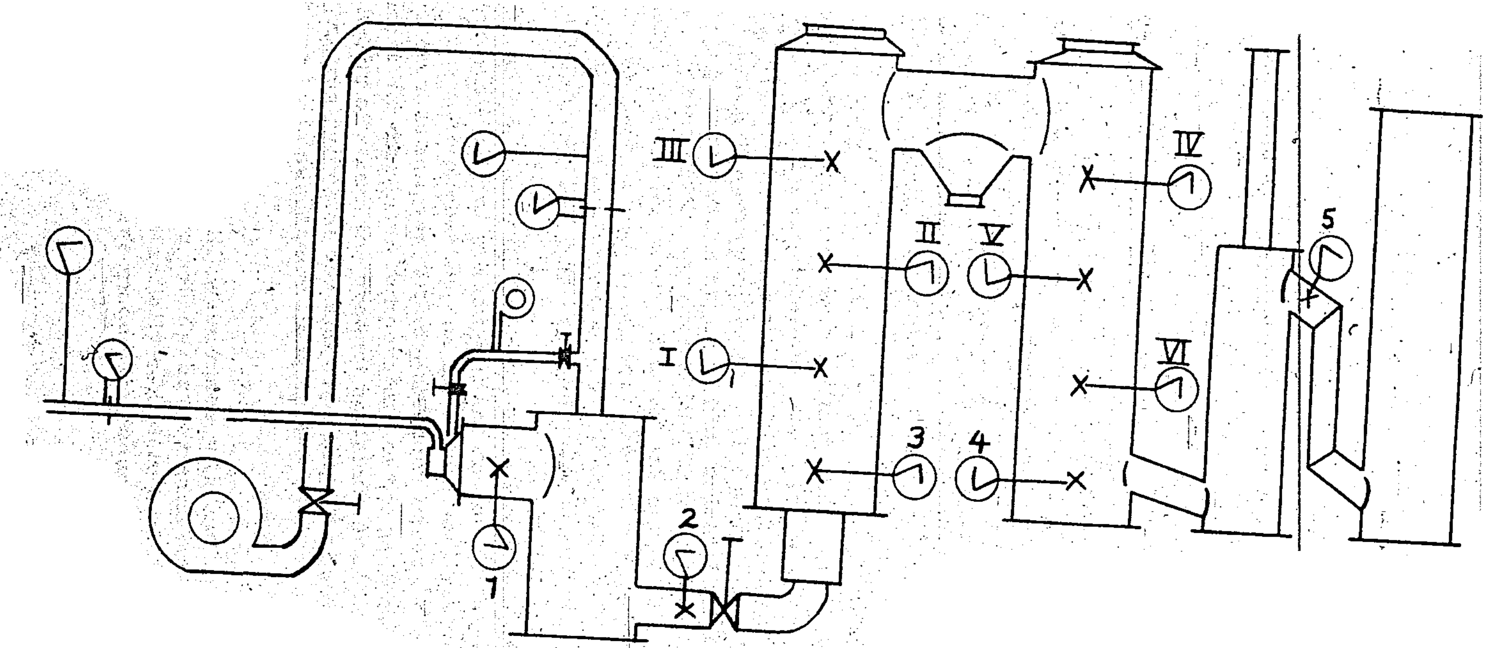


FIGURE 11

LOCATION OF THERMOCOUPLES(X)

heating value of a kilogram of coal.

D. Experimental Results; 1942 Operation

Experimental runs 1 to 30 inclusive were made during the period ~~of August 17 to December 21, 1942~~ after which the unit was shut down for overhaul. Operation was resumed on Aug. 4, 1943 and runs 31-40 were made between then and November 24, 1943 when the unit was shut down permanently due to exigencies of war. The two periods of operation were covered by two Demag reports from which the run data sheets have been reproduced as Tables II, III, IV, and V, pages 24 through 27.

The first eight test periods (Table II) in the interval from Aug. 17 to Aug. 26 incl. 1942, did not include quantitative measurement of the air used for gasification and therefore are not very significant. Most test periods were shorter than one hour and the longest was three hours. It was concluded necessary to have both reaction chambers at a temperature of 1200-1300°C. and some slag, either of ash or chamber lining, was found at the bottom of the first chamber after operating at an indicated chamber temperature of 1300°C.

Runs 9 and 10 were made with a shortened coal inlet tube in the bottom of Chamber No. 1 to facilitate ignition of the gas for preheating the chamber (See Fig. 10, page 18). Air was the gasifying medium preheated to about 400°C. by combustion of admixed fuel gas. Gas production amounted to 6.6 cu. meters per Kg. coal with an upper heating value of about 65 kcal per m^3. After the run a ring of slag was found in Chamber No. 1 about 1.5 meters above the end of the burner tube. Although the cause of this slag formation was not established, the short burner tube was suspected and therefore this tube was restored to its original length. It will be noted that the temperature in Chamber 2 for runs 9 and 10 was only 900-950°C.

Runs 11 and 12, Table III, page 25, were made with no preheating of the air used for gasification. Although there do not appear to be any strictly comparable runs with preheating the conclusion was reached that preheating by partial combustion was not advantageous because the reduction in oxygen content offset the increased temperature of the gasifying agent. (Using 450 and 280 Kg/hr of steam the product gas amounted to 5.97 and 6.28 m^3/Kg of coal with heating values of 557 and 648 kcal/m^3 at 1000-1200° indicated chamber temp.). In subsequent runs during 1942 no preheating was used.

Runs 13 - 20 (Table III) were made with four different rates of coal dust feed viz: 140,285,435 and 540 Kg/hr. At each rate one run was made with sufficient air to give substantially complete combustion (runs 13,15,17,19) and companion runs were made with reduced air rate to give gasification. Although steam was admitted with the intention of maintaining a ceiling temperature of 1300° in chamber 1 and 1100°C. in chamber 2 the reported temperatures vary considerably and their accuracy is uncertain. Gas yields were successively 6.60, 5.62, 6.55, and 5.88 M^3/Kg indicating no consistent trend with charge rate over this range. Gas heating values were 466, 542, 672, and 680 kcal/M^3 at the progressively higher rates of coal feed.

Beginning with this series of experiments, when temperatures and other variables had been stabilized as well as possible, gas samples were taken from top, middle, and bottom of each chamber to determine the change in composition with progress through the reaction zone. The results of these measurements for Runs 14, 16, 18 and 20 are shown graphically by Figures 12, 13, 14 and 15, pages 28 through 31. Similar curves were obtained for other experiments in which the same tests were made.

These curves indicate that the oxygen in the air was consumed rapidly in the formation of CO_2 which was complete before the second sampling point and possibly before the first sampling point. Subsequently the CO_2 concentration declined with a corresponding increase in CO and H_2, the latter resulting from the reaction of steam with CO or C. In general a nearly constant composition was reached before the outlet of the first chamber, but in some cases the CO concentration seemed to pass through a maximum and then decline in the second chamber, probably due to decomposition to CO_2 and C.

The indicated sequence of reactions is also believed to be significant since it means that heat will be transferred from the coal particles to the surrounding gas during the initial highly exothermic combustion with O_2 and that much of this heat must be returned from the gas to the particles during the endothermic reaction of CO_2 and H_2O with the remaining carbon in the subsequent section of the reaction zone.

These endothermic reactions will tend to be slow because they cool the surface of the reacting particles. This tendency may not be serious if the rate of heat transfer from the surrounding gas is sufficiently high. However, Gumz and Nistler believe that the latter rate can be suitably high only if the gas is at such a high temperature that ultimate fusion of the coal ash is unavoidable. Such reasoning points to the impossibility of a "dry" process, unless with very long reaction times in a unit of correspondingly low capacity, which seems to be contradicted by the claims of operability of the Koppers process.

Runs 21, 23 and 25, Table IV, page 26, were made with progressively increasing amounts of oxygen admixed with the gasifying air. Comparison runs 22 and 24 were made under similar conditions with normal air. The coal dust used in these experiments was somewhat coarser than for previous

TABLE II

POWDERED COAL GASIFICATION DATA - RUNS 1-10

Experiment No.	Dimension	1	2	3	4	5	6	7	8	9	10
Date		17.8	17.8	17.8	25.8	25.8	25.8	25.8	26.8	4.9	4.9
Nature of Experiment		Gas	Gas	Gas	Gas	Gas	Gas	Gas	Gas	Gas	Gas
Length of Run	min.	30	30	30	70	25	180	30	15	40	60
Coal Dust Quantity	kg/h	432	432	432	-	580	390	390	475	240	240
"	t/Tg m^2	9.15	9.15	9.15	-	12.3	7.86	7.86	10.5	5.1	5.1
Upper Heating Value	kcal/kg	7440	7440	7440	7440	7440	7440	7440	7440	7440	7440
Lower Heating Value	"	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150
Fineness (Residue on 0.2 mm Sieve)	%	12	12	12	12	12	13	12	12	12	12
Gasifying Medium		Air	Air	Air	Air	Air	Air	Air	Air	Air	Air
Quantity	Nm^3/h	-	-	-	-	-	-	-	-	1380	1380
Steam	kg/h	300	300	300	250	350	0	0	0	0	0
Heating Gas to Preheater	Nm^3/h	80	80	80	70	70	70	70	85	54	50
Temperatures											
Portion I	°C	1170	1170	1170	1305	1180	1235	1230	1260	1230	1240
II	"	1120	1130	1150	1230	1160	1285	1290	-	-	-
III	"	1000	1010	1040	1220	1150	1270	1270	1240	-	-
IV	"	820	840	880	1130	1070	1150	1150	1205	930	940
V	"	710	720	770	1080	1030	1090	1095	1175	900	920
VI	"	-	-	-	-	-	-	-	-	-	-
2 (Temp. Gasifying Medium)	"	-	460	480	-	470	570	-	510	400	-
3	"	-	480	600	-	470	500	-	-	-	-
Gas Analysis											
Sample Point		VI	VI	VI	VI	VI	VI	VI	VI	VI	VI
CO_2	%	14.7	13.0	13.4	11.6	9.2	7.7	10.0	8.9	10.4	8.7
O_2	"	0	0	0	0.1	0	0	0	0	0.2	0.1
CO	"	5.4	8.0	6.2	12.1	18.1	17.2	12.5	15.1	12.9	15.8
H_2	"	-	-	1.0	9.1	15.7	8.7	6.0	6.5	7.0	7.2
CH_4	"	-	-	0	0	0	0	0	0	0	0
N_2	"	-	-	79.4	67.1	57.2	66.4	71.5	69.5	69.5	68.2
Gas Produced	Nm^3/h	-	-	-	-	-	-	-	-	1570	1600
Gas Yield	Nm^3/kg	-	-	-	-	-	-	-	-	6.53	6.66
Heating Value H_o upper	kcal/Nm^3	-	-	217	642	1025	785	561	645	603	697
H_u lower	"	-	-	213	599	950	743	532	623	570	662
Efficiency basis cold gas	%	-	-	-	-	-	-	-	-	53.0	62.4
Air consumption	Nm^3/kg	-	-	-	-	-	-	-	-	5.75	5.75
Gas velocity basis 1.2 m diam. at operating temp.	m/sec	-	-	-	-	-	-	-	-	1.71	1.71
Residence time in the Reaction Chamber	sec	-	-	-	-	-	-	-	-	13.5	13.5

TABLE III

POWDERED COAL GASIFICATION DATA - RUNS 11-20

Experiment No. / Date	Dimension	11	12	13	14	15	16	17	18	19	20
Date		10.9	10.9	23.9	23.9	25.9	25.9	29.9	29.9	2.10	2.10
Nature of Experiment		Gas	Gas	Gas	Gas	Gas	Gas	Gas	Gas	Gas	Gas
Length of Run	min	60	90	30	90	10	200	165	135	225	195
Coal Dust Quantity	kg/h	315	315	140	140	285	285	435	435	540	540
"	$\frac{t}{Tg\ m^2}$	6.7	6.7	2.97	2.97	6.08	6.08	9.26	9.26	11.5	11.5
Upper Heating Value	kcal/kg	7440	7440	7440	7440	7440	7440	7440	7440	7440	7440
Lower Heating Value	"	7150	7150	7150	7150	7150	7150	7150	7150	7150	7150
Fineness (Residue on 0.2 mm Sieve)	%	12	12	12	12	12	12	12	12	12	12.0
Gasifying Medium		Air	Air	Air	Air	Air	Air	Air	Air	Air	Air
Quantity	Nm^3/h	1680	1680	1250	850	2300	1400	3500	2500	4650	2700
Steam	kg/h	450	280	0	0	0	220	0	200	0	220
Heating Gas to Preheater	Nm^3/h	0	0	0	0	0	0	0	0	0	0
Oxygen/coal ratio	Nm^3/kg										1.05
Temperatures											
Portion I	°C	1200	1180	1290	1370	1140	1190	1040	1260	1020	1100
II	"	-	-	1290	1230	1220	1300	1200	1260	1130	1260
III	"	-	-	1370	1250	1420	1350	1420	1360	1350	1300
IV	"	1020	1040	910	860	1000	950	950	860	1070	950
V	"	1000	1020	990	950	1120	1050	1120	1000	1200	1070
VI	"	-	-	910	880	1020	980	990	900	1090	990
2 (Temp. Gasifying Medium)	"	40	40	40	38	34	38	30	35	32	40
3	"	-	-	-	400	-	140	-	150	170	180
Gas Analysis											
Sample Point		VI	VI	VI	VI	VI	VI	VI	VI	VI	VI
CO_2	%	11.2	11.2	16.4	11.9	17.5	12.1	16.8	8.6	16.1	10.2
O_2	"	0.4	0.2	0.4	0	0	0	0	0	2.0	0.1
CO	"	12.2	12.8	0	11.6	0.9	11.1	0.9	14.5	0.1	13.7
H_2	"	6.2	8.6	0	3.8	0	6.8	0.5	7.6	0	8.7
CH_4	"	0	0	0	0	0	0	0	0	0	0
N_2	"	70.0	67.2	83.2	72.7	81.6	70.0	81.8	69.3	81.8	67.3
Gas Produced	Nm^3/h	1880	1980	1220	925	2280	1600	3370	2850	4490	3170
Gas Yield	Nm^3/kg	5.97	6.28	8.72	6.60	8.0	5.62	7.76	6.55	8.32	5.88
Heating Value H_o upper	$\frac{kcal}{Nm^3}$	557	648	-	466	-	542	-	672	-	680
H_u lower	"	527	608	-	448	-	510	-	633	-	638
Efficiency basis cold gas	%	44.7	54.7	-	41.4	-	41.0	-	59.2	-	53.8
Air consumption	Nm^3/kg	5.33	5.33	-	6.07	-	4.92	-	5.75	-	3.68
Gas velocity basis 1.2 m diam. at operating temp.	m/sec	2.78	2.52	-	1.05	-	2.04	-	3.4	-	
Residence time in the Reaction Chamber	sec	8.3	9.2	-	21.9	-	11.3	-	6.8	-	6.24

TABLE IV

POWDERED COAL GASIFICATION DATA - RUNS 21-30

Experiment No. / Date	Dimension	21 3.11	22 11.11	23 13.11	24 18.11	25 24.11	26 1.12	27 4.12	28 15.12	29 17.12	30 21.12
Nature of Experiment		O_2-Gas	Gas	O_2-Gas	Gas	O_2-Gas		Gas	Lignite	Lignite	Lignite
Length of Run	min.	60	180	210	120	120	150	180	180	140	160
Coal Dust Quantity	kg/h	540	580	580	435	540	395		540	430	310
"	t/tgm^2	11.5	12.36	12.36	9.26	11.5	8.4	12.36	11.5	9.25	6.6
Upper Heating Value	kcal/kg	7440	7440	7440	7440	7440	7440	7440	5545	5545	5545
Lower Heating Value	kcal/kg	7150	7150	7150	7150	7150	7150	7150	5257	5257	5257
Fineness (Residue on 0.2 mm Sieve)	%	37.3	37.3	37.3	37.3	37.3	69.0	37.3	4	4	4
Gasifying Medium		Air+O_2	Air	Air+O_2	Air	Air+O_2	Air	Air	Air	Air	Air
Quantity	Nm^3/h	1903	2740	909	2350	536	1860	2170	1630	1260	960
Oxygen Content	%	34.9	21	41.3	21	47	21	21	21	21	21
Steam Quantity	kg/h	900	1111*	250	-	400	0	0	0	0	0
Oxygen/coal ratio**	Nm^3/kg	1.23	0.99	0.65	1.13	0.47	0.99	0.79	0.63	0.62	0.65
Temperatures											
Portion I	°C	1170	920	1230	1040	1400	1100	1230	1170	1220	1220
II	"	1235	1000	1360	1280	1150	1180	1130	1100	1100	1010
III	"	1390	1440	1420	1440	1190	1280	1290	1170	1120	1020
IV	"	1160	1340	1270	1260	1080	1080	1150	1040	1010	900
V	"	1070	1210	1140	1070	980	960	1060	1000	980	870
VI	"	840	1250	1160	1100	1020	1000	1100	1020	1000	880
2 (Temp. Gasifying Medium)	"	75	24	100	30	85	35	35	35	40	35
3	"	170	100	200	-	-	-	-	-	-	-
Gas Analysis											
Sample Point		Torch	Torch	Torch	Torch	Torch	Torch	Torch	Torch	Torch	Torch
CO_2	%	17.1	13.8	20.4	13.9	22.4	11.5	7.3	8.9	8.2	8.7
O_2	%	0.3	0.1	1.5	0.1	0.5	0.2	0.2	0.3	0.0	0.2
CO	%	18.3	8.5	21.4	6.1	21.6	9.5	15.5	18.0	19.9	18.1
H_2	%	16.6	9.3	20.7	2.6	25.6	2.8	6.4	8.1	8.4	8.0
CH_4	%	0	0	0	0	0	0	0.5	0	0	0
N_2	%	47.7	68.7	36.0	77.3	29.9	76.0	70.1	64.7	63.5	65.0
Gas Produced	Nm^3/h	1890	3140	1050	2360	1235	1650	2290	1790	1570	1030
Gas Yield	Nm^3/kg	3.5	5.41	1.81	5.42	2.29	4.18	3.95	3.32	3.65	3.33
Heating Value H_o upper	$kcal/Nm^3$	1060	541	1278	263	1433	373	711	791	857	791
" H_u	$kcal/Nm^3$	980	496	1178	251	1310	359	675	752	817	753
Efficiency basis cold gas	%	49.9	49.4	31.1	19.2	44.1	21.0	37.8	47.4	56.4	47.6
Gas velocity basis 1.2 m diam. at operating temp.	m/sec	3.74	5.10	1.51	2.9	-	2.30	2.68	2.02	1.56	1.19
Residence time in the Reaction Chamber	sec	6.14	4.5	15.2	7.9	-	10.0	4.61	11.4	14.7	19.4

*Believed by Gumz to be typographical error; should be 111.

**Not reported in original data.

TABLE V

POWDERED COAL GASIFICATION DATA - RUNS 31-40

Experiment No. / Date	Dimension	31 4.8.43	32 11.8.43	33 11.8.43	34 28-29.9	35 28-29.9	36 2-3.11	37 23-24.11	38 23-24.11	39 23-24.11	40 23-24.11
Nature of Experiment		Dust from above	Mixture	Pre-heating	--	Preheating		Preheating		--	Pre-heating
Length of Run	h	2	1.5	1.5	Duration 24 hr		14	Duration over 34 hours			
Quantity of Coal Dust	kg/h	360	410	410	360	360	430	430	430	430	430
Upper Heating Value of Coal	kcal/kg	7440	7440	7440	7440	7440	8005	8005	8005	8005	8005
Lower Heating Value of Coal	kcal/kg	7150	7150	7150	7150	7150	7758	7758	7758	7758	7758
Gasifying Medium		Air	Air+O_2	Air+O_2	Air	Air	Air	Air	Air	Air	Air
Temperature	°C	30	410	410	30	273	415	410	355	45	370
Quantity	Nm^3/h	1220		638	1680	1460	1641	1405	1405	1550	1575
Oxygen Content	%	21	ca. 17	29.8	21	21	21	21	21	21	21
Steam Quantity	kg/h	220	800	800	200	280	330	280	280	280	290
Heating Gas to Preheater	Nm^3/h	0	32.4	32.4	--	52	82.2	--	61	0	72.5
Reactor Temperatures											
Point I	°C	460	940	940	1310	1310	640	1000	1000	450	740
II	"	--	--	--	1330	1280	1400	1320	1400	1370	1350
III	"	1380	1080	1100	1160	1150	1230	1260	1360	1290	1280
IV	"	920	880	880	1040	1080	1150	1170	1220	1210	1200
V	"										
VI	"	740	--	--	950	1010	--	1000	1040	1080	1070
2	"	ca. 30	410	410	ca. 30	330	450	460	400	45	410
Gas Analysis											
Sample Point											
CO_2	Vol.%	8.3	12.65	18.2	9.3	10.1	10.2	8.9	9.6	10.3	8.9
O_2	"	0	0	0	0	0	0	0	0	0	0
CO	"	14.3	10.7	17.0	13.4	14.4	12.3	13.9	13.9	11.9	14.1
H_2	"	8.4	24.25	22.8	9.9	14.3	13.0	13.5	13.0	10.9	12.7
N_2	"	69.0	52.4	42.0	67.4	61.2	64.5	63.7	63.5	66.9	64.3
Gas Produced	Nm^3/h	1400	--	--	1970	1890	2010	1740	1750	1830	1935
Gas Yield	Nm^3/kg	3.89	--	--	5.48	5.25	4.67	4.04	4.07	4.26	4.50
Heating Value H_o upper	$Kcal/Nm^3$	690	1063	1208	707	870	767	831	817	692	813
H_u lower	$Kcal/Nm^3$	647	945	1100	660	802	704	766	723	639	753
Efficiency (cold gas basis)		0.36	--	--	0.519	0.55	0.395	--	--	0.368	0.411
Heat input to preheater	$kcal/Nm^3$					59	100	101	83		88

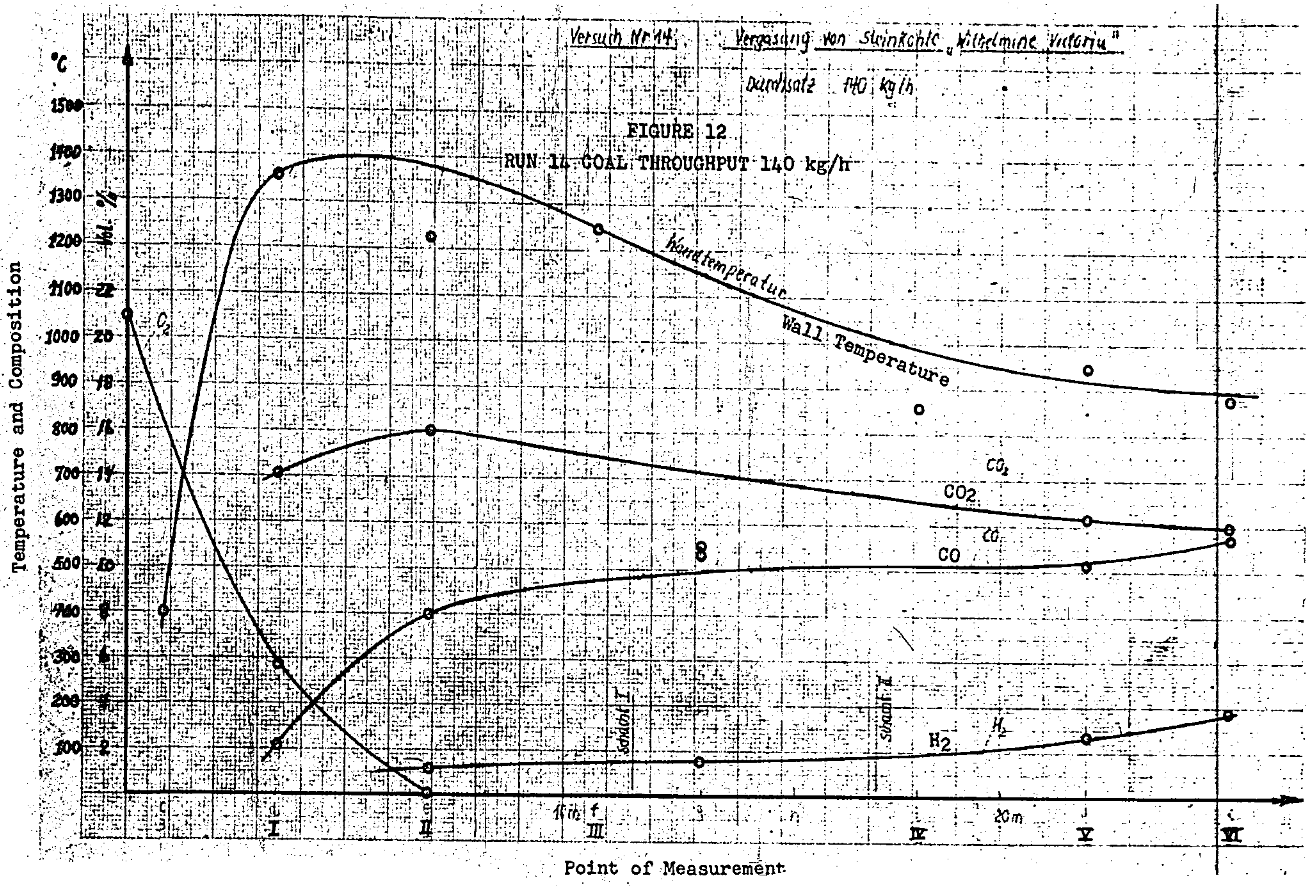


FIGURE 12
RUN 14 COAL THROUGHPUT 140 kg/h

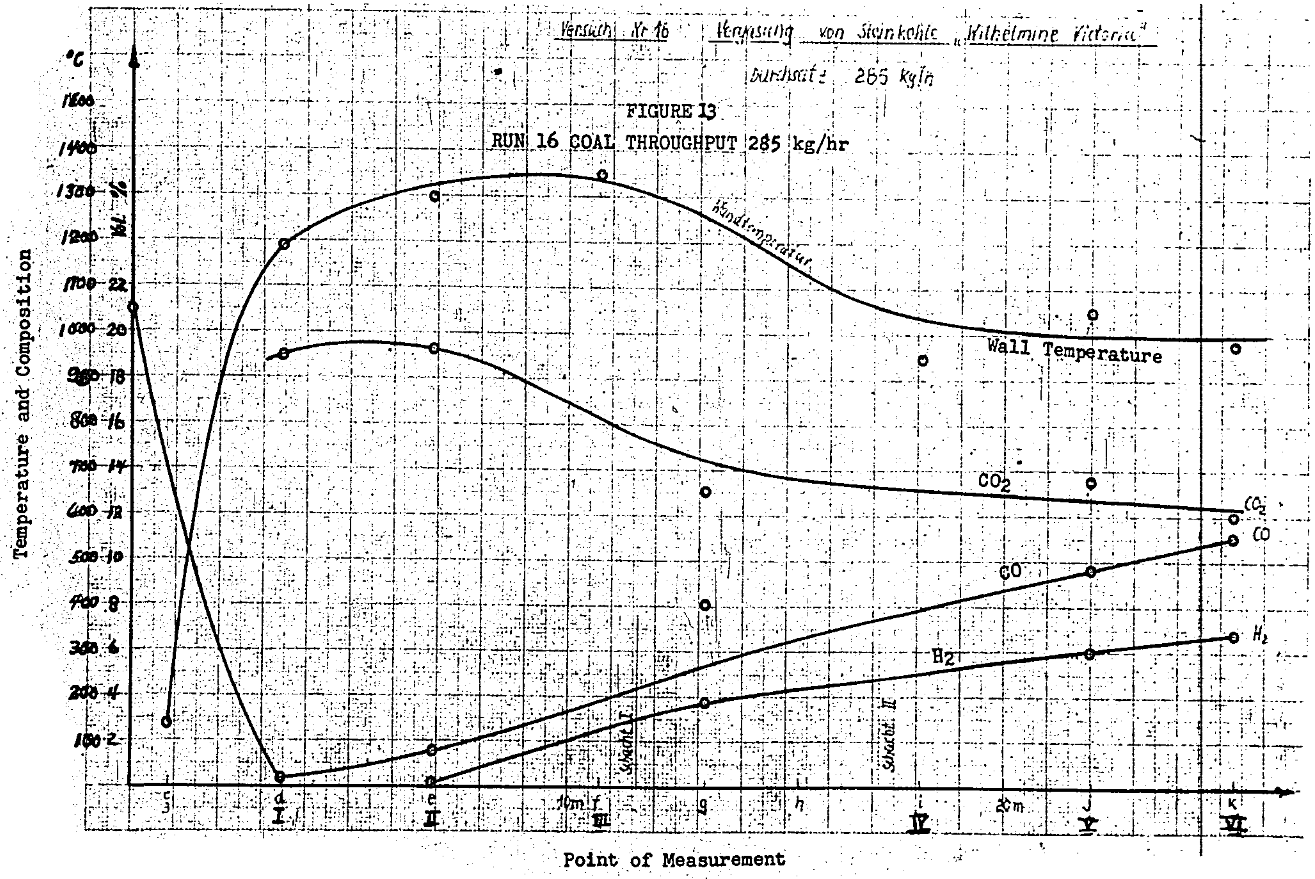


FIGURE 13

RUN 16 COAL THROUGHPUT 285 kg/hr

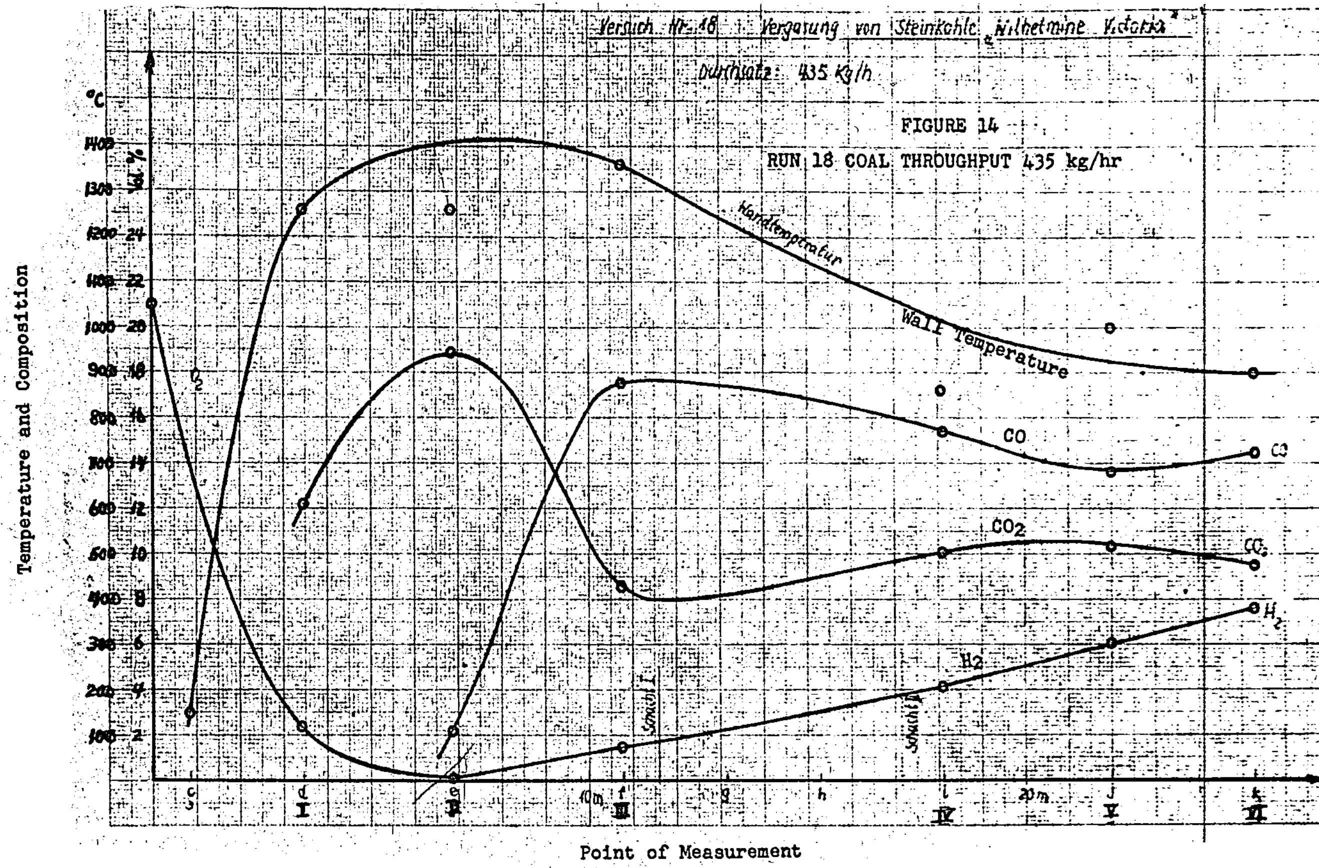


FIGURE 14

RUN 18 COAL THROUGHPUT 435 kg/hr

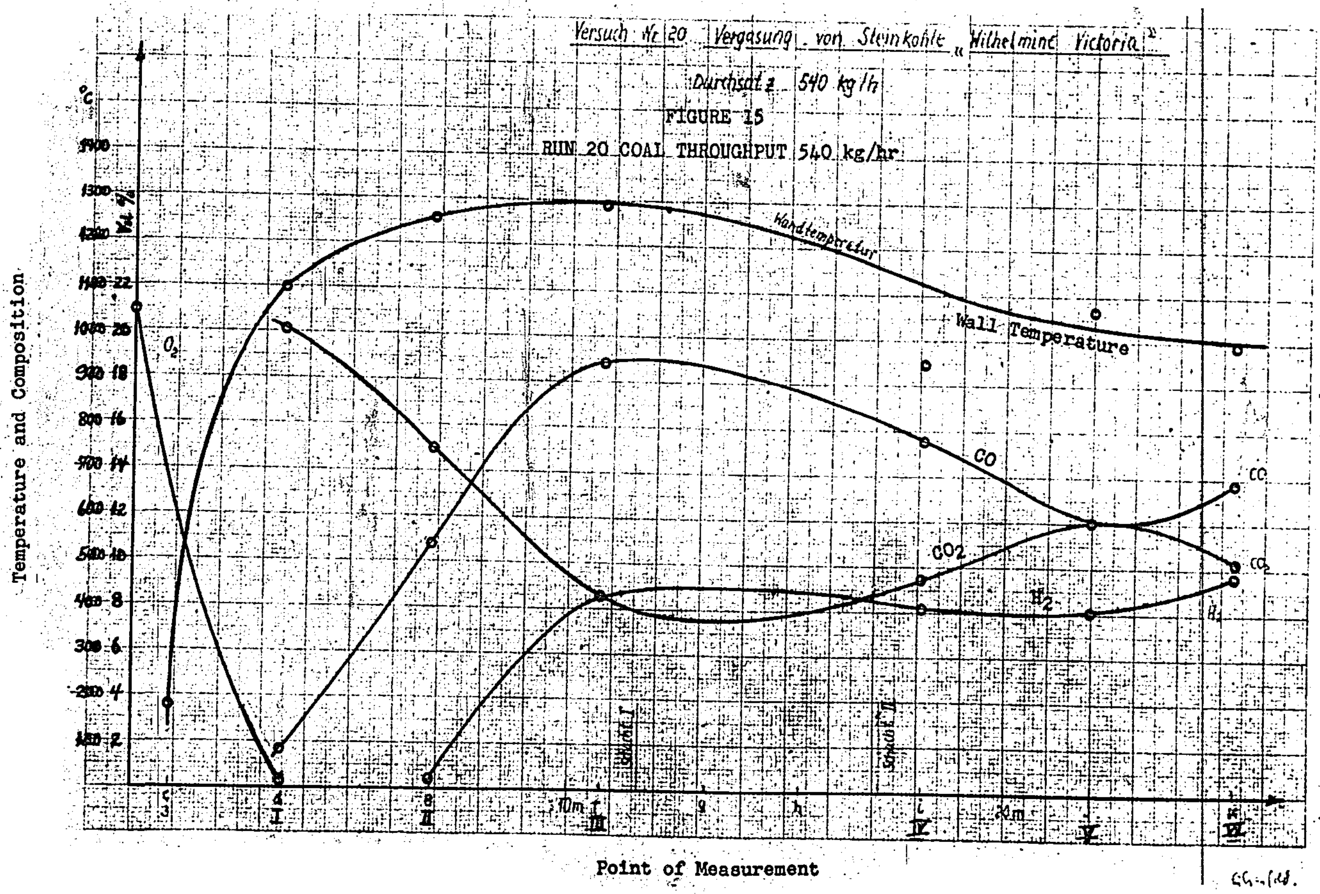


FIGURE 15
RUN 20 COAL THROUGHPUT 540 kg/hr

runs but Dr. Gumz expressed the opinion that the difference was not great enough to affect the results.

When using enriched air it was stated that large quantities of steam were required to prevent overheating of the reactors. However it will be seen that the quantity of steam did not decline regularly with declining oxygen/coal ratio which suggests that again the inaccuracy of reactor temperature measurement made proper adjustment of steam flow impossible. The heating value of the gas increased with increased air enrichment and corresponding reduction of nitrogen content of the gas.

Inexperiment 25 gas composition measurements were made at the middle of chamber 2 and at the wall at level VI but no significant difference was found. Special water cooled sampling tubes were inserted for these measurements since a quartz tube tried initially was fused, indicating much higher true temperatures at this point than recorded. This is further born out by the fact that a considerable accumulation of slag was found in chamber no. 1 at the end of run 25 as shown by Figure 10, page 18.

Experiment 26 was made with a distinctly coarser coal dust than used previously. The most nearly comparable run appears to be No. 22, although it involved a higher coal charge rate and higher ratio of steam to coal. So far as comparison is possible the use of coarse dust appeared to give less gas of lower heating value.

Run 27 was made with a relatively high ratio of coal to air in an attempt to reduce the ultimate CO_2 production. Steam was not required to prevent excessive indicated temperatures. The resulting gas had a relatively low CO_2 content, 7.3%, and a high heating value, 711 kcal/Nm^3, but the efficiency was only 37.8%.

Runs 28, 29 and 30 were made with lignite at charge rates of 540, 430 and 310 Kg/hr. and relatively low ratios of oxygen to coal. Indicated reactor temperatures were 100-200°C. lower than usual even without the introduction of steam. Gas yield and quality was good and thermal efficiency was high. The ratio of CO_2 to CO in the product gas was exceptionally low.

Inspection of the reaction chambers after run 30 showed the brick lining to be covered with a chocolate colored glaze which had penetrated the bricks to a depth of 5-10 mm. The mortar joints had been attacked more seriously than the bricks themselves. Although the analysis of the glaze agreed well with that of the bricks it was concluded that the slag was probably molten ash from the coal. In addition to being superficially attacked by this slag, the brickwork had undergone sintering, shrinking and settling as a result of high temperature operation. However, the cylindrical shape of the lining was not seriously distorted. In view of the probability that even higher gasification temperatures would be desirable it was recognized that a more durable reactor lining and better means of discharging molten ash would have to be developed for prolonged operation. Therefore during the early part of 1943 changes were made in the unit for the purpose of improving its performance in these respects.

E. Changes in Unit Construction

To permit the periodic discharge of fused ash a dip leg with a water seal was attached to the bottom of the first reactor as illustrated by Figure 16, page 34. This also served to indicate the accumulation of slag in the air inlet passage since the resulting increase in back pressure would blow the water seal.

Test blocks of different types of refractories were built into the lining of the first reactor at the level of temperature measuring point III (see Figure 11). The nature and location of these test blocks is shown by Figure 17, page 35. The result of their examination after the next period of operation is reported on page 37.

In addition to these changes in chamber No. 1, a new duct was installed to insure an adequate supply of hot air to the mill for drying the coal during grinding. After this change a mill discharge temperature of 100-120°C. (intake 600°C.) could be maintained when grinding 800 Kg/hr., thus insuring dry coal and smoother operation of the powdered coal feeding device.

F. Experimental Results: 1943 Operation

Experimental work was resumed in July 1943 and the data for the subsequent runs are summarized in Table V, page 27, from the second Demag report. In run 31 the powdered coal was supplied to the top rather than the bottom of chamber no. 1. At the end of this run the trap at the bottom of the chamber was filled with coarse coal particles. The gas yield was low, perhaps because of low average reactor temperatures. The possibilities of this method of operation can hardly be appraised on the basis of this one run.

Runs 32 and 33 were next made with the gasification air being preheated by combustion of admixed fuel gas and then enriched with extraneous oxygen to offset the oxygen lost by combustion. It was found very difficult to control the rate of oxygen addition since the oxygen supply pressure was low and variable. Yields of gas from these runs were not reported but it is interesting to note that these were the only runs made in

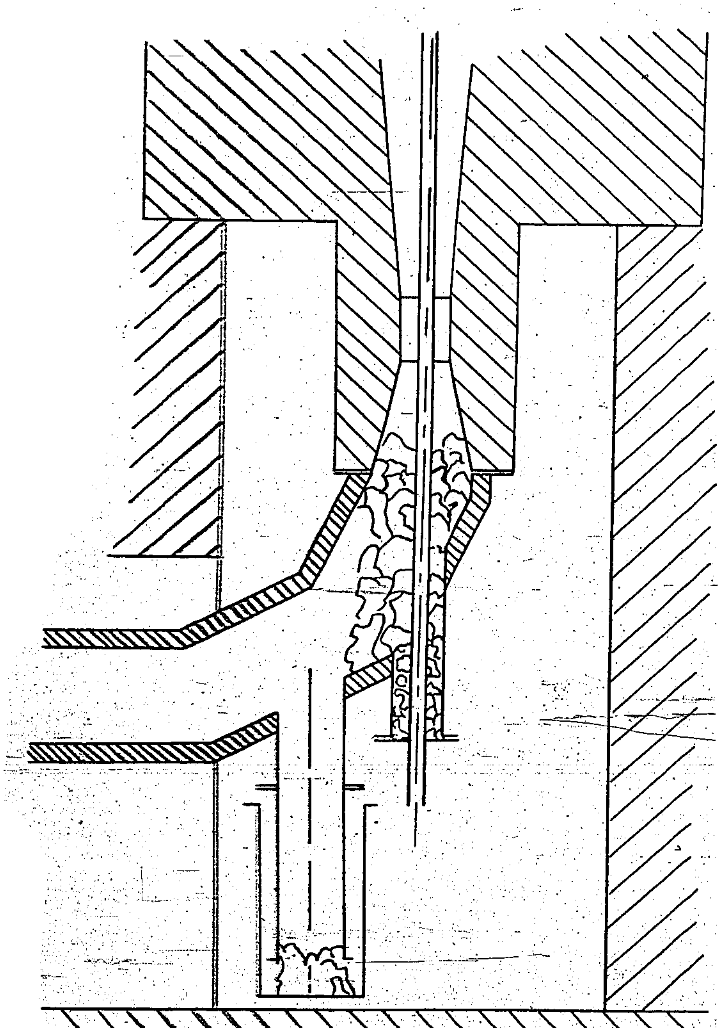
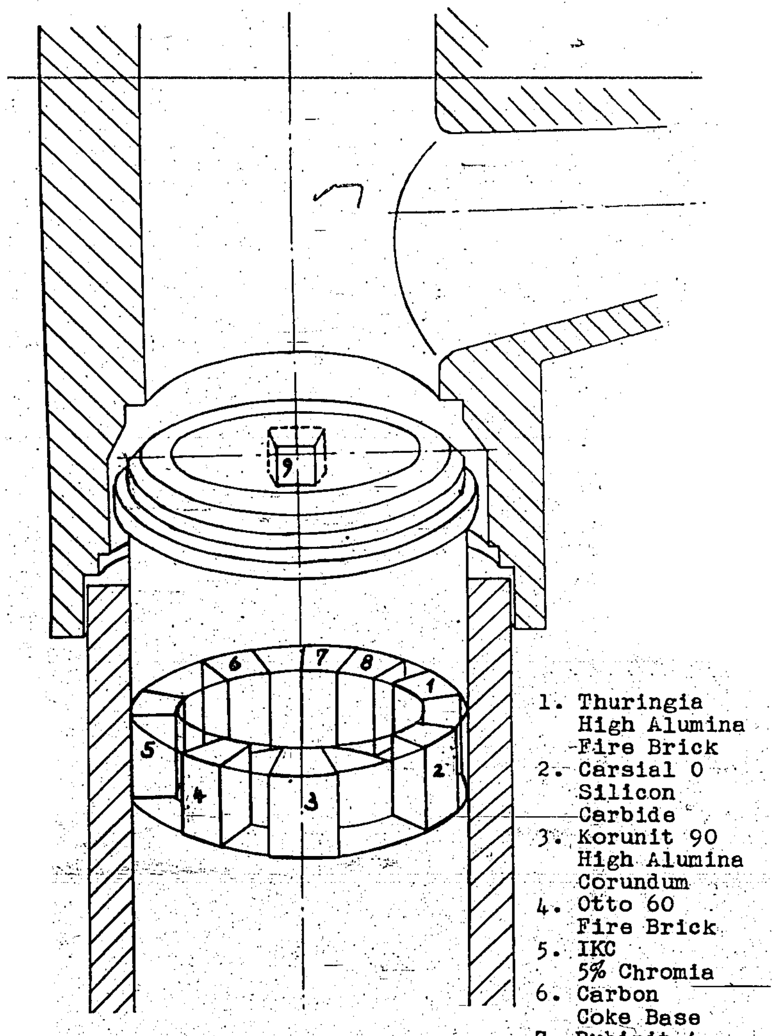


FIGURE 16

DIP LEG UNDER REACTOR NO. 1 AND SLAG ACCUMULATION IN RUN NO. 36



1. Thuringia High Alumina Fire Brick
2. Carsial 0 Silicon Carbide
3. Korunit 90 High Alumina Corundum
4. Otto 60 Fire Brick
5. IKC 5% Chromia
6. Carbon Coke Base
7. Rubinit A Magnesite Grade
8. Mullital X High Alumina-High Mullital Grade
9. Magnesite Brick

FIGURE 17

TEST BRICKS IN LINING OF REACTOR NO.1

which the H_2 concentration was substantially higher than the CO concentration. The heating value of the gas was high.

Since the combustion products from this preheating by admixture changed the reaction conditions so that comparison with air gasification ~~alone was difficult it was decided to complete and use the indirect air pre-~~ heater for subsequent runs. It was also decided to make longer runs in the future if possible, since conclusions from short runs might be very misleading because the large heat capacity of the generators would not permit the operation to reach truly constant temperatures. (The problem of measuring true reaction temperature remained unsolved).

Runs 34 and 35 were relatively long runs under apparently steady conditions without and with the indirect air preheater. A slightly lower production of gas of substantially higher calorific value was obtained with the preheater.

Subsequent runs were made on coal from the Shamrock mine which had a lower melting ash than the Wilhelmina-Victoria coal previously used and was more representative of Ruhr production in general. With this coal it was intended to determine the possible limit of air preheat when charging 430 Kg coal per hour. (This quantity of coal was the maximum which could be handled by a temporary air supply line in use while the regular air blower was being repaired).

After a short period 8 hours of operation with air preheated to 450°C. the unit had to be shut down because the lower part of the first reactor was plugged with slag. The nature of this plug is shown by Figure 18, page 38. Slag normally accumulated as a ring R on the chamber wall at the hottest zone some distance above the top of the coal inlet pipe. Dripping from the inner surface of this ring the slag was falling into the relatively narrow conical bottom of chamber I and when viscous, as in the case of Shamrock coal, would plug this zone. To avoid this difficulty the burner pipe was extended as shown by the dotted lines of Figure 18 with the hope of correspondingly raising the ring R and leaving more room below to handle slag which dripped therefrom.

With these changes Run 36 was made with air preheated to 450 °C. but only 14 hours of operation could be obtained before the bottom of chamber 1 was again completely plugged as shown.

After completing repairs to the air compressor Runs 37-40 inclusive were made to determine more exactly the effect of air preheating. Except for this factor other variables were essentially constant. With preheating to 370°C. (Run 40) the gas yield and heating value seemed to be slightly higher than without preheating (Run 39). However Dr. Gumz pointed out that such short runs (6.5 hrs.) were not sufficient for reaching temperature equilibrium and he doubted that any real effect of preheating was shown by these runs. Further evidence that the runs did not serve the intended purpose is provided by the relative constancy of indicated reaction temperature with or without preheating and with constant steam supply.

After the conclusion of runs 31-40 the interior of the reactors was examined. In the test zone of the first reactor the carbon bricks had burned out completely and the IKC and Rubinit A bricks had fallen out due to being used in insufficient thickness. However, a ridge of slag was found below the location of Rubinit A indicating that this brick had been attacked by slag before it fell out. The Magnesit brick (No. 9) had also been severely attacked by slag, and furthermore were badly cracked and loose in the setting presumably because it was not resistant to temperature changes.

Korunit 90 (No. 3) showed the least attack with no visible change on the surface or edges. The fire clay bricks Thuringia (No. 1) Otto 60 (No. 4) and Mullital X (No. 8) also stood up well. Carsial O (No. 2) also withstood the slag attack very well but could not be used in an oxidizing atmosphere because it is then burned to SiO_2.

In reactor No. 2 the brickwork was undamaged though covered with a uniform glaze of slag.

VI. DISCUSSION OF EXPERIMENTAL RESULTS

A. Material Balances

To get some measure of the accuracy of the rotary feed valve a charge of Shamrock coal was weighed into the mill bunker and then passed through the mill, dryer, separator and feed valve in the normal manner. The feed valve indicated the passage of 36500 kg. of coal dust compared with the weighed discharge of 39800 kg (dry basis) from the mill bunker. The deficiency of 10.5 per cent was believed to be mainly loss from the collector beyond the mill which was being run without filter bags because they imposed too much back pressure.

During the period of operation on Shamrock coal an attempt was made to obtain an ash balance. The ash content of the coal weighed to the

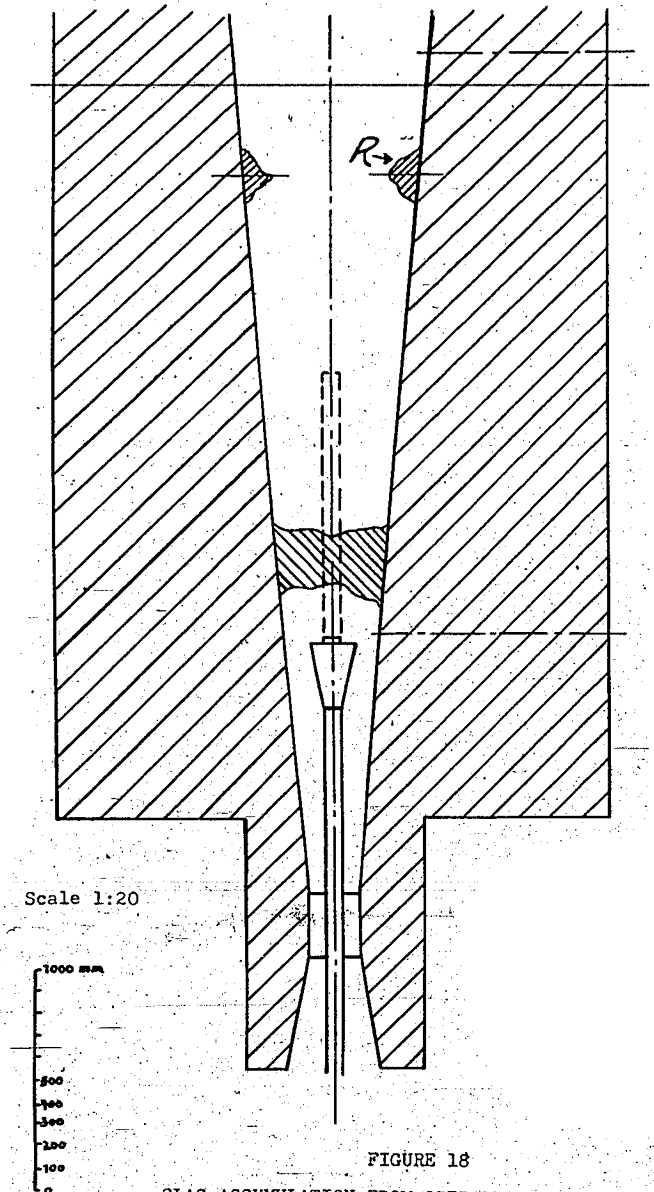


FIGURE 18

SLAG ACCUMULATION FROM OPERATION ON SHAMROCK COAL SHOWING INLET TUBE BEFORE AND AFTER RUN 35 mill was calculated to be 2414 kg. The ash in the products was distributed as follows:

Solid slag from the dip pipe	950 kg
Dry solids from the settling basin	
~~3300 kg with 10.64% ash~~	~~352 kg~~
6920 kg with 4.84 % ash	335 kg
Total ash recovered	1637 kg
Ash unaccounted for	777 kg
	=32.2%

This large discrepancy was due in part to unmeasured losses of coal dust between the mill and the reactor and to accumulation of slag in the reactor, with the latter probably being the major factor.

Another attempt to get an ash balance was made in run 36 and resulted in the recovery of about six per cent more ash than was charged indicating that the relatively high temperature in this run had released some accumulated slag from the walls of the reactor.

For the entire operation on Shamrock coal the carbon content of the sludge in the washer settling basin amounted to about 30 per cent of the carbon in the coal charged, assuming six per cent loss of coal between the mill and the reactor. From run 40 the carbon equivalent of the gas made was only 66.5 per cent of the carbon in the coal charged. The loss of 33.5 per cent was believed to be mainly unburned carbon in the settler.

The sediment recovered from the settling basin showed a lower ash content than the raw coal, which was presumed to be due to the formation of free carbon in the gasifying zone either by the decomposition of CO (Boudouard's reaction) or the cracking of hydrocarbons from the coal, or both. A considerable deposition of soot was observed in the system beyond the first reactor. The total loss of carbon (around 30 per cent) was recognized as prohibitive and it was suggested that dry recovery and recycling might be necessary.

B. Reactor Design

In view of all indications that operating temperatures must be so high that the ash would be molten and the slagging of the refractory lining might be serious, a reaction chamber with externally cooled walls was strongly recommended. This in turn would necessitate a relatively large diameter so that the cool walls would not too greatly reduce the temperature of the reacting mixture.

Nistler believes that the reactor diameter should be at least three meters which he estimates would reduce the reactor heat losses to about five per cent. The height of the reactor should be at least eight meters and preferably ten meters. A coal charge rate or 500 kilo per hour per square meter cross section is believed possible. A reactor of three meters internal diameter would thus handle about 3500 kg. per hour. It was recommended that any future experimental work be conducted with a reactor of abou this size.

Although the Ruhrgas experiments did not lead to the design of a commercial unit, Gumz was of the opinion that a commercial unit should have a capacity of at least 100 tons of coal per day.

C. Coal Composition

The Ruhrgas experiments revealed no effect of coal composition on the ease of gasification and Gumz claims that composition would be relatively unimportant in powdered coal gasification. Desulfurization of the gas produced would be unavoidable but is expected to be simple because of the extensive decomposition of sulfur compounds in the oxidation zone. However no experimental data along this line were available.

Although experimental operations did not demonstrate the effect of fineness of coal, Dr. Gumz stated that fine grinding is essential to avoid excessive unreacted carbon. Most of the Ruhrgas work was done on coal ground so that 90% would pass through a No. 65 Tyler screen. Even finer grinding was believed desirable. No information was available from the Ruhrgas work regarding the flow characteristics of coal particles of different size. In normal operation the coal would be completely entrained and not in the "fluidized" state.

Moisture content of the coal was stated to have the same effect on gasification as water vapor from any other source. However moisture content will influence grinding, and lignite should be predried to 13-17% water content to facilitate fine grinding. Gumz stated that weathering of the coal would have no effect on gasification by his process but no data were available bearing on this point.

Gumz believes that his process would be operable on high temperature coke or low temperature carbonization char, with the latter being somewhat more reactive. A further objection to operation on high temperature coke is its abrasive character and consequent wear on grinding equipment. The hydrocarbon gases recovered from carbonization can be blended to increase the heating value of the gas from the generator, if fuel gas rather than synthesis gas is desired.

D. Operating Procedure

When using air as the gasifying medium, preheating was concluded to be unnecessary to make a gas having a heating value of 700 kcal/Nm^3 from either Wilhelmina or Shamrock coal. With air preheating the heating value of the product gas was increased by an amount slightly greater than the quantity of heat supplied to the preheater. However, in no run was the gasifying agent preheated to more than 600°C.

Gumz stated that the maximum heating value theoretically obtainable by the gasification of powdered coal with air at atmospheric pressure is 1050-1200 kcal/m^3.

To attain the desired heating values of 950-1000°C. with air as the gasifying medium it was assumed that the coal would first be carbonized to give hydrocarbon gases which would be used to enrich the gas made by processing the powdered char from carbonization with steam and air.

Gas having heating value of more than 1000 kcal per m^3 was made with air enriched with oxygen. However, the Ruhrgas experiments included no runs with more than 47% oxygen in the gasification medium, and the effect of higher concentrations on gasification rate and gas quality is not known. The opinion was frequently expressed that operation with high oxygen concentrations would be easier than operation with air, but certainly the problems associated with high reaction temperatures would be aggravated.

In the Ruhrgas operations the thermal efficiency of coal conversion ranged from 36 to 62% and it was expected that 50 to 60% efficiency could be realized in a commercial plant. Commercial operation should include a waste heat boiler to recover part of the heat from the gases leaving the reactors at temperatures of 1000 to 1200°C. This heat would be used to generate high pressure steam to meet part of the requirements of the blowers, mill, and oxygen plant. Due to uncertainties in coal quantities no heat balance was calculated for the Ruhrgas plant.

Gumz believes that the coal charge rate can be about 500 Kg per sq meter reactor cross section although experimental work had not established this factor with any certainty. The coal dust would preferably be admitted through the side of the reactor near the bottom so that the bottom could be used solely for the discharge of molten ash.

Gumz was of the opinion that recycling of product gas, except possibly in small quantities for conveying the powdered coal would be detrimental because of its diluting effect on the reactant oxygen. Gasification in two or more stages was believed undesirable because of the difficulty of separating reactants between stages at high temperatures.

No measurements of the gum-forming constituents in the gas were made during the Ruhrgas experiments. However the opinion was expressed by Gümz that gas from hig process would give little trouble from gum or could be easily refined by conventional processes. No methods of measuring gum forming constituents had been developed.

Gumz reported that no special safety precautions were used on the Ruhrgas unit and no accidents occurred. However Nistler admitted that one explosion had occurred in the grinding mill but this was due to improper adjustment of the combustion gas generator for drying coal in the mill and should not be regarded as a normal hazard of the gasification process.

Neither Gumz or Nistler were very enthusiastic about the possibility of gasifying powdered coal under superatmospheric pressure although they pointed out that the recommended reactor with cooled walls might operate at moderate pressure like the Lurgi units. The feeding of powdered coal to a pressure unit was regarded as a difficult problem, for which no solution was offered.

E. Comparison With Other Processes

Nistler stated that he knew of no other experimental work in Germany on powdered coal gasification except that of Koppers, and regarding the Koppers process neither Gumz nor Nistler had any extensive or first hand information.

Gumz agrees with Koppers on the desirability of preheating the gasifying agent althoughtthe extent of preheating used experimentally was a maximum of 600°C. in the Ruhrgas work compared with 1200°C. recommended by Koppers. However Gumz points out that preheating in Cowper stoves as recommended by Koppers would require low grade yet clean fuel gas if it is to be economical, and the gas produced on the unit would probably be too costly for such use if made with oxygen to approach synthesis gas composition.

Gumz and Nistler did not regard the Winkler process as competitive since it operates on relatively coarse coal and the fine particles are carried out of the generator ungasified and are normally burned as powdered fuel for power generation. Likewise the Wintershall-Schmalfeldt process was regarded as in a different catagory since it was operable only on lignite as was limited in temperature by the quality of brick available for regenerator construction.

Proposals by Pintsch for gasifying powdered coal with externa heating and by Ritternhausen for using electrical heating were regarded as impractical.

F. Proposed Future Work

The Ruhrgas unit was not damaged by bombing but was shut down more than a year before the end of the war and robbed of a great many accessories which were needed for other more important work. Since the end of the war the plant has probably deteriorated for lack of care. It was not inspected during the present investigation, but according to Nistler it could be put back in operation if the necessary accessories could be obtained.

In January, 1944, Nistler recommended further work along the following lines:

1. Study the gasification of coke from low temperature carbonization, with stepwise variation of air preheating, with and without steam. Since such coke would contain little volatile matter, much soot in the product gas could be attributed to CO decomposition, the extent of which was indeterminate from runs on powdered coal.

2. Repeat experiments on gasification of Wilhelmina coal with different degrees of air preheating.

3. Study the gasification of the carbonaceous sludge from the washer, settling basin to determine the feasibility of recovering and recycling this material.

4. Operate with a single reaction chamber to see if higher CO concentrations and less soot can be obtained with shorter residence time. It had been suggested that a quench between the first and second chambers might give the same information. With a single chamber a further study of top feed of powdered coal was recommended.

In carrying out the above program it is obvious, though not specified, that more accurate means of measuring reactor temperatures would be very important.

Work on the existing unit along the above lines would be subject to serious apparatus limitations, and work with a reactor of larger diameter having cooled walls was recommended by both Gumz and Nistler.

APPENDIX 1

LIST OF GERMAN PERSONNEL

Personnel Interrogated

Dr. Wilhelm Gumz* German Mine Supplies Organization, Hyskenallee, Essen

Dr. Frederic Nistler** German Mine Supplies Orgainzation, Hyskenallee, Essen

Dr. Otto Pistorius, Demag, Duisberg

Dr. Schneemilch, Demag, Duisberg

Personnel not interrogated but known to have had some connection with the Demag-Gumz work.

Dr. Gummert	Ruhrgas, A.G., Essen
Dr. Kuckuck	Bischoff A.G., Essen formerly with Ruhrgas
Dr. Lilienfeld	Reichsbahn, Hannover, formerly with Demag
Dr. Mueller	Demag, Duisberg
Dr. Reerink	Ruttelnskamp 2, Essen-Bredeney
Dr. Schemman	Ruhrgas, A.G., Essen
Dr. E. E. Schulze	Demag, Duisberg
Dr. Traencker	Ruhrgas A.G., Essen

* Bibgraphy on page 45
**Biography on page 47

BIOGRAPHY OF
WILHELM MAX AUGUST GUMZ

Date of Birth	May 21st, 1901
~~Place of Birth~~	~~Rombach (Lorraine)~~
Present Address	Essen, Hufelandstr.68II
Citizenship	German
Religion	Protestant
Family	Married since 1933, two children
Military Service	None
Membership in Political Parties	None
Education	1907/16 Realschule (secondary school) at Rombach 1916/18 Lyceum at Metz (Realgymnasium) 1918/19 Practical duty with "Rombacher Huttenwerke" (Rombach blast furnace and steel works) 1919/20 Engineering University of Karlsruhe 1920/21 Duty as a draftsman with Gelsenkirchner Bergwerks A.-G., Abt. Hochofen (Gelsenkirchen Collieries, blast furnace department), technical office at Gelsenkirchen i/W. This interruptinn of my education became necessary from economic reasons. 1921/24 Engineering University of Darmstadt, concluded 1924 by diploma. Degree of Dipl.-Ing. 1938 Degree of Dr.-Ing., Engineering University of Berlin by the thesis "Gasification of Solid Particles in Suspension".
Employment	1924/25 Municipal electricity works of Mainz, supervising heat economy. 1925/29 Seimens-Schuckert-Werks A.-G., Berlin-Siemensstadt, department of power stations. Development and calculation of the Benson high pressure boiler and different thermodynamical work. 1925/29 Luftvorwarmer G.m.b.H., Berlin (Air pre-

Employment

heater Corporation of Berlin), a daughter Company of Aktiebolaget Ljungstroms Angturbin, Stockholm, Sweden Construction, development and sale of the Ljungstrom air preheater in Germany and most parts of Europe. Employment as chief engineer, later as the managing director.

1929/34 after the dissolution of Luftvorwarmer G.m.b.H. continuation of this activity as a chief engineer of Kraftanlagen Aktiengesellschaft, Heidelberg, consulting engineers.

Since 1934 Member of the management of Verein fur die bergbaulichen Interessen, Essen, now changed to German Mines Supplies Organization, charged with all problems of coal utilization (Combustion and gasification).

Other by-work

Editor of "Feuerungstechnik", a technical periodical from 1936 to 1944, author of different books and papers on problems of combustion, gasification, air preheating, steam boiler practice, coal, fuel utilization.

1947, March 25th. Contract with H.Q. USFET, Office of A.C. of S., G-2.

BIOGRAPHY OF
DR. FREDERIC NISTLER

Born on July 11th 1912 at Plana near Marienbad, Bohemia.

Present Address: Essen-Kellinghausen, Goldammerweg 8.

Nationality: German

State Citizenship: 1912-1918 Austrich-Hungarian Monarchy.
1918-1939 Czechoslovakian.
1939-now German. (Munich agreement)

Married since 1941, two children

Nationality of wife and children: Czechoslovakian.

State Citizenship: Czechoslovakian. Present Address: Plana u Mar. Laz., Smetanova 199/II. Czechoslovakia.

Education:

Public school and grammar school at Plana till 1930.
Engineering university at Prague from 1930-1935.

Employment:

1935-1937 assistent under Prof. Breinl, technical university of Prague, department for steam boilers and steam power plants.

1938 employment at "Braunkohlenforschungsinstitut" (bituminous coal research laboratory) at Freiberg, Saxonia, under Dr. Rammler. Plans and calculations of an experimental plant to study gasification of bituminous coal in suspension.

1939-1941 construction and running of this plant in Berlin.

1942-1943 employment at "Bergbauverein", Essen, under Dr. Gumz. Running of the experimental plant for gasification of powdered coal in suspension constructed by Demag-Ruhrgas-Bergbauverein according to calculationf of Dr. Gumz. Current work about combustion and gas producing combustion turbines.

1944 three month basic training at the Luftwaffe, then discharged for work to the Henschel aeroplane factory at Berlin. Work under Prof. E. Wagner (now U.S.A.) with the rockets "HS 298" and "butterfly" till the end of the war.

BIOGRAPHY OF
DR. FREDERIC NISTLER
(CONT'D)

Autumn 1945 employment as an interpreter for English, German and Czech at the American Civil Affairs Office at Plana, Czechoslovakia.

1946 till now: Employment in German Mine Supplies Organization at Essen under Dr. Gumz. Main work: Steam drive for road transport.

APPENDIX 2

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APPENDIX 3

QUESTIONNAIRE SUBMITTED TO GUMZ AND NISTLER BY FIAT

Information on the points enumerated below is desired with reference to your process for gasifying powdered coal. Please assemble all available information along these lines including supporting experimental data, drawings, calculations etc.; for discussion with FIAT representatives within about one week. This material is to be incorporated in a detailed report on your process and should be amplified in any way possible to make a complete and accurate report.

1. Record of all forms of apparatus and all methods of operation which were tried, and a discussion of the results obtained in each case. Difficulties encountered as well as success achieved are important.

2. The effect of kind of coal and fineness of grinding on its behaviour in gasification unit.

3. Details of equipment for feeding powdered coal to the reactor and operating characteristics of such equipment.

4. Description and drawing of all accessories which you regard as more or less standard equipment, such as preheaters, waste heat boilers, scrubbers etc. and their operating characteristics.

5. A discussion, theoretical and practical, of the design, construction and operation of the gasification chamber itself.

6. Recommended procedure for starting, running and shutting down such a unit.

7. Safety precautions and devices.

8. Difficulties likely to be encountered because of corrosion or erosion in any part of the system and preventive and remedial measures therefor.

9. Flexibility of the unit with respect to throughput and product gas composition.

10. Exact method of controlling the unit to make gas of any possible composition, particularly of high ratio of H_2 to CO.

11. Comparison of the process with other known powdered coal, gasification process including Demag, Schmalfeldt, Didier, etc.

QUESTIONNAIRE SUBMITTED TO GUMZ AND NISTLER BY FIAT (CONT'D)

12. Effect of coal composition and operating variables on organic sulphur content of the product gas.

13. Relationship between fluidizing or flow characteristics of the powdered coal and performance of the generator.

14. Extent of ash entrainment, under different operating conditions and any other important features of the ash handling problem.

15. Suitability of the process for operation at elevated pressures up to 20 atm or more.

16. Effect of moisture content of coal on generator performance and gas quality.

17. Operating conditions applying to heat balance examples given in paper.

18. Specific operating data for various coals and various gas compositions.

19. Possibility of energy exchange between generator and oxygen plant.

20. Effect of oxygen purity on operating characteristics of generator.

21. Methods of determining gum-forming constituents of gas and effect of operating variables on the content of such materials in the product gas.

22. Methods of removing gas forming constituents and other foreign materials from product gas.

23. Importance of the water gas equilibrium in determining composition of the product gas.

24. Effect of weathering of coal on its gasification characteristics.

25. Preferable operating conditions for making different types of heating gas instead of synthesis gas.

26. Preferable operating conditions for making synthesis gas of relatively high ratio of CO to H_2.

27. Effect of recycling part of product gas or supplying extraneous gas other than oxygen and steam with the coal.

QUESTIONNAIRE SUBMITTED TO GUMZ AND NISTLER BY FIAT (CONT'D)

28. Operability of the process on partially or completely carbonized coal.

29. Desirability of accomplishing the gasification in stages operated under different conditions.

30. Effect of size of unit on plant cost and cost of operation.

31. Factors determining most economical size of unit.

H. V. ATWELL

11th April, 1947