PB 85165 $1.75

FIAT FINAL REPORT NO. 1303

KOPPERS POWDERED COAL GASIFICATION PROCESS

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U. S. DEPARTMENT OF COMMERCE

2 Sept. 1947

KOPPERS POWDERED COAL GASIFICATION PROCESS

ABSTRACT

H. Koppers G.m.b.H. of Essen, Germany, under the immediate direction of their Mr. Totzek conducted experimental work on the gasification of powdered coal from 1938 to 1944. The first unit was built in the Brabag-Schwarzheide plant and subsequent units were at Rheinpreussen ~~Shaft IV near Homberg~~. In all cases the reactor was a horizontal drum with powdered coal introduced at one or both ends, and the gasifying agent, air or oxygen mixed with steam, being introduced at spaced points along the length of the drum so as to insure turbulent flow of the dust between inlet and outlet. Preheating of the gasifying medium to about 1200°C. was concluded to be essential and Cowper stoves were used for this purpose. Operation was only at atmospheric pressure. The final Rheinpreussen unit was estimated to have a capacity of 10 tons of coal per day but it never operated successfully because of excessive cooling by the water jacket. Previous units were somewhat smaller and no runs longer than five or six hours had been made. No commercial units were built but several proposals were made on the basis of about 0.5 M^3 oxygen consumption and $2M^3$ synthesis gas production per kg coal. No original experimental records were available to support claims made for the process.

KOPPERS POWDERED COAL GASIFICATION PROCESS

TABLE OF CONTENTS

TABLE OF CONTENTS (CONT'D)

LIST OF FIGURES

LIST OF FIGURES (CONT'D)

LIST OF TABLES

I. INTRODUCTION

Objective

The present investigation of work by H. Koppers G.m.b.H. in the field of powdered coal gasification was conducted under the auspices of FIAT with headquarters in Karlsruhe, Germany. The objective was to get complete information about the Koppers process for making fuel gas or synthesis gas from powdered bituminous coal or lignite. Several previous investigators had reported the existence of such a process and some had obtained and published meagre information regarding its operating characteristics. No previous investigation or report had been sufficiently comprehensive to permit an appraisal of the value of the process for the gasification of coal in the United States.

Evaluation

The FIAT investigators succeeded in obtaining a fairly detailed statement of the course of Koppers experimental work and the conclusions reached. Koppers officials could not be shaken in their contention that all experimental data and reports had been destroyed by bombing and fire. Thus documentary proof of statements made from memory is completely lacking. A limited number of original drawings of experimental units and proposed commercial units were obtained.

The largest unit built by Koppers had a powdered coal capacity of about six metric tons per day and the longest run made on such a unit was about five hours. The latest modification of this unit did not give entirely satisfactory operation because of excessive cooling of the reaction zone by its water jacket. Nevertheless the Koppers officials believed that they had a commercially operable process, and from 1941 to 1943 they were making proposals for commercial units. Such units were never built because of the exigencies of war.

The present writer does not feel that the Koppers experimental work justified their confidence as to the commercial operability of their process. However the more complete picture which we now have regarding the course of this experimental work may be a very useful foundation for further research and development in the United States.

II. NUMBER AND SCOPE OF INVESTIGATIONS

The Koppers offices in Essen were visited by CIOS investigators on 15 April, 1945 and the information then obtained was summarized in CIOS report XXVIII-36, Item 30, by E. B. Peck and A. Parker(1). The data therein on powdered coal gasification relate only to a proposed unit for Brabag at Schwarzheide. Documents obtained in this connection are reproduced on Technical Oil Mission Microfilm Reel 43 frames 209 to 278 inclusive.

Representatives of the U.S. Navy Technical Mission in Europe interrogated Koppers officials in May 1945 and obtained documents which are reproduced on Technical Oil Mission Microfilm Reel 188 beginning with frame 20951. These include five pages of heat and material balances dated 4 June 1945, as well as undated flow diagrams, graphical representations of heat balances and reproductions of blueprints. So far as can be determined no report on these documents has been published.

About September 1946 the Koppers officials were interrogated by FIAT investigators Johnson and Bushow but no report on powdered coal gasification has been issued as a result of this investigation. According to Dr. Koppers the material given to these investigators included a copy of an unpublished address by Totzek summarizing the Koppers experimental work, which he said was not given to the U.S. Navy investigators.

The present investigation was conducted during the period from 10 April to 27 May, 1947. The conferences were initiated by Dr. W. F. Faragher, Chief of the Fuels and Lubricants Unit, Industry Branch, FIAT. Most of the interrogations were conducted by B. M. Rosenthal and the writer. During the later stages of the investigation French interests were represented by Mr. D. deReseguier, of the Institut du Petrole, Paris. Various representatives of the British Military Government, including Messrs. Shaw and Follett of the North German Coal Control and Dr. Eskreyss of the British Chemical Industry Control, were very helpful in issuing permits and orders which made it possible to obtain the desired documents and information from Koppers officials.

Frequent visits were made to the Koppers offices in Essen for the interrogation of Messrs. Koppers and Totzek, and written answers were obtained to a formal questionnaire regarding various aspects of their work, which is reproduced in Appendix 5, page 49. Persistent questioning failed to shake their story that all original data had been destroyed by bombing and fire, and therefore all statements as to the actual and expected performance of Koppers powdered coal gasification units must be accepted with some reservations.

(1)Peck, E. B., and Parker, A., Report on H. Koppers G.M.&H., Essen. CIOS Item No. 30, File No. XXVIII-36. 28 June 1945.

All documents obtained from Koppers during the present investigation are being reproduced on Technical Oil Mission Microfilm reel No. 238 for future reference. Prints or copies therefrom may be obtained through the Library of Congress. The documents themselves are being returned to the Office of Technical Services, U.S. Department of Commerce.

III. OUTLINE OF KOPPERS EXPERIMENTAL WORK

Recognizing the importance of being able to gasify lignite or non-coking bituminous coal the Koppers Company built a unit for gasifying lignite briquettes in the plant of Brabag at Schwarzheide-Ruhland in 1935. This process was started to be successful but left a considerable residue of fine coke which could not be gasified in any available generators. Therefore an experimental unit for the gasification of this fine coke was built in the Schwarzheide plant in 1938. This unit was not successful but it indicated the most promising lines for further research.

Studies of coal dust gasification were continued in a unit built by Koppers in the plant of Rheinpreussen at Homberg in 1940. Eventually the performance of this unit was stated to be very satisfactory and on the basis of data obtained there proposals were made for the erection of commercial units. Due to exigencies of war the experimental work at Rheinpreussen was discontinued in 1944 and no commercial unit was ever built.

The general course of this work was reviewed by Totzek in an unpublished paper read at a meeting of the Power Committee, in Essen, 12 June, 1942.

IV. GENERAL CONSIDERATIONS IN POWDERED COAL GASIFICATION

Totzek[1] points out that the gasification of powdered coal with air involves first the combustion of part of the coal and its distillation products with all available oxygen, which is an exothermic reaction and quite rapid. Subsequently the resulting CO_2 and H_2O must undergo reaction with unburned carbon, which is endothermic. Not only must the required heat be available in the system but it must be transferred to the coal particles so that they will remain at an active reaction temperature, which was indicated by Koppers experiments (not further specified) to be 300-400°C. above the values usually stated in the literature.

(1) Totzek; Arbeiten der Heinr. Koppers G.m.b.H. über restlose Vergasung; Vortrag vor dem Energieausschuss. (Essen) 12 June 1942 (Unpublished Address).

It was concluded that the provision of long contact times to attain heat transfer and the desired completeness of reaction was impractical. As an alternative the use of an excess of carbon would probably give desired gas compositions but would be objectionable because of the difficulty of recovering and recycling the unconverted carbon. However by the use of oxygen or enriched air as the combustion medium it was concluded that complete gasification of powdered coal could be accomplished. Furthermore by thus avoiding or limiting the amount of nitrogen charged to the generator the concentration of CO and H_2 in the product gas could be raised, which is important in the production of synthesis gas. For this purpose Totzek stated that the concentration of CO + H_2 in the product gas should be at least 82%, in which case the concentration of CO_2 would be so low that it need not be reduced further by scrubbing. Furthermore the use of oxygen gives considerable flexibility in the ratio of CO to H_2 which can be attained in the product gas. Assuming the use of oxygen to be essential, Totzek points out that preheating of the gasifying medium and using very finely-ground coal as for powdered coal combustion will keep the oxygen consumption at a minimum.

With respect to the production of synthesis gas in particular Totzek pointed out that it is important to minimize the content of resin forming materials which will foul the synthesis catalyst and are costly to remove, and also it is desirable to insure the conversion of sulfur in the coal to compounds in the gas of a type readily removed by conventional rough and fine purification procedures.

V. BRABAG-SCHWARZHEIDE LIGNITE BRIQUETTE GASIFICATION

In an attempt to accomplish the production of synthesis gas directly from lignite or non-caking bituminous coals Koppers started the construction of a unit in August 1935 for the gasification of brown coal briquettes in the Schwarzheide-Ruhland plant of Braunkohlenbenzin A.G. This unit involved carbonization and partial gasification of the briquettes by a recirculating stream of gas and steam heated in a Cowper stove to 1250°C. The heat requirements were met by converting the carbonized residue from the briquettes to fuel gas in a rotating grate convertor. The latter operation was successful only if the coke retained sufficient mechanical strength, and this was not always the case. Thus the problem arose of making fuel gas from the relatively fine char resulting from the crumbling of these lignite briquettes.

The original briquette gasification unit started operation in April 1936 and had a capacity of 25,000 m^3 of normal synthesis gas per hour to be used in the Brabag Fischer-Tropsch plant. The operation of this unit was stated by Totzek to be entirely successful and within one year the construction of additional units was begun to give a capacity of 4,320,000 m^3 of synthesis gas per 24 hours. The consumption of briquettes was to be 3600 metric tons per day and the gas production was 1200 m^3 per ton. No report on the performance of this unit by American or British technical investigators has been found but a flow diagram was included in CIOS report No. XXVIII-36 Item 30 and is reproduced herewith as Figure 1, page 7. Koppers gave to the FIAT investigators a print of their drawing IOS 111 860 dated 29 July 1936 showing details of the Cowper stove and combustion shaft, presumably associated with this unit, but this drawing is not suitable for reproduction in this report. A drawing obtained by the U.S. Navy Technical Mission reproduced on Tech. Oil Mission Microfilm reel 188 section 36-U apparently relates to the same unit but is difficult to identify with certainty.

VI. BRABAG-SCHWARZHEIDE COKE DUST GASIFICATION

In 1938 an experimental unit was set up at the Brabag Schwarzheide plant to study the production of fuel gas from finely divided lignite coke. The design of the reaction chamber used in this unit is shown by Figure 2, page 8, taken from Koppers drawing IOS 92,915. Another Koppers drawing, IAK 112,745, shows the general arrangement of the Schwarzheide powdered coke unit but is not suitable for reproduction in this report. The following comments on the performance of this unit are essentially a translation of statements by Totzek in answer to the FIAT questionnaire.

"The Brabag reaction chamber was intended to give an accentuated relative motion between the gas and coke particles. In a powdered coal burner part of the coke was to be burned in admixture with steam. At a second point additional powdered coke was to be introduced and agitated with the hot flue gas mixture to reduce the flue gases and steam. The results were unsatisfactory. Only about 30% of the coke was gasified and the rest settled out in the dead spaces. The heating value of the gas was only about 800 kcal/m^3."

"Instead of using powdered coke in the burner, butane from the plant residue gas was burned with the hope of reducing the resulting combustion gases with coke dust. This was based on the following reasoning. In the combustion of coke dust the principal product is CO_2. Steam is admixed cold and reduces the temperature considerably. However in the combustion of butane considerable water vapor is produced in addition to CO_2 and at a higher temperature level. The results of operation with butane fuel were somewhat more favorable. However, continuation of experiments along this line did not seem advisable since even here extensive conversion of the added coal dust was not obtained."

"In order to completely gasify a particle of coal dust it is necessary for the gasifying atmosphere to have a certain relative motion and furthermore the path through which the particle travels must be sufficiently long so that the particle is brought to reaction temperature and is then allowed sufficient time of contact for reaction. The velocities in the apparatus used were too low and not sufficiently controlled to gasify the entire particle. The greatest part of the coal dust settled out along the way to the gas exit and thus escaped gasification."

Although this unit was not successful its operation indicated other lines along which greater progress might be expected. At the same time it was concluded that future experiments should be conducted on powdered bituminous coal since any process which would gasify this material should be well suited to the gasification of the much more reactive lignite. In order to be near a suitable supply of bituminous coal the experimental work at Schwarzheide was discontinued and a new program was instituted at Rheinpreussen Shaft IV between Moers-Meerbeck and Homberg.

VII. RHEINPREUSSEN COAL DUST GASIFICATION

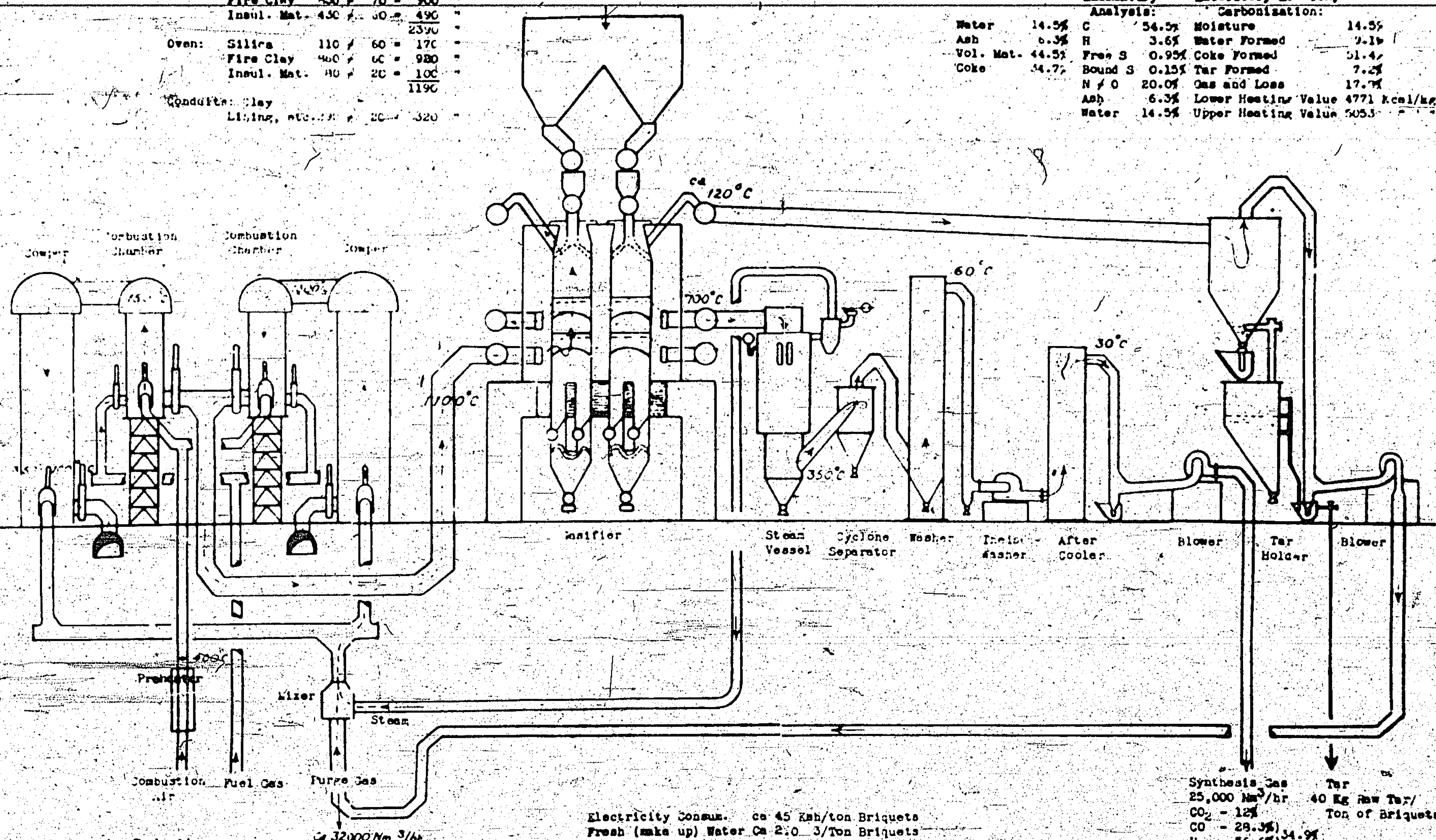
The best source of information regarding the Rheinpreussen gasification unit seemed to be Mr. Totzek who was the Koppers engineer in charge of this work. During the present interrogation Totzek insisted that none of the men engaged in the Rheinpreussen experiments would have any more knowledge of the data than he has and that no experimental records escaped destruction. However Mr. Totzek was able to locate a number of drawings of various experimental units and produced correspondence files regarding proposals for commercial units which were under discussion with Rheinpreussen and Brabag. Mr. Totzek was interrogated personally on several occasions and he also furnished detailed answers to a written questionnaire. In this way the following summary of experimental work, including that at Rheinpreussen Shaft IV, was assembled.

For the experimental plant at Homberg, Rheinpreussen furnished a site and provided coal and utilities. On special occasions analyses of gas from the experimental unit were run in the Rheinpreussen laboratories but otherwise, according to all accounts, the Rheinpreussen representatives had no contact with the experimental work. They were not permitted to visit the plant and were not given any experimental data or reports. In fact Koppers has kept this work quite secret and no one outside of the Koppers organization has been found who knew anything of consequence about the Rheinpreussen experiments.

The first form of reactor tried at Rheinpreussen is shown by Figure 3, page 9, reproduced from Koppers drawing IOS 146,506. The assembly of this reactor with accessories is shown by Figure 4, page 10, reproduced from Koppers drawing IOS 146,511. In succeeding Rheinpreussen units different reactors were tried with no substantial changes in the accessories. This design was based on experience at Schwarzheide which

Refractory Material:					
Cowper:	Silica	870 ≠ 130	=	1000	Tons
	Fire Clay	830 ≠ 70	=	900	"
	Insul. Mat.	430 ≠ 60	=	490	"
				2390	"
Oven:	Silica	110 ≠ 60	=	170	"
	Fire Clay	460 ≠ 60	=	920	"
	Insul. Mat.	80 ≠ 20	=	100	"
				1190	
Conduits:	Clay				
	Lining, etc. [illegible] ≠ 20		=	320	"

		Elementary Analysis:		Laboratory Low-Temp. Carbonization:	
Water	14.5%	C	54.5%	Moisture	14.5%
Ash	6.3%	H	3.6%	Water Formed	9.1%
Vol. Mat.	44.5%	Free S	0.95%	Coke Formed	51.4%
Coke	34.7%	Bound S	0.15%	Tar Formed	7.2%
		N ≠ O	20.0%	Gas and Loss	17.7%
		Ash	6.3%	Lower Heating Value	4771 Kcal/kg
		Water	14.5%	Upper Heating Value	5053 " "



For Preheating:
1300 Kcal. (Lower Heating Value) per Kg. Briquets
= 1200 Kcal. (L.H.V.) per Nm^3 Synt. Gas
As Fuel Gas-Generator Gas from Brs. Coke
Fuel Gas Heating Value: 1300 Kcal/Nm^3

Electricity Consum. ca 45 Kwh/ton Briquets
Fresh (make up) Water Ca 2.0 3/Ton Briquets
Boiler water Ca 1.0 " "
Steam Requirements Produced in Plant.

Synthesis Gas
25,000 Nm^3/hr
CO_2 - 12%
CO - 28.3%)
H_2 - 56.6%) 84.9%
CH_4 - 1.0%
N_2 - 2.1%
Dust Content: 20 mg/Nm^3
Synt. Gas free from Tar & Oil Vapors
" " " " Resins, etc.
Synt. Gas Yield: 1200 Nm^3/Ton Briquets

Tar
40 Kg Raw Tar/ Ton of Briquets

FIGURE 1

BRABAG LIGNITE BRIQUETTE GASIFICATION PLANT

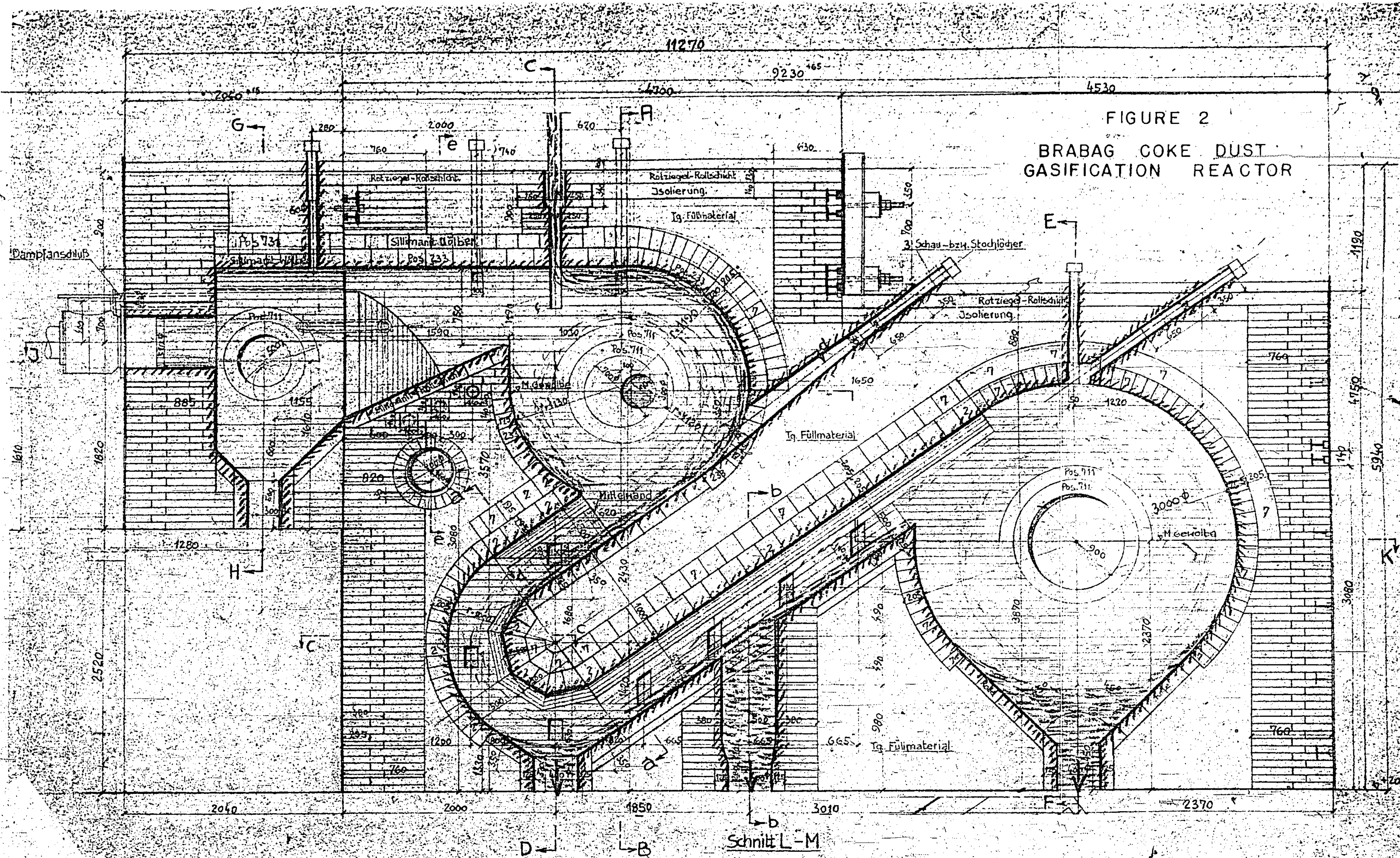


FIGURE 2
BRABAG COKE DUST GASIFICATION REACTOR

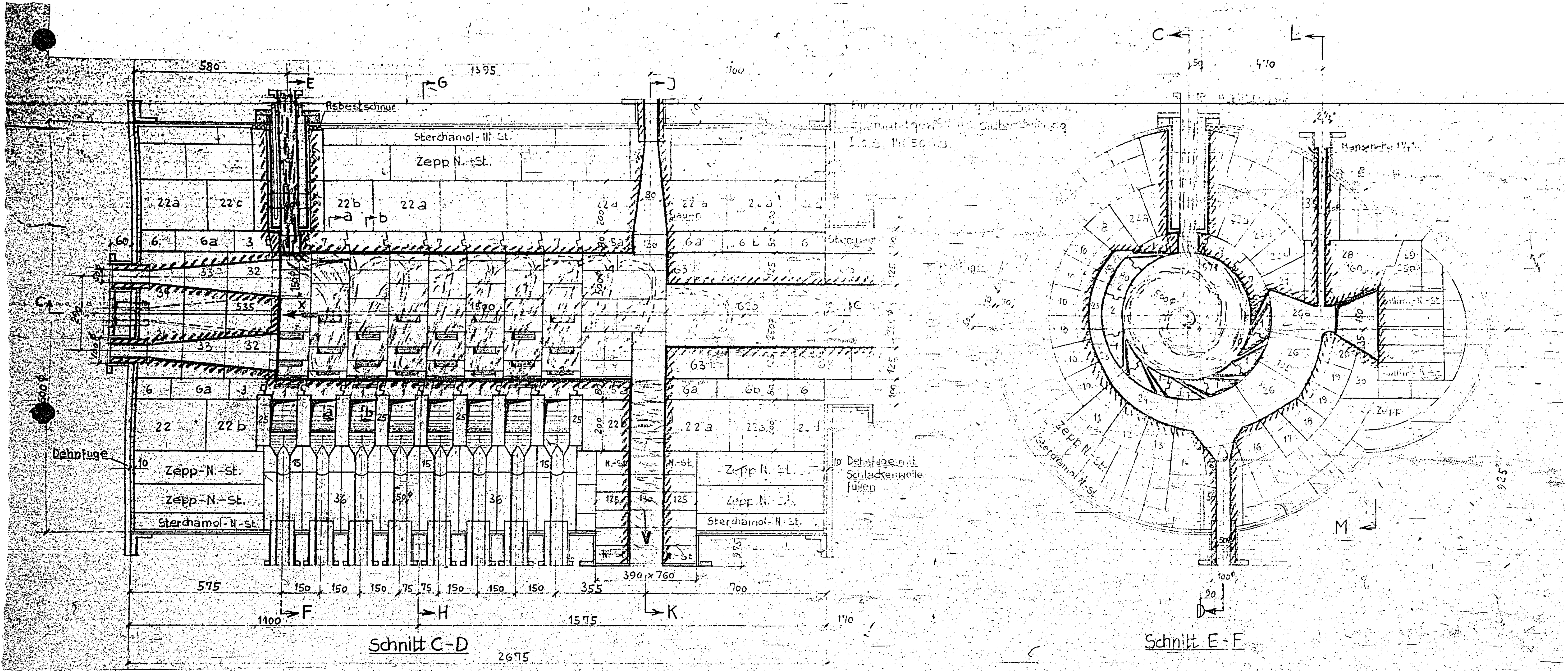
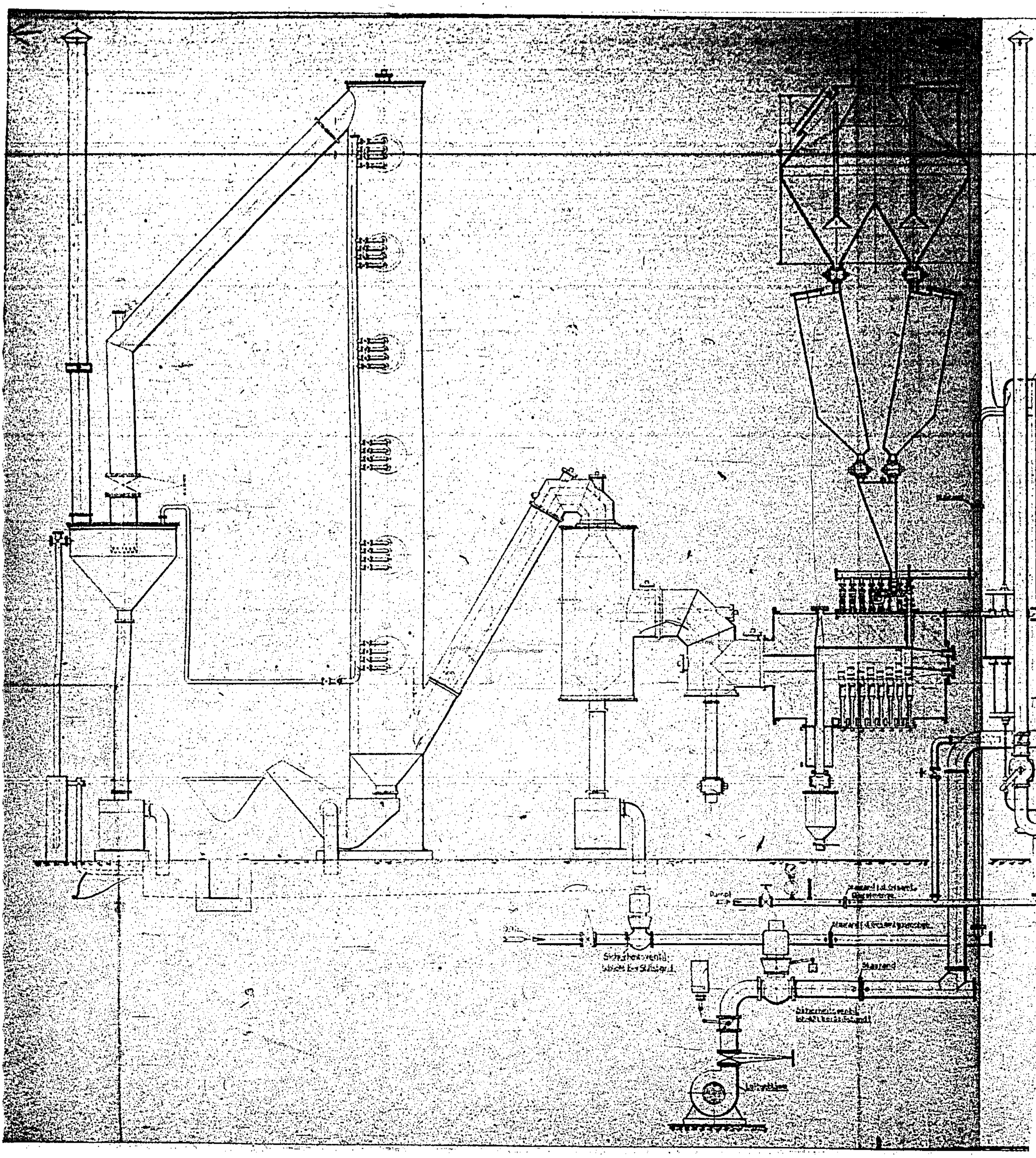


FIGURE 3

RHEINPREUSSEN
POWDERED COAL GASIFICATION
REACTOR NO. 1


Dampf
Sicherheitsventil
Staurand

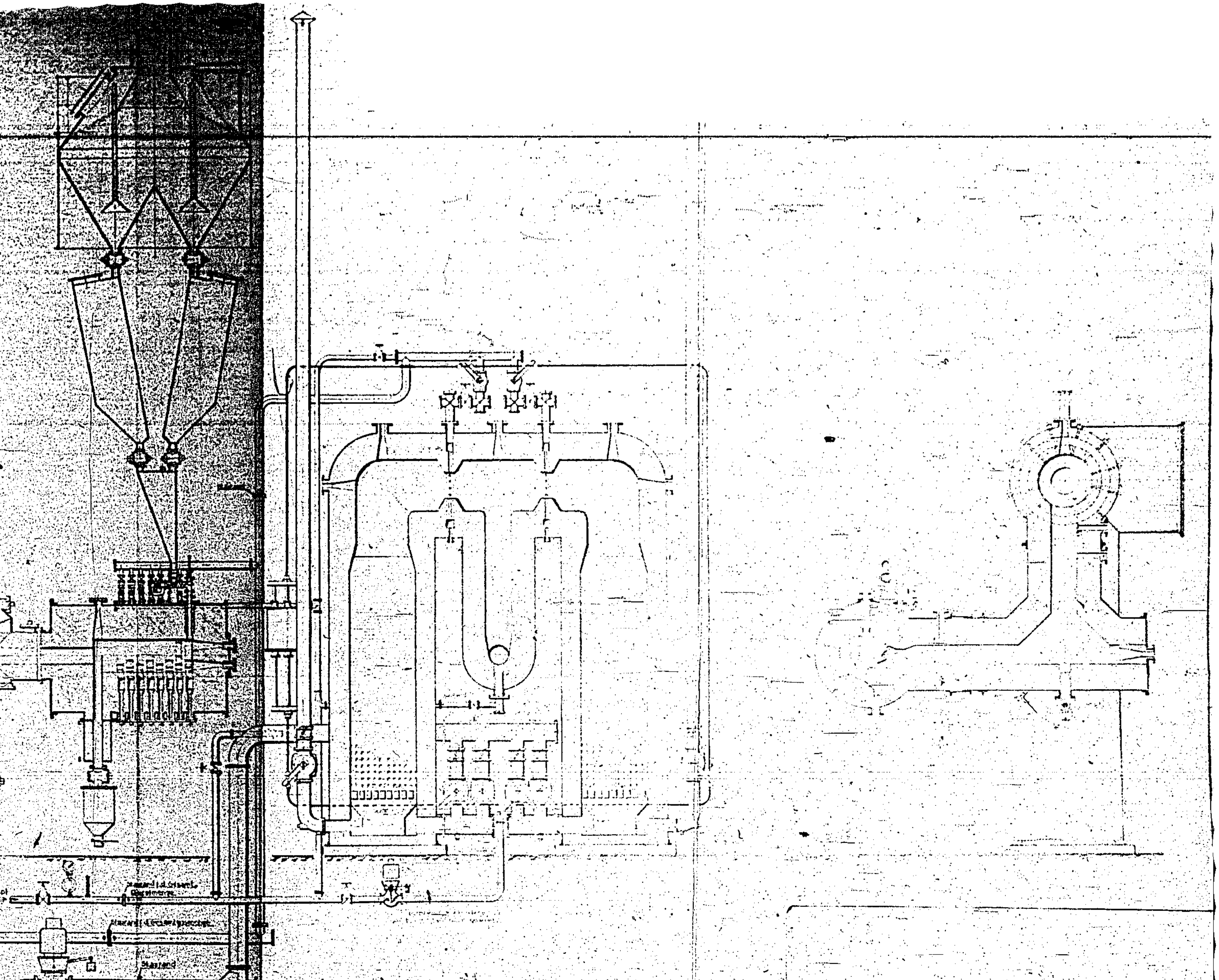


FIGURE 4

RHEINPREUSSEN GASIFICATION PLANT ASSEMBLY indicated the importance of intense agitation of the reaction medium with the coal dust particles.

"To simplify the experiments, gas instead of coal dust was used for the primary combustion. This was brought through a duct system into a cylindrical gasifying chamber and was admitted to the gasifier through nozzles directed tangentially into the bottom. The coal dust was allowed to fall freely into the front end and was carried through the gasifier. By this arrangement the coal dust was forced to travel through the gasifier in small spirals which was expected to insure a sufficiently long path of travel. The velocities at the entrance to the gasifier were so high that the carbon was forced to remain in suspension."

"Experiments with the cold apparatus showed that the underlying considerations were sound. The coal dust would travel through the gasifier in a spiral path in suspension in the cold medium. These experiments were carried out in a wooden model of the same design. After the apparatus had been brought to temperature and coal was to be gasified, a considerable collection of dust was observed on the walls. This dust remained fast. The carbon was completely gasified and the ash remained behind and slagged the generator. Sillimanite had been used as a lining material and was not resistant to attack by slag. After a few days operation, the generator was completely destroyed and could no longer be used."

"The generator was reconstructed several times in the same form and was equipped with nozzles varying in number and arrangement. Instead of being located in the bottom, the nozzles were located in the upper walls. However, these changes did not improve the results. The coal dust was driven against the bottom of the gasifier and accumulated there. Although measurable results were obtained from operation with brown coal coke (heating value 900 kcal. per cubic meter with about 50-60% gasification), the gasification of caking bituminous coal was not possible because the dust would settle out and coke, thereby obstructing the passage."

"It was concluded from the results of this work that velocities were still too low to hold the larger particles of coal in suspension while the fine particles were swept out without complete gasification because of insufficient relative motion in the gasifying atmosphere. In order to prevent slag accumulation the temperature of the combustion gas was reduced to about 900°C. With respect to slagging, some improvement resulted. However, the degree of gasification was still poorer so that a continuation of the experiments along this line appeared futile."

"In general it was concluded from the experiments conducted up to this time that the strictly mechanical difficulties such as settling out of dust, slagging etc., were so great that exact measurements of the degree of gasification, gas quality, economy et cetera could not be made".

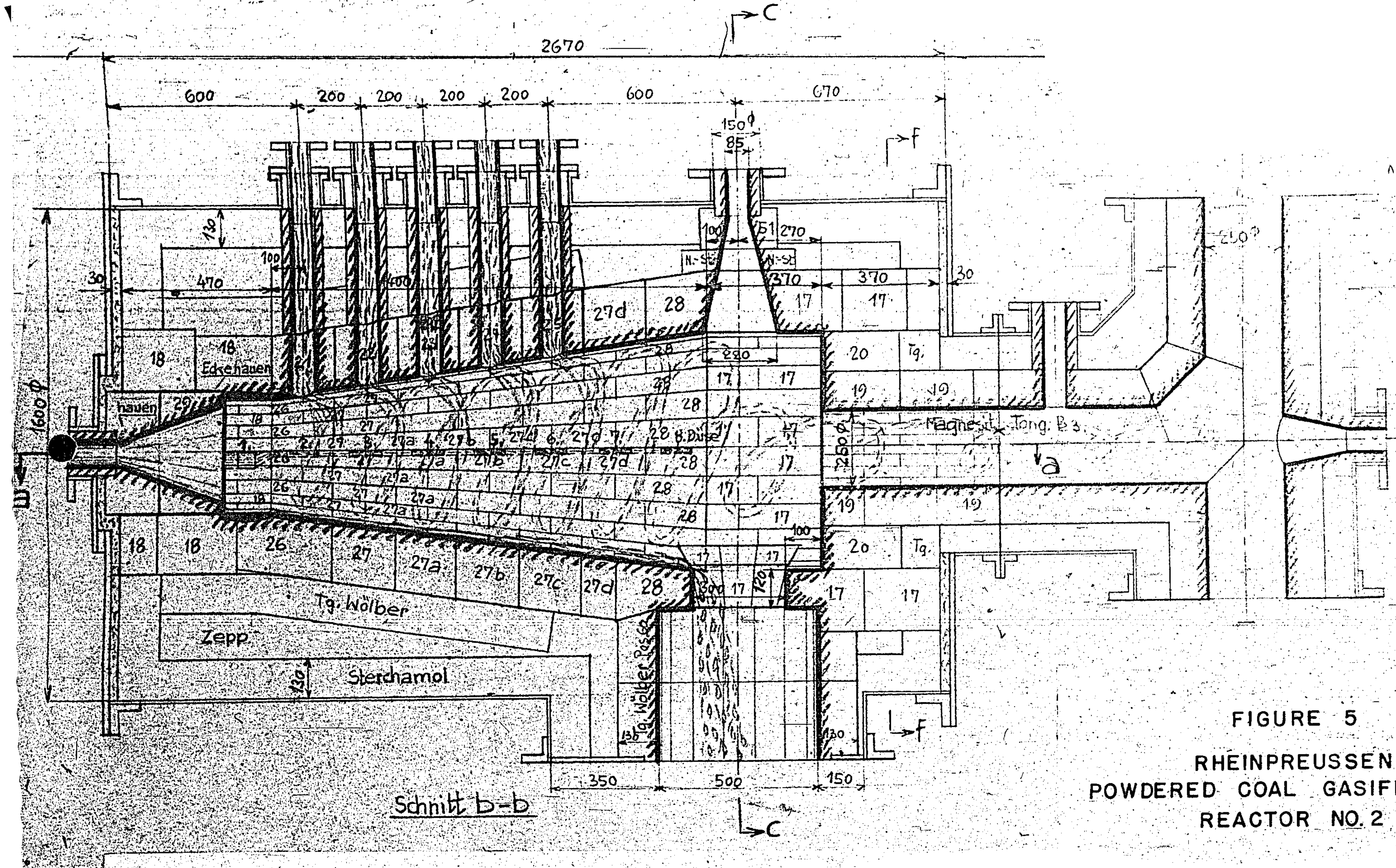
"Observations during these experiments led to the next form of apparatus shown by Figure 5, page 13, (taken from Koppers drawing IOS 146520). This design was based on the premise that since slagging cannot be prevented it is necessary to operate at a considerably higher temperature ~~so that the slag can flow as a liquid and that every effort must be made under~~ all conditions to keep the dust away from the bottom of the gasifier or to keep it continuously swirling without letting it come to rest. How these objectives were attained is shown by Figure 5. The coal dust was introduced from above through five separate inlets. As lining material, a slag resistant magnesite was chosen."

"Even with these expedients, the difficulties encountered in the preceding reactor were again present, that is, the coal dust was not maintained entirely in suspension. The particles of coal which settled out were completely gasified but formed a viscous slag. The gasifier could not be kept clean. The degree of gasification and the gas quality were unsatisfactory and could not justify continuation of the experiments along this line."

"One of the most important conclusions reached, was that means must be found to keep the slag more fluid. The necessary temperature s however, cannot be obtained with flue gas. For this reason the flue gas was supplied with an appreciable excess of air. The production of a fluid slag however was obtained only when a highly preheated mixture of air and steam was introduced in place of flue gas. To this end it should be noted that the apparatus was equipped with a regenerator as is still used on the experimental unit."

"With this method of operation however, the exit gas temperature is very high, in the vicinity of 1600°C., as is experienced in the coal dust firing of smelting furnaces. With this method of operation the larger particles of coal are completely burned or gasified while the smaller particles especially from the last inlets, escape reaction because of insufficient relative motion between them and the gas medium. In spite of the higher preheat of the gasifying medium, (air and steam to about 1200°C.) the high exit gas temperature changed the gas concentration so that heating values of only 800 to 900 kcal/m^3 were obtained. In comparison with the previous experiments it is seen that the gas quality was not improved although the degree of gasification of the coal was better, but still not satisfactory."

"In continuing the experiments special efforts were made to find some way of accomplishing complete gasification of the carbon. To this end the coal particles must be maintained entirely in suspension. A procedure used in powdered coal combustion was chosen, the apparatus



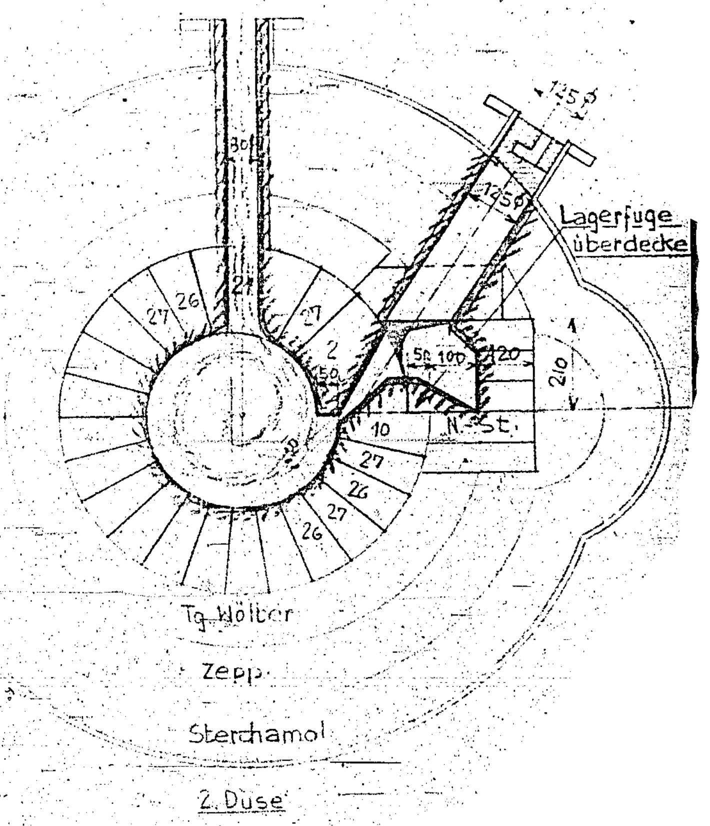


FIGURE 5

RHEINPREUSSEN
POWDERED COAL GASIFICATION
REACTOR NO. 2

for which is shown by Figure 6, page 16, (taken from Koppers drawing IO 146531, dated 25 October, 1941. Details of the air and gas connections to this unit are shown by Koppers drawing IOS 146523, not reproduced in this report. Details of the entire unit are shown by Koppers drawing IAK 146551 which is not suitable for reproduction here) In this procedure the coal dust was introduced at the head end of the gasifier by means of a side stream of cold air and the hot air-steam mixture was introduced through a mixing nozzle in the head of the reactor and through separate nozzles extending along one half of the length of the reactor."

"When using lignite and lignite coke a practically complete gasification of the carbon was attained. The slag was quite fluid. The gasifier chamber was given a conical form in order to provide a natural outlet for the slag."

"Experiments with bituminous coal showed that the degree of gasification would be considerably poorer and the gas concentration would be maintained only because of the high content of volatile constituents in the coal. For complete gasification of this coal the preheat temperatures of the steam-air mixture must be still higher with a simultaneous increase in the exit gas temperature. However, even with these expedients of extensive increase in the preheat temperature of the gasifying medium and high exit gas temperatures, economical gasification of bituminous coal dust by means of air is not attained."

"At this stage of experimental work the results justified the following conclusions: 1) with higher preheat (up to 1200°C.) of the gasification medium (air, steam) the more reactive coals such as lignite and lignite coke can be economically converted to heating gases, 2) the gasification of bituminous coal dust for reasons set forth above does not appear to be economical."

"After the experiments for the preparation of air gas had reached a practical conclusion at this point, experiments for preparation of water gas were begun. These experiments were carried out in the apparatus last described in such a manner that a mixture of steam and recycle gas was preheated to 1200°C. in the regenerators (Schmalfeldt principle). The coal dust was carried into the gasifying chamber with a partial stream of this mixture."

"The principal consisted in using the sensible heat between 1200° and about 900°C. for the gasifying process that is, the quantity of heating gas was maintained so high that the heat of reaction will be contained within these temperature limits."

"The experimental results indicated that the mechanical conditions in the generator were normal but the degree of gasification was still poor. Even with lignite it was possible to convert only a small percentage, approximately 20%, of the solid constituents in addition to driving off the volatile components. In the gasifying of bituminous coal dust the behavior was even poorer and therefore because of the poor economy the experiments were not carried further along these lines."

"In summary it can be said that it is not possible to gasify coal dust in a recycle gas stream at a temperature level of about 1200°C. This must be due to the fact that the gasification is an entirely endothermic process and the rate of gasification falls off rapidly with decreasing temperature. The residence time in the gasifying chamber must be almost infinitely great in order to attain satisfactory results. The data available previously for a similar method of operation showed this clearly, since a calculation of the material balance showed that even in such an operation the content of volatile constituents is driven out and all of the solid carbon is recovered as such. It cannot be considered complete gasification."

"These results point to a considerable elevation of temperature in the gasification process and this is possible only with the help of oxygen if a satisfactory gas composition and degree of gasification is to be obtained."

"Next the recycle gas-steam mixture was replaced by an oxygen-steam mixture. This mixture was brought to a temperature of about 1000-1200°C. in the regenerator. To loosen up the coal and somewhat improve its distribution, the coal dust was blown in by a superheated gas-steam mixture."

"This step was completely successful and the results are set forth in the address of 12 June, 1942. It was observed that as a result of the hot oxygen-steam mixture a very rapid ignition of the coal dust took place and by calculation a temperature of more than 2000°C. was obtained. This temperature accelerated the gasification process so greatly that the coal dust was gasified to the extent of about 95%. The exit temperature was about 900-1000°C. with lignite and lignite coke, and about 1200°C. with bituminous coal. Since the heat in this method of operation is used up completely for gasification there are no superheated zones in the gasifier and the ash occurs only to a very small extent as a liquid which forms small drops on the walls and falls into the ash outlet."

At this stage of the experiments, the final results of which were set forth in Totzek's address of 12 June 1942, the Rheinpreussen unit was destroyed by bombing. It was subsequently rebuilt as shown by Figures 7 and 8, pages 17 and 18, taken from Koppers drawings IOS 146,544 dated 15 September 1942 and IOS 178,452 dated 22 December 1942 respectively. A

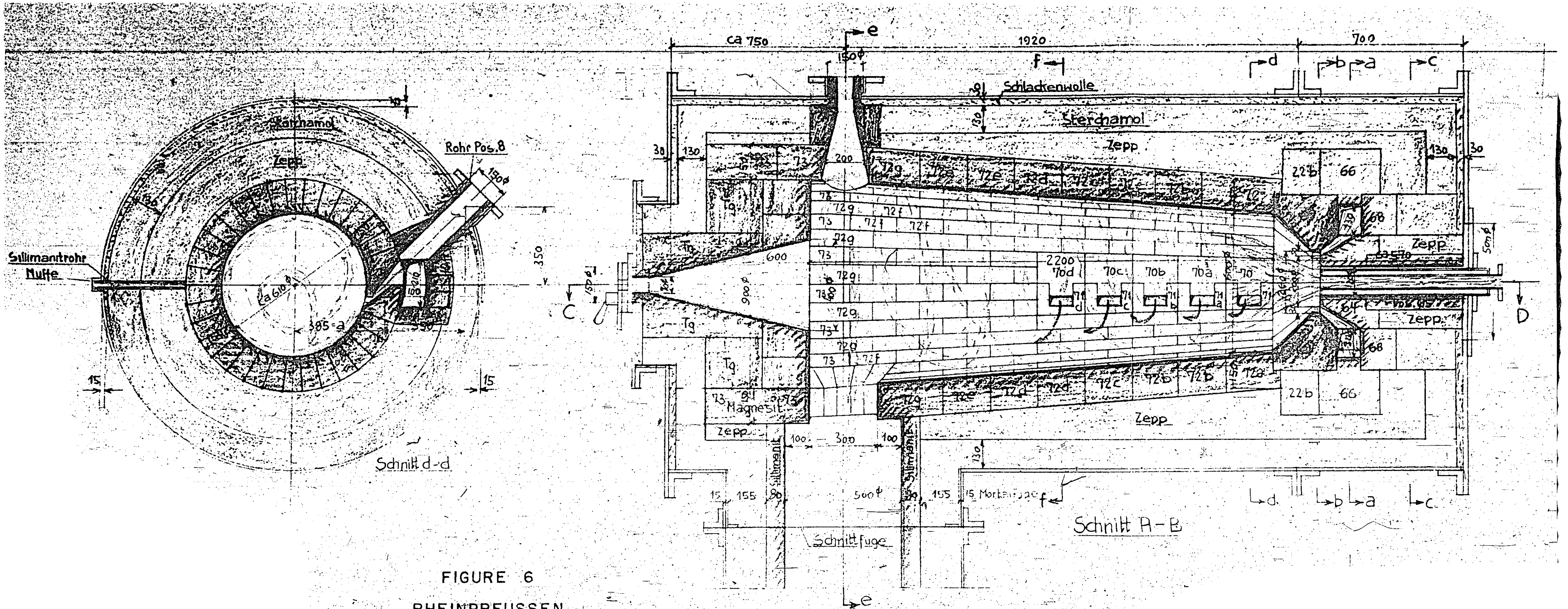


FIGURE 6

RHEINPREUSSEN
POWDERED COAL GASIFICATION
REACTOR NO. 3

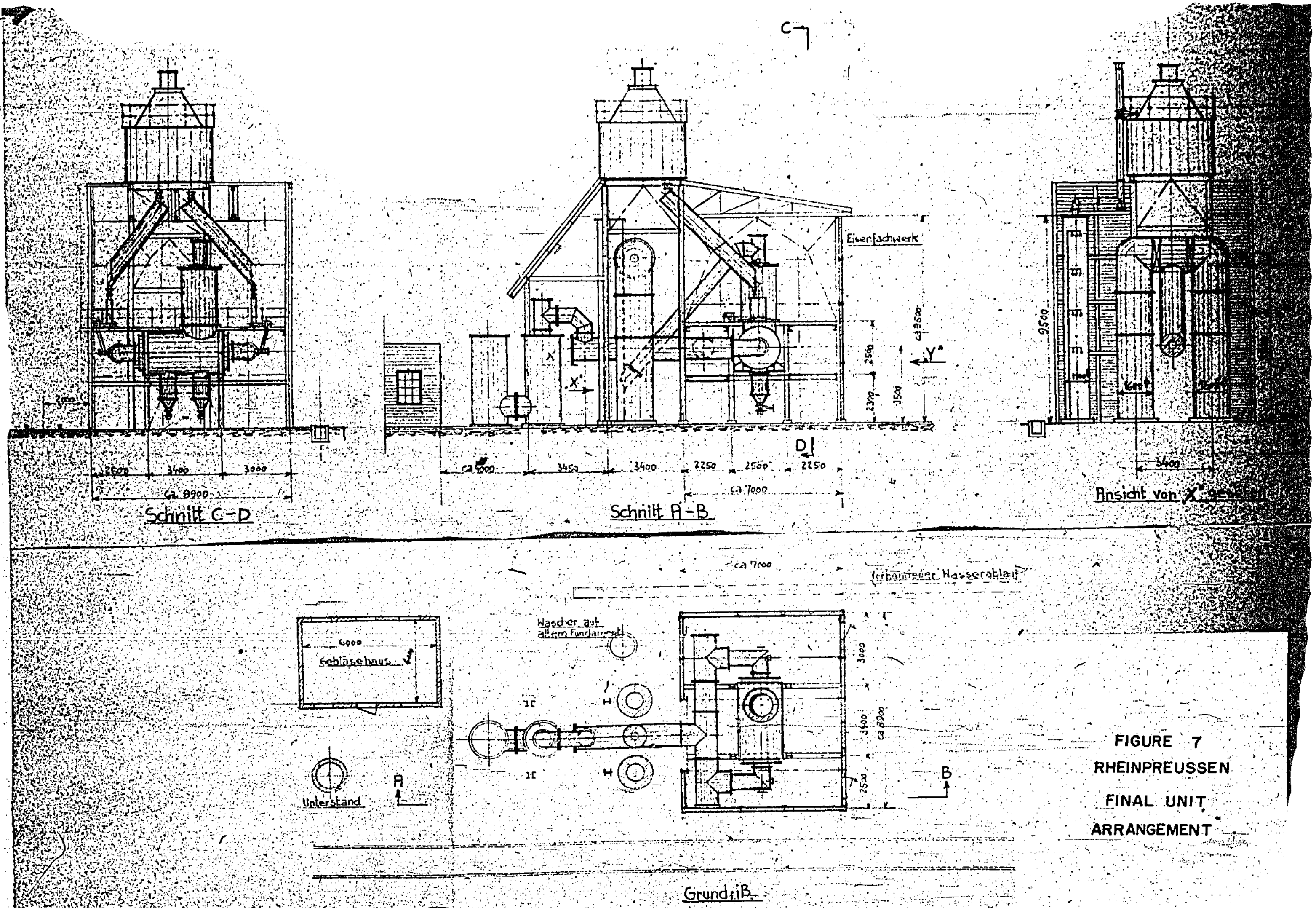


FIGURE 7
RHEINPREUSSEN
FINAL UNIT
ARRANGEMENT

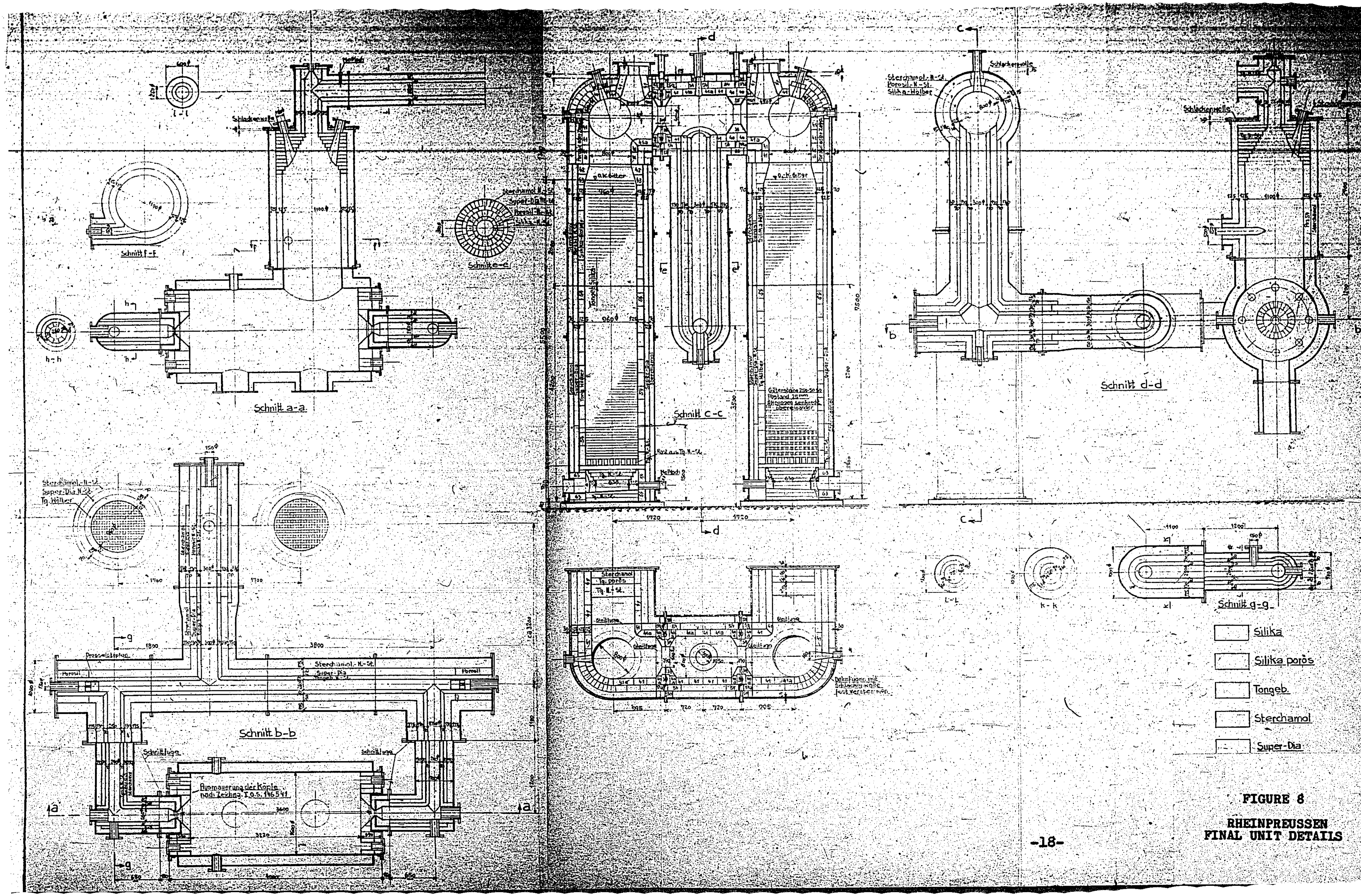


FIGURE 8

RHEINPREUSSEN FINAL UNIT DETAILS

simplified flow diagram of the unit is shown by Figure 9, page 21, from Koppers drawing IOS 178,479 and the reactor is shown in some detail by Figure 10, page 22, from Koppers drawing IOS 178,480. The general assembly of the unit is shown by Koppers drawing IAK 146,551 which is not suitable for reproduction in this report. The Koppers drawings reproduced as Figures 9 and 10 are undated but from the dates on other drawings in the same numerical series it appears that they were made after 17 June 1943, thus being about six to nine months later than the drawings used for Figures 7 and 8, pages 17 and 18. During this period the unit was not in operation so any changes in design must have been adopted for reasons other than experimental results. The most important change incorporated in this final design is the use of a water jacketed reactor having powdered coal inlets at both ends. It is understood that the reactor actually had conical ends as shown by Figure 10, page 22, rather than square ends indicated by Fig. 8.

Operation of this unit was begun in 1944 and continued until September when exigencies of war caused a permanent shutdown. Runs were made only with air because of the scarcity of bottled oxygen on which the plant was dependent. According to Totzek satisfactory gasification was not attained and this was attributed to excessive cooling of the reaction zone by the water jacket.

The unit was inspected by the writer on April 3, 1947 and appeared superficially to be in good condition. However Totzek said it had been robbed of many essential parts and had deteriorated so that in his opinion it would cost 30,000 marks to restore it to operating condition. Then he estimated it would have a capacity of 10 to 25 tons of coal per day and would require about 500 cubic meters of oxygen per ton of coal.

VIII. DISCUSSION OF EXPERIMENTAL RESULTS

In addition to the above comments on the performance of successive types of experimental reactors Totzek expressed his personal opinions on many other aspects of coal dust gasification in answer to the FIAT questionnaire. These views are summarized below.

A. Coal Characteristics

Koppers experiments indicated a substantially greater reactivity for lignite or lignite coke than for bituminous coal. This difference would be especially important in the preparation of fuel gas by reaction with steam and air without oxygen enrichment. Totzek stated that lignite had been gasified at 900°C. while the usual temperature for bituminous coal was 1200°C.

The coal should be ground to the same fineness as used for powdered coal combustion, that is, so that 80% would pass a 4900 mesh sieve. Uniformity of particle size would also be desirable since particles less than 0.05 mm in diameter tend to escape gasification because of insufficient motion relative to the gasifying medium, and particles coarser than 0.1 mm in diameter tend to fall out of the gas stream before they react. The Koppers process was stated to be operable on any coal or coke therefrom, provided it could be ground to the required fineness.

Totzek recommended the use of screw feeders for handling the powdered coal as for powdered coal combustion but admitted that these had given trouble on the experimental units. He thought that more uniform flow might be obtained by a rotating valve feeder, but Gumz and Nistler, who had used such a feeder on the Ruhrgas unit, held exactly the opposite opinion. Apparently this problem is not completely solved. For high pressure operation Totzek suggested a feeder such as used for coal dust engines, not further specified.

Koppers had no data on the relationship between sulfur content of the coal, operating conditions, and sulfur content of the gas. However Totzek pointed out that the sulfur in their gas had always been easily removable by standard procedures.

The water content of the coal was stated to be important chiefly because of its effect on ease of grinding. On this basis water contents should not exceed the following limits

Bituminous coal	2%
Lignite	15%
Peat	35%, dependent on nature of the peat.

In the generator, water in the coal has the same effect as steam from an extraneous source.

Weathering of the coal was stated to have no effect on gasification properties but this does not seem to be in agreement with the observed difference in reactivity of different kinds of coal. It was suggested that ageing might affect the content of available hydrogen. No data along these lines were available.

B. Operating Procedure

The following information on operating procedure was given mainly in Totzek's answer to the FIAT questionnaire -

"To start up a Koppers unit it is first warmed up with air preheated in the recuperators. When one Cowper regenerator reaches ignition temperature its burner is lighted and the hot gas is passed through the gasifier. When operating temperature is reached the regenerators are switched

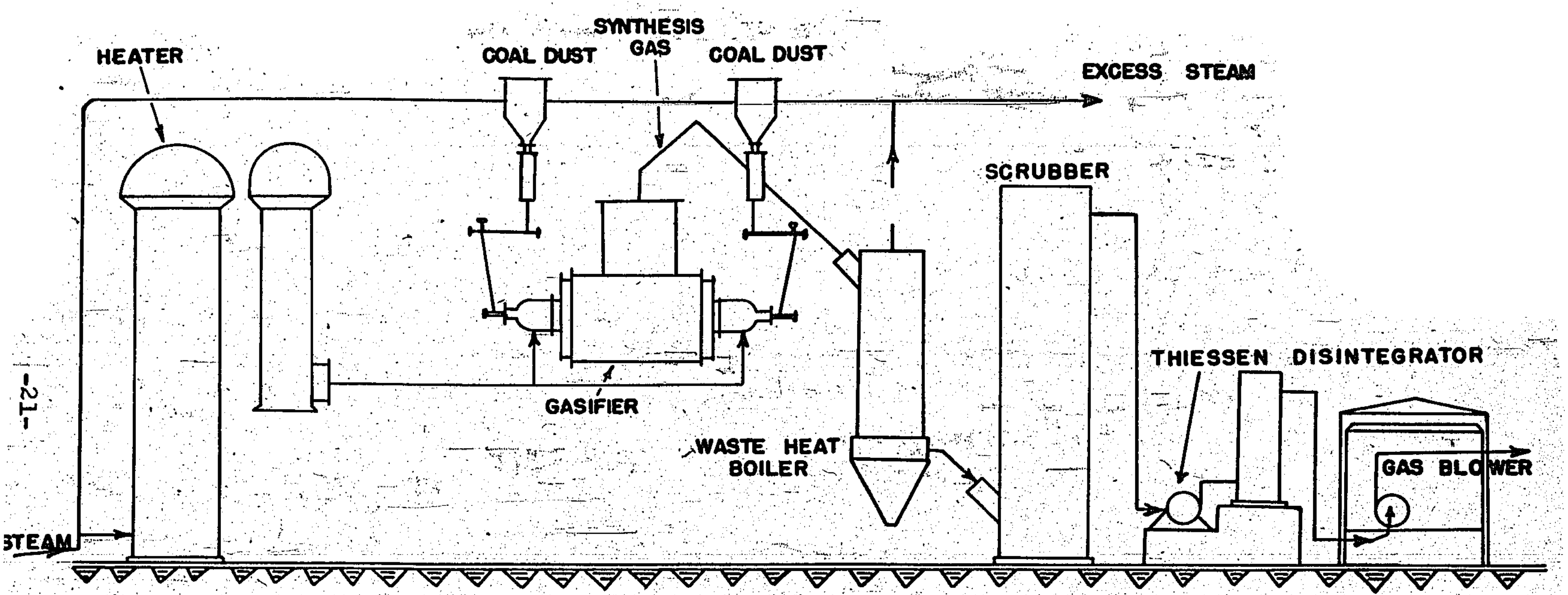


FIGURE 9

RHEINPREUSSEN

FINAL UNIT FLOW DIAGRAM

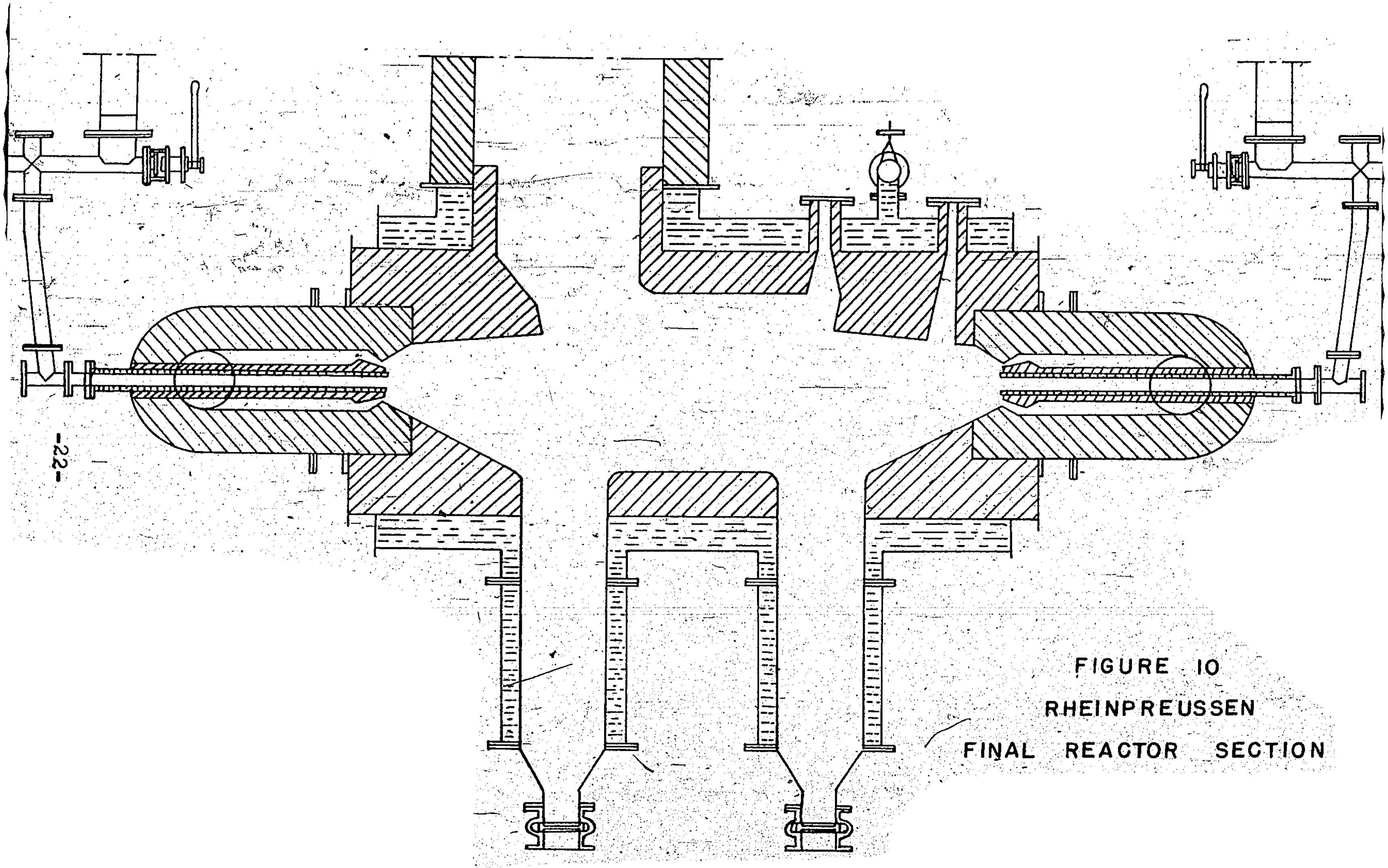


FIGURE 10
RHEINPREUSSEN
FINAL REACTOR SECTION

to automatic cycling and an air-steam mixture is supplied to the Cowper. Simultaneously the powdered coal feed is started and the air to the Cowper is replaced by oxygen to the desired extent. In this way the individual burners of the gasifier are brought into operation. After the equipment beyond the gasifier has been purged with combustion products, the blowers are started. Every half hour the Cowpers are switched so that the air-steam supply to the reactor is not interrupted."

"In shutting down the unit, the oxygen supply is first replaced by air. Thereafter the powdered coal streams are shut off in succession so that only flue gas is passing through the unit. After the apparatus is purged with flue gas the Cowpers are shut down."

The greatest danger in operation, according to Totzek, is the interruption of coal supply which would permit relatively pure oxygen to pass through into the gas holder. To minimize this danger it is recommended that several burners be attached to a single gasifying chamber with the expectation that the supply to all burners would not be interrupted simultaneously. Totzek admits that additional safety precuations would be needed on a commercial unit but they would have to be developed by experience.

Corrosion or erosion of equipment ahead of and beyond the reaction chamber was not observed in the Koppers experimental operations and was not expected to be serious in commercial units. However Totzek admits that long time deterioration of the reactor itself could not be predicted on the basis of the relatively short operating experience to date. The longest runs on the Rheinpreussen unit were only four or five hours duration so this may be a very serious uncertainty.

Totzek intimated that a powdered coal gasifier would not have much flexibility in charge rate since coal and gasifying medium must be definitely proportioned and high flow rates would give incomplete reaction while low flow rates would permit coarse particles to settle out. However no data were offered on this point. Totzek had calculated that the normal time of contact of coal particles in the Rheinpreussen reactor was 1/2 to 3/4 seconds, but even in this short time, with suitable preheating, practically complete gasification was obtained.

The ratio of H_2:CO in the product gas is dependent on coal composition to the extent that a "high volatile" coal will contain a higher ratio of hydrogen to carbon. Gas composition, is also influenced by coal reactivity since this determines the temperature level required to get complete conversion in a reasonable time. With the temperature and coal composition fixed, the gas composition will normally be governed by the excess steam in accordance with the water gas equilibrium. This will obviously influence the

CO_2 concentration as well as the $CO:H_2$ ratio. There is a definite limit to the permissable excess steam and hence the hydrogen concentration, determined by the tendency of excess steam to lower the reactor temperature. The $H_2:CO$ ratio can be increased if desired by a subsequent convertor (water gas shift) stage.

In spite of persistent questioning, Totzek made no specific statement regarding the distribution of ash in the Koppers process. He maintained that it was essentially a "dry" operation in contrast to the claims of Gumz that temperatures must be so high that all ash will be fused. However Totzek's written summary of the Rheinpreussen experiments admitted that some molten drops of ash formed in the generator and the final generator was given a sloping bottom to drain this molten ash. In fact in the early stages of this work special effort was made to insure that the ash would be molten and quite fluid. In such short runs as made at Rheinpreussen the normal ash distribution might not be attained. No ash balance data were available, but Totzek said the ash recovered from the product gas contained about 40% carbon. No free carbon was observed in the gas.

Totzek felt that operation under superatmospheric pressure would be undesirable unless a high methane content was desired in the gas, as was characteristic of the Lurgi middle pressure operation.

For conversion of highly reactive coals, high purity (98%) oxygen might not be necessary but for bituminous coals and coke therefrom the highest possible purity of oxygen would be desirable to attain the necessary reaction temperatures. No data on this point were available.

Water gas produced in the Koppers coal dust generator was tested for resin forming constituents by passing 4000 m^3 of the gas from a gas holder through activated charcoal. No condensible hydrocarbons were recoverable from the charcoal which was construed to indicate no resin forming constituents. Water gas from a conventional generator was stated to give a positive test by this procedure. Even from bituminous coal the Koppers process gave gas containing no methane. This freedom from hydrocarbons was attributed to the high gasifying temperatures and low pressure. No treatment of the gas to remove resin forming constituents appears necessary. Totzek pointed out that some very fine ash may be carried through the recommended washers and that an electrostatic precipitator may be desirable for final clean up ahead of synthesis units.

No advantage was seen in the recycling of residue gas or the introduction of extraneous gas. If such gases were used to convey the powdered coal their quantity should be limited lest they extract too much heat from the reaction. Multistage conversion was thought to be definitely objectionable because of the difficulty of separating unconverted dust between stages.

C. Plant Design

Koppers regarded the accessories to the reactor itself as standard equipment which had been fully proved in other types of service. The Cowper regenerators, and the recuperators which preheat air and fuel gas for them, had been used extensively and successfully for gas cracking (methane oxidation) at Rheinpreussen, and for recycle gas heating in the Schwarzheide briquette gasification plant. Details of a Cowper unit proposed later for Brabag are shown in Koppers drawing IAK 132,315 dated 17 August 1942, which is not suitable for reproduction here. Waste heat boilers had been used in many industries and static washers were standard equipment with water gas generators. The Theissen disintegrator was commonly used for washing blast furnace gas.

Totzek expressed the opinion that powdered coal gasification units should have a capacity between 50 and 300 tons of coal per day for maximum economy. A plurality of units, but not more than ten, was recommended to insure a substantially continuous supply of gas to a synthesis plant. These were admitted to be offhand opinions and no supporting figures were offered.

In spite of the small size and limited operation of the Rheinpreussen experimental unit, Totzek said that Koppers was, and still is, ready to build and guarantee commercial units of the same type.

D. Comparison with Other Processes

Totzek professed knowledge of only the Schmalfeldt process as used at Lutzkendorf and Ruhland. He pointed out that the latter unit was shut down permanently after a short period of operation, indicating some operating difficulty. Totzek concluded from similar operation of the Rheinpreussen unit (page 14) that the Schmalfeldt principle of reacting powdered lignite with a preheated mixture of recycle gas and steam is unsound because sufficiently high temperatures can not be attained.

Although he had no detailed knowledge of the Gumz-Ruhrgas experimental work, Totzek thought that Gumz had little practical knowledge of powdered coal gasification and that his theories were unsound in that they disregarded the lack of relative motion between very fine particles and the suspending medium.

IX. PROPOSED COMMERCIAL UNITS

Koppers correspondence between November 1941 and September 1942 (TOM Reel 43 frames 259-278), indicates that one, and possibly two, powdered coal gasification units had been proposed for Rheinpreussen. It was stated that these proposals were based on the performance of the experimental unit but no details of proposed design are given. A memorandum dated 16 July 1942, frames 260-266, gives estimated quantities and costs as quoted in Table II, page 31.

Correspondence extending from December 1941 to April 1942 (TOM Reel 43 frames 219 to 244) concerns a unit proposed for the Zeitz plant of Brabag, where the Winkler process was also being considered. Confidential data on operating costs of the Winkler process at Brabag-Boehlen were produced for comparison with the estimated Koppers costs. The problem was to gasify powdered coke from lignite which Koppers contended could not be done completely in a Winkler unit.

The design of the proposed Zeitz unit is not shown in the microfilmed correspondence. However a Koppers drawing IAK 131,928 dated 15 January 1942 showing this unit was given to the present investigators and is reproduced in part as Figure 11, page 27. Although this is not a detailed drawing it does show the reactor as a small horizontal chamber below the coal bunker, which is generally similar to the form being studied on the Rheinpreussen unit at that time. A presumably later drawing of the same type of unit was presented with the Totzek address of 12 July 1942 and is reproduced as Figure 12, page 28. The plant for which this was intended was not specified. Although horizontal reactors are shown in each case it appears that changes in the method of introducing coal and hot gases were being recommended as work on the Rheinpreussen unit progressed.

In presenting this diagram Totzek stressed the fact that the form of the reactor was the distinguishing feature of the unit, and he said that a more detailed discussion of the reactor would come in a later paper. Under interrogation he insisted that no such later discussion had ever taken place.

Letters dated 13 April and 17 May 1943 (TOM Reel 43 frames 210-218) relate to a unit proposed for the Schwarzheide plant of Brabag, also to gasify powdered lignite coke. These documents are the basis of CIOS Report No. XXVIII-36 Item 30 and later publications by Newman[1,2]. The Newman publications include a sketch of a powdered coal gasification unit from a Koppers patent application furnished privately by one of the authors

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(1) Newman, L.L. Oxygen Gasification Processes in Germany A.I.M.M.E. Technical Publication No. 2116. Class F, Coal Technology, Nov. 1946.

(2) Newman, L.L. Oxygen Production and Utilization in Gas Making Processes. Report of Gas Production Committee. American Gas Association 1946.

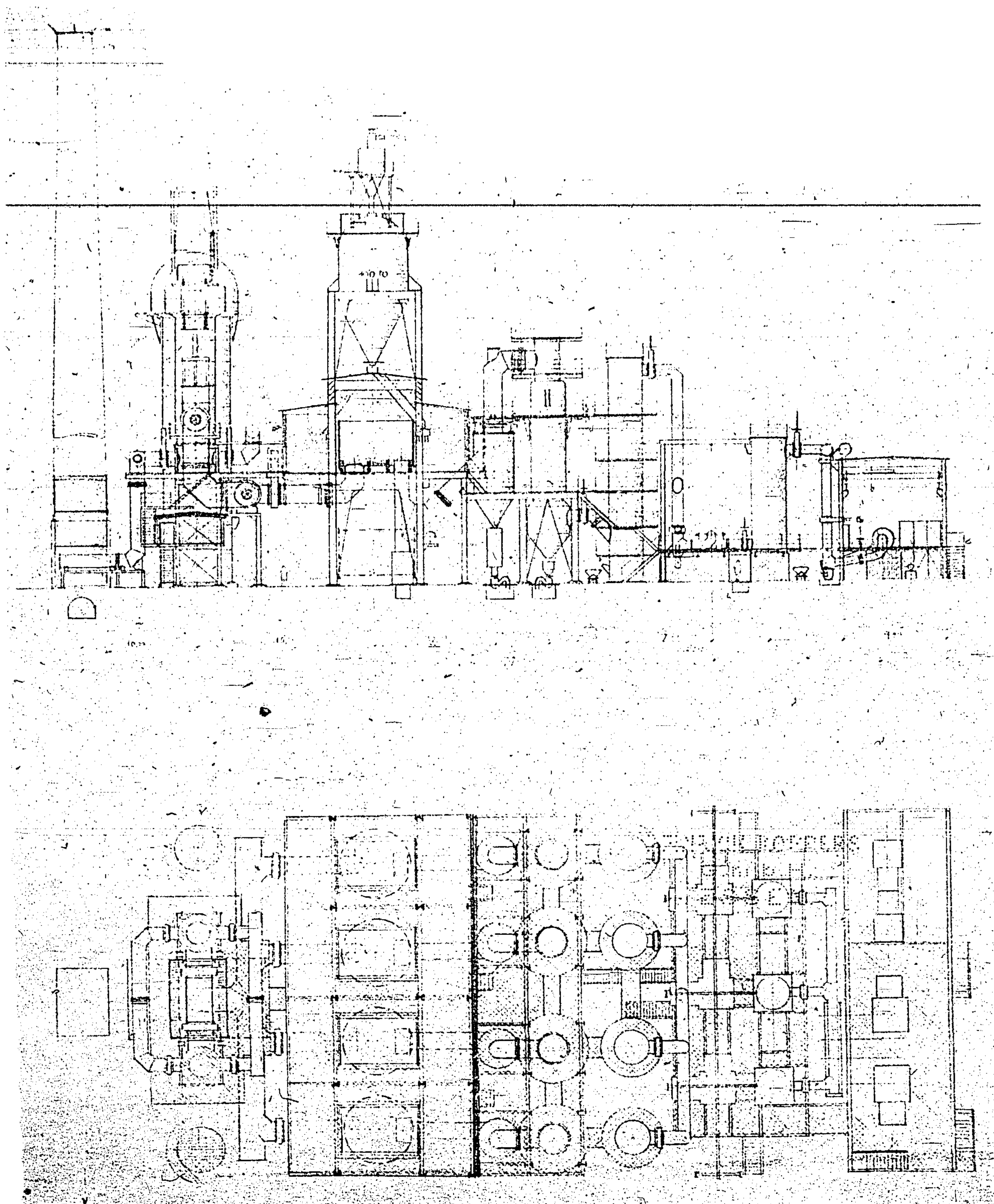


FIGURE 11

BRABAG-ZEITZ
PROPOSED PLANT

IAK 131 928

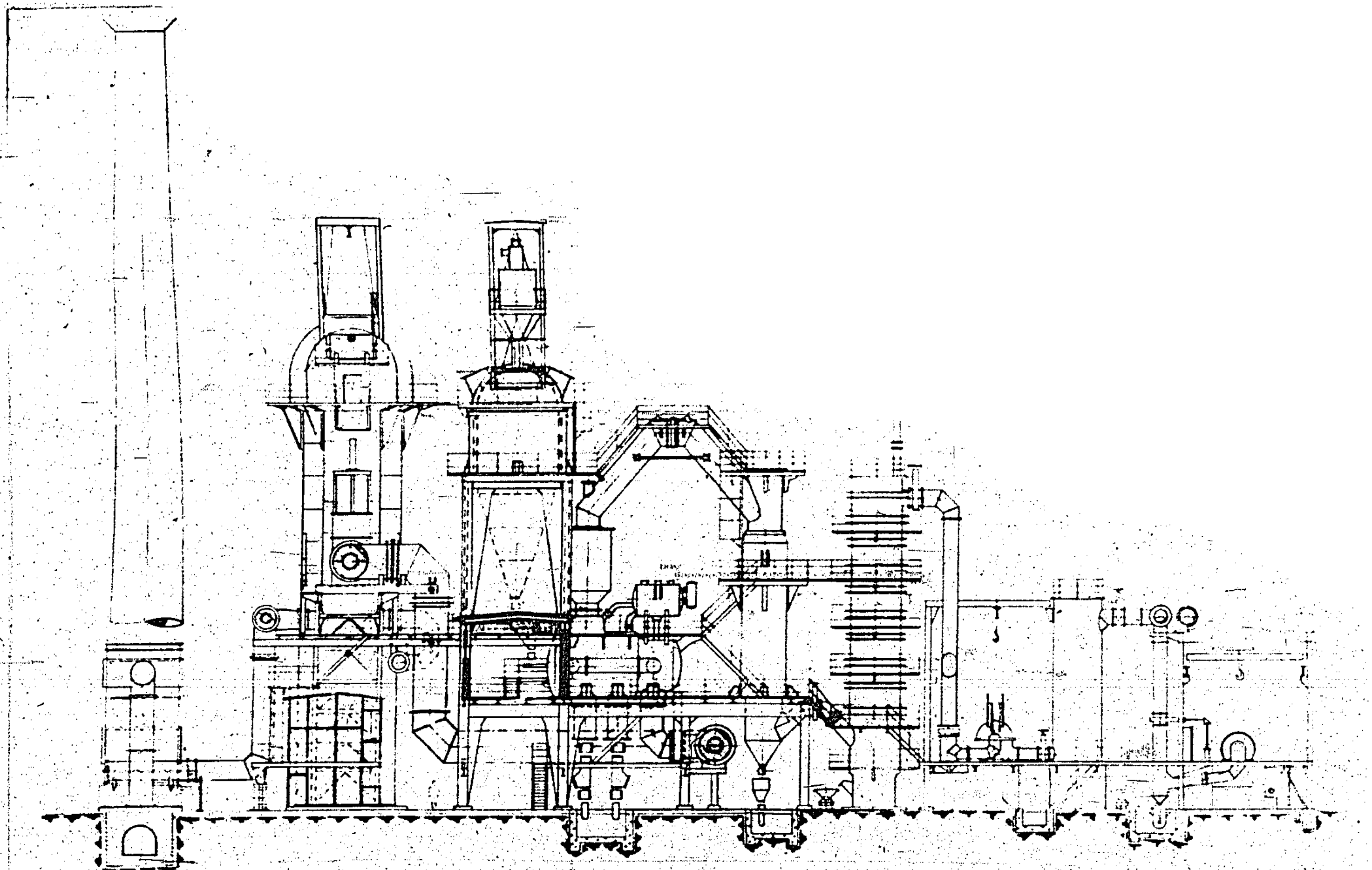


FIGURE 12

PLANT FOR COAL DUST GASIFICATION

Heinrich Koppers

of the CIOS report. However no such form of apparatus was mentioned by Totzek to the present investigators and it is entirely different from the forn under development at Rheinpreussen from 1940 to 1944, and likewise from the form shown in the proposal for Brabag-Zeitz in 1942, Figure 11, page 27. Therefore it is believed that the patent sketch does not illustrate what Koppers ultimately regarded as an operable unit.

The expected performance of the Brabag Schwarzheide unit is given on page 33.

X. PREDICTED PLANT PERFORMANCE

Since it was impossible to obtain actual experimental data for any of the Koppers work on powdered coal gasification it is difficult to appraise the validity of claims made on different occasions for the operating characteristics of their process. However these claims are reproduced on the following pages in chronological order for whatever value they may have.

(A.) Brabag-Zeitz Proposal

Apparently the first proposal for a commercial unit for Brabag-Zeitz came late in 1941 since a Koppers memorandum dated 19 December 1941 (TOM Reel 43 frame 237) refers to previous discussions and gives some data on expected performance of the unit, which was to gasify 300 tons per day of lignite coke containing 20% ash. The oxygen consumption was estimated to be 0.51 m^3 per Kg coke and the gas production was to be 2.18 Nm^3 per Kg coke. The gas composition was stated to be as follows:

CO_2	18.61 vol %
CO	40.25 vol %
H_2	40.25
N_2	0.73
H_2S	0.16

The only information available regarding the design of this plant is Koppers drawing IAK 131,928 reproduced in part as Figure 11, page 27.

A Koppers memorandum dated 13 April 1942 (TOM Reel 43 frame 225) includes a cost estimate apparently prepared for Brabag-Zeitz and covering the gasification of powdered lignite instead of lignite coke. From these data Table I, page 30, has been prepared. Comparative operating costs for a Winkler unit are included in the original document indicating a figure of 2.11 Pfg per Nm^3 $CO+H_2$ for Winkler compared with 1.82 Pfg per Nm^3 $CO+H_2$ for Koppers. However the comparison is admitted to be questionable since the Winkler data were based on the gasification of lignite coke, which was given the same money value as the raw lignite assumed for the Koppers process. The Winkler process was claimed by Totzek to be inoperable on raw lignite.

TABLE I

BRABAG ZEITZ POWDERED LIGNITE GASIFICATION PROPOSAL

Investment, including reserve Cowper		RM5300000
Operating Costs per Nm^3 water gas		Pfg.
1.	Amortization and Interest 15%	0.2870
2.	0.16 Nm^3 oxygen at Pfg. 3.1	0.4960
3.	0.539 Kg coal at RM 9 per ton	0.4770
4.	24 worker shifts per day at RM 2 per hour including supervision	0.0560
5.	0.120 Kg outside steam at RM 1.50 per ton	0.0180
6.	0.035 Kw hr Power at Pfg. 1.5	0.0525
7.	20 liters circulating water at Pfg. 2.0 per m^3	0.0400
8.	0.53 liters boiler feed water at Pfg. 20.0 per m^3	0.0105
9.	650 Kcal outside heat at RM 1.0 per million Kcal	0.0650
10.	2.5% repair costs basis investment	0.0477
	Total	Pfg. 1.5497

Production 760,000 Nm^3 water gas per 24 hrs.
645,000 Nm^3 $CO + H_2$ per 24 hrs.
Operating cost total per Nm^3 $CO + H_2$ Pfg. 1.82

(B) Rheinpreussen Proposal (1941-1942)

Although operating conditions for this unit are not specified, some data on the quantities involved are given in a memorandum dated July 16, 1942 regarding operating costs of several alternative proposals for Rheinpreussen. From this letter Table II, page 31, has been prepared, summarizing the cost calculations for a bituminous coal dust gasification unit with five operating generators, for the direct production of synthesis gas having a $CO:H_2$ ratio of 1:2 and producing 60,000 m^3 per hour or 1,440,000 m^3 per day. The product gas composition was expected to be as follows:

CO_2	18% vol
CO	27
H_2	54
N_2	1
	100%

TABLE II

RHEINPREUSSEN POWDERED COAL GASIFICATION PROPOSAL

Expenditures, daily

1.	Coal 514 tons	at RM 14.0	RM 7200
2.	Oxygen 230,000 m^3	at RM 0.025	5750
3.	51 man-shifts labor	at RM 12.0	612
4.	Power 36,000 Kcal	at RM 0.02	750
5.	Circulating water 25,000 m^3	at RM 0.02	500
6.	Fresh water 2500 m^3	at RM 0.02	50
7.	Boiler feed water 720 m^3	at RM 0.20	144
8.	Fuel gas 547 x 10^6 Kcal	at RM 4.50	2460
9.	Steam, 3 atm. abs. 662 tons	at RM 1.50	994
10.	Amortization, interest, maintenance 14% of RM 9,000,000		3450
	Total daily expense		21880

Credit, daily

1.	Steam, 16 atm. abs. 700 tons	at RM 3	2100
	Net operating expense		19780
	Operating cost per Nm^3 synthesis gas		Pfg. 1.370
	Operating cost per Nm^3 $CO + H_2$		Pfg. 1.690

(C) Totzek Address of 12 June 1942

Table III, page ~~32~~ summarizes the estimated performance figures for the Koppers process on different coals as taken from an attachment to the Totzek paper. Graphical representations of heat balances and operating costs for the production of synthesis gas or fuel gas from the different solid fuels are given in the original paper.

TABLE III

SUMMARY OF ESTIMATED PERFORMANCE DATA, 1942

	Bituminous Coal		Lignite		Lignite Coke
Coal Analysis					
Water Wt. %	1.95		13.00		5.0
Ash Wt. %	8.93		5.95		21.0
Volatile Wt. %	22.30		51.40		6.3
Crucible Coke Wt. %	77.70		48.60		93.7
Gross Heating Value KCAL/kg.	7650		5120		6054
	Synthesis Gas	Fuel Gas	Synthesis Gas	Fuel Gas	Fuel Gas
Product Gas Composition					
CO_2 Vol. %	11	7	14	6	6
CO Vol. %	54	21	35	27	26
H_2 Vol. %	34	16	50	20	18
N_2 Vol. %	1	56	1	47	50
Gross Heating Value KCAL/Nm^3	2505	1023	2342	1329	1253
Plant Quantities					
Gas Production Nm^3/24 hr.	760,000	1,280,000	760,000	985,000	1,045,000
CO + H_2 Production Nm^3/24 hr.	669,000		645,000		
Coal Dust Consumption Tons/24 hr.	362	388	400	400±	357
Plant Cost RM	5,000,000	5,000,000	5,000,000	5,000,000	5,000,000
Gas Yield Nm^3 per kg. Coal	2.1	3.3	1.9	2.44	2.93
Gas Heat Content KCAL per kg. Coal	5260	3390	4450	3275	3666
Steam Production kg. per kg. Coal	0.985 (2 atu.)	2.85 (20 atu.)	0.665 (2 atu.)	1.0 (2 atu.)	1.29 (2 atu.)
Steam Consumption kg. per kg. Coal	0.300 (2 atu.)	0.45 (2 atu.)	0.510 (2 atu.)	0.1 (2 atu.)	0.31 (2 atu.)
Excess Steam kg. per kg. Coal	0.685 (2 atu.)	2.85 (2 atu.)	0.155 (2 atu.)	0.9 (2 atu.)	0.98 (2 atu.)
Fuel Gas Consumption KCAL per kg. Coal	254		450		
Oxygen Consumption Nm^3 per kg. Coal	0.525		0.304		

(D) Brabag Schwarzheide Proposal (1943)

The data for the proposed Brabag-Schwarzheide plant are taken from documents on TOM Reel 43, Frames 210-218, which were also summarized in CIOS Report XXVIII-36, Item 30.

Brabag-Schwarzheide required a plant to produce 100,000 Nm^3/hr. of synthesis gas (CO/H_2 = 1.65/1), from upper Silesian coal or low-temperature coke, for medium pressure Fischer synthesis over an iron catalyst. The coal and coke specifications were not given except that it would be ground so that 75 per cent would pass through a 49,000 mesh sieve. The finished gas must be free of condensible hydrocarbons and the sulfur removal must present no difficulties.

The coal and product gas analyses were given as follows:

Coal Analysis			Product Gas Analysis		
Water	1.95 wt %		CO_2	11.0 vol. %	
Ash	8.75 wt. %		CO	54.0 vol. %	
Volatile	22.3 wt. %		H_2	34.0 vol. %	
Residue	77.7 wt. %		N_2	1.0 vol. %	
Gross heating value kcal/kg.		7650	Net heating value kcal/Nm^3		2505

On the basis of 1 kg of powdered coal the following quantities were estimated.

Gas production	Nm^3	2.10
Oxygen consumption	Nm^3	0.57
CO_2	Nm^3	0.14
Fuel consumption	kcal	350
Steam production kg. at 16	atm. abs. 350°C.	0.71
Steam consumption kg. at 3	atm. abs. sat.	0.40

For the production of 100,000 Nm^3/hr. of synthesis gas for 8000 hours per year Koppers proposed to build six units (one in reserve) each costing 2.7 million R.M. or a total cost of 16.2 million R.M. It was estimated that the gas would cost 1.7 pfg. per Nm^3.

(E) Estimates Obtained by Navy Technical Mission (1945)

The documents obtained by U.S. Navy investigators include five pages of data on heat and material balances, dated Essen, June 4, 1945 and apparently prepared specifically for the Navy investigators. These data are not the same as any given in the Appendix to the Totzek address of June 12, 1942. Two graphical representations of heat balances included with the Navy documents likewise differ from any in the Totzek paper. The data for Rheinpreussen bituminous coal differ slightly from similar data given to FIAT investigators. Simplified diagrams of the pilot plant equipment were the same in each case.

The data for the gasification of bituminous coal and lignite are summarized in Table IV, below:

TABLE IV

KOPPERS DUST GASIFICATION DATA GIVEN TO U. S. NAVY INVESTIGATORS JUNE 1945

	Bituminous Coal	Lignite
Raw Dust Analysis Wt. %		
Water	1.95	13.00
Ash	8.75	5.18
H_2	4.27	4.71
Carbon	80.50	56.20
Combustible S.	1.88	0.33
Nitrogen	1.19 }	20.58
Oxygen	1.46 }	
Gross heating value, kcal/kg	7977	5313
Extraneous steam Nm^3/Kg	1.407	0.860
Extraneous oxygen Nm^3/Nm^3 gas	0.246	0.206
Extraneous oxygen Nm^3/Kg	0.608	0.379
Preheat temperature °C.	1200	1200
Reactor exit temperature °C.	1200	1000
% Carbon conversion	94	95
Thermal Gasification Efficiency %	75	79.6
Synthesis gas produced Nm^3/Kg	2.47	1.84
$CO+H_2$ in gas produced vol. %	84	80
Product gas analysis vol. %		
CO_2	15.0	19.0
CO	42.0	35.0
H_2	42.0	45.0
N_2	1.0	1.0

The heat balance for the bituminous coal operation is shown diagramatically by Figure 13, page 35, and for lignite by Figure 14, page 36.

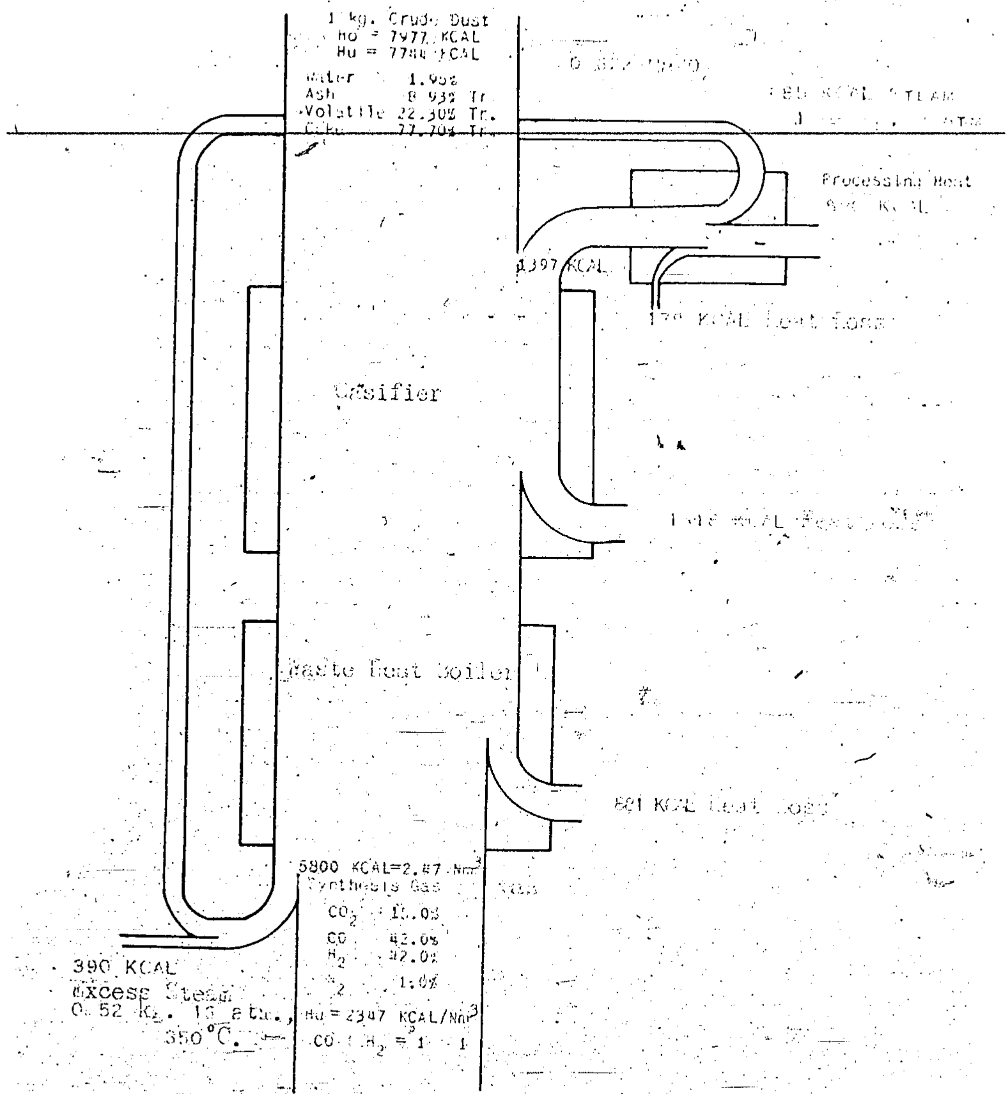


FIGURE 13

HEAT FLOW DIAGRAM FOR SYNTHESIS GAS PRODUCTION FROM BITUMINOUS COAL DUST

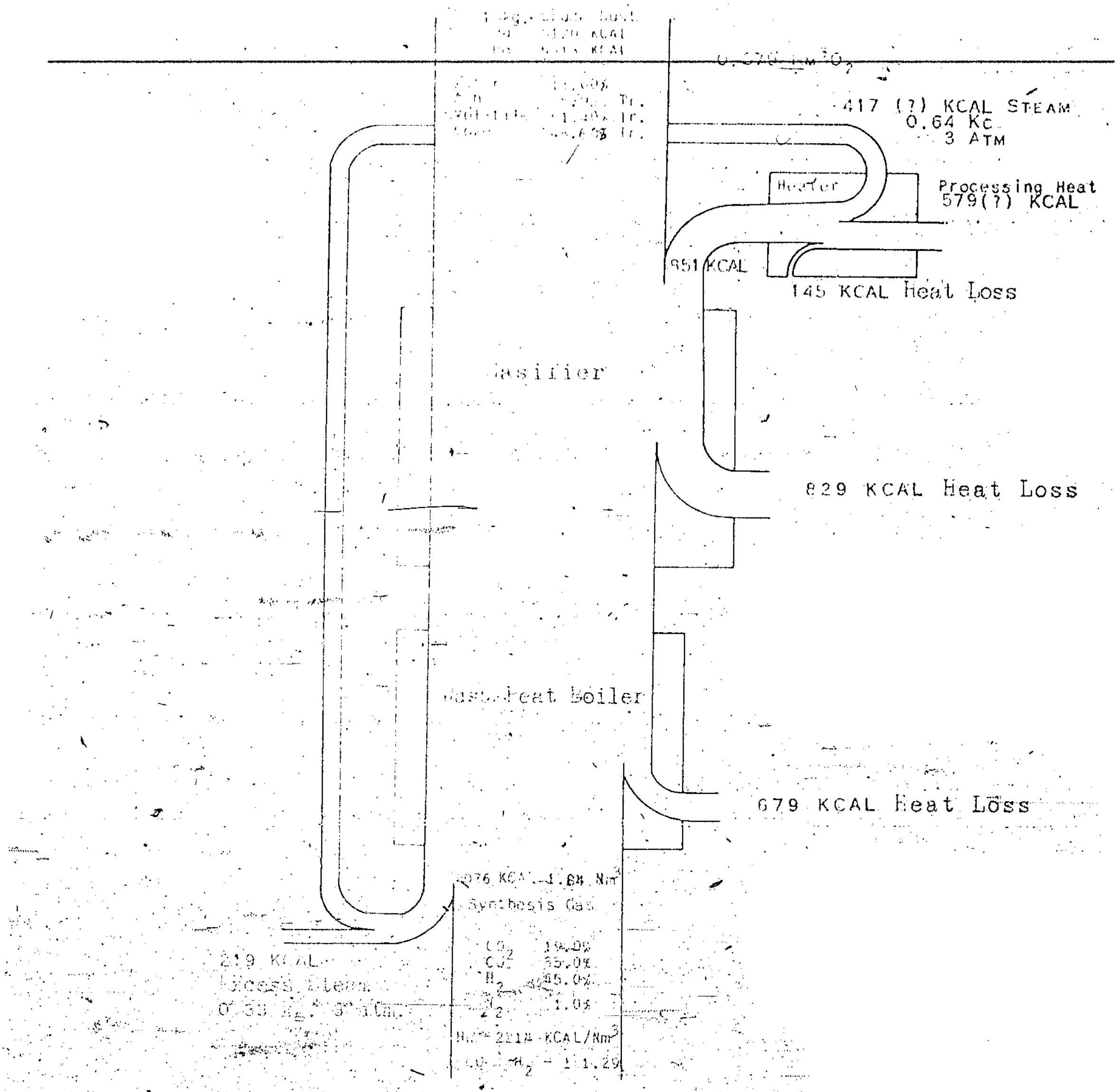


FIGURE 14

HEAT FLOW DIAGRAM FOR SYNTHESIS GAS PRODUCTION FROM LIGNITE DUST

(F) Information Given to FIAT Investigators (1947)

Table V, page 38, was submitted by Totzek in response to repeated requests for experimental data and was stated to be based on actual operation, although run numbers and operating conditions were not specified. In addition Totzek furnished the following discussion of efficiency of conversion which he said was indicative of performance which Koppers had obtained experimentally and was willing to guarantee for any new unit.

Material Balances

As a supplemental answer to the questionnaire submitted by FIAT, Totzek furnished the following material balance which he insisted was based on experimental data (not shown) and could surely be realized in commercial operation.

Bituminous Coal Analysis Wt. %

Water	1.95
Ash	8.75
H_2	4.27
C	80.50
S (combustible)	1.80
N_2	1.19
O_2	1.46

Product Gas Analysis Vol. %

CO_2	15
CO	42
H_2	42
N_2	1
Vol. Gas Per Kg Coal	2.3 Nm^3

Carbon Balance: (Basis 1 Kg. Coal)

Introduced as coal	0.805 Kg
Withdrawn as gas	0.705 Kg
Loss	0.100 Kg

In experimental operations carbon losses of 8-14% were observed, the magnitude being largely dependent on the uniformity of fineness of the coal. For the following calculations a carbon loss of 12% was assumed.

TABLE V

DUST GASIFICATION DATA FROM TOTZEK, 1947-

	BITUMINOUS COAL			LIGNITE		LIGNITE COKE
COAL ANALYSIS WT. %						
WATER	1.95			13.00		5.00
ASH	8.93			5.95		21.00
VOLATILE	22.30			51.40		--
GROSS HEATING VALUE KCAL/KG	7744			5120		6054
	SYNTHESIS GAS			SYNTHESIS GAS	FUEL GAS	FUEL GAS
GAS ANALYSIS VOL. %						
CO_2	11.0	15.0	18.0	19	6.0	6.0
CO	54.0	42.0	33.0	35	24.0	26.0
H_2	34.0	42.0	48.0	45	17.0	18.0
N_2	1.0	1.0	1.0	1	52.0	50.0
NET HEATING VALUE KCAL/KG	2505	2347	2230	2214	1162	1248
GAS QUANTITY NM^3/KG	2.10	2.15	2.40	1.84	2.50	2.70
OXYGEN CONSUMPTION NM^3/KG	0.57	0.62	0.53	0.38		
FUEL GAS CONSUMPTION KCAL/KG	415	890	1600	579		
CO_2 CONSUMPTION NM^3/KG	0.14					

Hydrogen Balance

Hydrogen in the gas	0.97 Nm^3
Hydrogen from the coal	0.47 Nm^3
Hydrogen from steam	0.50 Nm^3

Oxygen Balance

Oxygen in the gas	0.83 Nm^3
Oxygen from decomposed steam	0.25 Nm^3
Extraneous oxygen required	0.58 Nm^3

(The small quantities of oxygen, nitrogen and sulfur in the coal were neglected).

Extraneous Steam

The quantity of extraneous steam supplied is the amount required to react with the carbon plus the excess needed to attain the desired gas composition in accordance with the water gas equilibrium. Graphs furnished by Koppers for the water gas equilibrium in the presence of, and absence of, carbon are given here as Figures 15 and 16, pages 41 and 42, respectively. In practice it was found that gas composition approached the values for equilibrium in the absence of carbon and these values are used for calculations since they give some margin of safety in the steam requirements. On this basis the excess steam required to attain the desired gas composition at 1200°C. was calculated as 0.86 Nm^3 per Kg coal, making the total steam requirement 1.36 Nm^3 or 1.09 Kg per Kg coal. Deducting 0.02 Kg water in the coal the extraneous steam requirement becomes 1.07 Kg/Kg coal.

Totzek stated that experimental operation on bituminous coal gave ratios of H_2 to CO "ranging from 1.5 to 2.0 with corresponding CO_2 concentrations ranging from 18 to 8%". However the data submitted did not show that a ratio of 2:1 was ever attained directly and the reported CO_2 concentration was higher for higher ratios of H_2:CO. Reactor exit temperatures of 1200°C. were observed experimentally.

Heat Balance, basis 1 Kg raw coal

Input

Gross heating value of coal	7700 kcal
Preheat of steam to 1200°C.	684 kcal
Total	8384 kcal

Output

Net heating value of product gas	5400 kcal	64.5%
Carbon loss	700 kcal	9.2%
Sensible heat of wet gas	1450 kcal	17.2%
Radiation and Conduction losses	764 kcal	9.1%
	8384 kcal	

FIGURE 15

WATER GAS EQUILIBRIUM CONSTANT Kpw
IN THE PRESENCE OF CARBON

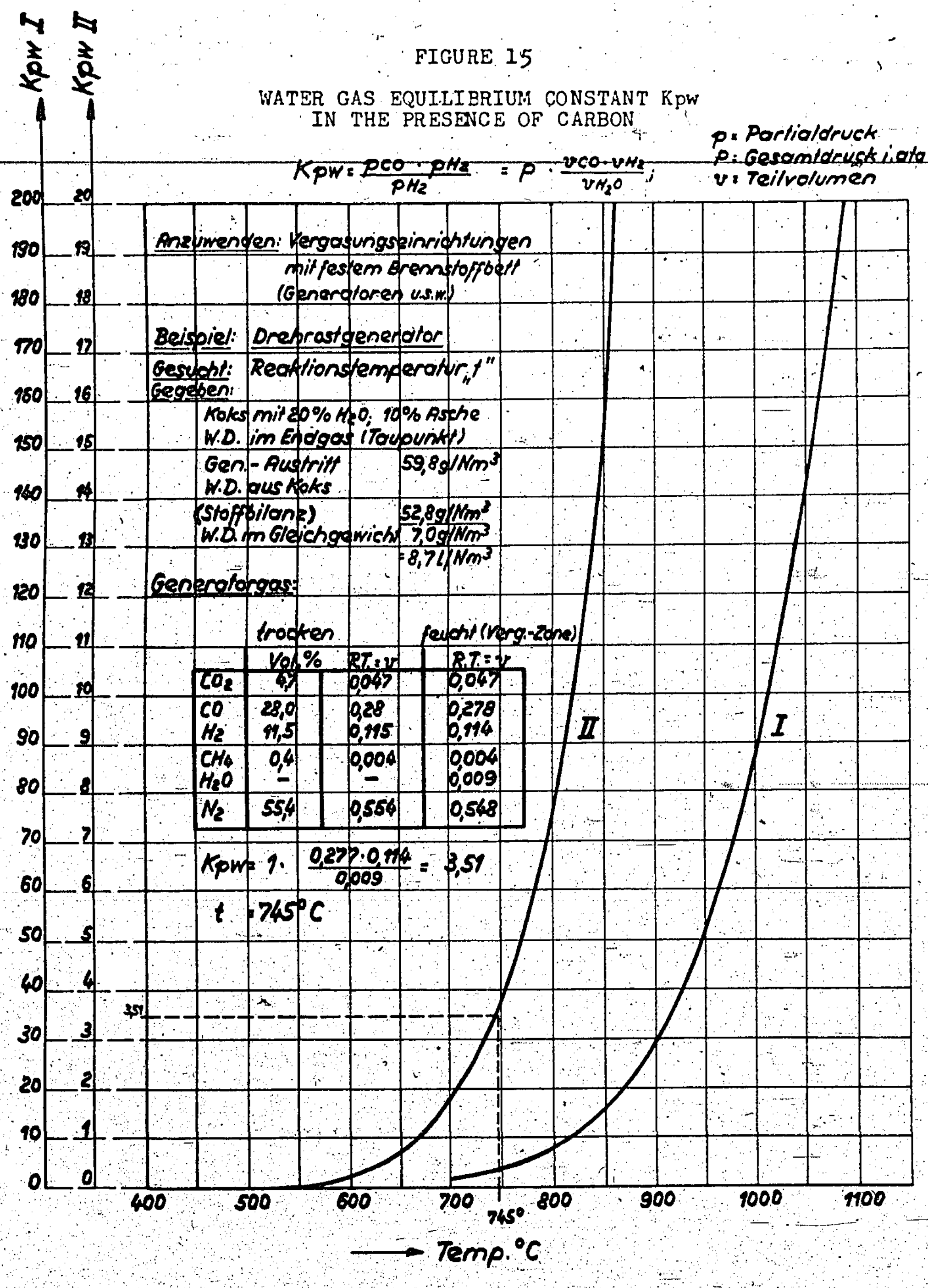
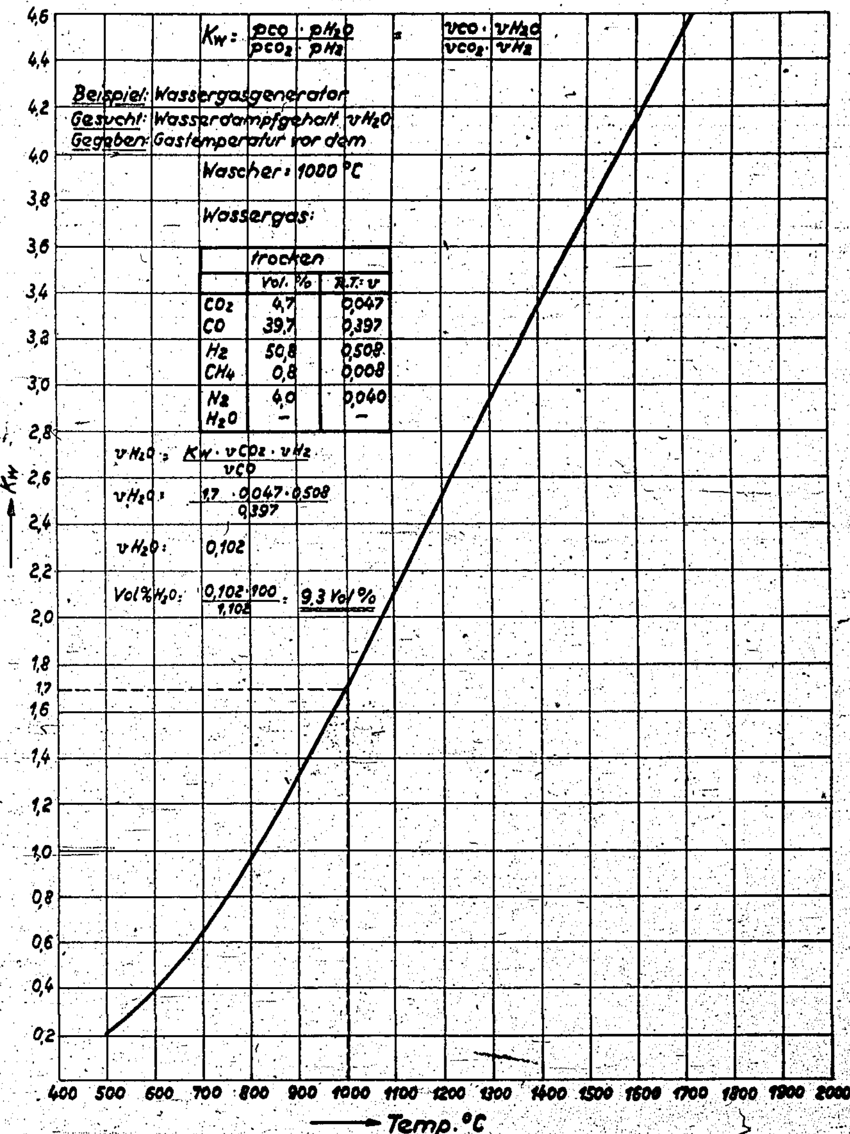


FIGURE 16.

WATER GAS EQUILIBRIUM CONSTANT Kw
ONLY IN THE GAS PHASE IN THE
ABSENCE OF CARBON



APPENDIX I

LIST OF GERMAN PERSONNEL

Dr. Hans H. Koppers, President of H. Koppers G.m.b.H.
Mr. Gapp, Director of H. Koppers G.m.b.H.
~~Mr. Totzek, Chief Engineer of H. Koppers G.m.b.H.~~
Mr. H. Kost, Former Head of Steinkohlen Bergwerk Rheinpreussen, Homberg
Dr. Strueven, Chemist, Rheinpreussen Treibstoffwerk, Moers

German Personnel not interviewed but known to have had some connection with Koppers work

Mr. Daniels, Design Engineer, Koppers, Essen
Mr. Schurhoff, Draftsman, Koppers, Essen
Mr. Hahn, Project Engineer, Koppers, Essen

APPENDIX 2

LIST OF TARGETS VISITED

H. Koppers, G.m.b H. 29 Moltke St., Essen (Main Offices)
Steinkohlen Bergwerk Rheinpreussen Shaft IV between Moers-Meerbeek and Homberg. Site of Koppers experimental unit

APPENDIX 3

BIBLIOGRAPHY

(1) FIAT, Fuels and Lubricants Unit

Questionnaire regarding powdered coal gasification, transmitted to Koppers by letter from North German Coal Control dated 12 April 1947.

(2) Koppers G.m.b.H.

Written answers to FIAT questionnaire, transmitted to North German Coal Control by letter from Totzek dated 2 May 1947.

(3) Lowry, H.H. and Rose, H.H.

Coal and Coke Research at H. Koppers G.m.b.H., Essen CIOS File No. XXXI-31 Item 30. (Makes Brief reference to powdered coal gasification system, stating that all records had been previously taken from Koppers by a U. S. Navy Officer).

(4) Newman, L.L.

Oxygen Gasification Processes in Germany A.I.M.M.E. Technical Publication 2116 Class F, Coal Technology November 1946.

(5) Newman, L.L.

Report of Subcommittee on Use of Oxygen in Gas Manufacture. 1946 Report of Gas Production Committee, American Gas Association.

(6) Peck, E. B. and Parker, A.

Report on H. Koppers G.m.b.H., Essen. CIOS Report File No. XXVIII-36, Item 30, 28 June 1945.

(7) Totzek

Arbeiten der Heinr. Koppers G.m.b.H. über restlose Vergasung. Vortag vor dem Energieausschuss 12 June 1942. (Unpublished Address).

(8) U.S. Technical Oil Mission, Microfilm Reel 43

Frames 209 to 278. Documents collected by CIOS investigators Powell, Peck, Parker and Hollings, April 1945.

APPENDIX 3 (CONT'D)

BIBLIOGRAPHY (CONT'D)

(9) U.S. Technical Oil Mission, Microfilm Reel 188

Item 34-U beginning Frame 20951. Documents collected by U.S. Navy Technical Mission in Europe, May-June, 1945.

APPENDIX 4

LIST OF MATERIAL EVACUATED

No equipment was evacuated in connection with this investigation. However prints of a number of drawings were obtained, in addition to the Koppers documents listed in Appendix 3, and the numbers and descriptions of these drawings are given below:

LIST OF KOPPERS DRAWINGS

IOS 92,915	28 July 1938 Dust Gasifier Brabag C 3892
ISO 111,860	7 October 1936 Assembly of the Cowper and Combustion Shaft Brabag V 564
IAK 112,745	Undated Plant Assembly (Brabag) Ruhland Dust Gasification e 3892
IAK 131,928	15 January 1942 300 Ton Dust Gasification Plant Brabag-Zeitz Project
IAK 132,315	17 August 1942 Gas, air, and steam lines for Heater Unit Brabag V 728
IOS 146,506	30 November 1939 Lining of the Dust Gasifier (Rheinpreussen) Dust Gasification C 3939
IOS 146,511	5 September 1940 Schematic Representation of Dust Gasification Rheinpreussen C 3939
IOS 146,520	22 April 1941 Magnesite Lining Rheinpreussen Dust Gasification C 3939
IOS 146,523	5 June 1941 Arrangement of air and gas connections to the feed spiral. Rheinpreussen C 3939

LIST OF KOPPERS DRAWINGS (CONT'D)

IOS 146,531 — 25 October 1941
Lining of the Dust Gasifier Head-Dust inlet
Rheinpreussen C 3939

IOS 146,544 — 15 September 1942
Section and Plot Plan
Rheinpreussen C 3939a

IOS 146,551 — Undated
Assembly
Rheinpreussen Dust Gasification C 3939

IOS 178,452 — 22 December 1942
Lining of the Regenerator and Conduits
Rheinpreussen C 3939a

IOS 178,479 — Undated (about July 1943)
Schematic Representation of the Koppers Coal Dust (Gas) Generator Plant.

IOS 178,480 — Undated (About July 1943)
Section through the Coal Dust (Gas) Generator

APPENDIX 5

QUESTIONNAIRE ADDRESSED TO KOPPERS BY FIAT, 11 APRIL 1947

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 behavior 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.

QUESTIONNAIRE ADDRESSED TO KOPPERS BY FIAT, 11 APRIL 1947 (CONT'D)

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

12. Effect of coal composition and operating variables on organic sulfur 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 gum 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.

QUESTIONNAIRE ADDDRESSED TO KOPPERS BY FIAT, 11 APRIL 1947 (CONT'D)

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.

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

11 April 1947