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"TEN YEARS OF OXYGEN-GASIFICATION AT LEUNA"

BY

OBERINGENIEUR SABEL

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BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE
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"TEN YEARS OF OXYGEN - GASIFICATION AT LEUNA"

by OBERINGENIEUR SABEL

TRANSLATED BY D.G.FRASER AND R.J.MORLEY

ON BEHALF OF

BRITISH MINISTRY OF FUEL AND POWER

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Translator's Notes

The existence of this document became known in May 1945 to one of us (RJM) during a visit to the I.G. factory at Leuna on behalf of the British Ministry of Fuel and Power; the I.G. were told to have a photostat prepared and this was collected and brought back to England in June, by a member of a British Ministry of Supply Mission. The original should have come to London as a C.I.O.S. document in the normal way, but at the time of writing it has not been traced.

The report, which in effect summarizes the experiences and opinions of the leading I.G. expert on this subject, has been considered worthy of full translation. Such a translation has been made, with the addition of the minimum of notes by the translators, intended to clear up a few expressions, peculiar to Leuna. The subject matter will be critically reviewed in later subject reports.

Below is a short glossary of translations used here:

Hüttenkoks :	hard coke (≡ metallurgical or oven coke).
Steinkohle :	bituminous coal.
Schwelkoks = Halbkoks :	semi-coke (≡ low temperature coke).
Grude or Grudekoks :	grude (= brown coal low temperature coke).
Hartgrude :	hard grude (see note on p 3).
Rohschlacke :	"semi-ash" (see note on p 2).
Feinkörnig :	particulate (= fine-grained)
Körnig :	grained
Stückig :	lump
Generator :	generator [The German word is used both for the English "generator" and "producer", although occasionally and indiscriminately the German word "Erzeuger" is used for "producer". When using oxygen and steam the usual definitions break down and the term "generator" is used throughout this translation].
Brassert and Pintsch :	Proprietary names for manufacturers of ordinary make and blow water gas generators, operating normally on hard coke.
Drehrostgenerator :	The term "Drehrost" has been retained in the translation: if translated as "rotary-grate type" it is less distinguishable from the Pintsch-Brassert generators.

Abstichgenerator : Slagging generator.

Schachtgenerator : Shaft Generator.

Schwelgenerator : Carbonisation generator, in which coal is carbonised in the upper portions and sinks down into the generator proper.

Schwelvergasung : Carbonisation-gasification, where the two processes occur in the same vessel.

Schwelgas : Carbonisation gas.

Figures - All figures in the text have been replotted, using data from tables where available.

Gas Measurement - Throughout gas quantities written as M^3 are measured dry at 15°C and 735.5 mms Hg (i.e. 1 kg/cm2), which is standard at Leuna. Gas quantities written as NM^3 are measured dry at 0°C and 760 mms Hg.

D.G.Fraser.
R.J.Morley.

TEN YEARS OF OXYGEN-GASIFICATION AT LEUNA

Leuna Works, September 15th, 1942.

SABEL

OBERINGENIEUR.

TEN YEARS OF OXYGEN-GASIFICATION AT LEUNA

On the 7th December 1932 a Linde air-separation plant, which was to be used exclusively to make oxygen for water gas production by oxygen -gasification, was put into operation at Leuna for the first time. In the past ten years oxygen-gasification has been tried out in numerous processes with both lump and particulate fuels. The following is a summary of the most important of these processes.

Start-up and Development of Oxygen-gasification at Leuna

Prior to 1929 about 3,000 M^3/hr of impure oxygen, containing about 55% oxygen and 45% nitrogen, was available at Leuna from four Linde air-separation plants, used for producing pure nitrogen for ammonia synthesis. Until 1928 this impure oxygen went to waste into the atmosphere. From 1/6/28 it was partly used in the gas plant, by adding it to the blast of the slagging generators, manufacturing power gas, but this ceased in 1931. The oxygen content of the blast was increased to 24%.

We then suggested this oxygen should be utilized for synthesis gas production, since the Winkler "make and blow process"* for the gasification of particulate dry brown coal had not come up to expectation.

No useful information had then been published on the gasification with oxygen of particulate or lump material. The experiments of Vandeveer and Parr 1) with a laboratory furnace producing 2-3 M^3 gas were a failure; the single large-scale test of Drawe 1) could not be repeated and, like the very first experiment of Hempel 1) in Dresden in 1899, is of no practical significance.

Apart from these three attempts, in which large-size fuel had been used, published material was purely theoretical, and this, partly due to lack of actual experience, led to mistaken ideas, particularly the apprehension felt about the effect of high temperatures on the danger of slagging and on damage to the materials of construction of the generator.

The experiments on oxygen-gasification in the Winkler generator, which were started in February 1929, were limited at first to the production of ammonia synthesis gas, using mixtures of oxygen and air, because the use of pure oxygen then appeared to be too dangerous. From February 1929 to April 1930 the groundwork on gasification of grude and dry coal was done in a small experimental generator with a shaft area of 2 M^2, and this led to the continuous production from June 1930 of about 10,000 M^3/hr of mixed gas for ammonia synthesis in No.1 generator in building Me 278.

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*"Blase-Gase-Verfahren" - an early Winkler process operating a boiling-bed on a make and blow cycle, using air and not oxygen. Trans. note.

1) See literature references on p 32.

After this first success it soon became possible, on the basis of the information so obtained, to use mixtures of pure oxygen and steam to make a nitrogen-free water gas, suitable for hydrogenation. In June 1930 nitrogen-free water gas was produced experimentally from grude and in April 1933 on the full-scale from dry brown coal. It was shown that slagging, which was so much feared with pure oxygen, could be controlled just as well as when running with air, and further, that the methane content of synthesis gas could also be kept sufficiently low in large scale operation, in spite of using uncarbonised dry brown coal, so that this new water gas could be used for synthesis.

Today there are seven Linde-Fränkl air-separation plants at Leuna making 98-99% oxygen, which is used in Winkler generators for the continuous production of 50-55,000 M^3/hr of nitrogen-free $H_2 + CO$.

When in 1936 oxygen-gasification in Winkler generators was considered at Böhlen by the Braunkohle-Benzin-A.G. for the production of hydrogen from particulate grude, we were able to give exact guarantee figures, based on actual experience, for the consumption of fuel and oxygen and for the purity of hydrogen, using a fuel not tested for the quality of its ash. On acceptance the guarantee figures were maintained without difficulty, just as they are today in the works built subsequently at Magdeburg and Zeitz.

After solving the problem of oxygen-water gas production in Winkler generators, oxygen-gasification of grained and lump material in a fixed bed was studied. From July to December 1931 the first experiments were made in a small slagging generator, using oxygen and hard coke with the result that since October 1935 two Linde-Fränkl air separation plants, specially installed for the purpose, have made pure oxygen continuously for the production of 20,000 M^3/hr nitrogen-free water gas in slagging generators. The fuel used in this case is "semi-ash" from the Pintsch generators of the water gas plant, containing about 50% carbon.

Experiments on the production of water gas with oxygen in a fixed bed were then extended in 1936 to brown coal briquettes and lump grude. Many variations of oxygen-gasification were carried out systematically in an experimental apparatus with complete tar condensation e.g. carbonisation-gasification with a common outlet for carbonisation gas and water gas, or with a separate outlet for water gas, free from carbonisation gas, and also preheating the steam-oxygen mixture to temperatures of 200-900°. The experiments were then extended to the full scale generators of the water gas plant, using hard coke and lump grude, thereby obtaining full scale experience for larger units.

When about 1938 hard grude[*] came on to the market as a new and improved product of the brown coal industry, a further Linde air separation plant was ordered, so as to make water gas in the Pintsch generators of the gas plant, using oxygen to gasify hard grude obtained at Deuben from "Ringwalzen" briquettes. So begins oxygen-gasification of a new fuel, which is conceivably a suitable substitute for Westfälischen hard coke at Leuna, but one which cannot be used for water gas manufacture - at least as yet - by the old make and blow process.

When this new Linde plant is put into operation at the beginning of 1943, 26% of the hydrogen needed in the works at Leuna will be obtained by oxygen gasification, partly of dry brown coal and grude in Winkler generators, partly of "semi-ash" in the slagging generator and partly of hard grude in Brassert generators.

Meanwhile as a consequence of the varied nature of the oxygen-gasification experiments and of the oxygen-gasification processes at Leuna, our experience of using oxygen, and of the necessary safety precautions, had progressed so far that in May 1941 useful suggestions and performance figures could be given, when bituminous coal semi-coke was being considered for hydrogen production at the Auschwitz factory; this semi-coke could only with difficulty be used for water gas manufacture by methods other than oxygen-gasification.

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[*] Probably "Hartgrude" is the name given to carbonised briquettes made by the "Ringwalzen" or "ring-roll" process, whilst "Grude" is the name given to carbonised briquettes made by the older "Strangpressen" or "extrusion" or "plunger-press" process. It is known [see C.I.O.S. Report, Item 30 File No.XXXII-14 "Deutsche Erdöl A.G. Regis] that the former process yields a much harder product, described as a high class fuel for domestic use, whilst the latter process yields a weaker product, used for power production and general industrial use. [Trans. Note].

The Reaction Mechanism of Oxygen-Gasification

Firstly we have the following well-known water gas reactions.

$C + H_2O = CO + H_2$ - 1393 kcal per 2 NM^3 ($CO + H_2$)
$C + 2H_2O = CO_2 + 2H_2$ - 963 " " 3 NM^3 ($CO_2 + 2H_2$)

As in almost all technical processes for making water gas the first equation, with its greater heat requirements, preponderates in oxygen-gasification, on account of the high temperatures used, viz. over 900°.

The heat required by the water gas process must be balanced by external sources of heat; apart from chemical heat requirements in forming water gas, the other heat losses of the process must also be balanced, e.g., the sensible heats of the gases made, of the undecomposed steam, of the solid residue, radiation and, for slagging producers, the heat of fusion of the slag as well. The heat required for the reaction between carbon and steam and the other heat losses are balanced in oxygen-gasification by the heat liberated in the simultaneous combustion of a corresponding amount of oxygen. Oxygen can be burnt to either CO or CO_2.

$C + O = CO$ + 1190 kcal for 1 NM^3 CO
$C + O_2 = CO_2$ + 4235 " " 1 NM^3 CO_2

As an example of how oxygen can react, two practical oxygen water gas analyses have been mathematically split into the above four equations; the split of the analysis of 1 NM^3 water gas is arranged, so that the components of the equations are subtracted in steps. 1)

a) Hard Coke with Oxygen and Steam in the Brassert Generator

	CO_2 NM^3	CO NM^3	H_2 NM^3	N_2 NM^3	H_2O NM^3	O_2 NM^3	Heat Change kcal
1 NM^3 water gas	0.227	0.347	0.403	0.009			
disp.H_2 & N_2 from coke			0.005	0.002			
	0.227	0.347	0.398	0.007			
from $C + H_2O = CO + H_2$		0.347	0.347		0.347		- 484
	0.227	-	0.051	0.007			
from $C+2H_2O = CO_2+2H_2$	0.0255	-	0.051		0.051		- 24
	0.2015	-	-	0.007	-		
from $C+O_2 = CO_2$	0.2015	-	-	-	-	0.2015	+ 852
	-	-	-	0.007	0.398	0.2015	+ 343

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1) This calculation is a form of the normal H_2-O_2 balance, giving a clear overall picture, since the amount of the various reactions can be followed simultaneously. For simplicity CH_4 has been ignored, but for accurate calculation must of course be taken into account, along with carbonisation gases obtained by gasification of bituminous fuel.

Accordingly for 1 NM^3 water gas, 0.2015 NM^3 O_2 + 0.007 NM^3 N_2 (oxygen about 97% pure) is converted to CO_2 and 0.398 NM^3 steam is decomposed; the gasification liberates 343 kcals, which balance external losses!

b) Hard Coke with Oxygen and Steam in the Slagging Generator.

	CO_2 NM^3	CO NM^3	H_2 NM^3	N_2 NM^3	H_2O NM^3	O_2 NM^3	Heat Change kcal
1 NM^3 water gas	0.057	0.640	0.287	0.009			
disp.H_2 & N_2 from coke			0.005	0.002			
	0.057	0.640	0.282	0.007			
from $C+H_2O = CO+H_2$		0.282	0.282		0.282		- 380
	0.057	0.358	-	0.007			
from $C + O = CO$		0.358				0.179	+ 425
	0.057	-	-	0.007			
from $C+O_2 = CO_2$	0.057					0.057	+ 242
	-	-	-	0.007	0.282	0.236	+ 287

Accordingly of 0.236 O_2 + 0.007 N_2 (oxygen about 97% pure) about $\frac{1}{4}$ is converted to CO_2 and $\frac{3}{4}$ to CO. 0.282 NM^3 steam is decomposed, 287 kcal are available to cover external heat losses.

In both examples the sequence of reactions is taken arbitrarily. One could also first calculate the reaction $C + 2H_2O = CO_2 + 2H_2$ or $C + O = CO$ and finally $CO + H_2O = CO_2 + H_2$. The final result, with respect to steam decomposed, oxygen used and heat liberated, would always be the same. The practical man will always welcome the simplest and clearest split of the analysis, because, in spite of extensive research work and a large technical literature, there is still no certainty about the actual order, in which the various reactions occur.

In the Brassert generator (Case (a) more oxygen is burnt to CO_2 than in the slagging generator. This is because of the greater internal heat requirement of the larger quantity of undecomposed steam in the Brassert generator.

Instead of steam CO_2 can also be made to react with carbon, given the necessary heat of reaction by combustion of oxygen, according to the equation:

$$C + CO_2 = 2\ CO \quad - 1841\ \text{kcal} \quad \text{per } 2NM^3\ CO.$$

For example:

c) Hard Coke with Oxygen and CO_2 in the Slagging Generator

	CO_2 NM^3	CO NM^3	H_2 NM^3	N_2 NM^3	CO_2 used NM^3	O_2 NM^3	Heat Change
1 NM^3 water gas	0.061	0.902	0.027	0.01			
disp.H_2 & N_2 from coke			0.005	0.002			
	0.061	0.902	0.022	0.008			
from CO_2 used			0.022	0.001	0.023		
	0.061	0.902	-	0.007			
" " "	0.061				0.061		
	-	0.902	-	0.007			
from $C + CO_2 = 2CO$		0.442			0.221		- 390
	-	0.460	-	0.007			
from $C + O = CO$		0.460				0.230	+ 550
	-	-	-	0.007	0.305[1]	0.230	+ 160

Thus for 1 NM^3 water gas 0.230 NM^3 O_2 + 0.007 NM^3 N_2 (O_2 = 97%) are used. Oxygen is wholly burnt to CO; 0.305 NM^3 92% CO_2 is about 75% decomposed, and 160 kcal are liberated to cover external heat losses. The overall picture of the simple theory of oxygen-gasification can be seen by imagining a shaft generator divided into two chambers by a vertical wall; on one side of the wall occurs the strongly endothermic reaction of steam with hot carbon, whilst on the other side the heat necessary for this is produced by burning oxygen to CO_2 or CO. The wall is not there in reality and all reactions proceed side by side, so that the actual sequence of the various reactions is in practice of secondary importance.

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1) 92% CO_2, about 7% H_2, 0.3% N_2.

The Technical Principles of Oxygen-Gasification.

The first big difficulty in using pure oxygen for water gas production is slagging of the fuel, and this will happen very quickly at the high temperatures used, if fluctuations occur in the oxygen-steam mixture. A second unpleasant difficulty is the effect on grates, tuyères, oxygen supply pipes, generator brickwork and metal walls resulting from changes in the oxygen-steam mixture or from strong local slagging, which has previously occurred. At first we met considerable difficulty from both effects until we found that the usual methods for mixing steam and air under the grate could not be used for mixing steam and oxygen. The resultant poor mixing led to stratification and the formation of regions of higher oxygen concentration, and this caused severe slagging and burning of the grate and tuyères.

There were similar failures later in 1935, when, neglecting this previous experience, we tried introducing steam and oxygen separately through the tuyères of the slagging generator in Me 240.

The first basic principle for oxygen-gasification is: "mix oxygen and steam or oxygen and CO_2 at some distance from the generator and use only a homogeneous mixture under the grate or in the tuyères." In practice a distance of 10-15 m, if possible incorporating a bend or restriction plate, has proved adequate for good mixing. This makes it unnecessary to use copper tuyères or delivery lines of copper or any other special material to prevent attack.

In the light of this it is interesting to note that leakage of water from the stirrer of a Winkler generator or from the water-cooled ash discharge could result in severe slagging. This can only be explained by assuming that locally, through condensation of water vapour from the steam-oxygen mixture, strong oxygen-enrichment occurs directly over the grate. A similar phenomenon was also met in the Pintsch-Brassert generator with oxygen-gasification through a leaking stirrer.

Careful mixing of oxygen and steam is thus essential for oxygen-gasification, but this is not always recognised, although it appears so simple and obvious. It is well-known, that Lurgi still get a lot of slagging in their pressure-oxygen generator probably because oxygen and steam are not sufficiently well mixed, and at the only place in Germany, where besides us oxygen-gasification is used in slagging generators (Thyssen, Mülheim-Ruhr, after the patent of Galoscy, DRP 573,112), they have changed over to building pre-combustion chambers before the slagging generators, in which oxygen and gas are pre-combusted, giving a highly superheated steam-gas mixture, which is then introduced into the fuel bed, so that in effect only endothermic reactions occur inside the generator. These elaborate precautions, which also reduce the output of the producer, are completely superfluous if there is early intimate mixing of oxygen and steam.

The high concentration of oxygen, e.g. 30-40% on the Winkler generator and up to 55% on the slagging generator, involves certain operational dangers. If in the slagging generator, owing to irregularity in fuel or flux, lumps of slag build up in front of the tuyères then such lumps of slag can so obstruct the path of the oxygen that the oxygen immediately strikes on the hot fuel, leading to attack of the brickwork and metal wall of the generator; e.g. it happened in one oxygen slagging generator that the oxygen leaving the tuyère was deflected by a lump of slag and burnt a hole in the wall of the water jacket. The escaping water quenched the generator; the process, which may have taken only a few seconds, was noticed but the danger was not immediately appreciated, with the result that oxygen entered the water gas main and together with water gas from a neighbouring generator caused a destructive explosion in the coolers and gas mains. ⁄ See Fig. 1 ⁄

Similar burning through of the wall often happened earlier in the Winkler generator, only there the consequences were not so unfortunate, because this had no water jacket.

Oxygen can of course also get into the upper part of the generator and thence into the water gas mains, gasholder, etc., if the fuel bed level in the generator is lost. Two serious explosions in outside factories ("Lizenzwerken") were caused in this way.

The <u>second basic principle</u> of oxygen-gasification is, therefore, the most careful supervision of operations.

In order to study the course of an oxygen break-through, the fuel supply to a small Winkler generator with 2 M^2 shaft area was shut off, whilst maintaining the full flow of oxygen and steam. The course of the oxygen break-through, as shown by CO_2, is illustrated in Fig. 2. Therefore, all oxygen-generators at Leuna have a small flame, working with a selenium cell. When the flame goes out an alarm sounds, and the operator must immediately turn off the oxygen supply.

As well as this precaution, each Winkler oxygen generator has duplicate pressure gauges, fitted with alarms, showing the height of fuel.

If by any chance 1) steam is omitted from the oxygen-steam mixture, the grate naturally begins to burn in the undiluted, dry oxygen. This has happened twice on our water gas plant, through the carelessness of the operator on the Drehrost generator; the damage can be considerable. There is also a possibility of the hot fuel bed discharging into the atmosphere. Therefore an independent steam connection, the so-called "emergency steam", is provided under the grate.

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1) e.g. in an outside factory the spindle of a vertical steam valve on the main steam line broke, and there was danger of the valve closing.

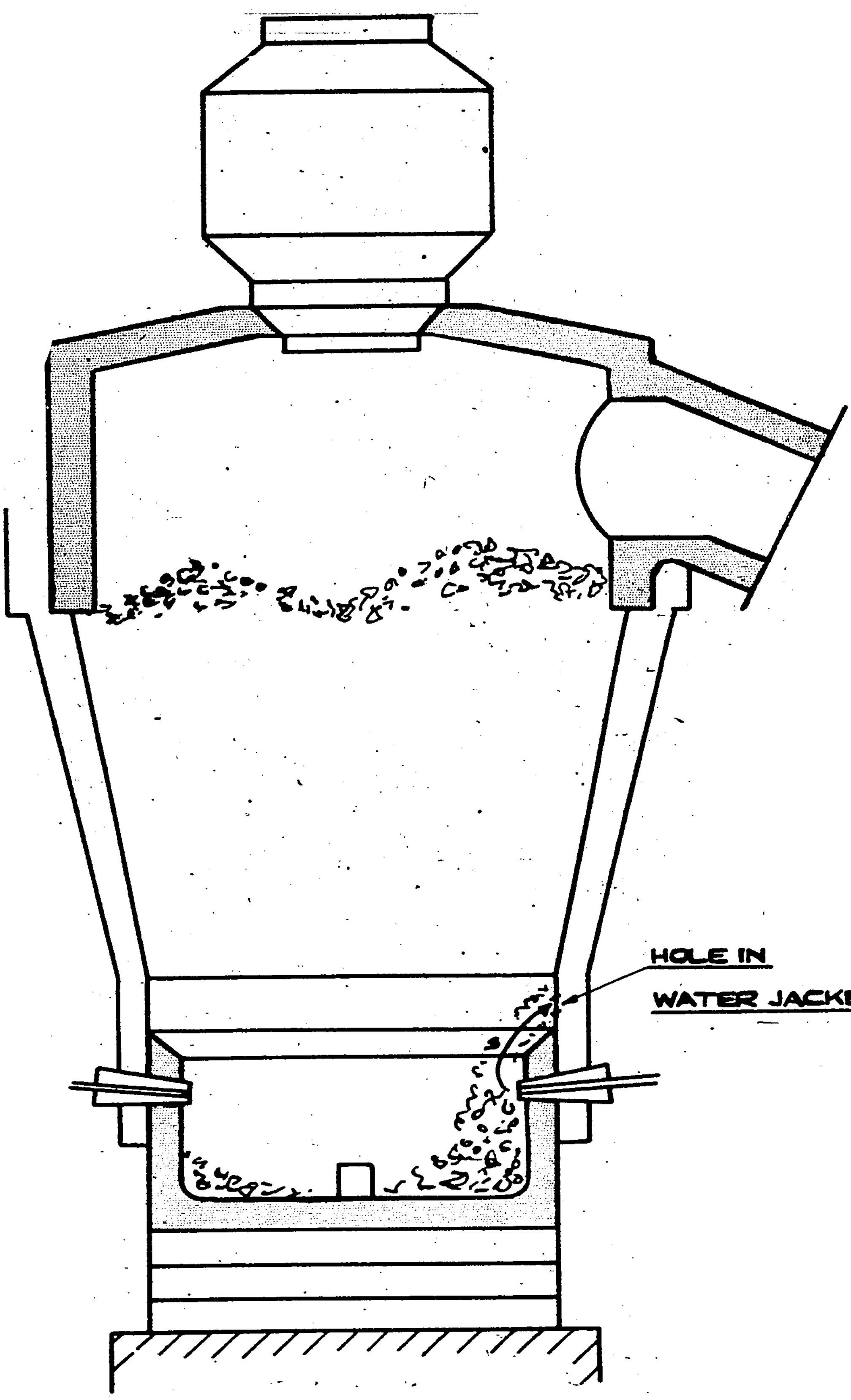

FIG. 1.

Each time an oxygen generator is started up or shut down the grate is purged with CO_2 or N_2.

Besides the generator the oxygen blowers, which compress dry oxygen to 5 m water column, can also be a source of danger. In the course of the development of oxygen-gasification at Leuna and the outside factories some oxygen blowers have actually fired. Such fires, apart from the destruction of the blower, are dangerous, since large clouds of iron oxide make access difficult and the very hot oxygen-iron flames can easily cause the fire to spread. Such fires started either by oil running from a bearing when the sealing water was left off, or else by the rotor........

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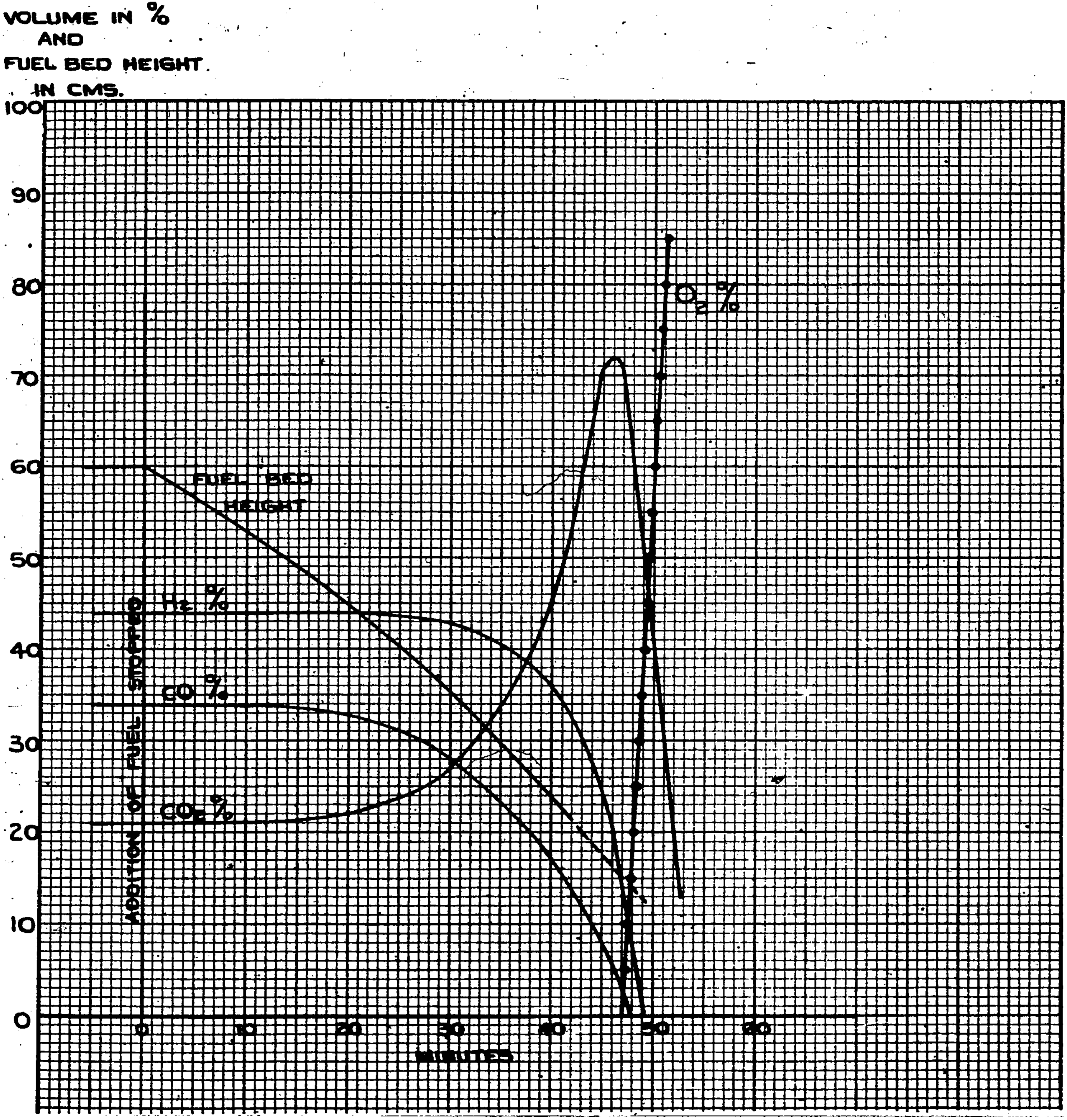
FIG. 2.

CHANGE OF GAS COMPOSITION WITH AN OXYGEN BREAK-THROUGH



Fuels for Oxygen-Gasification and Comparison with the "Make and Blow" Process

The price of 1 NM^3 $CO + H_2$ from hard coke is about 10% higher using oxygen-gasification than when using the normal make and blow process. The saving of coke by using oxygen and the simpler plant for continuous gasification does not - with the present-day price of oxygen at 1.7 to 2.0 Pfg./NM^3 - balance the cost of the extra oxygen. In the subsequent usage of water gas a further charge against oxygen-gasification of hard coke is incurred, because the quantity of catalysed gas ("Kontaktgas") and consequently the gas in the first three stages of compression and the gas to be scrubbed with water at pressure are increased by an amount of CO_2 corresponding to the oxygen used.

In practice 1) the comparison is as follows for hard coke gasified in various ways.

Test Number	-	3	1	5	-
Process	Make and Blow in Brassert with steam	O_2-Gasification in slagging generator with steam	O_2 gasification in Brassert with Steam	O_2 gasification in slagging generator with CO_2	Make and Blow in Brassert with CO_2 2)
Analysis CO_2 %	5.0	6.8	22.7	6.1	24.6
CO %	42.0	61.4	34.7	90.2	68.8
H_2 %	49.0	31.0	40.3	2.7	5.1
N_2 %	4.0	0.8	2.3	1.0	1.5
per 1 $NM^3 H_2$ (97% pure) are needed:					
Hard Coke kg	0.620	0.530	0.560	0.590	0.70
Oxygen NM^3	-	0.261	0.290	0.269	-
Steam to generator kg	0.763	0.370	1.06	-	-
" to CO conversion plant kg	0.600	0.710	1.09	1.24	1.38
Total Steam "	1.363	1.080	2.15	1.24	1.38
per 1 NM^3 pure H_2 is used:					
Moist Catalysed gas at exit of system NM^3	2.44	3.18	3.25	4.05	4.72
Dry catalysed gas before compressor"	1.68	1.88	1.95	2.22	2.37

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1) For the calculation a gas with 6% CO and 1.5% CO_2 before hydrogen purification is assumed; CO regeneration gases have not been considered, but assumed to be used for another synthesis (at Leuna for NH_3 sysnthesis); 5% H_2-losses have been assumed.

2) In the comparison the substitution of steam by CO_2 as gasification

(continued at foot of page 11.)

In test (1) using hard coke with O_2 and steam in the Brassert, the generator was very cold; if the test had been longer it is quite possible that steam could have been saved.

It can be seen at once from the above efficiencies, that the amount of oxygen needed is not small, that the savings in coke and steam are not great and that the additional load on the compressors, in terms of quantity of gas compressed, is correspondingly great. Theoretically the extra amount of compressed gas should correspond exactly with the oxygen used. That this is numerically not the case here is due to the fact that for the comparison with "Make and Blow" a water gas with 4% N_2 has been taken, which therefore contains a small quantity of oxygen derived from the air.

A calculation in Reichmarks shows that the cost of pure hydrogen by gasification of hard coke with oxygen, costing 1.7 Pfg/NM^3, is about 8-15% higher than by the old "Make and Blow" process.

Oxygen-gasification is not yet competitive for good hard coke; its proper use is for the production of hydrogen from fuels, not suitable for "Make and Blow" but which are cheaper than hard coke. Fortunately there is a whole series of such suitable fuels:-

particulate dry brown coal	in the Winkler generator
particulate grude	in the Winkler generator
lump grude and hard grude	in Drehrost, Brassert, slagging
brown coal briquettes (carbonisation-gasification)	in shaft generator with carbonisation superimposed
non-caking bituminous coal nuts (carbonisation-gasification)	- ditto -
bituminous coal semi-coke	in Drehrost, Brassert & slagging
poor quality hard coke, e.g. upper Silesian hard coke waste, and fines from hard coke and semi-coke, 5-10mm.	- ditto -

Both brown and bituminous coal dust can be utilized quite well with oxygen-gasification, although these consume more oxygen than the above fuels and methods of gasification, because gas exit temperatures are essentially higher when gasifying dust. The increase in oxygen consumption is however not too great that it could not be compensated for by a low price for coal dust.

Cont'd.from p.10

2) medium which has often been suggested, is included. It may be seen from the figures that the amount of gasification steam used, by which is meant the steam consumed by generator + CO conversion plant is not any less, and that the CO_2 to be recirculated would enormously overload the CO conversion plant and the compressors and also of course the pressure water scrubbing process. This addition of CO_2 to the generator, unless it is desired to produce CO, is fundamentally wrong.

All the fuels named have been systematically tested at Leuna since the development of the Winkler process for gasifying dry brown coal with oxygen; information on the most important results is given in the accompanying tables. At Leuna it is out of the question to increase gasification of dry brown coal in the Winklers, because the coal requirements of the factory make big demands on the mines in the neighbourhood. Also Winkler oxygen-gasification needs considerably larger oxygen plants than gasification in shaft generators.

In these circumstances hard grude is the ideal fuel for replacing Westphalian hard coke for oxygen-gasification at Leuna. This would be certain to lead to a considerable cheapening of hydrogen. Although the present day selling price of hard grude is higher than for industrial grude [normal Lurgi grude from "Strangpressenbriketts"] it is known that the production costs for hard grude are not only no higher than for industrial grude but are even somewhat lower.

The conversion of our coke water gas plant to hard grude does not involve any great changes. Fortunately the output, in $H_2 + CO$, of a generator using hard grude is the same, and probably even somewhat greater than that with the "make and blow" process. Adjustments have to be made only to the water services because the sulphur content of water gas is higher than with hard coke. What adjustments will have to be made for the higher H_2S and CO_2 content of water gas made from hard grude, during sulphur purification, CO conversion and in the first three stages of compression, cannot be assessed until the Linde air-separation plant, due to start up in 1943 making oxygen for gasification of hard grude, has been running for some time. It is certain, however, that these adjustments, after allowing for the lower production cost of hard grude, will still result in a considerable cheapening of hydrogen.

Besides the low production cost of hard grude, which permits transportation from more distant Central German mines, there is the pleasantness of handling, which is scarcely less than that of hard coke. Loading and unloading do not cause a dust nuisance, whilst rightly handled hard grude is not liable to spontaneous combustion, and like hard coke it is easily stored. It has been stored at Leuna on the open ground for months without difficulty. Breakage during transport and handling is not serious. Fines and dust can be screened out immediately before the water gas generators, and can, like dry fly dust ("Flugstaub"), be fed to the Winkler generators, where the hard grude "breeze" can be turned to good account; in this it is unlike hard coke breeze, which cannot be gasified.

In a few months time oxygen-gasification of hard grude at Leuna will commence by making about 9,000 M³ $CO + H_2$/hr, and one hopes and expects, that with the return of normal conditions, the process will make great progress.

Besides oxygen-gasification of hard grude in Central Germany, it is to be expected that this type of gasification, with its simple technique will also have a good future in Upper Silesia. Moreover non-caking bituminous coal can be used for manufacturing hydrogen by carbonisation-gasification, and particularly, Upper Silesian semi-coke; the latter has already been chosen for Auschwitz.

The Results of Tests and Large Scale Operation

In the following tables the analyses and consumptions, with several check calculations, are summarised for the oxygen-gasification of:

Hard Coke
Bituminous Coal semi-coke
Brown Coal Grude
Dry Brown Coal and
Brown Coal Briquettes

Oxygen-Gasification of Hard Coke with Steam

Table I

Test Number	(1)	(6)	(3)	(4)	(7)	(8)
Process	in the Pintsch Brassert	in the Pintsch Drehrost	in the slagging generator	in the slagging generator	in the slagging generator using "semi-ash"	in the Pintsch Brassert "Waschkoks"
Record note of	9.5.41.	2.9.37.	29.5.41.	1.6.42.	17.5.39.	17.11.41.
Gas analysis CO_2 %	22.7	22.4	6.8	5.7	9.7	23.6
CO %	34.7	35.5	61.4	64.6	66.5	35.7
H_2 %	40.3	40.7	31.0	28.7	22.9	39.7
CH_4 %	1.4	0.5	0.0	0.1	0.0	0.5
N_2 %	0.9	0.9	0.8	0.9	0.9	0.5
Sulphur in Gas H_2S g/NM³	3.8	- 3)	4.3	- 3)	2.7	- 3)
organ.S "	0.31	- 3)	0.380	- 3)	0.380	- 3)
Consumptions: measured						
Oxygen (98-99%) NM³/NM³CO+H₂	0.267	0.252	0.262	0.260	0.347	0.324
L.P.Steam kg/ " "	0.985	0.802	0.346	0.294	0.207	1.21
C incl. losses " " "	0.454 1)	0.452	0.424 2)	0.436	- 3)4)	0.486
Coke " " " " "	0.518 1)	0.51	0.490 2)	0.496	- 3)4)	- 3)
Gas output NM³dry/M² shaft	690	890	920	2100	1100 5)	710
Gas exit Temperature °C	500°	- 3)	400°	390°	200°	- 3)
Check Calculations						
Oxygen NM³/NM³CO+H₂ from analysis	0.268	0.260	0.242	0.256	0.350	0.290
undecomposed steam kg/NM³ dry gas	0.420	0.284	0.075	0.047	0.002	0.592
%age steam decomposition	43 %	53 %	76.5%	83 %	98 %	35 %
% Oxygen in steam-oxygen mixture	18 %	21 %	35.5%	41.5%	58 %	16.5 %
C in gas as % of used C	93 %	91 %	93 %	93 %	-	89 %
Heat change per 1 NM³ dry gas, kcals	+ 343	+ 321	+ 232	+ 280	+ 611	+ 394
Residue from heat balance for radiation and sensible + heat of fusion of the ash, as % of heat throughput of fuel	3 %	- 3)	2.7 %	4.4 %	12 % 6)	- 3)
"Gas formation temperature" water gas °C	1060°	920°	1250°	1150°	1350° 7)	[1240°]
- do - producer gas °C	651°	660°	777°	794°	765°	648°

---

1) 87.2 % C, 7.9 % ash, 3.9 % H_2O
2) 86.8 % C, 9.1 % ash, 1.8 % H_2O
3) not determined

continued on page 15.

4) 45-50% C, remainder - slag
5) Limited by charging and removal of the large quantity of ash, but higher outputs possible.
6) High heat of fusion of the large quantity of molten ash.
7) With 0.002 kg undecomposed steam, cannot be calculated.

Oxygen-Gasification of Bituminous Coal Semi-Coke with Steam TABLE II

Test Number	(9)	(10)	(10a)	(12)	(13)	(14)
Process	in the Pintsch Brassert	in the slagging generator	in the slagging generator 1.4m ID	in the slagging generator "Karsten-Centrum"	in the shaft generator 1.1m ID "Weber briquettes"	in the slagging generator 0.4m ID "Königin Luise"
	Fürsten Mine	Fürsten Mine				
Record note of:	4.11.41.	25.5.42.	31.7.42.	25.5.42.	19.11.40	19.11.40.
Gas analysis CO_2%	21.1	2.9	2.5	3.2	24.0	6.2
CO %	32.8	66.3	67.0	67.0	21.5	57.3
H_2 %	44.6	30.1	29.6	29.4	52.5	35.4
CH_4%	1.1	0.0	0.2	0.0	1.9	0.8
N_2 %	0.4	0.7	0.7	0.4	0.1	0.3
Sulphur in gas H_2S g/NM^3	1.8	5.4	2.6	2.5	- 9)	- 9)
organic.S "	0.130	0.7	0.56	0.425	- 9)	- 9)
Consumptions - measured						
Oxygen (98-99%) NM^3/NM^3 $CO+H_2$	0.255	0.262	0.263	0.243	0.188 6)	0.220
L.P.Steam kg/ "	0.813	0.232	0.243	0.215	1.200 6)	0.300
C.incl.losses "	0.427	0.539	0.445	0.542	0.352	0.415
Semi-coke incl. losses kg/NM^3 $CO+H_2$	0.545 1)	0.670 3)	0.605 5)	0.667 4)	0.460 7)	0.540 7)
Gas output NM^3 dry/ M^2 shaft	720 2)	890 3)	1380	920 4)	400	1600
Gas exit temp. °C	400°	345°	350°	345°	650°	- 9)
Check Calculations						
Oxygen NM^3/NM^3 $CO+H_2$ from analysis	0.238	0.256	0.255	0.267	0.174	0.235
undecomposed steam kg/NM^3 dry gas	0.325	0.039	0.050	0.030	0.536	0.070
%age steam decomp.	48 %	83 %	79 %	86 %	40 %	75 %
% Oxygen in steam-oxygen mixture	19.2 %	47 %	46 %	50 %	10 %	38 %
C in gas as % of used C	89 %	71 % 8)	87 % 11)	72 % 8)	98 % 10)	90 % 11)
Heat change per 1 NM^3 dry gas, k.cals.	+ 302	+ 324	+ 312	+ 361	+ 136	+ 277

continued on page 16

TABLE II (Cont'd)

Test Number	(9)	(10)	(10a)	(12)	(13)	(14)
Process	in the Pintsch Brassert	in the slagging generator	in the slagging generator 1.4m ID	in the slagging generator "Karsten-Centrum"	in the shaft generator 1.1m ID "Weber briquettes"	in the slagging generator 0.4m ID "Königin Luise"
	Fürsten Mine					
	4.11.41.	25.5.42.	31.7.42.	25.5.42.	19.11.40.	19.11.40.
Residue from heat balance for radiation and sensible + heat of fusion of the ash, as % of heat throughput of fuel	3%	3.8%	4.7%	0.5%	2%	-9)
"Gas formation temp." water gas °C	930°	1475°	[2050°]	1250°	840°	1130°
" producer gas	655	835°	930°	834°	604°	774°

1) 7% ash, 9.5% H_2O
2) 5 - 30mm. grain size
3) 11% ash, 1% H_2O. 10-40mm. grain size
4) 8% ash, 1% H_2O, 5-40mm. grain size
5) 74.1%C, 9.6% ash, 9.8% water, grain size 6-13mm under 5%
6) Steam-oxygen mixture preheated to 600°C
7) Weber briquettes with 9.2% ash and 5.4% H_2O, 77%C
8) First test, high losses at the slagging hole and measurements not wholly reliable
9) not determined or not determinable
10) briquatte pieces sieved from ash and used again.
11) high rate, therefore, much fly dust.

TABLE III

Oxygen-Gasification of Grude with Steam

Test Number	(15)	(16)	(17)	(18)	(20)
Process	in the shaft generator 1.1m ID, grude from Bitterfeld briquettes 1)	in the slagging generator Deuben lump grude with "semi-ash" 1 : 1	in the Drehrost	in the Brassert	in the slagging generator
			Deuben hard grude		
Record note of :	18.9.39.	27.10.39.	15.11.40.	9.5.41.	27.10.39.
Gas analysis CO_2%	22.9	7.5	32.0	25.0	5.4
CO %	25.4	62.2	6.4	26.0	62.4
H_2 %	49.7	29.3	60.0	46.9	31.2
CH_4%	1.2	0.0	1.1	1.5	0.0
N_2 %	1.0	1.0	0.5	~~0.6~~	1.0
Sulphur in gas H_2S g/NM³	1.6	- 10)	10.1	26	13
organic.S "	0.3	- 10)	0.18	0.74	0.87
Consumptions - measured					
Oxygen (98-99%) NM³/NM³ CO+H_2	0.160 5)	0.269	[illegible]087	0.159	0.276
L.P. Steam kg/ " " "	0.0 1)	0.286	2.65 2)	0.750 12)	0.266
C.incl.losses " " " "	0.390	0.392	- 10)	0.395	0.482
Grude incl." " " " "	0.530 1)	- 10)	0.77 4)	0.72 7)	0.80 8)
Gas output NM³dry/M² shaft	680	1000	540	1120	930
Gas exit temp. °C	-	200°	410°	326°	240°
Check Calculations					
Oxygen NM³/NM³ CO+H_2 from analysis	0.160	0.258	0.073	0.176	0.220
Undecomposed Steam kg/NM³ dry gas	0.135	0.046	1.310	0.185	0.04
%age steam decomp.	72 %	83 %	26 %	66 %	84 %
% Oxygen in steam-oxygen mixture	15.5 %	42 %	2.3 %	16 %	39.5 %
C in gas as % of used C	91 %	104 %	-	98 %	80 %
Heat change per 1 NM³ dry gas kcals	[+ 67]	+ 314	- 112 2)	- 120	+ 230
Residue from heat balance for radiation and sensible + heat of fusion of the ash, as % of heat throughput of fuel	[± 0]	8 % 11)	~10 % 9)	~ 2 %	3.7 %
"Gas formation temp." water gas °C	600°	970°	660°	650°	1030°
" " producer gas	635°	730°	504°	630°	795°

TABLE III (Cont'd)

1) Grude from carbonisation shaft at 550-600°, steam-oxygen mixture 220°; 73.6% C, 10.3% ash.
2) Steam-oxygen preheated to 625°
4) 19% ash, 6% H_2O
5) calculated
7) 54% C, 16.9% ash, 22% H_2O
8) 60% C, 17.4% ash, 18.0- % H_2O
9) high radiation losses due to steam preheating
10) not determined
11) large quantities of slag
12) high pressure steam

Oxygen-Gasification with CO_2 as Gasification Medium

TABLE IV

Test Number	(5a)	(5)	(11)	(19)
Process	Hard coke in the slagging generator	Hard coke in the slagging generator	Semi-coke from "Fursten Mine" in the slagging generator 0.4m ID.	Hard Grude from Deuben in the Pintsch Brassert
Record note of:	13.11.39.	29.5.41.	27.5.41.	17.1.42.
Gas analysis CO_2%	3.0	6.1	4.0	25.3
CO %	92.5	90.2	86.0	65.7
H_2 %	3.0	2.7	8.2	8.0
CH_4 %	0.0	0.0	0.8	0.4
N_2 %	1.5	1.0	1.0	0.6
Sulphur in gas H_2S g/NM^3	2.2	3.1	4.3	12.5
organ. "	2.7	1.5	0.67	3.6
Consumptions - measured				
Oxygen (98-99%) NM^3/NM^3 CO +H_2	0.310	0.318 1)	0.238 4)	0.265
CO_2 (90-93%) " " "	0.258	0.328	0.286	0.600
C.incl.losses kg/ " "	0.460	0.473	0.54	0.454
Fuel incl. losses - do -	0.530 6)	0.545 2)	0.620 4)	0.735 5)
Gas output NM^3dry/M^2shaft	930	720 3)	1700	1100
Gas exit temp. °C	400°	420°	325°	260°
Check Calculations				
Oxygen NM^3/NM^3 CO+ H_2 from analys.	0.266 1)	0.256 1)	0.238	0.223
Undecomp. CO_2 as % of gas made	3.- %	6,1 %	4,0 %	25,3 %
%age decomposition of CO_2	86.- %	78,- %	83,0 %	39.0 %
% Oxygen in CO_2/O_2 mixture	49.5 %	43.5%	45.5 %	29.5 %
C in gas as % of used C	87.- %	84.-%	70.- % 7)	84.- %
Heat change per 1 NM^3 dry gas kcals	+ 220	+ 180	+ 157	+ 114

(Continued on Page 19)

Oxygen-Gasification with CO_2 as Gasification Medium (Cont'd) TABLE IV

Test Number	(5a)	(5)	(11)	(19)
Process	Hard coke in the slagging generator	Hard coke in the slagging generator	Semi-Coke from "Furstem Mine" in the Slagging generator 0.4m I.D.	Hard Grude from Deuben in the Pintsch Brassert
	13.11.49.	29.5.41.	27.5.41.	17.1.42.
Residue from heat balance for radiation and sensible + heat of fusion of the ash, as % of heat throughput of fuel	2.5%	1.2%	1.2%	1 %
"Gas formation temperature" producer gas	860°	832°	850°	723°

---

1) ~~Calculated quantity, more accurate than the measured quantity,~~ apparently in error.
2) 86.3% C, 9.1% ash, 1.8% H_2O.
3) Still capable of being increased.
4) 88.5% C, 5.6% ash, 0.4% H_2O, quantity not determined.
5) Grain size: hazelnut to walnut; 61.8%, C, 20.5% ash, 13.2% H_2O.
6) 87.2% C, 11.8% ash, 1.0% H_2O.
7) Very Small Generator.

Oxygen-Gasification of Brown Coal in the Winkler Generator

In the record note "water gas with oxygen in the Winkler Generator" of 2/2/34 a preliminary estimate of consumptions, made when justifying the new Linde-Fränkl plant, is compared with the achieved figures.

TABLE V

Referred to 1 M³ $CO + H_2$ 1)	Requirement of dry brown coal, 6% H_2O kg estimated	actual	O_2 - Requirement, 98% M³ estimated	actual
Mixed Gas	0.805	0.825	0.278	0.280
Water Gas	0.840	0.800	0.350	0.330

Gas Composition :		Mixed Gas	Water Gas
	CO_2	17.0 %	19 %
	CO	33.0 %	38 %
	H_2	33.0 %	40 %
	CH_4	1.5 %	2 %
	N_2	15.5 %	1 %

The results were obtained with dry brown coal from the mine Elise II; present day consumptions are somewhat higher, with higher CO_2 content of water gas, since in general poorer coal, e.g. Tannenberg mixed with Deuben grude, has to be used.

In the report mentioned it is stated : "Severe slagging at first caused a good deal of maintenance. The grate of No.1 generator was renewed at least three times between June and October 1933; in addition it underwent 5 major repairs." Today slaggings are quite unknown.

The latest improvement to the Winkler generator is a full-scale grateless generator of the simplest construction, which entirely avoids even the very infrequent repairs to the grate, and which in addition uses about 10% less fuel and oxygen.

Oxygen-gasification in the Winkler generator at Leuna and at the outside factories of Böhlen, Magdeburg and Zeitz has proved to be the safest water gas process using particulate brown coal or grude.

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1) Gas quantities at 15°C and 735.5 mms Hg.

TABLE VI

Oxygen-Carbonisation-Gasification of Brown Coal Briquettes

(Theissen 14% H_2O) in the shaft generator with alternating steam-oxygen mixtures (without preheating), and steam-oxygen mixture at 220°C.

Test Number		21	22	23	24	25
Record note of:		20/4/37				
Gas analysis	CO_2 %	26.5	28.0	35.5	40.8	43.8
	CO %	21.4	18.0	5.4	3.2	2.4
	H_2 %	44.6	46.0	51.5	51.4	45.4
	CH_4 %	5.6	7.0	6.0	4.4	6.2
	N_2 %	1.6	1.0	1.7	0.2	2.2
S in Gas H_2S g/NM^3 dry) organ. S " ")		not determined				
Consumptions per NM^3 CO + H_2						
Oxygen (98-99%)	NM^3	0.194	0.194	0.200	0.238	0.260
L.P.Steam	kg	0.825	0.92	1.92	3.00	4.00
C incl. losses) Brown coal briquettes) including losses)	"	Average 0.62[2) kg brown coal briquettes per NM3 gas including tar production[1)				
Gas output NM^3 dry/M^2 shaft		640	600	320	210	185
Gas exit temp.(carbonisation zone)	°C	180°	200°	230°	270°	-
Check Calculations :						
Oxygen requirement (100%) per NM^3 H_2 + CO(calculated)		0.150	0.133	0.127	0.225	0.350
Undecomposed steam kg/NM^3 gas		0.216	0.230	0.700	1.258	1.576
%age steam decomposition		60%	61%	36%	23%	18%
% oxygen in steam-oxygen mixture		16%	14.4%	7.8%	6.1%	5%
"Gas formation temperature" water gas	°C	640°	600°	530°	520°	515°
"Gas formation temperature" producer gas	°C	610°	595°	510°	460°	435°

1) Briquette with 14% H_2O, 10% ash, 55% C and 16% Fischer-tar

2) With 20% C in the ash.

Observations on the Tables

All data refer to 0° and 760 mm Hg, unless otherwise stated.

The results (unless otherwise stated at the head of the column) have been obtained with Pintsch-Drehrost generators and Pintsch-Brassert generators of 3 - 3.2 m I.D. and with slagging generators of 2.1 m I.D. at the bottom and 3.4 m I.D. at the top.

Shaft outputs refer to the highest cross section still filled with fuel.-

The check calculations given show mostly, but not always, satisfactory agreement with the measured values; with practically gas-free fuel, such as coke, the agreement is of course better than with fuels containing hydrogen or with bituminous fuels, with which it is notoriously difficult to obtain good balances from experimental data. Where there are obvious errors, the calculated values are put in parenthesis.

In order to illustrate the fundamental course of oxygen-gasification of lump fuel in a stationary bed as a function of the operating temperature of the generator, all dry gas analysis in Tables I - III, i.e. covering the results for hard coke, bituminous coal semi-coke and grude, have been plotted in Fig.3 against the per-cent content of O_2 in the oxygen-steam mixture.

It is seen that it is possible to vary the ratio CO : H_2 over the whole range from 1 : 2 to 2 : 1. The region of the colder method of working extends to about 22% O_2 in the mixture; for this purpose simple shafts generators, Drehrost generators or Pintsch-Brassert generators are used. The last are particularly useful if one wishes to obtain low carbon in ash ("guter Ausbrand") by using a hot generator, where slag is already beginning to soften. In the range of about 22 to 35% O_2 in the mixture there is no gasification method available; above 35% O_2 in the mixture we enter the region of the slagging generator; the extreme limit for normal cokes and "semi-ash" is reached with 55-60% O_2 in the mixture, and at that point the materials of construction of the generator begin to be severely attacked as a result of the high working temperatures.

In our record note of 7/3/33, using the few data then available, we attempted to represent the correlation between dry gas analysis and the operating temperature of the generator. The earlier diagram* shows the same characteristics as the new one, based on curves drawn up for all the numerous tests carried out.

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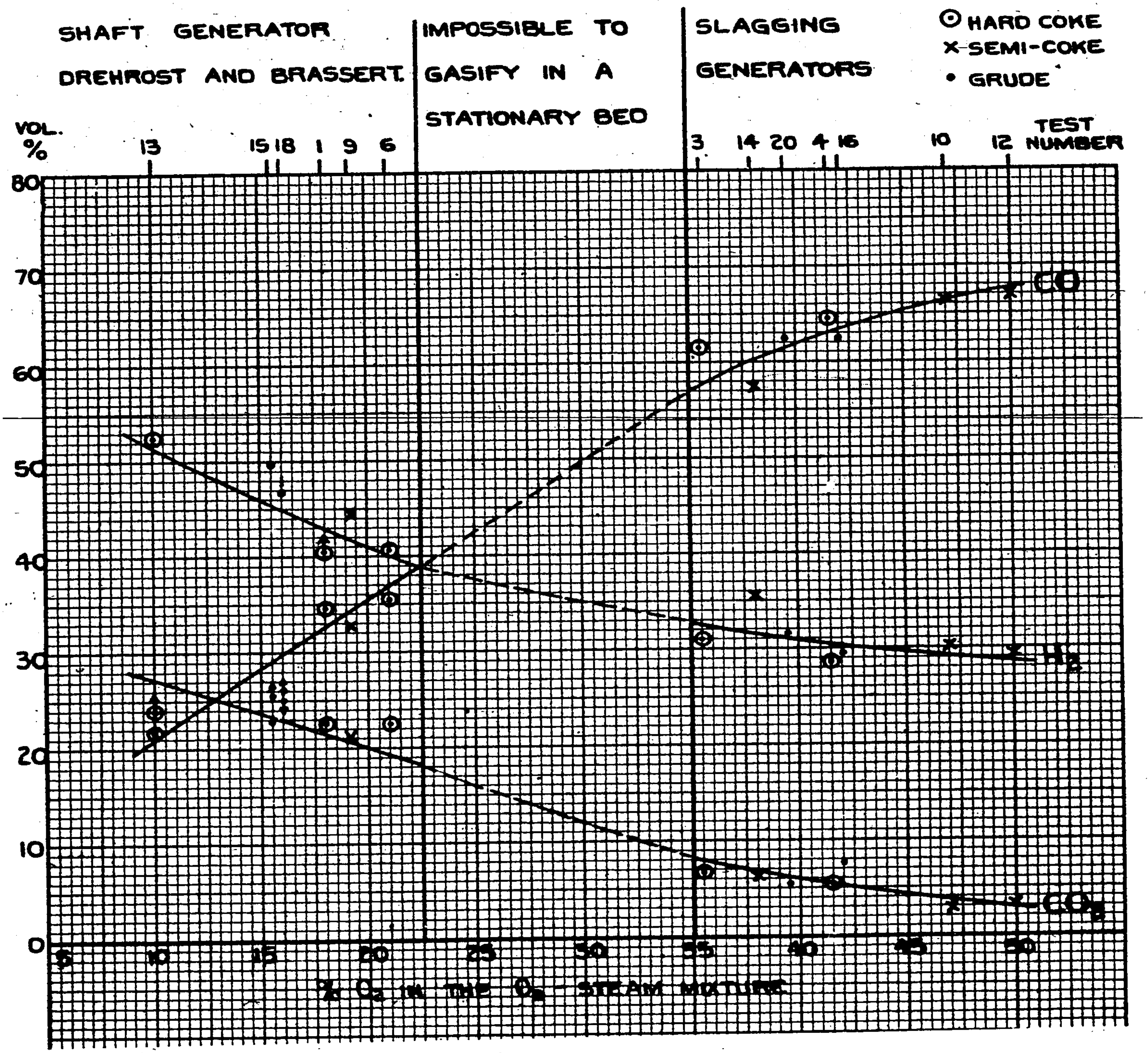
* not reproduced here, because it uses only a few data and is less accurate than Fig.3 - Trans. note.

FIG. 3.

GAS ANALYSIS AS FUNCTION OF % O_2 IN BLAST



Steam consumption and percentage steam decomposition, corresponding to Fig.3, are shown in Fig.4.

Almost pure CO can be produced by oxygen-gasification with CO_2 as gasification medium, if coke is used as fuel. In other respects Table IV and Fig.5 show a similar picture to gasification with steam.

CO gas made from coke contains about 3% H_2. About 2% of it is added along with the CO_2 used as gasification medium, as our CO_2 contains 5-6% H_2, about 0.5% comes from residual hydrogen in the coke and 0.5% from moisture in oxygen and CO_2. By using pure dry CO_2 and "semi-ash" or very well degassed coke, the hydrogen content of the CO made would be reduced to less than 0.5%.

The partial addition of CO_2 to the normal steam-oxygen mixture allows the CO : H_2 ratio to be varied in a convenient manner.

When CO_2 is used for gasification in the Brassert generator it is very interesting that the ash of Deuben hard grude behaves quite differently than when oxygen and steam are used. When using steam and a steam-oxygen mixture of 16% O_2, which according to all other evidence should not result in slagging, ash removal causes great difficulty. On the other hand when using CO_2 an oxygen content of 30% can be used. The difference is much too great to be explained solely by the larger heat requirements, of CO_2 decomposition, for the same amount of CO + H_2 produced. At present we are still working on this subject. In the laboratory it has so far been established, that by ashing the coal in a stream of CO_2, the softening point of the ashes from Deuben grude, Hermine-Henriette coal and Fürsten mine coal, is raised by about 200-300°, without really raising the melting point and without altering the chemical composition of the ashes, Mixtures of CO_2 and steam gave intermediate values.

A further interesting fact is that when using CO_2 in the Brassert generator the water gas made contains no more CO_2 than water gas made with steam and oxygen.

It can further be concluded from the tables that steam consumption decreases the hotter the generator can be run, without increasing the oxygen consumed per NM^3 CO + H_2; it is also well known that the carbon content of ash is lower the hotter the generator. With the slagging generator practically the only carbon loss is in fly dust. As steam decomposition improves with hotter running, the output of useful gas per unit of shaft area also becomes greater; this is particularly striking if the output of useful gas per M^2 shaft area is expressed in CO + H_2.

FIG. 4.

% O_2 IN BLAST VERSUS STEAM USAGE AND DECOMPOSITION

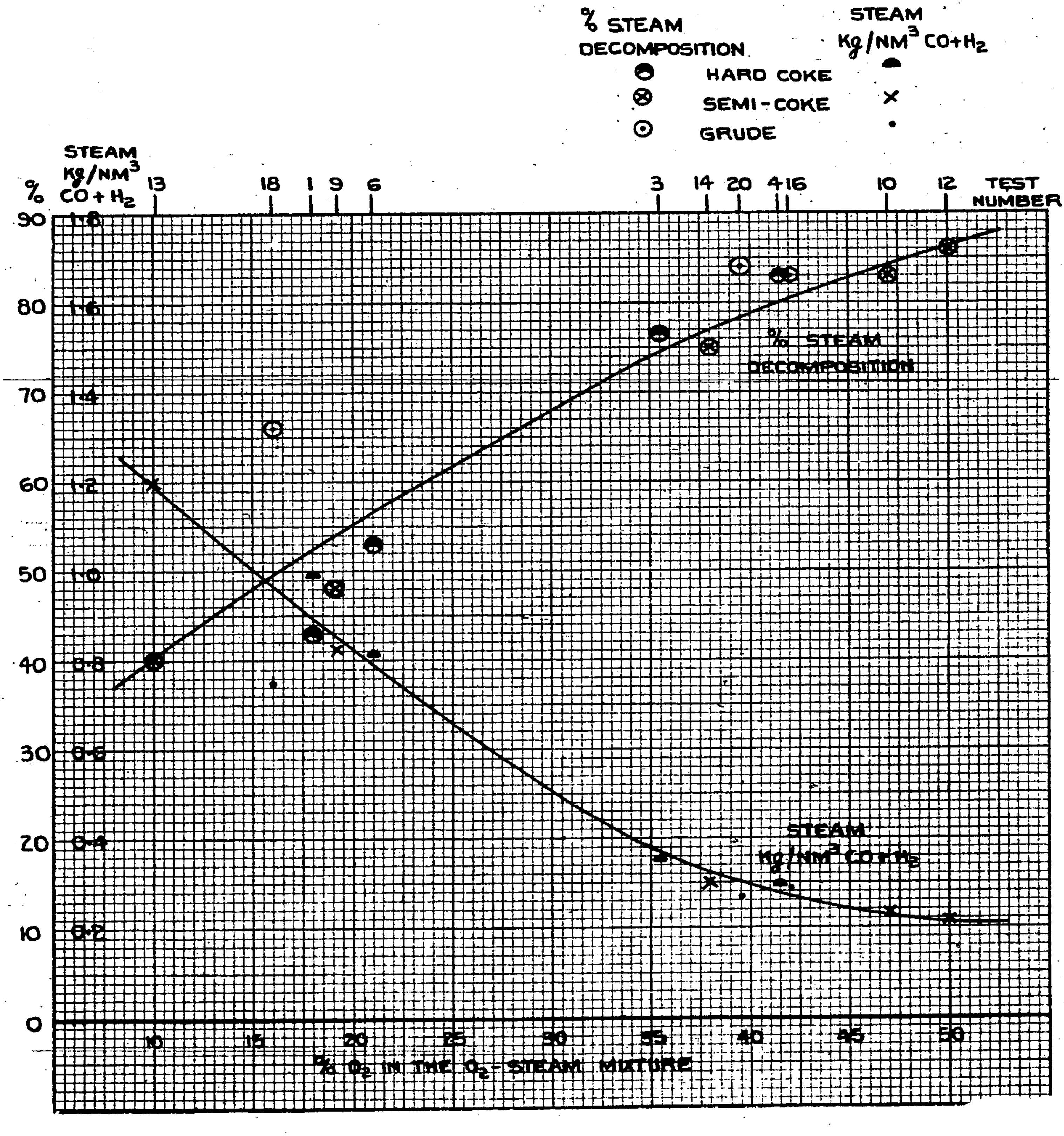
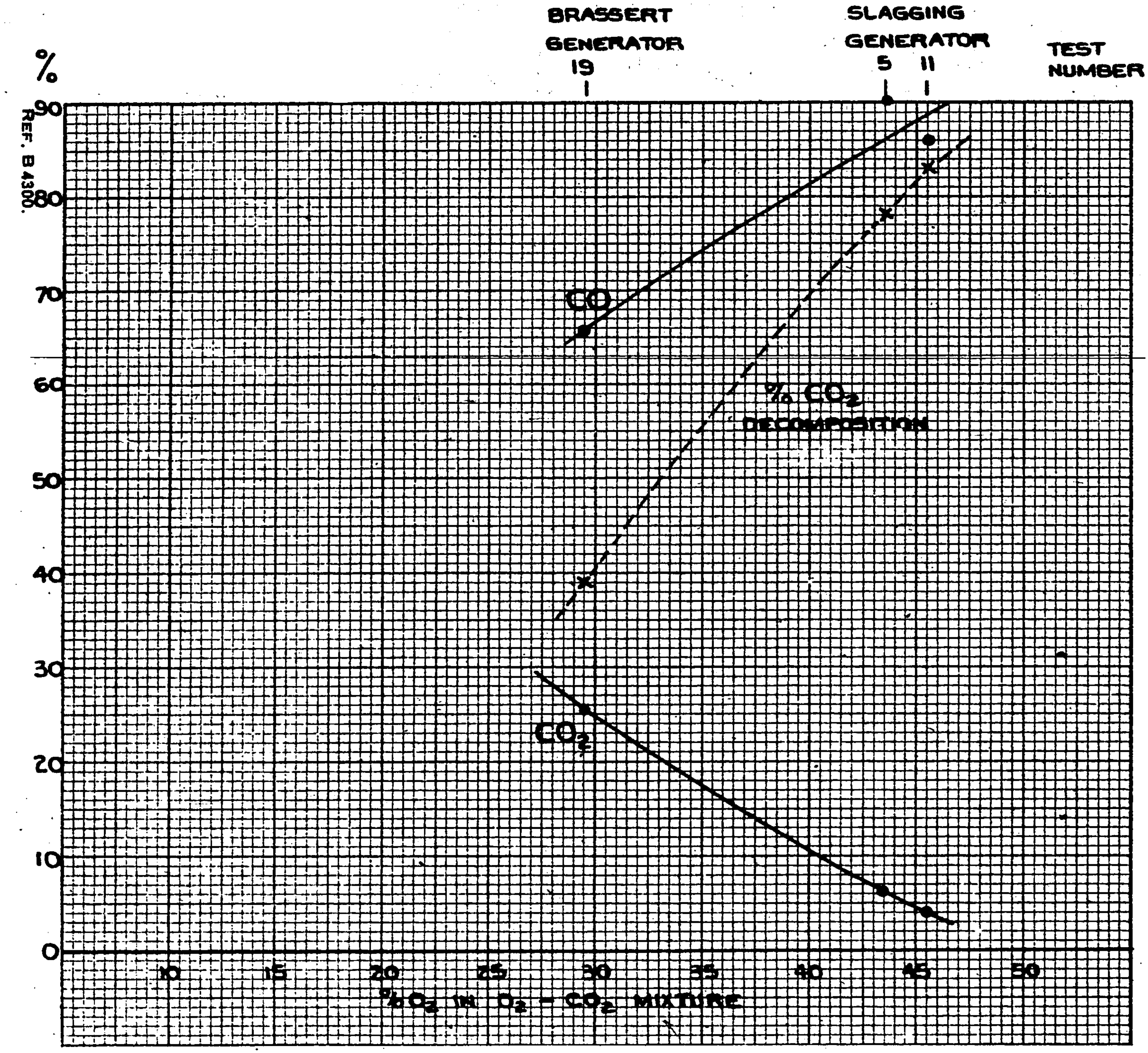


FIG. 5.

GASIFICATION WITH CO_2



The tables also confirm the well-known fact that it is advantageous to run the generator hot so as to favour as much as possible the reaction $C + H_2O = CO + H_2$ rather than the formation of CO_2 and the CO formed should not be converted before the CO- conversion plant. The extreme case, represented by Test Number 17, Table III, shows how much steam must be used at the lowest outputs in order to make catalysed gas ("Kontaktgas") directly in the generator. What is found to be wrong in the extreme case also holds for intermediate cases; running the generator hot is normally the correct method.

According to these considerations the slagging generator ought to be superior to all other generators for oxygen-gasification. The consumptions in the Tables and the summary on Page 10 show that this is actually the case, judged from a purely efficiency point of view. Whether slagging generators are built in individual cases depends of course not only on efficiency, but also on technical considerations and especially on the suitability of the fuel concerned.

With most fuels one can use steam-oxygen mixtures containing up to 16-17 % O_2 in the Drehrost or Brassert generators. This is the limit beyond which there is a serious danger of slagging. From about 30-55% oxygen in the mixture one can operate with liquid slag removal.

Although we know that the shaft generator should be run as hot as possible, several series of experiments were carried out, in order to find out the effect of running the generator colder, in order to make "catalysed gas" (Kontaktgas) in the generator itself; this is not unlike the Pattenhausen water gas process . Table VI gives the results of such an experiment for carbonisation-gasification of brown coal briquettes.

Figures 6 and 7 show the results of the experiment for Theissen briquettes, gasified with oxygen in the carbonisation generator.

The experiment was actually carried out by starting with a constant introduction of 400 kg steam and the maximum addition of O_2, 16%, at which point slagging became imminent. The oxygen-steam mixture was not preheated. Then the amount of oxygen was slowly cut down. Corresponding to the increase in undecomposed steam the gas output, calculated as dry gas, of course fell.

It is seen that the generator with 5% oxygen in the mixture still works very well (with a reaction zone temperature of 600°) and produces directly an acceptable "catalysed gas". Unfortunately the amount of steam used and the reduction in output render this method of working quite out of the question.

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x In which steam and gas is preheated and recirculated to gasify the fuel completely, without internal use of air or oxygen. Trans.note.

FIGS. 6 AND 7. (SEE TABLE VI)

CARBONISATION-GASIFICATION OF BROWN COAL BRIQUETTES EFFECT OF VARIOUS O_2 RATES AND OUTPUTS WITH CONSTANT STEAM RATE.

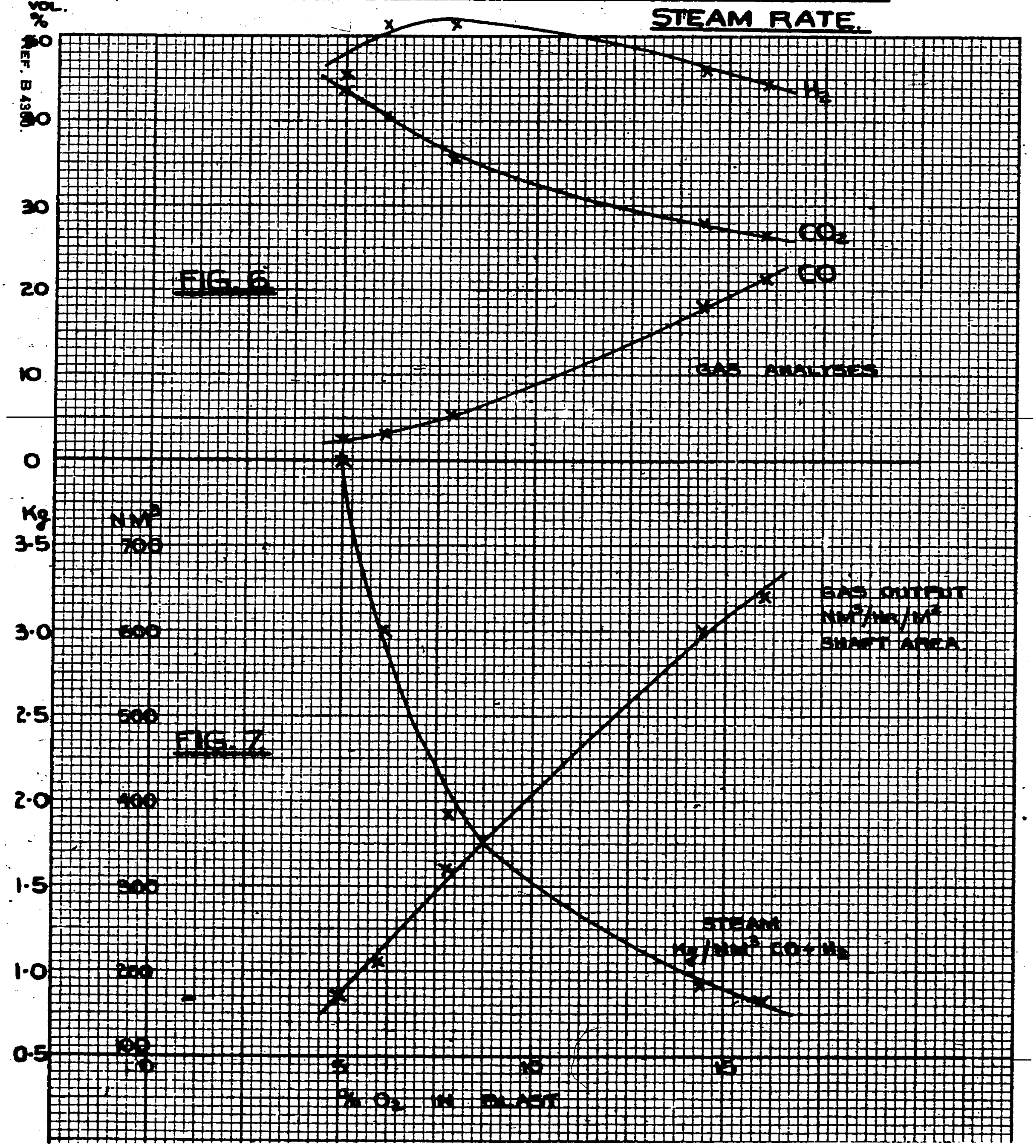
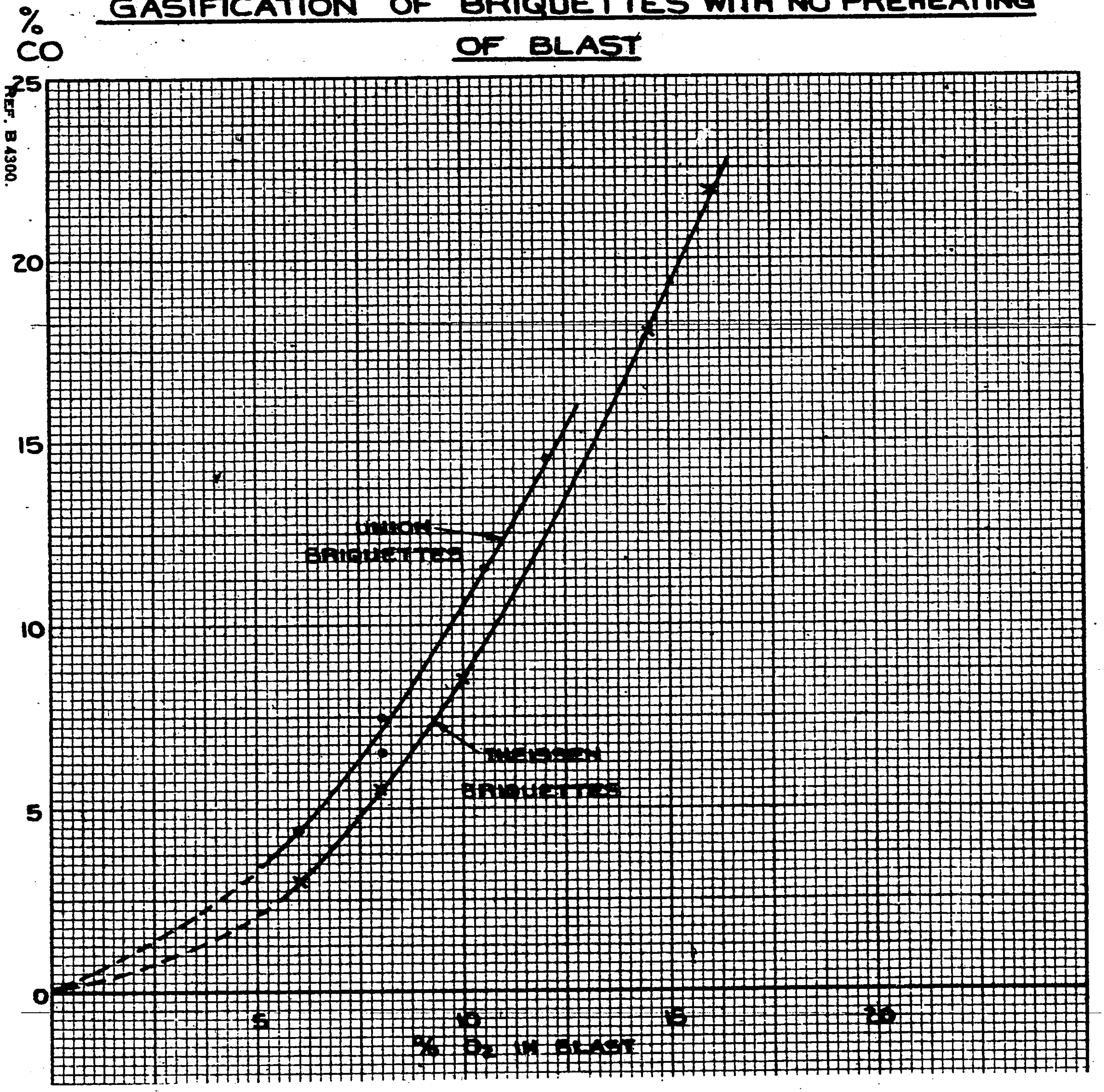


FIG. 8.

GASIFICATION OF BRIQUETTES WITH NO PREHEATING OF BLAST



When the experiment was repeated with Rhine "Union" briquettes the same picture was obtained, although with the same conditions somewhat more CO was formed than with Central German "Theissen" briquettes.

In general it is true for oxygen-gasification that preheating of the gasification medium results in a saving of oxygen. Calculated from the heat change this saving must amount to 0.03 - 0.01 parts of oxygen per NM^3 $CO + H_2$, depending on whether the oxygen burns to CO_2 or to CO and how much steam is used in the generator.

The experiment was actually made with grude from Bitterfeld briquettes (report of 18/9/39) in a shaft generator surmounted by a carbonisation chamber, so that the carbonised grude entered the lower part of the generator at a temperature of 550 - 600°C. The graph shown in Fig.9 was obtained, showing the oxygen consumption per NM^3 $CO + H_2$ as a function of the preheat temperature, for about the same steam decomposition and about the same shaft output.

On the average it is estimated that for the above case about 0.018 parts of oxygen are saved per NM^3 $CO + H_2$ for every 100° of preheat ~~temperature.~~

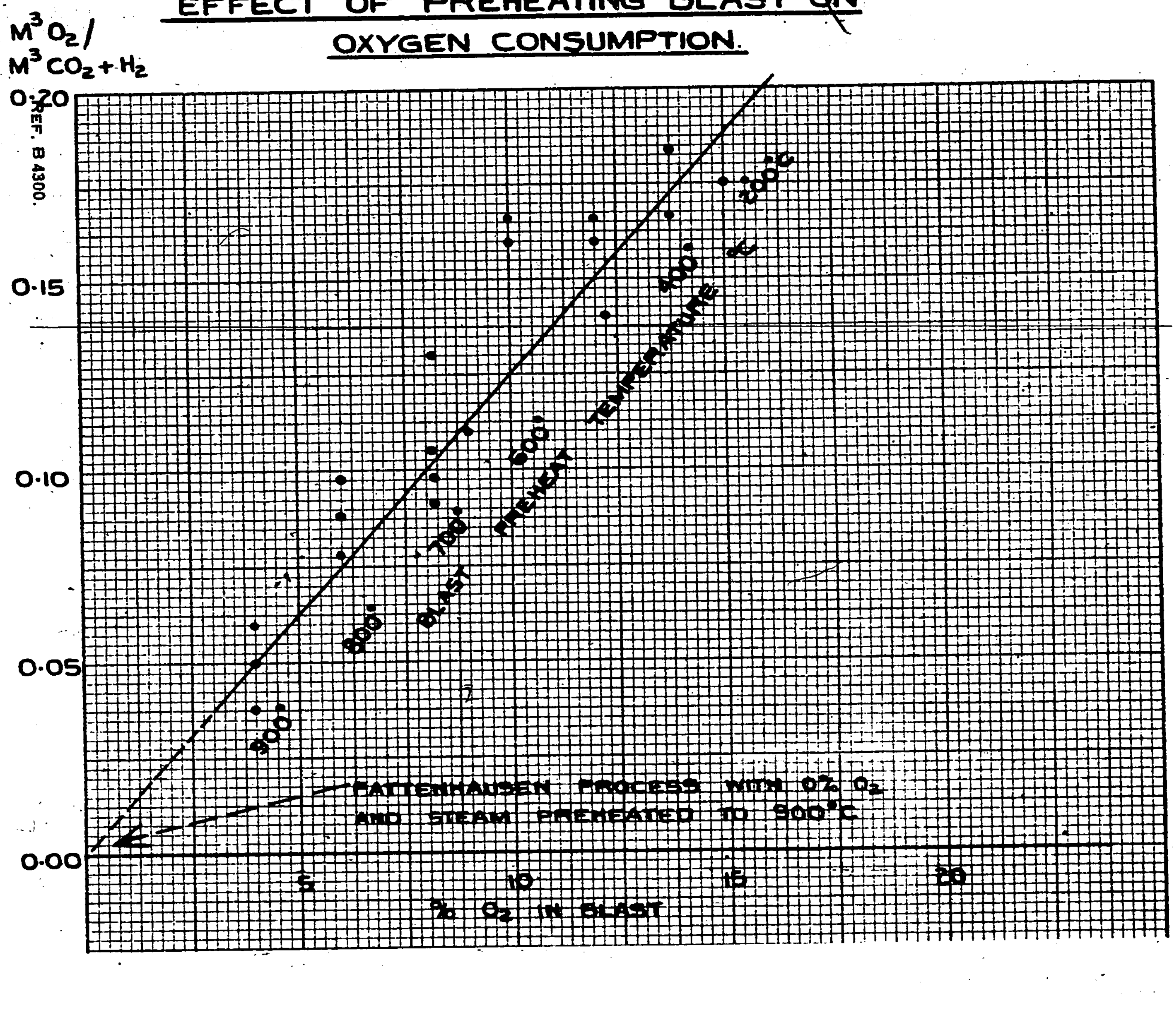
The savings compared with a normal consumption of 0.25 M^3 O_2/M^3 $CO + H_2$ are, therefore, not insignificant and would, e.g. by preheating to 400°, amount to 25% of the oxygen requirement without preheating. Whether it would be worth while complicating the gasification plant by installing preheaters is a matter for investigation in each particular case. In those cases of oxygen-gasification where the gas exit temperature is low there is not much waste heat available; moreover at lower preheat temperatures the oxygen saving is still small, whilst the preheaters are no simpler. High preheat temperatures require external heating, and Brassert grates, as an example are not very suitable for operation with preheated blast. Moreover preheating introduces certain dangers of its own, when not confined to preheating of the steam only. Therefore, we recommended for the oxygen-water gas plant at Auschwitz the initial omission of preheaters for the sake of simplicity of plant and operation, but leaving room for installing preheaters later on.

In Tables I - IV are shown the amounts of heat liberated, which leave as sensible heat of exit gases, undecomposed steam, ash and slag and as radiation, as deduced from check calculations, based on the corresponding analyses. If the sensible heat of the exit gases and undecomposed steam is deducted, there is still a residue. This residual heat is lost as radiation and sensible heat of slag, and is expressed in the table as %age of the total throughput of heat in the fuel. It is seen that these losses are mostly similar to those usually experienced in generators; where they tend to zero the measurements for fuel consumption are apparently somewhat too favourable.

The Tables are so arranged as to provide quick reference to the behaviour of fuels actually gasified. They also enable trials with other fuels to be started along the right lines.

FIG. 9.

EFFECT OF PREHEATING BLAST ON OXYGEN CONSUMPTION.



Oxygen-Gasification of Dust

Oxygen-gasification of fuel dust is of little interest to operation at Leuna. The cost price of brown coal dust is only slightly below that of lump dry brown coal. Grinding costs and the cost of special arrangements for bunkering and transport make it less advantageous to use dry brown coal dust, considering the convenience of handling brown coal briquettes. Moreover the oxygen requirements - if oxygen-gasification of briquettes and brown coal dust is being considered - is essentially less for briquettes than for dust. This is particularly true for gasification of dust with liquid slag removal; it is quite obvious that the high exit gas temperatures in this kind of gasification result in high oxygen consumptions.

It may be a different case with hard coal dust, in particular for caking coal, which is difficult to gasify in any other way. Here the high cost for oxygen might be offset by the low fuel price. But at Leuna we have no hard coal dust at our disposal for experimental purposes.

In order to get an idea of the possibilities of gasifying fuel dust, we have carried out several series of experiments, in which dry brown coal dust was gasified with oxygen with liquid slag removal in a small experimental generator of 400 mm. internal diameter. The experiments were varied between complete combination of the dust and optimum gasification to water gas. The fuel dust used was dry brown coal from Tannenberg, with about 10% H_2O, 54% C and 14% ash. The dust came from the electro-filters of the steam drying plant and consisted of 80% below 0.5 mm and 20% below 0.1 mm, and was thus fairly coarse.

The results are shown in Figs.10 and 11.

CO_2 was used for blowing in the fuel dust; one could also of course have added steam and thus obtained a gas richer in H_2. Removal of liquid slag caused no particular difficulty.

One can see the high consumption of oxygen per NM^3 $CO + H_2$ in that part of the series of experiments which were run to make water gas; the high gas temperatures, required to permit fusion of the ash, necessitated an overall reaction, which was strongly exothermic, i.e. a lot of oxygen had to be consumed. In a larger generator, with relatively lower radiation losses, the oxygen consumption would be appreciably less, but it would always remain above that of the Winkler generator or even of the shaft generator, in which the fuel in passing down the shaft returns a large part of the sensible heat of the exit gases to the reaction zone.

The poor carbon efficiency, in that part of the series of experiments, run to make water gas, is due to the formation of fly ash. Analysis at various heights in the generator showed that this was due solely to the smallness of the generator[1]. Likewise when making water gas from oxygen and dust in a larger generator with lower outputs/shaft area, there should be no practical difficulty in ensuring complete combustion of the ash and the removal of all the ash as liquid slag.

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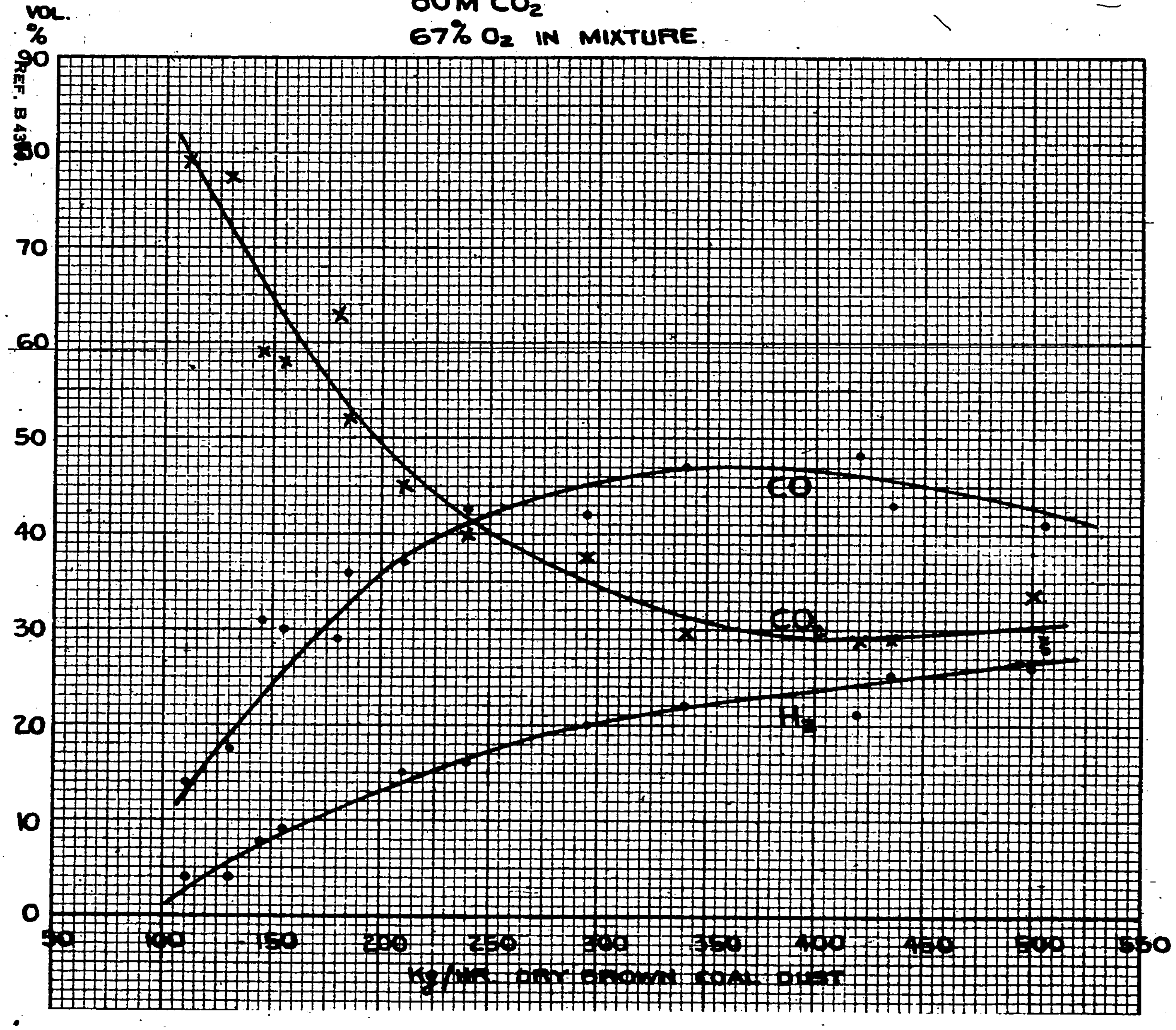
1) At 300 kg/hr dry brown coal the generator made over 3000 M^3/hr gas per M^2 shaft area!

FIG. 10.

OXYGEN GASIFICATION OF BROWN COAL DUST

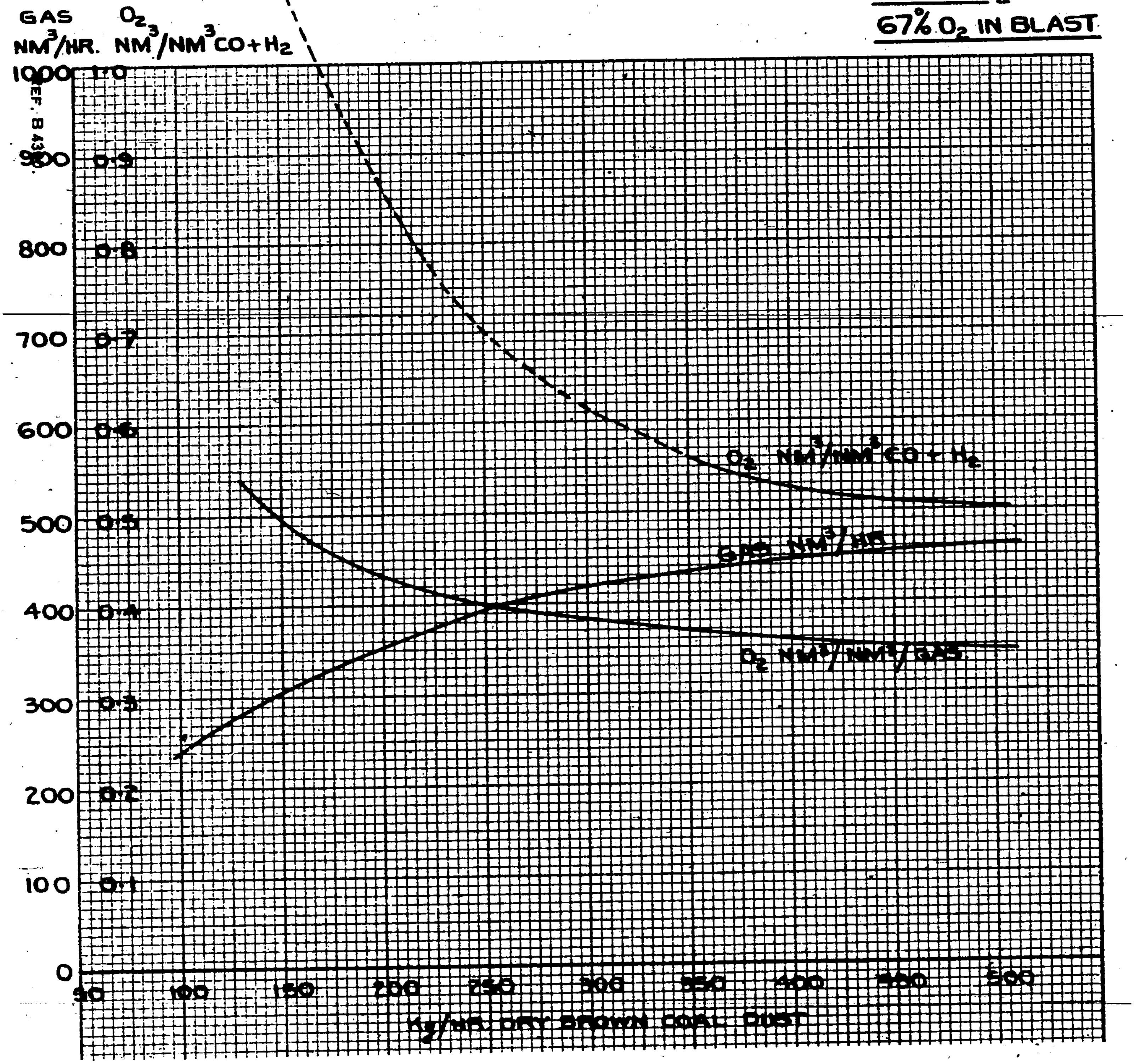


ALL WITH 160 M^3 O_2
80 M^3 CO_2
67% O_2 IN MIXTURE

FIG. 11.

OXYGEN GASIFICATION OF BROWN COAL DUST

BASED ON PERFORMANCE WITH $160 M^3 O_2$
$80 M^3 CO_2$
$67\% O_2$ IN BLAST



If oxygen-gasification is not operated with removal of liquid slag, oxygen is certainly saved, but the high carbon content of ash must be taken into consideration. It does not pay in this type of gasification to grind the dry brown coal, because such material can be very well gasified in Winkler generators. In a Winkler generator dust is gasified with oxygen above the fuel bed; there dust originally contained in the fuel, as well as the dust which is continuously formed by attrition in the lower, boiling fuel bed, is gasified to water gas at temperatures below the fusion point of slag.

Unfortunately the amount of dust coming in with the fuel naturally fluctuates somewhat; but the appropriate addition of oxygen above the fuel bed cannot be continuously adjusted to suit, because there is no measurement of the amount of fine dust contained in the fuel. Certain inefficiencies in fuel utilisation must, therefore, be accepted as inevitable. When there is a strongly fluctuating dust content of the fuel, a preliminary screening into dust and coarse material and an exact estimation of dust and of oxygen to be added above the bed, will ensure constant and satisfactorily complete combustion, a procedure which will be tried out on one of the Winkler generators at Leuna, when the opportunity arises.

Preheating of the gasification mixture, if possible by utilizing waste heat in the water gas made, is particularly advantageous for gasification of dust with its high oxygen consumption. This is just as true for water gas generators, operating on dust with liquid slag removal, as for Winkler generators. To try out on a Winkler generator the effect of preheating the blast with its own waste heat, an apparatus has been prepared on No.1 Winkler generator on Me 278, which will be connected up at a suitable opportunity. This producer is particularly suited for running with preheated blast, because it has no grate.

Thermal Considerations of Oxygen-Gasification

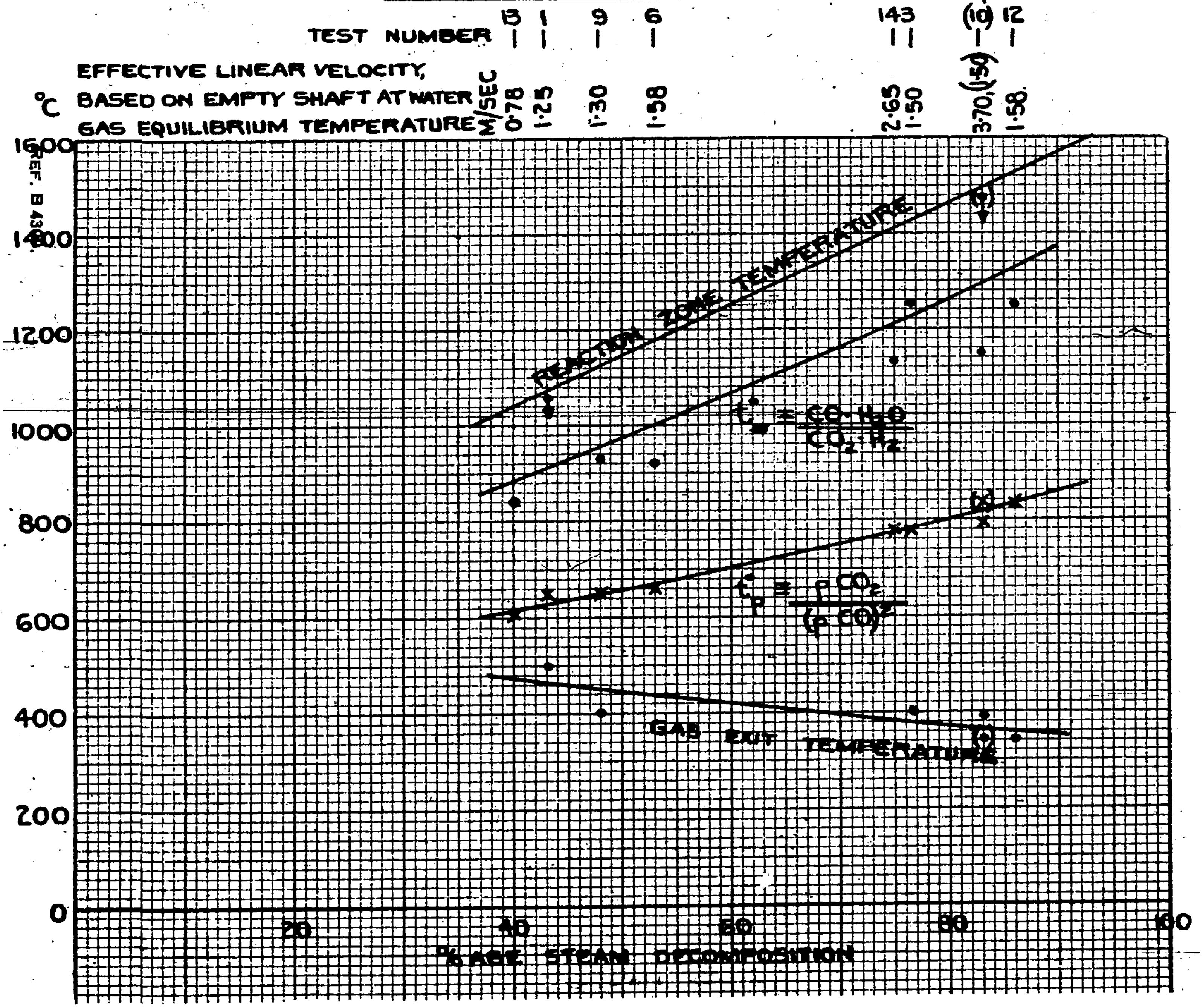
If the components of the gas analysis are inserted in the water gas equilibrium formula $\frac{CO \cdot H_2O}{CO_2 \cdot H_2} = K$, one finds for each of the analysis in Tables I & II, i.e. with coke as fuel, a characteristic temperature which can be called "the apparent water gas equilibrium temperature" or the "gas-formation temperature". Similarly one can calculate the "apparent producer gas equilibrium temperature". If the points for single analyses are plotted together with the temperature of the hottest reaction zone, Fig.12 is obtained.

The apparent water gas equilibrium temperatures are scattered on account of inaccuracies in measurement and calculation, the latter particularly at high temperatures, where the amount of undecomposed steam present is quite small. But there is no doubt that the apparent water gas equilibrium temperature is higher with hotter generator operation than with colder.

FIG. 12.

HARD COKE AND SEMI-COKE, APPARENT EQUILIBRIUM TEMPS.

(SEE TABLES I AND II)



At first sight this appears contrary to expectation, if it is assumed that with the same fuel the water gas reaction in the fuel bed always proceeds to approximately the same temperature.

An explanation of the form of the water gas equilibrium curve cannot be made on the basis of observations published in the literature on the conditions governing the water gas equilibrium in water gas generators.

But one can assume the following, which is not in the least at variance with the achieved curves shown.

When a mixture of oxygen and steam is introduced into the reaction zone, one cannot talk about attainment of water gas equilibrium so long as any oxygen is still present. Inside the hottest reaction zone of the generator, however, the products of combustion rapidly tend to reach equilibrium with the steam or with the hydrogen formed from it. Equilibrium is not reached at the highest temperature prevailing in the reaction zone, but the reaction approaches nearer to equilibrium the hotter the reaction zone. Hence the observed curve for the water gas equilibrium temperature shown in Fig.12 slopes up to the right, and the apparent equilibrium temperature for hot generators is higher than for cold generators.

Besides the tendency to reach equilibrium in the reaction zone at the temperature prevailing there, a secondary reaction occurs in the layer above the reaction zone, where hot gases coming from the reaction zone meet the hot fuel, which however has not yet begun to react; here the hot fuel acts as a catalyst. It is obvious that this secondary tendency of the gas to reach an equilibrium, corresponding to this temperature, is favoured by the higher temperatures of hotter generators. But this mean, that the curve of the water gas equilibrium temperature rising steeply to the right in the diagram, is again forced downward.

The net result of both processes is characterised by the form of the "apparent water gas equilibrium" curve.

According to general ideas the producer gas equilibrium, i.e. the ratio carbon dioxide to carbon monoxide plays no part in the water gas generator. But plotting the calculated values for the producer gas equilibrium temperatures in Fig.12 gives essentially the same form of curve, showing a dependence on the temperature at which the generator is run.

If one supposes, therefore, that the producer gas equilibrium is attained essentially more slowly, and is to some extent hindered by the water gas equilibrium in its attainment, the form of the producer gas equilibrium curve in Fig.12 does not conflict with the conception that the apparent equilibrium temperatures, for the ratio $\frac{pCO_2}{p(CO)_2}$, just as for water gas, are higher with hotter than with colder generators.

If the same calculations and diagrams are made for Table III, i.e. for grude, an appreciably more reactive fuel, curves are obtained, which are similar in character to those for coke, except that the "equilibrium temperatures" are lower than with coke. (See Fig.13).

Corresponding plots (Fig.14) for carbonisation-gasification of brown coal briquettes yield curves of a similar character. Of course owing to water gas containing some carbonisation gas, the curves are not strictly correct and only in a general way are they comparable with the other curves. In spite of the presence of carbonisation gas the character of the curves is the same, i.e. higher equilibrium temperatures with higher generator temperatures.

The curves for "apparent producer gas equilibrium temperature" for oxygen-gasification with CO_2 are also comparable. (see Fig.15).

The "equilibrium curves" for oxygen-gasification are of particular interest, because it is not possible with any other kind of gasification to cover so wide a range in the various possible ways of running a generator on the same fuel.

The curves show clearly that the reaction zone temperature is the factor governing the apparent equilibrium obtained. That the linear velocity is of secondary importance can be deduced from Fig.12 where the calculated linear velocities (based on an empty shaft at the equilibrium temperature) are given. It should be noted, from tests 3 and 4, that doubling the effective linear velocity had no influence on the apparent equilibrium.

In practice it is not possible to make any direct use of these conclusions, but they assist in the critical examinations of gasification processes; so experiments are at present being carried out to make clearer the relationship between the various reactions.

Patents Position In The Field Of Gasification Of Solid Fuels With Oxygen.

Gasification with oxygen had reached the industrial stage and was already very fully described in D.R.P. 108,158 as early as 21/5/1898. Likewise the Swiss Patent 75,030 of 28/2/17 claimed the production of high grade mixed gases by using a mixture of technical oxygen with steam. Further the English Patent 142,874 of 28/11/17 described a generator for making raw gas for ammonia synthesis with the use of oxygen. These patents have now completely expired, so that there is no patent restriction on gasification of solid fuels with oxygen.

FIG. 14. FIG. 13.

GRUDE AND BRIQUETTES: APPARENT EQUILIBRIUM TEMPS.

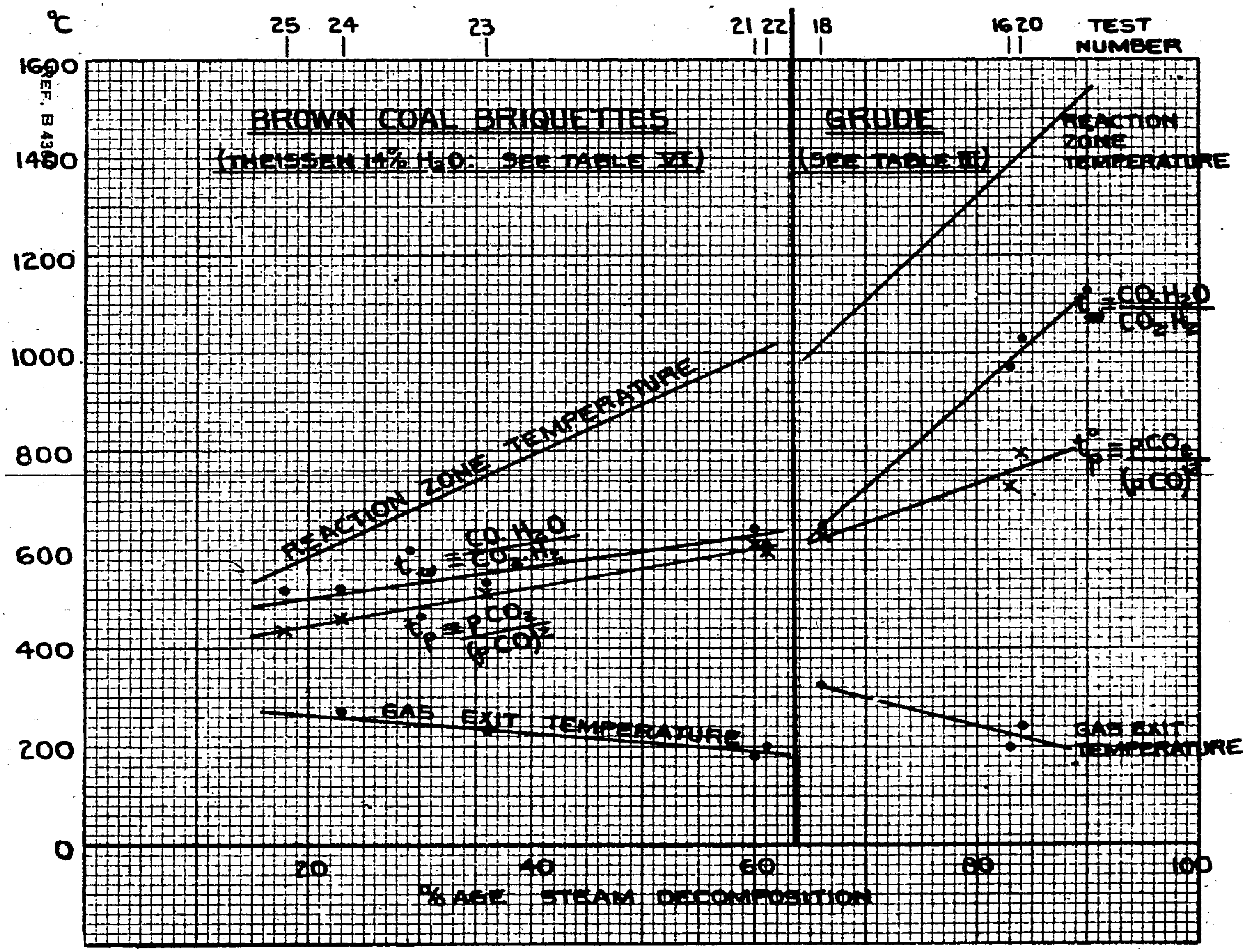
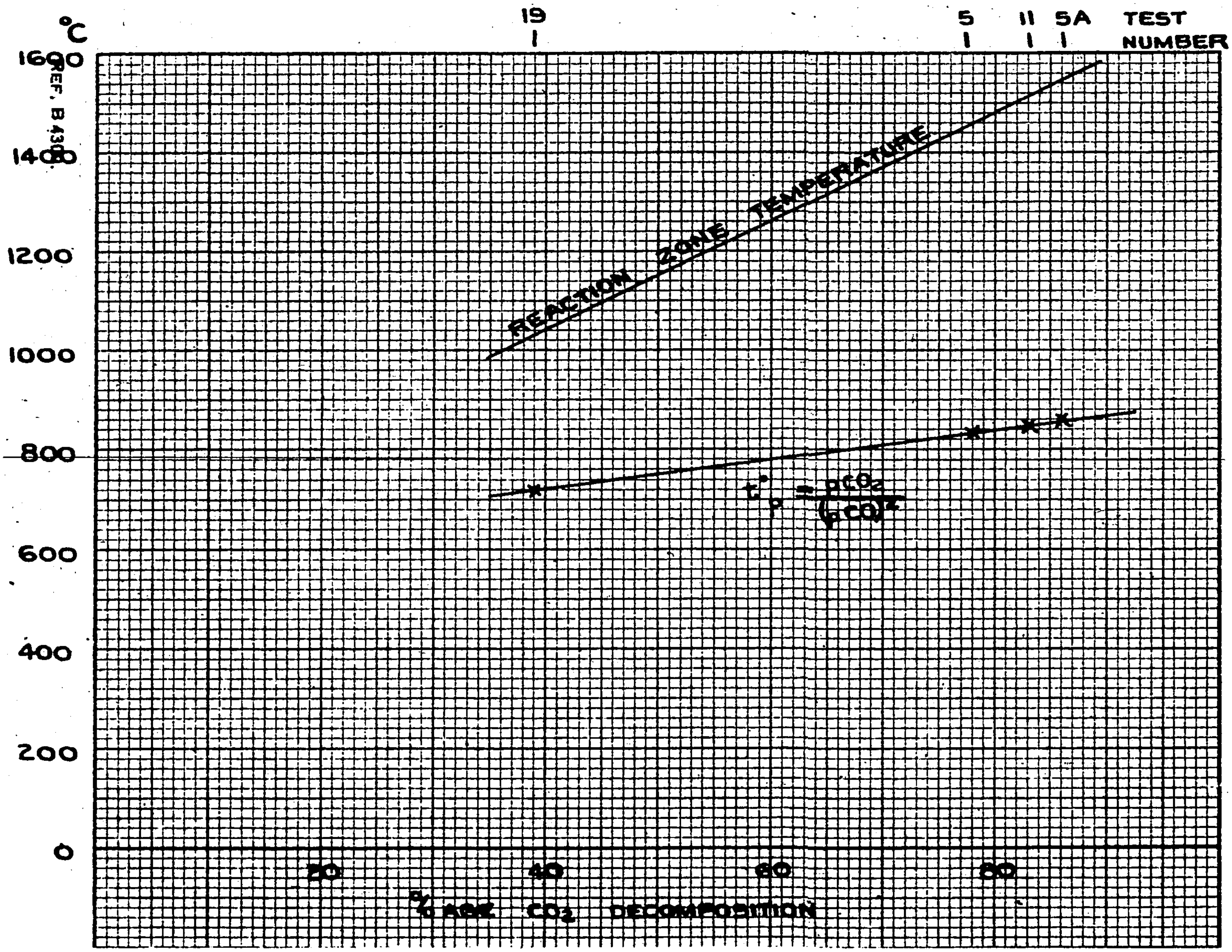


FIG. 15.

APPARENT EQUILIBRIUM TEMPERATURES WITH CO_2 AS GASIFICATION MEDIUM. (SEE TABLE VI)



Therefore, the patents now valid cover only special ways of operating the process. Here we may refer to the summaries of the Merseburg Patent Office, dated 22/6/32 and 3/7/42. The following additional processes are worthy of mention:

D.R.P. 573,112. Dipl.-Ing. Zsigmond v. Galocsy and Karl Koller. In this process a solid, liquid or gaseous fuel is burnt with oxygen in a chamber separated from the gas producer, the oxygen being saturated with the amount of steam required by the gasification process, and the flue gases are introduced into the producer, with the addition of more oxygen if so required.

A further process for the gasification of fuel dust with oxygen appears to have been developed recently by the firm of Heinrich Koppers, Essen. Details are not yet available.

Our own patents or applications are the following:

D.R.P. 701,232 (O.Z.9,622)

Carbonisation-gasification with special recirculation of carbonisation gas, from which a part of the gas is drawn off and together with oxygen is blown through a specially shaped domed grate in the generator.

O.Z. 11,545.

Process for the gasification of particulate waste fuel in a slagging generator, whereby the fuel in a damp condition is fed, together with lump fuel, into the top of the generator, and the dry flue dust, after separation from the gases produced, is blown back pneumatically into the generator. The application has been published.

O.Z. 12,375.

Process for the production of water gas in the slagging generator with oxygen, with simultaneous decomposition of hydrocarbon-containing gas, whereby the hydrocarbon-containing gas is preheated by indirect heat exchange with the gases made, and the preheating temperature is regulated by returning a certain amount of slag to the generator. This application has likewise been preheated.

An addition to this was made recently, according to which control of the preheating temperature was done by introducing water or cold gas into the top of the generator.

O.Z. 12,695.

Oxygen-gasification in the Pintsch-Brassert generator, whereby a layer of slag is maintained on the grate, of such a height that the stirrer moves practically only in the slag.

O.Z. 13,090.

Gasification of solid fuel, whilst maintaining a deep layer of slag on the grate, at the same time using a grate, whose width of slot is at least as great as the average grain size of the fuel.

O.Z. 13,147.

Gasification of solid fuel with oxygen and carbon dioxide, wherein the oxygen-carbon dioxide mixture under the grate should contain 25-40% oxygen.

In addition work on the following applications is going on :

(1) Nozzles for introducing gasifying agents and hydrocarbon containing gases into the oxygen-slagging generators, wherein the tube for introducing hydrocarbons is so attached to the inner wall of the water-cooled nozzles, that it is in this way cooled by them.

(2) A slagging generator, the base of which consists of a sort of brick-lined sheet metal stuffing box, which is so designed that the generator shell, suspended from above, can expand through the bottom.

(3) A tapping hole for discharge of liquid slag from the slagging generator, consisting of a sheet-metal box, lined with its own slag.

~~(4) Nozzles with special liners for oxygen gasification in~~ slagging generators.

We also possess D.R.P. 577,725 (O.Z. 7377).

Process for operating slagging generators, whereby the fire zone is only maintained periodically at such temperatures as to cause liquefaction of the slag, the fire zone being run during the remaining time at appreciably lower temperatures,

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