IV. HYDROGENATION

A. General.

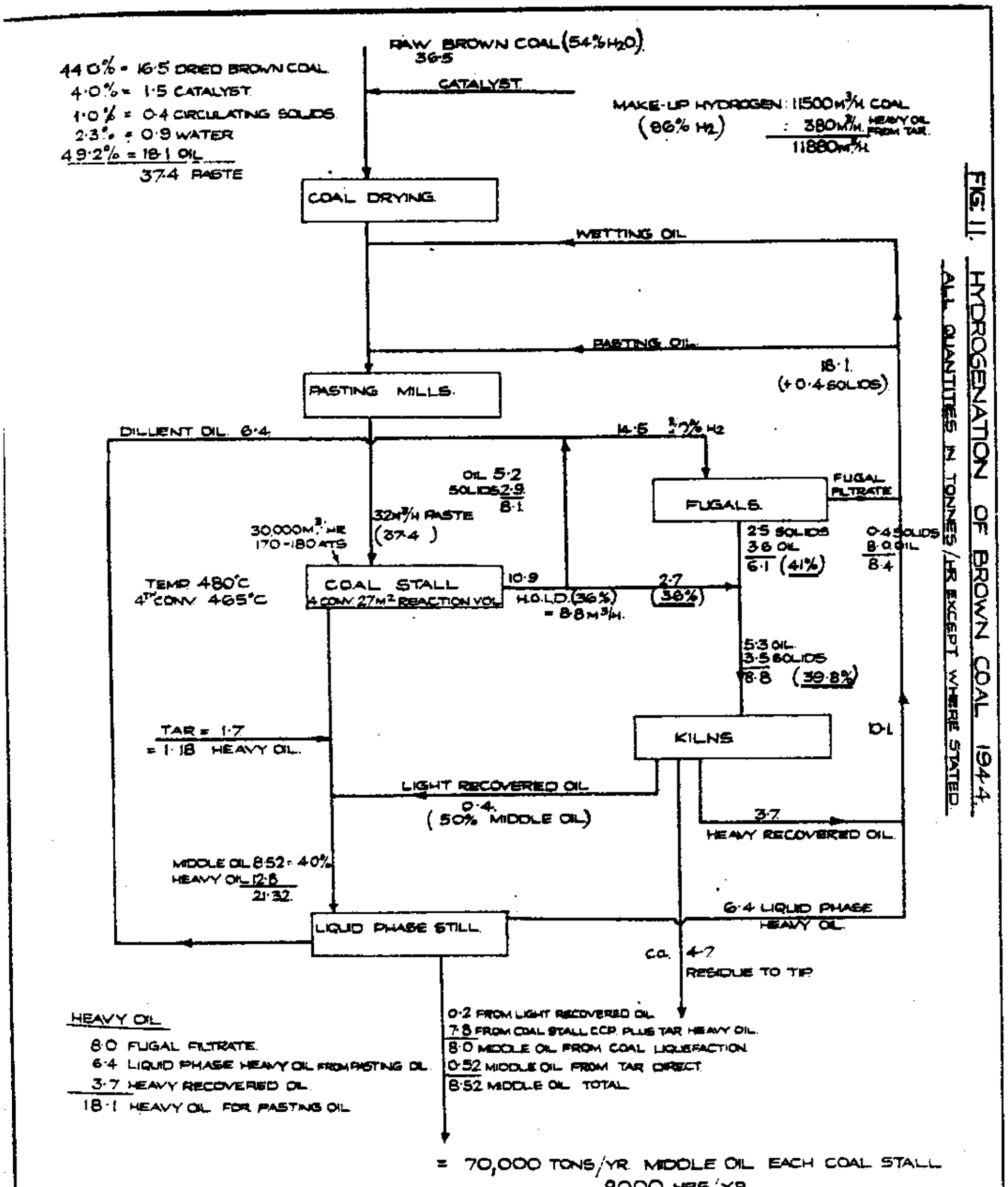
Leuna was the world's first commercial scale hydrogenation plant and also the first to operate on coal (brown coal). In its present form, the Leuna hydrogenation plant consists of 10 liquid phase coal or heavy oil stalls, 5 vapour phase presaturation units and 3 stalls for splitting hydrogenation of middle oils to gasoline. In 1943 and the first half of 1944, the average rates of consumption of the various feedstocks were :-

Dry Brown coal	1,100,000 Tons/year.
Brown coal Tar	120,000 "
Bituminous coal tar oil	40-50,000 "

Production of final liquid products was slightly more than 600,000 T/yr and, according to Dr.Butefisch, these products were made up of 40% aviation base gasoline, 20% motor gasoline, and 40% Diesel oil. In addition, some 150,000 Tons/year of by-product hydrocarbon gases were obtained and these were used for synthesis of isooctane or alkylate (butane), for liquefied gas fuels (propane or propane + butane) and for manufacture of synthetic lube oils (ethane).

In July 1944, Leuna suffered a surprise air attack and, because of the absence of facilities for safe emergency draining of the coal hydrogenation converters, the plant was coked up. The coal-paste preparation plant was also badly damaged. At the same time, damage to the nearby Brabag hydrogenation plants prevented them from hydrogenating all the available brown coal tar. It was therefore decided to change over Leuna from brown coal to brown coal tar and 5 or 6 coal stalls were modified for hydrogenation of liquid phase heavy oil. During the second half of 1944 it was possible to operate the normal liquid phase and vapour phase process for conversion of brown coal tar to gasoline but production was interrupted more and more by continued air raids and, following particularly heavy attacks in January 1945 in which the tar fugals were put out of action, operations had to be limited to a single stall working a modified T.T.H. process (see Ludwigshafen and Zeitz reports). Crude tar input was only 250-300 Tons/day.

The information given in the following sections was obtained from Dr.Schunck, Director and Manager of the hydrogenation section of Leuna, Dr. Becker his principal assistant and stalls manager, Ing.Cron., hydrogenation section engineer and Dr.Pichler, a costs expert attached to the hydrogenation section.



RAW BROWN COAL (54% H2O)
36.5
CATALYST
44.0% = 16.5 DRIED BROWN COAL
4.0% = 1.5 CATALYST
1.0% = 0.4 CIRCULATING SOLIDS
2.3% = 0.9 WATER
49.2% = 18.1 OIL
37.4 PASTE
MAKE-UP HYDROGEN: 11500 M³/H COAL
(86% H2)
: 380 M³/H HEAVY OIL FROM TAR
11880 M³/H
FIG. 11. HYDROGENATION OF BROWN COAL 1944.
ALL QUANTITIES IN TONNES/HR EXCEPT WHERE STATED.
COAL DRYING
WETTING OIL
PASTING OIL
PASTING MILLS
18.1
(+0.4 SOLIDS)
DILUENT OIL 6.4
14.5
FUGALS
FUGAL FILTRATE
OIL 5.2
SOLIDS 2.9
8.1
32 M³/H PASTE
(37.4)
30,000 M³/HR
170-180 ATS
2.5 SOLIDS
3.6 OIL
6.1 (41%)
0.4 SOLIDS
8.0 OIL
8.4
TEMP 480°C
4TH CONV 465°C
COAL STALL
4 CONV 27M² REACTION VOL
10.9
H.O.L.D. (36%)
= 8.8 M³/H.
2.7
(38%)
5.3 OIL
3.5 SOLIDS
8.8 (39.8%)
TAR = 1.7
= 1.18 HEAVY OIL
KILNS
10.1
LIGHT RECOVERED OIL
0.4
(50% MIDDLE OIL)
3.7
HEAVY RECOVERED OIL
MIDDLE OIL 8.52 = 40%
HEAVY OIL 12.8
21.32
6.4 LIQUID PHASE HEAVY OIL
LIQUID PHASE STILL
CO. 4.7
RESIDUE TO TIP
HEAVY OIL
8.0 FUGAL FILTRATE
6.4 LIQUID PHASE HEAVY OIL FROM PASTING OIL
3.7 HEAVY RECOVERED OIL
18.1 HEAVY OIL FOR PASTING OIL
0.2 FROM LIGHT RECOVERED OIL
7.8 FROM COAL STALL CCP PLUS TAR HEAVY OIL
8.0 MIDDLE OIL FROM COAL LIQUEFACTION
0.52 MIDDLE OIL FROM TAR DIRECT
8.52 MIDDLE OIL TOTAL
= 70,000 TONS/YR MIDDLE OIL EACH COAL STALL
8000 HRS/YR
MAY 9TH 1945

B. Brown Coal Hydrogenation

(i) Outline of present process.

The brown coal hydrogenated at Leuna is obtained from local open workings owned and operated by the I.G. As delivered to the plant, it contains 54% water and 5.5% ash. The ash and moisture free coal substance has the analysis - 71% carbon, 5% hydrogen, 5-6% sulphur, 17-18% oxygen and 1% nitrogen. A high proportion of the ash constituents of the coal is sand with erosive properties.

The hydrogenation process as applied to brown coal is summarised in the flowsheet shown in Fig.II. The wet coal together with about 4% of its weight of catalyst (Bayermasse obtained as a byproduct in the manufacture of aluminium) is dried down to 5% water. The product is immediately wetted with part of the recycle pasting oil in order to avoid dust difficulties and explosion risks and is fed to the grinding and pasting mills where it is mixed with the rest of the recycle pasting oil. The resulting "paste" containing some 44% dry coal (49% total solids) is injected into the hydrogenation stall which operates at a pressure of 230 atmospheres. It is heated together with circulating gas (900 - 1,000 M^3 circulating gas/M^3 paste) firstly by interchange with outgoing vapour products and finally in a gas-fired tube preheater. The reactants then enter the first of (usually) 4 converters at a temperature of about 430°C. This temperature is quickly raised by the heat of reaction to 490°C and is then controlled at this figure, by introduction of cold circulating gas at suitable points, until the reactants leave the third reactor. Under the latest operating conditions, this average reaction temperature in the last reactor is dropped to 475°C by introduction of more cold circulating gas. The total circulating gas used for temperature control is about 1000 M^3/M^3 paste fed.

A small amount (100 litres/hour) of reactant is continuously drawn off at the bottom of the first reactor in order to prevent the build up of sand and the formation of "caviar" i.e. small spheres consisting of coke formed round a central sand particle. This draw off is automatically controlled.

The products leaving the last converter pass to a hot catchpot where liquids and vapours are separated at a temperature of about 440°C. The liquid products are cooled by passage through finned air coolers and are let down to atmospheric pressure. Approximately two thirds of this heavy oil let down (Abschlamm) is diluted with 75% of its weight of distillate heavy oil and the mixture is centrifuged. The "filtrate" is recycled as pasting oil and the "concentrate" mixed with the remaining "Abschlamm" is carbonised in "Schnecken ofen" for recovery of its vaporisible oil content. All the ash of the original coal, the unconverted coal and the new formed asphalt is purged as coke from the "Schnecken ofen".

The vapours leaving the hot catchpot are cooled by interchange with the incoming coal paste and by passage through a water cooler. Condensed liquids are separated from recycle gas in a cold catchpot and the former are let down in three stages (45 ats, 4 ats and 1 at.) in order to separate the dissolved gases into "lean" gas for use as fuel and "rich gas" from which butane, propane and ethane are separated. The cold catchpot liquid product is finally distilled together with recovered oils from the "Schneckenofen" (when brown coal tar is hydrogenated simultaneously, this is also introduced at this stage) to give a gasoline + middle oil fraction of 335°C end point as overhead and a heavy oil "bottoms". The light product is passed on for vapour phase hydrogenation and the bottoms are recycled either directly to coal pasting or indirectly as "Abschlamm" diluent oil via the fugals. Gas from the cold catchpot is boosted back to the inlet of the plant via a gas washing plant in which hydrocarbons and nitrogen are dissolved in oil (heavy middle oil ex cold catchpot liquid product) in order to maintain the required hydrogen partial pressure (170-180 ats).

Under these latest operating conditions this paste throughput is slightly under 1.2 M^3/M^3 of reaction space/hour corresponding to 0.46 Tons ash and moisture free coal/M^3 reaction volume/hour. Throughput and reaction temperature are adjusted so that there is no net make of heavy oil. The yield of 0-335°C light product is 49-50% by weight on the ash and moisture free coal fed. Unconverted coal purged in the Schneckenofen coke amounts to 1.5% on the original ash and moisture free coal. (This is not apparent from the flowsheet in Fig.II since no distinction is made between organic and inorganic solids and no indication is given of the change in weight of the latter due to chemical reduction during the hydrogenation reaction). Gas make in the hydrogenation of brown coal is 25.75% on the amf. coal. This is made up as follows:-

Carbon monoxide	1.45%
Carbon dioxide	9.15%
Methane	4.15%
Ethane	3.60%
Propane	4.75%
Butane	2.65%
Total:	25.75%

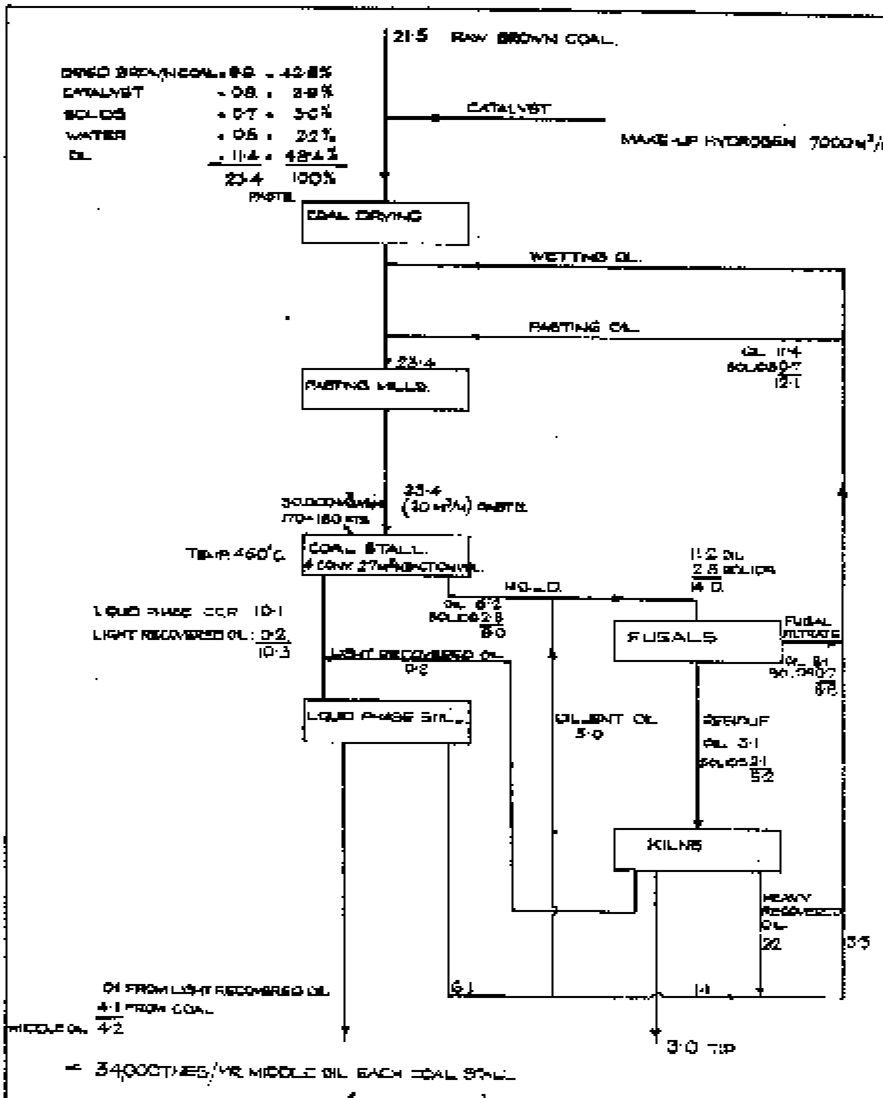


FIG III HYDROGENATION OF BROWN COAL 1939-1940.
ALL QUANTITIES IN TONNES/HR EXCEPT WHERE STATED.

MAY 8TH 1945

Oil lost in the carbonisation of Abschlamm and Abschlamm concentrate amounts to 8.5% by weight on the ash and moisture free coal.

The following figures shew roughly the carbon balance for this process :-

IN	Carbon in brown coal	100
OUT	Carbon in unconverted coal	2.0
	Carbon in coke and gas made by decomposition of asphalts in sludge carbonisation.	11.5
	Carbon in CO and CO_2	4.4
	Carbon in hydrocarbon gases	17.6
	Carbon in sundry losses	1.0
	Carbon in Petrol + Middle oil product	63.5
	Total	100.0

Hydrogen consumption is 800 M^3/Ton of ash and moisture free coal hydrogenated or 6.6-6.7% by wt.

(ii) Consideration of process improvements made since the war.

The process described above, although much the same as regards yields as that operated before the war, shews a marked improvement in output per stall. Fig.III is a typical Leuna flowsheet for brown coal hydrogenation in a single stall in 1939-1940 and it shews that the coal throughput rate then obtainable was only 0.32 Tons amf. coal/M^3 reaction volume/hour or 70% of that achieved in more recent times. The improvement which has been made is actually greater than this, because in addition to a throughput of 0.46 T. of amf. coal, 0.047 T/hr of tar heavy oil is now hydrogenated in each M^3 of reaction space.

With fixed pressure and catalyst conditions the only method for increasing the rate of hydrogenation of a given raw material to a given extent is to increase reaction temperature. The extent to which this can be done is, however, limited because of the following considerations:-

(a) For a given extent of hydrogenation, (i.e. in this case, complete conversion of coal to petrol and middle oil with only sufficient new formed heavy oil to replace sludge carbonisation losses) increase in temperature increases the yield of gas, asphalt and unconverted oil at the expense of petrol and middle oil. The increase in asphalt make is particularly serious because, in order to keep the viscosity of the recycle pasting oils down to a workable figure, all new formed asphalt must be destroyed in sludge carbonisation and this results in an appreciable loss of carbon from the hydrogenation system. Further, the carbonisation plant itself gets into operating troubles when the asphalt content of the feed is too high.

(b) Unless special precautions are taken to cool the products before they enter the hot catchpot, increase in reaction temperature leads to a reduction in the amount and, therefore, an increase in the solids content of the Abschlamm. One of the most serious practical difficulties encountered in the brown coal hydrogenation process has been due to coke formation on the hot catchpot walls and this is more difficult to avoid the higher the solids concentration in the liquid product.

The secret of the increase in throughput of the Leuna stalls is that, by attention to a number of process details, the I.G. have been able to get round some of the above limitations and so increase the mean reaction temperature by 20-25°C.

Firstly, automatic controls have been widely adopted. The mixing of Abschlamm and fugal concentrate in the proper proportions for feeding to carbonisation is automatic and this, coupled with the provision of a large buffer storage for carbonisation feed, has led to much steadier running of the Schneckenofen and has enabled a higher average asphalt content feed to be used than was the case when a margin had to be allowed for possible errors in hand mixing. The hot catchpot level is also automatically controlled; this eliminates the danger of the periodic drying out of the walls of this vessel which greatly encourages coke formation and, therefore, allows a higher solids content of Abschlamm to be tolerated.

Secondly, the I.G. staff have found that, when the hydrogenation process is operated in the normal way using a gradual upward temperature gradient in the reactor system, much of the asphalt make is produced in the last converter where temperature is at a maximum and hydrogen partial pressure is at its lowest. Dropping the temperature in the last converter materially reduces the asphalt make and it also helps to reduce the solids content of Abschlamm and, therefore, the hot catchpot coking danger.

At Leuna, this reduction of temperature in the last converter can be practised only in conjunction with high feed rates resulting in a high rate of heat evolution per stall. At lower throughputs, the loss of recoverable heat by cooling the last converter introduces a preheater capacity limitation.

The Leuna staff feel that still greater throughputs would be possible if it were not for two other limiting factors, (1) erosion of preheater tubes and (2) the capacity of the existing Schneckenofen. With the present high rates, preheaters have to be shut down for examination every 120-150 days and this shut-down takes 6 days. Incidentally, the general maintenance shut-down of a brown coal stall takes 25 days and occurs, normally, every 15 months. Kugel ovens are considered to be superior to Schneckenöfen and several were on order for installation on the Leuna plant.

iii) Details of Plant Equipment.

Paste Mills. These are simply horizontal rotating ball mills fed from each end with the appropriate quantities of dried coal and pasting oil, measurement of both being automatically controlled. The paste leaves the mill via slots cut in the side and passes through a 1 mm. screen for removal of nibs of coal, tramp iron, etc.

Paste Injectors. These are ram pumps, the power for both injection and suction strokes being hydraulically supplied. Injection rate is varied by controlling the rate of entry of water into the hydraulic cylinder.

The gland packing for these injectors had latterly been lead alloyed with 0.1% Cadmium and this had been satisfactory. Before the war, tin packings were used.

The I.G. had ceased to use nitrided rams because of the wide variation in quality which had been experienced. Ordinary case-hardened rams of 400 B.H. were being used.

Paste Interchangers consist of a bundle of 199 tubes in a forging 600 mm. diameter and 18 M long. Formerly 241 tubes were used but trouble was experienced with chokes. The tubes are zinc treated.

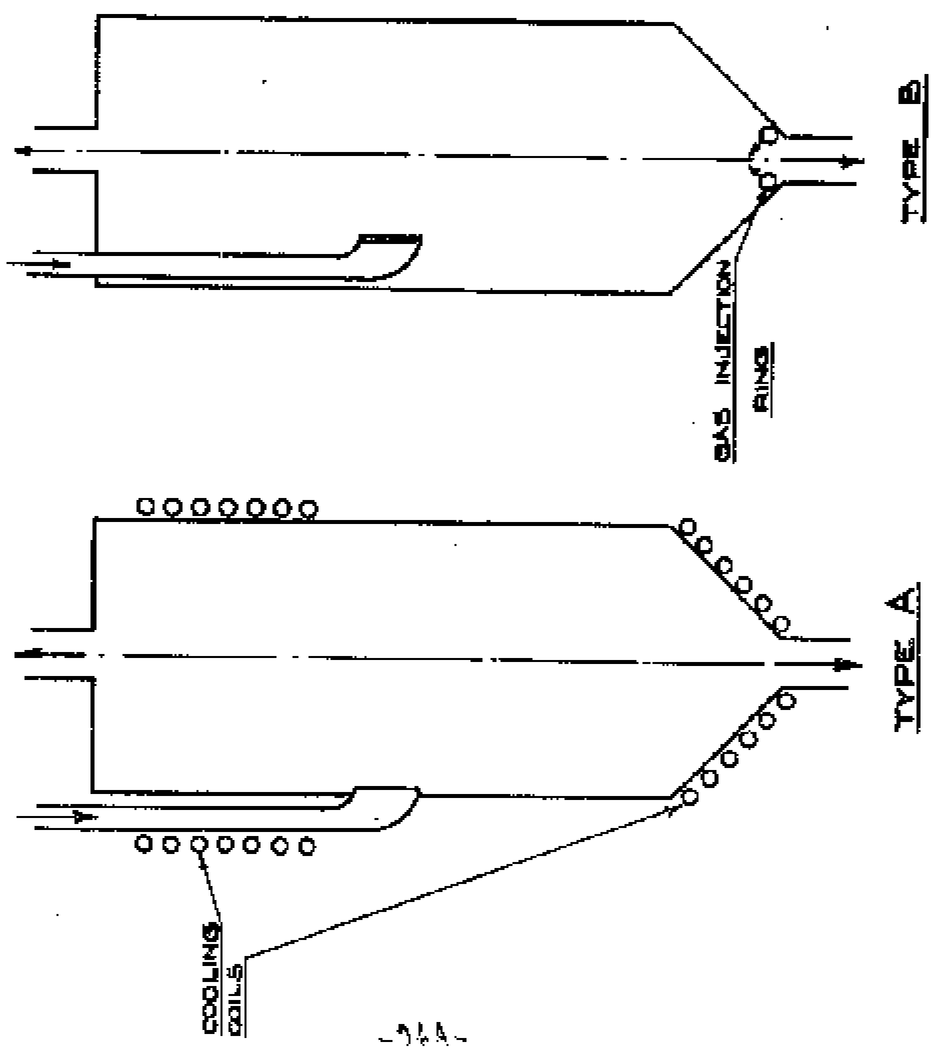
With a paste feed rate of 30 M^3/hour and a gas rate of 20,000 M^3/hour the K value is 250-200.* Interchangers are stripped every two years.

Paste Preheaters. These are gas-fired convection type heaters of the standard I.G. rectangular design. The tube hairpins are 15.5 M long, 120 mm. bore and 171 mm. external diameter. They are fitted with fins 4 mm. thick and 10 mm. apart and which give the tubes an internal/external arearatio of 1 : 20. 6-7 hairpins are used in a normal preheater the average overall K value of which is 180-150. With high feed rates errosion of the hairpin bends is appreciable and the average life of a bend had fallen to 18 months. It was proposed to change to tubes of 160 mm. bore and 229 mm. external diameter with fins 4 mm. thick and 320 mm. square spaced 16 mm. apart. The hairpins were to have been made with a pitching of 500 mm. instead of the standard 400 mm.

* Units for K value: Kg cals/M^2/^oC/hour.

FIG. IV

HOT CATCHPOTS



Brown coal stall Converters. Leuna used converter forgings of a variety of sizes varying from 800 - 1200 mm. diam. and from 11 - 18 M. in length. A stall had four converters and the size was usually such that the total stall reaction volume was roughly 27 M^3.

Hot Catchpot. Several designs have been tried in an attempt to reduce coking. The type most commonly adopted is shewn in Fig.IV A. It is fitted with gas cooling coils between the forging and inner catchpot wall and the inlet pipe for reactants is outside the inner vessel. The idea of the cooling tubes at the top of the catchpot is to ensure sufficient condensation that the walls never dry out. Another type (Fig.IV B) has no cooling coils but cold gas is introduced at the bottom of the vessel via a ring distributor. It is claimed that the stirring provided by this method helps to reduce coke formation.

Let down valves. These are fitted with "Widia" inserts but even so they have a life of only 200-400 hours.

Sludge carbonisation kilns. Leuna has 26 Schneckenofen arranged in sets of two. Each kiln comprises two horizontal steel tubes 2 ft. in diameter and 30 ft. long, arranged one above the other and sitting inside a brickwork gas-fired furnace. Each tube is fitted with peddles, fixed with a slight pitch on to a central rotating shaft, and these scrape the inner wall of the tube free from adhering coke. Loose iron bars are attached to the peddles in such a way that, as the peddle rotates, the bars are lifted to fall later with sufficient force to dislodge coke deposited on the peddle.

The average feed rate is 2.5-3.0 M^3/hour falling to 1.8 M^3/hour after 50 days when the unit is taken off line for cleaning.

Gas Circulators. The coal and heavy oil hydrogenation system at Leuna normally employs 5 or 6 circulators each of 80-85,000 M^3/hour capacity. The machines throw a maximum pressure of 30 ats. They are operated at constant speed and circulation rate is varied by controlled bypass. Stall pressure is hand controlled and it was stated that swings of up to 20 ats are observed.

Gas washing. Purification of the circulating gas is carried out in 9 towers each 1300 mm. diameter. Wash oil (a heavy cut of liquid phase hydrogenation middle oil) is injected partly with three throw pumps and partly by means of three machines driven by let down engines operating on the saturated wash oil. The wash oil feed rate was controlled automatically in order to maintain a constant hydrogen content of circulating gas.

<u>Automatic Controls.</u> Full details of the various automatic controls were obtained but these are amongst the documents (2nd Leuna visit) which have not yet reached London.

3. <u>Brown Coal Tar Hydrogenation</u>

The Leuna flowsheet for hydrogenation of Central German brown coal tar is shewn in Fig.V. The crude tar which contains 1% water, 0.5% solids and 1-3% asphalts, is fugalled to remove slightly over 2% of its weight of sludge which is sent to carbonisation for oil recovery. The cleaned tar is mixed with "Leuchtöl", i.e. recovered oil from brown coal carbonisation gases (the crude tar + Leuchtöl mix usually contains 45% by weight of heavy oil boiling above 325°C, 35-40% distilling between 180 and 325°C and 15-20% boiling below 180°C) and with the crude product from the liquid phase hydrogenation of heavy oils. This mixture is distilled to give a 0 - 325°C fraction as overhead and a heavy oil bottoms which is the feed to the hydrogenation stalls.

The plant employed is substantially the same as in the case of coal hydrogenation with the exception that a special pump is installed for hot recycle of liquid from the hot catchpot to the inlet of the preheater.

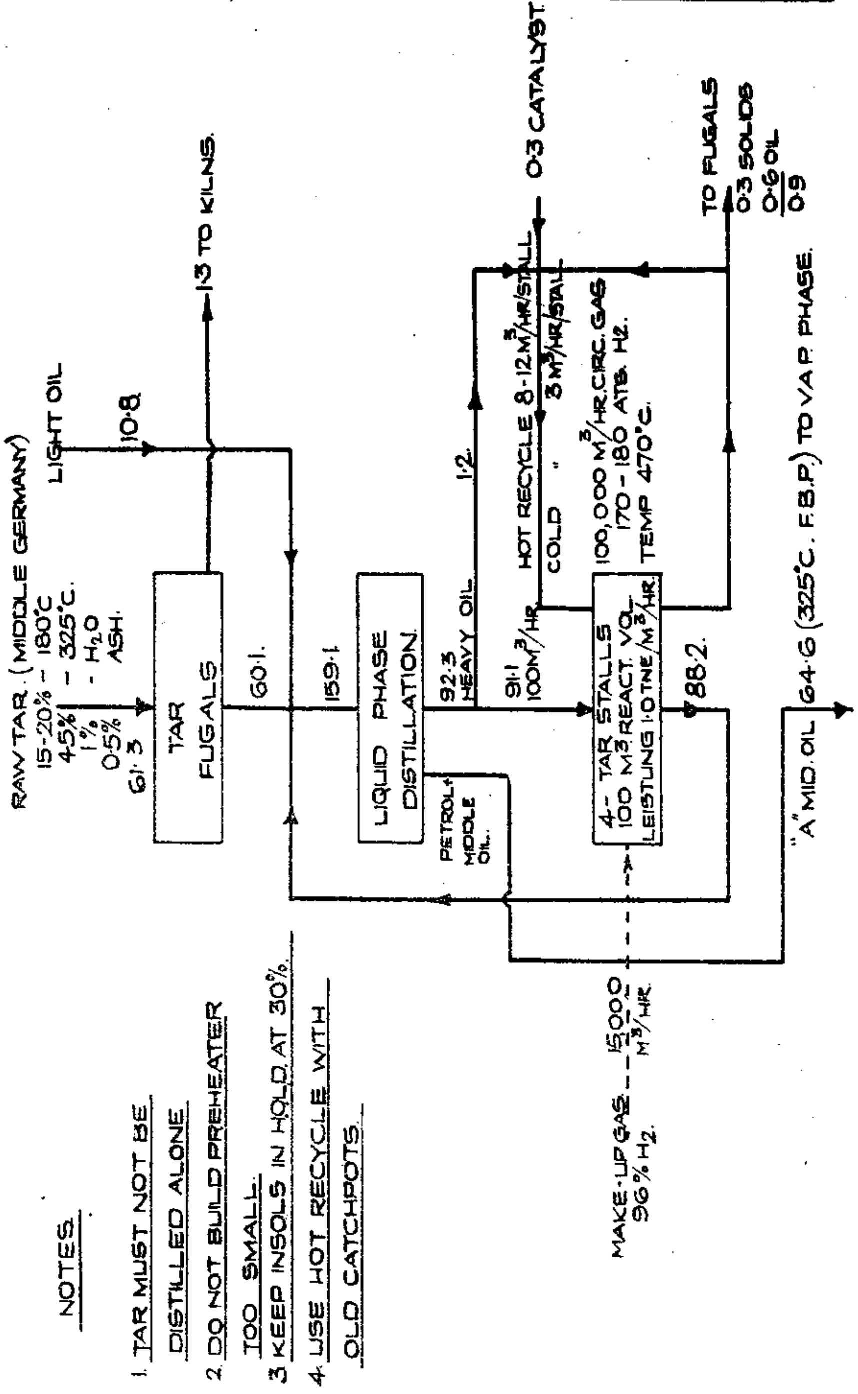
Hydrogenation conditions for heavy oil are :-

Circulating gas/Oil feed	1,000 M^3/Ton.
Mean Reaction Temperature	480°C
Oil feed rate	0.9 - 1.0 kg/litre catalyst/hour.
Pass Conversion of heavy oil into lighter products.	35%
Total Pressure	230 ats.
Hydrogen Partial Pressure	170-180 ats.
Catalyst	5 - 6% Iron on Crude coke in suspension in the reactants.

The catalyst (10927) is made by impregnation of the coke obtained from Winkler generators with the necessary amount of ferrous sulphate and caustic soda solutions in stoichiometric proportions. The impregnated coke is dried and ground so that not more than 2% remained on a 10,000 mesh screen. There is no washing step in the preparation of this catalyst. Make up catalyst is introduced as a suspension in part of the heavy oil feed usually injected into the hot liquid recycle system. Catalyst consumption is roughly 1% by weight on the fresh 325°C heavy oil feed.

FIG. V FLOWSHEET FOR PETROL FROM BROWN COALTAR

ALL QUANTITIES TNE/HR EXCEPT WHERE STATED.



NOTES.

1. TAR MUST NOT BE DISTILLED ALONE
2. DO NOT BUILD PREHEATER TOO SMALL.
3. KEEP INSOLS IN HOLD AT 30%.
4. USE HOT RECYCLE WITH OLD CATCHPOTS.

The main purpose of the hot liquid recycle from the hot catchpot to the preheater is to increase the velocity of liquid in the former and so reduce coke formation. The rate of recycle necessary depends on the hot catchpot design. With the later types, hot recycle can be eliminated and it was stated that Brux operated in this way.

In order to purge spent catalyst and non-hydrogenable material in the tar, there is a small let down from the hot catchpot. Part of this product is recycled direct and the remainder treated in fugals to give a concentrate which is carbonised for oil recovery.

The yield of petrol and middle oil obtained by liquid phase hydrogenation of brown coal tar heavy oil is just over 80% by weight. Hydrogen consumption is 3.9 to 4.0% by weight. It is interesting to note that the petrol + middle oil production "leistung" per M^3 reaction volume is lower from brown coal tar heavy oil than from brown coal. The figures are 0.25 - 0.26 Tons/M^3/hour for tar heavy oil and 0.29 - 0.30 for coal.

D. Vapour Phase Hydrogenation of Middle Oils.

(i) Process conditions and yields.

Leuna operate the two-stage process, i.e. straight through presaturation to convert nitrogen compounds to ammonia and to hydrogenate the greater part of the oxygenated components followed by splitting hydrogenation with recycle of unconverted middle oil.

For each stage the plant consists simply of a preheater, two interchangers, three or four converters, a cooler and a cold catchpot. Reaction volume per stall is usually about 25 M^3. For the first stage, Leuna, in common with most other German hydrogenation plants, have changed from 5058 (tungsten sulphide) in the form of 10 mm.pellets, to 8376 (25% tungsten sulphide + 3% nickel sulphide on alumina) catalyst used in the form of cubes. This was found to be at least as good as 5058 for reduction of phenols and superior to 5058 in that it gave less splitting to comparatively low quality petrol. It was not as good as 5058, however, for destruction of nitrogen compounds which is the most important function of the presaturation stage.

Leuna achieved an oil throughput of 0.6 - 0.8 Tons/ M^3 catalyst/hour in the presaturation stage, for which an average temperature of 410°C and a hydrogen partial pressure of 210-220 ats. was employed. Circulating gas to oil ratio was 2,500 M^3/Ton. The high hydrogen partial pressure in the vapour phase stalls is achieved by introducing all the make up hydrogen for both liquid and vapour phase systems into the vapour phase circulating gas. A purge from this system is used as make up to the liquid phase.

Gas made in the presaturation step is the equivalent of 3% of the carbon in the feed. Roughly half this gas (by weight) is butane, a third propane and the remainder ethane and methane in approximately equal proportions. The yield of butane-free product depends of course on the oxygen, nitrogen and sulphur content of the feed. In the case of total 0-325°C product from brown coal tar it is 95% and hydrogen consumption is 3.9% by weight. Using petrol + middle oil from brown coal hydrogenation as feed, the yield of saturated product is 97% and hydrogen consumption 3.7 - 3.8%.

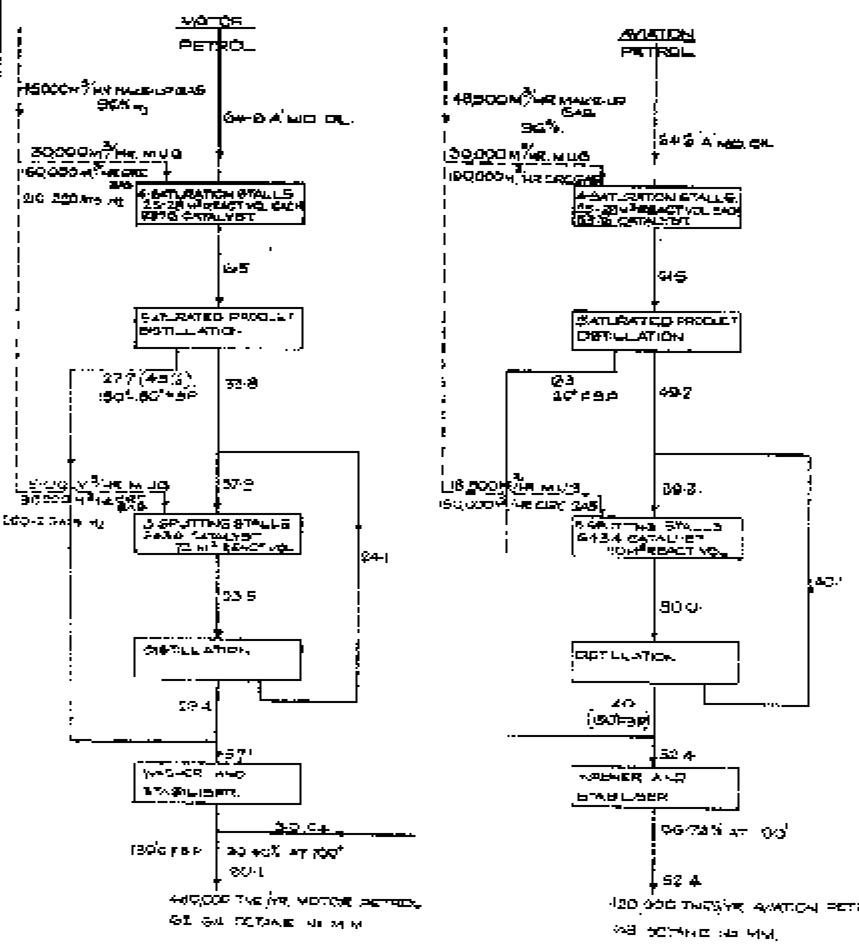
The saturated product from both brown coal and brown coal tar contains an appreciable amount of material boiling in the petrol range. This fraction has a comparatively poor knock rating and it is desirable to keep it separate from the better quality product obtained by splitting hydrogenation. It is, therefore, usual to distil the saturation product, taking overhead a 0 - 150 or 160°C cut if motor gasoline is the desired end product or a 0 - 120°C fraction if aviation base petrol is being made. It was stated that 0 - 120°C saturation stage petrol ex brown coal hydrogenation has a motor method octane number of 70-71 while the rating of, the corresponding product from brown coal tar was only 68-70. Presaturation stage petrol is frequently used as feed for the D.H.D. process.

The middle oil from the presaturation stage contains 2-3 mgs. nitrogen per litre. It can be used direct as a Diesel fuel and has a Cetane number of 40-42 and a pour point of -15°C. The pour point can be lowered to -40°C by cutting 15% from the higher boiling end but this reduces the Cetane number to 38.

Splitting hydrogenation of saturated middle oil is carried out over a tungsten sulphide on Terrana earth catalyst (6434). Other process conditions are :-

FIG. VI FLOWSHEET FOR PRODUCTION OF MOTOR OR AVIATION PETROL FROM BROWN COAL MIDDLE OIL

ALL QUANTITIES TNS/HR EXCEPT WHERE STATED



	For Motor Gasoline.	For Aviation Base Gasoline
Oil throughput Kgs/litre catalyst/hour	0.8	0.8
Conversion/pass	60%	55%
Circulating gas/oil feed ratio. M^3/Ton	1,500	1,700
Hydrogen Partial Pressure	210 - 220 ats.	210 - 220 ats
Temperature	400°C	410°C

Circulating gas is water washed before entering the stall to reduce nitrogen to less than 0.1 mgrm/litre oil feed. Motor gasoline is cut to an end point of 190°C and has a volatility of about 30-35% at 100°C. Aviation base gasoline distils 65-70% at 100°C and has an end point of 150°C.

When making motor gasoline, 15% of the carbon in the 150-325°C saturated middle oil feed is converted into hydrocarbon gas consisting of 83% by weight of butane, 15% propane, 1% ethane and 1% methane. It is possible, however, to include 40-50% of the butane in the final petrol so that the net weight yield of motor gasoline is 91-92% on the feed.

20% of the carbon in the 120-325°C feed is converted into hydrocarbon gas of the same composition as given above when making aviation base petrol. It is not possible to include butane in the liquid product and the net yield is thus only 81% by weight.

Figs. VI and VIII shew diagrammatically the conversion to two grades of petrol of middle oil from liquid phase hydrogenation of brown coal tar (including Leucht81) and brown coal respectively. They shew that the following overall yields are obtained :-

	Motor Gasoline	Aviation Base Petrol
Brown coal tar		
(a) wt% on crude tar including Leucht81	83	72.5
(b) wt% on liquid phase petrol + middle oil	93	81
Brown coal		
(a) wt% on ash and moisture free coal	46	40
(b) wt% on liquid phase petrol + middle oil.	95	83

Overall hydrogen consumption figures are:-

(1) Brown coal tar (including Leuchtöl) to Motor gasoline -

6.9 - 7.0% by weight on tar or 8.3 - 8.4 Tons Hydrogen per Ton Motor gasoline.

(2) Same feed to Aviation petrol -

7.3% on tar or 10.0 Tons H_2/Ton petrol.

(3) Brown coal to Motor gasoline -

9.4% wt. on ash and moisture free coal or 20.3 Tons H_2/Ton motor gasoline.

(4) Brown coal to Aviation base -

9.6 - 9.7% wt. on a.m.f. coal or 24.0 Tons H_2/Ton aviation base.

The final blend of motor gasoline from brown coal tar has a C.F.R. motor method octane number of 62-64, while aviation base from the same raw material has a rating of 68. Corresponding ratings for petrols ex brown coal hydrogenation are about two octane numbers higher.

(ii) Details of Plant.

Injectors. Normal three throw pumps are used with electric drives. S.B.A. rings for gland packing had not been very satisfactory and the I.G. had used ACACIA wood packing with considerable success. These new packings had a life of about 1,800 hours.

Interchangers were similar to those in use in liquid phase stalls except that those in use in saturation stalls had 241 tubes. K value for both was 300-200.

Preheaters. On the saturation stalls the preheater consisted of 4 or 5 elements of 90 mm. bore, 127 mm. external diameter tube heated electrically. Normal gas-fired preheaters were used in splitting stalls - each contained about 25 elements of 90 mm. bore tube and had a K value of 200 - 180.

Reactors. The main feature of vapour phase hydrogenation reactors is the arrangement of the catalyst in beds with intermediate mixing chambers into which cold circulating gas is introduced in order to give the necessary temperature control. The Leuna engineers do not appear to have been very progressive as regards improvements in design of these bed converters and the operating staff seemed satisfied with the present reactors although they are capable of much smaller throughputs than those in use, for example, at Billingham.

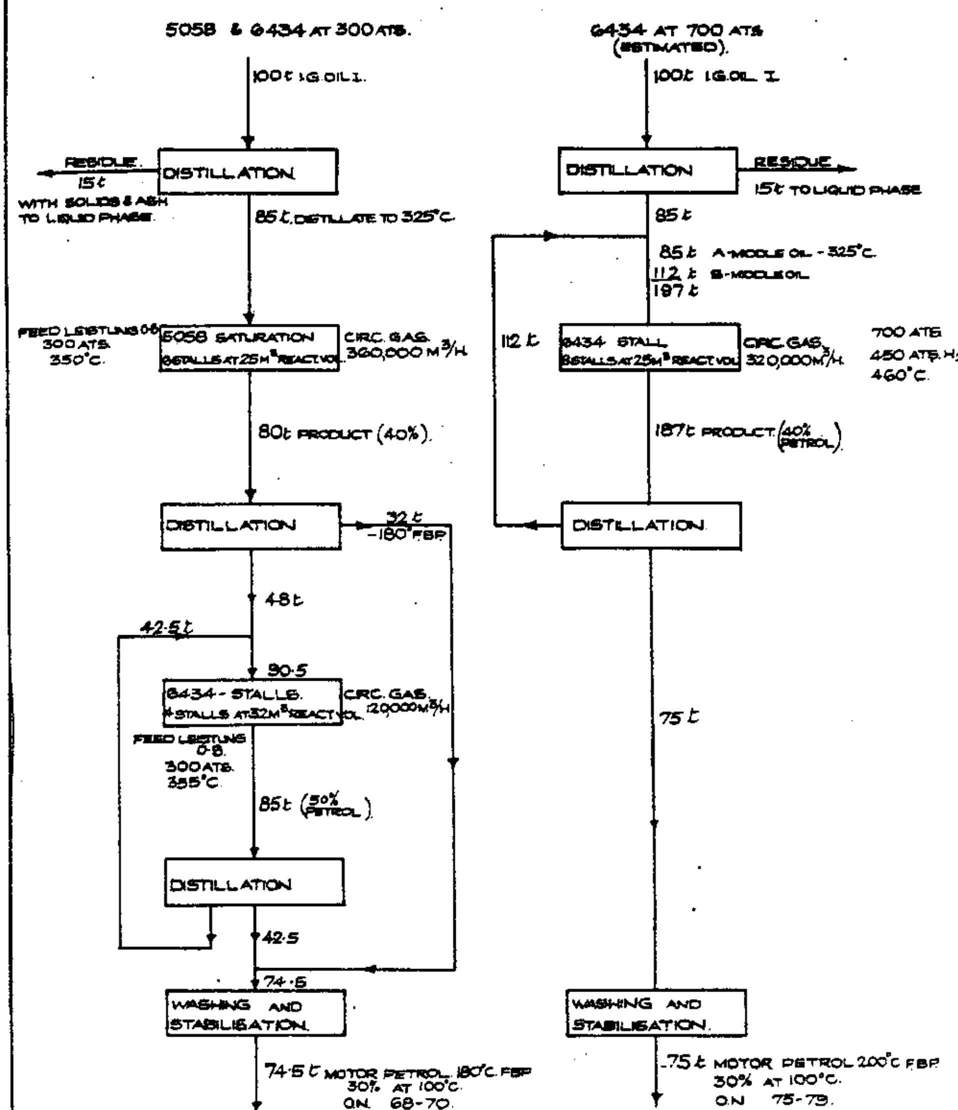


FIG VII. COMPARATIVE FLOWSHEETS FOR PETROL FROM BITUMINOUS COAL TAR MIDDLE OIL.

The forging body was formerly lined with stamped cement asbestos. During the war, Leuna has used fired bricks of "Schamotte stein" with apparent success.

Coolers. The K value of vapour phase hydrogenation stall coolers was stated to be 400 - 500 kg cals/°C/M²/hour.

E. Vapour Phase Splitting Hydrogenation at 700 atmospheres Pressure.

This was not practised at Leuna but the research for the Lutzkendorf plant of the Wintershalle A.G. was done in the Leuna laboratories. Dr.Becker supplied comparative data for 300 ats two stage (presaturation followed by splitting hydrogenation) and 700 ats. direct treatment over 6434 when using bituminous coal tar middle oil (creosote middle oil) as feed. These data are given in Fig. VII.

It will be seen that the weight yield of petrol of 30% volatility at 100°C is substantially the same in the two processes but that the high pressure method gives a product higher in anti knock rating by 5-10 octane numbers. Dr.Becker was unable to give figures for hydrogen consumption but presumably the 700 ats process requires less hydrogen because of the greater concentration of aromatics in the final product. Incidentally this aromatic content and also the octane number of the petrol could be increased still further using a "diluted" catalyst such as is employed at Welheim instead of 6434.

In the 700 ats. process overall petrol production leistung is 0.37-0.38 kgs/litre catalyst/hour. This compares with 0.29 kgs/litre 5058 + 6434 cat./hour for the 300 ats. two stage method. Since 700 ats. converters have only 75% of the catalyst capacity of vessels of weight used for 300 ats, there is no saving in reaction vessels using the higher pressure process. Because the conversion/pass using 700 ats. and non-saturated feed is low - 43%, the amount of distillation involved is rather higher than is the case in the normal two stage 300 ats. process. If it is essential to produce petrol of high aromatic content and an octane number of 75-79, there is clearly an advantage in using the 700 ats. method (possibly with a less saturating catalyst than 6434) instead of the conventional two stage method followed by D.H.D. treatment of the saturation stage naphtha.

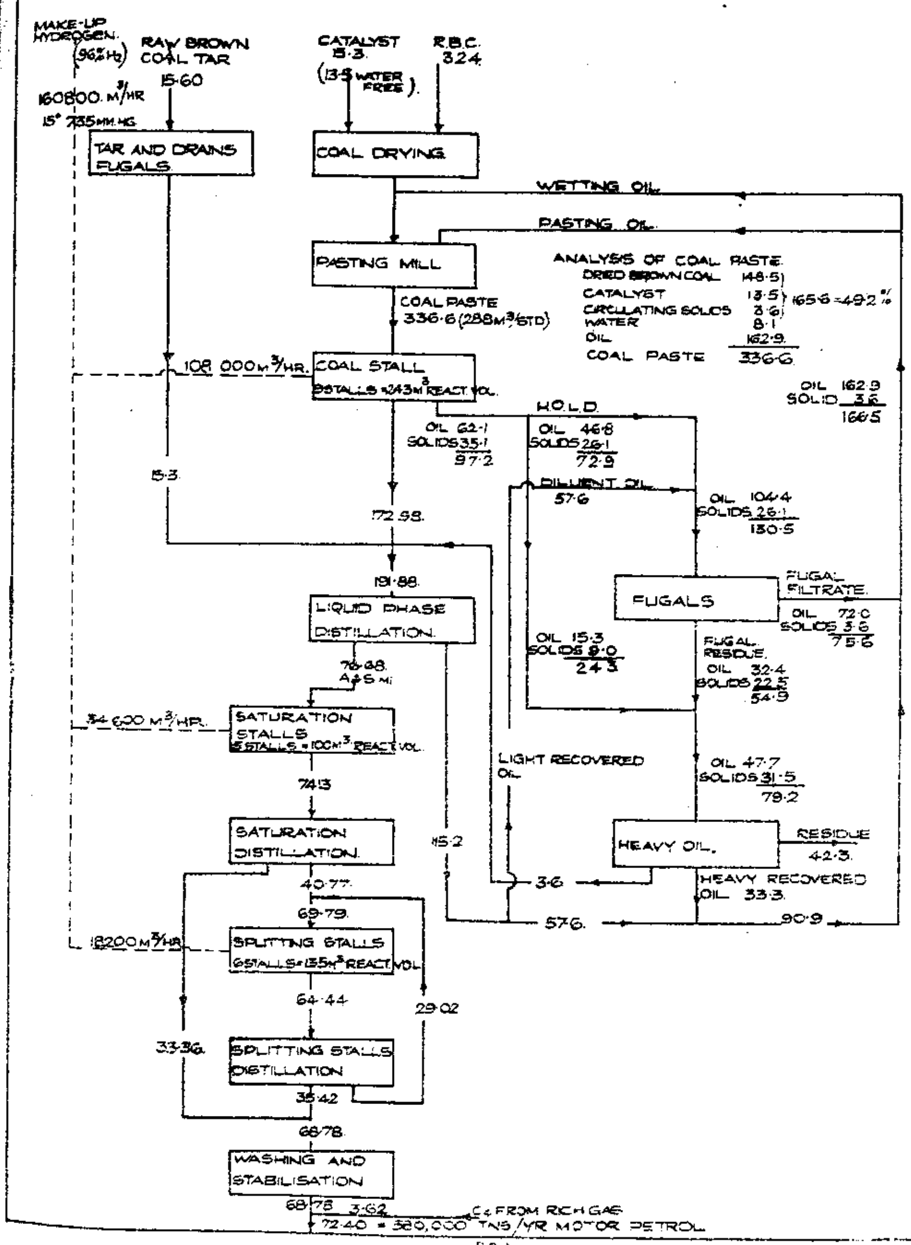
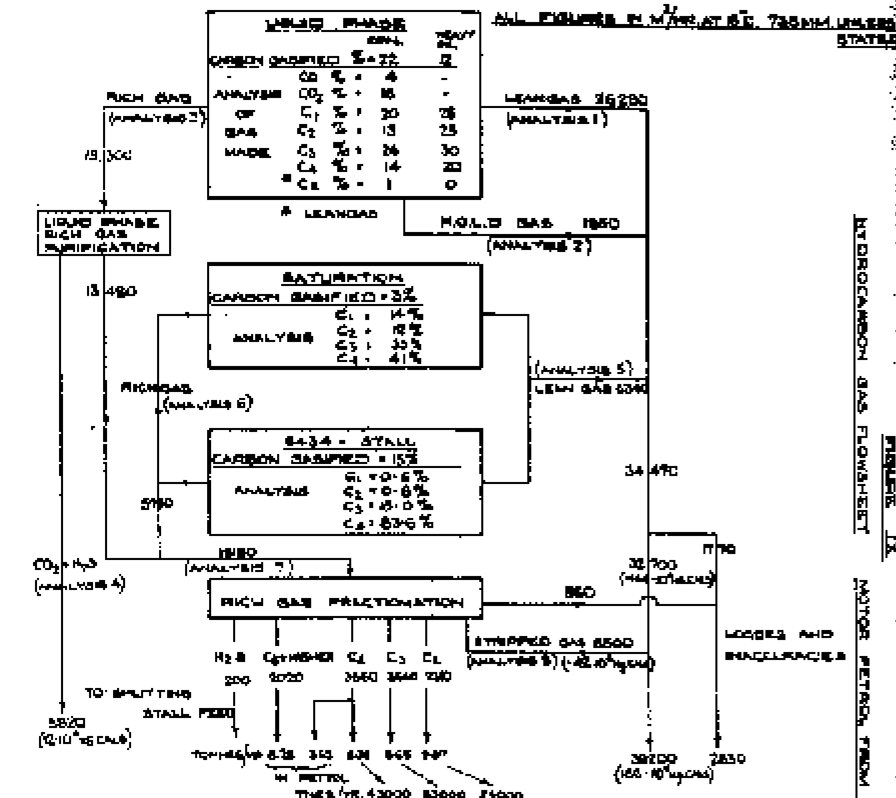


FIG. XIII FLOWSHEET FOR MOTOR PETROL FROM BROWN COAL BY HYDROGENATION

ALL QUANTITIES IN TNES/HR UNLESS STATED

ALL FLUID PRODUCTS ARE GAS FREE BUT INCLUDE C_5



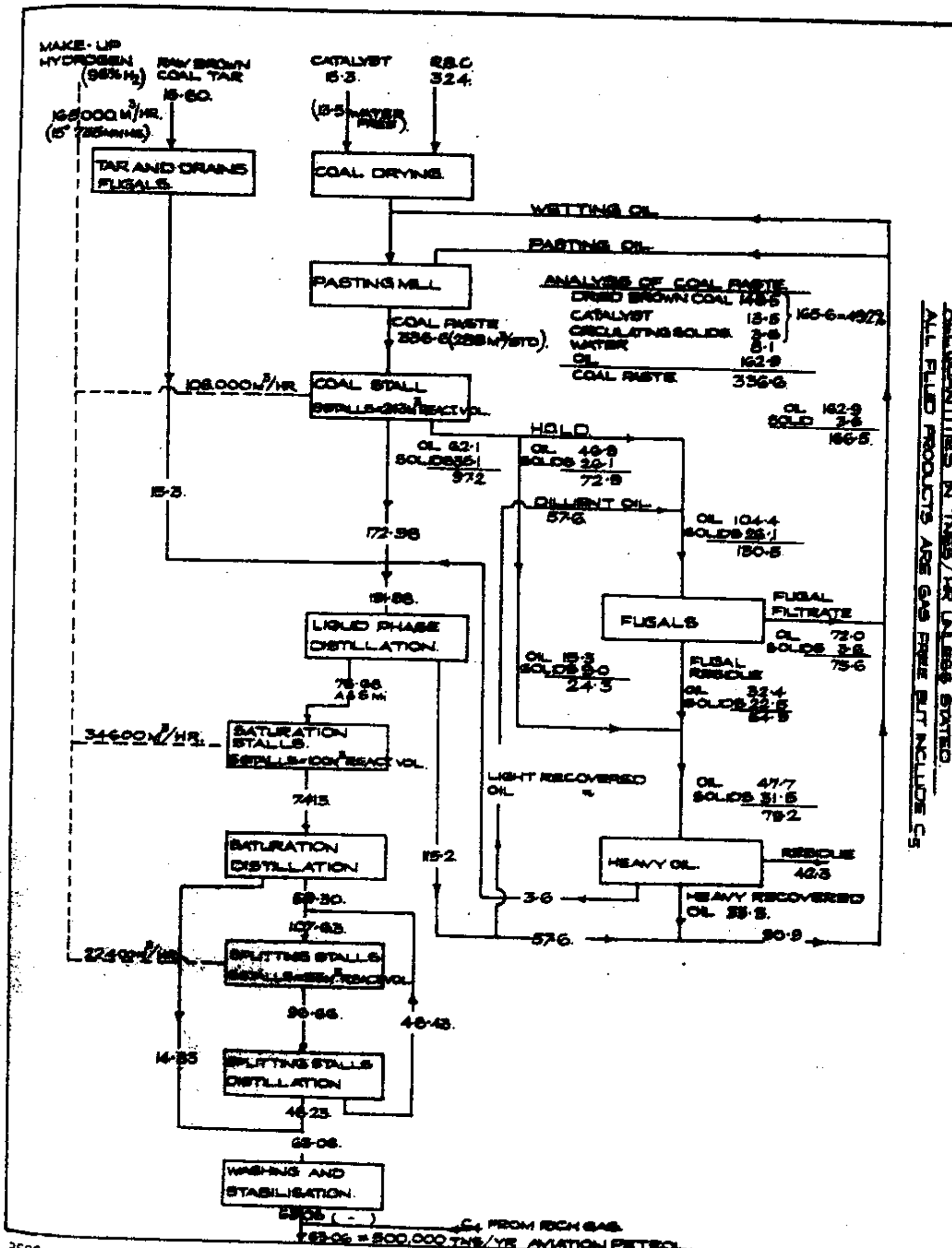
ANALYSES (VOLUME %)

	1	2	3	4	5	6	7	8
H_2 %	42·	29·6	5·7	-	67·0	6·6	7·8	21·8
N_2 %	8·6	8·7	5·1	-	17·6	3·5	3·1	8·7
CO %	5·0	3·5	1·4	-	-	-	1·4	3·5
CO_2 %	10·7	18·6	16·5	60·1	-	-	-	-
H_2S %	1·8	4·1	12·0	39·9	0·6	3·4	1·1	-
C_1 %	25·3	21·3	17·2	-	14·9	6·3	16·7	55·5
C_2 %	4·3	8·7	14·7	-	1·3	3·5	16·9	6·9
C_3 %	2·0	7·9	16·0	-	3·2	14·8	20·3	1·1
C_4 %	0·3	3·2	9·1	-	3·0	45·3	20·1	-
C_5 + HIGHER %	0·1	2·4*	5·6	-	0·4	16·4	10·6	-
HEATING VALUE KCAL/M³	4330	7240	11200	2070	3810	21400	17000	6460
DENSITY KG/M³	0·67	1·01	1·480	1·85	0·475	2·03	1·09	0·489

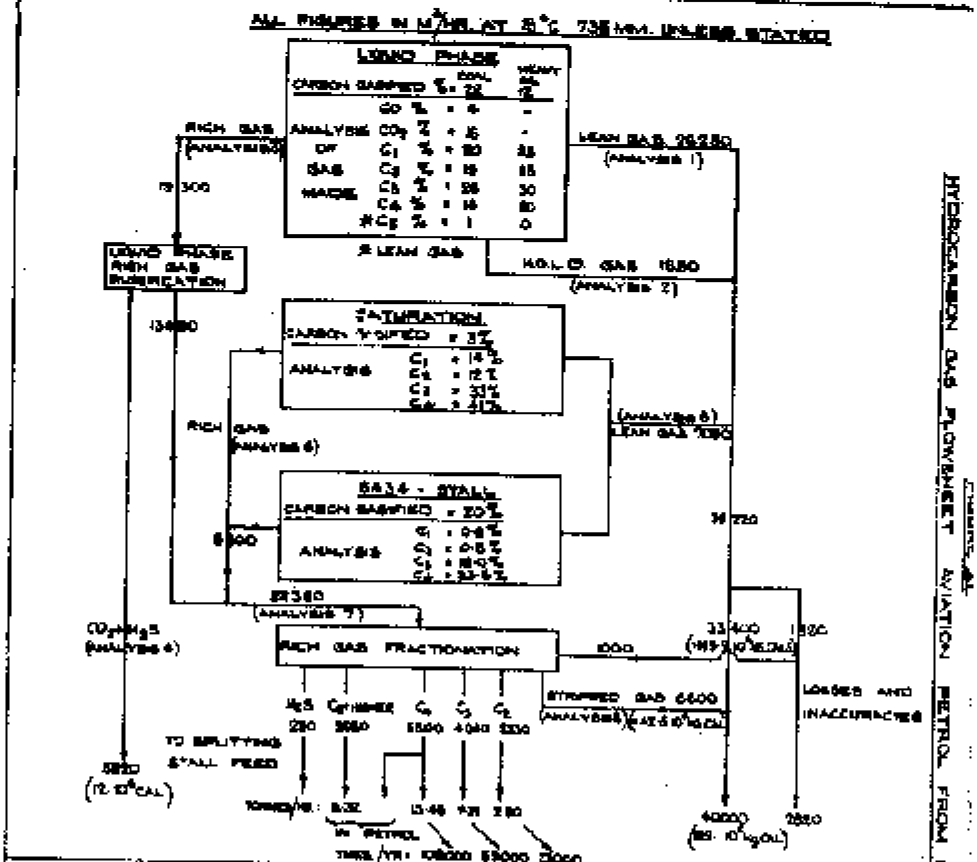
FIGURE IX
HYDROCARBON GAS FLOWSHEET
MOTOR PETROL FROM BROWN COAL

FIG. X FLOWSHEET FOR AVIATION PETROL FROM BROWN COAL BY HYDROGENATION.

ALL QUANTITIES IN TNS/HR UNLESS STATED.
ALL FLUID PRODUCTS ARE GAS FREE BUT INCLUDE C_5



HYDROCARBON GAS FLOWSHEET AVIATION PETROL FROM BROWN COAL



ANALYSES (VOLUME %)

	1	2	3	4	5	6	7	8
H_2 %	42·1	38·6	5·7	-	60·0	4·5	8·1	22·1
N_2 %	8·5	5·7	2·1	-	77·0	2·4	2·7	8·8
CO %	6·0	3·5	1·4	-	-	-	1·2	3·6
CO_2 %	10·7	15·8	18·2	60·1	-	-	-	-
H_2S %	1·8	6·1	4·0	39·9	0·7	2·7	1·1	-
C_1 %	25·3	21·9	17·2	-	14·6	5·4	17·2	55·2
C_2 %	4·3	8·7	14·7	-	1·3	3·6	13·7	9·1
C_3 %	2·0	7·3	16·0	-	2·3	14·1	19·4	1·3
C_4 %	0·3	3·2	7·1	-	3·1	49·7	25·8	-
C_5 + HIGHER %	0·1	2·4	5·6	-	0·6	17·6	12·0	-
HEATING VALUE KCAL/M³	4330	7240	11200	2070	4330	23000	16300	6460
DENSITY KG/M³	0·67	1·01	1·480	1·66	0·843	2·17	1·71	0·659

TABLE I

COST CALCULATION FOR PRODUCTION OF PETROL FROM BROWN COAL.

	Unit	Cost per Unit. RM	Motor Petrol Production				Aviation Petrol Production			
			Per hour.		Per Tne Motor Spirit		Per hour.		Per Tne Aviation Spirit	
			Quantity	RM	Quantity	RM	Quantity	RM	Quantity	RM
A. Materials										
1) Raw Materials										
Brown Coal	Tne	3.00	324	972.00	4.475	13.43	324	972.00	5.138	15.41
Brown Coal Tar	"	80.00	15.60	1248.00	0.215	17.24	15.6	1248.00	0.247	19.79
2) Other Materials										
Make-up Gas (96% H_2)	M^3	0.042	160800	6753.60	2221	93.27	165000	6930.00	2617	109.90
Red Earth (dried)	Tne	20.00	15.3	306.00	0.211	4.23	15.3	306.00	0.243	4.85
Catalyst and other chemicals.				144.80		2.00		182.00		2.89
3) By-Products										
Butane x	Tne	170.14	5.35	910.25	0.074	12.57	13.48	2293.49	0.214	36.37
Propane x	"	170.14	6.65	1131.43	0.092	15.63	7.39	1257.33	0.117	19.94
Ethane	"	110.00	2.87	315.70	0.040	4.36	2.90	319.00	0.046	5.06
Hydrogenation Gas	10^3 T.Cals	7.00	198	1386.00	2.735	19.14	204	1428.00	3.235	22.65
B. Running Costs (See Table II)				6637.43		91.67		6916.89		109.69
Production Cost			72.40	12318.45	1.000	170.14	63.06	11257.07	1.000	178.51
C. Loading & Evaporation	Tne	3.00	72.40	217.20	1.000	3.00	63.06	189.18	1.000	3.00
D. On-Costs (I.G. direction, research &c)				1220.66		16.86		1220.66		19.36
WORKS COST			72.40	13756.31	1.000	190.00	63.06	12666.91	1.000	200.87

x Valued at cost of production of Motor Petrol.

TABLE II.

BUILD UP OF RUNNING COSTS.

		Motor Petrol Production per hour		Aviation Petrol Prodn. per hour	
		Quantity	RM	Quantity	RM
Labour Costs.			677.62		695.75
Wages	hrs.	447.51	524.65	459.01	538.47
Salaries			111.98		115.07
Social Insurance			40.99		42.21
Energy Costs			2,394.95		2,513.74
Water	m^3	10,253.2	147.71	11,342.73	163.87
H.P.Steam	Tne.	280.15	849.77	303.20	919.57
I.P.Steam	Tne.	112.93	225.83	125.66	251.28
L.P.Steam	Tne.	150.54	337.19	152.59	341.76
H.T.Electricity	KW/hr.	15,460.47	317.86	16,451.88	332.85
L.T.Electricity	KW/hr.	3,761.12	77.82	3,929.78	81.31
Fuel Gas 10^3	Tne Cals.	83,747.51	743.82	87,991.65	781.62
Brown Coal	Tne.	45.063	139.46		139.46
Other Forms (Gas)			7.19		4.58
Repair Costs			1,496.85		1,561.71
Wages	hrs.	371.97	451.61	383.60	465.56
Material			299.45		321.52
Workshop & Material oncost.			745.79		774.63
Working Material			57.63		59.35
Traffic Charges			154.53		154.90
Works General Charges			297.93		308.11
Capital Charges			1,139.34		1,190.10
Taxes			154.04		158.53
Various Costs			323.81		334.01
Credits			59.31		59.31
			6,637.43		6,916.89

Remarks: 1. The supplementary charges are based on calculations made in Feb. 1943 for Motor Petrol or Aviation Petrol.

2. The rates for wage earners average 1 RM/hr. Owing to surcharges for holidays-with-pay, payment during illness, etc, the actual running cost rate averages 1.17 RM/hr. In peace time this surcharge was less. In the repair charges the payment for unworked hours has been included in the Workshops charges; the hourly rate of 1.20 RM/hr, therefore, is the actual rate of payment.

3. In a modern plant it is estimated that the Wages, Energy Requirements and Repair Charges would be 10-20% less.

TABLE III

BUILD-UP OF HYDROGENATION COSTS
(Based on values of Nov.1943 and a Motor Fuel Production of 72.40 Tnes/hr)

	Coal - Steam Drying		Coal - Gas-fired Drying		Paste Preparation		Paste Injection		Coal Stalls		H.O.L.D. Fugals	
	Qty/hr	RM/h.	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr.
01. Wages		23.69		90.20		51.31		34.84		78.73		22.69
Wages to IG workers Hrs.	12.73	15.42	48.40	60.96	27.42	33.42	22.92	27.32	51.33	61.87	12.38	14.52
" "foreign " "	4.37	3.50	11.66	11.74	6.10	6.13	0.24	0.20	0.02	0.02	3.86	3.55
Salaries		3.40		12.67		8.81		4.98		11.53		3.34
Social Insurance, &c.		1.37		4.83		2.95		2.34		5.31		1.28
02. Energy Costs		96.73		236.98		78.47		97.86		256.13		17.26
L.P.Water (Take M³ / Cr. M³)	1.47	0.01										
H.P.Water "			0.47	0.01	6.66	0.10	238.93	3.53	1895.48	27.98	6.67	0.10
Drinking Water "	0.93	0.09	2.52	0.24								
Cooling Water (Take " / Cr. ")									302.64	10.14		
Condensate, Oil free"	35.82	9.29	0.34	0.09								
" Oily "					4.51	0.61	0.53	0.07	7.49	1.01	1.31	0.18
H.P.Steam Tne.	3.35	10.15	0.57	1.73	12.65	38.31			12.83	38.85	6.31	19.11
Back Pressure Steam."			0.35	0.69	3.89	7.78					3.11	6.23
L.P.Steam "	37.88	85.24	0.93	2.08	2.19	4.93	1.29	2.91	5.39	12.13		
H.T.Electricity KWH	20.20	0.30	2760.56	41.71	1222.19	18.46	5971.41	90.20	1112.28	16.80	185.65	2.85
L.T. " Power "	137.25	2.84	471.76	9.76	443.90	9.19	56.56	1.17	42.28	0.87	68.89	1.43
" " Light "	8.81	0.18	32.28	0.67	11.20	0.23	5.87	0.12	2.04	0.04	2.33	0.05
Fuel Gas M³			3385.25	30.06					19283.33	170.52		
Workshops Gas. "											0.43	0.01
Nitrogen 90lbs/in²"	263.89	4.30	45.25	0.74	866.53	4.13						
CO_2 7 lbs/in² "	3020.06	2.60	5686.36	4.90	1754.30	1.51			55.34	0.06	191.89	0.17
Towns Gas "												
Acetylene "												
Compressed Air "	90.65	0.31	1921.90	6.40					10.18	0.03		
Raw Brown Coal Kg			45062.94	139.46								
Bit. Coal and Coke"												
03. Repair Costs		27.86		95.86		173.79		37.93		346.81		38.22
Foreign Wrkrs.Wages Hrs.	0.63	1.04	6.88	8.96	0.45	0.55	0.07	0.07	0.59	0.64	0.92	1.83
" " Material & oncosts. Hrs		0.04		5.20		42.20		8.41		10.95		2.72
Stores Material		1.11		7.76		8.53		2.37		50.43		3.02
" " supplement		0.18		1.27		1.38		0.30		8.29		0.49
Workshops Wages. Hrs.	8.73	10.73	24.38	29.79	38.12	46.09	8.29	10.09	82.82	99.98	9.74	11.63
Workshops Costs.s'ment		14.69		41.95		72.50		16.53		170.98		18.26
Repairs-Transport charges.		0.07		0.93		2.54		0.07		5.54		0.27
04. Running Materials		0.65		3.27		11.32		0.66		1.33		1.40
Materials		0.59		2.86		11.00		0.57		1.31		1.24
Stores supplement		0.06		0.41		0.32		0.09		0.02		0.16
05. Traffic Costs		0.02		12.05		41.84		0.10		1.21		0.78
06. Works General Charges		9.28		35.06		22.21		14.14		37.16		9.26
Wage & Salary s'ment.		7.02		26.83		15.12		10.01		22.73		6.74
Fire Brigade		1.50		5.68		1.63		0.79		7.14		0.61
Post Office Costs.		0.76		2.55		5.46		3.34		7.29		1.91
07. Capital Charges		20.60		145.83		68.17		15.49		168.21		23.29
Writing off.		15.68		113.00		50.69		12.94		142.04		18.94
Interest		4.74		32.83		17.48		2.55		26.17		4.35
08. Taxes		4.93		21.18		11.98		6.40		17.79		4.76
09. Various Costs.		2.14		59.23		8.68		0.37		24.39		7.59
Laboratory		2.02		20.71		7.70				23.84		7.17
Other Costs.		0.12		0.68		0.98		0.37		0.55		0.42
Raw Material Stores				37.84								
Part cost Pipe-Bridges												
" " Factory Wtr. System				43.76								
" " Tip Charges				4.43								
10. Credits												
Production: Total:		185.90		747.85		467.67		207.79		931.76		125.25

TABLE III (Cont'd)

	Unit	H.O.L.D. Kilns Qty/hr	H.O.L.D. Kilns RM/hr	Tar Pumps Qty/hr	Tar Pumps RM/hr	Liquid Phase Distillation Qty/hr	Liquid Phase Distillation RM/hr	Gas Washing Plant Qty/hr	Gas Washing Plant RM/hr	Circulation Qty/hr	Circulation RM/hr
01. **Wages.**			77.80		21.38		21.66		23.37		20.86
Wages to DG workers.	hrs	43.75	51.93	13.36	15.94	12.35	14.83	12.60	14.80	11.89	13.89
" " Foreign "	"	14.83	15.31	3.19	3.28	0.80	0.92	1.03	0.99	1.92	1.83
Salaries			6.71		3.75		4.55	0.003	6.02	0.009	3.67
Social Insurance etc.			4.34		1.41		1.35		1.42		1.2[illegible]
02. **Energy Costs**			388.79		21.84		230.08		23.84		152.7[illegible]
L.P. Water {Take	M³										
L.P. Water {Cr.	"										
H.P. Water	"	566.20	8.36	23.79	0.35	540.62	7.98	13.67	0.20	11.95	0.16
Drinking Water	"	0.52	0.03			0.96	0.09				
Cooling Water {Take	"										
Cooling Water {Cr.	"										
Condensate - Oil free	"										
" Oily	"	14.86	1.93	2.92	0.40	1.87	0.25	0.17	0.02	12.17	1.62
H.P. Steam	Tns	8.86	26.82	3.93	10.68	1.12	3.40	2.16	6.61	28.45	96.17
Back Pressure Steam	"							1.96	3.92		
L.P. Steam	"	25.79	58.05	3.59	8.08	8.64	19.44	0.20	0.45	1.05	2.37
H.T. Electricity	KWH	180.34	2.72	3.21	0.07	1116.73	16.87	1330.07	20.08	2957.83	44.68
L.T. " Power	"	67.64	1.40	198.20	4.10	118.69	2.46	10.87	0.23	45.55	0.94
" " Light	"	0.71	0.04			0.47	0.01	2.02	0.04	2.03	0.05
Fuel Gas	M³	23431.90	208.10			19721.42	174.96				
Workshops Gas	"					6.90	0.46				
Nitrogen 90lbs/in²	"					304.20	4.96				
CO_2 7 lbs/in²	"	205.61	0.18	410.69	0.36			10.52	0.17		
Towns Gas	"										
Acetylene	"										
Compressed Air	"	9.25	0.03								
Raw Brown Coal	Kg.										
Bit.Coal & Coke	"										
03. **Repair Costs.**			143.23		21.66		62.80		50.54		55.50
Foreign workers wages	hrs.	0.73	1.35			2.32	3.90	0.20	0.37	0.01	0.01
" " material & oncosts.			6.80		0.56		5.00		3.04		5.02
Stores Material			14.12		1.71		1.44		5.32		6.43
" " supplement			2.30		0.27		0.17		0.85		1.06
Workshops wages.	hrs.	38.36	45.51	5.76	7.08	16.50	17.68	13.08	15.31	13.56	15.62
" costs supplement			71.22		11.62		50.94		25.90		26.58
Repairs - Transport charges.			1.93		0.36		0.77		0.15		0.18
04. **Running Materials**			4.46		0.85		1.17		0.85		3.44
Materials			3.96		0.76		1.05		0.74		2.97
Stores supplement			0.50		0.09		0.12		0.11		0.43
05. **Traffic Costs**			32.50		0.33		0.04		0.04		0.06
06. **Works General Charges**			36.04		8.09		10.16		10.02		7.96
Wage & Salary S'vent.			22.94		7.21		6.25		6.70		4.10
Fire Brigade.			2.64		0.14		1.64		2.09		1.81
Post Office Costs			10.45		1.73		2.27		1.25		2.05
07. **Capital Charges**			115.99		3.52		48.21		57.78		42.44
Writing off			94.12		2.64		42.10		50.15		37.67
Interest			21.87		0.88		6.11		7.63		12.77
08. **Taxes**			16.84		4.55		4.97		5.46		5.93
09. **Various Costs**			10.84		26.10		9.02		1.33		4.20
Laboratory			3.69		3.29		0.91		1.31		
Other Costs			7.15		0.67		0.10		0.02		
Raw Material Stores					22.14		8.04				0.28
Part Cost Pipe Bridges											
" " Factory Ttr. System.											
" " Tip charges.											
10. **Credits**											
Production: Total:			801.51		113.70		380.10		173.57		274.6[illegible]

TABLE III (Cont'd)

	Vapour Phase Injection		Vapour Phase Stalls		Vapour Phase Distillation		Petrol Wash		Depropanising Plant	
	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr
01. **Wages.**		21.70		48.72		27.96		2.61		9.13
Wages to IG workers hrs.	13.82	16.52	30.70	37.08	16.22	19.75	1.69	1.98	7.05	8.47
" " foreign " "	0.14	0.12	0.01	0.01	0.45	0.44				
Salaries	0.002	3.63	0.004	8.40	0.002	5.98		0.46		
Social Insurance etc.		1.43		3.23		1.79		0.17		0.66
02. **Energy Costs**		33.50		83.87		176.00		11.42		24.40
L.P. Water (Take) M³										
L.P. Water (Gr.) "										
H.P. Water "			1817.18	26.83	529.40	7.82	126.75	1.87	32.34	0.48
Drinking Water "					3.93	0.37				
Cooling Water (Take) "										
Cooling Water (Gr.) "			293.77	9.85						
Condensate. Oil free "										
" Oily "	0.87	0.12	0.21	0.03	1.80	0.24	1.71	0.23	3.02	0.41
H.P. Steam Tns	21.20	64.19	0.51	1.55	2.85	8.62			7.36	22.29
Back Pressure Steam "	19.07	38.13								
L.P. Steam "					7.31	16.45	4.15	9.34		
H.T. Electricity. KWH	488.27	7.38	1784.68	26.96	570.90	8.62				
L.T. " Power "			40.83	0.84	490.26	10.15	17.64	0.36	98.00	2.03
" " Light "	5.55	0.11	1.96	0.04	5.68	0.12	3.92	0.08	0.39	0.01
Fuel Gas M³			4244.73	37.39	13598.41	120.77				
Workshops Gas "			3.76	0.09	54.03	1.28				
Nitrogen 90 lbs/in² "					12.23	0.20				
CO_2 7 lbs/in² "	80.58	0.07	21.85	0.02						
Towns Gas "										
Acetylene "										
Compressed Air "			9.77	0.03	554.19	1.84				
Raw Brown Coal Kg										
Bit. Coal & Coke "										
03. **Repair Costs**		36.98		214.99		28.24		6.97		20.53
Foreign workers wages hrs.	0.22	0.29	0.25	0.26	0.21	0.26			0.21	0.22
" " material & oncosts		3.64		12.16		0.38		3.68		0.03
Stores material		4.95		64.97		1.29		0.17		1.42
" " supplement		0.83		10.88		0.22		0.03		0.21
Workshops wages hrs.	8.55	10.44	36.19	43.21	8.48	10.26	1.07	1.26	5.59	6.83
" costs supplement		16.61		82.19		15.07		1.83		10.64
Repairs - Transport charges.		0.22		1.32		0.76				1.18
04. **Running Materials**		2.93		3.76		0.64				
Materials		2.52		3.39		0.55				
Stores supplement		0.41		0.37		0.09				
05. **Traffic Costs**		0.05		1.37		0.13				0.04
06. **Works General Charges**		10.79		28.77		13.07		0.99		2.90
Wage & salary s'ment.		6.37		14.03		8.04		0.75		2.68
Fire Brigade		0.96		8.50		2.15		0.09		0.22
Post Office costs		3.46		6.24		2.88		0.15		
07. **Capital Charges**		17.54		179.66		27.98		2.62		8.49
Writing Off		14.52		150.48		22.84		1.88		7.57
Interest		3.02		29.18		5.14		0.74		0.92
08. **Taxes**		4.33		13.13		6.90		0.65		1.69
09. **Various Costs**		0.28		39.34		2.58		0.88		0.22
Laboratory		0.02		27.34		2.21		0.88		0.01
Other Costs		0.26		1.09		0.37				0.21
Raw Material Stores				10.91						
Part Cost Pipe-Bridges										
" " Factory Wtr. System										
" " Tip Charges										
10. **Credits**						etc 0.01				
Production: Total:		128.11		613.61		283.49		26.14		67.40

TABLE III (Cont'd)

	[illegible] Purification		Rich Gas Fractionation		Petrol Testing		[illegible] Intermediate Storage		[illegible] Intermediate Storage	
	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr
01. Wages		20.97		40.11		0.76		[illegible]		3.3[illegible]
Wages to ID workers-hrs.	8.60	[illegible]	24.47	35.34			10.15	42.01	2.18	2.43
" " foreign " "	3.94	4.06	0.55	0.44						
Salaries	0.00[illegible]	4.28	0.004	7.70		4.72	0.001	2.93		0.69
Social Insurance etc.		0.99		2.63		0.04		1.06		0.21
02. Energy Costs		452.77		294.30		0.15		75.26		13.34
Low Pressure Water (Indust.)	735.00	5.35								
(Dr.)	18.75	0.02								
High Pressure " m³	67.21	0.99	5685.55	55.90	5.49	0.08	14.35	0.21	1.42	0.02
Drinking Water "	0.86	0.02								
Cooling Water (Tube "										
(Dr. "										
Condensate - Oil free "										
" - Oily "	1.35	0.24	17.49	2.34	0.01					
High Pressure Steam "	42.74	90.87	99.78	302.17			9.41	3.27	2.61	0.7[illegible]
Back " " "	36.94	73.87	47.94	94.08			14.46	43.79	9.44	16.47
Low " " "	36.40	32.16	1.48	10.05			0.57	1.13		
H.T. Electricity KWH			857.44	16.10	0.03	0.06	8.92	20.06	0.89	1.99
L.T. " Power "	557.77	7.41	429.15	8.67	0.30	0.04	219.20	3.31		
" " Light "	1.16	0.02	4.21	0.09	0.04		535.51	6.94	57.06	1.19
Fuel Gas m³							0.55	0.01		
Workshops Gas "										
Nitrogen 90 lbs/in² "	5.08	0.08					32.42	1.34		
CO_2 / lbs/in² "	37.47	0.05								
Towns Gas "										
Acetylene "										
Compressed Air "	6.94	0.02	64.15	0.20						
Raw Brown Coal Kg									6.87	0.02
Bit. Coal & Coke "										
03. Repair Costs		37.61		42.31		3.31		25.40		6.64
Foreign Workers wages. hrs.	0.30	0.42	0.31	0.31			0.26	0.26		
" " material & concats.		0.76		0.35		0.01		2.84		
Stores Material		3.46		2.67		0.01		0.46		0.28
" " supplement.		0.74		0.76				0.05		0.05
Workshops Wages. hrs.	10.53	12.47	12.34	14.40	1.03	1.27	6.91	8.19	2.00	2.49
" Costs supplement.		19.76		25.26		2.02		12.54		3.81
Repairs - Transport charges.		0.42		0.36				0.11		0.01
04. Running Materials		1.04		1.46		1.00		0.39		0.01
Materials.		1.03		1.45		1.00		0.33		0.01
Stores supplement		0.01		0.01				0.06		
05. Traffic Costs		0.61		2.58		0.04		0.18		
06. Works General Charges		8.62		16.59		0.23		6.66		1.46
Wage & Salary a'ment		7.41		13.14		0.20		4.60		0.98
Fire Brigade		1.00		2.34		0.02		0.87		0.48
Post Office Costs		0.21		1.11		0.01		1.19		
07. Capital Charges		42.34		101.92		0.63		20.88		4.67
Writing off		32.59		78.30		0.49		17.51		3.92
Interest		9.75		23.62		0.14		3.37		0.75
08. Taxes.		4.71		9.88		0.17		3.36		0.73
09. Various Costs		21.82		14.10		0.02		1.70		0.46
Laboratory		7.25		6.22		0.02		1.37		0.86
Other Costs		0.16		0.79				0.33		
Raw Material Stores		0.41		0.09						
Part cost Pipe-Bridges		5.80						6.46		4.31
" " Factory Wtr System		1.82								
" " Pip charges										
10. Credits	Transferred to [illegible] Catalyst Plant [illegible] gas [illegible]			2.47						
Production: Total:		286.22		524.18		6.27		152.23		41.43

TABLE III (Cont'd)

	Hydrogenation Drain Wtr. Treatment		Hydrogenation Phenol Separation		Hydrogenation Phenol Washing		Total	
	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr
01. Wages		3.39		2.02		11.28		677.62
Wages to IG workers.hrs.	0.21	0.28	1.11	1.15	6.00	7.23	391.21	470.54
" " foreign " "	1.61	1.55					56.30	54.11
Salaries		1.47		0.74		3.35		111.98
Social Insurance etc.		0.09		0.13		0.70		40.99
02. Energy Costs.		3.54		6.15		19.20		2394.99
Low Pressure Water (Take M³					356.64	2.60	1093.11	7.96
Low Pressure Water (Cr. M³					351.32	1.60	371.09	1.69
High Pressure Water M³							9522.11	140.59
Drinking Water "					0.15	0.01	9.07	0.85
Cooling Water (Take "			2.66	0.10			2.66	0.10
Cooling Water (Cr. "							596.41	19.99
Condensate - Oil free "					3.82	1.11	39.98	10.49
" Oily "	0.23	0.03					84.28	11.59
High Pressure Steam the	0.37	1.13			5.58	16.90	280.15	849.77
Back " " "							112.93	225.83
Low " " "	0.41	0.09	0.58	1.30	0.14	0.03	150.54	337.19
H.T. Electricity KWH			53.11	0.80			15460.47	317.86
L.T. " Power "	113.67	2.35	0.46	0.01	75.10	1.55	3667.38	75.90
" " Light "			1.17	0.02	0.95	0.02	93.74	1.92
Fuel Gas M³							83665.04	741.80
Workshops Gas. "							65.72	1.54
Nitrogen 90 lbs/in² "					43.50	0.71	2633.62	26.63
CO_2 7 lbs/in² "			3240.38	2.79	10.53	0.01	14735.06	12.72
Towns Gas "			16.48	0.47	0.27	0.01	16.75	0.48
Acetylene "								
Compressed Air "			196.89	0.66	22.21	0.07	2881.04	9.61
Raw Brown Coal Kg							45062.94	139.46
Bit. Coal & Coke "								
03. Repair Costs		7.18		1.31		12.42		1496.85
Foreign Works Wages. hrs.	0.17	0.18					14.73	20.82
" " material & oncosts.		0.86		0.08		0.53		116.26
Stores material		0.95		0.06		0.98		188.19
" " supplement.		0.15		0.01		0.15		30.60
Workshops Wages hrs.	1.62	2.00	0.41	0.49	3.52	4.37	357.24	430.79
" Costs supplement.		3.04		0.67		6.30		698.31
Repairs - Transport Charges.						0.09		16.88
04. Running Materials		0.25		0.70		16.04		57.63
Materials		0.22		0.68		15.96		54.19
Stores supplement		0.03		0.02		0.08		3.44
05. Traffic Costs						0.24		154.53
06. Works General Charges		1.34		0.77		3.42		297.93
Wage & Salary supplement.		1.03		0.77		3.20		200.62
Fire Brigade.		0.27		0.20		0.19		42.37
Post Office Costs.		0.04				0.03		54.34
07. Capital Charges		10.25		4.63		5.20		1139.34
Writing off.		7.94		3.83		4.08		921.10
Interest.		2.31		0.80		1.12		218.24
08. Taxes		1.01		0.48		2.21		154.04
09. Various Costs		7.72				0.39		228.86
Laboratory		7.38				0.04		134.24
Other Costs		0.34						14.87
Raw Material Stores						0.35		79.75
Part cost Pipe-Bridges								16.66
" " Factory Wtr. System		26.28						73.86
" " Tip charges.								4.43
10. Credits.			For H_2S make 1 Tne Cal.	7.04	For Creosote Oil "S" Kg.	49.79		59.31
Production: Total:		60.96		9.02		20.61		6637.43

[redacted]

TABLE IV

Extra Charges for Aviation Petrol.

	Circulation		Vapour Phase Injection		Vapour Phase Stalls		Vapour Phase Distillation		Rich Gas Fractionation		Total	
	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr.
01. **Wages**				5.59		12.54						18.13
Wages to IG workers hrs.			3.56	4.25	7.90	9.54					11.46	13.79
Wages to foreign workers, hrs.			0.04	0.03							0.04	0.03
Salaries.				0.93		2.16						3.09
Social Insurance etc				0.38		0.84						1.22
02. **Energy Costs**		10.23		8.62		21.59		40.62		37.69		118.75
L.P. Water (Take M^3												
L.P. Water (Or. M^3												
H.P. Water "	0.92	0.01			467.74	6.91	122.17	1.80	497.79	7.35	1088.62	16.07
Drinking Water "							0.91	0.09			0.91	0.09
Cooling Wtr (Take "												
Cooling Wtr (Or. "					76.62	2.53					75.62	2.53
Condensate, Oil free "												
" Oily "	0.94	0.13	0.22	0.03	0.05	0.01	0.42	0.06	2.91	0.39	4.54	0.62
H.P. Steam. Tns.	2.19	6.65	5.46	16.51	0.13	0.40	0.66	1.99	14.61	44.25	23.05	69.80
Back Pressure Steam "			4.91	9.81					7.82	15.64	12.73	25.45
L.P. Steam. "	0.08	0.10					1.69	3.80	0.28	0.59	2.05	4.57
H.T. Electricity KWH	227.82	3.45	125.68	1.90	459.38	6.94	131.75	1.99	46.78	0.71	991.41	14.99
L.T. " Power "	3.52	0.07			30.51	0.22	113.14	2.34	37.55	0.78	164.72	3.41
" " Light "			1.43	0.03	0.50	0.01	1.31	0.03	0.70	0.01	3.94	0.08
Fuel Gas M^3					1092.59	9.62	3138.11	27.86			4230.70	37.48
Workshops Gas. "					0.97	0.02	12.47	0.30			13.44	0.32
Nitrogen. 90lbs/in² 10^3							2.82	0.05			2.82	0.05
CO_2 7 lbs/in² "			20.74	0.02							20.74	0.02
Towns Gas. "												
Acetylene "												
Compressed Air "					2.51	0.01	127.89	0.45	10.34	0.03	140.74	0.47
Raw Brown Coal. Kg												
Bit. Coal & Coke "												

TABLE IV (Cont'd)

	Circulation		Vapour Phase Injection		Vapour Phase Stalls		Vapour Phase Distillation		Rich Gas Fractionation		Total	
	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr	Qty/hr	RM/hr
03. Repair Costs				9.52		55.34						64.86
Foreign Workers Wages. hrs.			0.06	0.07	0.06	0.07					0.12	0.14
" " Material & Oncosts. hrs.				0.94		3.13						4.07
Stores material				1.28		16.72						18.00
" " supplement.				0.20		2.80						3.00
Workshops Wages. hrs.			2.20	2.69	9.31	11.12					11.51	13.81
Workshops Costs Supplement.				4.28		21.16						25.44
Repairs - Transport chrgs.				0.06		0.34						0.40
04. Running Materials				0.75		0.97						1.72
Materials				0.65		0.87						1.52
Stores supplement				0.10		0.10						0.20
05. Traffic Costs				0.02		0.35						0.37
06. Works General Charges				2.78		7.40						10.18
Wages & Salary supplement.				1.64		3.61						5.25
Fire Brigade				0.25		2.19						2.44
Post Office Costs.				0.89		1.60						2.49
07. Capital Charges				4.52		46.24						50.76
Writing off				3.74		38.73						42.47
Interest				0.78		7.51						8.29
08. Taxes				1.11		3.38						4.49
09. Various Costs				0.07		10.13						10.20
Laboratory						7.04						7.04
Other Costs				0.07		0.28						0.35
Raw Material Stores						2.81						2.81
Part cost Pipe-Bridges												
" " Factory water system												
" " Tip charges												
10. Credits												
Production Total:		10.23		32.98		157.94		40.62		37.69		279.46

F. Hydrogenation Costs.

On the instructions of the Ministry of Fuel & Power a special effort was made to get detailed information on the economics of the hydrogenation activities at Leuna. During our visit, Dr.Pichler went through the whole of the available records and made the following summary of brown coal hydrogenation costs.

Figs. VIII to XI present the basic flowsheet data for hydrogenation of brown coal to motor and aviation petrols using the latest Leuna high throughput conditions. They are typical of the Leuna operations during 1943 and early 1944.

Table I gives an analysis of the cost of production of motor and aviation petrols according to these flowsheets in terms of raw material costs, operating costs and capital charges, credits for hydrocarbon gases being taken into account.

Table II shows a breakdown of the operating costs in terms of operating labour, labour and materials for repairs, electric power, fuel gas, steam, etc. "Overhead charges" and obsolescence are shown as part of the operating cost. Labour is given in man/hours and consumptions of the various utilities are also quoted so that it is an easy matter to translate these costs to apply to British or American conditions.

Table III gives a still more detailed breakdown of operating costs for production of motor petrol by providing a detailed analysis of the costs in each section of the plant, e.g. coal drying, coal pasting, liquid phase coal hydrogenation, presaturation, splitting hydrogenation, etc.

Table IV shows the costs additional to those set out in Table III which are incurred when aviation base petrol is made.

These cost data will be analysed in a later report.

It is interesting to note that although the full cost of production of aviation base petrol was only 200 RM/Ton, the Leuna realisation was stated to have been 340 RM for this grade and 310 RM for motor gasoline. On the basis of these figures, the I.G. had a profit margin of about 80×10^6 RM/year in respect of Leuna hydrogenation activities alone. Dr.Pichler said that this very high return was allowed in order to compensate the I.G. for its heavy expenditure in developing the hydrogenation process.

FIG XII FLOWSHEET FOR D.H.D.

BASED ON ACHIEVED RESULTS 1ST QTR 1944.

ALL FIGURES TNES/HR EXCEPT WHERE STATED.

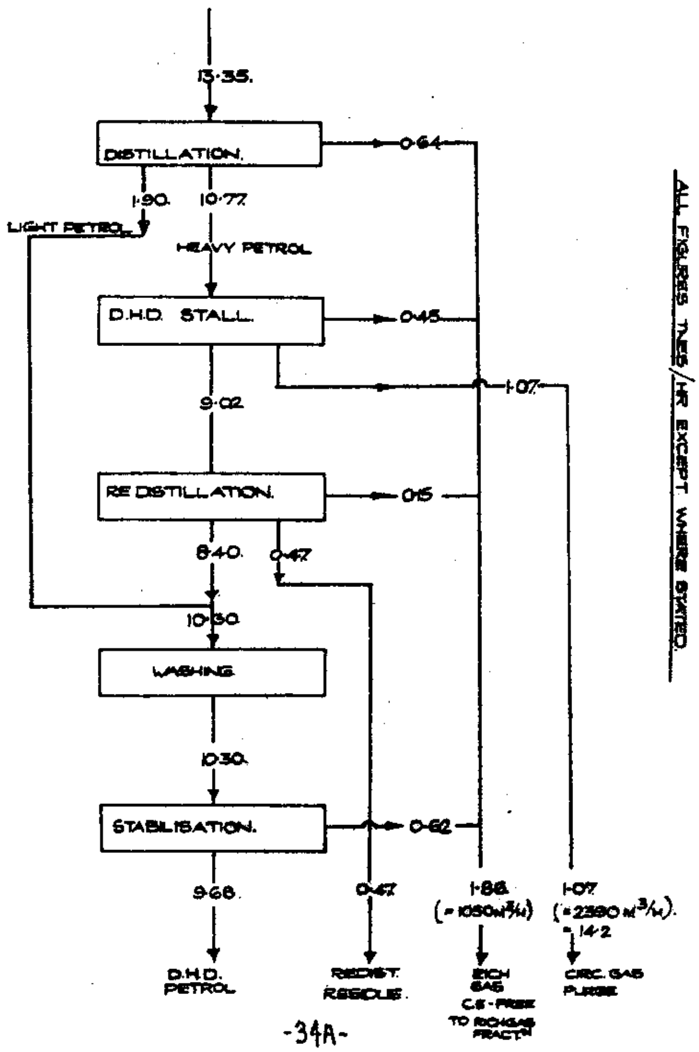


FIG. XIII

FLOW DIAGRAM. D.H.D PROCESS.