During this period the use of oxygen for welding was growing and, of course, has continued to the present. Something more than 900 separate plants for nitrogen and/or oxygen manufacture have been built by the Linde Company from 1903 to the present.

The field of application of oxygen for process purposes has been materially expanded by the development of the so-called Linde-Frankl process. The fundamental difference between this process and the older Linde method of manufacturing nitrogen and oxygen is that regenerators rather than tubular exchangers are used to reduce the energy requirement for the air liquefaction process. The change simplifies and cheapens the production of moderately pure oxygen (e.g. 98%) to an extent not likely to be fully appreciated without detailed study. The process, however, is not usable alone, for the production of a higher purity oxygen than 98%, for reasons which will become apparent later.

C. ORIGINAL PROCESS - LINDE COMPANY

For completeness the reader is reminded that the original Linde process for liquefaction of air depends on the so-called Joule-Thompson effect, whereby air under high pressure when throttled through a valve will show a temperature reduction. The amount of temperature reduction with an adiabatic system is a function of initial temperature as well as pressure.* By arranging for continuous heat exchange between incoming high pressure air and outgoing air after throttling expansion, progressive decrease in absolute temperature can be effected until finally part of the outgoing air will be sufficiently cooled to precipitate as liquid phase.

Commercial application of the phenomena involves introduction of all practical means to -

(1) prevent the entrance of heat from outside the apparatus;
(2) effect heat exchange between streams circulating within the equipment;
(3) purify the air prior to processing so that traces of disturbing impurities do not interfere with the continuous operation.

* The data for the phenomenon, said to be used by the I.G. Farben, are given in Fig. 9 herein. These data were not obtained during the Linde Co. visit, but were abstracted from unpublished(?) I.G. Farben reports.

The separation of the liquefied air, which is of course, a mixture of about 20 wt. per cent liquid oxygen, and 80 wt. per cent liquid nitrogen, is effected by continuous distillation. The separation does not differ in principle from ordinary continuous fractional distillation except as is dictated by the circumstance that the temperature of separation is some 200° C. below the general surroundings. It is well known, of course, that the thermodynamic efficiency of a process is improved if small temperature differences only are caused to exist when heat exchange or conversion is involved. Usually, however, the investment required to obtain such conditions is not justified. In the liquid air field, however, the operating costs involved in attaining the low temperature level required, justify the large capital expenditure, so that the above mentioned principle is demonstrated on larger scale in this field, perhaps, than in any other field of commercial manufacture.

In describing the original Linde process above, compression of all the air to the highest required pressure was contemplated. It was pointed out long ago, however, by Lackman that the requirements of the distillation separation of air were such that only part of the air need be compressed to a high pressure and expanded. The rest of the air can be compressed to moderate pressures and cooled by heat exchange to a low temperature and then directly introduced into the fractionation equipment. Due to the low pressure drop characteristic of Frankl heat regenerators, the Linde-Frankl process can make use of this fact very effectively as will be later indicated, so that only a small portion of the total air liquefied is compressed to high pressure.

D. THE LINDE-FRANKL PROCESS - DESCRIPTION

The Frankl regenerators utilize the well-known principle of exchanging heat between gas streams by alternately heating and cooling solids packed in a tower through passage first of one gas and then the other through the packing. Four regenerators are used in the Linde-Frankl process--two on the cold nitrogen and two on the cold oxygen gas--as these gases emerge separately from the process equipment. Each of the regenerators is in turn used to cool incoming air at a pressure of about 4.5 Atmos. gauge. The timing of the cycle is adjusted with reference to the volume of the regenerators and the mass of packing material such that the temperature fluctuations at the upper and lower ends of the regenerators or "accumulators" are not too great.

The packing which has proved best for the accumulators, both from the standpoint of heat storage and also from the requirement of low pressure drop, is that proposed by Frankl. It consists of porous "pancakes" about one inch thick and of such diameter as to fit closely within the regenerator vessel. In making up such pancakes, two 1-inch strips of aluminum sheet each with corrugations or riffles at an angle of 45° to the center line are laid together so that the corrugations are at right angles. The strips are thus held apart about 1/8" except at a series of points where they touch at the top of the corrugations. When the "strip pair" is wound up into a 1-inch flat spiral, the above mentioned circular pancake is formed and is thereafter held together by clamping wires. Figure 1a will make the construction clear. In packing the regenerator shell, a series of these pancakes is inserted, each laid flat on the one next below, until the regenerator vessel is finally filled as required. The assembly of the porous pancakes is such that a myriad of gas channels is presented for gas flow in the direction of the axis of the chamber. Altogether it is possible to arrange matters so that more than 1,000 square meters of heat exchange surface is presented by one cubic meter of the assembled packing.

Before describing the process for producing 98 to 99% oxygen, it should be stated that a number of different designs have been and are used according to the size of plant, cost of power, and needs of a specific installation. This description is based on the accompanying flow sheet, Fig. I, stated by the Linde Company to be one of the more useful of the several variations of the process. Other schemes of operation using Frankl regenerators will probably be clear, once the principle of use in the following case is understood.

Referring now to the flow sheet (Fig. I), the following describes the operations after the equipment is in temperature equilibrium. The turbo compressor shown at the lower right compresses all of the air which is to be processed, to about 4.6 atmos. gauge, after which the stream is cooled indirectly by the adjacent water cooled surface. About 95% of this compressed and cooled air is then led through the cold accumulators of Frankl design. The cooling in the Frankl accumulator precipitates water vapor and carbon dioxide on the extended packing surfaces and the air finally reaches liquefaction temperature before passing out and into the bottom of the pressure fractionating column, (1), operating at about 4.4 atmos. gauge. Liquid containing about 39% oxygen is drawn off from the base of this fractionating column

and sent under its own pressure through a filter, (2), to remove traces of ice and/or solid carbon dioxide. The filtered liquid then passes to a point in the upper fractionating column where the mixture composition corresponds to that mentioned above.

The upper column operates at about 0.2 atmos. above normal pressure and separates the feed liquid by nitrogen reflux at the top into "pure" gaseous nitrogen at the top and "pure" liquid oxygen at the bottom. (NB--Boiling points at atmospheric pressure are as follows: Nitrogen = -195.8° C; Oxygen = -183.0° C).

The heat for fractionation in the low pressure (upper) column comes from the condensation of gaseous nitrogen rising to the top of the pressure column directly below. The tubular heat exchanger at the base of the upper column, and integral with the top of the lower column, thus has a double purpose. It supplies the heat for fractionation in the upper column and furnishes the reflux nftrogen liquid for the lower column, the heat exchange being made possible because of the "inversion" of temperature caused by the pressures chosen for the two columns. Part of the condensed nitrogen liquid at the top of the lower column, where it serves as reflux and is in turn flash vaporized to form the above-mentioned pure gas product. This nitrogen gas leaves the system by way of the Frankl regenerator assigned to nitrogen service at a temperature only 3°- 4° C below surrounding temperature.

The boiling liquid at the base of the upper column is substantially pure oxygen, and the proper proportion of the gas rising therefrom is deflected as oxygen product through the corresponding one of the Frankl regenerators. It emerges from the Frankl as the product stream of oxygen and at only 3 or 4° C below atmospheric temperature.

Each of the product streams, i.e., the "pure" nitrogen and the "pure" oxygen, remove by evaporation from the corresponding Frankl regenerator, the ice and solid carbon dioxide left from cooling of the incoming air in the previous phase of their operation. Thus each of the Frankl regenerators is not only again reduced in temperature, but is also put in a clean condition for good heat transfer, as well as for the further removal of water vapor and carbon dioxide from air led through in the next succeeding cycle. The evaporation of solids is complete enough so that, ideally, there is no need ever to remove the precipitated components by allowing the Frankls to

warm up. In actual practice, it often happens that several months elapse between such cleaning periods.

It should be noted, however, that the purity of both the oxygen and the nitrogen is somewhat impaired by the evaporation of the solids just mentioned, and also by the addition of the inevitable residue of air which is left in the regenerators after the air cooling part of the cyclic operation. Both sources of impurity are reduced in part by venting the pressure air before introducing the cold product streams, and sometimes by further venting the initial "pure" products, either wasting them entirely, or under certain conditions, passing them back to the process. It is obvious that many combinations of factors, such as cost of operation, relative value of higher vs. lower purity gases, undesirability of introducing too much water and carbon dioxide back into the system, etc., find interplay, together with the prejudice of operators, to effect many variations in actual practice at this point. In any case, however, the cycle is under the action of controllers, and when once manually set up proceeds with intermittent attention of the operators only. It is, however, quite impossible by any variation of the details of operation to attain the highest purity of products when the Frankl regenerator system is used as described.

It should be emphasized, however, that one of the important advantages of the Linde-Frankl scheme is directly connected with the disadvantage in respect to purity of products just mentioned. The offsetting advantage is that the inlet air to the process (with the exception of a small proportion to be presently mentioned) does not need to be scrubbed free of carbon dioxide and water vapor, such as is invariably necessary to prevent fouling stoppages when the older tubular type heat exchange is employed. A second advantage accrues from the very low pressure drop which can be secured with the Frankl regenerators in comparison to tubular exchangers effecting the same heat exchange at small temperature differences. Thus with the Frankl equipment it is not necessary to compress the gas initially to as high an intermediate pressure before cooling and introducing it to the fractionating column as would be the case if tubular exchangers were used.

It will be apparent that the process as described up to this point does not provide for the actual low temperature cooling required to overcome losses and inefficiency in operations. This is obtained by high pressure air liquefaction as follows: A relatively small high pressure compressor (extreme lower left of

the flow diagram, Fig. 1, takes suction on the cooled product from the after-cooler of the turbine air compressor and deflects to itself some 4.5% of this 4.6 Atmos. pressure air after drawing it through an alkali washer to remove carbon dioxide and most of the water vapor. The purified air is then compressed to about 180 Atmos. and thereafter is first water cooled and then cooled indirectly by ammonia refrigeration. (NB--The ammonia system is entirely separate from the rest of the equipment.) The refrigerated air passes through to two interchangers, Nos. 5 and 6, which together cool it to such a temperature that, after expansion, into a point near the middle of the upper (low pressure) fractionating column, it liquefies completely.

The low temperature cooling fluid for exchangers 5 and 6 is part of the liquid nitrogen from the top of the pressure column drawn through leveling pot 3. This liquid nitrogen, amounting to some 15% of the total weight of air being processed, is gasified and slightly superheated in passage through exchanger 6, after which it is expanded--without condensation--in the small expansion turbine (at the extreme right and middle of the diagram). Expansion is from the 4.3 - 4.2 Atmos. gauge, maintained in the lower column, to the 0.2 - 0.15 Atmos., gauge, employed in the upper column. The expanded nitrogen, recooled by the process of the expansion itself, passes through tubular exchanger 5 and to the atmosphere--or, more usually, is combined with cold nitrogen going to the Frankl. It may, however, be taken as a small stream of pure nitrogen product.

It must be noted that the necessity for removal of carbon dioxide prior to high pressure compression of the small stream of gas just described is due to the fact that tubular exchangers, 5 and 6, must be used in place of Frankl regenerators. This is necessary since the heat exchange is between gases on the one side having a pressure of some 180 Atmos. and streams of nitrogen on the other side at substantially atmospheric pressure.

Typical quantities and temperatures may be given to amplify the above description. Figures were obtained from Dr. Richard Linde. All volumes are expressed in cubic meters, reduced to 760 mm. Hg. and 0° C. The unit of time is one hour.

Total Air Processed 11,900 m^3 comp. to 4.6 At
765 m^3 " " 180 At
12,665 m^3

	Nitrogen Frankls		Oxygen Frankls
Low Press. Air m^3	9190	(	2250
Cold Nitrogen m^3	9530	(	
Cold Oxygen m^3		(	2335

Total product Oxygen is as given for "cold" oxygen. Sum of oxygen and nitrogen produced is 12,235 m^3, shrinkage from volume of total air processed is due to purging and losses.

Typical temperatures as follows:

Air into unit + 15° C.
Combined air from both Frankls -172° C.
(Nitrogen into Frankl, 1 & 2, -175° C.
Oxygen into Frankl, 3 & 4, -172° C.

Both "pure" streams out of Frankls at about + 13° C.

Typical Column conditions would involve:

	Lower Column	Upper Column
(1) Pressure	4.2 At. Gauge	0.2 At. Gauge
(2) Temp. °C. Top	-182	-194
Bottom	-172	-185
(3) Reflux Liquid	Not directly given	3900 m^3 (Liq. N_2)
(4) Product[M] Top	705 m^3 N_2 (Liq.)	9530 m^3 N_2 (gas)
Bottom	6900 m^3 (Liq.Mix)	2432 m^3 (Liq. O_2)
(5) Plates	24	36
(6) Plate Spacing	90 mm.	90 mm.

[M] NB Amounts expressed as gas.

E. THE NUMBER AND LOCATION OF LINDE-FRANKL PLANTS

Altogether nearly 100 Linde-Frankl plants have been ordered but about 25 of these were canceled due to circumstances connected with the war. The tally, as we understood it, is therefore about as follows for the actual construction of Linde-Frankl plants:

Outside Germany, 7 plants, as given below.
Inside Germany, or occupied territories, 69 plants.

The average size of the plants inside Germany was stated to be about 3,000 cubic meters per hour of 98% oxygen. The largest installation of all was said to be that at Brüx, Czechoslovakia, where 10 units, each of 3,300 m^3/h. 98% oxygen capacity, existed--or existed before bombing. Incidentally, the present condition of the various installed plants either in Germany or elsewhere was not known by the Linde Company at the time of our visit. If the writer's observation of several German plants constitutes a typical sample, one might hazard the guess that most of the German plants have not been seriously harmed and can be relatively easily repaired.

We were informed that all of the plants installed outside of Germany or German-controlled territory are contained in the list given as Table 1 on the next page.

TABLE 1

TABLE 1

Serial No. of Plant	Ordered	Company Placing Order	Place of Installation	Production - m^3/h	Purity (% O_2)
5	1932	Panstwowa Fabryka Zwiazkow Azotowych w Moschicah, Moscice	Moscice (Poland)	500 O_2	98
17	1936	I.G. Farbenindustrie A.G., Ludwigshafen (Contractor)	Nippon-Tar (Japan)	2266 O_2	98
18	1936	Rep. of U.S.S.R. in Germany, Berlin	Leningrad	3500 O_2	98
19	1936	" " " "	"	3500 O_2	98
24	1936	Vereinigte Glühlampen- u. Elektrizitäts-A.G., Ujpest, (Krypton-Producing Plant)	Ajka (Hungary)	25000 (Air Processed)	-
31	1937	Bamag-Meguin A.G., Berlin, 3. Contractor	Irvine (Scotland)	930 O_2	98
32	1937	Bamag-Meguin A.G., Berlin, 3. Contractor	Irvine (Scotland)	930 O_2	98

F. COST OF OXYGEN FROM LINDE-FRANKL PLANTS

No very usable cost figures for oxygen manufactured by Linde-Frankl plants could be obtained during our visit, but the following data, given in a conversation, were said to be typical:

Electric power requirement is about 0.5 kw/nm^3 of 98% O_2 produced. If electric power costs 1.5 pfg./kw. hr., the total cost of 98% oxygen was said to be distributed as follows:

Electric power = 50%
Amortization and interest = 40% (Interest being taken at 5% on investment)
Other costs of operating labor=10%

The above cost allocation was said to be sound for German conditions in the case of plants producing 2,000 m^3/hr. oxygen or more.

Despite the almost irresistible temptation to translate these figures into dollars, it seems very doubtful if it is the part of wisdom to do so. In the writer's opinion, one should recognize an impossibility for what it is. The chief interest in obtaining a dollar cost figure is to determine what might be expected from some plant subsequently built. German labor conditions, manufacturing conditions, and all other items going into investment and power costs will doubtless be so changed that sound assumptions cannot be made at the present moment. So far as past conditions are concerned, the Dollar equivalent of the Mark comes into question. The less one is familiar with the background of German prewar and war economics, the more ready he is to assign a dollar equivalent to the Mark under the Nazi regime. With full realization of the unsatisfactory condition which remains when leaving this discussion as at present, the writer prefers not to translate cost figures any further than may be implied by the single statement that the power requirement typical of the larger size Linde plants is about 0.5 kw/nm^3 of 98% oxygen produced.

Table 2, below, gives some detailed power consumption figures for Linde-Frankl plants as a function of the purity of the oxygen mixture produced. These figures include all the power required for an operating unit and the two rows of figures at the bottom of the table show corresponding figures for two of the higher purities when tubular exchangers are used in place of

Linde-Frankl regenerators. It should be noted that the last column of the table shows that it is more convenient to speak of power costs in terms of cubic meters of nitrogen removed in order to make the various mixtures. In going from 40% oxygen to 98% oxygen, it will be noted that the power consumed per m of nitrogen removed, increases a little more than 25%.

Table 2

Power Consumption Figures for the Production of Oxygen of Various Purities

Purity of the produced Oxygen Mixture	Power Consumption per m^3 Oxygen Mixture	Power Consumption per m^3 pure Oxygen (100%) in Oxygen Mixture	Volume of Nitrogen to be removed from the air per m^3 Oxygen Mixture	Power Consumption per m^3 Removed Nitrogen
% O_2	KWH/m^3	KWH/m^3	m^3/m^3	KWH/m^3
40	0.09	0.22	0.92	0.095
60	0.19	0.315	1.87	0.1
80	0.31	0.39	2.83	0.11
90	0.38	0.425	3.31	0.115
98	0.445	0.455	3.69	0.12
To be compared with the figures for a large plant utilizing tubular exchangers:				
98	0.65	0.665	3.69	0.175
99.7	0.73	0.73	3.77	0.195

G. MISCELLANEOUS

The Linde Company was under the necessity which beset nearly all German manufacturers, before and during the war, namely, of conserving all special metals. Copper is the ideal material for low-temperature work and has always been used for the purpose. Dr. Richard Linde advised us that due to shortage of copper many steels were tried. With all but one exception these proved unsatisfactory for low-temperature operation. However, steel No. 445 of the German list of war steels was satisfactory, and or "Deutro TT-A 23," said by Dr. Linde to be a steel of composition:

Carbon	0.4%
Manganese	18%
Chromium	3 to 5%

It was not clear whether this steel was identical with No. 445 mentioned above or not, but reference to the German list of war steels--not available at present writing--may clear this point. "Deutro" steels were made by Deutsche Rohrenwerke A.G. (Düsseldorf, Ger.) but reference to a 1937 Catalogue shows no listing as Deutro TT-A23.

Dr. Linde was quite specific to the effect that the preferred material for low temperature work was copper and that in spite of its higher purchase cost fabrication was somewhat simpler and that in the end it was the cheapest material available for low-temperature work. Ordinary soft solder is entirely satisfactory for sealing copper joints as in tube sheets, and this procedure is of course much cheaper than any which can be used where steel is involved. Furthermore, drawn copper tubes of thin wall section are practical, whereas the tubes with equally thin wall cannot be obtained in any steel, particularly one of analysis such as the above, which cannot be classed as easy-working material.

H. SEPARATION OF GASES OTHER THAN AIR BY LOW TEMPERATURE--LINDE PROCESSES

A short discussion of gas separation processes was also had with Dr. Linde, though the time available was so short as to give only fragmentary information. Furthermore, it was found that Dr. Linde himself was not particularly conversant with the details of these processes. Those of his engineers who were more conversant with the matter were not available during the afternoon visit.

J. HISTORY

It may be mentioned that the Linde Company first entered into the field of gas separation other than air in 1910--in order to make hydrogen, principally for fat hardening, from water gas. While a few plants of this character were built, the Bamag process for hydrogen production and also that of the I.G. rendered the Linde process of little commercial interest. The matter was only taken up again seriously in 1924, when Semmet-Solvay applied to Linde in 1924 for a plant to make hydrocarbon separation from gas which they expected to have available at their ammonia plant at Ostende, Belgium.

It is a fact that carbon monoxide is very soluble in liquid nitrogen, and plants using this method of removing carbon monoxide from hydrogen or other gases were manufactured in considerable numbers between the years of 1925 and 1931. This was the period in which low-temperature plants to manufacture hydrogen and nitrogen in the proper ratio for ammonia synthesis thrived. There were said to

be some 200 units of this character in operation.

K. HYDROGEN-NITROGEN, FOR AMMONIA PRODUCTION

Figure 2 shows the over-all features of a plant to process gas from coke ovens and make a principal product gas suitable for ammonia manufacture. The rectangle at the upper righthand corner of Figure 2 is shown in detail on Figure 2-a. It is outside the scope of this report to go into detail as to this operation, but it is believed the main features will be apparent by a study of the diagram.

Briefly, coke oven gas is compressed, benzole is separated, and carbon dioxide is washed out first by water and then by suitable alkali solution. Precooling of the washed product is accomplished by an ammonia cooling system and the purified cooled coke oven gas then passes to the low temperature equipment shown on Figure 2-a. Heat exchange with outgoing products cools the material to precipitate out methane as liquid and the carbon monoxide is washed out of the gas by liquefied nitrogen, liquefaction being carried out by the well-known Linde method, making use of the Joule-Thompson effect. The liquefied products, including liquefied methane and ethylene, also the liquid stream of carbon monoxide dissolved in nitrogen, pass out of the equipment after exchanging "cold" with the incoming materials. A somewhat different version of the low temperature part of a unit to make the raw material for ammonia synthesis is shown in Figures 3 and 3-a. Its operation will be clear on following the flows shown in the diagrams.

Figure 4 is a partial diagram and Figure 5 is a complete flow diagram of equipment which the Linde Company installed in Japan. The equipment of the installation given by Figure 5 consisted of two aggregates for nitrogen manufacture at the rate of 1,500 cubic meters per hour and two gas aggregates each 5,000 cubic meters per hour of a mixture of hydrogen and nitrogen. Here again a complete discussion of the diagrams is outside the scope of this report, but it is believed that those acquainted with the art will find little difficulty in following the flows.

In recent years the Linde Company has been called upon to manufacture numerous plants for the separation of hydrocarbon gases by low temperatures. As in the case of the low temperature equipment shown in Figure 6 the purpose was to produce pure methane by separation of coke oven gas as well as the separation of "converted" water gas.

While it is not intended to fully detail conditions maintained in the equipment of Figure 6, it may be mentioned that the coke oven gas entering at the upper left of the diagram was under a pressure of 12 At. and at -40° C by reason of precooling in an ammonia cooled installation which is not shown. The complicated exchanger system indicated by items 1, 2 and 3 effects precipitation of ethylene and also of liquid methane which is distilled in column 4 and taken as a pure stream at the upper lefthand corner of the page. The gas, substantially free of methane, passes from separator 10 into the wash column 6, such entering gas having a composition of about 8% nitrogen and 88% hydrogen, together with 4% CO which is to be washed with nitrogen in this low temperature apparatus.

Liquid nitrogen is prepared by high pressure compression of nitrogen not shown except as the incoming high pressure line at the upper righthand corner of the diagram. Exchangers 11, 12, 13 and 14 bring this nitrogen to low temperature with the assistance of exchanger 8, which is just before the expansion valve where the Joule-Thompson effect causes liquid nitrogen to precipitate and form the wash liquid for column 6. The mixture of nitrogen and nitrogen freed from carbon monoxide by this washing then passes out through heat exchangers 3, 2 and 1 in series to make a suitable raw material for ammonia synthesis. The pure methane stream has already been discussed and other streams which may be taken from the unit will be apparent from a study of the diagram.

The apparatus just described for the production of pure methane involves the use of nitrogen as refrigerant but may be said to constitute the link between the older avenue of effort of the Linde Company and a newer field, namely, the separation of pure components from mixtures of light hydrocarbon gases. Figures 7 and 8 show two designs for the recovery of ethylene from its admixture with higher and lower boiling hydrocarbons.

L. SEPARATION OF HYDROCARBON MIXTURES

Figure 7 shows a design for separating hydrocarbons which does not use liquid ethylene as a circulation stream for low temperature cooling. The reader will probably find no difficulty in following the flows in the diagram, but it may be mentioned that after compressing the crude gas in Compressor 1 and precooling it with ammonia refrigeration (not shown), propane is separated out with fractionation at the base of column 8. Reflux is maintained by ammonia. The gas then passes to additional cooling by an evaporating mixture of C_2 constituents, then is used as a reboiler stream at the base of column 9.

It is filtered free of ice and other solids, and then finds its way into the middle of column 9. Fractionation occurs under the action of liquid methane reflux to produce a mixture of C_2 compounds at the base and pure methane at the top. This mixture is vaporized by exchanger 12 and passes to column 10, where it is fractionated to a bottom stream of liquid ethane and a top product of liquid ethylene.

Liquid ethylene for refluxing column 10 is obtained by a circulation stream with the aid of compressor No. 3, which, however, only compresses the ethylene to about 4 Ats. Methane reflux to column 9 is also obtained by recirculation through compressor 2, which compresses same to about 40 Ats. Both the ethylene and methane are precooled by exchangers shown in the diagram before the expansion and liquefaction stage just prior to entrance into the top of their respective columns.

Figure 8 shows similar processing of a hydrocarbon gas containing all constituents up to and through the C_3 fraction, together with a trace of C_4. The scheme can be easily followed in the diagram, which is more detailed than Figure 7, especially in that the pressures in all the columns and at various other parts in the apparatus are indicated. Referring to the diagram, note that the compressor at the lower lefthand corner compresses the crude gas from one At. and normal temperatures in three stages to 30 At. gauge, after which it is ammonia cooled in A24 and then passes (through filters) into column 1, where propane reflux is furnished at the top by ammonia coils and where outside heat furnishes the energy for reboiling the bottoms.

The depropanized overhead passes to column III which takes all methane overhead and a mixture of C_2s at the bottom. Cooling for reflux at the top is obtained by boiling a fractionated mixture of ethylene at about 1 At. pressure, the vapor being the ultimate ethylene product from the plant. Reboiling at the bottom is obtained from an ethylene stream which has been dried but not cooled after compression from a fraction of an atmosphere to 40 Atms.

The bottom mixture of C_2s is expanded in heat, but not material, exchange, with the vapors of methane rising from the column III and the heat of vaporization so picked up allows the mixed feed to column IV

to be in the gas phase. Column IV separates the mixture into ethylene (top) and ethane (bottom). The gaseous overhead of substantially pure ethylene at 0.2 Atm. is warmed by heat exchange and then passes to a four stage piston compressor which compresses part of it to 40 Atm. The path of the 40 Atm. material is (a) through drier, (b) through Column III reboiler as aforementioned, (c) through ammonia coolers, (d) through filter and then to expansion for cooling in the top of Column III, after which it leaves equipment through exchangers as product ethylene. The portion of the ethylene which is compressed to only 4 Atm. is withdrawn from the 2nd stage of the compressor, is filtered, then passes inside the reboiler tubes of column IV, and is then expanded to form reflux ethylene for column IV.

From the pressure conditions one may surmise the column conditions to be somewhat as follows:

		Col. I	Col. III	Col. IV
Pressure (gauge)		30 Atm.	(28-29 Atm) (1)	0.2 Atm.
Temperature	Top (^oC)	-	- 104	- 127
	Bottom (^oC)	83-86	About 0 depending on constitution of mixture.	- 109

Note (1): Pressure is estimated only on basis that boiling (product) ethylene, probably at only slightly above 1 Atm., is used to condense methane together with fact that there would seem to be no reason to reduce pressure from column I other than by a small amount for independence in control of column III.

The interested reader with facilities and data for heat balances at hand may proceed to make better estimates of column conditions than the above table represents. Temperatures were in all cases estimates from a very crude Cox chart. No information other than that on flow sheet was available to present report writer, who was handicapped by lack of fundamental data and/or time and facilities to accumulate them from library research.

M. CONCLUSIONS

It is a source of regret to the writer of this report that circumstances did not permit the expenditure of at least a full day's additional time to accumulate more detailed and exact information on the

methods
separation of hydrocarbon gases by Linde. Other groups had the opportunity of spending a much greater length of time at this location, and their reports will no doubt be much more detailed. It seems apparent, however, that the Linde designs do not involve any procedures which are actually novel in the sense that they embody any new principles or procedures which would not occur to those acquainted with the art. The distinguishing feature of the design of Linde plants in general is that heat recovery is practised to a very extended degree. Under other manufacturing conditions and with other rates of amortization of investment, labor and power costs for the operating plant, it may well be that smaller heat recovery is economical, even at the expense of greater power cost. Dr. Richard Linde stated that the theoretical minimum requirement to separate nitrogen and oxygen from air (both - presumably(?) - 99.5% pure) was 0.2 Kw hr per nm_3. It will be noted from Table I that this minimum is only exceeded some 2.5 times in large plants, and Dr. Linde was of the opinion that any significant improvement in efficiency was unlikely so far as air separation plants were concerned.

The Linde Company has perhaps had more extended experience than any other in the field of commercial plant design for very low temperatures and their findings, as exemplified by unit designs, warrant thorough and extensive study, and all the more so, since different economic conditions in the future in Germany and elsewhere, will doubtless mean that older designs need modification even though, possibly, they were of the soundest, when initiated.

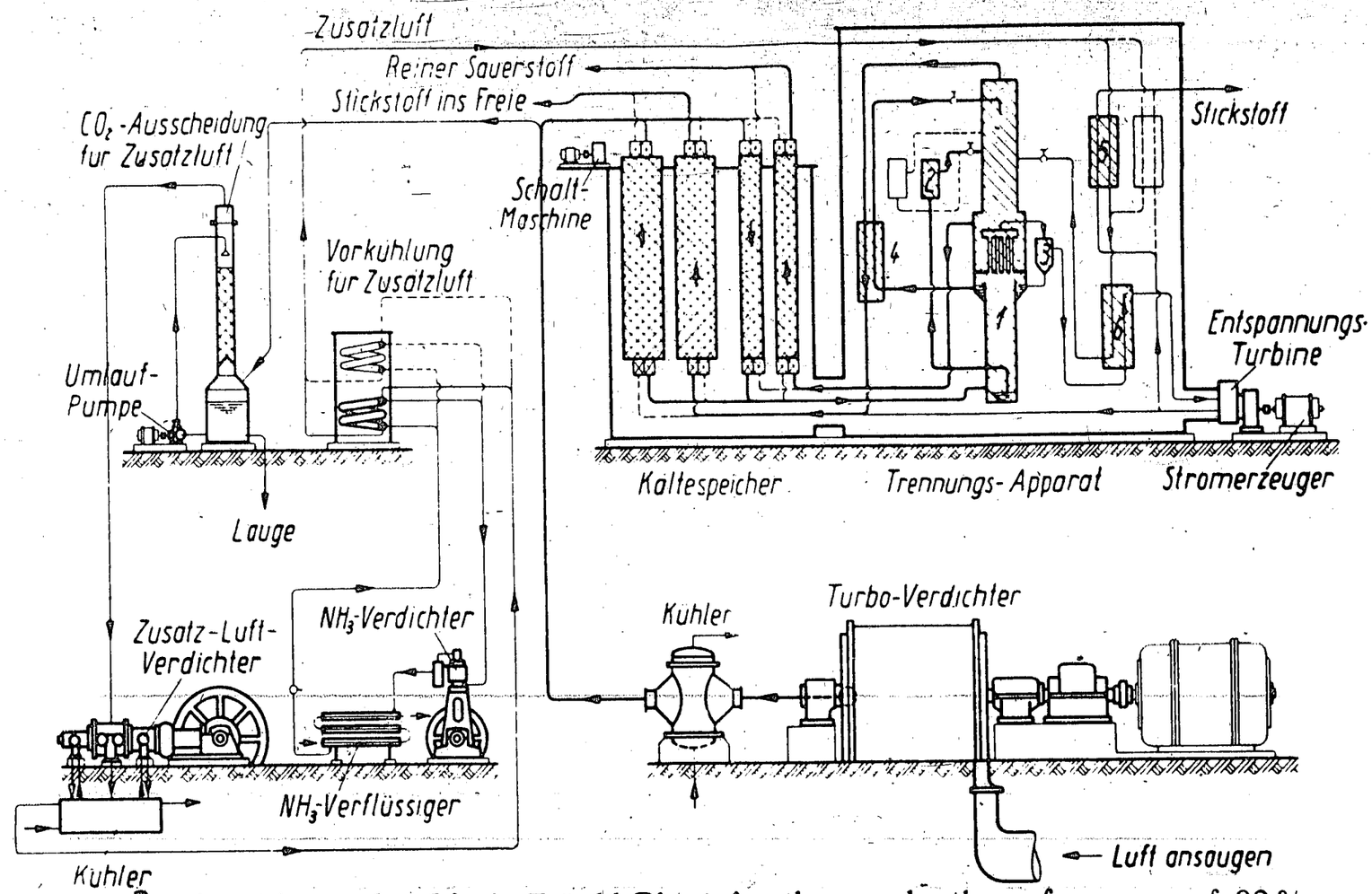


Fig. 1 Flow sheet of a Linde-Fränkl Plant for the production of oxygen of 98 %.

1 = Rectification columns / 2 = Filtre for purification of the liquid oxygen coming from the 1st column 3 = Separating vessel / 4, 5 and 6 = Counter-current interchanger.

Zusatzluft	Additional-Air	Lauge	Caustic Soda Lye	Entspannungs-Turbine	Expansion Turbine
Reiner Sauerstoff	Pure Oxygen	Schaltmaschine	Reversing Engine	Zusatz-Luft-Verdichter	Additional-Air Compressor
Stickstoff ins Freie	Nitrogen in the open	Kältespeicher	Cold Accumulator	NH_3-Verdichter	NH_3-Compressor
CO_2-Ausscheidung für Zusatzluft	CO_2-Absorption for additional-air	Trennungs-Apparat	Separating Apparatus	NH_3-Verflüssiger	NH_3-Liquefyer
Vorkühlung für Zusatzluft	Precooling for additional-air	Stromerzeuger	Electric Current-Generator	Turbo-Verdichter	Turbo-Compressor
Umlaufpumpe	Circulating Pump	Kühler	Cooler	Luft-Ansaugung	Air Intake

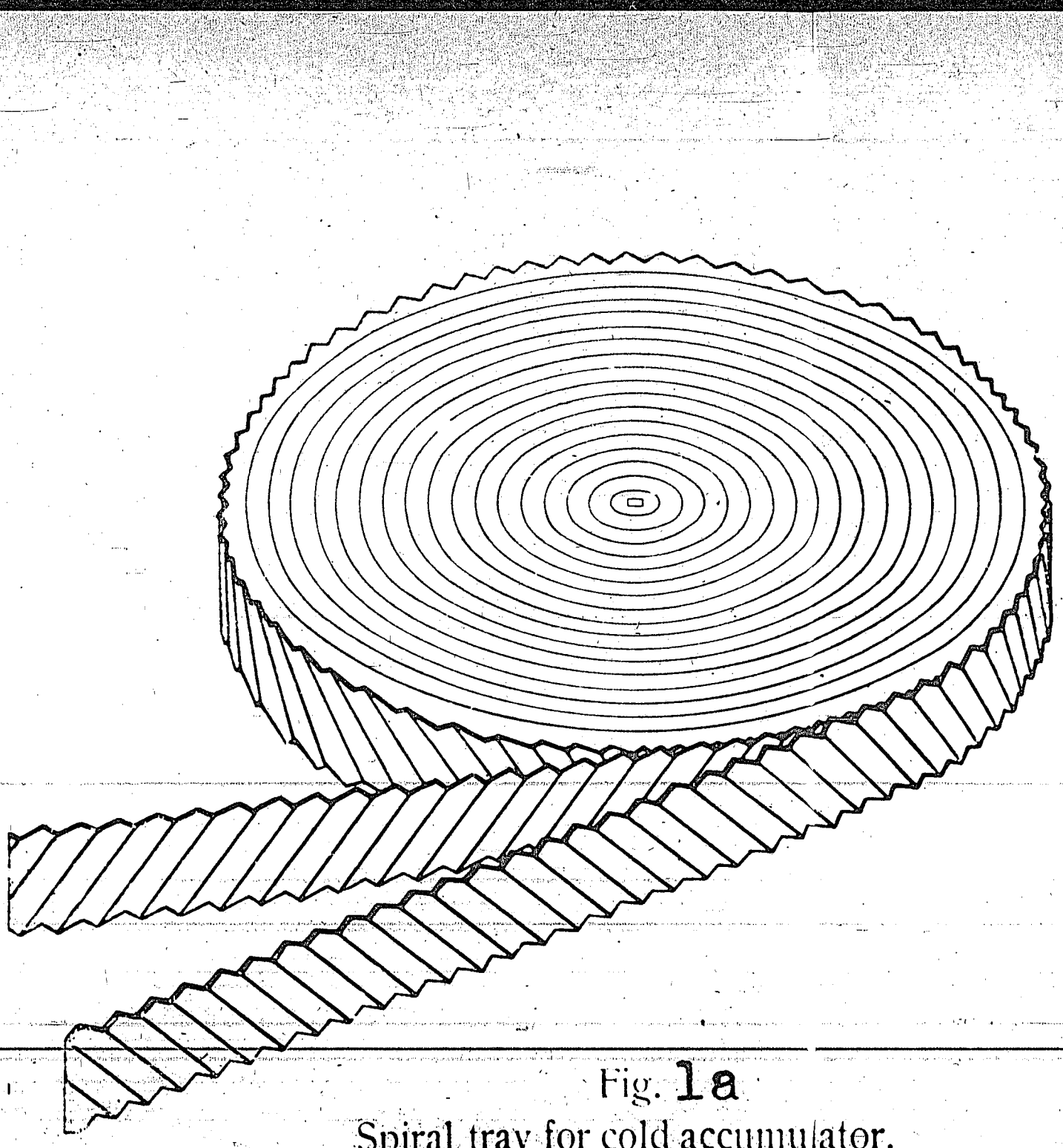


Fig. 1a
Spiral tray for cold accumulator.

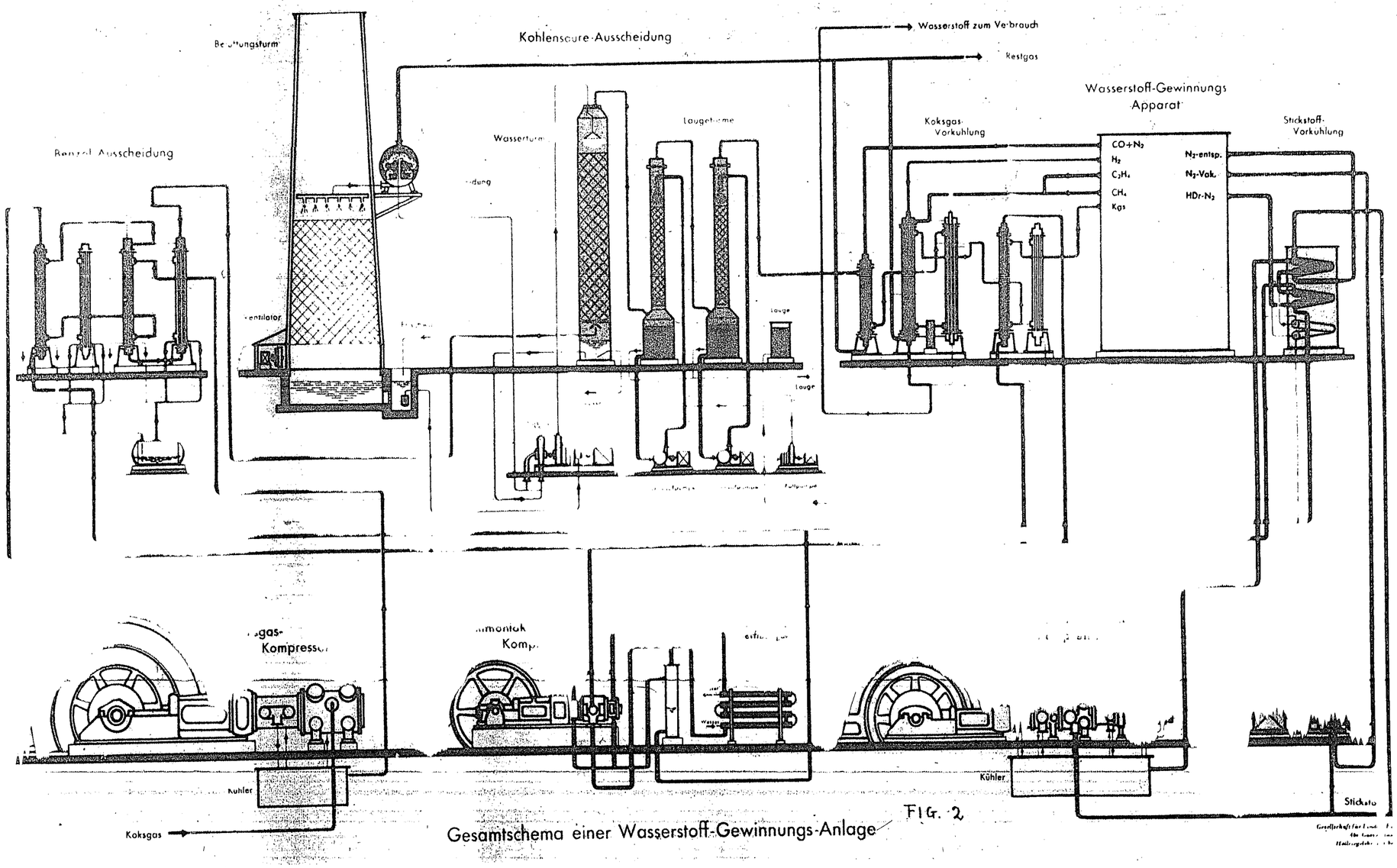
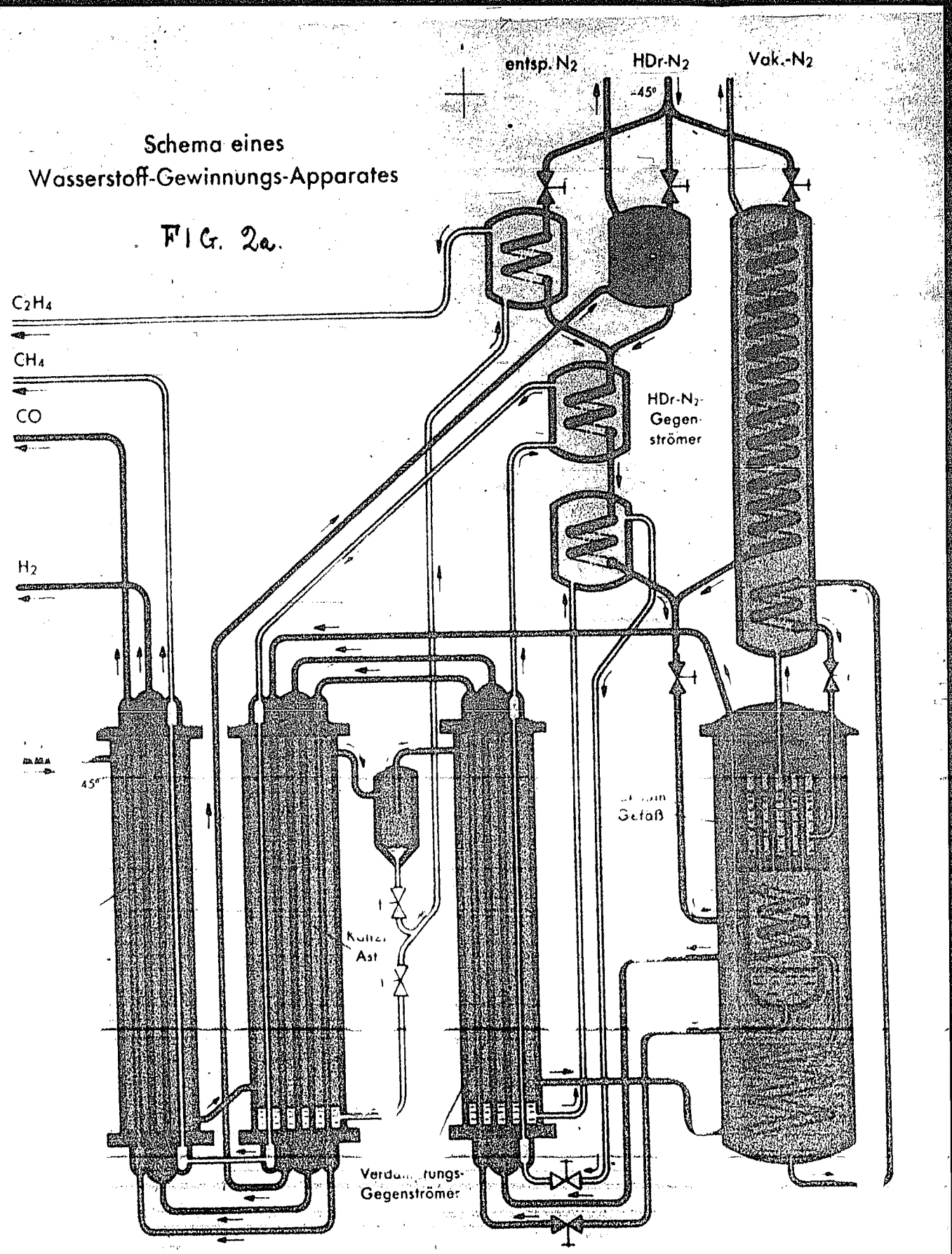


FIG. 2

Gesamtschema einer Wasserstoff-Gewinnungs-Anlage

Schema eines
Wasserstoff-Gewinnungs-Apparates

FIG. 2a.



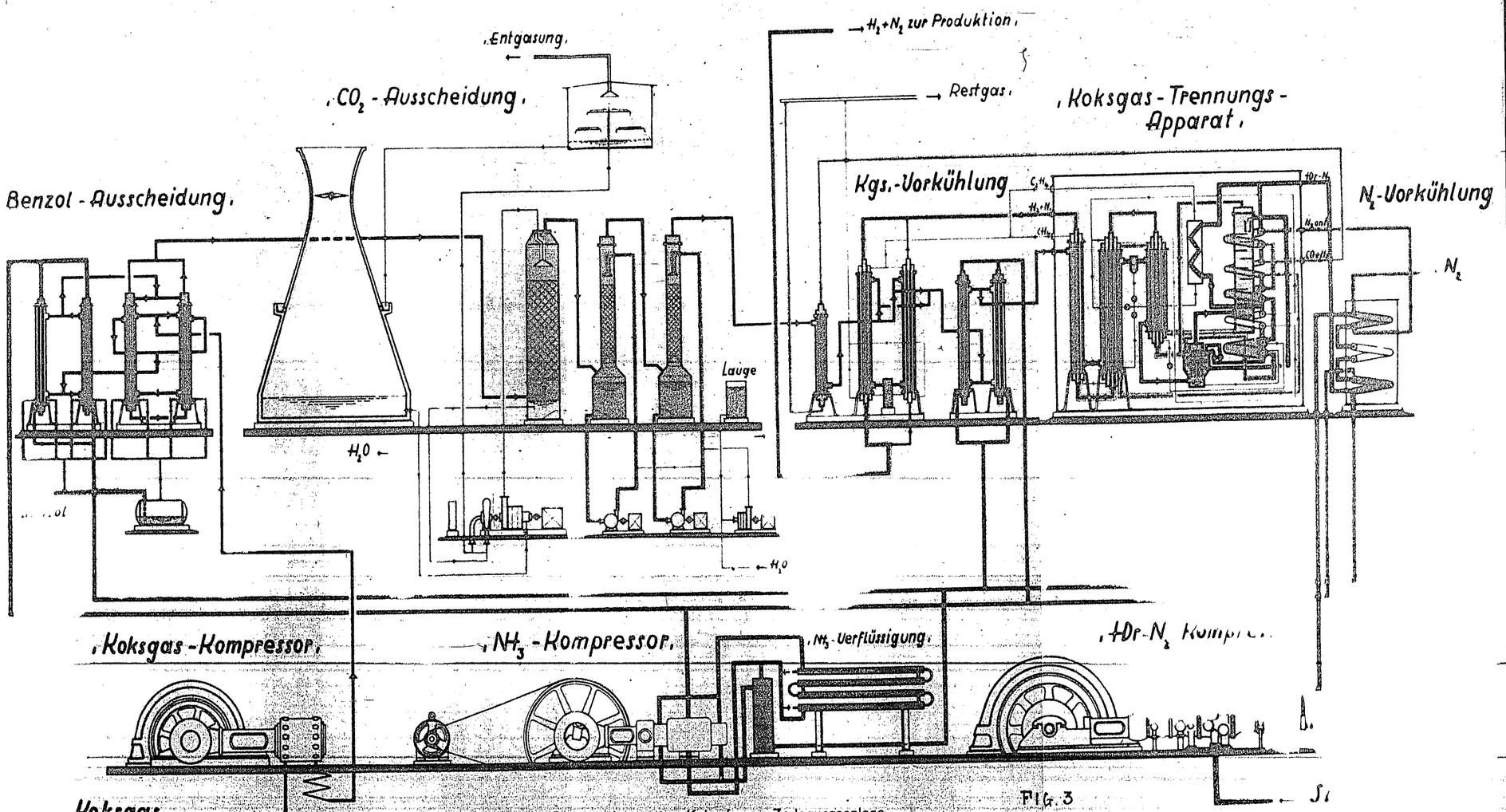
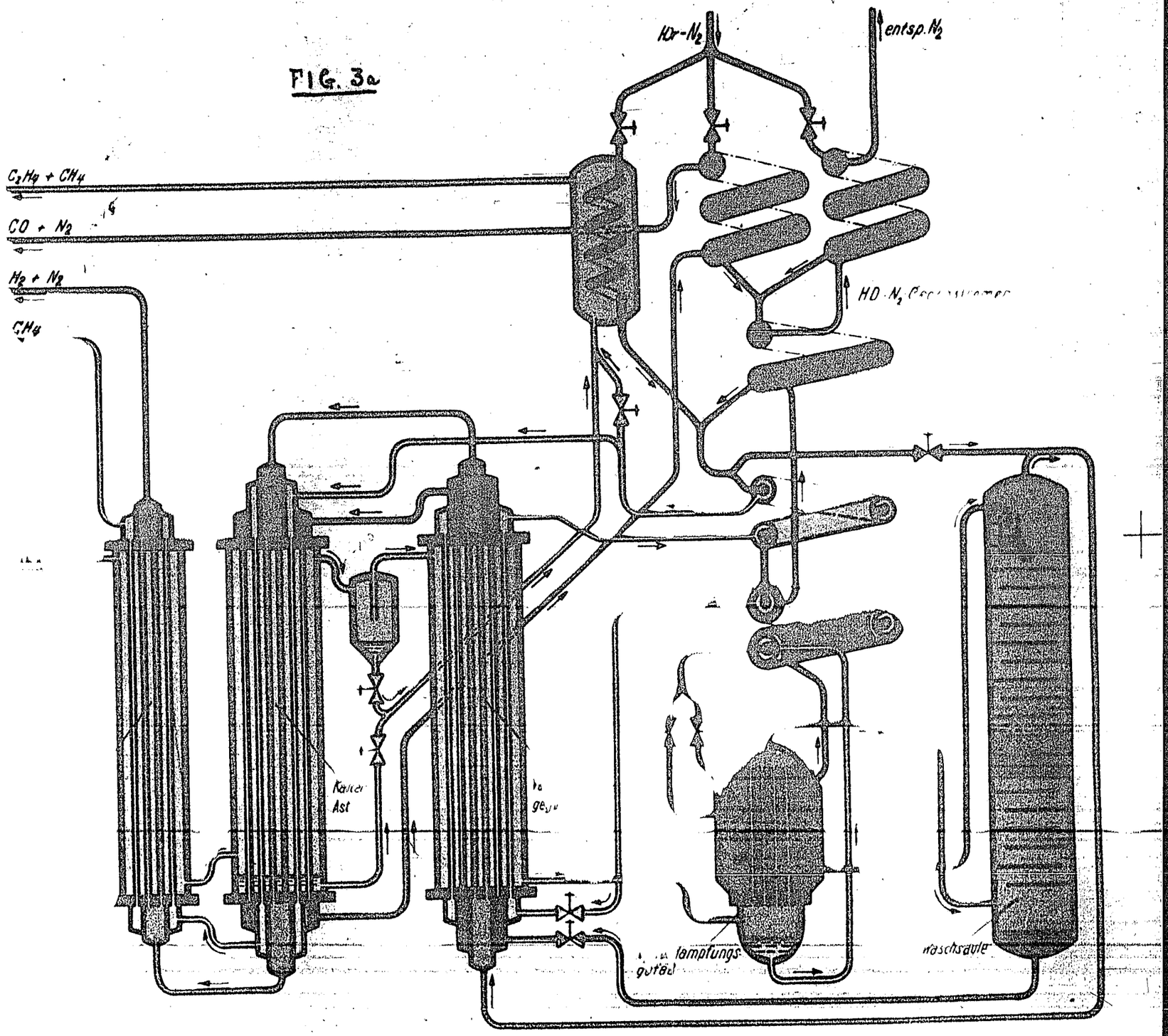


Fig. 3

Gesamtschema einer Koksofengas-Zerlegungsanlage.

FIG. 3a



Linde's Eismaschinen
Abt. Gasverflüssigung
Hollriegelskreuth bei München

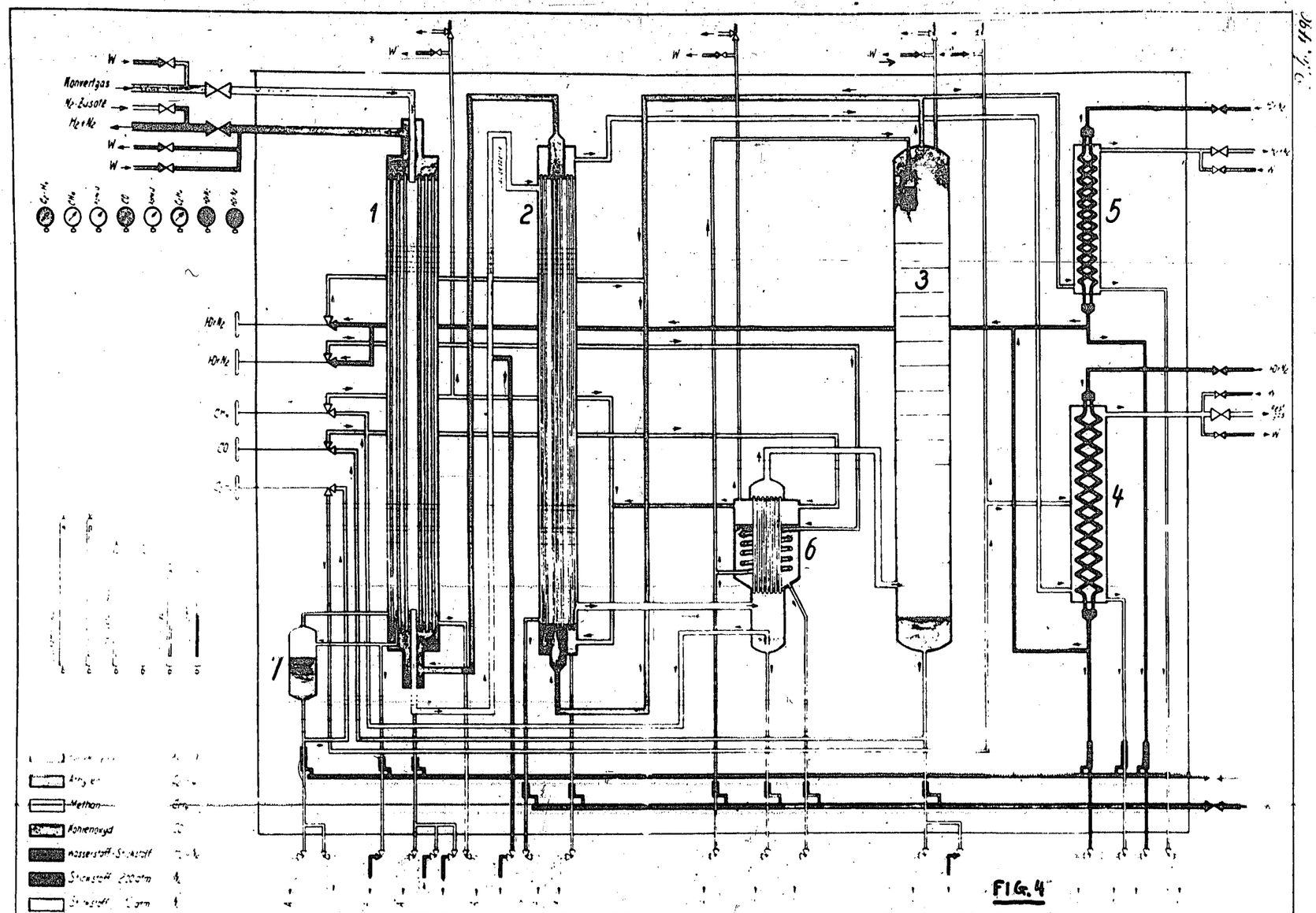

W
Konvertgas
N_2-Zusatz
H_2+N_2
1
2
3
4
5
6
7
H_2+N_2
CH_4
CO
CO_2
Argon
Methan
Kohlenoxyd
Wasserstoff-Stickstoff
Stickstoff 200atm
Stickstoff 1atm
Restgas
Ammoniak
Lauge
1. Kontakt-Normalumsetzer
2. Kontaktofen-Gegenstromer
3. Wasserabscheider
4. Kreuzgegenstromer H_2N_2-Restgas
5. Kreuzgegenstromer H_2N_2-NH_3
6. H_2N_2-Verdampfungskühler
7. Sammelbehälter
8. Kühlschlange

FIG. 4

26490

Kühlwasser

Luftkühler

Luftkühl Umwälzpumpen

Frischluft Pumpe

10 Atü Luft Umwälzung

10 Atü Luft u. Stickstoffkompressor

10 Atü Kompressoren

10 Atü Luft N2 Vorkühler

Konvertgas - Gegenstromkühler

Konvertgas Niederdruck kompressoren

Konvertgas Umwälzung

Konvertgas (O2)

Reinigung

Gas Trennungspumpe

Gas Lauge Umwälzpumpen

Abgas Turbinen Kompressor

Gas Lauge Umwälzpumpen

Entgasungskessel

Ausblaskessel vom Kühlern

Gas Lauge Umwälzung

Punktierte App. u. Leitungen werden nicht v. Fa. Linde geliefert!

Konvertgas

N2 Vorkühler

N2 Apparate

Konvertgas

Apparate

Ausblaskessel von Apparaten

Farben-Erklärung

N2-Teil	Gas-Teil
Niederdruckluft	Konvertgas
Hochdruckluft	Hochdruck Stickstoff
Stickstoffrein	Zwatz Stickstoff
Stickstoffarm	Wasserstoff-Stickstoff
Sauerstoff	Restgas
Lauge Umlauf	Lauge Umlauf
Lauge Frisch	Lauge Frisch
Anwärmung	Kondensatwasser
	Anwärmung
	Sicherheitsleitung

FIG. 5

Schema der Anlage Toyam Japan

7288

XXVII-55

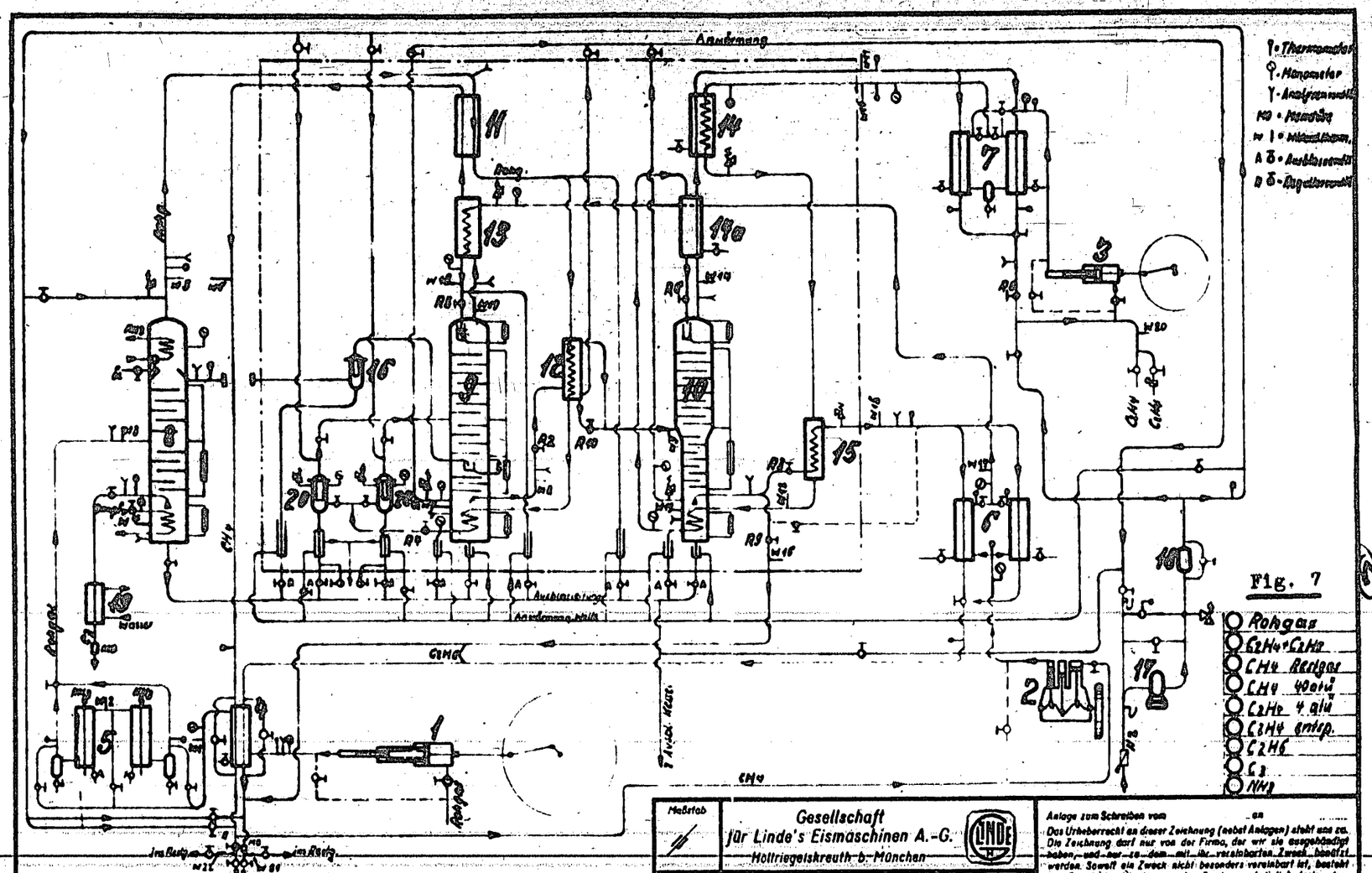
6c

Kgs.
H_2+N_2
CH_4
C_2H_4
$CO+N_2$
Restgas
HDr.N_2
Ndr.N_2
N_2entsp.
Lauge
Anmg.

Blechmantel(6)

FIG. 6

	Gesellschaft für Linde's Eismaschinen A.-G.		
	20.2.40		
H 229/30			
	Schimaschitti eines Apparates z. Zerlegung von Koksofengas m. Gewinnung von reinem Methan oder zur Zerlegung von konzentriertem Wassergas.	9.420	48,786



1	Rohgas-Kompr.	8	C_2 Säule	15	C_2H_6 Verdampfer
2	CH_4 Kompr.	9	CH_4 Säule	16	Filter
3	C_2H_4 Kompr.	10	C_2H_2 Säule	17	Anwärm-Gebläse
4	Rohg Gegenstr. Kühler	11	Rohgas Gegenstr.	18	N_3 Anwärmer
5	Ammn. Vorkühler	12	C_2 Verdampf. Gegenstr.	19	C_3 Nachkühler
6	CH_4 Gegenstr. Kühler	13	CH_4 Vorflüssiger	20	Filter
7	C_2H_4 Gegenstr. Kühler	14	C_2H_4 Gegenstr.	21a	Filter

Fig. 7

Maßstab	//	Gesellschaft für Linde's Eismaschinen A.-G. Höllriegelskreuth b. München	
Werkstoff	//		
Kommission	H 175	Datum / Name / Genehmigt / Karten	
		Gezeichnet 27.11.41 Kamm	Fach
		Geprüft 27.11.41 N	Gruppe
		Normgepr. 27.11.41 Hl	Reg

Schema einer Acetylen-Anlage ohne Hdr-C_2H_4 Kreislauf

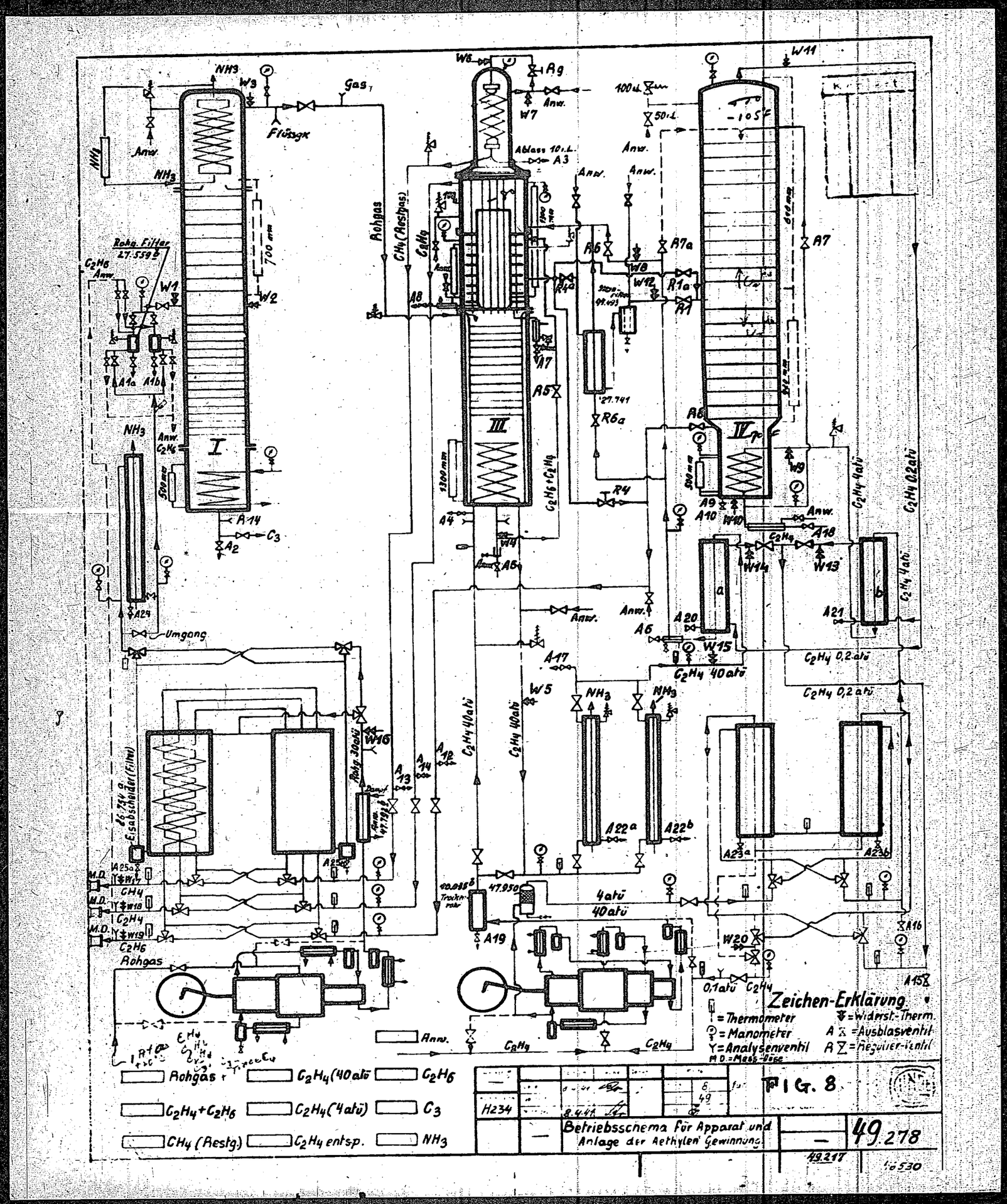
Anlage zum Schreiben vom ... an ...

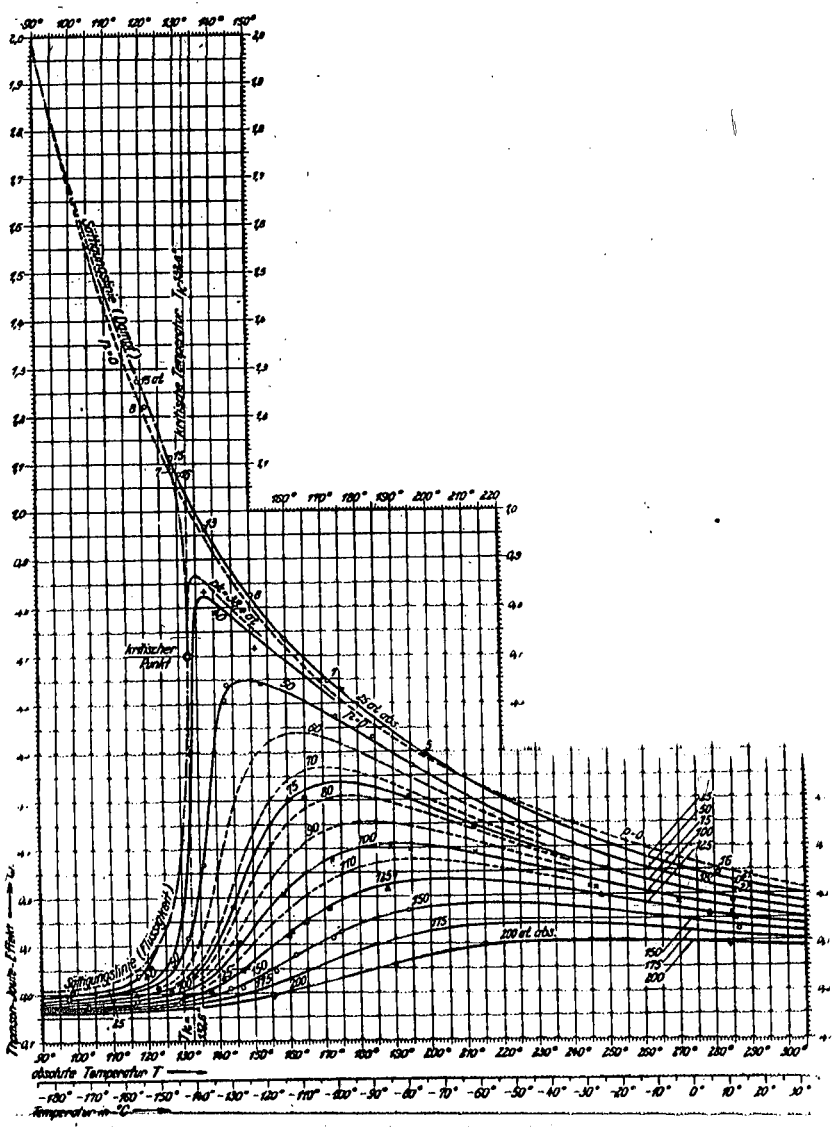
Das Urheberrecht an dieser Zeichnung (selbst Anlagen) steht uns zu. Die Zeichnung darf nur von der Firma, der wir sie ausgehändigt haben, und nur zu dem mit ihr vereinbarten Zweck benützt werden. Soweit ein Zweck nicht besonders vereinbart ist, besteht der Zweck der Überlassung der Zeichnung lediglich darin, dem Empfänger den Betrieb der auf der Zeichnung dargestellten Maschinen, Apparate oder Einrichtungen zu erleichtern. Die Zeichnung ist vom Empfänger geheimzuhalten und auch so aufzubewahren, daß sie Unbefugten nicht zugänglich ist. Durch die Entgegennahme der Zeichnung erklärt sich der Empfänger mit den vorstehenden Bedingungen einverstanden.

Ersatz für —

Entstanden aus 7338

77245


NH3
W3
Gas
Flüssgk
Anw.
NH3
700 mm
Rohg. Filter 27.539
C2H6 Anw.
W1
W2
A1a
A1b
NH3
Anw. C2H6
500 mm
I
A14
C3
A2
A24
Umgang
W6
A9
Anw.
W7
Ablass 10 l.
A3
Rohgas
CH4 (Restgas)
C2H6
A8
A7
A5
1300 mm
III
C2H6+C2H6
R4
A4
W4
A5
Anw.
Anw.
A6
A17
W5
C2H4 40 atü
NH3
W16
Rohg. 30 atü
A12
A14
A13
C2H4 40 atü
C2H4 40 atü
A22a
A22b
A25a
A25b
CH4
C2H4
C2H6
Rohgas
A19
47.950
Trockner
4 atü
40 atü
W11
100 l.
50 l.
-105°
Anw.
A7
A7a
R6
R1a
W8
W12
R1
R4a
27.741
R6a
A6
IV
500 mm
W9
A9
A10
W10
Anw.
C2H4
A18
W14
W13
C2H4 4 atü
C2H4 0,2 atü
a
b
A21
A20
A6
W15
C2H4 40 atü
C2H4 0,2 atü
A23a
A23b
A16
A15
W20
0,1 atü C2H4
Anw.
C8H8
C2H4
Zeichen-Erklärung
= Thermometer
= Manometer
Y = Analysenventil
M.D. = Mess-Dose
= widerst.-Therm.
A X = Ausblasventil
A ∑ = Regulier-Ventil
Rohgas
C2H4 (40 atü)
C2H6
C2H4+C2H6
C2H4 (4 atü)
C3
CH4 (Restg)
C2H4 entsp.
NH3
H234
8.4.41
Betriebsschema für Apparat und Anlage der Aethylen Gewinnung
FIG. 8
49.278
49.217



Differentialer Thomson-Joule-Effekt der Luft bei tiefen Temperaturen,
dargestellt durch Kurven konstanten Druckes in Abhängigkeit von der Temperatur
Versuchspunkte: ⊙ unter 25 *at* (die beigefügten Zahlen geben den Druck in *at abs* an)
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FIG. 9.

Item 30
File XXV-24

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Report No. 287

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DIE STAATLICHE MATERIALPRUFUNGSANSTALT AN DER TECHNISCHE HOCHSCHULE

Fuels and Lubricants

H. M. Weir, U.S.
L.L. Newman, U.S.

[1945]

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18 p. illus.

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Personnel of Team

H. M. WEIR, U.S. Petroleum Admin. for War
I. L. NEWMANN, U.S. Bureau of Mines,
Department of the Interior

VISIT TO
DIE STAATLICHE MATERIALPRÜFUNGSANSTALT AN DER TECHNISCHEN HOCHSCHULE AT CANNSTATTERSTR, 212,
STUTTGART, GERMANY

Introduction

In the afternoon of May 31, 1945 Mr. L. L. Newmann and Dr. H. M. Weir visited the testing laboratory of the German state mentioned above and discussed the work which had been done there on lubricant additives made for the purpose of increasing allowable bearing loads. On account of the impossibility, in view of all circumstances, of spending more than an afternoon at this point, the inquiries were solely confined to the above subject and the individuals interrogated were, in the order seen,

Dr. K. Wellinger
Institut für die Materialprüfungen des Maschinenbaues
Staatl. Materialprüfungsanstalt an der Techn. Hochschule Stuttgart
Stuttgart- O, Cannstatterstr. 212

Prof. A. Wewerka
Maschinenlaboratorium der Techn. Hochschule, Institut für Wärmekraftmaschinen, Stuttgart- O, Dammstr. 5

Dr. E. Ott
Laboratorium für organische Chemie und organisch-chemische Technologie, Stuttgart, Keplerstr. 7

The institute at Stuttgart was one of 7 testing laboratories of somewhat related character. They were named to us as follows:

1. Das Staatliche Materialprüfungsamt Berlin- Dahlem
2. Die Staatliche Materialprüfungsanstalt an der Techn. Hochschule Stuttgart
3. Das Staatliche Materialprüfungsamt bei der Techn. Hochschule in Aachen
4. Die Staatliche Materialprüfungsanstalt Darmstadt
5. Das Versuchs- und Materialprüfungsamt an der Techn. Hochschule Dresden
6. Das Staatliche Materialprüfungsamt Breslau
7. Die Materialprüfungsämter der Bayerischen Landesgewerbeanstalt Nürnberg.

Order of listing said to be that of size and importance, the first named being largest, etc.

While the Prüfungsanstalt at Stuttgart was not badly damaged by bombing there was some damage and there had been considerable interference with the work being carried on. Incidentally the Technische Hochschule itself

had been very badly damaged by bombs and a large part, perhaps all of it, was unusable, without very extensive repairs.

Those divisions of all of the above Materialprüfungsanstalten, if any, and perhaps some other institutions which had been entrusted with the investigation of lubricating oils were under the general direction, in this respect, of Prof. R. Glocker, of the Institute für Metallphysik, Stuttgart Seestr. 71. Dr. Glocker was not in Stuttgart at the time of our visit.

Investigation of Oil Additives.

The work on this subject at the Stuttgart Testing laboratories had been jointly carried out with personnel at several locations. Preparation of the organic chemicals was under the direction of Dr. Ott; initial testing with a small friction machine was under the direction of Dr. Wellinger. When results justified preparation of larger quantities of treated lubricant tests of same were made on larger scale under the direction of Dr. Werwerka and if these tests, in turn, showed promise, then practical tests were made on auto engines or on aviation engines, the latter being carried out by the Daimler-Benz Co.

So far as was learned practically all the work at this location had been directed to additives which were organic phosphorus compounds. A dissertation by Gerd Muller laid before the faculty of the Technische Hochschule on Dec. 1, 1944 was said to be an excellent summary of the work done. Its title was "Die Darstellung von Phosphorverbindungen und ihre Anwendung in Schmiermitteln." This dissertation is to be microfilmed and will accordingly be available for detailed study by those interested.

For present purposes a table given on pages 49 and 50 of the dissertation is set down herein as Table 3. Structural formula of the addition materials mentioned in the table are given in Table 2. It will be observed that the numbers assigned to the compounds are the same in both tables. The load and friction values given in Table 2 were obtained on the testing machine in one of the laboratories under Dr. Wellinger's direction. Figure 1 is a general view; Figure 2 shows the nature of the machine so far as rubbing parts and friction measurement are concerned.

Pure sliding friction is supposed to be measured by the machine which is arranged so that the lower

annular surface of a cylindrical collar bears against three segmental surfaces which are fixed on a balancing beam arrangement whereby load can be applied vertically upward against the end of the rotating collar. The bearing surface is submerged in the oil to be tested which is held at constant temperature by suitable air cooling. The three segments of the fixed side of the bearing present altogether a surface of 33 sq. millimeters. With a rotation velocity corresponding to 1 meter/sec. a half hours test would give an equivalent sliding distance of about 2 kilometers. It may be mentioned that the use of three segmental surfaces was an artifice to get higher bearing loads which was also useful in regulating the temperature. It was stated that reproducible grinding of the original flat surfaces could be obtained after practice together with machine precision in fashioning the three segmental bosses such that the ground surface was not affected.

Test procedure was briefly to "run in" the bearing surfaces of which the fixed surface was often steel St 60.11 - normalized, and the upper rotating surface was either cylinder alloy EC 124, lead bronze or silver. Running in was for (?) hours at a load of 120 Kg/cm². The bearing was then dismantled, examined, cleaned and then remounted. Tests of bearing using a fresh oil sample and progressively increasing loads were carried out - each test loading being applied for 2 kilometers sliding contact. When the sliding surface seized, same was of course apparent on the friction load indicator by a sharp rise of values of friction. The load value just below seizure was taken as "Max. Load" carried.

Table 3 below shows results with different additives using two sliding surfaces each of which was steel "EC 124," (presumably a German war steel).

(Reviewer's Note: Whenever the concentration actually used had been determined as an optimum the designation n appears behind the "figure" for "Concentration, %."

Table 2

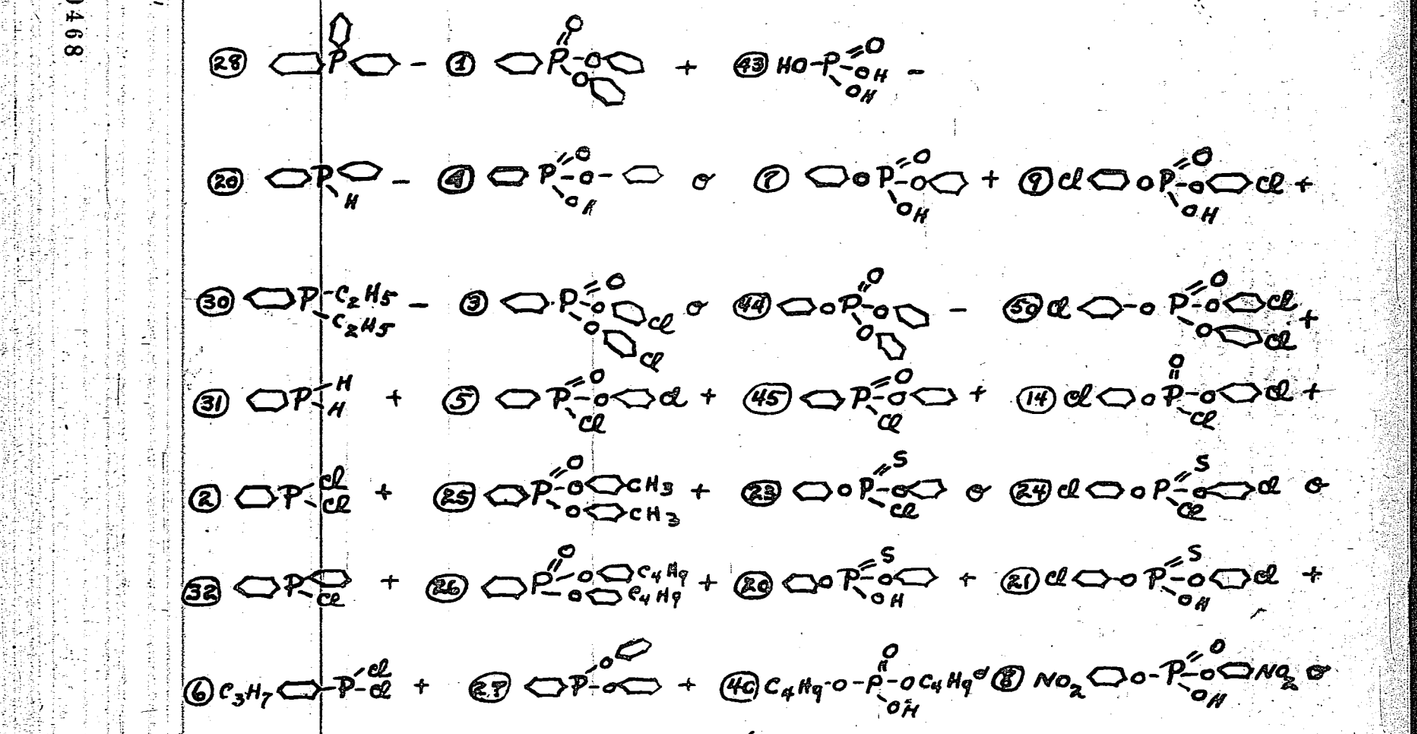


Table 2 (continued)

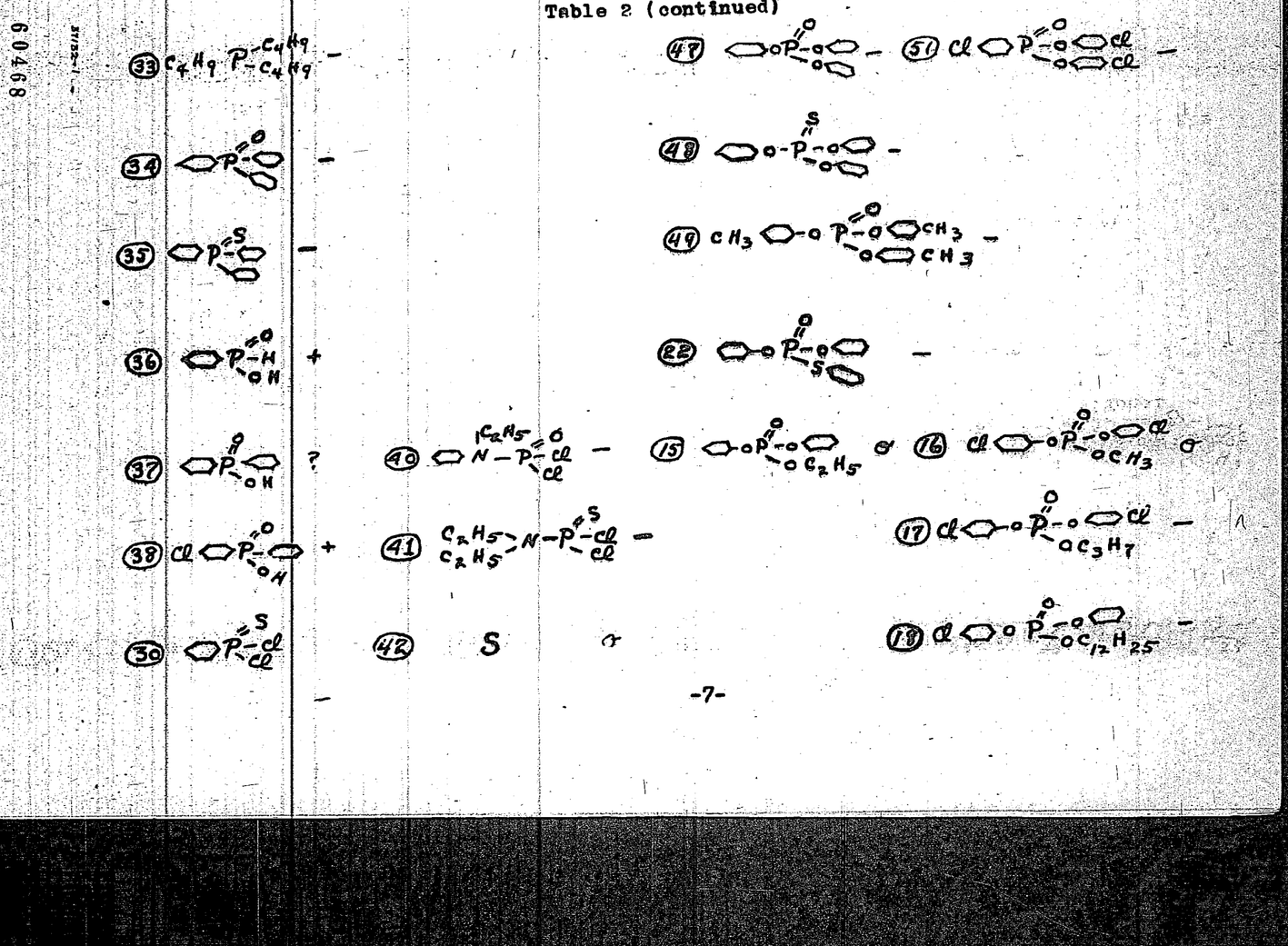


Table 3 -

No.	Addition Agent	Conc. %	Max. Load Kg./sq.cm.	Friction Start	"Value" Finish	Notes
	None. Test oil was German "Rot ring" All additions agts were added to this oil. See footnote 1	--	150	0.08	--	--
	None. "Pure"Essolub 20	--	120	0.13		
	None. "Pure"Essolub 40	--	120	0.10		
7	Diphenylphosphat	1.0 m	750-1000	0.01	0.01	+ 1% Laurylalkohol
1	Phenylphosphinsäurediphenylester	1.2 m	600-1000	0.02		
4	Phenylphosphinsäuremonophenylester	1.0	450	nieder		
2	Phosphenylchlorid	0.1 m	850	0.01	0.01	
36	Phosphenylige Säure	0.3-0.4 m	750	0.01	0.01	
38	"No.891"I.G.Farben	0.8 m	450	0.01	0.01-0.02	
	"No.1534"I.G.Farben	1.0 m	450	0.04	0.08	
9	Di-p-chlorphenylphosphat	1.0 m	1400	0.01	0.01	
9	" 1 Std. auf 200° erhitzt	1.0	1400	0.01	0.02	
15	Diphenyläthylphosphat	1.5	550	0.025	0.025	

-8-

Table 3 - Cont'd.

No.	Addition Agent	Conc. %	Max. Load Kg./sq.cm.	Friction Start	"Value" Finish	Notes
49	Trikresylphosphat + Ölsäure	1.5) 1.0)	450	0.02	0.02	
50	Tri-p-chlorphenylphosphat	1.0	150	0.08		
12	Di-2,4-dichlorphenylphosphat	1.0	500	0.02	0.08	
32	Diphenylchlorphosphin	0.4-0.5 m	950	0.01	0.01	
6	Isopropylbenzaldichlorphaspin	0.5	750	0.01	0.02	
13	Dikresylphosphat	1.0	350	0.015	0.06	
48	Triphenylthiophosphat	1.0	15 m	0.08		
22	Diephenylthiophenylphosphat	1.0	180	0.06	0.08	
16	Di-p-chlorphenylphosphorsäuremethylester	1.0	1400	0.02	0.02	mit Chlorid verunreinigt
	" "	0.5	850	0.01	0.01	
10	Di-p-bromphenylphosphat	1.0	1100	0.01	0.02	
21	Di-p-chlorphenylthiophosphat	1.0	1050	0.02	0.02	
20	Diphenylthiophosphat	1.0	800	0.02	0.02	
8	Di-p-nitrophenylphosphat	1.0	550	0.02	0.08	

-9-

Table 3 - Cont'd.

No.	Addition Agent	Conc. %	Max. Load Kg./sq.cm.	Friction Start	"Value" Finish	Notes
17	Di-p-chlorphenyl-phosphorsäure-propylester	1.0	1400	0.02	0.02	verunreinigt
	" "	1.0	150	0.08	0.08	gereinigt
18	Di-p-chlorphenyl-phosphorsäurelau-rylester	1.0	150	0.04	0.08	
11	Di-p-fluorphenyl-phosphat	1.0	1400	0.01	0.01	
14	Di-p-chlorphenyl-phosphorsäuremono-chlorid	1.0	950	0.01	0.01	
	dsgl. 1 Stde auf 300° erhitzt	1.0	150	0.08		
	dsgl.	0.6	650	0.01	0.01	
3	Phenylphosphin-säuredi-p-chlor-phenylester	1.0	500	0.04	0.06	
5	Phenylphosphinsäu-remono-p-chlor-phenylestermono-chlorid	1.0	650	0.02	0.02	verharzt
23	Diphenylphosphorsäure-sulfochlorid	1.0	300	0.03	0.04	
24	Di-p-chlorphenylphos-phorsäuresulfochlorid	1.0	550	0.04	0.07	
	Phenylphosphinsäuredi-phenylester chloriert	1.0	450	0.04	0.07	

Table 3 - Cont'd.

No.	Addition Agent	Conc. %	Max. Load Kg./sq.cm.	Friction Start	"Value" Finish	Notes
42	Schwefel	0.008	450	0.10	0.14	x
41	Diäthylamin-N-sulfo-chlorphosphin	1.0	150	0.08		
40	Monoäthylanilin-N-oxy-chlorphosphin	1.0	200	0.04	0.08	
25	Phenylphosphinsäuredi-kresylester	1.5	850	0.02	0.08	
26	Phenylphosphinsäuredi-p-butylphenylester	1.5	750	0.04	0.09	
27	Phenylphosphinigsäure-diphenylester	1.0	900	0.04	0.04	

Footnote 1. With exasperating consistency the PhD candidate writing this dissertation fails to give any quality indication or source for the oils used as basis for additives!! German "Rot ring" oil as analyzed for the OTIB (Enemy Oil Committee) in Nov. 1944 gave following specification figures. Different figures have been recorded under this name but it may be that the oil used for tests corresponds to analysis given. (See next page)

x Concentrations higher than those in the Table 3 were also investigated but for the most part poorer results were obtained. Experiments with smaller concentrations, except in cases where the x sign indicates that the known optimum concentration was tried, are stated to have been started.

Date	June 1944
Laboratory in which analysed	Gulf Research & Development Co., Pennsylvania State College
Sample No.	TD-219 "Hot ring" oil
Gravity, °API	28.0
Color, N.P.A.	4 ½
Pour Point, °F.	-15
Flash Point, O.C., °F.	445
Fire Point, O.C., °F.	515
Viscosity at 100° F., Kin, C.S.	264.6
Viscosity at 210° F., Kin, C.S.	20.49
Viscosity at 100° F., S.U.S.	1223
Viscosity at 210° F., S.U.S.	100
Viscosity Index	98
Carbon Residue (Conradson) %	0.49
Chlorine	--
Sulfur, %	0.16
Neutralisation Number	0.02
Saponification Number	0.40
Fatty Oil %	None
Corrosion, Cu Strip, 3 hrs. at 212°F.	Tarnish
Ash %	0.01
Nature of Ash	--

Tests on other materials were also made, the materials being found to be without any effect as addition reagents. The list forms Table 4 below, in which the German comments are not translated. Reference numbers are to a bibliography to be found only in microfilm copy.

Table 4

(a) Diphenylphosphinsäure, deren Lösungsverhalten zu schlecht ist.
(b) Oxypnosphazobenzolanilid (0.6%)
(c) mit Diphenylphosphat in Xylol präparierte Laufringe.
(d) 3% Salizylsäuremethylester (käuflich von Schuchardt, Görlitz), der von Evans und Elliot[141]) angegeben wurde.

Swan-/

Table 4 - Cont'd.

(e) 2 % Benzolsulfochlorid, das sich die Gulf Oil Co. patentieren liess[142]). Das Präparat wurde nach Gattermann aus Benzolsulfonsäure dargestellt[143]).
(f) Naphthalintetrachlorid, patentiert von Evans[144]), dargestellt aus Naphthalin nach Schwarzer[145]).
(g) Chloriertes Diphenylsulfid in 1 %iger Lösung, angegeben von der General Elektric Co[146]), dargestellt aus Diphenylsulfid[146]).
(h) Monochlorthianthren, dargestellt nach Fries und Vogt[147]).
(i) Diphenylsulfid, dargestellt nach Hartmann, Smith und Dickey[148]).

Certain of the addition agents were also tested in the special bearing test stand in the "Maschinelaboratorium der Techn. Hochschule, Stuttgart Forschungsinst. für Wärmekraftmaschinen" under the direction of Prof. Wewerka. In the machine used a loose bearing of special bearing metal is positioned between two fixed bearings, and the loose bearing could be loaded as desired by means of levers actuated by a hydraulic cylinder. Loads up to 1000 kg. cm^2 of bearing surface could be applied by this device. The bearing itself had 45 mm dia. and was 20 mm. long.

Swan-/

Clearance was 0.09 mm. The nitrided ground and lapped steel shaft was commonly operated at 3000 R.P.M. Test procedure consisted in measuring temperature of the bearing--by thermo-couples--as the load was increased. The temperature rose sharply as the maximum load was reached. Almost simultaneously friction increased so substantially that the motor fuses blew out and thus stopped the test. Most of the elements of the test machine which have been mentioned can be seen in the photograph Fig. 3. Test of numerous oils showed that the maximum load which could be carried on a given type of bearing is a function of the pressure on the oil fed to the bearing, such that the equation

$L = kp^{1/3}$ held, where L = Load in the units used, kg/sq cm.
p = oil pressure in kg/cm^2
and k = const. of proportionality.

Plots on double logarithmic paper indicated that the equation holds at least over the range of from 0.2 At. gauge to 3 or 4 At. gauge.

In Table 5 below are given the maximum loads which could be carried by several different bearings when supplied with Lub oil "BC8" both with and without addition agents. The oil itself had and Engler Vis. of 4.5 at 50° C.

Table 5

Tabular figures are maximum load carried ($Kg\ cm^2$) when bearings supplied by oil at 1 At. pressure.

	Lead Bronze	Silver	Special Brass	Light Metal "Mahl 124"
Lub.Oil without Additives	270	390	300	600
0.05 % Phosphenylchlorid	490	500	140	--
0.3 % phosphenylige Säure	450	740	350	700
0.6 % 891 I.G.Farben	410	1200	440	780
1.2 % Phenylphosphinsäu-rediphenylester	780	470	1000	760

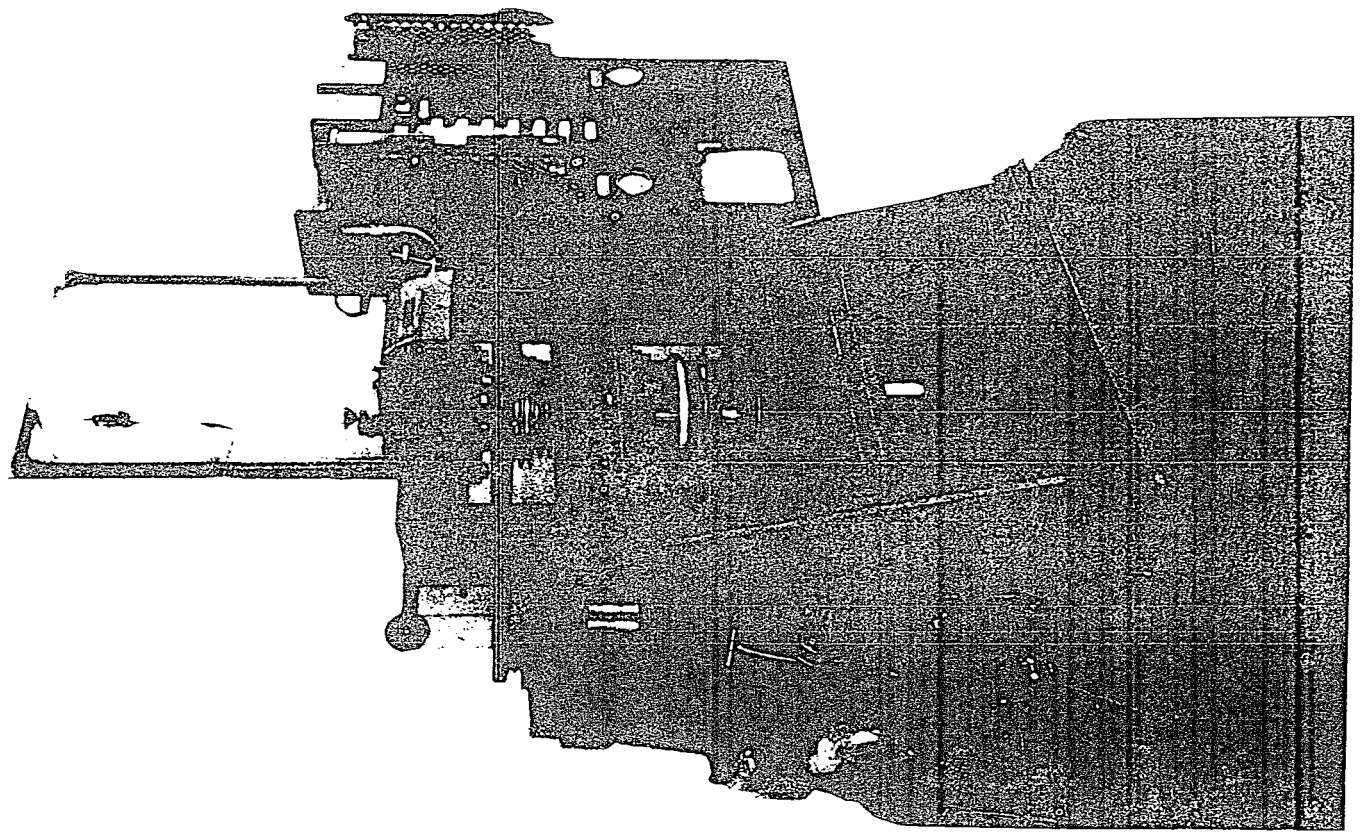
The author of the dissertation claims that the results of Table 5 show a broad correspondence with the results of Table 3 using the first test machine.

Aside from the two testing machines already mentioned a "four ball machine" using four ball bearings as proposed by G. D. Boerlage (Engineering 136/46 (1933)

was used for testing the additives. Results are tabulated in the dissertation but the tabulation will not be given here. It is available from the microfilm.

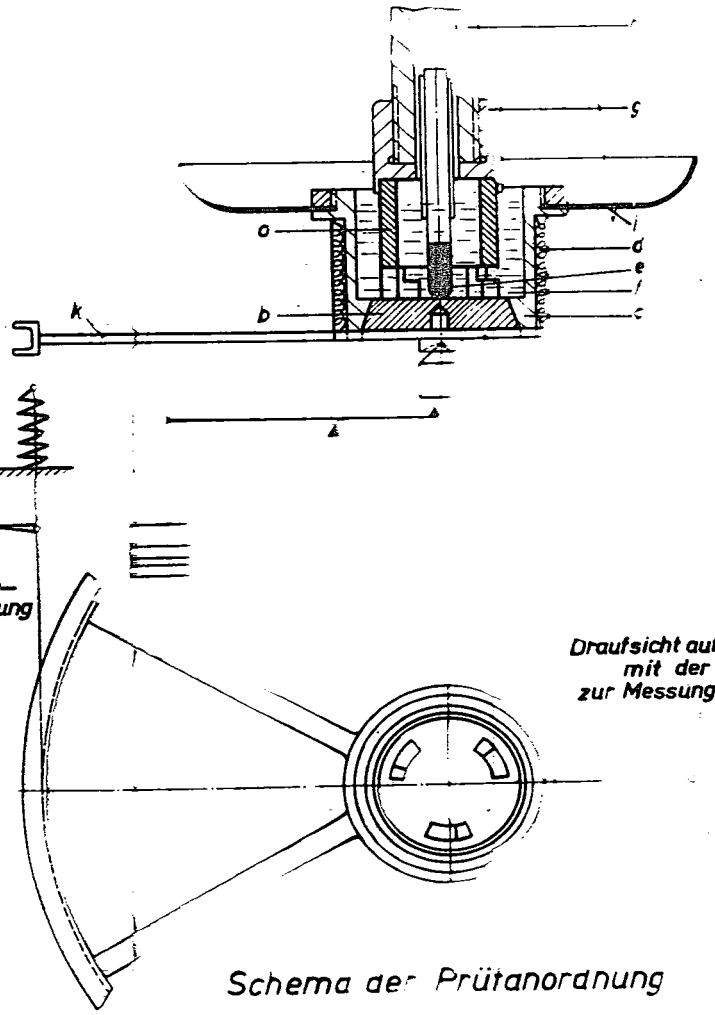
In addition to much other matter to be found in the dissertation there is a section on the methods used to prepare the various materials of Table 2. But in common with the rest of the manuscript this section is not critical even though, in the introduction to the dissertation the significant effects of small impurities in additives affecting lubrication, is stressed.

No very tangible conclusions are drawn from the work which did not uncover any oil additives of startling properties and the chief reason for the present discussion is that it does record in a general way what was alleged to be the experience of the Materialprufungsamt at Stuttgart so far as making oil additives during the war years is concerned. In addition this summary can serve as a guide for the microfilm and may be of some use to those who contemplate some work on phosphorous bearing additives such as were studied during the work on this project.

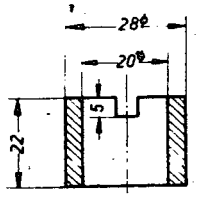


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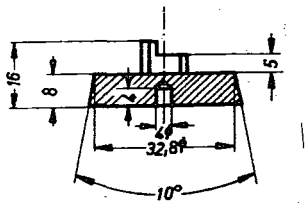
37132-I

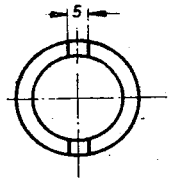


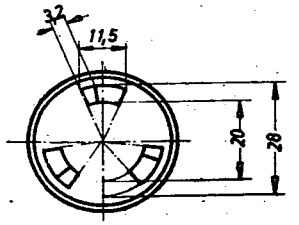
Schema der Prüfanordnung



Umlaufende Probe







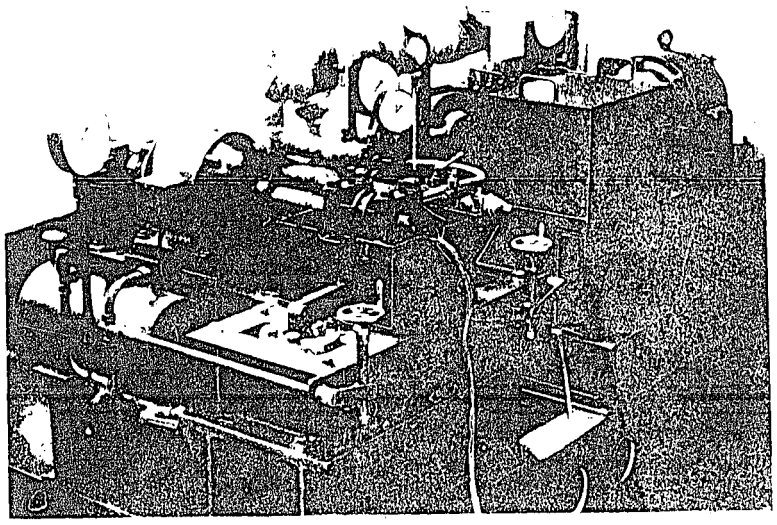
Ruhende Probe

Abmessungen der Probekörper

Draufsicht auf die untere Probe mit der Vorrichtung zur Messung des Drehmomentes

FIG. 2

a = umlaufende Probe
b = ruhende Probe
c = Einspannkonus
d = Heizkörper
e = Kontaktthermometer
f = Ölbad
g = Mitnehmerkopf
h = hohle Antriebswelle
i = Ölüberlauf
k = unterer Probenhalter mit Vorrichtung zur Messung des Drehmomentes



Copy 1

FINAL REPORT NO. 83

ITEM NO. 24

KAISER WILHELM-INSTITUT FUER ARBEITSPHYSIOLOGIE

(Physiology of Exercise and application to industry, particularly Mining)

KAISER-WILHELM-INSTITUT FUR ARBEITSPHYSIOLOGIE
(Physiology of Exercise and application to industry, particularly Mining)

REPORTED BY

A.C. BURTON
NATIONAL RESEARCH COUNCIL

TARGET NO 24/107

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

[1945]

37 pp. Bibliography

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APPENDIX 1 - Description of the activities of the Kaiser Wilhelm-Institut fur Arbeitsphysiologie

APPENDIX 2 - Short description of the work of the Institute

APPENDIX 3 - List of published work of the Institute and reprints evacuated

1. Name of Target

Kaiser-Wilhelm Institut für Arbeits physiologie.
CIOS Target No. 24/107. (See also Final Report No 24 - XXVI - 31).

2. Location

The Institute was formerly at Dortmund. Due to the hazard of bombing it was dispersed in the spring of 1944, one section going to Bad Ems, another to Diez a.d.Löhn, and some remaining at Dortmund. It is planned that all will be re-established at Dortmund by the middle of October. Damage at Dortmund amounted to 10%.

3. Date of Visit and Personalities seen

Prof. Alfred Muller - Physiologist
Prof. Otto Graf - Psychologist
Dr. Straub - Biochemist
Dr. Kraut - Biochemist

Prof. Gunther Lehman, the former director, is said to be in prison-camp, having been an Army Medical Officer at Chartres. Dr. Hendrich Kraut was not seen, as he was at Dortmund, but was contacted later.

Dr. Graf was visited at Diez on 24 September and went also to Bad Ems, where the following two days were spent at the Institute. The visit was made with Col D.B. Dill, U.S.Q.M.C. (of the Harvard Fatigue Laboratory).

4. Nature of work of Institution.

A prepared statement from the Institute, including financial statement is appended (Appendix 1). It will be seen that it is largely supported by the mining industry. A previous final report (CIOS No 24 - XXVI - 31 by Dr. McCarthy, Pathologist) is already available. A summary statement in English (Appendix 2) has also been prepared by the institute and has been issued at the present time to convince the occupation authorities that the institute should be re-established. The principle interest of the institute have been the physiological efficiency of the workman at his work in relation to his industrial output, and the effects upon it of the type of work, working conditions, nutrition, and physiological factors. There were four main divisions to the institute:

(a) Physiological under Dr. Lehman and Dr. Muller.

(b) Psychological under Dr. Graf.

(c) Chemical & Nutrition under Dr. Kraut.

(d) A Statistical Dept. serving all the other departments.

The institute has been of very great assistance in the past to the industry, and its recommendations have been widely adopted in the mines. Most of its publications have been in the internationally edited journal "Arbeitsphysiologie". A large number of reprints, published since 1939 and not yet available in Canada and the U.S. were secured. (~~Marked in Appendix~~) (See Appendix 3)

The former staff was of about 120 research assistants, but it is planned to reopen with about 50, and not to exceed 75 in the future.

Only a few highlights only of the work that appear to merit close study from the practical point of view can be noted in this report. The unique contribution of the institute has been the making of physiological studies actually at the place of work on the workers, while they were engaged in their normal tasks.

5. Important Physiological Findings.

(a) Relation of Output of the Mines to the Nutrition of Miners.

For the last 5 years in Germany it has been possible to know the calorie consumption (of the food) of the miners since there was rigid control. Studies of family statistics and measurements of oxygen consumption (by Douglas Bags) throughout the day supplemented these figures. It has been shown that over this period of years the output of coal per ton has been strictly proportional to the calories in the food provided. When the calorie provision was reduced, there was a short period when the output was kept up at the old level, but the men soon lost weight and the output fell to give the same ratio of cals/ton of coal produced as before. Thus the physiological efficiency remains the same, and it can be stated that 1 ton of coal costs about 1200 cals in food.

This relation was verified by experiments in groups of Russian miners (P.O.W.) More food was given until the maximum output was achieved. When cigarettes were given in addition, the output increased again, but only at the cost of loss of weight by the men. The ratio of tons to calories was once more a constant. Before the war, the miners consumed 4000 cals/day. The ration has been as low as 1500 cals in the last six months but 3400 cals has been authorized. The point was made that

the output to be expected will be in strict proportion, and there is no possibility of evading the physiological law.

(b) Distribution of Food to Miners

The difficulty arose that when extra food was given to the miners in realisation of the facts above, much of this was given by the men to their families. To prevent this, the extra food had to be given to the men actually at the mine or the factory. The authorities were persuaded to give 1000 cals/day in hot food actually at kitchens in the mines.

(c) Protein Requirement of the Workers

Many experiments in the laboratory, with work on bicycle ergometers, proved that the minimal requirement of protein to maintain physiological efficiency was 60-80 gms/day. However when the protein content of the food of workers was gradually lowered towards this minimum, the output fell off before it was reached. Protein has evidently a stimulating effect. It has also been shown that low protein decreases the output of highly skilled workers (mental rather than physical work) A lack of ideas seems to result, which has become obvious to the directors of Engineering Depts. in Dortmund. Experiments on animals with reduced protein but adequate calories have also been made, showing a reduction of motility of the animals.

(d) Work Analysis - Static and Dynamic Work

Dr. Muller has studied the increase of heart rate (by an ingenious gadget described later) in relation to the increase in heart rate in work where all the muscles are in motion (as on an ergometer or treadmill) and where there is little motion (supporting weights and 'straining' against fixed objects). There is a remarkable difference. In each case the increase in heart rate is closely proportional to the oxygen consumption, but the heart rate increases much more in static work. In a case where the pulse rate was 60 for 200 cc/min of O_2, it rose to 120 for 1200 cc/min of dynamic work, but to 120 for only 600 cc/min of static work. The difference has been shown to be due to the cutting off of circulation to the muscles in static work.

This finding gives a means of estimating how much a given industrial task involves static or dynamic work, by measuring the rate of increase of heart rate with O_2 consumption. Tasks should be designed to eliminate static work as far as possible.

(e) Ventilation of Lungs as related to O_2 consumption.

Dr. Muller had made a special study of the correlation between

the oxygen consumption in work and the minute volume of respiration. In some 350 experiments on 40 subjects the mean ratio of ventilation to O_2 consumption was 21. The correlation coefficient between the two was 0.70. If the quotient (21) was plotted against the oxygen consumption there was a close correlation. The mean quotient was 22 for 800 cc O_2/min, and the quotient decreased by 0.7 for each increase of 200 cc. Dr. Muller had then constructed a curve for estimating O_2 consumption from the ventilation. On a single test the error might be as high as 20%, but on groups of 5 men he found it was less than 5%. He felt that the relation might be used with confidence on large groups of workers.

(f) Statistics of Weight of Population.

Curves of average weight for different ages were shown, based on figures for 30,000 persons, before the war, in 1940 and in 1942. These showed a marked decrease in weight for the older people but little for those under 21. The reason why older men lost weight so readily might be that they could not make fat out of carbohydrate, which now is the major part of the diet. The miners in one year lost an average of 8.5 kilos. It was pointed out that to raise the output of the miners now, required not merely a corresponding increase in the calories supplied, but an additional amount initially to build up this weight deficit.

6. Findings in Psychological - Physiological & Pharmacology

(a) Work Studies

Many studies had been made of just what a worker does each minute of his working time, his interruptions, pauses etc. and charts of calorie output were prepared. The 'work curve' in general rose to a maximum in the morning, fell towards noon and rose to a smaller maximum in the afternoon. By making the speed of a conveyor belt vary in accordance with the normal work curve, Dr Graf had produced a 10% increase in output. The latest development was a 'pace-maker' clock that could be in front of a piece-worker. It indicated how many pieces should be done at this time and how many had been done. Its speed could be set to follow the work-curve. Of the 8 hours of work, only 6 hours might be really working. Why not cut down the hours to 6. This had been tried and there had been no decrease in output. The pauses were reduced, rather than the actual working time.

(b) Effect of drugs on efficiency - Benzidrene & Caffeine

Much work had been done on benzidrene, caffeine and on a mixture of caffeine 0.05% and Cardiazol 0.1%. Benzidrene should be avoided at all costs, as it was very habit forming.

Tolerance was developed until a doze of 30 mgs would produce no effect. Benzidrene increased the efficiency of muscular coordination and the 'flight of ideas', but not the speed or accuracy of mental arithmetic. There was a bad 'negative' after effect, and the duration of bendidrene effects was too long for practical use.

Caffeine, especially with cardiazol, was much better and was not habit forming. The addition of sugar and of milk prolonged the action and reduced its intensity.

The taking of sugar tablets, in heavy work, increased its efficiency, but vitamin B had to be given with it to ensure its utilisation.

7. Chemical Nutrition Studies

The research now being undertaken was the determination of amino acids in different proteins and whether the addition of certain amino acids, now freely available, (Leucin) would not benefit the workers. Also it was planned to find which of the amino acids were important in maintaining the capacity for work.

8. Observations on effect of present Nutrition

Dr. Muller had interesting data on the effect of the present poor diet (1200 - 1500 cals) on heart rate. The mean of 30 laboratory workers (Basal) was only 58.5, with some below 40. The explanation suggested was that the heart did not lose weight with the rest of the body, and to give the reduced output. required, the rate was slowed.

During the two days, this investigator ate the same food as the labpratory workers. The total bulk consumed is enormous and it was utterly beyond the capacity of the investigator to eat enough. Even so, to give sufficient calories there was a great deal of distension and gas. The Germans seemed to be able to consume vast quantities of bulk food, nearly all based on potatoes. There has evidently been an adaptation in the size of the stomach and in the flora of the G.I. tract.

9. Laboratory Equipment & Methods

A feature of this laboratory has been the ingenious and effective devices used. Of special interest, but already described in the literature, were the light and small photoelectric device on the lobe of the ear which enables the heart rate of workers to be recorded continuous during their work, the new type of ergometer where both speed and force of work were kept constant, and the methods of taking and transporting gas-samples from the factories and mines. There was also a very simple and effective

device for continuous perfusion. A new small calorimetry chamber had been constructed for study of radiation and other heat exchanges. To deliver radiation from outside, without an interposing glass window, it was planned to use a 'wind-curtain' consisting of a sheet of flowing air, blown from one rectangular nozzle and sucked in another at the other side of the 'window'. This had apparently been used extensively at the doors of aircraft hangars and the interior could be kept warm without any obstruction to entrance.

10. General Comment & Recommendations.

This Institute has been the only one of its kind in Germany, and has set a high standard for the practical application of the physiology of work. It should be able to play an important role in the solutions of the present problems of coal production in Germany.

It is considered possible that the methods of study here developed have not been completely applied to the present problem of coal production in Great Britain, particularly the complete work study and the realisation of the direct relationship and output to nutrition. If this be so it is recommended for consideration that Prof. Muller (who speaks very good English) be consulted in this connection.

The present urgent problem of providing coal for Germany seems to be one of lack of man-power rather than the availability of the miners. If this be so, the work of this institute emphasises a very practical point. Is is that for every pound of food that is shipped to workers of the Ruhr mines this winter, from one half to one and a half tons of coal (depending on the type of food) is saved and need not be shipped to Germany. Thus it is more than 1000 times more economical to ship food to these miners than to have to supplement the coal supply of Germany.

APPENDIX 1

A b s c h r i f t

Description of the activities of the Kaiser-Wilhelm-Institut für Arbeitsphysiologie.

"Arbeitsphysiologie" signifies the study of the physiological principles of human work and the application of the results on all occupations, having the welfare of workers as their ultimate object.

A. Theoretical Arbeitsphysiologie.

I. Physiological principles of muscular work.

1. The transformation of matter and energy in the organism during work.
The transformation of matter and energy in the organism during work is the fundamental problem of theoretical Arbeitsphysiologie. The methods for indirect calorimetry on different muscles were improved in order to study the influence on energy consumption of working speed, of exercise, of partaking motion of body-parts, of work done in balancing and stabilizing the body and of static effort. Connected to these problems is the question of how shall we nourish a man doing muscular work and how much protein f.i. has to be given or how much vitamin B_1 is necessary for a complete transformation of all the carbohydrates in the food.

2. Circulation during work.
A good deal for research was carried out, to understand the oxygen supply to and the carriage of waste products from the muscles as a limiting factor for maximal work and endurance. It could be shown, that static effort induces much fatigue by impairing the blood supply to the muscles. To overcome this obstacle, the organism increase the circulation. The ratio energy consumption to pulse rate has therefore proved to be a valuable measure of the fatigue induced by a certain type of work.

3. The regulations linking metabolism and circulation.
The study of the nervous and hormonal regulations linking circulation and metabolism is another field of our research. By developing a special method for the continued determination of adrenalin in the blood it could be proved that this hormon effects the readiness for work (ergotrop reflex).

4. The participation of sense organs and of the central nervous system in the performance of work.
The following items are dealt with:
a. Investigation of the coordination of sensoric and motoric performances underlying skilled and accurate

work.
b. The knowledge of general principles of an optimal arrangement of rest-pauses.
c. The study of the psychic readiness to work, especially the relations to the sympathetic nervous-system.
d. The elucidation of the nature of "nervous-exhaustion" and of the so called "nervous effort", induced by certain types of work, and also of the psychological problems concerning the limits of the readiness for work.
e. The pharmalogical influencing of work, especially the study of drugs used to increase work or to lower fatigue.

II. General principles of professional work.

1. Physiological and psychological factors.
Many experiments have been made, to find out how professional work is influenced by age, constitution, individual ability and adaptation. Keeping away from psychological vocational test, we concentrated on a few principal questions of physiological qualification, for instance for heavy muscular work and for work in a standing position. We tried also to predict the professional and physiological date, observing and comparing the development of apprentices in the iron industry and other occupations during several years of their education.
It was investigated to which extent daily output of a workman depends on sleep and recreation on the disposition to work (f.i. Adrenalin), on the will to work, on the claim on attention and on changes in working speed during the day (work curve).

2. External factors.
Lately a climatic chamber was constructed, in which work will be studied under various atmospheric conditions.
In the course of these experiments it will be investigated which kind of artificial threads is best used in making clothes for workers.
The influence of ultraviolet rays and of water and salt in hot environments was tested. Other experiments dealt with the effects of glucose, phosphates and drugs (pervitin, coffein, cardiazol, veritol among others) on work partly under hypoxic conditions. It was also studied how muscular work interferes with behaviour under low oxygen tensions. The effects of vibrations on man were another item of research. Experiments concerning dark adaptation and vision in the twilight were undertaken to determine the lowering of output in ill-lighted work places.

B. Practical Arbeitsphysiologie

I. Description of the external working conditions and the effects on the workers.

1. Workplace.
An exact description of the workplace and of the specific performance of work done in it gives the base line for the valuation and for improvements of professional work. Detailed time and motion studies during the whole working day were undertaken chiefly in coal mines and in the steel and iron industry.

2. Physical effort.
a. Heaviness of work.
We now know the heaviness of work (measured in calories) for many occupations.
b. Muscular fatigue.
We succeeded for the first time to measure with new methods simultaneously the energy consumption as proportion of the heaviness of work and the pulse rate as indicator of the fatigue in two plants of the steel and iron industry, receiving thereby the total physical effort of work-men in their workplaces.

3. Nervous effort.
A method was introduced for continuous control of effort, adaptation and fatigue during the whole day in time-fixed work (conveyor-work). The compensation of an insufficient disposition to work by additional will power is claimed to be an important factor in "nervous effort". The participation of consciousness in more or less automatic work was tested. To clear the causes of "overfatigue" we analysed how far it is due to an habitually bad performance of work or too high an amount of work. Related to the questions of accident proneness are experiments on additional reactions required in the course of normal work.

4. Additional factors increasing effort.
Other factors, which render work more difficult as uneasy atmospheric conditions, unsufficient illumination, noise, dust, CO, unsuitable clothes are registered in the usual physical and chemical terms. Their influence on output is measured.

5. Nutrition of workers.
To illustrate the nutrition of workers we selected statistical dates on nutrition under physiological views with Hollerith-machines. We used dates collected by ourselves on miners as well as the extensive dates collected by the "Statistische Reichsamt" for nearly all occupations.
The consumption of food-stuffs and calories was related to wages and heaviness of work. Investigations on the

work done by Russian workers under increased rations showed clearly the connection between nutrition and amount of work, and led to a general raising of the rations for Russian workers.

II. Measures for increase of professional work

1. Improvements of working conditions.

a. Design of tools and machinery in relation to the operator.
It could be shown, that tools used in agriculture and forestry vary widely in shape all over the country and induce very different energy expenditure. This is especially true of antique implements as shovel, hammer, scythe and saw. We made a point of it, to find forms inducing least possible energy expenditure and little fatigue. A special knife for scratching pines in order to get resin was examined on the same lines. We published further reports on the correct form of stairness and ladders, and on the best arrangement of handwheels, handles and pedals. The efficiency of bicycling and wheel-barrow-pulling was investigated. Much work was done on solving the problem of construction compressed-air-driven hammers without reactions and damage on the operator.

b. Optimal performance of work.
The optimal performance of elementary work, i.e. of types of work, which are found to be parts of complicated procedures, was thoroughly studied. Thereby we found out which way and which speed is best for lifting weights, for turning a crooked handle, for push and pull in horizontal and vertical directions, for carrying weights on a horizontal or inclined plane. Other reports dealt with the exertion induced by cow-milking and house-keeping.

c. Influencing the course of work.
Based on general results of research in rest pauses optimal arrangements of rest pauses concerning length, regime and number of pauses were introduced in factories. The study of the physiological work curve resulted in finding ways to make under free or time-fixed working conditions the course of the work optimal. For free work an instrument was devised, showing to the workman at any time the ration of his real to his physiologically optimal working speed and enabling him to free and easy adaptation ("Arbeitsschauuhr"). For time-fixed-work on the conveyer the spped of the later was regulated according to the physiological readiness for work, a method resulting in lower fatigue and less faults in spite of unchanged or even higher output.

2. Improvements in the physical condition of the worker.

a. Adaptation on work by exercise.
Good work is based on careful educating and drilling of the worker. The "Arbeitsschauuhr" mentioned above has

proved to save time in schooling new workers for the right working speed.

b. Appropriate nutrition and beverage.
Finding the appropriate nutrition for every kind of occupation are the aims of our experiments on nutrition. Careful studies on workers doing heavy work cleared the needs on protein, fat, calcium and phosphates. Further tests dealt with the quantity of vitamins, especially vitamin B_1, necessary to keep up working capacity and with the problem how to get this quantity with the usual food supply.
The adequate rate of drinking was cared for in work aggravated by heat. Experiments on colliers resulted in finding that a decrease of work during the shift is often due to unsufficient supply of beverage.

c. Ultraviolet radiation.
Ultraviolet radiation as a way to maintain health and to increase work has been introduced in coal mines on our advice.

Our practical research was chiefly done in the mining industry, in the iron and steel industry, and in agriculture and forestry.

Sources of income in the fiscal year 1943/1944.

Konto...	3 142,60	RM
Interests...	1 756,11	"
Kaiser-Wilhelm-Gesellschaft zur Förderung der Wissenschaften...	80 000,--	"
Reichsernährungsministerium...	147 000,--	"
Reichs-knappschaft...	60 000,--	"
Fordergemeinschaft der deutschen Industrie...	100 000,--	"
Bezirksgruppe Nordwest der Eisenindustrie...	10 000,--	"
Wirtschaft sgruppe Bergbau...	16 000,--	"
Verein für die bergbaulichen Interessen...	18 979,55	"
Kosspende von diversen Zechen...	5 086,41	"
Troponwerke Köln...	6 000,--	"
Luhn A.G., Wuppertal..	2 000,--	"
Zellstoff-Kunstseiden-Ring, Schwarza, Thüringen..	6 000,--	"
Friedrich Alfred-Hütte, Rheinhausen...	1 000,--	"
Quarzlampengesellschaft, Hanau, Stiftung einer Höhensonne...	750,--	"
Summa:	457 714,57	"

APPENDIX 2

The Kaiser-Wilhelm-Institut für Arbeitsphysiologie Bad Ems and Diez a.d.Lahn

The following lines describe the organisation and activities of the Kaiser-Wilhelm-Institut für Arbeitsphysiologie merely in a rough sketch. Annected are:

1) A detailed description of the Institutes research-work,
2) a complete list of papers published by the Institute in the last years.

Organisation: The Kaiser-Wilhelm-Institut für Arbeitsphysiologie is one of the 36 Institutes of the Kaiser-Wilhelm-Gesellschaft zur Forderung der Wissenschaften in Berlin. This Foundation has succeeded to keep up independent scientific research in the days of monarchy and republic as well as under the Hitler-regime, holding that nothing but uninfluenced research can promote science in its principles. The Kaiser-Wilhelm-Gesellschaft and her Institutes have always mastered the task to find patrons with a broad understanding for her aims. Situated formerly in Dortmund, the Institute für Arbeitsphysiologie was evacuated to Bad Ems and with a smaller group to Diez - to avoid the troubles of air raids. The staff numbers 113. The annual expenses amount to half a million Marks.

Subjects of investigation: The principle problems of the Institute is dealing with are the raising of efficiency and the lowering of fatigue among workers by applying physiology and natural sciences in factories and workshops. All influences taking part in human efficiency are thoroughly examined, especially nutrition, drugs, climate and constitution. Bad working conditions and unsuitable tools are improved by controlling the energy consumption and the circulation of workers during their work. Rest-pauses are adapted to the individual rhythm of man. Methods for use under factory-conditions are developed.

International relations: The interest in the results of the Institutes work is not restricted by national borders. This is clearly shown by its international collaboration in pre-war-time. The Journal of Arbeitsphysiologie, edited by the Institute, is aided by the following foreign professors: F.G. Benedict and D.B. Dill, both in Boston US., R.W. Hess in Zurich, C.Liljestrand in Stockholm and J. Lindhard in Kopenhagen. American, English, Russian, Swiss, Danish and other authors have often in their own language, published in this journal. There are many personal relations between scientists all over the world and scientists

of the Institute. Foreign scientists frequently came as fellow-workers to Dortmund. Even in war-time the results were published and freely accessible to anybody abroad (120 papers since 1940).

Outlook: The capacity of the Institute to contribute to the solution of the problems of general human interest mentioned above is guaranteed by the selection and training of its academic and technical staff, by the perfection of its highly specialized methods and apparatus and by the assortment of its library and bibliography. It cost many years to build it up to the present state of efficiency. There is no similar Institute in Western-Europe, ready to continue the peaceful task of what could be paraphrased: "M a k i n g w o r k e a s i e r".

APPENDIX 3

ARBEITEN AUS DEM KAISER-WILHELM-INSTITUT FUR ARBEITSPHYSIOLOGIE

(List of Papers by Kaiser-Wilhelm Institut for Arbeitsphysiologie, Dortmund to date)

DORTMUND

Im Laufe der letzten Jahre sind aus dem Kaiser-Wilhelm-Institut für Arbeitsphysiologie die nachfolgend aufgeführten Arbeiten hervorgegangen, von denen Sonderdrucke in beschränkter Anzahl noch vorhanden sind und an Interessenten gerne abgegeben werden.

Prof. Dr. Gunther Lehmann,

Direktor.

Herbst 1941.

Bei Bestellungen genügt die Angabe der Bestell-Nummer. Die mit * bezeichneten Veroffentlichungen sind durch den Buchhandel zu beziehen.

N.B. Reprints were obtained of those items in brackets.

Allgemeines.

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FINAL REPORT No. 119

ITEM No. 30

Copy 1

DEUTSCHE VERSUCHSANSTALT FÜR LUFTFAHRT (D.V.L.) INSTITUT FÜR BETRIEBSTOFF FORSCHUNG

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DEUTSCHE VERSUCHANSTALT FÜR LUFTFAHRT (D.V.L.)
INSTITUT FÜR BETRIEBSTOFF FORSCHUNG

Interrogation of Evacuated Personnel at Strass near Neuberg, Germany

August 4th and 8th
1945

Reported by

Captain C.C. Chaffee, U.S. Army Ordnance.
Dr. W.F. Faragher, US, Petroleum Administration for War.
Major W.H. Thomas, Br, Ministry of Fuel and Power

BIOS Target No. 30/1.04

Fuels and Lubricants

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE
32 Bryanston Square, London, W.1.

[1945]

38p.

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PERSONNEL OF INTERROGATING TEAM.

Captain C.C.Chaffee, U.S.Army Ordnance.
Dr. W.F.Faragher, U.S., Petroleum Administration for War.
Major W.H.Thomas, British, Ministry of Fuel and Power.

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1. INTRODUCTION.

The evacuated staff from Deutsche Versuchsanstalt für Luftfahrt (D.V.L.) - Institut für Betriebstoff Forschung having been located at Strass, near Neuberg, a visit was made to Strass with the primary object of interrogating Dr. Philippovich and his staff on matters concerning German aviation fuels and lubricating oils. This was carried out on August 4th and 8th 1945. The evacuated D.V.L. Staff at this location are as follows:-

Von Philippovich,	Dr. Phil.	In charge of INSTITUT FÜR BETRIEBSTOFF FORSCHUNG, D.V.L.
Glaser,	Dipl. Ing.	Engine testing of lubricants.
Krienke,	Dr. Ing.	Laboratory testing of lubricants.
Meyer-Burstrom,	Dr. Ing.	Laboratory investigation of Fuels.
Morghen,	Dr. Tech. Dipl. Ing.	Fuel research.
Seeber,	Dr. Ing.	Engine testing of fuels.
Broicher,	Ing.	Engine investigations and exhaust gas testing..
Wenzel,	Ing.	Engine investigations.
Kasper,		Fitter.
Schmidt, Dagmar		Typist.
Seyfarth		Laboratory Assistant.

2. SUMMARY.

(a) This report details information obtained by interrogation of Dr. Philippovich and other members of the staff of Deutsche Versuchanstalt für Luftfahrt (D.V.L.) - Institut für Betriebstoff Forschung evacuated from Adlershof, Berlin to Strass,

near Neuberg, Germany. The subjects discussed were limited to Fuel and Lubricant Utilisation and Performance.

(b) The Luftwaffe employed three main types of aviation fuel. A3 fuel of 80 C.F.R. Motor Octane Number and having an ethyl alcohol content of ca. 30% volume was used for training aircraft, B4 fuel of 89 Octane Number was the normal grade for operational aircraft and C3 fuel of 95 Octane Number was used in aircraft powered with high duty engines. In addition an easy starting fuel, comprising a blend of light gasoline and 5% lubricating oil and an unleaded "Running Out" fuel were also used. Recent specifications for these fuels are given. Safety fuels were not adopted by the Luftwaffe.

(c) All aviation fuels supplied to the Luftwaffe were required to pass specifications concerning general quality and in addition were required to give a minimum performance at both weak and rich mixture strengths in a supercharged single cylinder aero engine test involving the air cooled BMW 132 engine which was developed and standardised by D.V.L.

(d) An important factor in the utilisation of German aviation fuels was the use of 120° valve overlap in the aero engines. This enabled very good weak mixture performance to be obtained even with the highly aromatic C3 fuels.

(e) The non-aromatic German aviation fuels gave no stability or storage problems but trouble due to gum formation and lead precipitation was encountered when the highly aromatic fuels were introduced. These difficulties were however overcome by the addition of 0.01% vol. of a phenolic inhibitor extracted from Welheim synthetic gasoline.

(f) Galvanised filter corrosion with leaded fuels was overcome by the adoption of cadmium plated filters but increase in the Octane Number of B4 fuels to 95 by the addition of methylaniline and by increasing the T.E.L. content to 7.3 ccs./Imp. gallon was not adopted because of increased valve corrosion and sparking plug failures and increased cold corrosion.

(g) Diesel fuels were but little used by the Luftwaffe because the take off power obtainable by the use of diesel engines was insufficient.

(h) Recent specifications for Jet Propulsion Fuels and Fuel for Flying Bombs are given. These reveal little of a novel character, the former being of the Kerosine - light gas oil type having good cold test properties and the latter being an inferior motor fuel.

(i) Two grades of aero engine lubricating oils were employed by the Luftwaffe. A blend of synthetic bright stock and light solvent refined petroleum oil was employed for the high duty engines and a compounded oil containing 3-4% of voltolised rape seed oil for the other engines and for the aero diesel engines. These oils were designated S3 and V2 respectively.

(j) All supplies of these oils were required to pass ring sticking and wear tests in the BMW 132 single cylinder aero engine and also to pass a 100 hour type test in a main engine. The BMW 132 tests are described and also ring sticking tests carried out on a DKW 2-stroke single cylinder liquid cooled engine using petroil lubrication.

(k) No ring sticking additives were used in Luftwaffe aero engine oils but the I.G. oxidation inhibitor R was employed and also dichloro diphenyl phosphorous acid as a wear reducing agent. Paraflow and Paratone additions were not required in the case of S3 oils containing synthetic bright stock.

(l) D.V.L. carried out laboratory work on lubricating oils and lubrication which covered such aspects as the chemical reactions occuring during lubricating oil oxidation, wear tests in conventional friction machines and wear testers and also fundamental studies on surface tension etc. This work is briefly described.

3. AVIATION FUELS

(a) Methods of Manufacture and Specifications.

At the outset, a gasoline synthesis based on coal was sought which would allow an adequate production of good quality aviation gasoline of 87 Octane Number containing paraffins, isoparaffins and naphthenes and only a small quantity of aromatics. At this time large scale production of alkylate or isooctane was not considered on account of lack of the raw materials

although as the war proceeded an important production of these materials was achieved. At a later date however engine tests shewed that with aromatic fuels the take off power could be increased considerably by enriching the mixture strength and without experiencing detonation and for this reason, although aromatics are more sensitive to temperature conditions and mixture strength than other hydrocarbons, it was then decided to begin the large scale production of aromatic type fuels by dehydrogenation or aromatisation processes. These processes allowed the production of the so-called "100 Octane" class of German Aviation Fuels.

The various gasoline components available for blending in aviation fuel manufacture were as follows:-

Code Number	Description.	
VT100	Petroleum Gasoline.	
VT702	Leuna Hydro Gasoline.	
VT705	Scholwen do.	
VT707	Gelsenberg do.	
VT708	Politz paraffinic-naphthenic.	
VT810	Brabag Bohlen (5-15% aromatics)	
VT811	Zeitz.	
VT812	Brüx.	
VT813	Wesseling.	
VT330	Welheim.	
VT341	Ludwigshafen.	
VT342	Leuna.	
VT345	Scholwen Dehydrogenation Gasoline	
VT348	Pölitz do.	
VT350	Moos-Bierbaum.	
CV2b	Aromatised Aviation Gasoline.	
ET100	Iso-octane.	
ET110	Iso-octane or Iso-dodecane.	
ET120	Alkylate	Leuna
		Scholwen
		Pölitz
		Heydebreck
		Ploeschti
		Moos-Bierbaum.
VT302	Aviation Benzole.	
VT303	Diethylbenzene ex Huls.	

Three main grades of aviation gasoline were produced, namely A3 for training purposes, B4 for normal use and C3 for aircraft powered with high duty engines requiring high performance fuels.

(i) A3 Fuel.

Specification TL 147 - 257/4 for this fuel, dated November 1944, is reproduced in Appendix 1. It requires a minimum Octane Number of 80 with the addition of not more than 0.045 vol. % T.E.L. (2.05 ml./Imp. Gallon) but calls for an ethyl alcohol content of 27-33% vol. and a maximum aromatic content of 35% vol. The use of ethyl alcohol in this fuel was first permitted on August 18th 1944, the reason being shortage of T.E.L. and benzole.

(ii) B4 Fuel.

This aviation fuel had a minimum C.F.R. Motor Method Octane Number of 89 and was, in addition, required to give a performance in the standard BMW-132 single cylinder aero engine test at least equal to B4 reference fuel ("Eich B4") over the range of fuel/air ratio 0.8 to 1.15. Specification TL 147/304/4 dated November 1944 is reproduced in Appendix 2. B4 aviation fuels normally comprised either hydrogasolines from bituminous coal or mixtures of hydrogasolines from brown coal and aromatic type gasoline, alkylate or benzole.

(iii) C3 Fuel.

The specification requirements for this fuel were relaxed in August 1944 although the official Specification TL 147 - 330/3 was not replaced by Specification TL 147 - 330/4 until November 1944. Relaxations covered the following points:-

Sp.Gr.at 15°C.	Changed from 0.76-0.795 to 0.74-0.795.
Boiling Range.	50% temperature increased from 100°C to 120°C max.
	90% temperature increased from 160°C to 180°C max.
	FBP temperature increased from 180°C to 190°C max.

Storage Stability.

Increased from 3 months to 6 months, examination only being required after 3 months.

Single Cylinder BMW 132 Test.

This was retained but the fuel was required to give a performance at least as good as the reference fuel (Eich C3) over the restricted fuel/air ratio range 0.8 - 1.15 instead of over the range 0.75 - 1.3 previously insisted upon.

The amended Specification TL 147 - 330/4 is reproduced in Appendix 2.

C3 Fuels were manufactured by blending 80% vol. of aromatic type gasoline made by dehydrogenation with 20% vol. iso-octane or alkylate or alternatively by blending 45% B4 fuel with 25-30% diethyl benzene and 20-25% iso-octane or alkylate.

It should be noted that the Germans refer to C3 gasolines as 100 O.N. gasolines although the CFR Motor Method Octane Number requirements is only "about 95".

(iv) Starting Fuel. (Fl.-Anlasskraftstoff).

For easy starting a special fuel was used consisting of a blend of light gasoline and 5% lubricating oil. Specification TL 147 - 300/2 for this fuel, dated February 1944 is given in Appendix 3.

(v) "Running Out" Fuel.

To prevent corrosion of engines standing idle by the combustion products of leaded gasolines a so-called "Running Out" fuel was introduced which was lead free and of sufficiently high anti-knock value.

For high altitude flying a fuel was considered which would have the low vapour pressure of 0.2 atm. at 38°C. a density at 20°C of 0.800 and a Final Boiling Point of 185°C. which containing 20% iso-octane or alkylate would have a performance in the BMW 132 single cylinder aero engine at least equal to the reference fuel "Eich C3".

(vi) Safety Fuel.

The original idea in adopting the use of direct injection engines in the Luftwaffe was to use high boiling - i.e. "Safety" fuels. It is, however, necessary to define what safety really is because every fuel which is used to perform work by burning must be dangerous to a certain degree. For example, coal dust explodes under certain conditions. It was shewn in work carried out at D.V.L. Berlin that the idea of Safety embraces the properties of self-ignition (SZT) and inflammability (FLp) and the spreading of flames on fluid surfaces and safety fuels are of value if they are so viscous that they only give short flames in which case their lubricating value is an added advantage. Materials of this type were investigated experimentally but were not adopted. For their use the Ring method was proposed by the I.G. so that by the use of an "ignition oil" the sparking plug could be eliminated. Safety fuels were not used by the Luftwaffe because no need for such fuels arose and because their cold properties and storage characteristics had not been fully established.

(b) Engine Testing.

Engine tests on aviation fuels to determine the interrelation of engine constructional details, operating conditions, fuel type and knocking properties formed one of the main lines of work of the D.V.L. The facilities provided for this work were such that engine cylinders of widely different types could be studied, i.e. water cooled, air cooled, poppet valve, slide valve and sleeve valve, and gasolines of all chemical types could be examined.

One of the main results of this work was the development and standardisation of the BMW 132 single cylinder aero engine unit for the determination of aviation fuel performance and this unit was used widely in Germany in fuel development. The reproducibility of the performance curves was stated to be within 4-6% and although a liquid cooled engine such as the DB601 would have given better reproducibility the air cooled BMW engine was very much cheaper. The standard conditions used in the BMW test were as follows:-

RPM 1600
Intake air temp. 130°C - Supercharged.

Valve overlap.	40°
Cooling air pressure.	300 mm. Hg.
Oil Temperature.	90°C.
Cylinder Head Temperature	240-250°C. max.
Ignition	35°B.T.D.C.

and results were expressed in the form of a curve relating air-fuel ratio and mean effective pressure in the usual manner.

Philippovich stated that valve overlap had a profound effect on the shape of the performance curve obtained, the power drop at lean mixtures being markedly reduced with increased overlap, particularly at air intake temperatures below 100°C. At higher inlet air temperatures a reversed effect was sometimes observed. In general, however, with 120° overlap maximum power is obtained at about the theoretical air/fuel ratio and enrichment actually induces detonation. The effect is more marked in the liquid cooled D.B. engines than in the air cooled BMW engine and is brought about by the improved scavenging of exhaust products from the engine cylinder.

It is important to carry out single cylinder tests in engines of the same detailed construction and arrangement as the large scale engines otherwise the tests will be of little value in determining fuel behaviour in the main engine. This is illustrated in the graphs reproduced in Appendix 11.

Octane Number determinations were used for day to day control of fuel production and were carried out in CFR and later I.G. test engines. The supercharged I.G. engine (Oppau method) was also employed for determining performance curves as on the BMW 132 engine except that in this case the blower pressure was kept constant at 1000 mm. Hg. and the air/fuel ratio altered. This Oppau method agreed reasonably well with the larger engine and was widely used.

D.V.L. originally intended to develop a small fuel testing engine which would be suitable for testing lubricating oils as well as fuels but this idea was dropped at the outbreak of war and was not further pursued.

Philippovich stated that differences in the anti-knock properties of fuels gradually disappeared as the compression ratio was increased and that this tended to reduce the value of high performance fuels.

Pre-ignition was not a problem in German aero engines in spite of the wide use of aromatic type fuels but towards the end of the war BMW had reported its occurence and it was investigated in the single cylinder BMW unit.

(c) Gum Stability and Lead Stability.

The non-aromatic German Aviation fuels gave no stability or storage problems but difficulty was experienced as soon as the aromatic fuels were employed. Investigations on this phenomenon shewed that the initial oxidation of the hydrocarbons in such fuels caused the decomposition of tetra ethyl lead and that the lead decomposition products accelerated the oxidation of the hydrocarbons. This process leads finally to lead sludge and also to a decrease in anti-knock value and is only prevented by the use of suitable inhibitors. Such an inhibitor is a phenolic type extract obtained from Welheim synthetic gasoline and was used in 0.01% vol. concentration.

It was also found that leaded fuels caused trouble with galvanised fuel filters, zinc salts being formed which plugged the filters. This was overcome by the adoption of cadmium plated filters.

(d) Analytical Estimation of T.E.L. and Ethylene Dibromide.

A quick and accurate semi-micro method was worked out by D.V.L. for the estimation of T.E.L. It involved the precipitation of T.E.L. as diethyl lead chloride and its titration with dithiozone solution and was stated to be capable of an accuracy of at least 0.001% vol. In the case of fuels containing amines the analysis was preceded by treatment with dilute sulphuric acid to remove the bases.

Ethylene dibromide contents were determined by ionisation with zinc in conjunction with alcohol,

water, acetic acid and pyridine and then estimated by the Volhard method. This procedure uses only 25 cc. of fuel, takes 35 minutes to carry out and gives an accuracy of about ± 0.0005% vol.

(e) Anti-Knock Additives.

At one time the question of raising the anti-knock value of 87 O.N. gasoline to 100 O.N. by the addition of methylaniline and by increasing the T.E.L. content to 0.16% vol. (7.3 cc./Imp. gallon) was considered. This suggestion was, however, turned down because of increased valve corrosion, damage to sparking plugs and increased cold corrosion.

4. DIESEL FUELS

Diesel fuels were but little used by the Luftwaffe because take off power is insufficient with diesel engines. Both natural and synthetic oils were employed and the main requirements were good cold test properties and ease of ignition. As far as was known to Philippovich no ignition accelerators were employed. Specification TL 147 - 351/2 for Aero Diesel Fuel dated April 1944 is reproduced in Appendix 4. This specification demands a minimum Cetane Number of 50 and a Pour Point of -45°C max.

Diesel oil ignition value tests were carried out by the usual ignition delay or throttling methods but had little importance on account of the small demands on diesel fuel by the Luftwaffe.

5. JET PROPULSION FUELS.

As in the early days of the diesel engine it was originally considered that any type of liquid fuel could be burnt in jet units but experience shewed that it was necessary to establish somewhat stringent specifications if troubles in operation were to be avoided. Thus the fuels must have good cold test properties and allow easy starting, the sulphur content must be below 1.5% in order to avoid hot corrosion of the turbine blades, the coking properties must be good so as to avoid coke

formation in the combustion chambers, on ignition plugs, in slit mixers and on turbine guide vanes. It was also necessary to restrict the aromatic and phenol contents in order to reduce corrosion and attack of pump packing materials etc. Based on these requirements Specification TL 147 - 286/2 was formulated for Jet Propulsion fuel which was known as J2 Fuel. A copy of the October 1944 issue of this specification is reproduced in Appendix 5.

Owing to supply difficulties a running in fuel of lower specific gravity, higher vapour pressure and inferior cold test properties was introduced known as Einlauf J2. The October 1944 issue of the specification for this material is also given in Appendix 5. Aviation fuel was used for starting Junkers jet units.

It was stated by Philippovich that as combustion chamber and turbine design is improved the fuel requirements should become less stringent and they were already considering the use of fuels of up to 1% phenol content, 3% sulphur content, 2.5% Conradson Carbon and of higher viscosity (8°E. at 20°C.)

6. FUEL FOR FLYING BOMBS (E1)

The important requirements were cold stability, high calorific value and freedom for corrosion. Anti-knock value, distillation properties and gum content were of no significance as shewn in the specification dated September 1943 reproduced in Appendix 6.

7. D.V.L. RESEARCH ON COMBUSTION.

Combustion was studied by D.V.L. in collaboration with Prof. Jost who investigated adiabatic spontaneous ignition by compression and also slow oxidation at low temperatures along the lines originally followed by Pope, Dykstra and Edgar (JACS., 1929, 51, 1875, 2203, 2213). The work on adiabatic spontaneous ignition served to characterise a fuel according to its ignition delay and when the log of the ignition delay was plotted against temperature a straight line relationship was obtained.

Later, however, F.A.F. Schmidt of D.V.L. shewed that this linear relation only applied for relatively long delays and at higher pressures and at short delay times the relationship was not linear. This work indicated that Jost's assumption that knock depended only upon temperature was incorrect and that it was also influenced by pressure. This work led D.V.L. to enlist the assistance of Dr. Tiechmann, an earlier cooperator of Jost and he extended the work, but complete agreement with engine results was not obtained and it appeared that knock was not only caused by a simple heat explosion but also by a cold reaction having a negative temperature coefficient.

For determining the onset of detonation in engines the D.V.L. Zeiss Ikon indicator was developed which permitted taking not only the simple pressure diagram but also its first and second differentials with respect to time. This indicator gave substantially the same results as were obtained with the A.W.Schmidt and Heitung indicators, both of which are of the quartz type, but these gave some trouble due to noise deflections.

For analysing exhaust gases the D.V.L. exhaust gas tester operating on a thermal conductivity principle was constructed in portable form capable of operating on 6, 12 or 24 volts and incorporating a flow controller for standardising the gas velocity and a fine ceramic filter for cleaning the exhaust gas passing to the instrument. The construction of an indicator for analysing the very weak mixtures used in jet units was begun but was interrupted by the end of the war. This was based on the paramagnetic properties of oxygen.

8. AERO LUBRICATING OILS.

The Luftwaffe used two grades of aero engine lubricating oils, namely S3 and V2, specifications for which, dated June 1944, are reproduced in Appendix 7.

(a) S3 Lubricating oil was a blend of petroleum base oil, solvent refiner, and having a viscosity of about 6°E. at 50°C. with synthetic bright stock of viscosity about 6°E. at 100°C. the latter being produced by the polymerisation of ethylene (I.G. - Leuna) and by the polymerisation of olefines obtained by cracking paraffin wax (Rhenania and Politz). Code numbers for these oils and for the petroleum oil components were as follows:-

Synthetic Bright Stocks.

906	I.G. Leuna ex Ethylene.
1006	Rhenania ex Paraffin Wax.
1106	Politz ex Paraffin Wax.

Petroleum Oils.

607	Rhenania - Edeleanu Process.
707	Deutsche-Vacuum - Duosol Process.
807	Deurag-Nerag - Furfural Process.

S3 lubricating oil was used in most operational aircraft, particularly high duty engines such as the BMW 801 series and the Daimler-Benz 603 and 605 series.

(b) V2 Lubricating Oil replaced the previously used Aero Shell Medium Oil (ASM) and comprised a petroleum oil compounded with 3-4% of voltolised rape seed oil. It was supplied exclusively by Rhenania Ossag and found its main use in the lower duty engines and also in the Junkers Jumo 205 and 207 aero diesel engines for which it was particularly specified despite the fact that its ring sticking propensities were greater than in the case of S3 oil. The detergency properties of V2 oil were considered to be very good indeed.

(c) Additives in Aero Engine Lubricating Oils.

Detergency additives were not employed in Luftwaffe aero engine lubricants but many contained the I.G. additive known as "R inhibitor" the function of which was to improve oxidation stability. This inhibitor was, however, not always necessary as some of the synthetic oils were sufficiently stable without the inhibitor and in

this respect were superior to petroleum oils. On the other hand the lubrication behaviour of the S3 oil blend was often insufficient and the use of a chlorine containing phosphorous acid ester as lubrication additive was introduced (This is probably the J7 compound manufactured by I.G. at Leverkusen, i.e. dichloro diphenyl phosphorous acid).

The synthetic oil blends did not need the addition of either Paraflow or Paratone but these dopes were used in some petroleum lubricants.

(d) Running Out Oil.

For use in engines being set aside idle for an extended period, Nachlaufschmierstoff T 42, a very thin compounded oil, was employed. The same oil was employed for starting in the Russian winter campaigns as it had a Pour Point of -45°C. max. Specification TL 147 - 700/1 for this material, dated October 1943, is given in Appendix 8.

(e) Cold Starting Oils.

For starting at low temperatures, as was required for example in the Russian Campaigns, the normal lubricating oil grades S3 and V2 were simply diluted with gasoline, the quantity of the latter being adjusted according to the prevailing temperature, as much as 25% being used in some cases. Little was known of the field experiences in the use of diluted lubricants but it was stated that wear was reduced because of the easy starting obtained and that crank case explosions rarely occurred.

(f) Engine Testing of Lubricating Oils.

During the first two years of the war lubricating oil quality was not a problem but when some trouble was encountered with the bearings of Daimler-Benz engines it was decided to inaugurate full scale engine tests. The BMW 132 single cylinder aero engine unit was adopted as the acceptance test unit and all oils supplied to the Luftwaffe were also required to pass a 100 hour main Engine Test.

(i) Ring Sticking Tests.

The operating conditions used on the BMW 132 engine for this test were as follows:-

Compression Ratio	6:1
Supercharge	None
R.P.M.	2200
Approx. power	60 B.P.H.
Fuel Consumption	approx. 0.5 lb/BHP/H (B4 fuel used).
Ignition	30° BTDC.
Oil Inlet Temp.	110°C.
Oil Outlet Temp.	approx. 113°C.
Cylinder Temp. at Spark Plug.	256°C
Piston Temperature	310°C
Oil Consumption	about 0.04 lb./Hour.

Under these conditions oils were rated in terms of number of running hours possible before ring sticking occurred, the incidence of ring sticking being indicated by decrease in power and increase of blow by of combustion gases into the crank case. Typical results were as follows:-

Aero Shell Medium	3½ - 4 hours.
S3 Oil	8 hours
Intava Ro'ring	9 "
Intava Green Band (Pre-war Supply)	12 "

Experimental work at D.V.L. has shewn that the ring sticking property of lubricating oils is primarily dependent on the temperature prevailing in the piston ring groove. This is illustrated by the graph given in Appendix 9, in which running time is plotted against temperature for five different oils in the BMW 132 test under conditions somewhat different from those given above and shews that with rise in temperature the running time decreases to a minimum value and increases again with further rise in temperature up to a point (not shewn in the figure) where still further rise in temperature again results in a decrease in running time due to rapid carbonisation. It is considered by Philippovich that

the initial decrease in running time with rise in temperature is due to asphalt formation and that the subsequent increase in running time with rise in temperature is due to burning away of the asphaltic deposits.

Another ring sticking test developed by D.V.L. involved the use of a 2-stroke single cylinder liquid cooled D.K.W. unit fitted with a special piston having only one piston ring. Behind the ring in the groove are two small holes of 1.2 mm. diameter and blockage of these holes as indicated by an increase in power output is taken as a measure of ring sticking. Petroil lubrication is employed and the standard test conditions are as follows:-

Compression Ratio	5:1
R.P.M.	3000
Power Output	ca. 3.9 B.H.P.
Fuel	B4 plus 5% lube oil under test.
Air Intake Temp.	23 - 25°C.
Glycol coolant inlet Temp.	12 - 30°C.
Combustion Chamber Temp.	550 - 620°C.
Exhaust Temp.	470 - 480°C.
Ignition	30°BTDC.
Side clearance of piston.	0.15 mm.

In this test S3 oil and Intava Rotring give average ring sticking times of about 8 hours. It is essential in this test to control piston temperatures.

(ii) Wear Tests.

Various single cylinder test units (BMW 132, Siemens, NSU etc.) were employed for determining the lubrication properties of oils and extent of wear. Satisfactory results were obtained on these units after they had been adequately standardised and they were found capable of reproducible results and shewed up oil differences in such a manner as to allow good assessments of the effect of refining

treatments, compounding, graphitisation, etc. The tests also shewed that for a series of oils all having the same viscosity at 50°C. the extent of wear could vary by as much as a factor of 4.

The engine most widely used for wear tests was the BMW 132 single cylinder aero engine as used for ring sticking tests but different operating conditions were employed, namely -

Oil inlet temperature	120°C.
Oil outlet temperature	122°C.
Cylinder temp. at Sparking plug.	260°C.
Quantity of oil in circulation	8 - 10 litres.
Duration of test	6 hours.

In other respects the test conditions were unaltered.

Wear was assessed by careful weighing of the piston rings before and after test.

Dr. Philippovich stated that in general oils found to have good wear properties were not very good from the ring sticking point of view and vice versa, a possible reason being that the active molecules responsible for good lubricity not being very stable. Furthermore, the mechanical condition of the engine, particularly ovality of the piston and cylinder, were often more important than differences in the properties of lubricating oils of similar viscosity. American test engine methods normally operate under less stringent conditions and hence give longer running times.

Investigations were also carried out at D.V.L. in which a single cylinder engine was operated without fuel but by air at 200°C blown in with a supercharger at 2.6 atm. pressure to give the requisite operating temperature and mean pressure. In this way the effects of fuel and lubricant could be separated and wear figures were obtained of the same order of magnitude as when operating the engine normally. The chief difficulty experienced was in obtaining a supply of oil free air, the blowers being oil lubricated and appreciable oil leakage occurred into the

air stream.

(g) Laboratory Work on Lubricating Oils.

D.V.L. made attempts to determine the ring sticking properties of oils in simple laboratory type apparatus so as to avoid expensive and time consuming engine tests and in order to allow measurement of increased friction caused by asphalt formation. In this however they were not successful.

Laboratory tests on wear properties were made using standard Almen, Wieland, Thomas and Physikalisch Technischen Reichanstalt (Vieweg-Kluge) machines but these were not satisfactory as they gave variable results and a Four Ball apparatus was therefore constructed. This apparatus allowed the determination of friction coefficients with an accuracy of ± 0.001. It consisted of three balls touching each other on a plane representing the guide bearing and a fourth ball rotating in contact with the other three and operated by an air turbine filled with symmetrical tangentially arranged adjustable air jets. The test conditions were similar to those selected by Boerlage and the apparatus was so arranged that only very small lubricating oil samples were required and tests could be carried out over the temperature range -20°C. to +200°C. in various gas atmospheres and with a wide variety of bearing metals.

Investigations on the lubricity of engine oils revealed that differences in behaviour were due not so much to differences in chemical structure as to differences in sulphur content and reactivity of the sulphur compounds present towards the bearing metals. This conclusion was supported by general experience with Extreme Pressure lubricants and by the work of Professor Glocker at Stuttgart which resulted in the development of J7 chlorine-phosphorus dope.

This work led up to the estimation of the "reactive" sulphur contents of lubricating oils by heating in a current of hydrogen and determining

the amount of hydrogen sulphide formed.

Work was also carried out at D.V.L. and also by Prof. Wolf at the University of Halle on surface tension studies of oils in contact with mercury. Prof. Erbacher of the K.W.I. für Chemie in Berlin was studying the surface characteristics of metals by means of radio active elements and Dr. Seolich of the K.W.I. für Physikalische Chemie in Berlin carried out research on the orientation of lubricating oil molecules at oil-water interfaces. Erbacher and Seolich were awarded contracts for these researches from D.V.L.

The deterioration of lubricating oils in use by oxidation and thermal breakdown reactions was also investigated at D.V.L. and the line of work undertaken was to develop analytical procedures for determining the various oxidation products formed so that the mechanism of the processes leading to asphalt formation could be better understood. The scheme of analysis followed is given in Appendix 10. The work was very tedious and the method was not fully developed. Similar work was also carried out on pure cetane and on the use of chromotographic methods for analysis of the oxidation products.

Work on the lubrication properties of oils in the hydrodynamic flow range was also carried out by D.V.L. but the end of the war brought it to a premature conclusion.

In their work on lubrication problems D.V.L. cooperated with Maschinenelemente Fachgruppe Schmiertechnik des D.V.I. In this work a series of lubricating oils of different chemical types and viscosities (the so-called H oils) distributed by I.G. were examined in various testing machines to determine their behaviour with the object of relating lubrication ability with chemical type and sulphur content.

(h) Miscellaneous Information Concerning Aero Lubricating Oils.

Philippovich stated that the normal life

of aero lubricating oil was limited to 100 hours after which the used oil was returned to the manufacturer for re-refining. It was not reclaimed by conventional processes.

Oil centrifuges were developed for aircraft engines for the removal of sludge and materials which caused foaming. These were manufactured by Daimler-Benz and by Junkers and after their adoption no corrosion of bearings occurred which was traceable to the lubricating oil.

Jet propulsion units gave no special lubrication problems and as a result no investigations were carried out.

9. GREASES.

Calcium and aluminium soaps were found unsatisfactory as were the experimental batches of barium soaps. The change over to lithium base greases, however, brought about a considerable improvement particularly with regard to drop point and low temperature behaviour. Lithium greases were used for the lubrication of instruments. The lithium demand was only 1 ton/month and was easily met.

10. ANTI-CORROSION OILS.

The usual anti-corrosion oil contained originally 7-8% of naphthene sulphonate soap, which was difficult to procure. Thus as the war progressed the content of naphthene sulphonate soaps was lowered to 3-4% and in its place resin soaps from colophony were used. These soaps were very sensitive to oxidation and could therefore not be used for engine protection but only as additions to cooling water or glycol.

11. CODE NUMBERS FOR PETROLEUM AND SYNTHETIC OIL PRODUCTS

Dr. Philippovich was given a list of code numbers of various oils etc. taken from documents etc. obtained on previous trips and was asked to give their identity insofar as they were known to him.

He produced the following information:-

Hd-H140	A series of hydrocarbons and synthetic lubricants of various viscosities prepared by I.G.Leuna for tests by Professor Heydebreck and other interested parties for lubrication tests.
H426	Ester (ex abietic acid?) also prepared by Leuna for Professor Heydebreck.
R300	Diesel ignition oil prepared by I.G.(Peroxide?)
Autokollag.	This is Oildag and contains whale oil.
BH4	Flying Pressure Oil (Fliegerdrucköl) Hydraulic Oil?
K7	Shell Transformer Oil.
DA200	Olex Machine Oil.
NP2	Naphthenic Lubricating Oil of Russian origin.
ED24	Olex spindle and flushing oil.

Dr. Philippovich disclaimed any knowledge of the following products:-

Calupsol K	M70
R200	M71
129	M8
E Mischung II	M9
RCH Diesel Oil D509.	M10
Sulphur Product B	Z111
SS902	Z111a
F25	21Vc
TP57	Dibutin
S Product J	

SS978
F250
T/Z 900/5
T/Z 900/2
Elaol 4
AEM3
S Ester
SS970R
H268
X7
SS1593
1568/80

12. DOCUMENTS.

Dr. Philippovich stated that a number of documents were removed from the D.V.L. laboratory at Strass near Neuberg on June 7th 1945 by 1st Lt. W.F.Hergrueter, C.O., 943 OQMG PPL and delivered to O.T. IT., 7 Augsberg. It was ascertained that these documents were shipped on June 13th to Chief Ordnance Officer, Hq., Com Z, A.P.O. 887, U.S. Army, Attn. EEIS, Technical Division (Major Heintz). It was also ascertained that the documents were received at this address and reshipped from there to an unknown address, probably to SHAEF forward documents section.

Philippovich gave the following list of these documents from memory:-

1. Meeting "Knock behaviour and storage of fuels" 16-17.6.41.

2. Lubricating oil meeting, 1st part: "Friction and wear, low temperature behaviour".

3. FB 690. Investigation of lead free gasoline/benzene/alcohol blends (80 O.N. class and above) by A.v.Philippovich and H.Berg.

4. FB 891. The heat conduction of exhaust gases from Otto engines as means for the evaluation of mixture formation by H.Berg.

5. FB 1034. Influence of engine design and operating conditions on the knock behaviour of fuels (Collective report) by H.Berg.

6. UM523#2. Influence of engine design and operating conditions on the knock behaviour of fuels. 2.Interim report. Tests on a FIAT single cylinder test stand (injection operation) by H.Berg.

7. UM523#3. Influence of engine design and operating conditions on the knock behaviour of fuels. 3.Interim report. Tests on a DB.600 two cylinder test set up with fuels of 80 and 87 O.N. (carburettor operation) by H.Berg.

8. UM523#6. Influence of engine design and operating conditions on the knock behaviour of fuels. 6.Interim report. Tests on a DVL one litre sleeve valve engine (carburettor operation) by H.Berg.

9. UM523#7. Influence of engine design and operating conditions on the knock behaviour of fuels. 7.Interim report. Tests on a BMW 132 N single cylinder engine on a DVL foundation with injection and carburettor operation by H.Berg.

10. UM688. Influence of the lead content of fuels on the constructional parts of aero engines. 1.Interim Report. Tests on a Jumo 211 by Denkmeier and H.Kervien.

11. UM688/2. Influence of the lead content of fuels on the constructional parts of aero engines. 2.Interim report. Tests on a DB 605A by Denkmeier and H.Kervien.

12. FB1469. Fuel consumption measurement according to weight (gravity) in a tapped test vessel by Muhlner.

13. UM1049. Sulphur content and lubrication ability by A.v.Philippovich.

14. UM1364. Contribution on non-hydrodynamic lubrication by I.Morghen.

15. UM520. Testing the lubrication ability of oils on the Almen, Wieland and Thomas oil test machines by K. Mayer-Bugstrom.

16. FB 976. Testing of glycerine substitute as to its usability as a coolant by K. Mayer-Bugstrom.

17. FB 912. The estimation of the thermal stability of various aero engine oils by M.Richter.

18. Deutsche Kraftfahrforsching, Interim report 31 (T.H.Dresden). The behaviour of fuel injection and supply pumps in operation with different diesel fuels by K.Richter.

19. UM 518. On the constitution and properties of lubricating oils and their alteration by oxidation by O.Selter.

20. FB 875. Investigation of oils of German origin in the Siemens oil test engine by H.Wenzel.

21. FB 893/ 1. Special investigation with aero engine fuels by O.Widmaier.

22. FB 893/ 2. The boiling behaviour of aero engine fuels by O.Widmaier.

23. FB 893/ 3. Deposit formation of lead containing fuels by O.Widmaier.

24. FB 1107. The influence of aromatic compounds on the knock resistance of fuels.

25. FB.1186. Influence of fuels on deposit formation in lubricating oils by O. Widmaier.

26. FB 1325. Artificial and engine aging of lubricating oils by O.Widmaier.

27. 1252. O.Widmaier.

28. 1048. by O.Widmaier and L.Nenninger.

29. FB 1090. Influence of operating temperature on piston rings of various cast alloyed materials by M.Kahm and H.Platz.

30. 1081. by G.Fischer.

31. 690. Gross.

32. 1748 Jung.

33. 998 W.Linke.

34. 1108 "

35. 1164 "

36. 1207 "

37. T 172 Theiner.

38. T 254 Sabath

39. G 172 Bech/Kunselmann.

40. 213 15 W. Siedenburg.

41. 35 Nagel.

42. I.G. Report 298c.

43. Broschur Braicher.

44. Page Summary.

45. Page acknowledgement.

APPENDIX 1

SPECIFICATION FOR AVIATION FUEL A3.

Oberkommando der Luftwaffe.
TLR/M 2 III(A)

Sheet 21, issued November, 1944.
For Service use only.

Method of Test as in BVM 40/42 Edn. and alterations as in technical information service of RLM-GL-A-M since Oct. '43. No.	Specification	TL 147-257/4
	Appearance	Clear, free from undissolved water and acids, must contain no solid impurities
	Colour	Blueish, corresponding to 1.6 - 2.6 mg. of Sudan Blue GN per litre of colourless fuel.
7070 - 7094	Octane number	at least 80 with 0.045 Vol. % T.E.L.
7055	Density at 15°C.	0.700 - 0.770
7100 - 7113	Boiling Range	I.B.P. - not below 40°C. 50% Vol. point - about 100°C. F.B.P. - below 190°C. Distillation loss - 2% Vol. max. Reaction of residue - Trace of acidity only
7130 - 7138	Vapour Pressure	0.5 Kg./cm.² max.
7150	Freezing Point	As determined by initial crystallisation point, must not be above -50°C.
7160	Evaporation Residue	10 mg./100 ml. max.
7200	Corrosion Test	No grey or black spots or pitting in the copper strip test. (3 Hours at 50°C.)
7200 - 7211	Ethanol content	30 Vol. % (±3 Vol. %)
7270 - 7271	T.E.L. Content	0.045 Vol. % min. (up to 0.120 permitted for use at the Front)
7280 - 7282	Aromatic Content	35 Vol. % max.
Storage and Storage Stability	Containers of black plate or burnt lacquer treated. No zinc treatment. Since the alcohol content is accompanied by a certain danger of separation of the fuel, it is essential to keep out water. The specified "water safety value" (see Tagtt-Kz: I C qc, No. 4 Lfd. No. 342/44) is at least 0.7 Vol. %. Admixture of B 4 and C 3 with A 3 in storage tanks is in all cases prohibited. A monthly examination of A 3 is necessary.	

NOTE: Earlier delivery specifications for A 3 are hereby superseded.

APPENDIX 2

SPECIFICATION FOR AVIATION FUELS B4 AND C3.

Oberkommando der Luftwaffe.
TLR/M 2 III(A)

Sheet 22, issued November, 1944(1)
For Service use only.

Method of Test as in BVM 40/42 Edn. Alterations as in technical information service of RLM-GL/A-M since Oct. '43. No.	Description of Test	B 4	C 3
	Technical Specification	TL 147 - 304/4	TL 147 - 330/4
	Appearance	Clear, free from undissolved water and acids. Must not contain solid impurities.	
	Colour	Blueish (2) corresponding to an 4.0-4.3 mg. Sudan Blue GN per litre of colourless fuel	Greenish addition of 0.5 mg. Sudan Blue GN and 0.6 mg. Fluorol
7070 - 7095	Octane Number	89 min. with 0.115 Vol.% T.E.L.	about 95
7230 - 7239	Single Cylinder Performance	In the region = 0.8-1.15 the curve must be above that of the comparison fuel.	
7055	Density at 15°C.	0.700 - 0.760	0.740 - 0.795
7108 - 7113	Boiling Range I.B.P. 10 Vol. % min. 35 " " 50 " " 90 " " 95 " " F.B.P.	not below 40°C. 75°C. 110°C. - - 180°C. below 190°C.	not below 40°C. 80°C. - 120°C. 130°C. - below 190°C.
7130 - 7138	Vapour Pressure	0.5 kg./cm.² max.	0.45 kg./cm.² max.
7150	Melting Point	- 50°C. max.	- 60°C. max.
7160	Evaporation Residue	10 mg./100 ml. max.	
7200	Corrosion Test	No grey or black spots or pitting in the copper strip test.	
7280 - 7282	Aromatic Content	35 Vol. % max.	45 Vol. % max.
7270 - 7271	T.E.L. Content	0.115 - 0.120 Vol. % (3)	
7274	Ethylene Dibromide Content	0.050 - 0.053 Vol. % (4)	
7214	Inhibitor Content	-	0.01% by wt. (5)
	Storage Stability	After 6 months' storage, examination should be carried out every 3 months.	

NOTES: (1) Sheet 22 renders invalid :
(a) Specifications for fuels B4 and C3 in sheet 1, issued May, '44, and sheet 2, issued April '44.
(b) Technical Regulations 8/44, 11/44 and 12/44. These should be destroyed.
(2) When a mixed colour results on the addition of C3 to B4 a corresponding quantity of Sudan Blue GN (max. 2 mg./lt.) should be added.
(4) See also Techn. Regulation 3/44.
(5) " " " " 6/43.
(6) In special cases aviation fuel C3 delivered without inhibitor must not be held. However OKL Chef TLR/M 2 III should be informed.

APPENDIX 3

SPECIFICATIONS FOR AVIATION STARTING FUELS FOR OTTO ENGINES.

RLM-GL/A-M II

For Service Use Only.
Sheet 15, Issued March 1944.

Method of Test BVM 1940 Edn. and Technical Information Service. No.	Techn. Delivery Specification	TL 147 - 300/2 Feb. '44
	Composition	98-96 Vol. % light gasoline 4-5 Vol. % aero engine lub. oil. As oil additive, only aero-oil 83 or V2 permissible. For estimation of lubricating oil content see overleaf.
	Purity	The fuel must be water-white, free from undissolved water, acids and solid material.
7055	Density at 15°C.	0.640 - 0.675 kg./ltr.
7070 - 7095	Knocking Behaviour	Octane No. at least 70
7100 - 7115	Boiling Range	I.B.P. not above 30°C. to 35°C. at least 10 Vol. % " 100°C. at least 85 Vol. % F.B.P. not above 165°C. Residue not above 6 Vol. % Loss in distillation not above 6 Vol. %
7160	Residue on Evaporation	Not above 6% by wt.
7130 - 7138	Vapour Pressure at 37.8°C.	0.9 - 1.5 at.
7190 - 7191	Sulphur Content	Not above 0.1% by wt.
7200 Reflux Condenser 3 Hrs. at 50°C.	Corrosion	No grey or black spots or pitting in the copper strip test
	Storage	To be protected from direct sunlight and kept as cool as possible
	Stability on Storage	After storing for a year, examination of boiling ranges and octane number is necessary. The containers must be carefully re-sealed as soon as the samples have been taken. Containers which have been opened must be used up as soon as possible. In disputed cases a full analysis must be made. In the report, the filling date and filling sign of the party concerned must be given.

NOTE: The previous specification TL 147 - 300/1 of Sept. 1939 is hereby superseded and should be destroyed.

METHOD FOR THE ESTIMATION OF THE OIL CONTENT OF AVIATION STARTING FUELS.

(a) The starting fuel (100 ml.) is heated in an evaporation dish of the usual type on a vigorously boiling water-bath, with air-blast, until the gasoline has evaporated. The dish containing the oil is then dried in an oven at 110°C. for half an hour and weighed. The oil content is then calculated.

(b) Most of the gasoline is distilled off from 1500 ml. of starting fuel using an electric hot-plate and a distilling flask of the normal type. It is essential to avoid overheating of the oil. The residue from the distillation is transferred to a 250 ml. round-bottomed flask and saturated steam blown through it until the steam distillate contains no more gasoline.

The residual oil is separated using a separating funnel and freed from water. The analytical data of the oil obtained in this way must correspond to the specification for the oil used in the starting fuel.

APPENDIX 4

SPECIFICATION FOR AERO DIESEL FUEL K1.

RLM
GL/A - M II

For Service Use Only.
Sheet 2, issued April 1944 (1)

Method of Test BVM 1940/42 Edn. No.	Description of Test	K1
	Technical Specification	TL 147 - 351 / 2.
	Appearance	Clear, free from undissolved water and acids. Must not contain solid impurities.
	Cetane Number	50 min.
7055	Density at 20°C.	0.810 min.
7100 - 7113 Water Cooling	Boiling Range	I.B.P. about 160°C. 96 Vol. % min. at 350°C.
8075	Pour Point	-46°C. max.
8070	Viscosity at 20°C.	1.1°E. min.
Penisky-Martens	Flash Point	above 50°C.
8085	Acid Value	0.7 mg. KOH/g. max.
7190 - 7191	Sulphur Content	1% by wt. max.
8095	Ash Content	Traces only.
DIN 2 DVM 3763	Corrosion Test	4 mg. max.
8110	Conradson Test	0.1% by wt. max.
8105	Water Content	Traces only.
	Storage Stability	After storage for 1 year six-monthly tests are necessary.

NOTES: (1) Sheet 2, April 1944 supersedes Sheet 2, May 1942.
Copies still in existence should be destroyed.

APPENDIX 5

PROVISIONAL SPECIFICATION FOR JET FUEL J2 AND RUNNING-IN FUEL EINLAUF J2

Oberkommando der Luftwaffe
Chef der Technischen Luftrustung
As. : 85 g. TLR/M 2 III (A)

For Service Use Only
Sheet 14, issued Oct. 1944 (1)

Method of Test BVM 1940/42 Edn. of Technical Information Service No.	Technical Specification	J 2 VTL 147 - 286 / 2	Einlauf - J 2
	Appearance and Colour	Clear, free from undissolved water and acids, must not contain solid impurities.	
7055	Density at 15°C. kg./lt.	0.800 min.	0.760 min.
7130 - 7138	Vapour Pressure at 37.8°C.	0.2 kg./cm.² max.	0.5 kg./cm.² max.
8070 - 8072	Viscosity at +20°C. " 0°C. " -20°C.	1°E min. - - - - 3°E max.	1°E min. 3°E max. - - - -
8075	Pour Point (3)	below -25°C.	below 0°C.
7190 - 7191	Sulphur Content % wt.	1.5 max.	
7214	Phenol Content Vol. %	1.0 max.	
7280 - 7291	Aromatic Content Vol. %	45 max.	
8110	Conradson Test % wt.	1.6 max.	
8095	Ash Content % wt.	0.5 max.	
7225 - 7228	Lower Cal. Value (2)	9000 K.Cal./Kg. min.	
7200 DIN 2 DVM 3763	Corrosion Test. Copper Strip Zinc Strip	negative 4 mg. max.	
(3)	Filtrability (2) (Hammerich) at 400 mm. Vacuum	120 secs. max. at -25°C.	120 sec. max. at 0°C.
	Re-examination	After a year	
	Storage	The fuels must be kept apart from one another and from other fuels (A3, B4, C3, E1) during storage. Admixture with the remains of other fuels and admixture of the latter with J2 in pipe-lines, barrels etc. is strictly to be avoided.	

NOTES: (1) This sheet renders Sheet 14, March 1944 obsolete and the latter should be destroyed.
(2) This is only to be carried out during acceptance tests.
(3) See "Techn. Anord." 1/45 and 8.T.46.

APPENDIX 8

PROVISIONAL SPECIFICATION FOR FLYING BOMB FUEL E 1.

Planungsamt (Planning Dept.)
OL/A-M II B

Berlin 21/9/43
App. 4302.

(1) Appearance	clear, free from undissolved water and acids. Solid impurities must be absent.
(2) Density at 15°C.	0.740 - 0.760.
(3) Boiling Range.	I.B.P. 30.50°C. 10 Vol. % min. 75°C. 30 Vol. % min. 100°C. 95 Vol. % not above 220°C.
(4) Residue on Evaporation	50 mg./100 ml. max.
(5) Corrosion Test	no grey or black spots or pitting in the copper strip test.
(6) Separation	must not occur above -60°C.
(7) Cloud Point	the M. Pt. of the fuel, cooled until crystallisation commences, must not be above -60°C.
(8) Lower Cal. Value	9600 Kg. Cal./Kg. min.

APPENDIX 7

SPECIFICATIONS FOR AERO-ENGINE OILS S3 AND V2

RLM
GL A-M II

Appendon to DVL Nr. 1477/430
40/1510/43 g.
For Service Use Only.
Sheet 7, June 1944.

Method of Test B V M(1) 1938 Edn. No.	Military Name		S 3		V 2
	Filling Station Mark		VK, VB, NM, WD, WH, WN, WL, WR, WM, WY, WV, WF, WB, WG.	RG, HL, WD, WH, WN, WL, WR, WM, WG, WV, WF, WB, WG.	R G
	Technical Specification for Delivery		TL 147-502 TL 147-503 TL 147-506	TL 147-(561-563) TL 147-(571-573) TL 147-(581-583)	TL 147-500
	Appearance		The lubricating oil must be clear, free from undissolved water and mineral acids and must contain no solid impurities.		
8060	Refractive Index	Max.	1.4995	1.4990	1.5070
8065	Density at 20°C. kg./ltr.	Max.	0.897	0.895	0.920
8070	Viscosity		cs. °E.	cs. °E.	cs. °E.
	at 50°C.		125-137 (16.5-18.0)	125-143 (16.5-18.8)	133-144 (17.5-19.0)
	at 100°C.	Min.	18.5 (2.70)	19.0 (2.75)	19.4 (2.80)
	Pole Height	Max.	2.04	1.95	1.9
	Slope	Max.	3.45	3.35	3.4
8072	Viscosity Index	Min.	92	98	96
8075	Pour Point °C.	Max.	-17(2)	-20	-25
8080	Flash Point °C.	Min.	260	225	235
8081	Ignition Point °C.	Min.	300	255	270
8085	Acid Value mg. KOH/g.	Max.	0.06	0.06	0.1
8090	Saponification Value mg. KOH/g.	Max.	0.2	0.2	8.0
See note (3)	Evaporation Test (Dr. Noack) 250°C. % wt.	Max.	3.0(4)	11.0	5.0
8110	Conradson % wt.	Max.	0.35	0.25	0.5
8095	Ash Content % wt.	Max.	0.01	0.01	0.02
8100	Hard Asphalt % wt.		0	0	0
8105	Water Content % wt.		0	0	0

NOTES: 1. Constructional specifications for BVM Aero-Engines "Test Regulation for Aero-Engine lub. oils for use in Otto engines". Can be obtained from the Scientific Reports section (ZWB) of the DVL, Berlin-Aldershof, Rudower Chausee 16/25.
2. For S3, the filling station mark VK allows a max. setting point of -10°C.
3. "Angewandte Chemie" 1936. Vol. 49, page 386.
4. For S3 — VK the max. Noack Test value is 5.0.
5. The present sheet 7 supersedes the "Technical Acceptance Conditions for Aero-Engine Lub. Oils" issued by the R.L.M. L.C. II 2e on 15.3.36. Copies still in existence should be destroyed.

ABBREVIATIONS:- V = Vakuum K = Koln B = Bremen W = Wifo.

PREPARED BY :- Mineral Oil Section, Group GL/A-M II. This sheet is primarily intended for the suppliers. Thus there are two columns for S3 (to differentiate finished products from blended stocks) - see the other sheet 7 for military applications.

APPENDIX 8

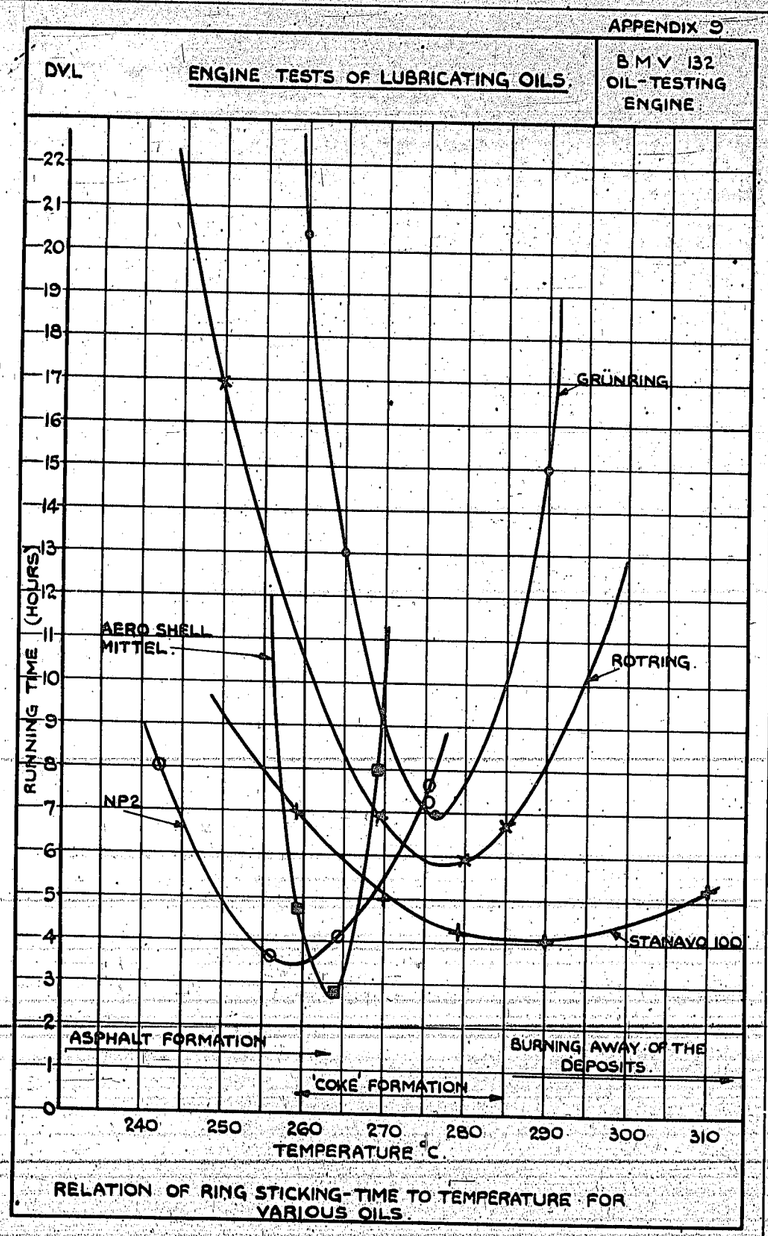
SPECIFICATION FOR RUNNING IN AERO LUBRICATING OIL T.42. (NACHLAUFSCHMIERSTOFF)

RLM-GL/A - M II — Oct. 43 Sheet 13.

Method of Test B V M 1938 Edn. *	Technical Specification	TL 147 - 700 / 1
	Composition	Selective Raffinate and Voltol
8055	Purity	The oil must be clear, water and mineral acid free and must contain no solid impurities.
8065	Density at 20°C. Kg/lt.	0.875 - 0.895
8070 - 8072	Viscosity	at 20°C. 8 - 9.5°E at 50°C. 2.5 - 2.9°E at -30°C. 800°E max.
8075	Pour Point	-45°C. max.
8080	Flash Point	155°C. min.
8085	Acid Value	0.15 mg. KOH/g. max.
8090	Saponification Value	5 - 6 mg. KOH/g.
8095	Ash Content	0.01 % wt. max.
8100	Hard Asphalt	0
8105	Water Content	0
	Miscibility	With Rotring (S 3) and Aero Shell medium (V 2) miscible in all proportions
	Storage Stability	After a storage period of 2 years, re-examination every 6 months is necessary.

* Instructions for B V M aero-engines "Testing Regulators for Aero-engine lub. oils for use in Otto engines" can be obtained from the D V L Berlin-Adlershof, Rudower-Chaussee 16/25.

APPENDIX 9

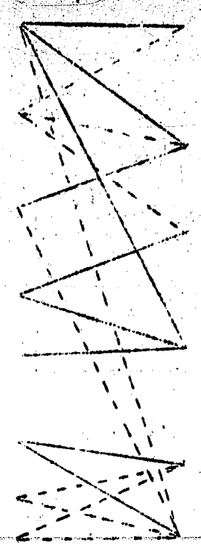


RELATION OF RING STICKING-TIME TO TEMPERATURE FOR VARIOUS OILS.

APPENDIX 10

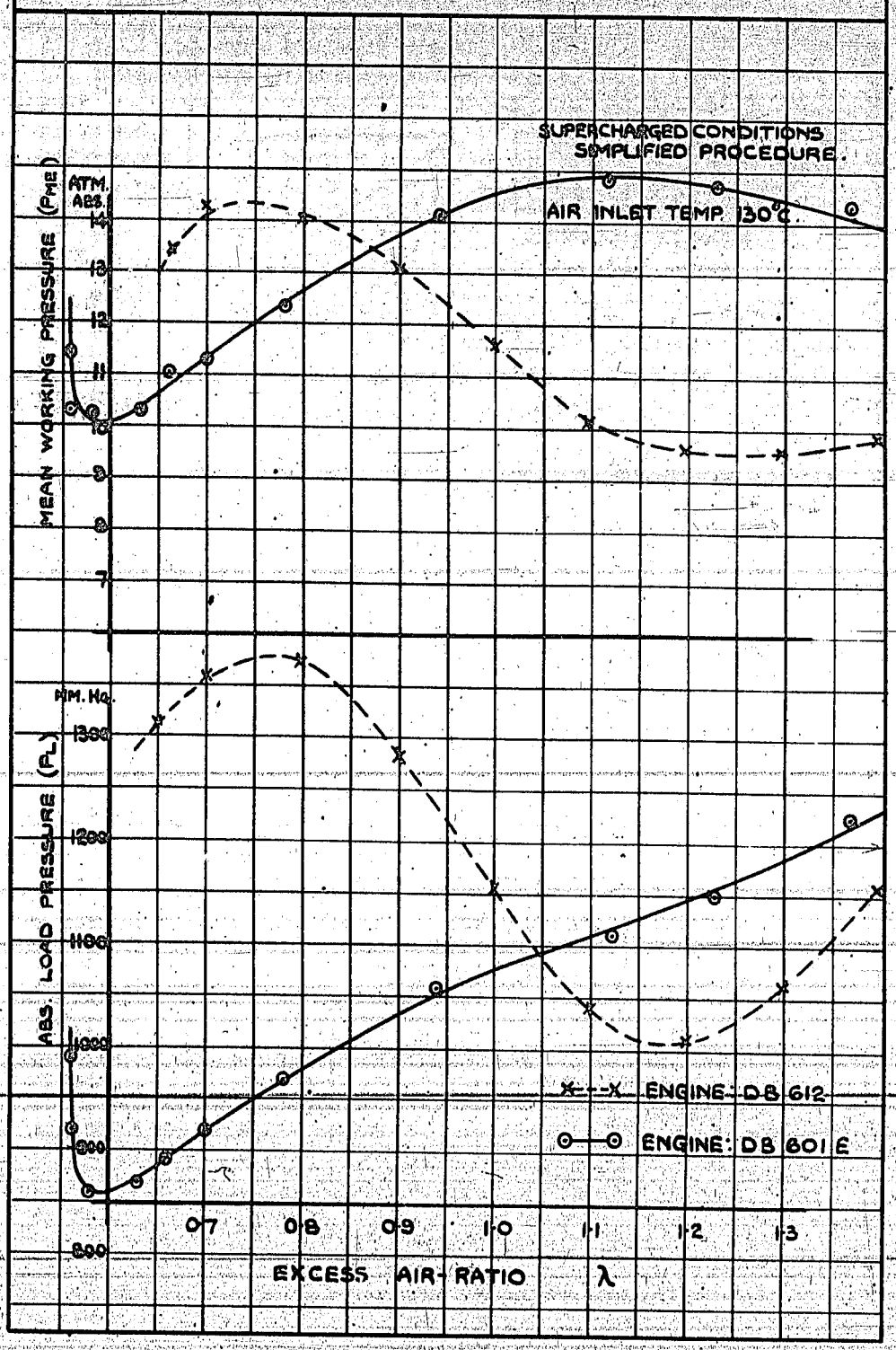
SIMPLIFIED SCHEMATIC DIAGRAM FOR DETECTING OXYGEN COMPOUNDS IN USED LUBRICATING OILS.

Solid Lines :- actually detectable compounds;
Dotted Lines :- principal possibilities for detection.

"Acids"	Carboxylic acids		titration with alcoholic potassium hydroxide
	compounds of an acid nature (hydroperoxides, phenols, enols etc.)		saponification and titration
" Esters"	acid anhydrides, esters etc.		acetylisation (Verley-Bölsing method)
Oxy-Compounds	primary and secondary alcohols, phenols		estimation by active hydrogen (Zerewitinoff method)
	tertiary alcohols (enols)		
Oxo-Compounds etc.	Ketone (aldehydes)		treatment with sodium alcoholate
	peroxides		
	ether-like compounds		treatment with the Grignard reagent.

DVL.

AN EXAMPLE OF THE TWO DIFFERENT FORMS OF THE KNOCKING BOUNDARY CURVE.



Copy 1

FINAL REPORT No. 118
ITEM No. 30

MUNICH TECHNICAL HIGH SCHOOL

Interrogation of Dr. E. H. Kadmer
and Dr. K. Schnauffer

Chaffee & Thomas

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BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

MAY 1946
REC'D.....
TIIC L.F. & L. S-C.

LONDON - H.M. STATIONERY OFFICE

MUNICH TECHNICAL HIGH SCHOOL

INTERROGATION OF DR. E. H. KADMER

AND DR. K.SCHNAUFFER.

August 1st - 8th 1945

Reported by:

Capt. C.C.Chaffee, U.S.Army Ordnance.

Major W.H.Thomas, British, Ministry of Fuel and Power.

BIOS Target No. C 30/181

Fuels and Lubricants.

British Intelligence Objectives Sub-Committee
32, Bryanston Square,
LONDON, W.1.

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------oOo------

PERSONNEL OF TEAM:

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Major W.H.Thomas	British, Ministry of Fuel and Power.

1. SUMMARY

(a) Dr. E.H.Kadmer and Dr. K.Schnauffer of the Munich Technical High School were interrogated on the subjects of Fuels and Lubricants over the period August 1st - 8th, 1945.

(b) Kadmer is a recognised expert on lubricants and during the war served for three years in the German Army in charge of a fuel inspection Company in campaigns in France, Jugoslavia and Russia. In October 1943 he was released from the Army to carry out researches on lubricating oils at the Munich Technical High School on behalf of Oberkommando des Heeres, Heereswaffenamt, Wa. Pruf 6 and Wa. F.IIa., and also for Reichsforschungsrat, Bevollmächtigter für Mineralölforschung. Schnauffer was in charge of Forschungsinstitut für Flug und Kraftwagenmotoren at the Technical High School, Munich.

(c) The interrogation of Kadmer produced valuable results. He was not very knowledgeable on fuels but gave the names of experts in this field who should be able to give any further information required. With regard to lubricants, however, his information was extensive, especially with regard to published literature.

(d) Kadmer has carried out a considerable amount of work in the development and use of cutting oils containing mineral oil sulphonates in conjunction with firms in the German Armament Industry He has also developed a high pressure viscometer and carried out work on lubricating oil aging and lubrication properties.

(e) The information obtained from Schnauffer was meagre and of practically no value.

2. INTRODUCTION

After being located at Munich, Dr. Kadmer was requested to prepare a brief report on his work on fuels and lubricants during the war, to state for whom the work was carried out and to indicate the main results obtained.

He was also requested to supply answers to detailed questionnaires on fuels and lubricants. Dr. Schnauffer of Forschungsinstitut für Flug und Kraftwagenmotoren of the Technical High School, Munich, was requested to give answers to a less extensive questionnaire. The information so obtained is the subject matter of the present report.

3. ALLOCATION OF RESEARCH AND DEVELOPMENT WORK ON FUELS AND LUBRICANTS BY GERMAN GOVERNMENT DEPARTMENTS.

According to Kadmer, research work was allocated by the following organisations:-

(a) Der Reichsforschungsrat, Abteilung der Bevollmächtigter für Mineralölforschung - Prof. Dr. Bentz. His deputy was Prof. Dr. G.R. Schultze.

(b) Oberkommando der Heeres, Heereswaffenamt.
Wa. Prüf.6. Reg. Baurat Dr. K.O.Müller, Dr. Hagemann.
Wa. F.II. Ober. Rat. Prof. Dr. Eschenbach, Reg. Baurat Dr. Pistorius.

(c) Forschungsführung der Luftwaffe.

(d) Deutsche Versuchanstalt für Luftfahrt (DVL)

(e) Kriegsmarine (exact department unknown).

Among the research institutes who carried out this work Kadmer drew attention to the following:-

Name	Institut	Collaborator
Prof. G.Beck	Institut für Kraftfahrwesen T.H.Dresden	Dr. R.Poppinga
Prof. G.Berndt	Institut für Messtechnick T.H.Dresden	
Prof.Heidebrook	T.H.Dresden	
Prof. Heinze	Institut für Braunkohlen u.-Mineralölforschung T.H.Berlin	Prof. Marder
Prof. W.Kamm	FKFS, Forschungsinstitut für Kraftfahrwesen und Fahrzeugmotoren T.H.Stuttgart	Dr. Widmaier Dr. Graff Dr. Nenninger

Name	Institut	Collaborator
Prof. H.Kluge	T.H. Karlsruhe	
Prof. A.Nägel	T.H. Dresden	
Prof. W.Nusselt	T.H. Munich	
Prof. H.Opitz	Labor für Werkzeugmaschinen T.H. Aachen	
Prof.H.Schallbroch	T.H. Munich	Dr. Lango
Prof. A.W.Schmidt	Institut für Chem. Technologie, T.H. Munich	Prof. Kadmor Dr. Knoulo
Prof.K.Schnauffer	Lehrkanzel für Luftfahrt T.H. Munich	Dr. Weber
Prof. L.Ubbelohde	T.H. Berlin	Dr. Jostes
Prof. M.Ulrich	T.H. Stuttgart	Obering Gaubitz
Prof. Reinsch	T.H. Berlin	Dr. Rixman Dipl.Ing. Riedel

4. WORK CARRIED OUT BY DR. E.H.KADMER.

(a) Historical.

Kadmer was admitted to the Institut für Chemische Technologie und Versuchslaboratorium für Mineral-öle of the Technische Hochschule, Munich in 1935/36 at which time the Institut was directed by Prof. A.W.Schmidt. Admittance was obtained by Kadmer after presentation of a thesis entitled "On the Natural and Artificial Aging of Automotive Engine Oils". The original of this thesis was destroyed in an air raid on Landshut but a copy may be in the Munich Technical High School Library which is only partly destroyed. An extract of the thesis was published in "Oel und Kohle", 1937, 101 and 102. In 1938, when Kadmer was a lecturer at the T.H., Munich, engaged in research on oils and greases, he prepared, in collaboration with his assistant (Fräulein Dr. Röglsperger) a booklet entitled "Emulsifying Agents and Technical Emulsions" which appeared in 1939 (Verlag für Chem. Industrie, H. Ziolkowsky. Augsburg. 52 pages). At the same time Kadmer wrote his well-known book "Schmierstoffe u. - Maschinenschmierung" (Lubricants and Machine

Lubrication) which was published by Verlag Gebr. Borntträger, Berlin. (First Edition 1940, 2nd Edition 1941, 3rd Edition destroyed in an air raid on Berlin, 4th Edition is with a printer in Chemnitz and a 5th Edition is now being prepared by Kadmer).

When war broke out in 1939, Kadmer was called up into the German Army but in 1940 he was released at the request of T.H.Munich and between February and May 1940 was engaged in work on the working up of Zisterdorf Asphaltic Bottoms into Steam Cylinder and Aero Engine Oils, which was requested by Reichsforschungsrates das Forschungsthema (National Research Council). The work was reported under the Code Name "Ka.1/04/2 - Oils-Greases" to Deutsche Forschungsgemeinschaft, Berlin-Steglitz, Grunewaldstrasse 35.

In June 1940, Kadmer was again called up for Military service, this time with OKH, Wa.Prüf. 6, and was put in charge of a chemical unit (fuel inspection company) in which position he took part in the campaigns in France, Jugoslavia and Russia until October 1943. During this time Kadmer found time to write the book "Kraftstoff Fibel" (Guide to Fuels) which was written in Russia 1941/42 and published in 1943 (Verlag, Union Deutsche Verlags-Gesellschaft, Roth and Co. Berlin). Transport difficulties, however, prevented distribution of the book. During 1943 two papers by Kadmer appeared in "Oel und Kohle" entitled: (1) "A Contribution to the Study of Mineral Oil Emulsions from the Colloidal Aspect", and (2) "On the Dipole Moment and the Lubricating Power of Oils". A further paper was prepared by Kadmer at about this time for discussion purposes, and was addressed to Deutsche Forschungsgemeinshaft, at Berlin-Steglitz. It was entitled "An Attempt to Calculate the Octane Number of Benzine-Benzol mixtures from Boiling Behaviours, Refractivity and Solubility in Aniline".

In October 1943, Kadmer was again released from Military service in order to take up work at the Munich Technical High School where he was awarded the following research contracts:-

No.	Contract Awarded by	Annual Allocation	Title of Research Contract
I	Oberkommando des Heeres, Heereswaffenamt, Wa. Prüf.6.	RM. 10,000	The Thermal Loading of Oils in Gear Boxes and Hydraulic Transmissions No.SS 4010-0015-9511/43 dated 10.2.44.
II	do.	RM. 10,000	Determination of the Constitution of German Army Oils by High Vacuum Distillation No.SS 4010-0015-9512/43 dated 10.2.44.
III	Reichsforschungsrat, Bevollmächtigter f.-Mineralöl-forschung, Berlin, N.4, Invalidenstr. 44	RM. 20,000	Substitute Oils for Metal Working in the Armaments Industry with and without the Formation of Shavings. No.SS 4104-0170/43-1/44 dated 19.1.44.
IV	Oberkommando des Heeres, Heereswaffenamt, Wa. Prüf.6.	RM. 10,000	Investigations on the Lubricating Power of Oils. No.SS 4010-0015-9501/43 dated 10.2.44.
V.	Oberkommando des Heeres, Heereswaffenamt, Wa.F.IIa	RM. 25,000	The Production of an Improved Flame Thrower Fuel having a Greater Range. No.SS 0070-4003/44 dated 12.5.44.
VI.	Reichsforschungsrat, Bevollmächtigter f.- Mineralöl-forschung, Berlin, N.4, Invalidenstr.44.	RM. 10,000	Working up Residual Oils by Sulphonation, Sulphochlorination and Extraction. No.SS 4104-0109/44- II/44 dated 15.5.44.

After the destruction of the Munich High School Laboratories in the Summer of 1944 by air raids, the Kadmer research group was evacuated to Landshut in the varnish factory of Mittermayer G.m.b.H., and to Kulmbach in the brewery of Sandler A.G. The personnel were dispersed as follows:-

To Landshut -

Prof. Kadmer, Dipl. Ing. Eduard Theumert, Dr. Lambert Pany, Peter Held (laboratory assistant), Gerda Goschenhofer (laboratory assistant) and Mrs. Johanna Theumert (secretary).
Collaborators with this group were Ing. Max Wieland in Grafing, Upper Bavaria and Ing. Heinrich Diener in Nürnberg. The following candidates for Doctorates were also at Landshut, - Dipl. Ing. Rudolf Kreeb of BMW, Plant 1, Munich, and Dipl. Ing. Karl Heilmeier of BMW, Plant II, Allach.

To Kulmbach -

Dr. Hermann Schultes, Dr. Hans Martin Fischer, Dr. Lothar Fourier, Richard Sanger (Manager), Johann Winkler (laboratory assistant) and Dr. Heinrich Hammen (liaison with Metallgesellschaft A.G., Frankfurt/Main).

The Kadmer research group was dissolved on June 1st 1945 and the research accounts were closed by the Allied Military Government, Financial Dept., Holbeinstrasse, Munich, on July 23rd 1945. The sum of RM. 12,358.04 under the blocked accounts Nos. 13549, 13605 and 13685 was transferred to the Military Government on the same date.

(b) Summary of Earlier Work.

(i) The Working up of Zisterdorf Asphaltic Bottoms into Steam Cylinder Oil and Aero Engine Oil. (Feb. - May 1940).

Zisterdorf asphaltic bottoms from Nova A.G. Vienna, comprises 30-35% vol. of Zisterdorf crude oil and had not hitherto been fully utilised. Inspection data were as follows:-

d 20°C.	0.985
n 20/D	1.5564
Viscosity	715°E. at 50°C.
	30°E. " 100°C.
	4.85°E. " 150°C.

W.p.	2.81
m.	3.97
Flash Point	336°C.
Composition -	
Oil	65.0% (n D 1.5256)
Oil Resins	22.6% (n D 1.6296)
Asphaltic Resins	7.2%
Hard Asphalt	0.6%
Carbenes, Carboids and Carbon	4.6%
	100.0

Hydrogenation was first attempted in the high pressure hydrogenation plant of the Chem. Techn. Institut at T.H.Munich at temperatures of 200-500°C. and pressures of 200-460 atm. using 2.5% molybdic oxide and 2.5% tungstic oxide as catalyst. At 330°C. and 380 atm. the reaction began after 5 hours and became violent at 430 atm. and 400-450°C. After a three-hour fall in pressure, namely from 420 to 340 atm. at a constant temperature of 450°C. the reaction was regarded as complete. The hydrogenated product was a yellowish red light oil having a density of 0.862 and a refractive index of 1.5050. Distillation gave 50.8% of a benzine of boiling range 50-200°C. having a refractive index range of 1.387 to 1.451 and 49.2% of a yellowish red dark oil of n D 1.589 and viscosity 29°E. at 0°C., 6.7°E. at 20°C. and 2.02°E. at 50°C. which was completely soluble in acetone. At a maximum hydrogenation temperature of 300°C. and at 360 atm. pressure the asphaltic bottoms were unchanged. For this reason no further work on hydrogenation was carried out.

Acid Treatment. The asphaltic bottoms were diluted with an equal quantity of Zisterdorf spindle oil (5.2°E. at 20°C., n D 1.4998) and treated with 5% sulphuric acid at 45°C. with air stirring. The resin soon separated in the form of lumpy aggregates with considerable loss of oil yield. The treated oil (n D 1.5125) was boiled with 1.5% calcium oxide and 4.5% fullers earth and on filtering gave a dark brownish black filtrate (n D 1.513, d 0.915, 6.7°E. at 50°C) which was vacuum distilled at 2 mm. Hg. pressure. After separation of the light oil fraction 49% of residual oil remained (n D 1.528, 97°E. at 50°C., 7.5°E. at 100°C., Hard asphalt 0.186%, Flash Point 243°C.). This was the process adopted, but

with centrifugal separation after acid treatment, and good quality lubricants were produced.

(ii) A Contribution to the Study of Mineral Oil Emulsions from the Colloidal Aspect. (1943)

Only oil-water dispersions were considered. The preparation of the emulsifying oils was carried out using the emulsifying agents E.70, E-24, E-25 and E-41 and the most diverse mineral oils. After elucidation of the colloid chemical behaviour of such mineral oil emulsions they were found to obey, very nearly, the following laws.

(a) The quantity of emulsifying agent required increases with the viscosity of the mineral oil used.

(b) Certain constituents of mineral oils (oily resins, etc.) are necessary for stable emulsions and on the other hand sharply refined or synthetic oils respond badly or not at all to such emulsifying agents.

and (c) Colloidal graphite only gives stable dispersions in mineral oils which themselves can readily be emulsified.

For use in practice it is recommended to dissolve the emulsifying agent in mineral oil and then to emulsify with hydrophilic graphite suspended in water instead of making a suspension of oleophilic graphite in oil, mixing with emulsifiers and emulsifying with water.

(iii) Dipole Moments and the Lubricating Power of Oils. (1943).

The work of Mander suggested that the dipole moments of oils were related to lubricating properties. Kadmer was, however, able to shew that no such relationship existed.

(iv) Attempted Calculation of the Octane Number of Benzine-Benzol Mixtures from Boiling Range, Refractivity and Aniline Point. (1943)

The boiling range - refractivity curves of motor fuels from the most varied sources (when free from alcohol and benzol) show an almost regular relationship, which strays only within narrow limits (see "Kraftstoff-Fibel" p. 108). Addition of benzol alters the curve and this change in shape again varies regularly.

If the octane values for very large numbers of fractions of commercial benzines are determined for certain boiling/refractivity ranges, groups of octane value curves can be plotted which permit of additive calculation of Octane Number by simple fractionation of a benzine or an alcohol-free benzine-benzol mixture and estimation of the nD values of the separate fractions.

Refs: Kadmer, Oel u. Kohle 1943, 517
" " " " 1943, 836
Heinze, Marder, Doring and Blechstein, Oel u. Kohle 1941, 8.

(c) Summary of Work Carried out since October 1943 for OKH and Reichsforschungsrat, Bevollmächtigter f. - Mineralölforschung.

(i) Investigation No. 1 "The Thermal Loading of Oils in Gear Boxes and Hydraulic Transmissions".

Development of a New High Pressure Viscometer (Doctorate Thesis by Dipl. Ing. Heilmeier). January, 1945.

Heilmeier has developed three types of high pressure viscometers and the third form is suitable for the measurement of oil viscosities at pressures up to 9000 kg/cm^2. Earlier measurements shewed agreement with "pressure viscosity" values obtained by Kiesskalt, Dow, Fenske and Morgan, Bradford and Vandergrift. The third type of the Heilmeier high

pressure viscometer comprises a cylindrical casing the upper part of which has a flanged boring in which the piston moves. The piston head is provided at its upper end with a pressure ball bearing so that the piston, when under pressure, can still be rotated about its longitudinal axis by a lever arm. In the hollow part of the casing is a tube, the lower end of which is a push fit into the boring. The external diameter of this tube is chosen so that it can be taken out of the casing and replaced again by way of the boring. Inside the tube is a weight which can fall freely with sufficient clearance. The dropping weight is provided with an axial hole carrying a shaft eccentrically mounted in the cover and bottom of the dropping tube. By turning this eccentric shaft the dropping weight can be arrested or freed. By manipulation of the lever the dropping weight can be allowed to fall freely for any required time. Since this free fall occurs in the oil to be tested at known temperature and pressure, the velocity of fall is proportional to the viscosity. The velocity of fall follows from the height "h" fallen through in time "t". The measurement of "h" is made through a hole in the top of the dropping tube and is accurate to fractions of a millimetre. A patent has been applied for.

Demands made on Oil in Fluid Steering Gear Equipment (Buttner type) Used in Tanks (Gear Wheel Works, (Zahnrader-fabrik), Augsburg, formerly Renk A.G.

It was found that under the severe conditions obtaining a noticeable oil-thinning occurred, whereas oil-thickening might have been expected.

Aging of Oil by Circulation Pumping.

This was a project for the aging of oil by circulation pumping through different calibrated tubes with self-heating of the oil. This was intended for test-purposes, especially for synthetic oils liable to oxidation and sensitive to foaming (Ruhrchemie, Brabag, I.G.).

Serial Trials on Oil Aging Using the H W A Apparatus of Noack.

Army engine-oils and various synthetic oils were artificially aged at different temperatures for various periods of time in the Noack apparatus. The earlier assumption that the progress of aging could be followed by the increase in viscosity is quite wrong. Oil thickening is primarily a result of vapour losses and is only to a secondary extent due to inner changes in the residual oil.

Studies on the progressive aging of oils were also commenced but all the samples were destroyed during an air raid on Landshut.

(ii) Investigation No.II. "Determination of the Constitution of German Army Oils by High Vacuum Distillation". 1944.

The purpose of this work was to determine qualitatively and quantitatively the content of Brightstock of viscosity about 30°E. at 50°C. Oils examined in this way comprised Rheinpreussen Oils M056, M057, M058, M059, M060 and M061; Ruhrchemie oils 1200 and 3500; Brabag Oil ZR30 and various natural oils. The work carried out included solvent treatments and led to the development of the idea of "solvent range" ("Solvent-Bereiches").

(iii) Investigation No.III "Substitute Oils for Metal Working in the Armaments Industry with and without the Formation of Shavings".

Reports issued on this work (see under "Documents") were summarised by Kadmer as follows:-

Report No.III (1). Progress Report on Metal Working and Lubrication (May 1944)

This report gives a discussion on the reproducibility of experimental results.

Drawings of Kadmer's proposed experimental set-up were stated to be with:

Mauserwerke, A.G., Oberndorf/Neckar (Ing. Reichert and Ing. Rottler).

B M W Works I, Munich (Dipl. Ing. Kreeb).

Siemens - Reiniger, A.G., Erlangen.

Metall and Eisen G.m.b.H., Nurnberg.

Neumeyer G.m.b.H., Munich.

Noris - Zundlicht, A.G., Nurnberg and

Dynamite, A.G., Nurnberg.

Report No. III (6). Lubricant Testing in the Deep Drawing of Small Cartridge Cases (September, 1944)

This work was carried out by Dynamite, A.G. Nurnberg, together with Obering Reinecke, Ing. Gronemann and Ing. Diener. The following were tested: 1% grain (curd) soap, a 5% boring oil concentration, a 5% emulsifiable drawing grease, 2% of Kadmer experimental compound I with 1% Cosan (colloidal sulphur), 3% Kadmer experimental compound 3 and a 1.5% concentration of the latter with 0.5% of colloidal graphite. As a standard of evaluation the number of drawing rings used up per 100 kg. of cartridge cases was employed; limits of straying were determined and vary between 100 and 180% in spite of the most careful work. The effect of phosphatising is discussed.

Report No. III (7). Replacement of Cutting Oils by Emulsions in the Deep Boring of Rifle Parts with Hard Metals. (October, 1944)

This was carried out by the Mauserwerke, A.G., Oberndorf, together with Ing. Reichert. The substitute (for Shell-Jumag) was prepared from Kadmer Products 1 and 2, colloidal sulphur and colloidal graphite additive. Studies of the viscosity-temperature behaviour of the emulsions and

of "Standzeit" i.e. the number of finished cases per sharpening of the borer were made. The "Standzeit" results were as follows:-

Shell Jumag			57 cases
Kadmer I 25%			42 "
Kadmer 2 10%			35 "
Kadmer 2 5%	and 0.5%	Cosan	39 "
Kadmer 2 10%	and 1%	Cosan	50 "
Kadmer 2 15%	and 1.5%	Cosan	61 "

Report No. III (8). Testing of Emulsions in the Fine Turning of Engine Cylinders. (October 1944)

This work was carried out by B.M.W., Munich, together with Dipl. Ing. Kreeb. "Standzeit", i.e. number of cylinders per tool were 15.8 with 1% soln. of the boring medium Ho and 23.4 with 1.6% Trupon boring oil.

Report No. III (9). Milling Trials with Emulsions. (October, 1944)

These trials were carried out by Mauserwerke, A.G., Oberndorf together with Ing. Reichert solely to discover whether it is at all possible to obtain reproducible "Standzeiten" in milling work. Extensive results showed that with present methods this cannot be done.

Report No. III (13). On the Lubricating Power of Oils During the Shaving Process Occurring in "Clearing" (Raumen). (January 1945).

This work was carried out by Mauserwerke, A.G., Oberndorf together with Ing. Reichert. The result is very interesting, since all the high pressure lubricants and additives active at the interfaces are much inferior to simple "fatting" of mineral oils. The "Standzeit" of the clearing tool is directly connected to the degree of "fatting".

Report No. III (14). Cooling and Lubricating by Emulsions in Horizontal Barrel Boring with Rapid Steel Deep Borers. (February 1945).

Carried out by Mauserwerke, A.G.. together with Ing. Reichert. Various emulsion-like products and soap solutions were tried out. The view often expressed that in emulsions and lubricating greases only the mineral oil has lubricating properties appears to be wrong. In this and similar processes the opposite is true, since the soap helps in the splitting away of shavings and the mineral oil is inactive as the numerical results show.

Report No. III (15). Irregularities in "Standzeit" in Deep Drawing Processes. (February 1945).

This work was carried out by Metall und Eisen G.m.b.H., Nürnberg and Neumeyer A.G., Nürnberg with Ing. Schmidt. The influence both of the metal and of the lubricant on the "Standzeit" was examined in different processes of cold spraying and deep drawing of steel. It is very difficult. if not impossible, to isolate clearly the crucial moments in the procedure. Unsuitable lubricants soon fail, but suitable ones can hardly be compared since the "Standzeit" strayings of the tools are much too great.

(iv) Investigation No. IV. "Investigations of the Lubricating Power of Oils.

Report No. IV (2). New Observations on Friction, Wear and Lubricating Power with the Almen-Wieland Oil Testing Machine. (May 1944).

Mineral oils refined to various degrees, solvent extracts, fatty oil blends, high pressure oils, emulsions, various bearing metals and also phosphatised bearing surfaces were tested in several series of experiments.

It is shown that the testing machine (sent from America), after modification by Wieland for

German use, is suitable not only for the evaluation of extreme pressure lubricants with high bearing and gear pressures, but also for the evaluation of metal working oils and emulsions.

(v) Investigation No.V. "The Production of an Improved Flame Thrower having a Greater Range".

Kadmer had no reports available on this work and stated that all these were with OKH, Wa. F.IIa.

(vi) Investigation No.VI. "Working up Residual Oils by Sulphonation, Sulphochlorination and Extraction.

Four reports were obtained from Dr. Kadmer dealing with this work (see under "Documents") and these are briefly summarised below:-

Report No. VI (4). The Sulphonation of Various Mineral Oils for the Preparation of Acid Tar. (June 1944)

Nine series of experiments on the sulphonation of mineral oils, using 1.84 sulphuric acid and fuming sulphuric acid containing 20% SO_3 are described. Methods for washing and neutralising the freshly formed tars are discussed.

Report No.VI (10). The Experimental Product Kadmer-Luers V/Ka-L. (October, 1944)

This comprises the test of a patent application entitled "A process for the preparation and use of water soluble oil-repelling lubricants and cutting liquids".

Freshly formed acid tars from mineral oil refining are washed and neutralised with less than an equal quantity of water or brine and then freed from mineral oil by extraction with oleophilic and hydrophobic solvents. Many examples of use in the metal working industry are quoted.

Report No. VI (16). Large Scale Experiments with V/Ka-L Product. (February 1945)

Favourable and unfavourable results of trials in various works are described, e.g. Noris-Zündlicht, A.G., Nürnberg; Hering A.G., Numberg; Joh. Reitzammer, Nürnberg; Haas and Matthes, Nürnberg; Bayr Reisszeugfabrik, Nürnberg; Siemens-Reiniger A.G.; Erlanger and Mauserwerke A.G., Oberndorf. The water soluble potassium or sodium saturated mineral oil sulphonates will have an important future so far as it is technically possible to prepare them free of salt in order to avoid corrosion. These products are to a great extent stable to salts, acids and alkalies.

Report No. VI (18). Water Soluble Lubricants for Metal Working. (April, 1945).

Salts carried over with the Ka-L product interfere greatly because of their corrosive nature, although the product itself is absolutely stable towards them. Dr. Hammen critically and thoroughly examines the situation and tries out the product in a purified state in the Almen-Wieland oil testing machine.

5. DR. KADMER'S ANSWERS TO DETAILED QUESTIONNAIRES DEALING WITH FUELS AND LUBRICANTS.

Reproduced below are the questions put to Dr. Kadmer together with full translations of his answers.

Q U E S T I O N N A I R E

No. 1.

FUELS.

AVIATION FUELS.

1. Fuel Rating Methods.

Question 1. How are aviation fuels rated in
(a) small scale engines?

(b) full scale single cylinder aero engines?
(c) multicylinder main engines?

2. What relative importance is attached to rich mixture and weak mixture performance?

3. How is rich mixture performance measured?

4. How is weak mixture performance measured?

5. What work is in hand for the development of fuels having improved weak mixture characteristics?

6. To what extent is the C.F.R. Research, or similar method used, and why?

7. What degree of inter-correlation is obtained between small scale engines, single cylinder full scale aero engines, and multicylinder main engines?

8. What flight tests have been carried out to assess the antiknock requirements of fuels?

9. What reference fuels are used

(a) under 100 Octane Number, or corresponding rating?
(b) over 100 Octane Number?

Answer. For exhaustive information on questions regarding methods of testing aviation gasoline, it is suggested that the members of the Arbeitsgemeinschaft für Klopfmesskunde (Group for Knock Measurement Technique), be interrogated, especially Drs. E.Singer (Oppau), Jantsch, Witschakowski and Dannefelser. It would also be advantageous in this connection to question Wa. Ostwald (Heppenheim/Bergstrasse) and Dr. O.Widmaier of Prof. Dr. W.Kamm's Institute at the Technical High School, Stuttgart and also the appropriate members of the D.V.L. i.e. Von Philippovich and Seeber. Members of

the Rechlin Experimental Station of the Luftwaffe in the British occupation zone should also be questioned.

2. German Aviation Fuels.

Question 1. To what specifications are C-3, B-4 and A-3 fuels produced?

Answer. C-3 aviation fuel had an Octane No. of 95-97. B-4 was 85-87 Octane Number and A-3 had an Octane No. of 74-76.

Question 2. What is the reason for the high aromatic content of the German C-3 fuel, and for its excessive margin of rich mixture performance? For what planes is this type of fuel specified?

Answer. Interrogate Dr. Vollbrecht of the Wifo, Unterphaffenhofen, near Munich. C-3 fuel was used in the Me109 and Focke-Wulf 190, B-4 for the Ju 52 and all training and transport machines, A-3 for the Ju 87, Ju 88 and He 177. J-2 fuel was used for the jet fighters.

Question 3. From what components are C-3 fuels blended at the blending points?

4. What trouble has been experienced with fuels containing small amounts of water?

5. What difficulties have been experienced with highly aromatic fuels? (Effect on synthetic rubber, etc.)

6. How important is gum stability considered? What gum inhibitors are used?

7. What trouble has been experienced with vapour lock due to excessive fuel volatility, and also to dissolved air? How were these troubles overcome?

8. To what extent are cracked fuels used for aviation purposes?

Question 9. What work has been done on the development of safety type fuels?

10. What engine studies have been carried out on the effect of engine factors, such as valve overlap, etc., on fuel performance, particularly at weak mixtures?

11. What general methods are used for cold starting, and to what extent were special priming fuels used, and of what components did these consist?

12. To what extent was "run-out" fuel used in an effort to combat cold corrosion?

Answer. Interrogate Dr. Hartmann, formerly an engineer of the air staff and leaden of the regional fuel research station for Luftgau VII, Unterpfaffenhofen near Munich.

N.B. Dr. Hartmann was questioned later but he gave no pertinent information.

3. Anti-Knock Additives.

Question 1. What factors decided the amount of lead to be incorporated in aviation fuels?

Answer. The lead content was limited by the corrosion of exhaust valves.

Question 2. What attempts have been made to increase the amount of TEL beyond the present amount.

Answer. Dr. Hartmann should be able to answer this.

Question 3. What experience has been obtained on spark plug fouling, exhaust valve corrosion, etc.? What effect has TEL on overhaul periods? Has any connection been found between type of oil and cylinder head deposits?

Answer. See Werner - Motortechn Zeitschr. 1952, 52. (The Effect of Ethyl Fluid on Sparking-Plugs").
No definite connection can be found between oil-type and cylinder head deposits, since the latter are due more to the fuel than to the lubricant as shown by the lead content

of the so-called "oil-coke" (Oelkohle).

Question 4. What difficulties have been experienced with lead deposition in storage and what inhibitors, if any, were developed to cure this? Was any special test devised to evaluate lead stability?

Answer. Research Report No. 1144 of the D.V.L. (1939) contains a survey of the effect of additives on the storage stability of fuels. The authors are Meyer-Bugstroem and Seeber.

Question 5. What laboratory methods are used to determine the lead content of a fuel?

Answer. The normal lead chromate precipitation method, described in "Kraftstoff-Fibel" (Kadmer) p.155. The rapid method (Ulrich) is described in the same book, p.136. See also VDI 1938, 346, and O.Widmaier, FKFS Rapid Method, "Luftfahrt-Forschung" 1943, 181. In addition, Morghen has further developed the dithiozone method as described in a DVL research report.

Question 6. What work has been carried out on alternative anti-knock agents?

7. What work has been done on the development of new lead evacuants, and in what percentage of theoretical are they used?

8. What experience has been obtained with water injection, or other supplementary booster fuel?

9. Has any trouble been experienced due to cold corrosion as a result of the use of leaded fuels, and what steps were taken to combat such effects?

Answer. Dr. Hartmann should be able to answer these questions.

4. Detonation Research.

Question 1. What work has been done on the rationalisation of factors controlling detonation, and on the fundamentals of combustion, e.g. Muhlner experiments?

2. What experimental work has been carried out on pure hydrocarbons?

3. What work has been done to investigate pre-ignition, and on the development of pre-ignition ratings of fuels?

Answer.
(a) G.H.Schultze - Fundamental Thermodynamic Research in the Chemistry of Oil - (Oel u. Kohle 1942, 1448).
(b) Jost - Physico-Chemical Foundations of Engine Combustion (Chem Zeitg.1939,257).
(c) Meurer - Recent Research on the Combustion Process in the Otto Engine (Oel u. Kohle 1942, 667).
(d) Berg - Normal knocking and glow-ignition combustion in the Otto engine (Motortechn Zeitschrift 1941, 359).
(e) Muhlner - Pre-reactions in the Otto engine (VDI, 1943, 333).
(f) Neubert - Pre-reactions in the Otto Engine (Automobiltechn Zeitschrift 1943, 70)
(g) Muhlner - Research on Pre-reactions in the Otto Engine - (Luftfahrt Forschung, 1942, 249)
(h) Dreyhaupt - New theories of Engine Ignition Processes on the basis of special Molecular Physical Observations (Forschung Ingenieur Wesen) (VDI) 1940, 215.
(i) Zinner - Theoretical Foundations for the Influence of Water Injection on the Working of Combustion Engines - (Forsch. Ing. Wesen (VDI) 1940, 276).

5. Gas Turbine Fuels.

Question 1. What specifications are laid down for

(a) Gas Turbine Fuels ?
(b) Flying Bomb Fuels ?
(c) Rocket Fuels?

2. What special requirements are necessary for these fuels and how have these requirements been met?

3. What developments are under way in connection with fuels for these types of engine?

Answer. Interrogate: Dr. Hartmann - Unterphaffenhofen.
Dipl. Ing. Lange - Rechlin.
Dr. Seeber - D.V.L.

6. Motor Fuels.

Question 1. What specifications were adhered to for military purposes, particularly in respect of knock rating, gum content, stability and vapour pressure, and what methods of test were applied. What changes in specification have occurred during the war, with dates of such changes?

Answer. Since 1943 the specification has been as follows:-

Research O.N:- 74, Motor O.N:- 70.
Boiling Range:- up to 75°C not below 25%
" " 200°C " " 95%
Reid V.P.:- not below 0.25 kg./cm^2
" above 0.6 kg./cm^2
Gum Test:- 12 mg./100 ml.
Gum Stability:- no definite specification

No changes of importance in the specifications were made by OKH, Wa. Prüf. 6 during the course of the war. For information on Gum Stability see Weller, Oel u. Kohle 1934, 527 and Conrad, Oel u. Kohle 1935, 728.

Question 2. Were any difficulties experienced when vehicles were operated on fuels with the higher lead concentration, such as the new tank fuel which was introduced towards the end of 1944 (2.5 - 2.75 ml. TEL/I.G.)? Was there any reason for eliminating entirely added aromatics from some of these blends? Was any change made either in composition or proportion of lead evacuants added to the Ethyl mix?

Answer. No difficulties worth mentioning are known to have occurred on increasing the concentration of T.E.L. from 0.4 to 0.6 cc./litre.

Question 3. What were the compositions of the various types of automotive gasolines, and of the main basic components? What happened to the Fischer-Tropsch gasoline, and what was the source of the large quantities of unsaturateds normally included in the blended gasoline?

Answer. The German army used four types of Otto fuels in the Russian campaign.

(a) Summer motor-spirit containing up to 40% of motor benzol.
(b) Winter motor-spirit, rich in olefines and with 0.4 - 0.6 mls. TEL/litre.
(c) Anti-cold "Katalyt-Lampenbenzine" (catalytic lamp benzine) boiling range 80 to 140°C.
(d) Starting Fuel, boiling range 35 - 140°C (also used in severe cold to dilute engine oil in quantities up to 15%)

Question 4. What effect did the cessation of Roumanian supplies have on the general position for motor spirit, and to what extent was Roumanian gasoline used in motor and aviation fuels?

Answer. The leaders of Betriebstoff-Untersuchungstrupps (fuel investigation force) stationed in Ploesti were entrusted with

all special questions concerning the blending of Roumanian benzines. They were Dr. Hammerich (present whereabouts unknown) and Dr. Otto Wittroch, Bad Godesberg/Rhein. Their interrogation would undoubtedly prove of interest.

Question 5. Was the general idea to work to a given Octane Number in blending these fuels, using Benzol and/or TEL as the adjusting agents, reducing the latter when more Benzol was available?

Answer. An Octane No. of 74 was specified and had to be rigidly maintained by the supply companies either by leading or benzol blending. The type of blending depended on the season of the year, especially in Russia, (summer fuels were coloured red and winter fuels yellow).

Question 6. To what extent has Methanol and and Ethanol been used as a blending agent for internal civilian consumption, for use in non-military vehicles in occupied territories, and for military purposes? What factors have lead to the small use made of these blending agents for the latter purpose?

Answer. Alcohol blending was forbidden for military purposes since insufficient care of the containers in wet weather might have caused separation. I have little knowledge of variations in the quality of civilian Otto fuels since I was away in the army.

Question 7. What quality of Aromatic blended component was used, i.e. was all the toluene extracted from the Benzol, and what happened to the higher aromatics?

Answer. Dr. Hammerich should be questioned regarding benzol blending as he is a member of the Benzolverband. Dr. Hagemann of the Ruhrchemie AG, Oberhausen - Holten, formerly

Benzolverband, can also give exhaustive information on the use of benzol.

Question 8. What disposal arrangements were made for Esthonian shale gasoline, and was any difficulty experienced in its use as a motor gasoline constituent? What tests, if any, were made to establish its suitability as a flying bomb fuel, particularly from the point of view of corrosion?

Answer. Dr. Hartmann and Dr. Vollbrecht (Wifo), Unterpfaffenhofen, near Munich, should be questioned regarding the use made of shale gasolines.

Question 9. To what extent have alternative fuels such as producer gas, acetylene, etc. been used for civilian and military purposes? What technique has been employed with these fuels?

Answer. Wood-gas generators were employed with success for the supply of the German troops in Russia, but only when experts directed the care of the vehicles and equipment. The organisation with the Central Army Group weathered the winter of 1942/3 successfully. Continued failures occurred in OT-units which were not properly maintained and the state of the engines was often very bad. Metal protected wood-charcoal generators were found satisfactory. On the home front trucks were run predominently on generator gas. Because of the lack of means of transport they were well looked after and therefore ran successfully. Results and experience are collected in the book "Generatorgas-Fahrzeuge" by Jantsch, 1944 Edition.

Question 10. What methods, if any, are used to determine road-Octane-Numbers, and how do the results correlate with test engine data?

Answer. Dr. Kneule and his collaborators have worked on road-tests and Octane Numbers in multi-cylinder engines at Seeshaupt, near Munich

and have prepared research reports on this work.
There is a brief survey in Kadmer's "Kraftstoff Fibel" pages 129-131.
The following are individual articles on the subject:-

Kneule - VDI, 1940, 869
Kühner - VDI, 1939, 293
A.W.Schmidt - Oel u. Kohle 1940, 350

Further detailed results are at the Institut für Kraftfahrzeuge, Technical High School, Stuttgart. (Prof. Dr. W.Kamm).

Question 11. What bench tests are carried out on fuels and lubricants performance, and what type of operation (e.g. full power continuous, or cyclic) is found to correlate best with actual operation?

Answer. Collected results and statistical evaluations are in the possession of Prof. Dr. W.Kamm (Stuttgart) Dr. v.Philippovich and Dr. Seeber, Dr. Kneule (Seeshaupt), Prof. Dr. Schnauffer (München-Hartmannshofen), all members of the Arbeitsgemeinschaft fur Klopfmesskunde (Group for Knock Rating Technique).

Question 12. How is wear in an engine measured?

Answer. The latest literature is as follows:-

(a) Siebel and Kehl.- Jahrb der Deutschen Luftf. Forschung. Wear Experiments on Piston Rings. 1937, II, 212.

(b) Ullman — Experiments on Piston Ring Friction. VDI, 1943, 442.

(c) Englisch — The Lubrication Process between Piston and Cylinder. VDI, 1942, 116.

(d) R.Poppinga — Wear and Lubrication, especially of Piston Rings and Cylinders. VDI Press, Berlin, 1941.

(e) Bopp — Cylinder Wear and Oil Change. Kraftstoff, 1940, 21 and 51.

(f) Beck and Bopp — Cylinder Wear and Oil Change under Different Running Conditions. Kraftstoff, 1939, 17 and 50.

(g) Beck — Cylinder and Piston Ring Wear. Deutsche Kraft Forschung, 1939 No.29.

(h) Moser — Cylinder Wear in Domestic and Foreign Auto Engines. Motortechn. Zeitschrift, 1942, 346.

(i) Baumann — Cylinder Wear. Automobiltechn. Zeitschrift, 1943, 237.

(j) Apel — Cylinder Wear with Different Running Surface Materials. Automobiltechn Zeitschr., 1942, 424.

(k) R.Poppinga — The Position of Wear Research in Germany. Automobiltechn Zeitschr., 1941 247 and 272.

(l) Thiemann — Wear Research Abroad. Automobilitechn Zeitschr., 1941 280, 313 and 335.

(m) Dies — Frictional Oxidation as a Chemico-Mechanical Process. V.D.I., 1943, 475.

(n) Bock Problems of Wear.
(Oel u. Kohle, 1943, 322).

7. Diesel Fuels. (Automotive, Aviation and Marine)

Question 1. What is the status of research on aircraft diesel engines?

Answer. Exhaustive information regarding research on aero-diesel-engines can be obtained at the Institutes of Prof. Dr. W.Kamm, Stuttgart and Prof. Dr. Schnauffer, Munich, as well as from Dr. Kneule, Seeshaupt, near Munich.

Question 2. What specifications are laid down for aviation diesel fuels and why?

3. What work is in hand on special fuels for aviation diesels?

Answer. Dr. v. Philippovich and Dr. Seeber, DVL and especially Dipl. Ing. Lange of Rechlin are best acquainted with fuels for aero diesels.

Question 4. From what components and how is K.1 fuel made?

Answer. Diesel fuel K.1 was a blend of the petroleum fuel K.2 with heavy benzine, the latter in quantities up to 30%

Question 5. To what extent is the Cetane Number considered an adequate measure of ignition qualities? How are they measured? What are the Centane Number requirements of average aviation, automotive, and marine diesel engines?

Answer. In the test evaluation of Diesel fuel, the Cetane-Number (Cetene-Number before the war) serves as the chief means of evaluating the ignition properties of Diesel Oils. The most common test procedure is that used with

the I.G.Prüfmotor with ignition delay maintained constant and varying compression-ratio. The DVL uses the ignition delay procedure with its test-bench Diesel, maintaining the compression ratio constant and measuring the length of the ignition delay in degrees of crank-angle. The HWA (Heereswaffenamt) has retained the starting procedure in which, at a constant inlet air temperature of 80°C., the inlet air is throttled back to the limiting ignition and the resulting suction in the inlet tube taken as a measure of the ignitability. Naturally one can make measurements in the HWA engine using the ignition delay method, but the values obtained are 10-20% lower than in the starting procedure. Kessler (Oel u. Kohle, 1938, 341), has reported a number of tests carried out for the Reichs-verkehrsministerium (Ministry of Transport) in which the variation in the cetane values according to the different methods of test is considerable. Wilke has reported a similar series of trials, done by IGF, in Automobiltechn Zeitschr., 1940, 377. A.W. Schmidt (Oel u. Kohle, 1941, 705) finds a usable agreement between values obtained by the two ignition delay procedures. The minimum Cetane No. for diesel engined army vehicles was set at 45, the specifications for aero and marine diesel engines are unknown to me.

Question 6. What work has been done on combustion and ignition accelerators, and to what extent are they used?

Answer. The most extensive work on the effect of ignition accelerators and their disadvantages (increased tendency to coking, corrosion) is that of Heinze, Marder and Veidt, which appeared in Oel u. Kohle, 1941, 422. A further report was made by Thiemann in Automobiltechn. Zeitschr., 1942, 454.

Question 7. What work has been done on cold starting aids, and what is the normal cold starting procedure?

Question 8. What filtering systems are used for diesel fuels?

Answer. No information is available.

Question 9. How is low Pour Point obtained, especially in conjunction with high Cetane Number.

Answer. The low Pour Point of the diesel fuels used by the Wehrmacht in Russia was obtained by the use of fractions from I.G. high pressure synthesis. These could be detected by the sharp smell of tetralin in the finished fuel, which none the less had a Cetane Number between 35 and 40.

Question 10. What general research has been carried out on combustion in diesel engines?

Answer.

(a) Pflaum	Mixture formation, combustion and fuel consumption in Diesel engines. (Motortechn. Zeitschr., 1942, 243.)
(b) A.W.Schmidt and A.L. Schmidt.	The engine evaluation of diesel fuels. (Motortechn. Z., 1942, 189).
(c) —	The use of fuels difficult to ignite in the Diesel engine. (Motortechn. Z., 1943, 194).
(d) Scheurmeyer and Steigewald.	The measurement of the ignition delay of compressed fuel-air mixtures in the investigation of knock tendencies. (Motortechn. Z., 1943, 229)
(e) Petersen.	Investigation of the ignition and combustion processes in Diesel engines working on the Vortex Chamber and Air-Reservoir principle. (Forschung Ing. Wesen (VDI)., 1937, 279).

(f) Pflaum	The diesel gas process with illuminating gas. (VDI, 1944, 593).
(g) Schaub	Fuel and engine in the starting of auto Diesel engines. (Automobiltechn. Z., 1943, 190).
(h) Blume	Mixture formation and combustion in the Diesel process. (Automobiltechn. Z., 1943, 36).
(i) Pischinger	Critical examination of views on the working process of auto-diesel engines. (Automobiltechn. Z., 1941, 489).
(j) Kremser	A high-speed diesel engine with air-intake by the Roots Blower. (Automobiltechn. Z., 1941, 193).
(k) Venediger	Observations on compression ratio. (Automobiltechn. Z., 1939, 27).
(l) U.Schmidt	Smoking in the auto diesel engine. (VDI., 1942, 205).
(m) Biseng	Ignition delay measurements using photocells. (VDI., 1942, 241).
(n) Kneule	The coking-tendency of diesel fuels. (VDI., 1942, 76).
(o) Schuch	The investigation of injection processes. (Motortechn. Z., 1941, 230).

(p) Wilke — Research on the process of combustion with diesel fuels. (Motortechn. Z., 1939, 43).

(q) Th.Schmidt — The present stage of development in the fuel insensitivity of diesel engines. (Oel u. Kohle, 1942, 733).

(r) Kessler — Standardisation of procedure and equipment in diesel fuel testing. (Oel u. Kohle, 1942, 1031).

Question 11. What types of diesel fuels are used in

(a) submarines?
(b) motor ships of all types?
(c) land vehicles?

Answer. (a) No information available.

(b) No information available.

(c) Army diesel fuel (Summer)

Boiling range	:	180 - 320°C.
Density (d/20)	:	0.810-0.850.
$n^D/20$	:	1.45 - 1.47
Aniline Point	:	52 - 68°C.
Cetane No.	:	45 - 56.

Army diesel fuel (Winter, for use on the Eastern front).

Boiling range	:	140 - 280°C.
Density $^d/20$	:	0.795-0.810
$n^D/20$	:	1.44 - 1.45
Aniline Point	:	48 - 56°C.
Cetane No.	:	42 - 47
Pour Point	:	below -40°C.

Question 12. What is the composition of the type of submarine fuel heavier than water?

Answer. No information is available.

Question 13. What is the reason for use of very light diesel fuels, almost in the kerosine range, for some types of small motor vessels?

Answer. No information is available.

Question 14. What importance is attached to boiling range and has any relationship been worked out between specific gravity, aniline point and boiling range, with Cetane Number? What importance is attached to aniline point?

Answer. Rothe (Dissertation, T.H. Munich, 1937) recommends the aniline point - density constant (AP/d) instead of the diesel index (D.I. = AP x API Gravity/100) Extending the work of Heinze and Marder (Brennstoff-Chemie, 1935, 286; Oel u. Kohle., 1935, 724; Deutsche Kraftfahrt Forschung, VDI., 1938, No. 7) Kadmer developed a graph showing the relationship between aniline point, density, refractivity, boiling-behaviour and cetane number (cf: Kraftstoff-Fibel, 1945, 167-171). The important point here is to fractionate the diesel fuels and to test the individual cuts for nD and aniline point. In the same work an attempt was made to correlate aniline point with the content of aromatics and unsaturated compounds in petroleum diesel fuels, oils from brown and hard coal tars, hydrogenated oils and "Kogasin".

Question 15. To what extent are diesel fuels from petroleum, brown coal, shale and Fischer Tropsch processes used?

Answer. The army diesel fuels coloured light yellow to yellowish brown consisted of varying blends of petroleum gas oil and gas oils from the I.G. high pressure hydrogenation and the Fischer-Tropsch synthesis.

The civilian diesel fuels coloured brown to reddish-black consisted of blends of petroleum gas oil, brown and hard coal tar oils and "Kogasin". Estonian, Germar and French shale-oils had only local importance as blending components.

Question 16. What is the significance of the phenol content present in some diesel oils?

Answer. Hydrogenated phenols, with suitable fractions from I.G. high pressure hydrogenation, were used as constituents of anti-cold diesel fuels. They were harmless as far as known in the limited percentage used.

8. Fuel Oils.

Question 1. What types and to what specifications are used for -

(a) heavy industrial?
(b) light industrial?
(c) Marine?

2. What experimental work has been carried out on combustion of fuels under boilers?

3. What main types of fuel oil burners are used?

4. To what extent are fuels of non-petroleum origin used?

5. Are coal suspensions used to any extent?

6. Has any difficulty been experienced on the incompatibility of the various fuel oils from different sources?

7. Has any trouble been experienced due to the entrainment of gases in fuel oils?

Answer. No information is available.

QUESTIONNAIRE

No.2

LUBRICANTS

1. Aviation.

Question 1. What general types of aviation oils are used, from what sources are they obtained and why were these sources chosen?

Answer. The Luftwaffe preferred "Rotring" and "Grunring" to "Aero-Shell", since experiments of the DVL have shown that "fatted" oils cause piston ring sticking sooner than do carefully refined and blended mineral oils. The base oil is a solvent raffinate (6-7E/50°) which is also carefully freed from wax: blending is carried out with bright stock from Zistersdorf or Reitbrook. Synthetic oils of the Ruhrchemie A.G. were added either not at all or in only small quantities, since the influence of oxygen at high temperatures causes a noticeable thickening. It is unknown to me whether an addition of additives was made either by the manufacturer or at the blending station (WIFO).

Question 2. What refining methods are used for aviation oils? To what extent are solvent refined oils incorporated in aviation oils?

Answer. I know only of the special case of the Oderfurt Mineral Oil Refinery A.G., Moravia, in connection with aero-engine oil production, where the "Barisol" process was used for wax removal and the "Suida-Nobel-Pöll" (SNP) process for refining.

Question 3. To what extent are synthetic oils used in the blending of aviation oils, and what advantages, if any, result?

Answer. Ruhrchemie synthetic oils have already been mentioned under 1. as being unsuitable. I.G. is supposed to have tried and recommended small quantities of other synthetic oils as additives. Whether these passed the experimental stage and what their particular nature may be is unknown to me. Synthetic oils of the Brabag (Brown-Coal-Benzine A.G., Works at Zeitz and Böhlen near Leipzig) as well as those of Rheinpreussen A.G., in Homberg, lower Rhine, are out of the question as components of aero-engine oils.

Question 4. To what extent is Voltol used in aviation oils? What are the reasons why it is or is not extensively used? What effect has Voltol on V.I. or pole height?

Answer. Voltolisation was not further developed to any extent in Germany, the principal reasons being, apparently, economic ones. Since "Endvoltol" shows no exceptionally good viscosity-temperature relationship, there is no particular reason to use it as an aero-engine oil component.

Question 5. Are the advantages of the incorporation of detergent type additives recognised and have these additives been developed for use in aviation oils?

Answer. Additives increasing the lubricating power and not adversely affecting stability are generally recognised as useful and necessary. I.G. especially endeavoured to develop suitable materials of which, however, I have no detailed knowledge.

Question 6. Are viscosity-temperature susceptibility improvers of the Oppanol-Gemisch polyisobutene type used in aviation oils?

Answer. Oppanol was added only experimentally to aero-engine oils.

Question 7. Have additives of any other type been used in aviation oils, if so, what are they and what results are obtained by their use?

Answer. No information available.

Question 8. What troubles have been experienced with:-

(a) Oil frothing?
(b) Ring sticking?
(c) Bearing corrosion?

and what remedies have been found?

Answer. (a) Some interesting work on oil froth formation in aero-engines was contributed by O.Reinhardt to the Techn. Berichten f. Wissenschaftl. Berichtwesen der Luftfahrtforschung 1944 No. 6. From it can be derived the quantity of air dissolved or suspended in oil at different temperatures at 2,5 atm. pressure. The only known method for removing froth is the fitting of oil centrifuges which work less because of the separation of large quantities of gas than because of the pressure increase in the centrifuge which brings the greater part of the undissolved foam generating gases into solution. In the same number (6/1944) of the Techn. Berichte is an article by Schumacher on the solubility of gases (nitrogen, oxygen, air, carbon dioxide, hydrogen, carbon monoxide) in fuels and oils at various temperatures. This paper is also worthy of note.

(b) The following recent works and reports on ring-sticking research and testing may be of interest:

(i) Glaser — The Influence of Working Conditions on the Running-time until Piston Ring Sticking. (Deutsche Luftfahrt Forschung, 1939, Bericht. No. 1022).

(ii) Widmaier — The Influence of the Fuel on Deposit Formation in Lubricating Oil. (Deutsche Luftfahrt Forschung, Ber, No. 1186-1940).

(iii) Wenzel — The Influence of the Working Conditions of a Single Cylinder Engine on Lubricating Oil Behaviour. (Deutsche Luftfahrt Forschung, Ber. No.518-1935).

(iv) Riekert & Kulm — Fracturing of the Piston Rings as a consequence of the Measurement of the Quantity of Lubricating Oil. (Deutsche Luftfahrt Forschungs Ber.No.758-1937).

(v) Riekert & Kulm — The Influence of Engine Working Temperature on the Piston Ring Sticking Time. (Deutsche Luftfahrt Forschungs Ber. No. 621 - 1936).

(vi) Schökel — Lubricant Testing in the BMW 132 F Single Cylinder Engine. (Deutsche Luftfahrt Forschung, Untersuchungen u. Mitteilungen No. 574 - 1939).

(c) No information is available.

Question 9. Have any particular combinations of bearing metals given trouble with any particular oils and if so, how were the troubles overcome?

Answer. Cd-Ag and Cu-Pb bearing metals are very sensitive to untreated mineral oils. There are American patents covering the addition of metallic soaps and chlorinated metallic soaps to overcome this drawback. Since Cd-Ag alloys were not used for bearings in Germany during the war there was no need to

develop treated oils of this nature.

Question 10. What engine tests are carried out on an oil before it is accepted for aviation use and by what methods are the merits of a given oil assessed? If small scale engines are used for oil testing, how do they correlate with main engine performance?

Answer. Ring-sticking test runs were made by DVL in the single cylinder Siemens test engine (v. Philippovich, Oel u. Kohle, 1937, No. 47 and Luftfahrt Forschung 1937, 254). The FKFS used an Argus As 10C engine (DL - Forschung, Ber. No. 621 - 1936) or a BMW 132 F engine (DL - Forschungs Ber.No.574, 1939). Regular experimental flights were associated with these test runs.

Question 11. Has any connection been found between condition of valves and spark plugs on leaded fuels and type of oil?

Answer. No.

Question 12. What laboratory tests are considered most important and has any laboratory procedure been evolved which ties in closely with actual behaviour in an engine?

Answer. The most important laboratory tests for aero-engine oils are considered to be: Density and refractivity, viscosity-temperature gradient, Conradson and Ramsbottom tests, estimation of oil- and asphaltic-resins by the so-called earth method (Erden Methode), the Noack aging test, the so-called DVL dish method and the test-run in the single cylinder BMW engine. No laboratory method has been found which gives information as to the behaviour of the oil when actually in an engine, because in practice the oil is not solely responsible for damage, fuel combustion always playing some part. I have repeatedly suggested the separately driven hot-air engine for evaluation of oil behaviour in the laboratory so that the oil under test may be kept free of fuel-contamination.