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GERMAN NAVAL FUEL OIL

SEPTEMBER 1945

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TECHNICAL REPORT NO. 333-45

GERMAN NAVAL FUEL OIL

SUMMARY

This report covers the study of German Naval Fuel Oils. The data was obtained from Danisch Nienhoff, Kiel, Flensburg and Flehmude.

September 1945

U. S. NAVAL TECHNICAL MISSION IN EUROPE.

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GERMAN NAVAL FUEL OIL

1. Introduction.

In order to complete the general survey by the U. S. Naval Technical Mission in Europe of the German synthetic oil industry, a trip was made to Kiel, Hamburg and Flensburg to study German Naval fuel oils. The problem of fuel oil supply during the war was a difficult one for the Germans, due to the lack of natural petroleum and the scarcity of certain synthetic components for proper blending. The manner in which these difficulties were analyzed and overcome is of considerable interest to the U. S. Navy, in view of current long range planning to develop shale oils and synthetic products.

In general, the Germans were faced with the same problems of stability and compatibility, in storage and on board, as the U. S. Navy. They have also had accidents due to explosive fuels which they have overcome successfully. They have studied their problems in much the same manner as our navy but have not attempted to construct a unit such as the N.B.T.L. test heater. Furthermore, the synthetic oils used and the limitations of furnace design required an additional study of combustion characteristics within the furnace which the U.S. Navy has not, in general, had to do. It is interesting to note that every ship in the German Navy, including submarines, was equipped with a Jentsch oil testing unit which was operated by specially trained personnel. A constant check on all the important specifications was hence always available without requiring shipment of samples to land-based laboratories. The Jentsch test unit is particularly valuable for discovering explosive fuels.

2. Conclusions and Recommendations.

The information and data obtained on the manufacture, blending and use of synthetic fuels should be carefully reviewed by U.S. experts as a guide to future long range programs.

Conclusions and Recommendations (Cont'd)

The use of the Jentsch Test Unit should be studied as a possible means of spotting dangerous explosive fuels, both on board ships and in bulk storage installations.

3. Demands for Fuel Oil

The German Navy required in 1942 and 1943 an average monthly supply of fuel oil of:

For the fleet and coastal defense craft....	80,000 tons
For transports, cargo, and general operations.....	10,000 "
Total	<u>90,000 tons</u>

At the beginning of 1945, the demands were:

For the fleet and coastal defense craft....	65,000 tons
For transports, cargo and general operations.....	5,000 "
Total	<u>70,000 tons</u>

At the beginning of the war the following quantities were on hand:

From Mexican and Roumanian crude.....	450,000 tons
Lignite tar oil.....	12,000 "
Hydrogenated pitch oil.....	15,000 "
Total	<u>477,000 tons</u>

At the end of the war, the following quantities were on hand:

Various residues.....	133,000 tons
Crude petroleum.....	53,000 "
Finished fuel oil blends.....	60,000 "
Total	<u>246,000 tons</u>

4. Sources of Supply

The main sources of German Naval fuel oil were as follows:

(a) Petroleum

- (1) Roumania (Pacura and others)
- (2) Germany (Nienhagen)
- (3) Mexico (up to 1940)
- (4) Iraq (from captured French supplies)

(b) Shale Oil

- (1) Esthonia
- (2) Wurtemberg

(c) Hard Coal

- (1) High temperature distillation tar
- (2) Low temperature distillation tar
- (3) Hydrogenation of same

(d) Lignite

- (1) Low temperature distillation tar
- (2) Hydrogenation of same

(e) Bitumen

- (1) Hydrogenation of same.

In general, the German Navy's supply of fuel remained fairly constant throughout the war. Bombing caused damage to both petroleum refineries and synthetic oil plants, but the loss from the former was generally made up by quantities of synthetic middle oils which could not be finished to gasolines at other plants and hence were available as Naval fuels.

Sources of Supply (Cont'd)

(a) Petroleum

The German Navy's supplies of natural petroleum fuel was very limited at the outset of the war and remained so throughout. Various residues were available from Roumania, especially Pacomra, which were of such inferior quality as to be unuseable for hydrogenation to better products. For this reason it was given to the Navy. Due to its very high pour point ($\approx 40^{\circ}\text{C}$) the Navy could only use it in coastwise vessels. At the outbreak of the war, the Roumanians supplied Germany with 30,000 tons/month. After Germany occupied that country the yield was raised to 90,000 tons/month. This increase allowed Germany to supply Italy with 50,000 tons/month for a year or so.

The oil production from the German field at Nienhagen was always reserved for lubricating oil manufacture, and only small amounts ever entered Naval fuel supplies.

Mexico supplied Germany with considerable amounts of oil before the war, but as the supply was cut off at the outbreak of hostilities, it played only a small part in the prosecution of the war.

Of greater importance to Germany were the large supplies of French Naval Oil taken after the fall of France. This oil was almost wholly reduced Iraq crude having a very high viscosity. As such it had to be blended, since its average viscosity was 35° Engler at 20°C (Max. values as high as 100° Engler at 20°C), to meet the German specifications of $12-15^{\circ}$ Engler at 20°C .

(b) Shale Oil

All shale oil used as a fuel oil came from Esthonia. This supply was cut off when Russia took over that country in 1939 but was again available after Germany invaded Russia. It amounted to 8,000 tons per month.

At the end of the war, considerable development of the Wurttemberg shale deposit was under way. As far as

Sources of Supply (Cont'd)

is known, only a very small amount of heavy Diesel fuel resulted from this work. The quality was poor and the oil was used only in farm tractors and not on Naval vessels.

The Esthonian shale oil is fairly heavy (API of 10°) and is very viscous at 5°C (470° Engler). It is fairly aromatic having a Conradson carbon of 4.1.

(c) Hard Coal Tars

Distillation units produced hard coal tars for the Navy through out the war at Hochfeld and Duisberg-Neiderich. These were bombed out in 1945, but extra capacity was made available for the Navy at Rauxel which kept up the yields of tars.

These tars by themselves are difficult to use because the anthracene and maphthalene which they contain settles out at 8°C. To overcome this, a hydrogenated pitch oil was added to the blend, which was made at Ruhrol-GmbH. This plant was bombed in 1944, so that the overall quality of Naval fuel oil was considerably lowered. The Navy partly overcame this quality change by altering their heating procedure in the ships bunkers.

(d) Lignite Tars

Considerable lignite tar was available in Germany for the Navy. This, like hard coal tar, was unuseable by itself as it contained 20% wax and had a pour point of 38°C.

A lignite tar oil was produced at Dea Rositz for the Navy at the rate of 12,000 tons/month. This plant was bombed in July 1944, greatly reducing the quality of the fuel blends.

5. Blending Procedure

* As was the case with other fuels, all heavy fuel oil blends were made at the Naval storage depots. The components were sent by their respective manufacturers to the Zentralburo who in turn diverted the stocks to the Naval Dumps, Achim, Flehmude, Blechhorde, Gydinia, and Wilhelmshaven.

Here the chemist in charge would analyze the fuels and blend them to meet pre-established specifications. In no case was a final blend made at the original source of supply, i.e. hydrogenation plant, coal distillation unit.

It is also important to note that the Germans were forced to use two quality fuel oils; one for ships entering the North sea where contact with British ships and planes was expected, and another of inferior quality for coastal and Baltic operations.

6. Quality of Components

The quality of the component used in blending up a finished oil is given in the following table.

The finished oil resulting from this blend was not unlike Navy Special Fuel Oil. The viscosity was 12-15° Engler, pour point below 0°C, sulfur content not over 0.05%. At the end of the war, due to shortages, the pour point rose to 8°C in the Baltic service. Also the large amount of pitch blends used often produced stack sparks which were most undesirable.

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PROPERTIES OF GERMAN FUEL OIL COMPONENTS

Specification	Topped Iranian Residue	Esthonian Shale Oil	Lignite Tar	Distilled Coal Tar	Hydrogenated Coal Oil Residue
Color(Ostwald	10	10	10	10	10
Sp.Gr.@20°C	0.923	1.005	0.947	1.015	1.096
API	22	10	18	8.5	-2
Visc.Engl.					
@50°C	210	470	6.5	2.15	77.0
@20°C	58	82	2.7	1.5	17.0
@50°C	5.5	7.3	1.3	1.1	2.4
@100°C	1.7	1.3	1.05	1.0	1.3
High Heat Value KCal	10,325	9,460	9,912	9,752	9,578
Low KCal Value	9,744	8,955	9,375	9,309	9,245
Analysis* C%	85.43	87.07	85.71	89.45	91.37
" H ₂	11.03	9.61	10.20	8.42	6.33
" S	1.81	0.86	0.66	0.34	0.58
" Creosote	0	26.0	16.0	4.0	0
Water Content	1.10	1.0	0.3	0.2	0.2
Ash Content	0.06	0.01	0.005	Trace	Trace
Acid Content (as SO ₃)	0.04	0.1	0.2°	0.024	0
Solvency-norm.Gasoline	0.65	7.8	2.8	0.02	0.23
Solvency-Alcohol Ether	3.61	0.5	0.8	0.05	0.35
Solvency-Xylol	0.02	0.76	0.16	0.05	0.02
Con Carbon	5.9	4.1	0.7	0.25	1.4
Flash Pt					
Pensky Martens °C	110	94	85	95	135
Pour Pt. °C	+1	-15	-15	-20	-21
Fire Pt. °C	186	146	136	130	184

* These data do not add up to 100%. The C & H₂ were probably found by combustion. The creosote was found separately.

RESULTS FROM JENTSCH TEST UNIT

Flash Pt. °C	112	96	89	94	132
Vaporization Time Secs.	160	90	50	30	70
Self Ignition Tem.	265	304	298	441	485
Higher Priming Value	500	550	540	600	580
Lower Priming Value	6.2	4.2	4.9		
Characteristic Priming Value	5.5	3.4	3.6		
Ignition Lag					
@320°C	1.5		11.3		
330°C	1.1		5.0		
340°C	0.8		2.2		
350°C	0.5		1.7		
550°C				2.5	0.9
Residue @					
500°C	5.5	3.4	Trace	Trace	2.2
350°C	61.0	3.6	7.6	0.6	22
Boiling No. Comparison No.	1	7	24	48	1
	35	21	23		
Oxidation Value	9.7	9.8	5.2	2.3	5
Oxidation Residue Height	8.5		12	20	10

The comparison numbers and ignition lag indicate that the topped Iranian crude has a much greater paraffinity than the other components. The oxidation residue heights show that the distilled tar oil is the most susceptible to chemical change while the topped Iranian crude and the hydrogenated coal oil are the least so.

7. Scope of German Tests

A great deal of work has been done on combustion testing. Dr. Meyer wrote an extensive report covering work done by the "Chemische und Physikalische Versuchs Anstalt" of the German Navy in 1939. In this he analyzed approximately 100 oils, both natural and synthetic, individually and in blends with one another. This report is available. A subsequent report on a much larger scope, dealing mostly with synthetic oils and their blends was printed but has been lost due to bombing. An attempt is being made to obtain a copy of this report as its contents should be very valuable.

Dr. Meyer proved that very heavy synthetic asphalts could be used as fuel oil if cut back with a non-asphaltic petroleum stock and a tar oil from carbonizing coal. To prevent the heavy asphaltic material from dropping out of solution, the relative amounts of distilled tar and petroleum cutter-stocks should be about the same.

He also did considerable work on measuring surface tension, as this has a large effect on miscability. He reports the following values.

1. Petroleum	27 dynes/sq.cm
2. Heavy Petroleum	31 "
3. Lignite Tar Oil	33 "
4. Hard Coal Oil	34 "
5. Esthonian Shale Oil	34 "
6. Hard Coal Tar Oil	40-41 "
7. Hydrogenated Pitch	42 "

The work on compatibility and stability of blends was done by Dr. W. Deman of the Krupp Gesellschaft at Essen. He was trying to develop means of using low temperature distillation coal tars in blends of fuel oil. Since this material contained much free asphalt and carbon,

Scope of German Tests (Cont'd)

the problem was a difficult one. He found that in blending tars and Diesel oils, certain blends could be used while others produced considerable sludge. That he was successful is proven by the fact that the German Navy was using mostly pitch as a fuel oil at the end of the war, without encountering any noticeable sludge trouble.

8. Analysis of Fuel Oils and Blends

In general the Germans analyze their fuel oil much the same way as is done in the U. S. The standard test of specific gravity, water content, viscosity, flash and fire points, pour point, and Conradson carbon are always made. In addition to these, certain solvency tests are run using "normal" gasoline, ether-alcohol, and xylol as solvents instead of benzol, cyclo-hexane, and iso-pentane as is done in the U. S. The "normal" gasoline is a narrow boiling range product having both iso and normal compounds.

These solvency tests are interpreted in much the same way as in the U. S. An attempt is made when making blends to get the proper distribution of solvency to keep the free carbon and heavy asphaltic compounds in solution. This is very important when mixing tars from coal distillation, hydrogenation, residues, etc. The danger of mixing a paraffinic cutter-stock with an asphaltic residue is well understood in Germany.

No attempt has been made by the Germans to develop anything like the N.B.T.L. test heater. Certain tests were run at Deschimag, Bremen on small boiler installations, but these were more of a burner development program than an oil testing procedure.

Considerable work has been done on measuring the surface tension of various oils. This was in conjunction with the Saacke burner which breaks up the oil drops to the desired size through a rotary spinning device. The optimum drop size and corresponding steam requirements of

Analysis of Fuel Oils and Blends (Cont'd)

of the burner were thus obtained.

9. Analyses

The combustion tests are carried out to obtain the proper burning characteristics i.e. flame length, ignition lag, smoke, residue, ash, while the compatibility tests deal with the problem of sludge formation under long time storage.

The combustion characteristics are generally measured on a "Jentsch Primary Value Tester". This piece of apparatus is placed aboard every German Naval vessel including submarines. The following tests are made on the one piece of equipment.

- (a) Flash point
- (b) Fire point
- (c) Self ignition temperatures
- (d) Lower priming value
- (e) Higher priming value
- (f) Characteristic priming value (from (d) and (e))
- (g) Residue at 350°C and 500°C
- (h) Conradson carbon
- (i) Vaporization time factor
- (j) Boiling number
- (k) Oxidation value
- (l) Ignition lag

From the above data, a comparison number is obtained through nomograms by which the various fuels can be compared with one another.

The unit consists of a solid steel block having 4 round chambers, 15 mm diam, and 38 mm high. The block is surrounded by a heating unit of high resistance wire, properly insulated. The temperature is controlled by a rehostat. In the middle of the block, between the 4 chambers, is a hole leading to the bottom of each of the 4 chambers. Through this, oxygen is passed from a measuring device which controls the quantity by an orifice.

Analyses (Cont'd)

An auxiliary stand with a mirror, electric light and air jet completes the general assembly.

One of the salient features of this unit is the small quantity of oil required. In many tests only drops are needed. The temperatures can be accurately measured, either by thermo-couples in the 4th chamber or by a thermometer.

The first figure obtained is the self ignition temperature. This is the lowest temperature at which the oil spontaneously ignites when oxygen is added. Many oils may have the same self-ignition temperature but the quantity of oxygen may vary from 1 to 10. The two variables, temperatures and oxygen content are combined in a factor, the lower priming value. It is: $l.p.v. = \frac{t}{b+1}$, where

t = the lowest self ignition temperature and b is the number of oxygen bubbles/min. 60 bubbles/min equal 5 cc of oxygen per minute.

Next the "higher priming value" is found. This is the temperature at which combustion occurs with no oxygen added, hence

$$b = 0, \text{ and } h.p.v. = \frac{T}{0+1} = t.$$

From the above two quantities, the "characteristic priming value" is found:

$$c.p.v. = \frac{t_h - t_e}{b+1}$$

where t_h and t_e are the temperatures of higher and lower priming values, and b = the no. of oxygen bubbles/min for the l.p.b. For low ignition delay, such as is wanted in diesel and fuel oils, the c.p.v. should be as high as possible i.e., a fuel should require small amounts of oxygen to produce its l.p.v. A gasoline to have good octane numbers should have a c.p.v. as low as possible, i.e.

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Analyses (Cont'd)

it should be able to be heated to a high temperature without igniting spontaneously, even in an oxygen rich atmosphere.

These facts are brought out in the nomograms drawn up by Dr. Jentsch for the two types of fuels. The physical characteristics are set by the boiling range and self ignition temperature. The final results, or "Comparison number" is comparable to octane and cetane ratings.

The boiling range is obtained on the test unit by an ingenious timing method in which the oil is put in a cylinder at 400°C and the volumetric amount remaining after a specified time is obtained.

The Conradson carbon value is obtained by placing 12 drops of fuel in a cup in the cylinder at 500°C for 2 minutes. The material remaining after that is placed in a colorimetric tester and a very quick value obtained.

The final test of importance is the oxidation test. This somewhat resembles the stability test used in America, but is again carried out on the Jentsch unit. One cc of oil is heated up in the unit to 250°C for 12 minutes while oxygen, at the rate of 300 bubbles/min. is passed through it. At the end of this time, the oil is mixed with 10 cc of "normal" gasoline (a mixture of iso and normal parafines) and allowed to stand for 15 minutes. At the end of this time the height of sludge is measured volumetrically.

Prepared by:

R. C. ALDRICH
Lieut. U.S.N.R.

10. Bibliography

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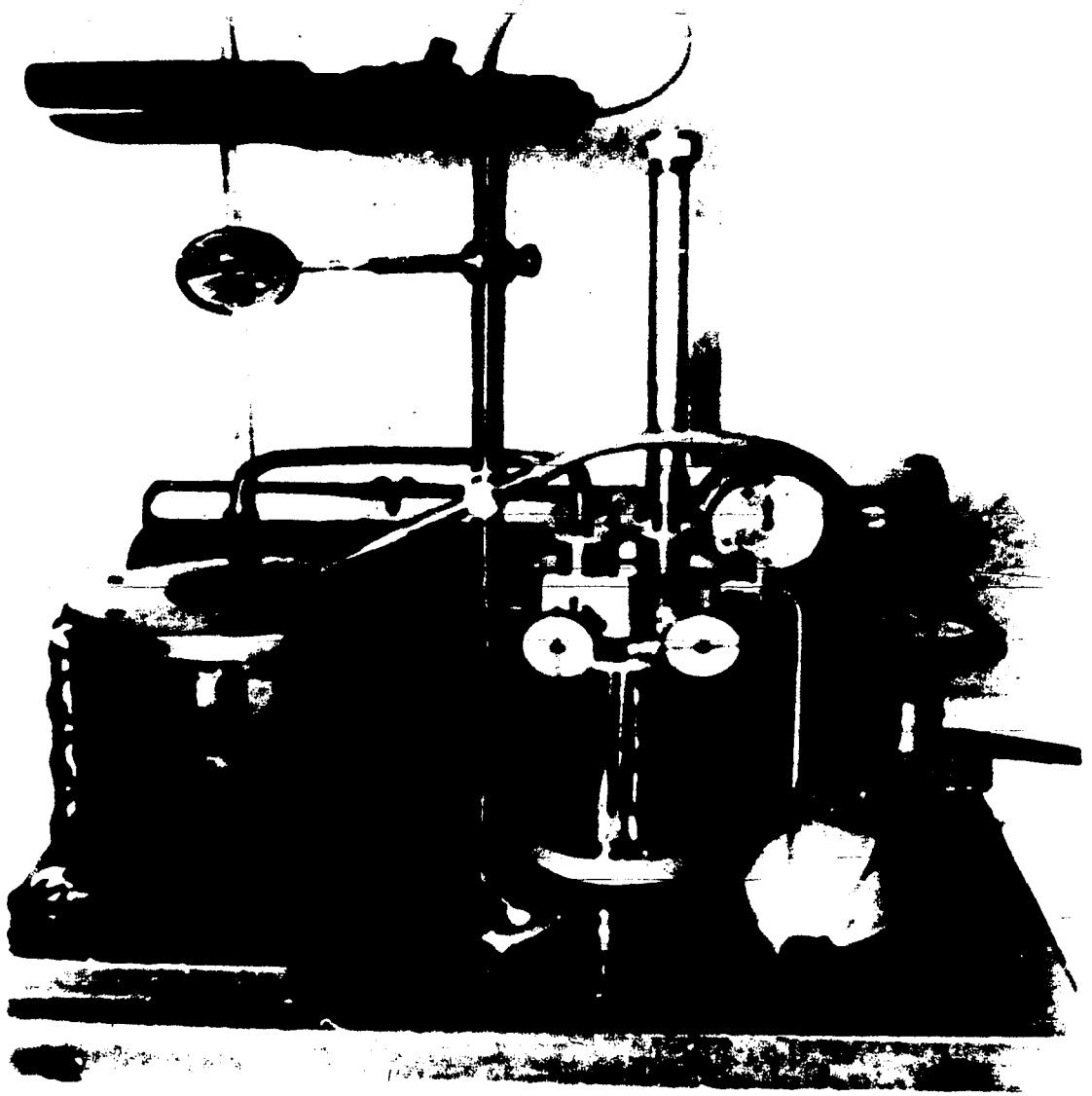
(b) "Bericht über Heizöle und Mischungsversuche mit Heizölen" von Dr. Meyer, Chemische Physikalische Versuchsanstalt (Report on Fuel Oils and Blends of the same, written for the Naval Physical and Chemical Laboratory, Dr. Meyer).

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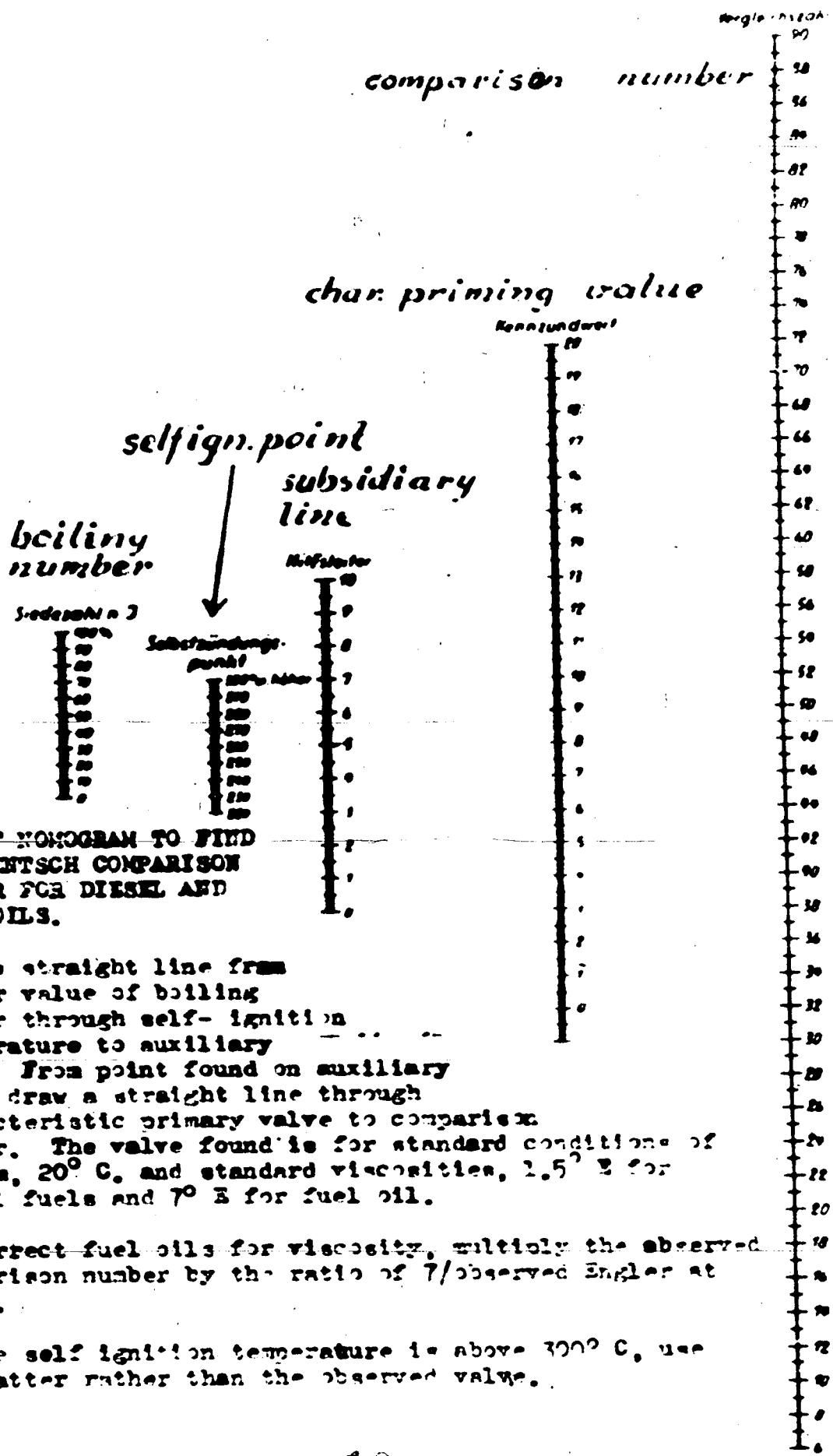
(d) An article published by Dr. Demann in Forschungsberichte Feb. 1943. "Viscosimetric Methods of Evaluating the Miscibility of Hydrocarbons, especially Fuel Oil".

(f) Patent of Dr. W. Demann
D.R.P. 710.665 Kl 42
Applied for 14-6-39
Awarded 18-0-41

(g) An article published by J. Pluckthun in "Forschungsberichte Jan 1942 entitled "Versuch über gegenseitige Lösungsvermögen von Teerölen" (Experiments on the mutual solubilities of tar oils).



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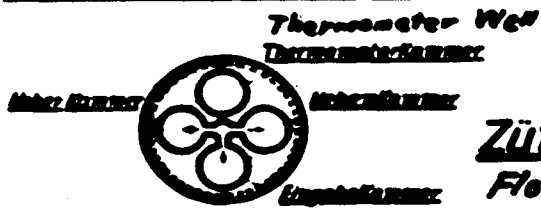
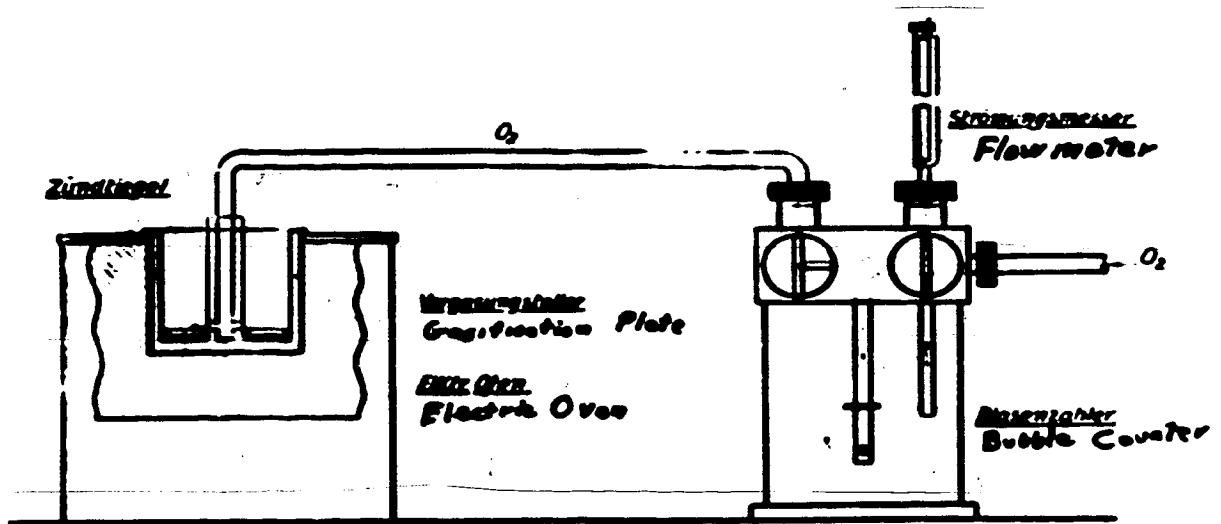
USE OF NOMOGRAM TO FIND THE JENTSCH COMPARISON NUMBER FOR DIESEL AND FUEL OILS.

Draw a straight line from proper value of boiling number through self-ignition temperature to auxiliary axis. From point found on auxiliary axis, draw a straight line through characteristic primary valve to comparison number. The valve found is for standard conditions of 760 mm, 20° C. and standard viscosities, 1.5° E for Diesel fuels and 7° E for fuel oil.

To correct fuel oils for viscosity, multiply the observed comparison number by the ratio of 7/observed Engler at 20° C.

If the self ignition temperature is above 300° C, use the latter rather than the observed value.

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Zündwertprüferschema.
Flow Sheet of Firing Valve Tester

Schnitt durch den Zündkessel.
Cross Section through Ignition Chamber