

III. CONSTITUTION OF LUBRICATING OIL

Apparatus for the Determination of Viscosity Temperatures Up to about 550 C

Dr. G. W. Nederbragt

Frames

2815-2815
2824-2825
2832-2833
2839-2846
2861-2863
2868-2869
2880-2884
2899-2900
2905-2912
2924-2933
2955-2962
2975-2980

Translation

III-7

INTRODUCTION

2815

In the general part of the last report concerning the constitution of lubricating oil (April Report III, 3), we suggested the development of the method of measurement for temperature-viscosity procedure as the point to be carried out first.

The following problems above all are to be solved by this investigation.

1. Which type of viscometer is most suitable for our purpose?
2. How can we obtain a constantly high temperature?

(to 1.) For the viscosity determination of lubricating oil and such, of which only a limited amount is at our disposal and which determination has to be over the greatest possible temperature range, in our opinion the only ones to be considered are:

- a. Apparatus with a capillary flow
- b. Apparatus with a falling body.

In order to get an idea about the advantages and disadvantages of these two types of viscometers, one would have to determine to which order of magnitude the viscosities which are to be measured belong.

Thereafter the measurement for both types of viscometers is calculated and the errors to be expected with these viscometers estimated.

SUMMARY OF THE EXPERIMENT

Erk and Eck¹ have proved that the temperature-viscosity curve of oil can best be described by the von Vogel equation:

$$\log \eta - \log C = \frac{A}{t + t_0}$$

With this equation for viscosity flow, the constant was calculated between 20 and 100 C and after that extrapolated to about 350 C for Golden Shell, Heavy and two pure hydrocarbons. Differentiation of this equation gives the temperature coefficient of viscosity at this highest temperature.

Although extrapolation over so great a temperature range is dangerous, it is to be assumed, however, that the determined value can be of use in the calculation of the calibration of the necessary apparatus.

III-8
2814

	η	250 C $\frac{1}{\eta} \frac{d\eta}{dt}$	η	350 C $\frac{1}{\eta} \frac{d\eta}{dt}$
Golden Shell Heavy	1.3 c.p.	.010	.6 c.p.	.006
16 N Butylhentriacontane $C_{35}H_{72}$.8	.006	.5	.004
Dihydrodiisomylanthracene $C_{24}H_{32}$.4	.012	.15	.007

For the measurement of a viscosity of about 0.1 centipoise a capillary flow with 0.2 mm diameter can be used. In case both the difference in height between the levels and the capillary length are about 10 cm, the flow time amounts to about 8 minutes (calculated according to Poiseuille Rule.)

The measurement in the apparatus with a falling body can be calculated according to the following formula (See Heinze 8)¹:

$$\eta = \frac{t(\gamma_v - \gamma_0)g}{s} \frac{d^3}{\sqrt{3(a + 2b)^2 + (2b)^2}}$$

where

η = viscosity
 t = flow time
 γ_v = density of falling body
 γ_0 = density of oil
 s = distance of fall
 d = diameter of falling body
 δ = clearance

The clearance, needed for the measurement of low viscosity at high temperatures is 0.05 mm, when a magnetically raised falling body of

(1) Phys. Z. 57, 113, 1936

iron has a $d = 1$ mm, a falling distance of 20 cm, and the least falling time of 30 seconds.

The capillary is made for practical reasons of glass; on account of the smallness of the clearance, between 20 and 350 C the value of the fractional expression in the above formula changes about 10 per cent. A falling body with a greater diameter was selected, so that this deviation was still greater.

CONCLUSION

III-9
2815

From the calculation it results that either a capillary flow type apparatus or a falling body apparatus remain technically feasible for the determination of the expected viscosity. In the latter case, however, on account of the small clearance rigid requirements are placed on the construction of the falling body and surrounding capillary, whereas more-over the coefficient of expansion must be as nearly the same as possible.

PLANS FOR WIDER INVESTIGATION

It is to be proved how a constantly high temperature is to be obtained for both types of viscosimeters.

III-17
2824

INTRODUCTION

From the calculation it results that for the expected low viscosities the capillary flow viscosimeter as well as the falling body viscosimeter are technically feasible. Experimentally it is to be proved, whether each of the two types can be easily handled at 350 C.

The manner in which the constantly high temperature is maintained best depends again on the type of viscosimeter. A viscosimeter with a falling body can be so simply designed that a metal block can be built in. Both types of viscosimeters can be placed in either a liquid or a vapor bath, since the former, however, must be renewed often in order to obtain a good visibility we have disregarded this solution and now only the use of the vapor bath will be taken under consideration.

SUMMARY OF THE INVESTIGATION

The viscosity of Spindle oil J2 was measured at various temperatures up to about 161 C, where the temperature by means of the vapors of a boiling liquid remained constant. A B.S.I. viscosimeter, that is a viscosimeter with capillary flow was used. With the same viscosimeter placed in an exactly regulated oil bath, the viscosity in the same temperature range was measured once more. The last measurement was made by means of a curve $\log \eta - \log C = A/t + t$. Moreover it was calculated which temperatures are to be placed in this equation in order to obtain that viscosity which are measured with the vapor bath. These temperatures displayed the following

variations of the temperature which prevailed according to the thermometer in the vapor bath: at 37 C \pm 0.3 C; at 65 C \pm 0.7 C; at 100 C \pm 0.6 C; at 116 C \pm 0.9 C; at 161 C - 1.8 C.

These variations were such that for the higher temperatures it was necessary to obtain another vapor bath, with a second glass wall surrounding the wall of the vapor space. The vapor of the inner space to be cooled flows between the two walls, thereby assuring that the viscosimeter was less strongly cooled down.

III-18
2825

Such a vapor bath, for which however no viscosimeter with a suitable looped piece was made, was subjected to a first experiment.

The two junctions of the thermocouples were brought into the vapor bath, that is from different heights and distance from the wall. The thermocouple in the vapor of benzophenone at 305 C showed temperature differences which varied according to the outer wall of the vapor bath even though it was provided with asbestos insulation. A small hole in the insulation made possible the handling of the viscosimeter.

CONCLUSION

A vapor bath gives - at least for oriented measurements - a satisfactory constant temperature.

PLAN FOR FURTHER EXPERIMENTS

A capillary flow viscosimeter and a falling body viscosimeter were made ready to be placed into the vapor bath. Difficulties such as oxidation, evaporation, etc. occur at highest temperatures.

III-22
2832

INTRODUCTION

In last month's report viscosity measurements were described which were carried out with a B.S.I. viscosimeter in a vapor bath up to a temperature of 161 C. These experiments lead to the conclusion that a vapor bath is very suitable at highest temperatures, supposing, that precautions have been taken to avoid heat losses; to that end a double wall around the vapor space has proved useful.

A question still open is which type viscosimeter has the advantage at higher temperatures. For the test a viscosimeter with capillary flow and a viscosimeter with a falling body exist. We will now report about the first measurement with a capillary flow viscosimeter at a temperature above 300 C.

SUMMARY OF THE INVESTIGATION

A B.S.I. viscosimeter was placed in a vapor bath in which the boiling liquid was benzophenone (diphenylketone). In order to avoid the

oxidation of oil a suitable accessory apparatus makes it possible to evacuate the viscosimeter, then to fill dropwise with oil and thereafter introduce nitrogen above the oil. The oil level was stopped at the exact height by means of drawing off the excess oil with a fine capillary. As for the rest, the normal handling of a B.S.I. viscosimeter was made difficult in our case because of the fact that no air was allowed in.

The first oil, that we filled in this way and heated to about the boiling point of benzophenone, BL3, a Venezuelan oil with E50 = about 25, proved to be volatile at 300 C. A part of it evaporated which condensed again on a colder place of the viscosimeter. The evaporation on the surface of the oil already suggests an error, which may be more inherent to the viscosimeter with capillary flow than the falling body viscosimeter. With pure materials this error is of slight significance, since with slight evaporation the viscosity remains constant, so that only the influence of the amount of liquid plays a part.

For the first measurement over 300 C it was considered expedient to eliminate the source of error caused by evaporation and a less volatile oil be used. Such an oil was Elk Bright Stock, A Pennsylvania oil with E50 = about 32.

At the temperature of boiling benzophenone, three series of measurements were made with this oil, for each series fresh oil was used.

Series I Temperature: 305 C	III-23
Flowtime in seconds: 164.8; 164.8; 165.2; 166.2; 164.8;	2833
Series II Temperature: 304.5 C	
Flowtime in seconds: 165.4; 165.8; 164.8; 166.2;	
Series III Temperature: 305 C	
Flowtime in seconds: 164.6; 165.2; 164.2; 164.6.	

The differences between the various measurements of each series are less than 1 per cent. Also the mean value of the measurements agree well. From this good reproducibility, it may be concluded that the marks on the viscosimeter are sharp enough to be observed in spite of the blur caused by the flowing benzophenone along the partition, and the smallness of the window in the insulation. The agreement between series moreover shows that the adjustment of the level, which occurred in the absence of air was accurate enough.

CONCLUSIONS

The measurement of the flowtime of Elk Bright Stock at the temperature of boiling benzophenone was found to give good reproducibility.

PLANS FOR FURTHER INVESTIGATION

To determine the flowtime of Elk Bright Stock in vapor bath at other temperatures and in so far as possible also in a very reliable liquid bath.

The viscosimeter which has been in a flame in order to mount a looped piece shall be calibrated anew.

INTRODUCTION

III-29
2859

The conclusion of last month's report was, that at the temperature of boiling benzophenone good reproducibility of flow time results with a B.S.I. viscosimeter. Now we shall establish that this is also the case at the temperature of boiling naphthalene, aniline, monochlorobenzene and benzene. The circumstance, that some measurements made in a precisely regulated oil bath agree closely with those mentioned above, increases confidence in the reliability, as does likewise the fact that the measurements lie on a smooth curve over the whole temperature range, which is extended by means of a measurement in a water bath at 30 C.

Since the measurements correlate satisfactorily and no further modifications were necessary. The calibration was accomplished.

SUMMARY OF THE EXPERIMENT

Elk Bright Stock was examined with a B.S.I. viscosimeter at the temperature of boiling naphthalene, aniline, monochlorobenzene and benzene.

Boiling naphthalene: Temperature: 217.8 C.
Flowtime in seconds: 558.6; 559
Boiling aniline (anhydrous): Temperature: 179.2 or 179.7 C.
Flowtime in seconds: 587.0 or 583.8
Boiling monochlorobenzene: Temperature 131.6 C.
Flowtime in seconds: 1379; 1375
Boiling benzene: Temperature: 80.5 C.
Flowtime in seconds: 6111; 6095.

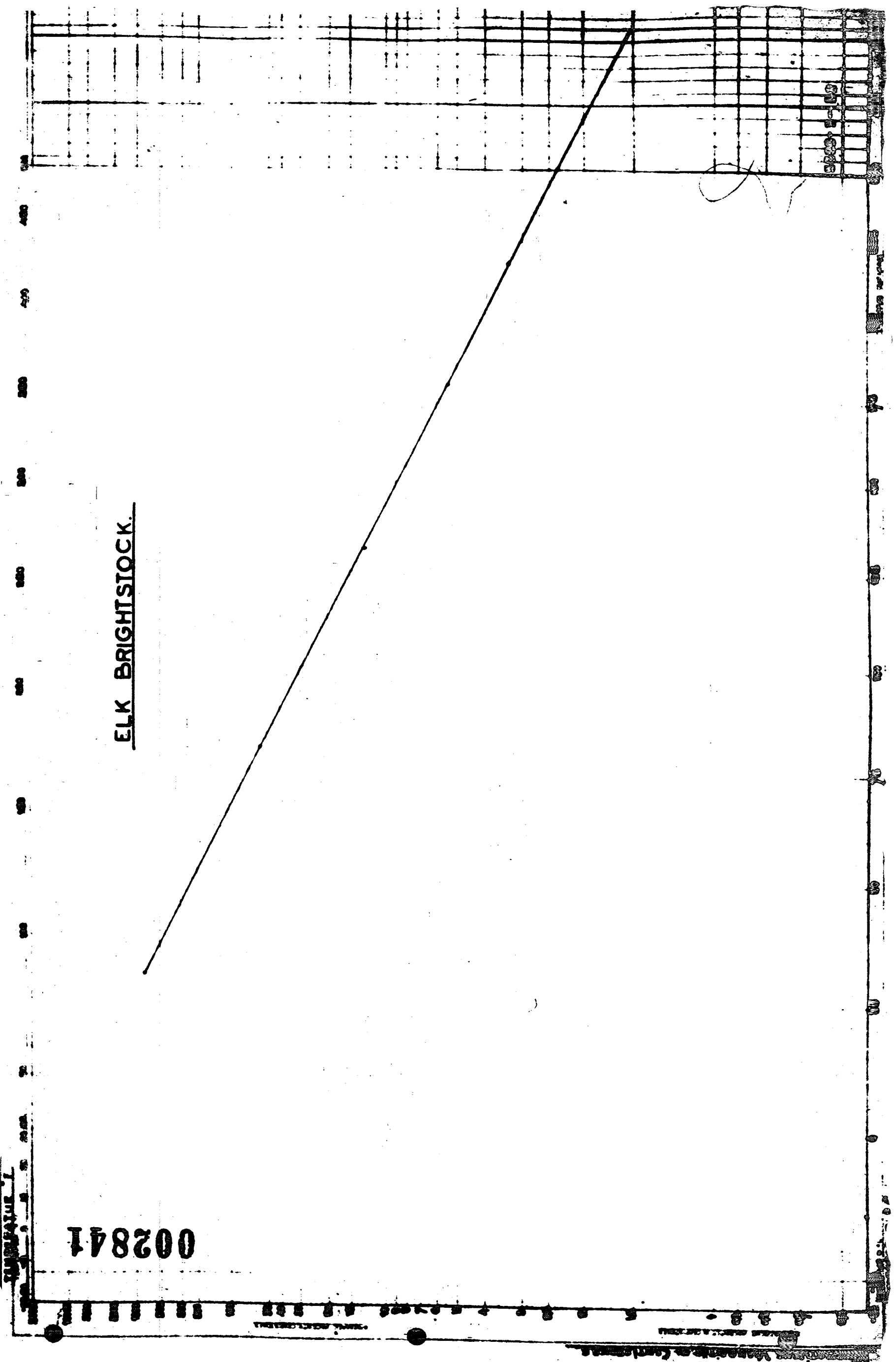
The above values increased to give a flow time of 8592.0 seconds when placed in the middle of a water bath at 30.0 C.

Besides the measurements in the vapor bath, the same measurements were carried out in an oil bath where the temperatures chosen were as close as possible to boiling aniline and boiling monochlorobenzene.

Oil bath: Temperature: 179.6 C.
Flowtime in seconds: 588.2; 584.4; 587.0
Oil bath: Temperature: 131.6 C.
Flowtime in seconds: 1385; 1380.

III-30
2840

The measurements in the vapor bath and in the oil bath are in very good agreement. Since the measurements thruout the whole temperature range were carried out without appreciable difficulty, the viscosimeter can be considered useful to carry out the calibration.



ELK BRIGHTSIOCK.

002841

TEMPERATURE

THE UNIVERSITY OF CHICAGO

THE UNIVERSITY OF CHICAGO

This calibration was carried out at 15 C with two oils. Thereby it results, that in order to obtain the number of centistokes, the number of seconds is to be multiplied by the following factor:

1° Oil: 0.009195; 0.009203; 0.009195
2° Oil: 0.009215; 0.009203.

The multiplication factor is dependent on the temperature and varies proportionally with the linear expansion of glass. Since the viscosimeter is made from Pyrex glass this means an increase of only 1 per cent between 25 and 305 C. Over the whole temperature range therefore, we calculate with a constant multiplication factor of 0.00921.

For the viscosity of Elk Bright Stock we obtained the following results:

30.0 C	791 centistokes
80.5	56.2 "
131.6	12.7
179.5	5.39
217.8	3.30
305.0	1.52.

From the above illustration Number 5659-5-B2 it is evident that when the viscosity is plotted on ASTM paper with $\log(100V_K \pm 0.8)$ against $\log T$, one obtains nearly a straight line. The measured viscosities at the highest temperatures are somewhat higher than would follow from the rectilinear extrapolation of the measurements at lower temperatures.

CONCLUSION

A viscosimeter with capillary flow was used for the measuring of viscosities at the higher temperatures. The highest temperature, at which viscosity can be measured is limited by the volatility of the oil.

PLANS FOR FURTHER INVESTIGATION

III-51
2842

Several representative oils were examined over a wider temperature range. The viscosity-curve on ASTM paper (viscosity log paper) again in these cases varies a little from the straight line; so the number of measurements can be limited.

In the meanwhile a falling body viscosimeter was delivered to the laboratory. With such a viscosimeter the evaporation of the oil was less troublesome.

INTRODUCTION

III-32
2845

As announced, the viscosity of a limited number of oils was measured

over a wide temperature range. We have obtained the following results with a synthetic Bright Stock.

SUMMARY OF THE INVESTIGATION

The viscosity of synthetic Bright Stock TMC 8225 was found to be:

37.8 C	706 centistokes
60.1	216
98.7	48.1
131.6	20.7
183.2	8.06
244.6	5.83
306	2.23

At temperatures around 100 C and beyond, the vapor bath and the viscosimeter with the factor of 0.00921 were used; at temperatures below 100 C we used a liquid bath and a viscosimeter with the factor 1.58.

The viscosity-curve makes nearly a straight line on ASTM paper.

PLANS FOR FURTHER INVESTIGATION

Aromatic and naphthenic oils are to be investigated.

INTRODUCTION

III-35
2844

The viscosity-curve was systematically determined on an aromatic and naphthenic oil. Evaporation was troublesome with naphthenic oil. With castor oil such was the case to a still greater degree. Oriented measurements were made with a falling body viscosimeter, a viscosimeter type which can prevent evaporation.

SUMMARY OF THE INVESTIGATION

The viscosity of a B.P. oil (TMC 6996) was determined at several temperatures below 100 C in the middle of a liquid bath, with a viscosimeter with a factor of 0.0634. The following values were found:

37.8 C (100 F)	182.5 centistokes
60.7 C	42.9
98.8 C (210 F)	9.69.

The viscosity was determined at several temperatures above 100 C in the middle of a vapor bath with a viscosimeter with a factor 0.00921. In order to control the agreement of both viscosimeters, measurements were made with the latter one at temperatures below 100 C as well. Of course it was found to have a very long flow time, for example, more than 5 hours @ 37.8 C,

37.8 C (100 F)	183.9 centistokes
98.9 (210 F)	9.72
132.0	4.58

184.5 C	1.96 centistokes
245.2	1.058
306.3	0.677

Plotted on ASTM paper, the viscosity-curve shows a clear deviation from a straight line. The viscosity at higher temperatures is higher than may be expected from the measurements carried out by means of extrapolation @ power temperature.

During the determinations of the viscosity of the Venezuelan oil BD₁ indications were found of the loss of volatile components. A brown deposit became evident on the somewhat colder parts of the side of the viscosimeter. The discoloration raises the question of whether oxidation also occurs with evaporation. On this basis the nitrogen, which was analyzed by passing it through a pyrogallol-KOH solution and over CaCl₂ and P₂O₅. The analysis showed that the oxygen content amounted to only 0.06-0.07 per cent.

III-34
2845

Since measurements at 280 C are in many cases unreliable owing to possible evaporation, it was decided to make a series of measurements up to about 240 C and after that to repeat some of the first measurements of the series. This repetition of measurements at a lower temperature necessitates that a little fresh oil be added in order to maintain the proper level.

For the viscosity of BD₁ the following values were found.

37.8 C (100 F)	46.6 centistokes	183.5 C	1.51 centistokes
98.9 C (210 F)	5.574	244.4	0.891
131.7 C	2.98	98.9 C (210 F)	5.619

Plotted on ASTM paper the viscosity curve of the Venezuelan oil BD₁ also deviated from a straight line.

In the determination of the viscosity curve of castor oil over a large temperature range, the evaporation was even more annoying than in the case of BD₁. The difficulties experienced on account of the vaporization of oils in the viscosimeter with effluent capillary has lead to the result that the development of the falling body viscosimeter, which we have discussed a few times already, will now be taken into consideration. There is at our disposal for the manufacture of a tube with uniformly round cross-section a KPG tube*, with a diameter of about 1 mm and a linear coefficient of expansion of 4.8×10^{-6} . Calculations in the May report have already proved, that it is desirable that the falling body and tube have nearly the same coefficient of expansion. On this basis a falling body was rolled from a special metal called "Fernico" which the N. V. Philips Gloeilampenfabrieken (Incondescent Lamp Works Company) in Eindhoven placed at our disposal and which has a

* a precision capillary molten from metal bolts.

coefficient of expansion of 4.4×10^{-6} at 120 C and 5.0×10^{-6} at 270 C. Since the instructions showed that the metal is attached in the oil at higher temperatures, the surface of the falling body was nickel plated.

A series of measurements was made with the falling body, where the tube was suspended in a vapor bath. Formerly the addition of the deaerated oil was at the bottom of the tube. The rising oil carries the falling body with, it is fixed in its highest position by means of an electromagnet. After a few minutes in which the oil should be a constant temperature, the falling body is released. Originally at a temperature fall times were obtained with variations of 1.3 per cent. In this case we obtained fall times with a variation of only 0.3 per cent by not cutting out suddenly the alternating current through the electromagnet, but instead allowing a regular decline in current intensity and so demagnetizing the falling body.

Likewise good results can not be attained when the temperature rises to 245 C; at this temperature the reproducibility was good. Repetition of the measurement at 184 C gives an increased value of 8 per cent. The viscosimeter was dismantled. It turned out the nickel plating had peeled off the falling body. The experiments were continued with a gold plated falling body and a glass falling body.

III-35
2845

CONCLUSION

Plotted on ASTM paper the viscosity curve of Balikpapan oil and Venezuelan oil BD₁ deviate clearly from a straight line. The viscosity at higher temperatures is higher than would be expected from the extrapolation of the measurements at lower temperatures. With the Venezuelan oil the measurements must be limited to temperatures below 245 C, since at higher temperatures the volatilization becomes troublesome. In the oriented measurements with the falling body viscosimeter good reproducibility of fall time was obtained

PLANS FOR FURTHER INVESTIGATION

The viscosity of several oils are to be examined over a wide temperature range. The investigation of materials which contain in addition to carbon and hydrogen many other atoms will begin simultaneously. For example, an ether with a long carbon chain will be considered. Such a material called dicycylether is already reported. A search through the literature concerning the viscosity of ether supports the experimental work.

The experiments on the development of a useful falling body viscosimeter will be continued.

INTRODUCTION

The experiments for the development of a useful falling body

III-49
2861

viscosimeter are to be continued. In the last report the first results with a viscosimeter of this type were given. This viscosimeter consists of a precision capillary with about a 1 mm cross section in which is located a metal falling body, which can be raised to its highest position with an electromagnet. After the attainment of temperature equilibrium, the falling body is set free by means of swift and regular lowering of the current intensity in the electromagnet. The body passes in its fall two marks and can after that be brought up again by the introduction of fresh oil in the capillary. The surface of the falling body, which was made from a metal with low coefficient of expansion, was nickel plated.

After a number of favorable measurements had been carried out, the nickel coating began to peel off. We experimented with gold plate to obtain better results. The falling body was newly polished, carefully cleaned of grease and hung in a gold bath. This bath contained 2 g. gold chloride, 1 g. potassium cyanide, 15 g. sodium sulfate and 60 g. of disodiumphosphate per liter of water. It gives a good gold plate of 0.001 mm thickness. The repeatability proved to be very good on a series of measurements carried out with the gilded falling body. After a while however, the gold plate just as with the nickel plate began to peel off. Fortunately, better results were obtained almost simultaneously in another direction, so that further experiments will be given up until a durable falling body can be made from metal.

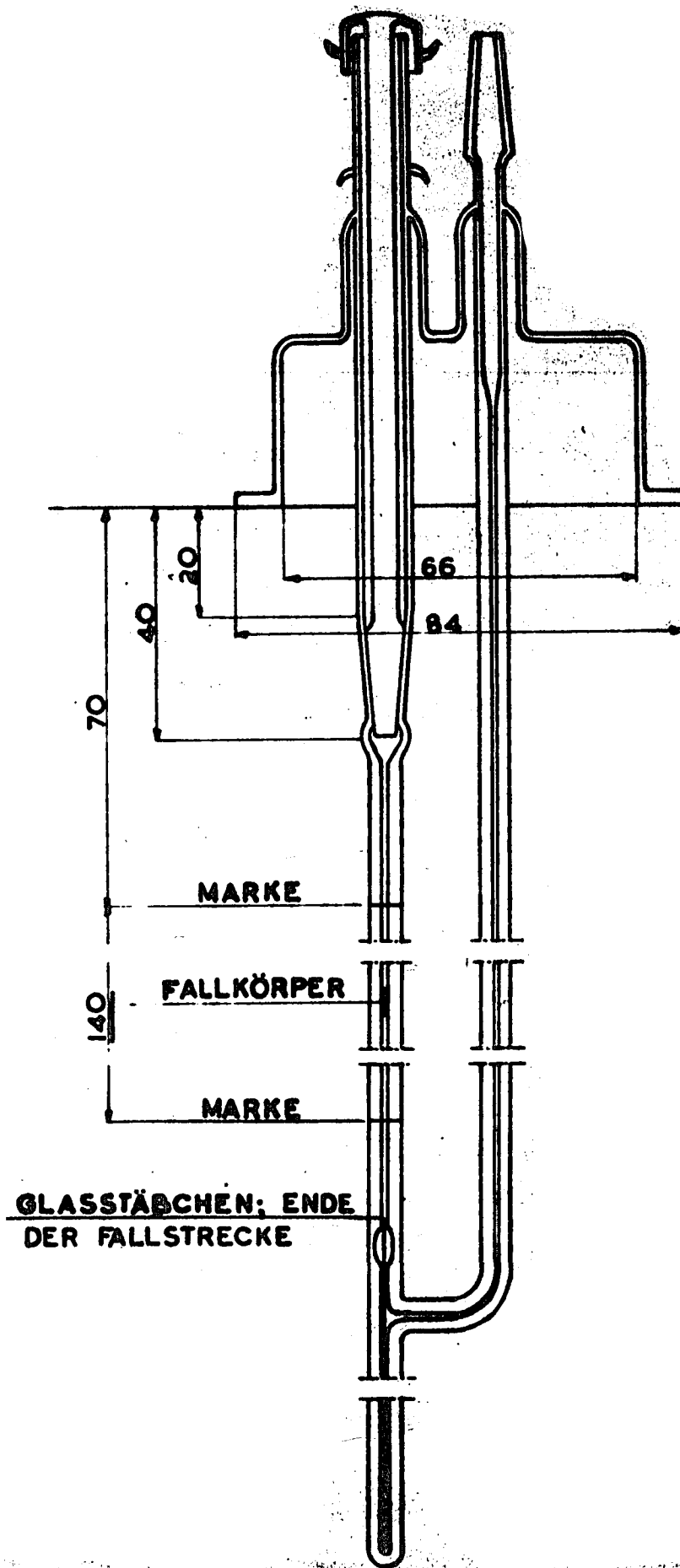
The better results were obtained with a falling body made from glass. The use of a falling body which cannot be raised by an electromagnet is made possible by a modification to the viscosimeter such that not much observing time is necessary for the standardization of temperature equilibrium. The glass falling body was originally cut from a solid glass rod, and the end plane ground. Such a falling body vibrated to some degree and the reproducibility of falling time was not as good as a falling body with a somewhat pointed head. However, when our expert mechanic made a falling body of the required form, this last difficulty was also removed. In what follows we did not carry out again the measurements with the gilded falling body, but limit ourselves to the description of the final form of the viscosimeter with a falling body made of glass.

SUMMARY OF THE INVESTIGATION

III-50
2862

The final form of the falling body viscosimeter was shown in the foregoing illustration 19094-A4. The most important parts are the falling body and its proper precision capillary. A short distance from the end a second capillary opens into the tube (surrounding the falling body) in which the oil is kept under a slight pressure of nitrogen. As long as the glass stopper at the end of the tube is raised, the oil flows in, thereby raising the falling body with it, as soon as the falling body is up, the stopper is allowed to drop. The falling body then level, begins

002863



to fall. This however, presents no difficulty because the oil is already in the feed capillary which has reached the proper temperature. It may be necessary to wait a few minutes between double determinations when the fall time is short. The time, necessary for the terminal face of the falling body to pass the distance between the upper and lower mark, is noted as the fall time. The terminal face is platinized in order to assure good visibility. Good reproducibility was obtained with the fall times.

CONCLUSION

The experiments in the development of a useful falling body viscosimeter lead to the manufacture of a viscosimeter with a glass falling body. We now have at our disposal an apparatus which can effect good service when the measurements with the capillary flow viscosimeter is made difficult by means of the evaporation of oil.

PLANS FOR FURTHER INVESTIGATION

A few oils are to be measured with both the falling body viscosimeter and capillary flow viscosimeter.

III-54
2868

INTRODUCTION

In the last report was described a falling body viscosimeter, which finds use when the measurements with a capillary flow viscosimeter are troublesome because of evaporation of the oil. At this time a few oils are being investigated with both viscosimeters.

SUMMARY OF THE EXPERIMENT

Penn. Neutral and LCT Penn. Bright Stock were tested with a capillary flow type viscosimeter (constant 0.00921).

The Hagenbach correction

$$\frac{\eta}{8\pi r \times \text{capillary length}} \times \frac{\text{volume per unit time}}{\text{kinematic viscosity}} = 100\%$$

was applied with $\eta = 1.00$ and at the maximum amounted to 0.9 per cent.

Penn. Neutral TMC 748

152.7 C	3.124 centistokes
184.7 C	1.658 "
246.1 C	.984 "
284.5 C	.775 "
306.7 C	.661 "

LCT Penn. Bright Stock TMC 364

80.6 C	59.6 centistokes
152.2 C	13.29 "
183.5 C	5.32 "
245.3 C	2.606 "
307.0 C	1.542 "

Both oils were tested in the falling body viscosimeter, whereby the viscosity was found when the density difference between the falling body and the oil was multiplied by a calibration constant. The oil density is determined simultaneously with the viscosity by hanging near the viscosimeter in the vapor bath a 5 cc pycnometer with a long calibrated stem. For the calibration constant eight values were obtained by means of comparison of every two measurements at the same temperature with both viscosimeters. Since the falling body and surrounding tube have the same coefficient of expansion, the calibration constant will change only slightly with the temperature, that is, no more than corresponds to the linear expansion of glass.

On this basis a single calibration value was averaged from the many and from it the viscosity calculated below.

III-55
2869

Pennsylvania Neutral TMC 743

<u>Temp.</u>	<u>Density</u>	<u>Dynamic Viscosity</u>	<u>Kinematic Viscosity</u>	<u>Deviation</u>
C		c.p.	c.s.	%
132.2	0.7865	2.487	3.161	+ 0.4
184.2	0.7540	1.264	1.667	+ 0.7
245.4	0.7154	0.715	0.997	+ 0.8
285.5	0.6913	0.527	0.762	+ 0.5

L.C.T. Pennsylvania Bright Stock TMC 564

<u>Temp.</u>	<u>Density</u>	<u>Dynamic Viscosity</u>	<u>Kinematic Viscosity</u>	<u>Deviation</u>
C		c.p.	c.s.	%
80.8	0.8537	50.2	58.8	- 0.5
185.5	0.7903	4.16	5.27	- 1.0
244.6	0.7533	1.951	2.590	- 1.2
305.8	0.7148	1.111	1.554	+ 0.2

In the last column of the above table are indicated the deviations in viscosity which were found when the measurements with the falling body viscosimeter were compared at the same temperatures with the measurements with the other viscosimeter. Although the agreement between the viscosimeters is fair, it can be said that the measurements with the capillary flow type viscosimeter are not substantially influenced by evaporation.

CONCLUSION

Two oils were investigated with a capillary flow type viscosimeter

and also with a falling body type viscosimeter. The agreement of the measurements show that evaporation has no influence. There are still a few oils more volatile than the ones mentioned before to be tested comparatively in both viscosimeters. The testing of pure materials has already begun.

February 1943

III-64

INTRODUCTION

2880

The investigation of the viscosity of pure materials was taken in hand. The first measurements were carried out with n-hexadecane, after that p-dicetylbenzene was investigated. Both materials were placed at our disposal by Prof. Wilbaut. The preparation of n-hexadecane was described in Recueil des Travaux Chimiques des Pays-Bas 58, 329 (1939). The value reported therein for the density $d_{20/4} = 0.77387$ lies between the value of Evans $d_{20/4} = 0.7752$ and the one of Deansley $d_{20/4} = 0.77335$. The sample of p-dicetylbenzene was tested as to purity by Mr. Ir. J. Verheus, for that a cooling curve was determined. It proved that the temperature decrease between the solidification limits amounted to only 0.2 C. If one rejects the possibility of a mixed crystal formation with an isomer, which has nearly the same freezing point, on account of the improbability, it can be concluded, that the preparation has a purity > 99 per cent. The freezing point is 53.0 C.

SUMMARY OF THE INVESTIGATION

First the density of n-hexadecane was determined with the help of a pycnometer of about 5 cc capacity with a long calibrated stem. Two fillings were used, in order that two series of measurements would be obtained.

Density of n-Hexadecane

100 F	0.7621 g/cm ³	79.9 C	0.7326 g/cm ³
80.2 C	0.7321	131.5 C	0.6959
131.8 C	0.6965	183.3 C	0.6577
183.7 C	0.6577	244.2 C	0.611

For the determination of viscosity of n-hexadecane a capillary flow type viscosimeter with a narrow capillary was used, this was so that the Hagenbach correction amounted to no more than 0.1 per cent. By means of the calibration with water and oil it was established, that in order to obtain the kinematic viscosity in centistokes the flow time in seconds is multiplied by the factor 0.000291.

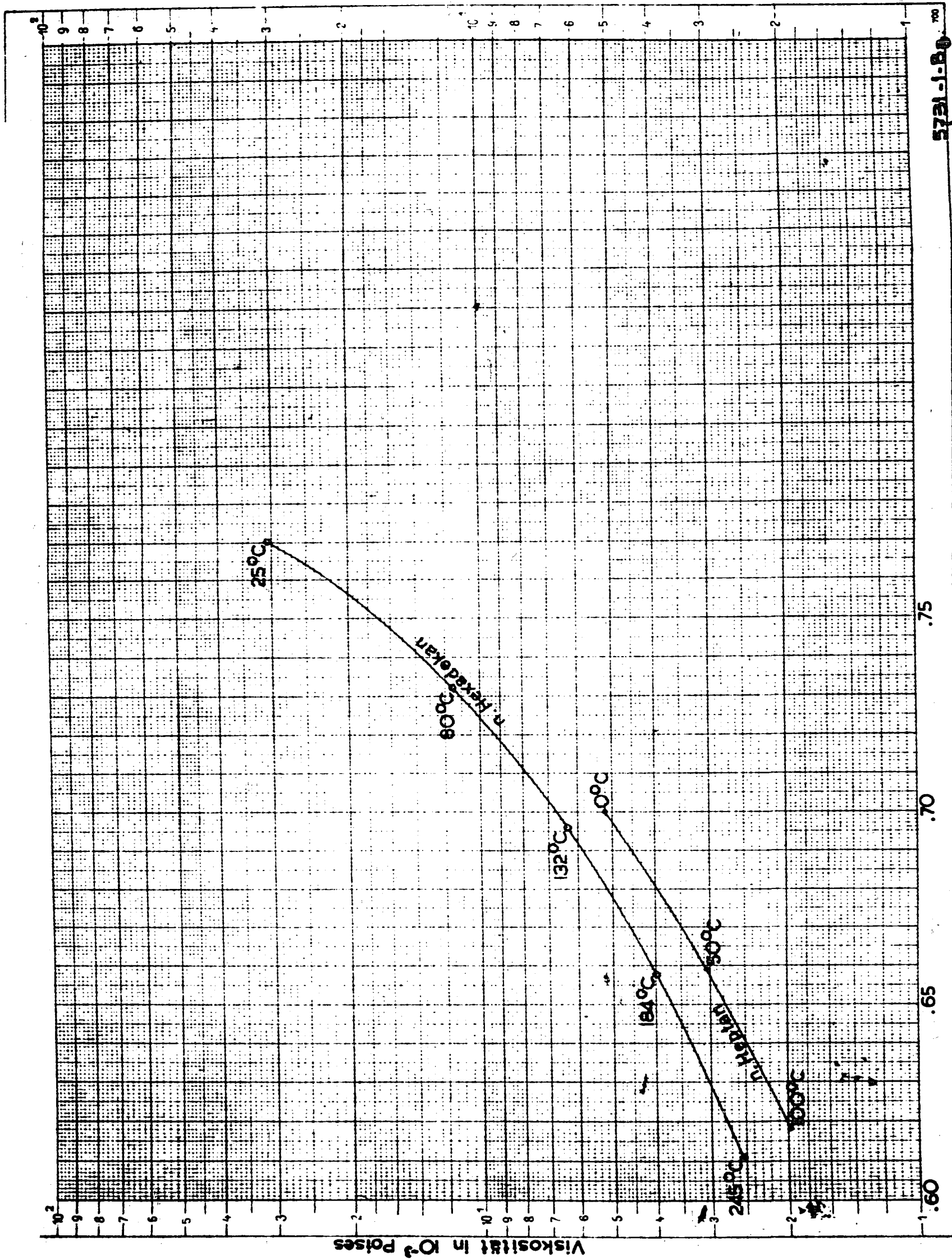
Viscosity of n-Hexadecane
(capillary flow)

III-65

2881

25.0 C	4.01 centistokes	3.09 centipoise
80.2	1.588	1.16 ^x
131.8	0.917	0.638
183.7	0.612	0.402
244.8	0.416	0.254

U02882



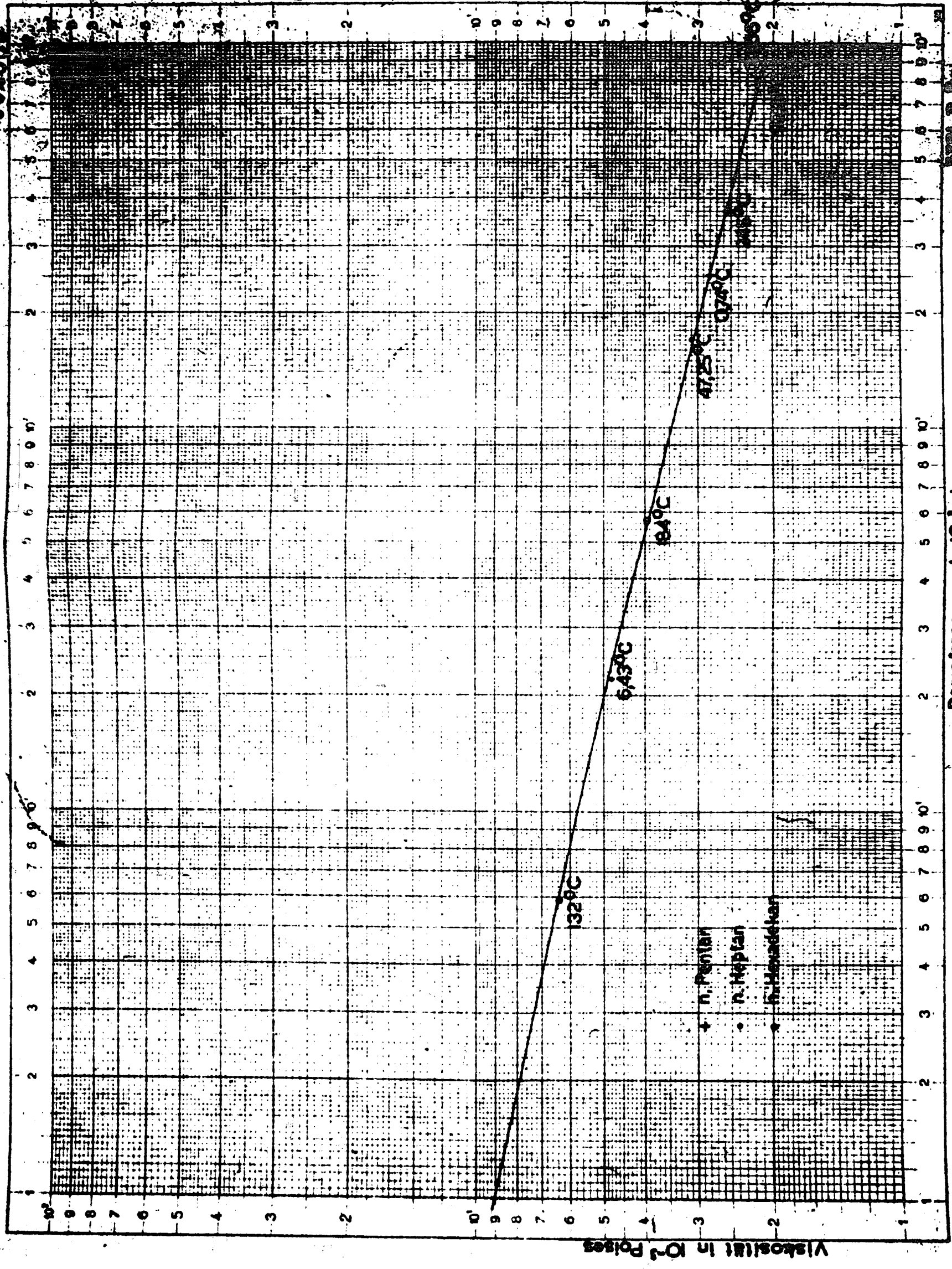
5731-1-B0

Eine Achse logarith. geteilt von 1 bis 100, Einheit 100 mm, die andere in mm.

Dichte in g/cm^3

Copyright Carl Schleicher & Schüll, Düren (Rhd.), N° 376 1/2 P.

00285



COPYRIGHT GAMB. GEWÜRZMISCH. & SEIFENFABRIK DÜREN/MI. NR. 366 1/2 P.

Dampfspannung in 10^{-3} atm. Beide Achsen logarith. geteilt. eine von 1 bis 100 die andere bis 10¹⁰.

SYD. P. P.

At approximately the same temperatures n-hexadecane was investigated with the falling body viscosimeter. A falling body whose calibration was established with water, was used, so that the fall time in seconds must be multiplied not only by the density difference between glass and liquid but also by the factor 0.00484, in order to obtain dynamic viscosity in centipoise. Calibration with an oil gave exactly the same value for the factor.

Viscosity of n-Hexadecane
(Falling body)

25.0 C	3.07 centipoise
79.9 C	1.161
131.5 C	0.638
183.3 C	0.399
244.2 C	0.252

One finds in literature a few values for the viscosity of n-hexadecane at temperatures lower than 100 C according to Evans¹, Ubbelohde and Aghte found in the year 1915, 1.136 centipoise for the viscosity at 80 C, while Evans himself found 1.172 centipoise. This new value lies between the two.

It is often recommended in literature to compare different viscosities of, for example, homologous materials with the same density. A similar point for discussion is also the comparison with materials of the same volatility.

While viscosities are almost always determined between 0 and 100 C such consideration remained limited on adjacent homologs. This is now changed because of the measurements on n-hexadecane at higher temperatures. In the foregoing diagram the viscosity was plotted as a function of the density and vapor pressure respectively.

On the viscosity-density diagram (5731-1-B3), the viscosity of n-heptane is also plotted, here the values which Evans¹ had calculated for 0, 50, and 100 C from the measurements of Thorpe and Rodgers were used. With similar densities, the viscosity of n-hexadecane and n-heptane differed widely.

On the viscosity-vapor pressure diagram (5731-2-B5) are plotted at the same time the viscosities of n-heptane and n-pentane, for which some measurements of Thorpe and Rodgers¹¹ were used. With similar vapor pressure the dynamic viscosity of such widely separated homologs as n-pentane, n-octane and n-hexadecane varied only a little.

After hexadecane, p-dicetylbenzene was investigated. The density was determined with the above mentioned pycnometer of about 5 cc capacity with a long calibrated stem and the viscosity with the falling body viscosimeter. The density values in the table indicated as calculated were found with the formula $d^v = 0.86407 - 6.173 \times 10^{-4}t - 3.75 \times 10^{-8}t^2$, which was calculated with the help of the method of small quadratics.

III-68
2584

¹ J. Instr. Petre. Techn. 1938, 24, 38
¹¹ Phil. Trans. A. 1895, 186, 397.

Density of p-Dicetylbenzene

	<u>Measured</u>	<u>Computed</u>
67.3 C	0.8225 g/cm ³	0.8224 g/cm ³
78.5	0.8152	0.8155
100.6	0.8017	0.8016
132.2	0.7820	0.7818
183.8	0.7492	0.7493
306.3	0.6715	0.6715

Viscosity of p-Dicetylbenzene
(Falling body)

<u>Temp</u>	<u>Reported</u> <u>Density</u>	<u>Dynamic</u> <u>Viscosity</u>	<u>Kinematic</u> <u>Viscosity</u>
80.6 C	0.8141	8.90 c.p.	10.93 c.s.
132.2	0.7818	3.50	4.48
184.0	0.7492	1.848	2.47
245.3	0.7104	1.062	1.495
306.3	0.6715	0.676	1.007

CONCLUSION

The viscosity of n-hexadecane was measured with both a capillary flow and falling body viscosimeter. The agreement of the measurements is satisfactory. No particular difficulty was experienced with the investigation of p-dicetylbenzene, melting point 53.0 ± 0.1 C.

PLANS FOR FURTHER INVESTIGATION

The investigation of pure organic materials will be continued. The small samples of principally unbranched paraffins, whose investigation described by Dr. Hazez in Report 8975 are still remaining, will probably be investigated with the falling body viscosimeter. Between the viscosity-temperature curve to be gained in this way, the missing ones may be found by interpolation. The viscosity-vapor pressure diagram appears to be a valuable aid for this interpolation. The final group of viscosity-temperature curves of unbranched paraffins to be obtained were of great value in the valuation of the viscosity curves of organic materials.

III-80
2899INTRODUCTION

The viscosity of octadecylbenzene and 1,1-diphenylhexadecane were determined. The octadecylbenzene sample number 38/3988 was received from Prof. Wibaut on May 5, 1938. The melting point according to specifications was 22.4 C.

SUMMARY OF THE INVESTIGATION

The density of octadecylbenzene was determined with the help of an approx. 1 cc pycnometer with long calibrated stem, the viscosity was measured by a falling body type viscosimeter. The density values indicated in the table as calculated were found with the formula $d^* = 0.87217 - 6.606 \times 10^{-4}t - 2.75 \times 10^{-8}t^2$, which was calculated from the measurements with the help of the method of small quadratics.

III-80
2899Density of Octadecylbenzene

	<u>Measured</u>	<u>Computed</u>
43.6 C	0.8453 g/cm ³	0.8433
81.0	0.8185	0.8185
132.4	0.7843	0.7842
184.0	0.7496	0.7497
245.6	0.7083	0.7083

Viscosity of Octadecylbenzene
(Falling body)

<u>Temp.</u>	<u>Reported</u> <u>Density</u>	<u>Dynamic</u> <u>Viscosity</u>	<u>Kinematic</u> <u>Viscosity</u>
40.0 C	0.846	7.39 c.p.	8.74
81.0 C	0.819	3.00	3.66
132.4	0.784	1.440	1.837
184.0	0.750	0.851	1.135
245.6	0.708	0.552	0.737
285.8	0.682	0.404	0.592

Before the last measurement at 285.8 C, due to a small repair the constant of the viscosimeter was 0.00488 instead of 0.00484. Also Mikeska¹ has measured the viscosity of octadecylbenzene at other temperatures. In order to make possible a comparison between the first and second above mentioned measurements, the line $\log \log (\text{number of c.s.} \times 0.8) = 8.31899 - 3.33695 \log T$ was drawn. By means of the second and third the line $\log \log (\text{number c.s.} \div 0.8) = 7.96633 - 3.19861 \log T$ was drawn.

In this way one can interpolate between the individual measurements at the temperatures applied by Mikeska.

	133.6 F	147.2 F	171 F	210 F
Mikeska (c.s.)	5.87	5.05	3.90	2.78
New interpolated measurements	5.87	5.03	3.92	2.79

The density of 1-1 diphenylhexadecane was determined with a 1 cc pycnometer at the same time the viscosity was determined with a falling body type viscosimeter.

Density and Viscosity of 1-1 Diphenylhexadecane
(Falling body)

<u>Temp.</u>	<u>Density</u>	<u>Dyn. Viscosity</u>	<u>Kin. Viscosity</u>
25.0 C	0.9070 g/cm ³	(34.9) cp	(38.5) cs
80.6	0.8707	5.37	6.17
132.4	0.8364	2.116	2.530
184.4	0.8014	1.133	1.414
245.8	0.7607	0.665	0.874
306.5	0.7165	0.431	0.602

The measurement at 25 C was taken with a B.S.I viscosimeter with $K = 0.0634$. The new viscosity value lies about 3 per cent lower than the value of Londa and Cech².

PLANS FOR FURTHER INVESTIGATION

The measurements on pentatriacontane are almost finished. We will begin with some other unbranched paraffins.

III-85
2905

INTRODUCTION

The viscosity of n-tetracosane (C₂₄H₅₀), n-pentatriacontane (C₃₅H₇₂) and n-tritetracontane (C₄₃H₈₈) was determined. The last two hydrocarbons were prepared in the laboratory of Prof. (Dr.) H. Bocker in Groninger. The n-tetracosane came from the laboratory of Prof. (Dr.) Wibaut.

Details about the preparation and further purification can be found in Report Number 8975 of Dr. W. M. Mazee. A sample of n-pentatriacontane whose preparation was described by Dr. Verberg in the March report (see III-75) was also investigated. Since this sample was large, it was possible to use both the falling body and capillary flow viscosimeter, and in this way the reliability of the first mentioned viscosimeter can be tested once more.

The measured results for the named unbranched paraffin hydrocarbons and the even earlier investigation of n-hexadecane were treated in various ways.

SUMMARY OF THE INVESTIGATION

The densities of the normal paraffins were determined with the help of a pycnometer of 1 c.c. capacity, with a long calibrated stem; the viscosities were measured with the falling body viscosimeter.

² S. Londa and J. Cech, Coll. Trav. Chim. Tchechoslovaque **6**, 423 (1934)

Density and Viscosity (Falling body) of
n-Tetracosane C₂₄H₅₀

<u>Temp.</u>	<u>Density</u>	<u>Dyn. Vis.</u>	<u>Kin. Vis.</u>
56.2 C	0.7757 g/cm ³	4.61 c.p.	5.94 c.s.
80.2	0.7600	2.872	3.78
131.6	0.7264	1.365	1.878
184.0	0.6915	0.790	1.142
244.8	0.6501	0.482	0.741
306.0	0.6041	0.314	0.520

Density and Viscosity (Falling body) of
n-Pentatriacontane C₃₅H₇₂

<u>Temp.</u>	<u>Density</u>	<u>Dyn. Vis.</u>	<u>Kin. Vis.</u>
80.5 C	0.7778 g/cm ³	6.68 c.p.	8.59 c.s.
110.4	0.7592	3.83	5.04
131.9	0.7459	2.778	3.72
184.0	0.7131	1.495	2.096
245.0	0.6748	0.868	1.286
305.7	0.6343	0.556	0.877

Density and Viscosity (Falling body) of
n-Tritetracontane C₄₅H₉₈

<u>Temp.</u>	<u>Density</u>	<u>Dyn. Vis.</u>	<u>Kin. Vis.</u>
90.0	0.7808 g/cm ³	8.61 c.p.	11.03 c.s.
112.4	0.7669	5.66	7.38
132.1	0.7543	4.15	5.50
184.2	0.7223	2.125	2.942
245.5	0.6850	1.195	1.745
306.2	0.6474	0.750	1.158

A sample of n-pentatriacontane prepared by Dr. Verberg was investigated with a capillary flow viscosimeter (No. H21-40, Factor = 0.002685) as well as with the falling body viscosimeter.

III-86
2906

Density and Viscosity of n-Pentatriacontane C₃₅H₇₂

<u>Temp.</u>	<u>Density</u>	<u>Dyn. Vis.</u>	<u>Kin. Vis.</u>
80.4 C	0.7783	6.74 c.p.	8.66 c.s.
184.0	0.7133	1.494	2.094
245.6	0.6740	0.863	1.281
306.3	0.6339	0.553	0.872

Falling Body Viscosimeter

<u>Temp.</u>	<u>Dynamic Viscosity</u>	<u>Kinematic Viscosity</u>
80.5 C	6.74 c.p.	8.66 c.s.
111.4	3.79	4.93
132.0	2.777	3.72
184.2	1.495	2.024
245.3	0.870	1.291
306.1	0.555	0.875

Difference in Viscosity Measurements after Conversion to the Same Temperature, Expressed in per cent of the Measurement.

<u>Temp.</u>	<u>Prepared by Prof. Wibaut</u>	<u>Prepared by Dr. Verberg</u>	
		<u>Falling body</u>	<u>Viscosimeter Hpl-40</u>
80.5 C	- 1.3	0	- 0.2
111.4	- 0.7	0	
132.0	- 0.1	0	- 0.1
184.2	- 0.1	0	- 0.6
245.3	- 0.5	0	- 0.2
306.1	0	0	

The agreement of the measurements with both viscosimeters is good, close as the agreement with the results of Prof. Backer with n-pentatriacontane.

The results for the normal paraffins obtained up to now are drawn graphically in various ways.

III-87
2907

1. The kinematic viscosity of n-hexadecane, n-tetracosane, n-pentatriacontane and n-tritetracontane are plotted on ASTM paper (See diagram 5758-1-B2). The measurements at the highest temperatures are no more off the line than the viscosity curve made at lower temperatures.

2. The logs of the kinematic viscosity are plotted against the logs of the vapor pressure (See diagram 5758-2-B3). In an earlier report, the dynamic viscosity was used for this kind of plotting. However, all the data at our disposal shows that the agreement between various homologs is better when the kinematic viscosity is used. The number at the measuring point gives the number of C atoms in the concerned paraffin hydrocarbon. The data for n-pentane, n-heptane, and n-octane comes from Thorne and Rogers, and compiled with other data into a table by Evans¹. The viscosity of methane at 90 C was borrowed from a publication by Bussler and Landermann¹¹.

1 J. Inst. Petr. Techn. 1933, 24, 38

11 J. Exp. Theor. Physics 1940, 10, 250 (Russian)

3. The logarithms of dynamic viscosity were plotted against the logarithms of the number of C atoms for several temperatures (See diagram 5758-3-B5). The points lie on a fairly good straight line. The measured results taken from Report No. 8975 of Dr. Mazee for n-C₂₁H₄₄ up to and including n-C₄₅H₈₈ lie on the straight line for 90 C.

4. The temperatures at which the dynamic viscosity reached 1, 2, 3, 4, and 5 were also plotted against the number of C atoms. (See Diagram 5758-4-B5). The relation was indicated again by a straight line, n-C₄₅H₈₈, however, deviated clearly.

The regularity described under 3 and 4 lead us to the attempt to describe by a single formula the viscosity of various unbranched paraffins with melting points up to 300 C,

$$\log M = AT \log \eta + BT + C \log \eta + D$$

in which the molecular weight M is used instead of the number of C atoms. The coefficients A, B, C and D were determined by means of the application of the method of small quadratics to the difference of both parts of the equation; thus resulting from the Report 8975 of Dr. Mazee on the viscosity of n-C₂₁H₄₄ up to and including n-C₄₅H₈₈ at 70 C, 80 C and 90 C, and from the February report (See III-65) on the viscosity of n-hexadecane at 25 up to 245 C, and from the above report on the viscosity of n-tetracosane and n-pentatriacontane up to 306 C. The viscosity of n-tritetracosane at higher temperatures was still not known or sufficient at the time of the calculation, as III-88 was later proved, the regularity was not as good that described under 2908 3 and 4. The method of the small quadratic gave the following values for the formula:

$$\log M = 0.001410 T \log \eta + 0.002530 T - 0.0605 \eta + 1.4342,$$

where T is in °K and η in centipoise.

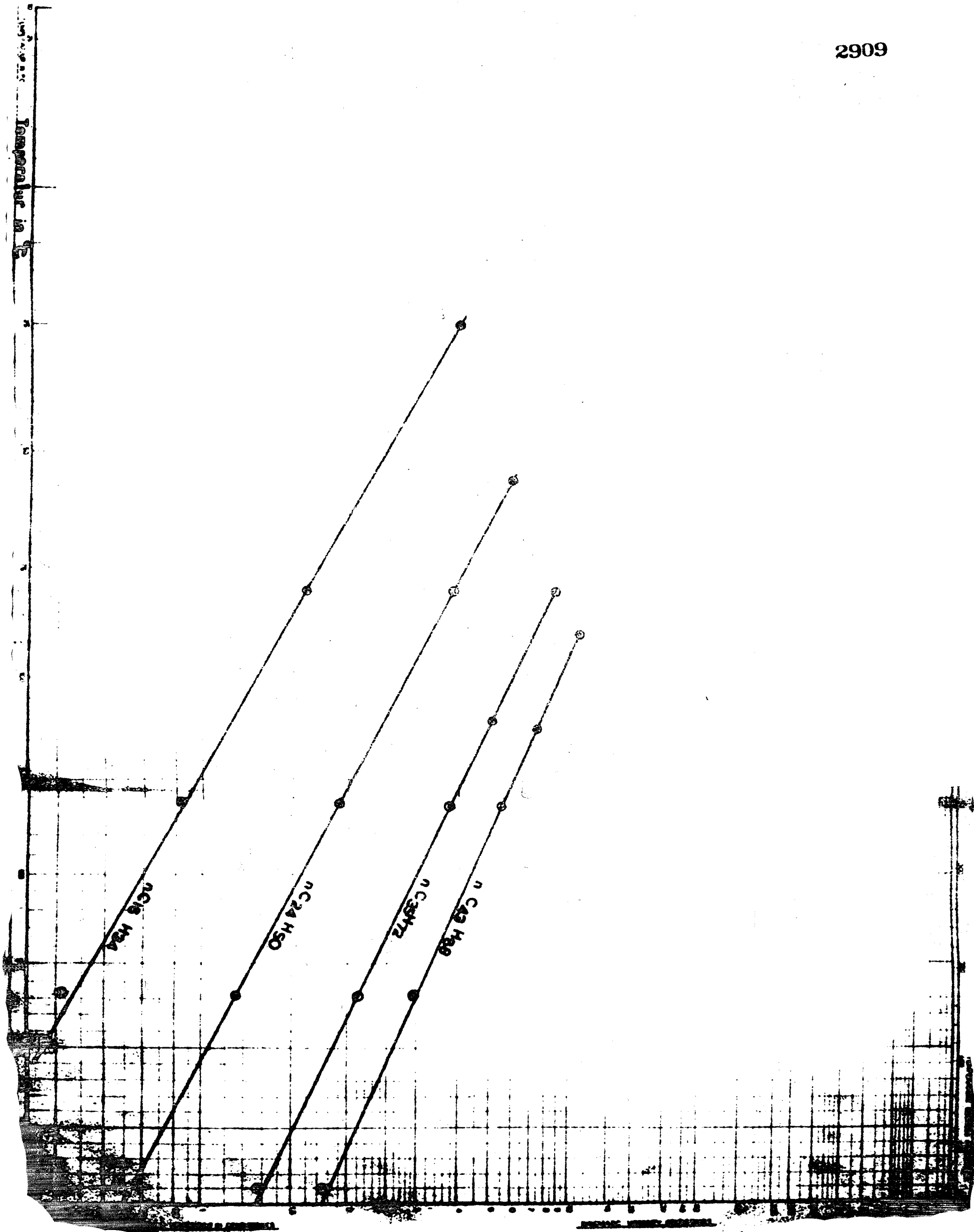
The amounts that the molecular weights calculated by the formula vary from the true value are given in the table below.

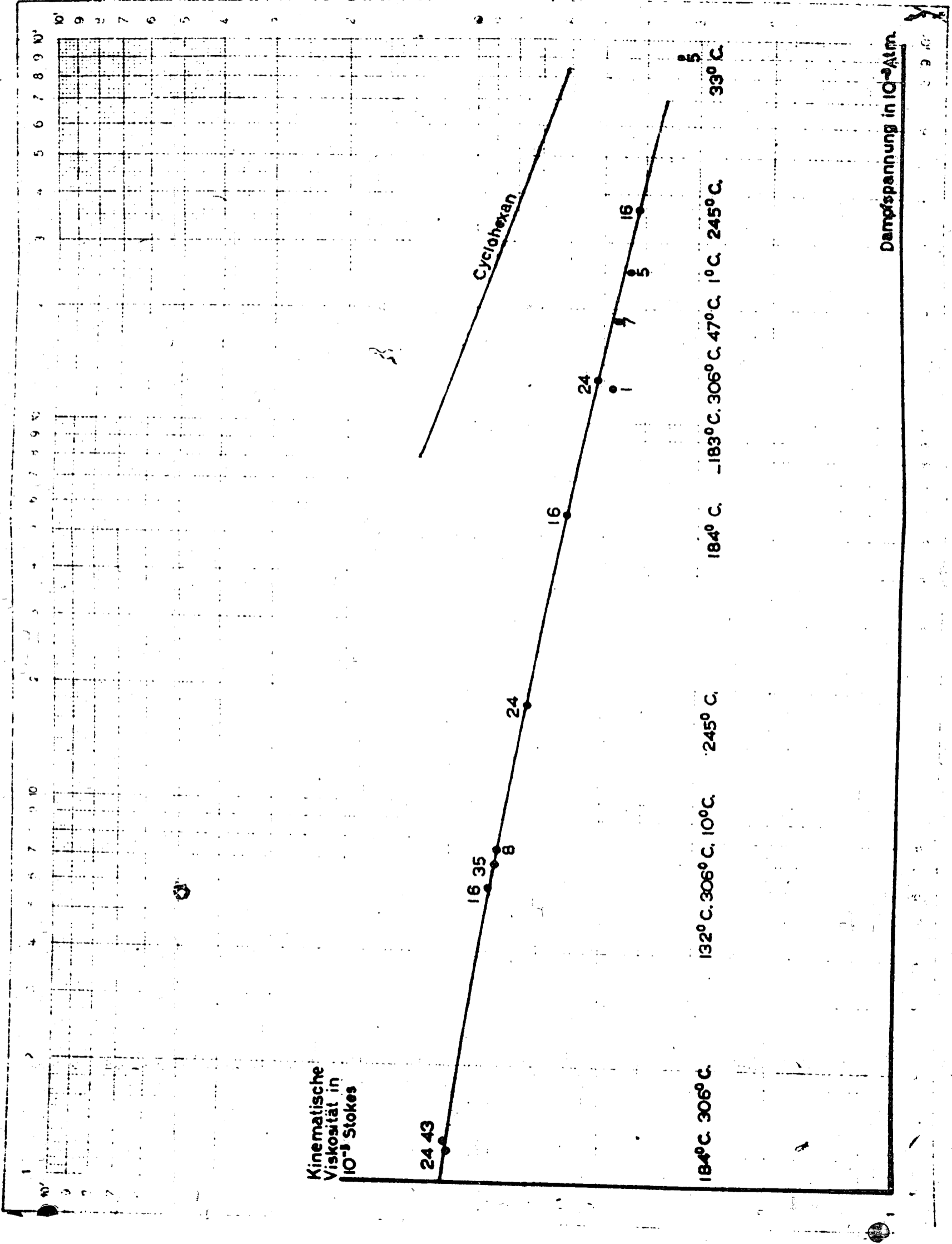
Hydrocarbons	Molecular Wt.	Deviation Formula		
		at 70 C	at 80 C	at 90 C
Heneicosane	296.3	+ 0.1 %	- 0.4 %	- 0.6 %
Tricosane	324.4	+ 0.0	- 0.3	- 0.9
Tetracosane	338.4	+ 0.2	- 0.3	- 0.6
Octacosane	394.5	+ 0.5	- 0.2	- 0.5
Tricontane	422.5	+ 1.6	+ 0.5	+ 0.1
Henricontane	456.5	+ 2.1	+ 1.4	+ 0.4
Tetratriacontane	478.6		- 0.5	- 1.5
Pentatriacontane	492.6		- 0.1	- 0.7
Hexatriacontane	506.8		- 0.2	- 1.0
Tritetracontane	604.7			- 1.0

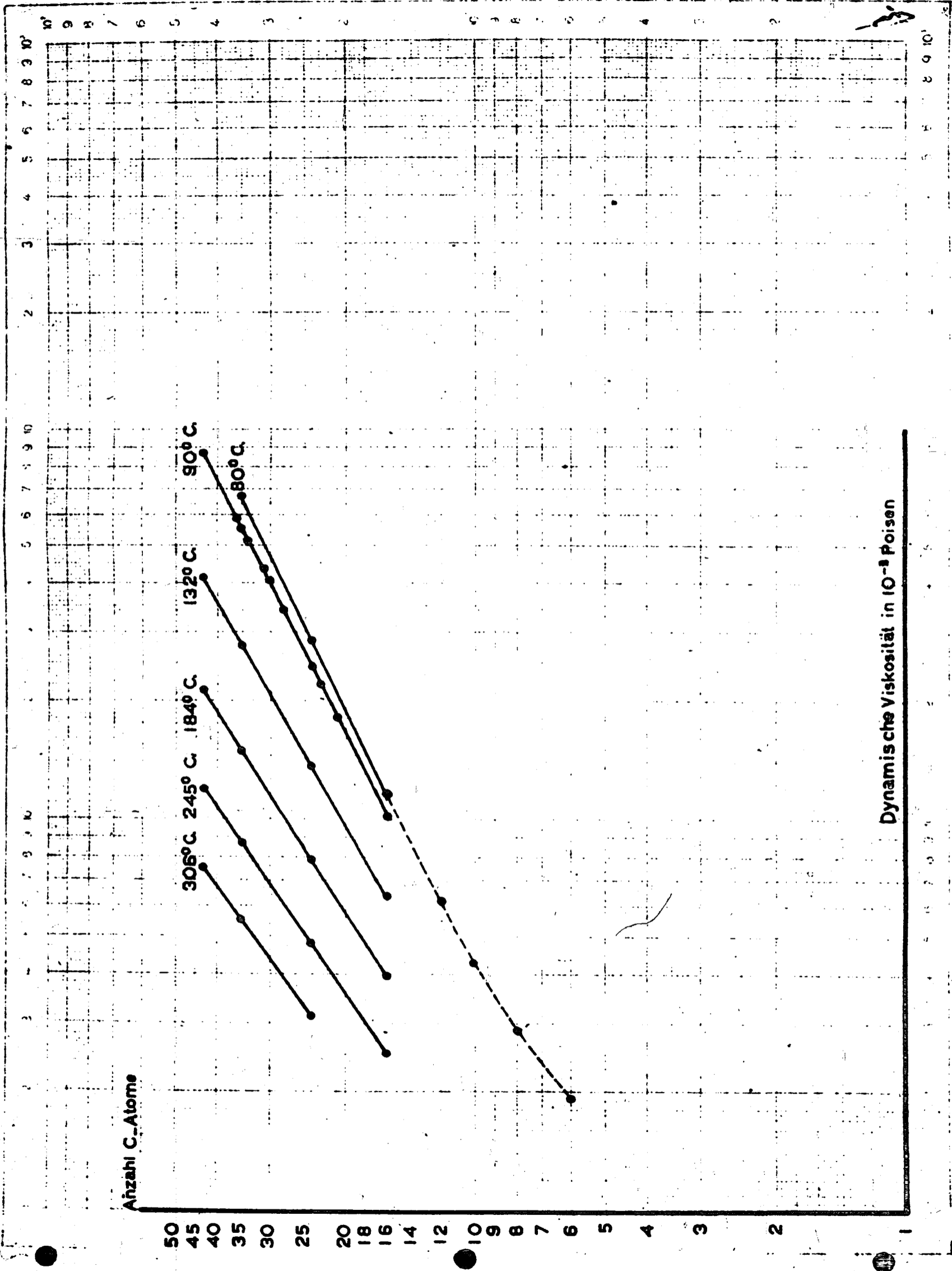
(Continued)

Kinematische Viskosität in Centistokes

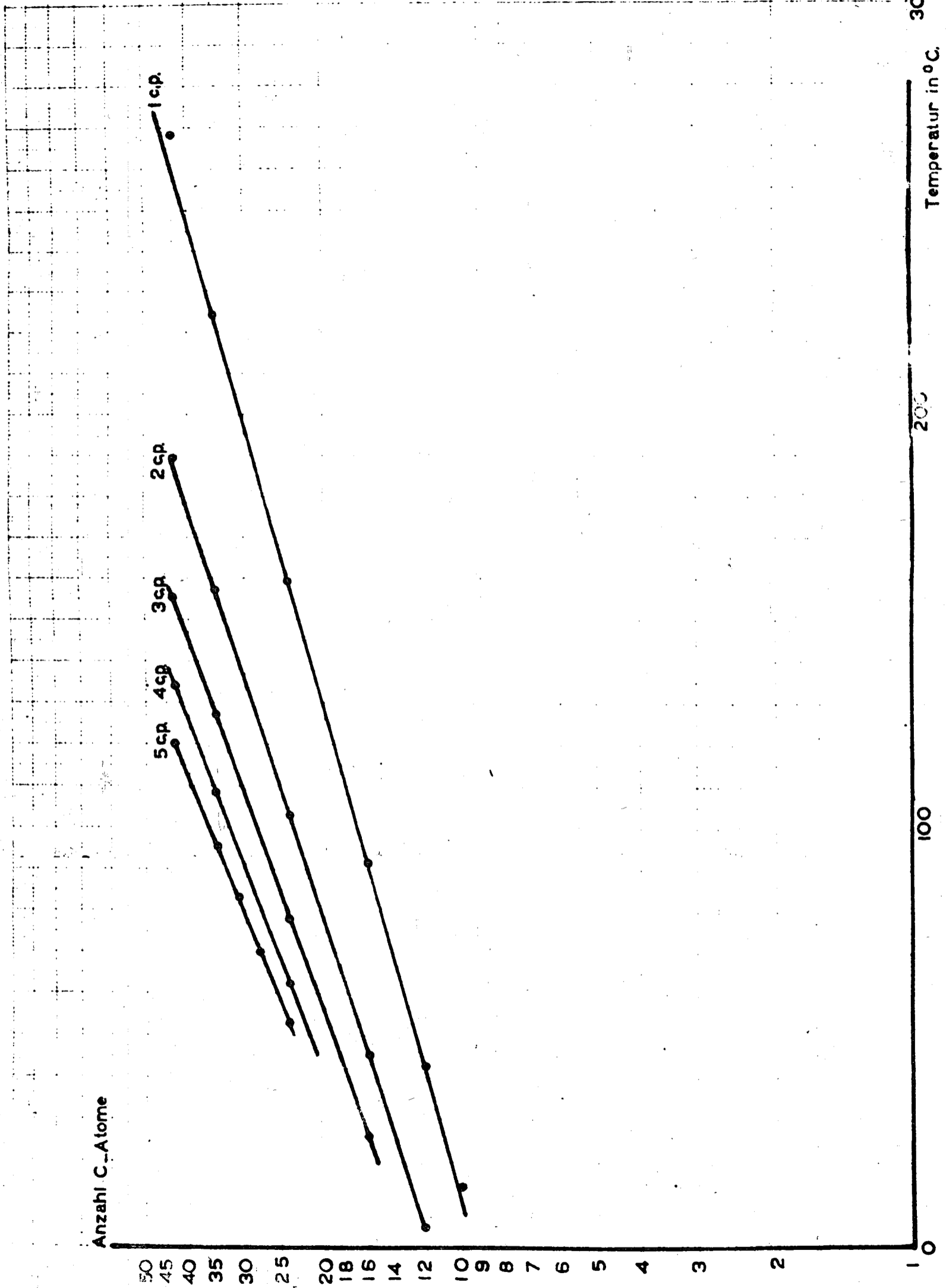
2909







002912



57584-B3

(Continued)

<u>Hydrocarbons</u>	<u>Molecular Wt.</u>					
Hexadecane	226.3	at 25 C	at 80 C	132 C	184 C	
		/ 2.1 %	/ 0.4 %	/ 0.9 %	/ 0.7 %	illegible
Tetracosane	358.4	at 56 C	80 C	132 C	184 C	
		/ 1.4 %	- 0.2 %	- 0.6 %	/ 0.3 %	
Pentatriacontane	492.6	at 80 C	110 C	132 C	184 C	245 C
		- 0.8 %	- 1.9 %	- 1.7 %	0.0 %	/ 2.6 %

If for a single temperature the viscosities of branched paraffins or cyclic hydrocarbons are introduced, the formula gives a graph in which case the viscosity-temperature curve of these hydrocarbons cut the group of curves of normal paraffins. However, it should be borne in mind, that the formula varies considerably for normal paraffins with more than 35 carbon atoms.

CONCLUSION

The viscosities of n-paraffins at higher temperatures are lower than would be expected from a straight line extrapolation on ASTM paper at lower temperature measurements.

The kinematic viscosity from methane up to and including n-tritetracosane at the same vapor pressure are nearly the same.

The viscosity from hexadecane up to and including n-pentatriacontane can be expressed over a wide temperature range in a simple formula.

PLANS FOR FURTHER INVESTIGATION

To measure the viscosity of a few branched hydrocarbons.

May 1943

III-99
2924

INTRODUCTION

In last month's report were mentioned the viscosities up to about 300 C of a few aromatic hydrocarbons and a series of normal paraffins. The only viscosities of aromatic hydrocarbons determined were namely diisobutyl-naphthalene, and in addition the branched paraffin hydrocarbons 5-ethyl-pentane, 10-nonylnonadecane and 7,12-dimethyl-9,10-di-n-hexylactadecane.

The diisobutyl-naphthalene (Sample No. 40/4885) came from Prof.

Wibaut; Ir. Verheus determined $d_{20/4} = 0.9323$ and $n_{20/d} = 1.5413$ (Lerer 1) gives the following numbers: $d_{0/4} = 0.9324$ and $n_{19/d} = 1.5410$.

The 3-ethylpentane, comes from Dr. Keulemans; has a boiling point of 93.5 C (Edgar 2) suggested for it 93.3 C.

Report No. 8975 contains more about the 10-nonylnonadecane of Prof. Backer and about the 7,12-dimethyl-9,10-di-n-hexyloctadecane of Prof. Wibaut.

In order to determine the influence of structure on viscosity, the viscosity of branched paraffins are compared with the normal paraffins. With regard to the structure of 3-ethylpentane (triethylmethane) and 10-nonylnonadecane (trinonylmethane) the comparison may be drawn from some other materials.

SUMMARY OF INVESTIGATION

The densities given below were determined with the help of a 1 cc pycnometer with a long calibrated stem. The viscosities were measured with a falling body viscosimeter.

Density and Viscosity (Falling body) of Diisobutyl-naphthalene $C_{18}H_{42}$

<u>Temp.</u>	<u>Density</u>	<u>Dynamic Viscosity</u>	<u>Kinematic Viscosity</u>
19.9 C	0.9324 g/cm ³		12.40 c.s.
55.8	0.9082	11.26 c.p.	5.23
79.7	0.8915	4.71	1.786
131.2	0.8550	1.527	0.939
183.1	0.8171	0.767	0.565
244.2		0.437	
245.1	0.7723		0.426
293.0		0.316	
293.2	0.7406		

The measured viscosities are much higher than the values given by Lerer, for example 7 c.p. at 54.8 C. III-100
2925

Density and Viscosity (Falling body) of 3-Ethylpentane C_7H_{16}

<u>Temp.</u>	<u>Density</u>	<u>Dynamic Viscosity</u>	<u>Kinematic Viscosity</u>
20.0 C	0.6973 g/cm ³	0.380 c.p.	0.545 c.s.
37.8	0.6823	0.316	0.464

(Continued)

- 1 M. M. Lerer, Ann. Off. Combust. liq. 8, 681 (1933)
- 2 Edgar, J. Am. Chem. Soc. 51, 1483, 1544, (1929)

Density and Viscosity of 3-Ethylpentane (Continued)

<u>Temp.</u>	<u>Density</u>	<u>Dynamic Viscosity</u>	<u>Kinematic Viscosity</u>
50.0	0.6711	0.280 c.p.	0.417 c.s.
65.0	0.6580	0.246	0.373
80.0	0.6441	0.215	0.334

The density and dynamic viscosity at 20 C agree fairly well with the value of Edgar: $d_{20/4} = 0.6984$ and $\eta_{20} = 0.377$.

Density and Viscosity (Falling body) of
10-Nonylnonadecane C₂₉H₅₈

<u>Temp.</u>	<u>Density</u>	<u>Dynamic Viscosity</u>	<u>Kinematic Viscosity</u>
20.0 C	0.8085 g/cm ³		
80.2	0.7691	3.25 c.p.	4.23 c.s.
131.9	0.7357	1.431	1.945
184.1	0.7008	0.799	1.140
245.2	0.6597	0.481	0.729
283.3	(0.654)	0.366	0.577

The viscosities agree well with those in Report No. 8975 for 0-90 C; for 80 C the report gives 3.26 c.p.

Density and Viscosity (Falling body) of
7,12-Dimethyl-9,10-di-n-Hexyloctadecane
C₃₂H₆₆

<u>Temp.</u>	<u>Density</u>	<u>Dynamic Viscosity</u>	<u>Kinematic Viscosity</u>
20.0 C	0.8250 g/cm ³	59.8 c.p.	48.4 c.s.
50.0	(0.805)	11.55	14.35
80.6	0.7833	4.87	6.22
132.3	0.7491	1.839	2.45
184.4	0.7147	0.945	1.319
246.0	0.6733	0.533	0.792
284.3	0.6475	0.391	0.604

The viscosities agree well with those in Report No. 8975 for 40 C and 90 C; the value given therein for 80 C is 4.92 c.p.

The density was measured after a necessary repair and subsequent new calibration of the pycnometer.

The new results are treated in various ways.

1. For valuation of viscosity-temperature curve of hydrocarbons with aromatic nucleus in graph 5773-1-B3 the log of the dynamic viscosities of diisobutyl-naphthalene and the further investigated p-dicetylbenzene, octadecylbenzene and 1,1-diphenylhexadecane are plotted against temperature. For comparison one finds on the same graph the curve for the normal paraffins hexadecane, tetracosane, pentatriacontane and tritetracontane. For p-dicetylbenzene and octadecylbenzene with an aromatic nucleus and long paraffin chain, the influence of temperature on their viscosity is similar over the entire temperature range to the normal paraffins. A greater influence of temperature is noticeable with 1,1-diphenylhexadecane with two aromatic nuclei and especially diisobutyl-naphthalene with two condensed rings outside of the branched paraffin chain.

2. For valuation of viscosity-temperature curves of branched paraffins in graph 5773-2-B3, the logarithms of dynamic viscosity of 10-nonylnonadecane, and 7,12-dimethyl-9,10-di-n-hexyloctadecane are plotted against the temperature. As comparative material one finds on the same graph the curves of the normal paraffins hexadecane, tetracosane, pentatriacontane and tritetracontane. The influence of the temperature on the viscosity is noticeably greater for the branched paraffins than for the normal; least at the lower temperatures. At higher temperatures the difference is not great, over 200 C the curve of 10-nonylnonadecane nearly coincides with the curve of n-tetracosane.

5. The kinematic viscosities of diisobutyl-naphthalene, 10-nonylnonadecane, and 7,12 dimethyl-9,10-di-n-hexyloctadecane are plotted on ASTM paper graph 5773-3-B3. In addition to the values in this report for 10-nonylnonadecane were used the viscosities at 0, 20, 40 and 60 C from Report No. 8975 by Dr. W. M. Mazee.

The viscosity varies slightly from a straight line with both branched paraffins, but only in the sense that at higher temperatures the experimental value is lower, which was also the case with normal paraffins. With diisobutyl-naphthalene, however, the viscosity varied markedly from the straight line. Here the viscosity at higher temperatures was higher than would be expected from the straight line extrapolation from the measurements at lower temperatures.

This was also established in the Oct.-Nov. 1942, Report (See III-33 ff) with Balik Papan oil and Venezuelan oil BD₁ which contains many carbon atoms in ring structure, while from the Report of August 1942 (See III 29 ff) and Sept. 1942 (See III-52), it is seen that the viscosity curves of Elk Bright Stock and synthetic Bright Stock are nearly a straight line on ASTM paper.

4. For the branched paraffins 3-ethylpentane, 10-nonylnonadecane and 7,12-dimethyl-9,10-di-n-hexyloctadecane the logarithms of kinematic viscosities were plotted against the logarithms of the vapor pressure.

The sample of 3-ethylpentane obtained from Dr. Keulmans added the following vapor pressure data: 0.66 atm. at 80 C; 0.40 atm. at 65 C;

0.22 atm. at 50° C. Extrapolation from a log p against 1/T diagram still gives 0.134 atm. at 37.8 C and 0.056 atm. at 20 C. The vapor pressure of both other branched paraffins was taken from Report No. 8975.

Graph 5773-4-B3 shows that the viscosities of the named branched paraffins are somewhat lower than the normal paraffins with the same vapor pressure. This is not the case with all branched paraffins, for example, not with 2,2,4-trimethylpentane whose viscosity was determined by Evans and which lies above this line for normal paraffins in the graph.

The 3-ethylpentane and the 10-nonylnonodecane, which have the same structure give points on the viscosity-vapor pressure graph, from which an almost straight line could easily be drawn.

5. On graph 5773-5-B3 is the viscosity for a large number of hydrocarbons at 80 C plotted against the number of carbon atoms. For the normal paraffins there is a curve which was used for tabulating data for each one with less than 16 carbon atoms (from Evans 3). The isoparaffins and olefins on the table of figures (from Evans 4,5) are indicated by a line, the aromatics and naphthalenes by a point. Heavy (or thick) lines were drawn for 3-ethylpentane and 10-nonylnonodecane and likewise other substances which included oxygen or nitrogen, yet possess a structure with 3 long chains. For tricaprln, trilaurin, trimyristin, tripalmitin and tristearin, the data from Joglekav and Watson⁶ was used, for tri-n-butylamine and tri-n-nylamine, the data from Bingham and Spooner⁷ was used.

From the graph it is evident that on the one hand the viscosities of the hydrocarbons differ from one another and on the other hand the points, which represent the molecules with three long chains lie very regular in relation to the line of the normal paraffins. Branch and ring formations have more influence on the viscosity than a single ester group or a nitrogen atom in a large molecule. The rest of which is made up of carbon and hydrogen. It is difficult to decide whether the influence of the temperature on viscosity is greater for the known triglyceride as well as the trinonylmethane than for the normal paraffins for the measurements of Joglekav and Watson only go up to 85 C, that is about up to the melting point of the like viscous normal paraffins. Moreover the temperature coefficient of the viscosity of tricaprln varies so much from the other triglycerides that such an inaccurate statement should not be used.

CONCLUSIONS

The branch hydrocarbons 10-nonylnonodecane and 7,12-dimethyl-9,10-di-n-hexyloctadecane are at the higher temperatures essentially less viscous than the corresponding normal paraffins. The viscosity-temperature curve, which at room temperature is evidently steeper than that of normal paraffins,

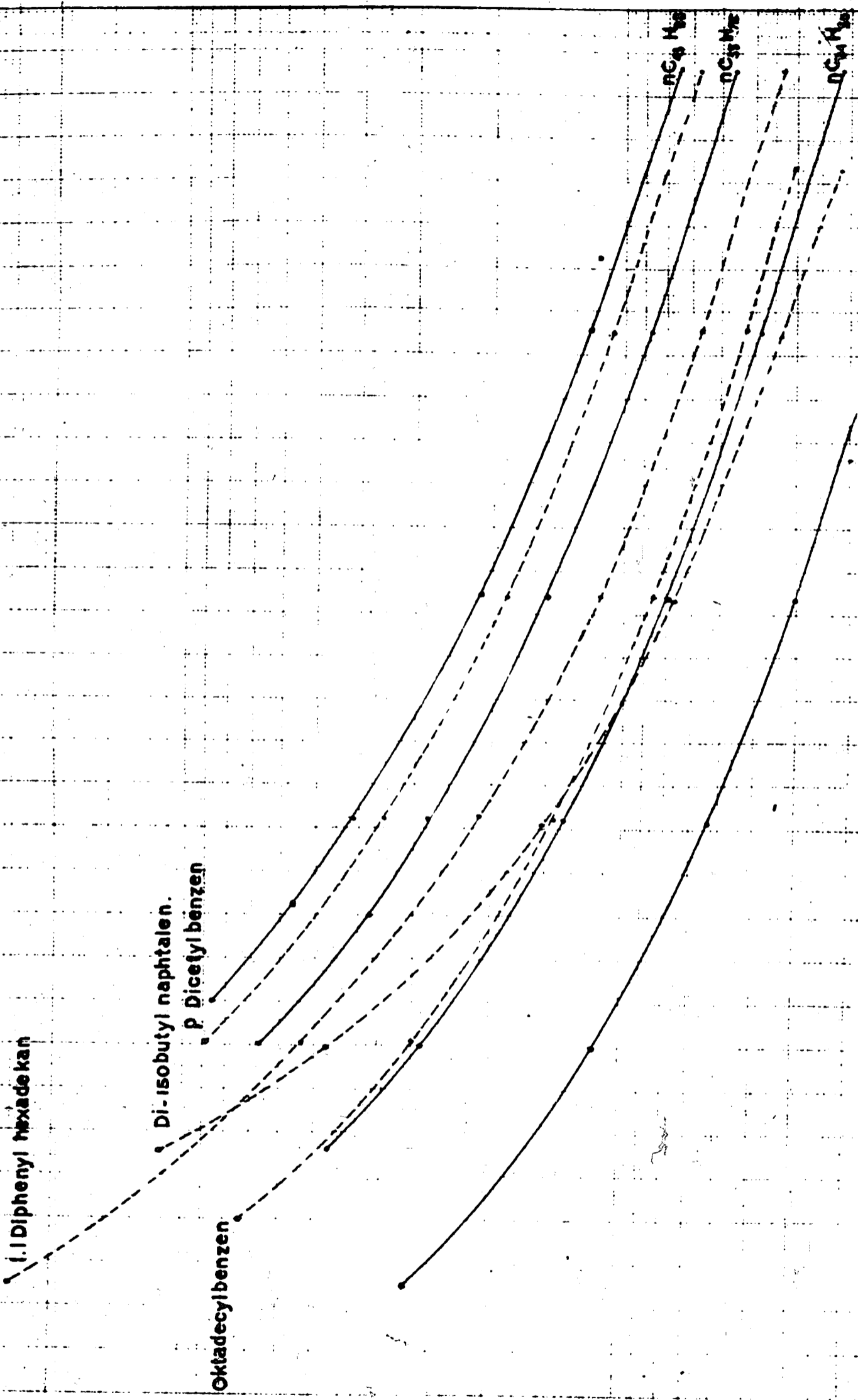
- 3 Evans, J. Inst. Petr. Techn. 24, 38 (1933)
 4 " " " " 24, 321 (1938)
 5 " " " " 24, 537 (1938)
 6 R. B. Joglekav and H. E. Watson, Journ. Soc. Chem. Ind. 47, 365T (1928)
 7 E. C. Bingham and L. W. Spooner, J. Rheology 3, 221, (1932).

002928

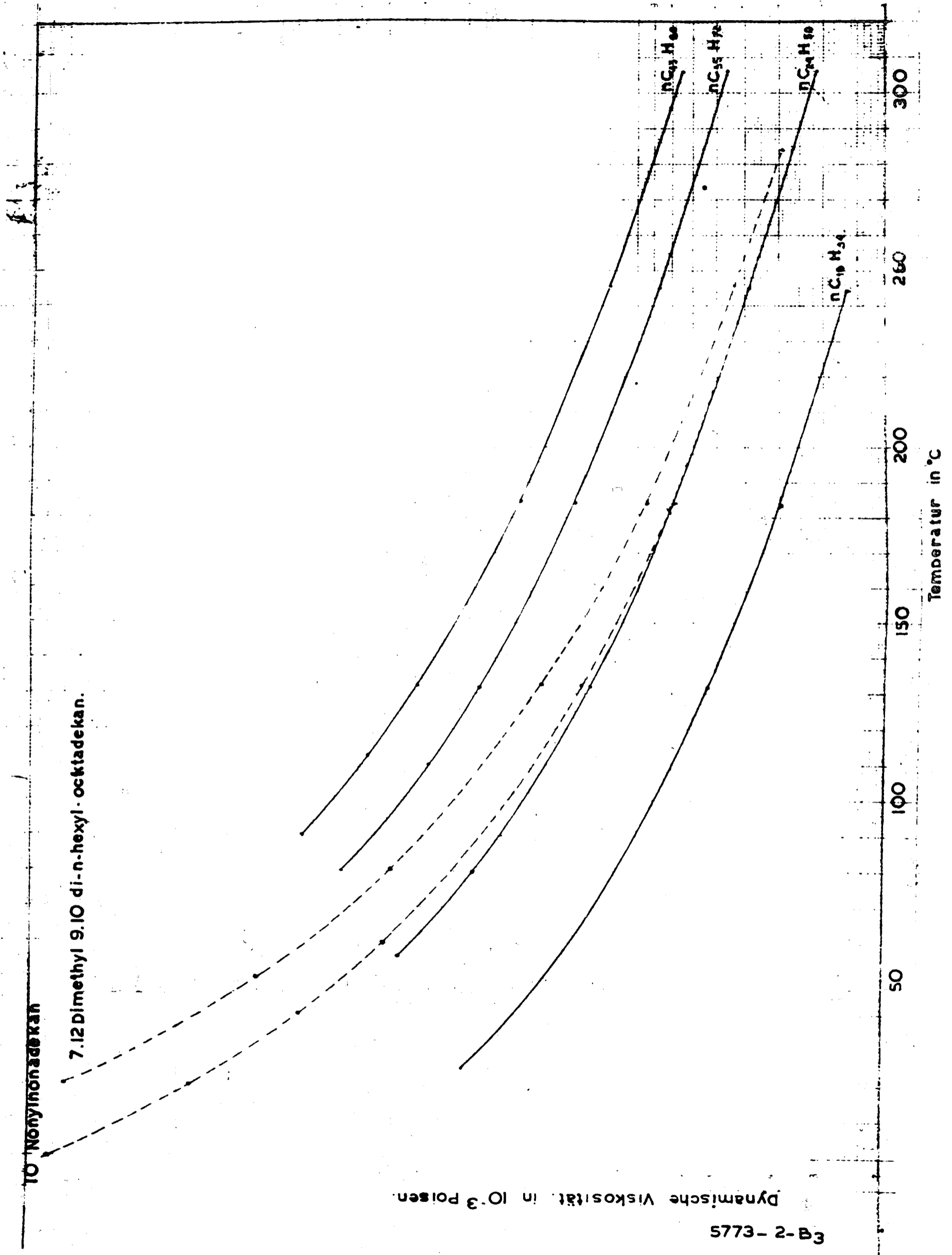
5773-1-B

Dynamische Viskosität in 10^{-3} Poisen.

Temperatur in °C



002929



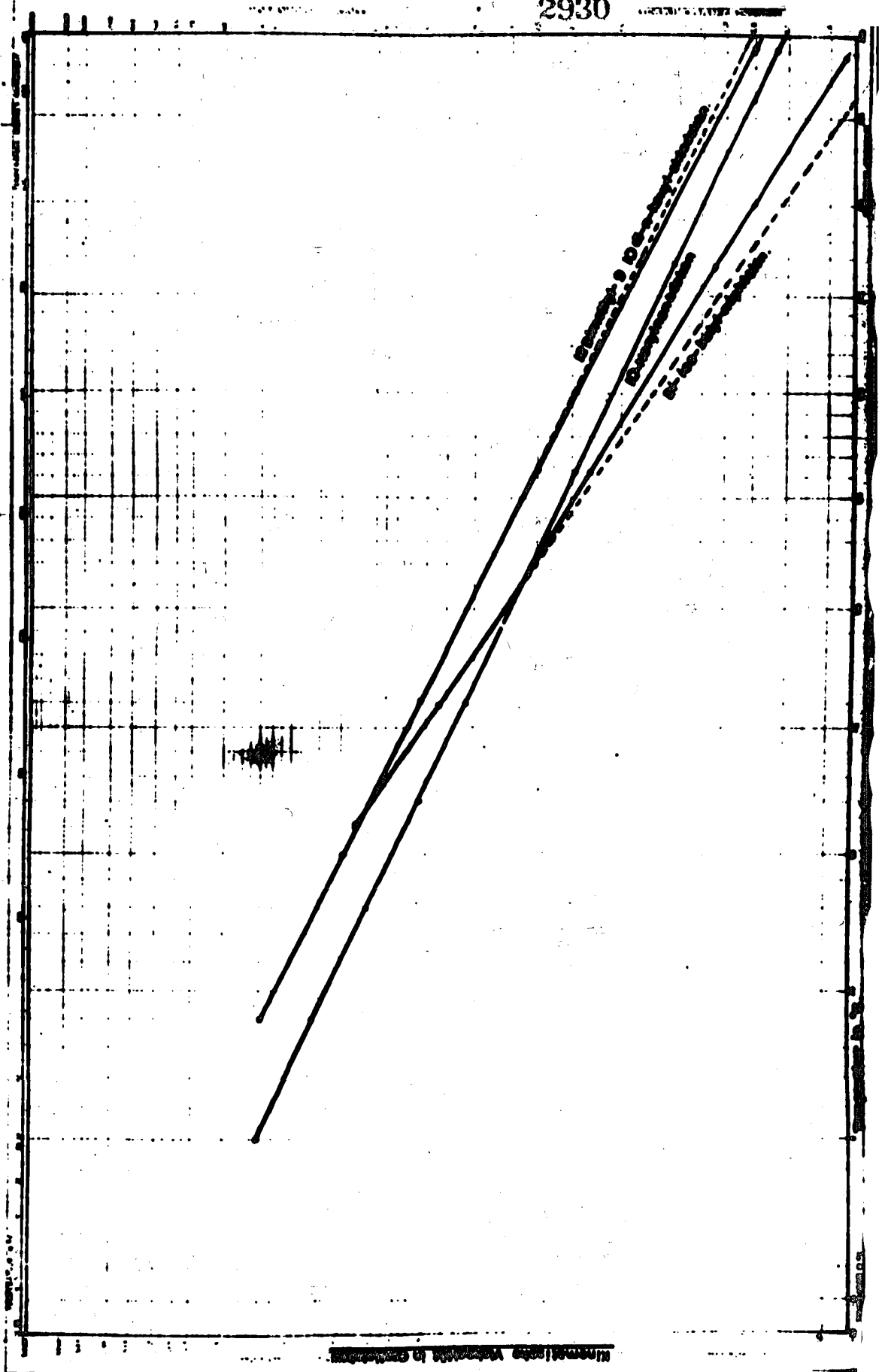
10 Nonylnonadekan

7.12 Dimethyl 9.10 di-n-hexyl-octadekan.

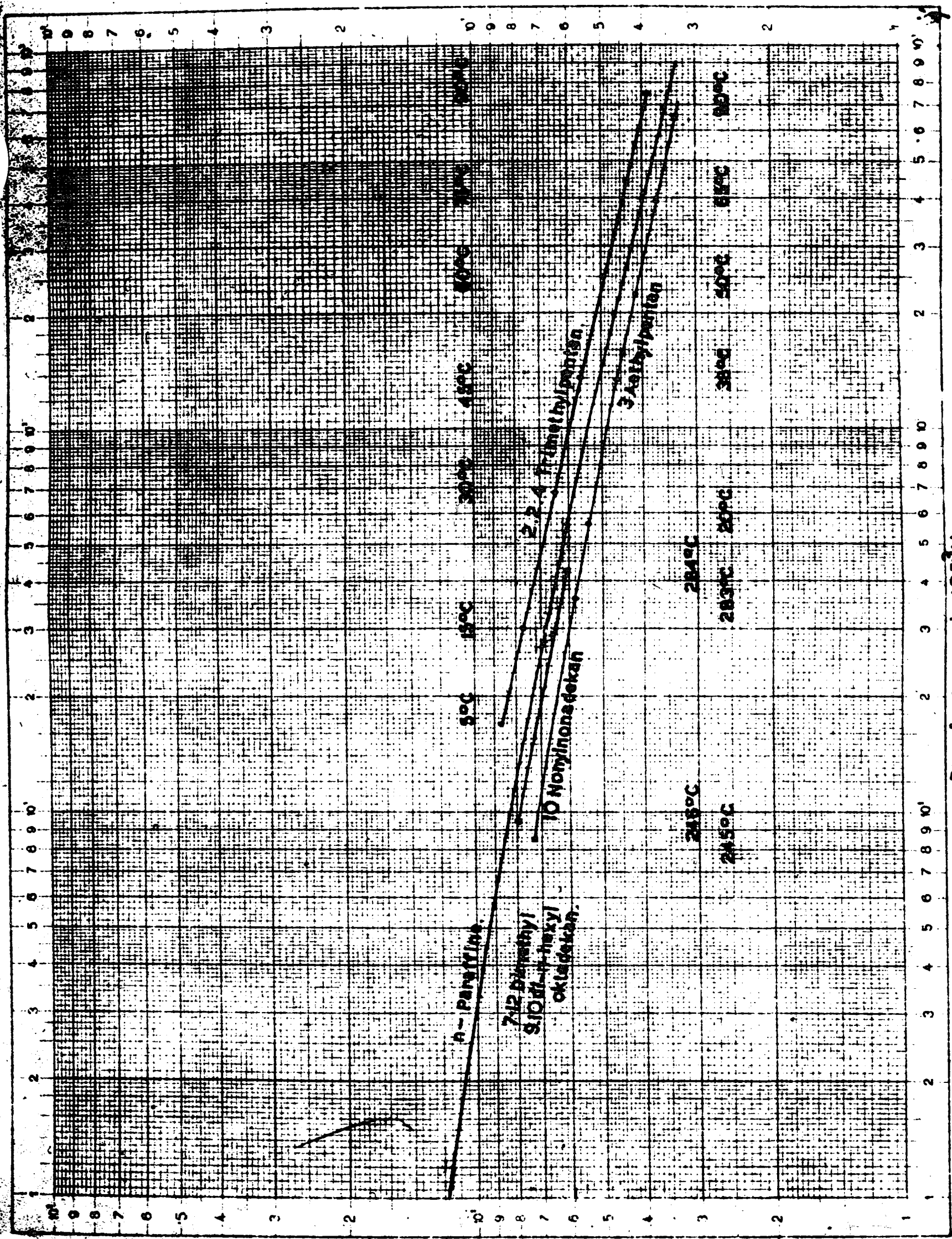
Dynamische Viskosität in 10^3 Poisen.

Temperatur in $^{\circ}\text{C}$

EA-2-475



002931



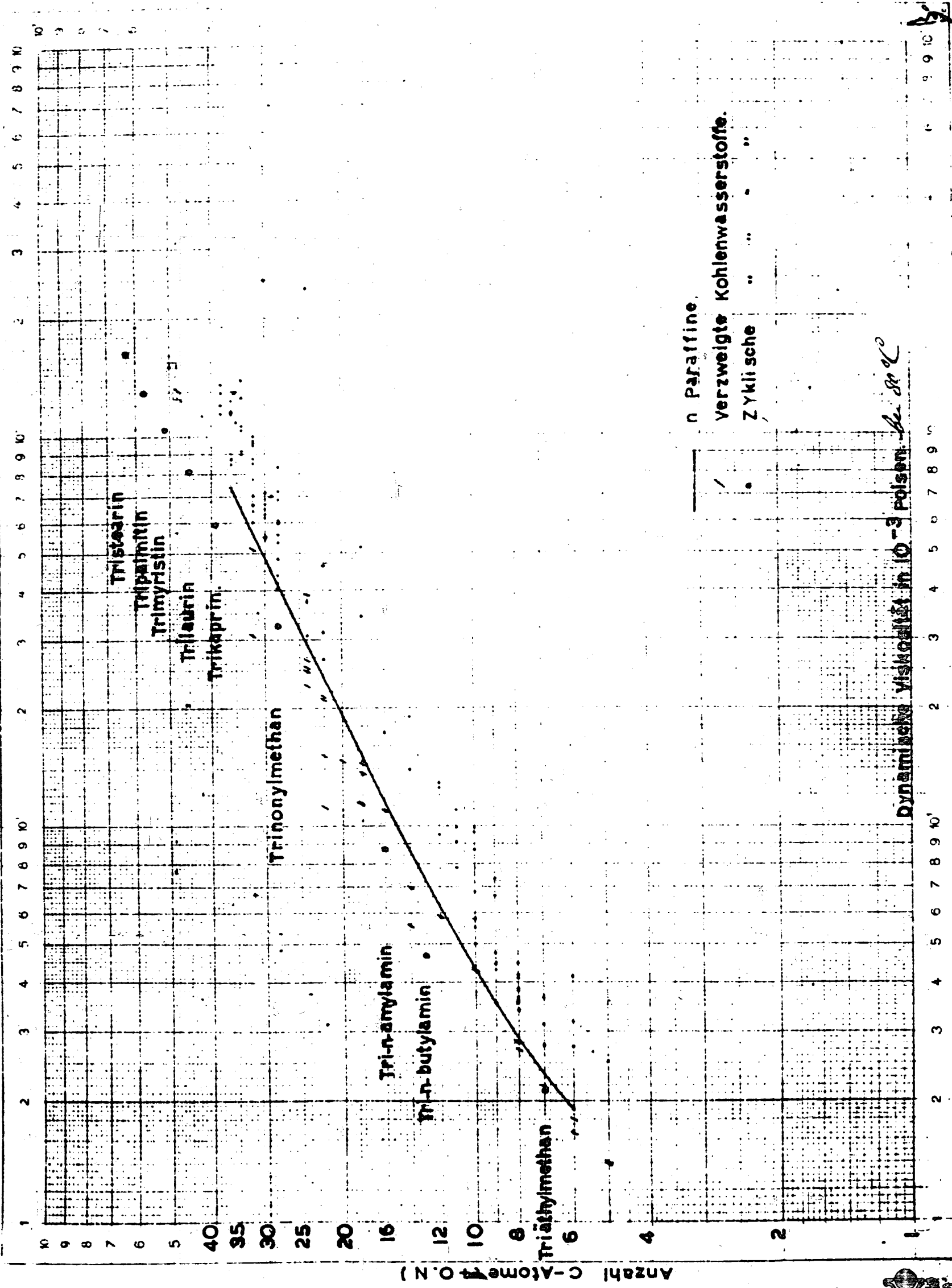
Kinematische Viskosität in 10^{-3} Stokes.

64-4-6775

Dampf spannung in 10^{-3} Atm.

Beide Achsen 1/100 geteilt, eine von 1 bis 100, die andere bis 1000, Einheit 100 mm.

COPYRIGHT GAMBEL-SCHEIDT & CO. INC. - DÜSSELDORF - U.S.A.



n Paraffine.
 verzweigte Kohlenwasserstoffe.
 Zyklische

is not a little higher. So the curve for 10-nonylnonodecane, which at room temperature lies over that of normal $C_{28}H_{58}$, converges at higher temperatures with the curve of $n-C_{24}H_{50}$.

The viscosity of diisobutynaphthylene at the higher temperature is higher than expected from a straight line extrapolation of the measurements at lower temperatures on ASTM paper. 2933

From the investigation of 3-ethylpentane and 10-nonylnonodecane, it is probable that hydrocarbons of this structure with similar vapor pressures have similar kinematic viscosities.

PLANS FOR FURTHER INVESTIGATION

There are still a few branched paraffins on hand to be investigated. Meanwhile Dr. Verberg will test Trioctadecylmethane. The viscosity time of these hydrocarbons, if they can possibly be purchased, will be compared with that of the triglycerides.

III-127
2955

INTRODUCTION

Hitherto only viscosity measurements of hydrocarbons at high temperatures have taken place. In this report that follows, first the information about the acid containing substances will be discussed, after that the further treatment of the hydrocarbon information. This further work included the installation of a new gaging thermometer and the small correction that follows, the conversion to round off temperatures and the ordering of a single diagram.

The acid containing substance, whose viscosity will be discussed, is dicetyether. This ether with a melting point of 52.5-53 C. came from the laboratory of Herrn Dr. Verhaus. Its viscosity was compared with the viscosity of normal paraffins. In this comparison only the lower values mentioned in the literature refer to ether.

SUMMARY OF THE EXPERIMENTS

For all the viscosity measurements an Anschutz thermometer with standard calibrated graduations was used. It had been standardized so that the calibrations had changed very little in the measurements of the past few years. The density and viscosity of the examined substance, based on the new calibrations and corrected to pure grade Celsius, were compiled in a table.

The density was plotted against the temperature in a diagram (Abb. 5800-1-B4), This made a line which deviated only a little from the straight line.

	Temp. in °C	Dichte in g/cm ³	Dyn. Visk. in cp		Min. Visk. in cS	Fluidität in poise ⁻¹	Spez. Vol. in cm ³ /g	
n. Hexadekan	25	(0,771)	3,07	3,09	3,98	32,6	1,297	
C ₁₆ H ₃₄	37,8	0,7621	-	-	-	-	-	
	80	0,7325	1,161	1,167	1,585	86,1	1,365	
	132	0,6958	0,634	0,636	0,911	157,7	1,457	
	184	0,6573	0,397	0,401	0,604	252	1,521	
	245	0,610	0,251	0,253	0,411	398	1,639	
n. Tetrakosan	56	0,7739	4,63		5,97	21,6	1,289	
C ₂₄ H ₅₀	80	0,7602	2,886		3,80	34,7	1,315	
	132	0,7260	1,355		1,866	73,8	1,377	
	184	0,6914	0,789		1,141	126,7	1,446	
	245	0,6495	0,479		0,737	209	1,540	
	306	0,6037	0,313		0,518	319	1,656	
n. Pentatria- kontan	80	0,7781	6,73	6,82	6,81	8,65	14,86	1,285
C ₃₅ H ₇₂	111	0,7587	3,78	3,81		4,98	26,5	1,318
	132	0,7457	2,765	2,769		3,71	36,2	1,341
	184	0,7130	1,493	1,494	1,493	2,09	67,0	1,403
	245	0,6744	0,864	0,868	0,863	1,281	115,7	1,483
	306	0,6337	0,553	0,554	0,552	0,873	180,8	1,578
n. Tritottrakontan	90	0,7809	8,63			11,05	11,39	1,281
C ₄₃ H ₈₈	111	0,7676	5,77			7,52	17,33	1,303
	132	0,7542	4,14			5,49	24,2	1,326
	184	0,7224	2,127			2,94	47,0	1,384
	245	0,6849	1,194			1,743	83,8	1,460
	306	0,6472	0,748			1,158	133,7	1,545
3 Äthylpentan	20	0,6973	0,380			0,545	263	1,434
	37,8	0,6823	0,316			0,463	316	1,466
	50	0,6711	0,280			0,417	397	1,490
	65	0,6581	0,246			0,374	407	1,520
	80	0,6442	0,215			0,334	465	1,552
10 Nonylnon- dikan	20	0,8085	-			-	-	-
	80	0,7693	3,27			4,25	30,6	1,300
	132	0,7355	1,427			1,940	70,1	1,360
	184	0,7008	0,799			1,140	125,2	1,427
	245	0,6594	0,480			0,728	208	1,517
	283	(0,634)	0,366			0,577	273	1,577
7.12 Dimethyl 9.10 di.n. Moxyl- tadukan	20	0,8230	39,8			48,4	2,51	1,215
	50	(0,804)	11,58			14,36	8,65	1,244
	80	0,7837	4,94			6,30	20,2	1,276
	132	0,7492	1,841			2,46	54,3	1,333
	184	0,7149	0,948			1,326	105,5	1,399
	245	0,6755	0,535			0,794	186,9	1,485
	283	0,640	0,394			0,608	254	1,543

002957

III - 12" -

	Temp. in °C	Dichte in g/cm ³	Dyn. Visk. in ap	Kin. Visk. in cS	Fluidität in poise ⁻¹	Spez. Vol. in cm ³ /g
2,2-Dimethyl- n-Dekanon	40	0,7829	8,45	10,79	11,83	1,277
	80	0,7567	3,28	4,33	30,5	1,322
	132	0,9223	1,489	2,06	67,2	1,384
	184	0,6884	0,837	1,216	119,5	1,453
	245	0,6472	0,498	0,769	201	1,545
	283	0,6192	0,379	0,612	264	1,615
1-Methylbenzol	80	0,8145	9,03	11,09	11,07	1,228
	132	0,7810	3,50	4,48	28,6	1,279
	184	0,7491	1,846	2,46	54,2	1,335
	245	(0,710)	1,060	1,493	94,3	1,408
	306	0,6714	0,675	1,005	148,1	1,489
	1-Methylbenzol	40	(0,846)	7,37	8,71	13,57
80		0,8193	3,06	3,73	32,7	1,221
132		0,7844	1,444	1,841	69,3	1,275
184		0,7495	0,850	1,134	117,6	1,334
245		0,7083	0,522	0,737	191,6	1,412
283		(0,662)	0,405	0,594	247	1,466
1-Dimethyl- n-Heptanon	25	0,8070	34,9	38,5	2,87	1,103
	80	0,8112	5,46	6,27	16,32	1,148
	132	0,8365	2,121	2,54	47,1	1,195
	184	0,801	1,136	1,417	88,0	1,248
	245	0,7608	0,666	0,875	150,2	1,314
	306	0,7165	0,431	0,602	232	1,396
1-Methyl- naphthalen	20	0,8323	-	-	-	-
	5	0,8081	11,21	12,34	8,92	1,101
	80	0,8014	4,68	5,25	21,4	1,122
	132	0,8543	1,501	1,757	66,6	1,171
	184	0,8164	0,759	0,930	131,8	1,225
	245	0,7720	0,432	0,560	231	1,295
283	0,7405	0,315	0,425	317	1,350	

The reciprocal of the dynamic viscosity, whose fluidity is plotted against the reciprocal of the density is then plotted against the specific volume. According to Batschinski¹ these would fall in a straight line. That, however, does not apply for hydrocarbons.

It was noticed in this reference that if at the same temperature, yet ascertain and at various pressures (von Wijk and Mitarbeiterin²) the kinematic fluidity was plotted against the specific volume. The hydrocarbons with low molecular weights would give a straight line and the hydrocarbons with high molecular weights would give a curve.

III-130
2958

Recently measurements have been carried out and results obtained for hydrocarbons, now first attention will be given to investigating the acid containing substances namely dicetylother.

The density was measured with the help of a pycnometer of about 1 cm³ with a long calibrated stem, the viscosity was measured with a falling body viscosimeter.

After repair of the steambath with a suitable ground piece; the viscosimeter was calibrated for each measurement the calibration constant was found to be a value of 0.00487, which agreed very well with the earlier found value of 0.00488.

Density and Viscosity for Dicetylother
C₃₂H₆₆O (Falling body)

<u>Temp.</u>	<u>Density</u>	<u>Dyanmic Viscosity</u>	<u>Kinematic Viscosity</u>
56.9 C	0.8067	9.04 c.p.	11.21 c.s.
80.6	0.7908	5.26	6.65
132.2	0.7576	2.282	3.01
184.1	0.7239	1.265	1.747
245.0	0.6842	0.748	1.085
282.6	0.6586	0.571	0.867

After rounding off the temperature
The converted values

56.0	0.8073	9.24	11.45
80.0	0.7912	5.33	6.74
132.0	0.7577	2.298	3.02
184.0	0.7240	1.266	1.749
245.0	0.6842	0.748	1.093
283.0	0.6583	0.569	0.864

1 A. Batschinki, Z, physik. chem. 1913, 84, 63
2 W. R. von Wijk, c.s. Physica 1940, 7, 45

The diagram (Abb 5880-3-B3) compares the viscosity time of dicetyether with the viscosity time of normal paraffins. For n-hexadecane the higher paraffins, the data from this report was used; for the lower paraffins, the viscosity values from Evans¹ tables were employed. Also in the figure are the viscosity values for di-n-amyl ether and di-n-butyl ether (Bingham and Spooner²) and from Von Thorpe and Rodger (3,4), the viscosity values for di-n-propyl ether, di-ethyl ether and ethyl propyl ether are plotted.

III-131
2959

Timmermans and others (5,6) examined various ethers at 15 and 30 C found for di-n-amyl ether 1.188 and 0.992 c.p.; for di-n-butyl ether 0.741 and 0.602 c.p., for di-n-propyl ether 0.448 and 0.376 c.p.; for diethylether 0.279 and 0.247 c.p. The agreement with the first mentioned values is good, with the exception of the yield of the diethylethers. For ethylpropylether Hilditch and Dunstan (7) with 0.5393 c.p. at 25 C found a higher viscosity than Thorpe and Rodger.

From the Figure (Abb. 5800-3-B3) it is clearly proved that temperature slope of the viscosity for the ethers with branched chains is about the same as that for normal paraffins. (Meanwhile the lower ether viscosities are more than the paraffins with a carbon atom.) Di-n-butylether and di-n-amylether are somewhat less viscous and dicetyether has about the same viscosity as the paraffin with the same number of carbon atoms.

The ethers had lower melting points than the paraffins with same number of carbon atoms, for example, di-n-amyl ether -69 C as compared with n-decane -32 C and dicetyether about 53 C, again n-C₃₂H₆₆ about 70 C.

CONCLUSION

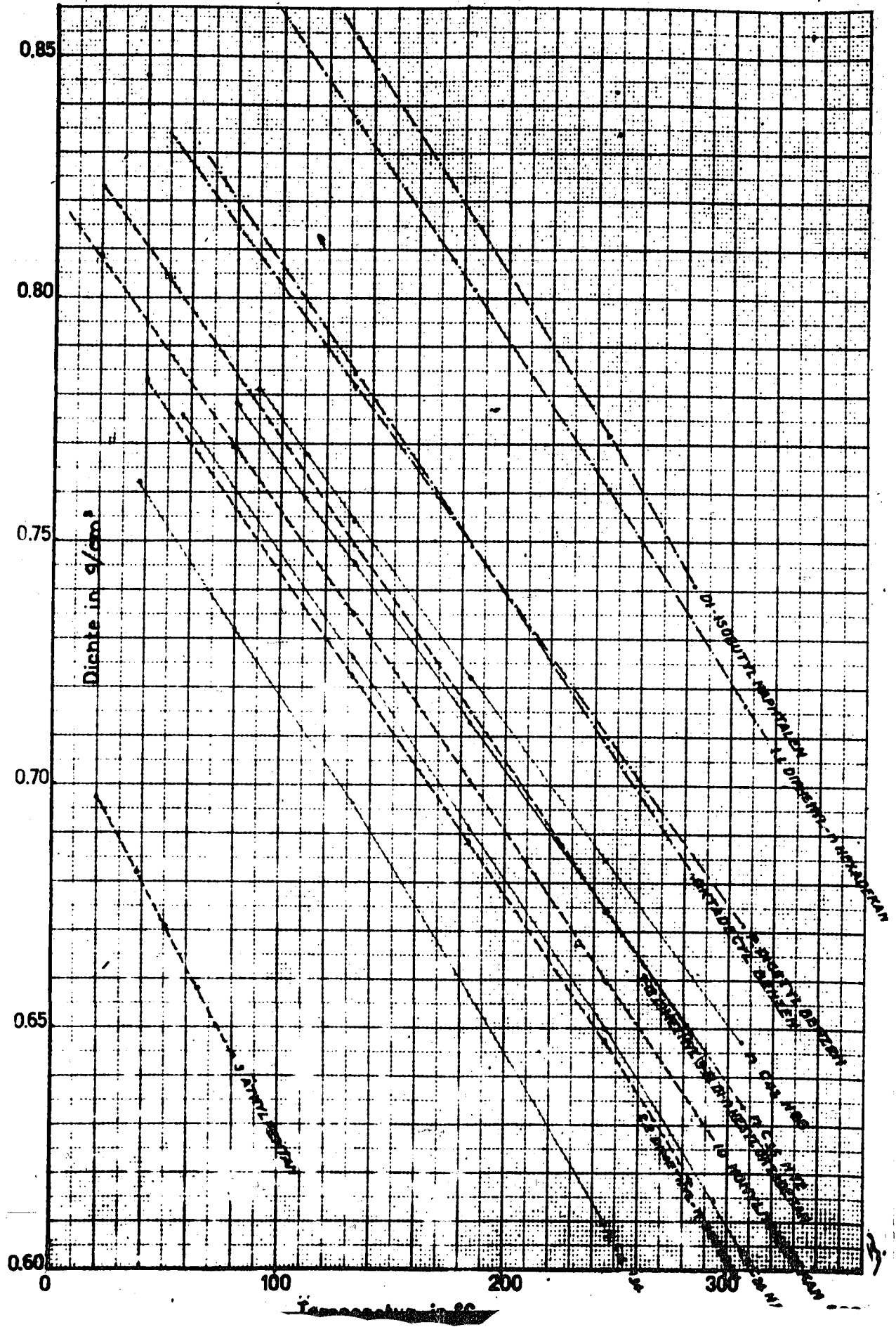
The density of the earlier investigated hydrocarbons follows almost a straight line with the temperature. The fluidity of the same hydrocarbons was plotted against the specific volume, as recommended by Batshinskii, forming lines, which distinctly deviate from the straight line.

The temperature slope of the viscosity for the straight chain ethers is nearly the same as for the viscosity of the normal paraffins.

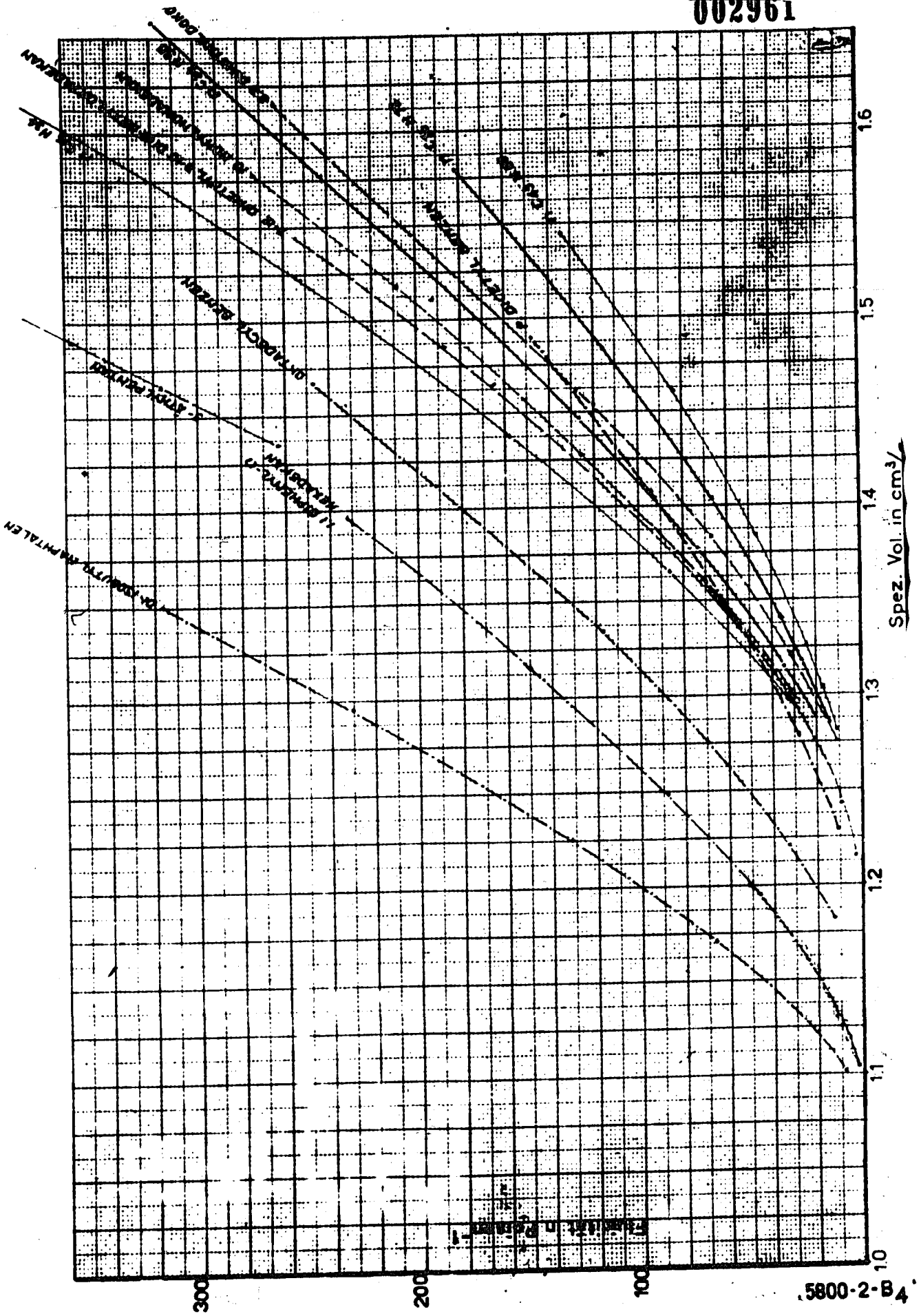
PLANS FOR FURTHER INVESTIGATION

The hydrocarbons concerned must be furnished finally by several synthesis. Dr. Verberg has investigated the existing program with good prospects of success. This synthesis of aliphatic hydrocarbons, with a number of carbon atoms (if possible, consecutive) without hydrogen on account of double or triple bonds, can be added.

1. Evans, J.I.P.T. 24, 38 (1938)
2. Bingham and Spooner, Journ. Rheology, 3, 221 (1932)
3. Thorpe and Rodger, Phil. Trans. 185 A, 397 (1894)
4. Thorpe and Rodger, Phil. Trans. 189 A, 71 (1897)
5. J. Timmermans and F. Martin, Jour. chim. phys. 25, 411, (1928)
6. J. Timmermans and Hennant Roland, Jour. chim phys. 27, 401 (1930)
7. Hilditch and Dunstan, Zt. Elek. Chem. 17, 929 (1911).

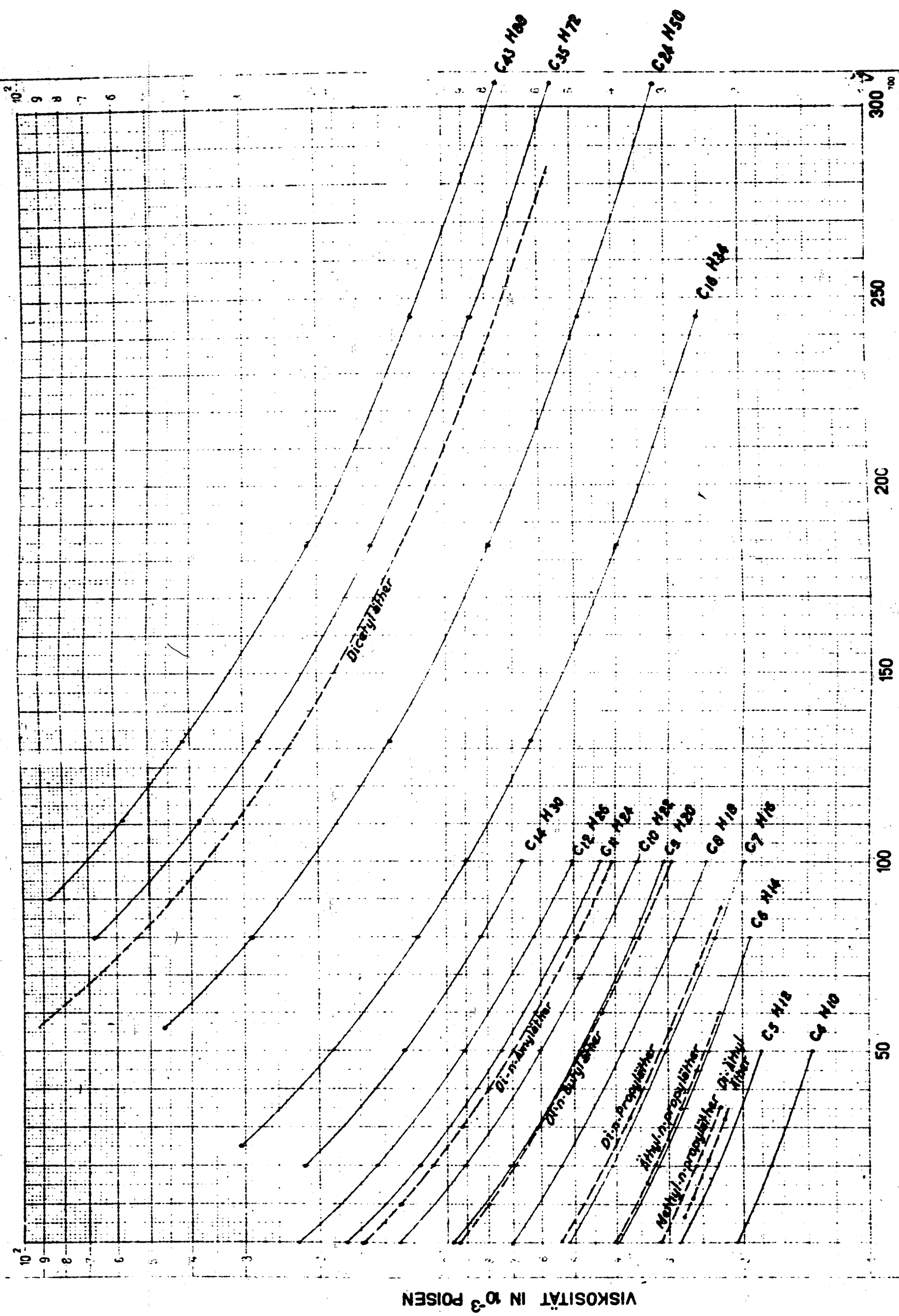


002961



5800-2-B₄

9029f2



In the meantime the investigation of substances, which contain not only carbon and hydrogen but also acid, will be continued. Another determination of the vapor pressure curve for dicetyl ether will be worked on.

2975

INTRODUCTION

The preceding report included the accumulated information on viscosity measurements for hydrocarbons. This information has been greatly enlarged upon. The logarithm of the viscosity was plotted against the reciprocal of the value for the temperature. For the normal paraffins the deviation from the straight line is not very large. This led us to interpolate the viscosity of the paraffins (with help of a method of small quadratic) calculated from the linear relation between the logarithms of the viscosity and the reciprocal of the value of the absolute temperature.

SUMMARY OF THE EXPERIMENT

The viscosity of the twelve investigated hydrocarbons was plotted on hyperbole-logarithm paper. From drawing 5826-1-B4 it is evident that logarithms of the viscosity plotted against the reciprocal values of the temperatures give no straight lines in general. The viscosity time for hydrocarbons over a large temperature range cannot be described with the formula $\eta = a / b/t$. For the normal paraffins the deviation remains such that the formula, complete with a deviation curve, is useful for interpolation purposes.

Using the method of the small quadratic) the following viscosities were computed for n-hexadecane, n-tetracosane, n-pentatriacontane and n-tritetracontane.

n-C ₁₆ H ₃₄	log $\eta = 2.0663 / 758.26/T$
n-C ₂₄ H ₅₀	log $\eta = 2.0316 / 882.81/T$
n-C ₃₅ H ₇₂	log $\eta = 1.9435 / 971.95/T$
n-C ₄₅ H ₈₈	log $\eta = 1.9063 / 1026.46/T$

The differences between the computed values for log η and the experimental values are plotted against the temperature in drawing 5826-2-B4. With the help of the formula and the accompanying deviation curve were the values (of log η and also η) for rounding off temperatures computed.

The figures enclosed in parenthesis in the table are extrapolation from a straight line, whose numbers however were obtained by interpolation. In diagram 5826-3-B2 the logarithms of the viscosities of n-hexadecane, n-tetracosane, and n-pentatriacontane and n-tritetracontane are plotted against the logarithms of their molecular weights. The measuring points for like temperatures are connected by a straight line. The handbook of Engler and Höfer states and Ubbelohde and Aghte agree that the viscosities

TABELLE.

Temp. in °C	n. Hexadekan			n. Tetrakosan			n. Pentatriakontan			n. Tritetrakontan		
	log η	η in cp	$\frac{\eta}{d}$ in cS	log η	η in cp	$\frac{\eta}{d}$ in cS	log η	η in cp	$\frac{\eta}{d}$ in cS	log η	η in cp	$\frac{\eta}{d}$ in cS
20	(0.5360)	(3.44)	(4.45)									
30	0.4410	2.76	3.60									
40	0.3515	2.25	2.96									
50	0.2699	1.862	2.47	0.7210	(5.25)	(6.74)						
60	0.1958	1.570	2.10	0.6290	4.26	5.50						
70	0.1279	1.343	1.817	0.5418	3.48	4.54						
80	0.0852	1.162	1.587	0.4606	2.89	3.80	0.8204	6.74	8.66			
90	0.0073	1.017	1.403	0.3876	2.44	3.24	0.7417	5.52	7.15	0.9363	8.63	11.05
100	0.9540	0.900	1.253	0.3199	2.09	2.80	0.6608	4.58	5.99	0.8504	7.09	9.15
110	0.9038	0.801	1.127	0.2568	1.806	2.44	0.5853	3.85	5.07	0.7690	5.87	7.64
120	0.8563	0.718	1.018	0.1980	1.578	2.15	0.5173	3.29	4.37	0.6873	4.98	6.54
130	0.8110	0.647	0.927	0.1428	1.388	1.908	0.4541	2.85	3.81	0.6302	4.27	5.65
140	0.7682	0.586	0.848	0.0912	1.234	1.711	0.3945	2.48	3.35	0.5668	3.69	4.92
150	0.7273	0.534	0.782	0.0430	1.104	1.546	0.3391	2.18	2.97	0.5071	3.21	4.32
160	0.6877	0.487	0.720	0.9974-1	0.994	1.406	0.2870	1.936	2.66	0.4508	2.82	3.83
170	0.6498	0.447	0.669	0.9542	0.900	1.284	0.2384	1.732	2.40	0.3975	2.50	3.42
180	0.6132	0.410	0.620	0.9132	0.819	1.180	0.1924	1.558	2.18	0.3471	2.22	3.06
190	0.5779	0.378	0.579	0.8742	0.749	1.090	0.1485	1.408	1.906	0.2998	1.994	2.78
200	0.5435	0.350	0.543	0.8362	0.686	1.007	0.1067	1.278	1.818	0.2552	1.800	2.53
210	0.5101	0.324	0.509	0.7997	0.631	0.936	0.0665	1.165	1.674	0.2127	1.632	2.31
220	0.4775	0.300	0.476	0.7644	0.581	0.871	0.0279	1.066	1.549	0.1723	1.487	2.12
230	0.4459	0.279	0.449	0.7301	0.537	0.814	0.9906-1	.979	1.431	0.1334	1.360	1.960
240	0.4149	0.260	0.423	0.6967	0.497	0.761	0.9543	.900	1.327	0.0955	1.246	1.811
250	(0.3849)	(0.26)	(0.401)	0.6641	0.461	0.714	0.9196	.831	1.237	0.0591	1.146	1.680
260				0.6323	0.429	0.671	0.8859	.769	1.156	0.0235	1.056	1.564
270				0.6014	0.399	0.631	0.8534	.714	1.085	0.9993-1	0.976	1.459
280				0.5715	0.373	0.598	0.8216	.663	1.017	0.9559	0.905	1.362
290				0.5418	0.348	0.564	0.7907	.618	0.958	0.9235	0.838	1.275
300				0.5118	0.326	0.535	0.7605	.576	0.905	0.8921	0.780	1.200

Die in der Tabelle eingeklammerten Ziffern sind durch Extrapolation über einige Grade, die übrigen Ziffern durch Interpolation erhalten. Im Diagramm 5826 - 3 - B 2 sind die Logarithmen der Viskositäten von n.Hexadekan, n.Tetrakosan, n.Pentatriakontan und n.Tritetrakontan gegen die Logarithmen der Molekulargewichte aufgetragen worden. Die Messpunkte bei gleicher Temperatur sind durch Geraden verbunden. Die im Handbuch von Engler und Höfer ¹⁾ angegebenen und von Ubbelohde und Aghte herrührenden Viskositäten von n.Tetradekan und n.Oktadekan liegen nicht auf diesen Geraden, die viel rezenteren Messergebnisse von Evans ²⁾ für n.Dodekan aber wohl. Aus den Tabellen von Evans ist weiter ersichtlich, dass die niedrigen Paraffinkohlenwasserstoffe abweichen. Obwohl natürlich nicht feststeht, dass die Viskositäten höherer Homologen wohl auf den Geraden liegen werden, haben wir diese doch nach

¹⁾ Engler-Höfer, Das Erdöl 1910, Vol. I, Seite 33.

²⁾ E. B. Evans, J.I.P.T. 24 (1950), 38.

of n-tetradecane, n-octadecane do lie on a straight line and according to recent measurements of Evans¹¹ the same applies for n-dodecane. From the tables of Evans it is also evident that the lower paraffin hydrocarbons may. Although it has not been established that the viscosities of the higher homologs probably lie on a straight line, we have drawn these out for the higher molecular weights, because we could use that diagram for the purpose of valuating the viscosity time of other substances.

CONCLUSION

Through the most technical research we had found that for the normal paraffins of dodecane and tritetracontane there exists a linear association between viscosity and molecular weight.

PLANS FOR FURTHER INVESTIGATION

The viscosity time for various substances will be estimated with the help of drawing 5826 3-B2. The investigation of several esters, which has already started, will be finished.