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A Method for the Estimation of The Aromaticity of Aviation Gasolines

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ABSTRACT

This report is aimed primarily at the weaknesses of its predecessor, NRL Report No. P-1872 which describes a method for aromatic analysis by refractive index measurements. The method described herein is unique in that unsaturated (olefin) hydrocarbons offer no interference to the aromatic determination. Allowance is made for the variations in base stocks and aromatic types among the many aviation fuels, so that up to 30% aromatics accuracy of $\pm$ 0.5% may be expected.

The technique involves only two measurements, i.e., the refractive index of the unknown and the refractive index of the liquid effluent from a column of activated carbon (or, where unsaturates are not present, silica gel). The entire analysis requires only four or five minutes and results are reproducible even among unskilled operators.

TABLE OF CONTENTS

Subject	Page
I. INTRODUCTION	1
(a) Authorization	1
(b) Statement of Problem	1
(c) Previous Work Done on the Problem	1
(d) Known Facts Bearing on the Problem	2
(e) Theoretical Considerations	2
II. DESCRIPTION OF METHOD	2
III. METHOD	6
IV. VERIFICATION OF METHOD	7
V. DISCUSSION	7
VI. ANALYSIS OF AROMATICS IN HYDROCARBON MIXTURES CONTAINING OLEFINS	8
BIBLIOGRAPHY	
APPENDICES	
Adsorption Characteristics of Silica Gel	Table I
Analysis of Blends of Aromatics with Non-Aromatic Hydrocarbons and Aromatic-Free Gasoline Base Stocks	Table II
Analysis of Commercial Aviation Fuels	Table III
Analysis for Aromatics in Several Unsaturated Blends	Table IV

I. INTRODUCTION

(a) Authorization

1. This investigation was conducted under Project Order 91/43 and especially authorized by Bureau of Aeronautics letter Aer-E-436-BES, JJ7G1, NP14, Serial No. 077596 of December 6, 1941 to the Director of the Naval Research Laboratory.

(b) Statement of Problem

2. The acute need for a simple accurate analytical method for determining aromaticity of aviation gasoline has arisen with the beginning of the current World War. Since then, this country, as well as our Allies, to which American planes are sent have resorted to aromatic-enriched fuel not only because of the superior rich-mixture characteristics it provides but also because of its greater availability from foreign refineries. However, since the design of aircraft fuel systems, gasoline storage and delivery systems, etc. are predicated upon the aromaticity of the fuel in that system, some measure of aromatic control must be imposed upon the gasoline used therein.

Many different systems have since been suggested for control procedure in determining aromaticity. Most of the methods present disadvantages either in that they are inaccurate, cumbersome, or are not adaptable to cover the many types of gasoline available. All known methods fail in the presence of unsaturated hydrocarbons which fact entails a separate analysis of the unsaturates (which by any existing method is itself uncertain) in order to correct the apparent aromatic value. This is due to the intermediate position the olefins occupy between the aromatic and paraffin hydrocarbons in all physical properties, e.g., solubility in picric acid, refractive index, polarity, specific dispersion, density, etc., upon which the various analytical procedures have been based.

(c) Previous Work done on the Problem

3. NRL Report No. P-1872 which consists of Part I of this investigation deals with a method based on the refractive index differential of the gasoline. While the underlying principle of the method was proved to be well founded both theoretically and experimentally, its usefulness was diminished chiefly by the interference of unsaturates. This report comprises Part II and describes a method which accomplishes the elimination of the error in determining aromatics due to the presence of unsaturates in the blend. Besides this very important consideration the following improvements have been made in the technique. 1 - Elimination of the preliminary (H_2SO_4) extraction, 2 - Absolute certainty in obtaining the refractive index of the base stock, 3 - Quick and simple conversion of weight percent to volume percent. In view of the fact, however, that the basis of the improved method is the same as the old,

it is believed appropriate, in the interest of clarity and continuity, to include in this report the theoretical discussion and general description of the method as outlined in Part I, since in both instances the same argument applies.

(d) Known Facts Bearing on the Problem

4. Refractive index measurements have been widely used by analysts to determine various constituents of gasoline including its aromatic content. It is well known that the refractive index of a given paraffinic or naphthenic gasoline increases with the aromaticity, giving at low aromatic concentrations very nearly a straight line when aromaticity is plotted against refractive index. However, because of unpredictable differences in composition (and therefore refractive index) of the various base stocks of different gasolines, the refractive index vs. aromaticity curves, as shown in Plate 1, are from the standpoint of analytical value, uncertain and even meaningless.

(e) Theoretical Considerations

5. It is obvious, from a study of Plate 1, that the only possibility of analysis of a gasoline by its refractive index is to construct curve from the base stock of that gasoline with known amounts of aromatics added, and from the resulting curve find the aromaticity of the unknown. It would be extremely difficult and time consuming to separate the aromatics from each sample of gasoline presented for analysis and construct such a curve from which to read the aromaticity of the unknown whole gasoline. An easier and more satisfactory method lies not in the use of a nA (refractive index vs. aromaticity) curve but a f(n)A (some function of refractive index vs. aromaticity) which will be independent of variations in base stock and thus give the same curve for any gasoline. The fact that all nA curves are the same general shape at low aromatic concentrations (i.e., very nearly straight lines) regardless of the composition of the base stock simplifies the problem and justifies the investigation in that direction.

II. DESCRIPTION OF METHOD

6. It is seen from Plate 1 that there are two fundamental differences between the nA curves of the various base stocks: (1) variation in displacement from the abscissa axis and (2) variation in slope.

7. The first of these variations arises from the difference in refractive index of the various base stocks. That is, a curve resulting from a series of known aromatic mixtures made from a base stock having a refractive index of 1.3850 would be closer to the abscissa than one constructed from a base stock with a refractive index 1.3950, provided, of course, the same coordinates were used in both cases. This variation is easily eliminated by plotting the change in refractive index of the gasoline before and after removal of the aromatic portion against aromaticity or $(n_x - n_b)$, where n_x and n_b = refractive index of unknown and

base stock respectively. Thus, all curves begin at the origin (when $a = 0$, $n = 0$) and at the same time are independent of any constituent in the base stock. Plate II shows the four nA curves of Plate 1 plotted as $(n_x - n_b)A$ or ΔnA.

8. It is evident from Plate 2 that nA curves do not account for the second variation mentioned above, i.e., variation in slope, which also accompanies differences in refractive index of the base stock. It is easily seen that as the refractive index rises, the flatter (more horizontal) will be the resulting nA and ΔnA curves; so that as in the extreme case, when the refractive index of the base stock approaches that of the aromatics, the nA and Δ nA curves become horizontal.

9. This variation in slope may be corrected by plotting the change in refractive index Δn divided by the greater possible change or $\frac{n_x - n_b}{n_a - n_b}$* where n_x equals the refractive index of the unknown and n_a and n_b are the indices of the aromatic portion and base stock, respectively. When this is done, it is found that all of the resulting curves are the same. Plate 4 shows the same four curves shown in Plates 1 and 2 plotted using the function mentioned. It is seen that up to 40% very little deviation is found.

10. Thus far, nothing has been said of the nature of the aromatic portion and the effect of variations therein on the index of the unknown. The individual role played by each of the three principal aromatic hydrocarbons, benzene, toluene and the xylenes (found in aviation fuel) on the refractive index of a given base stock is shown in Plate 3.‡ (Inasmuch as these three hydrocarbons constitute 80 - 100% of the aromatic portion of most gasolines they have been chosen as the basis of this study. Others, including ethylbenzene, tertiary butylbenzene, etc., are given a superficial consideration in Table II). Up to 25% aromatics any of these three hydrocarbons may be determined accurately to + 0.5% simply by reading all values off a mean curve midway between curves 1 and 3 on Plate 3. Thus, as an approximation, a mean curve from Plate 3 may be used in the determination of any of the three aromatics mentioned or a mixture of them in any proportion without serious error. Inasmuch, therefore, as only one curve is needed for the estimation of aromaticity of any mixture of the three hydrocarbons, the entity n_a in the formula mentioned above becomes a constant and equal to the refractive index of the aromatic blending stock used to produce the mean curve. Thus, the time consuming and difficult task of recovering and purifying the aromatics in order to measure their refractive index becomes unnecessary. It is seen from Plate 3 that the curve for toluene very nearly represents a mean curve, and may well be used as such, in which case $n_a = 1.4922$. However, in this work the aromatic blending stock composed of 37.5% xylene, 50% toluene, and 12.5% benzene which gave a refractive index = 1.4918 was used and which value is substituted for n_a in Plate 4.

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* A similar empirical relationship has been found by McArdle, et al, in their analysis of paint thinners. (1)

‡ - The use of cumene (isopropyl benzene) as a blending agent in certain aviation gasolines necessitated a consideration of this hydrocarbon in this respect. It was found that the cumene curve very nearly superimposes the toluene curve and, therefore, no error need be anticipated from the presence of that hydrocarbon in the unknown.

11. This function $\frac{n_a - n_b}{1.4918 - n_b}$ holds only for percentage aromatics by weight. If volume percentage is desired, it can be obtained from a knowledge of the densities of the unknown and its base stock at the same temperature at which the refractive indices were measured and calculated from the formula as shown

$$\text{Vol. } \% = \frac{Va}{Vx} = \frac{Vx - Vb}{Vx} = \frac{\frac{100}{Dx} - \frac{100 - \text{Wt. } \%}{Db}}{\frac{100}{Dx}}$$

where Va, Vx, and Vb are volumes of aromatics, unknown and base stock, respectively; Dx and Db are densities of unknown and base stock.

A careful study of the above formula reveals a much simpler and equally accurate procedure for conversion of weight percent to volume percent. If we assume a constant density of the aromatic portion, then for a given gasoline d_x is dependent upon d_b making only one independent variable in the equation; d_b, in turn, is directly proportional to n_b so that by knowing n_b we can easily find the volume percent/weight percent ratio. This relationship is plotted in Plate 13. The possibility of a varying aromatic density, resulting from varying proportions of the different aromatic hydrocarbons present cannot be denied but calculations show that any error resulting from this assumption is so small that it can be neglected. The ratio of weight percent and volume percent of the majority of aviation fuels falls around .81 - .83.

12. In order to measure n_b, or the refractive index of the base stock of the unknown, it is evident that the aromatic portion must be completely removed from a sample of the gasoline while the paraffinic and naphthenic hydrocarbons are left intact. Successful results have been reported in the quantitative removal of aromatic hydrocarbons from aromatic-paraffin-naphthene mixtures when the components of such mixtures have closely the same vapor pressures by percolation of the sample through a column of activated silica gel (2). While the method, as reported, is successful on binary or ternary mixtures, its adaptation to gasolines requires certain modifications. When the gasoline is passed through the silica gel column, the gel is progressively wetted by gasoline and absorption process raises the temperature of the gasoline in that vicinity to a noticeable extent. When typical aviation gasolines are percolated through the silica gel, the temperature of the front of the liquid column will rise above the boiling point of some of the components of the gasoline, e.g., isopentane, b.p. 28° C. Inasmuch as these low boiling constituents also have low refractive indices, the first 2 to 5 cc of filtrate from the column will have a high refractive index, apparently due to the removal by fractional distillation of the lower boiling (and lower refractive) constituents of the gasoline. Due to this fractionation the index of refraction of this first portion will be up to .004 units higher than the true base stock resulting in an error in the analysis of 3.0% if this figure were used as n_b. However, as soon as the wetting process is complete this fractionation ceases and the next portion of gasoline passing through the column provides the correct refractive index reading for the base stock.

Therefore, if sufficient volume of gasoline is passed through the gel, the error in refractive index, due to the fractionation resulting from the heat of wetting and adsorption is eliminated. The solution to this problem, however, introduces another. It is evident that silica gel will eventually become saturated with aromatics so that further adsorption cannot take place and effluent gasoline rapidly approaches the aromaticity of the unknown. These two facts make it apparent that the correct refractive index for the base stock can only be measured after the fractionated portion has passed and before the aromatic fraction arrives. This reading is extremely difficult to make if the gasoline contains over 25% aromatics, since the "hold-up" of gasoline in the interstices of the gel is approximately equal to the volume of aromatic-freed gasoline, so that it becomes extremely hazardous, using the technique outlined in Part I, to choose a portion for index measurement free from contamination from one source or the other. In Part I the separation of highly aromatic gasolines was accomplished only by a preliminary extraction with 98% sulfuric acid previous to the silica gel percolation in order to remove most of the aromatic portion and thus provide a wide fraction of the true base stock without contamination from either the fractionated portion or from the aromatic bearing portion of the effluent gasolines.

13. By a slight alteration in technique from the old scheme, not only may the refractive index of the base stock be more accurately and surely determined, but the preliminary H_2SO_4 extraction becomes unnecessary even on gasolines containing as high as 40% aromatics. The scheme is as simple as it is effective. If the effluent liquid is allowed to flow directly into the refractometer in 1 cc (or any small arbitrary volume) portions (by using the apparatus shown in Plate 6) the point at which the refractive index becomes constant, i.e., the refractive index of the base stock free from contaminants is easily observed. The curves shown in Plate 7 clearly demonstrate this.

14. It is seen from Table I that silica gel shows no preferential adsorption capacity for any of the common naphthene or paraffin hydrocarbons found in the gasoline range, at least insofar as can be detected by the Abbe refractometer. By allowing a mixture of naphthenes and aliphatics to percolate through a silica gel column the change in refractive index is less than 0.0001 unit. Had any one of the constituents of the mixture been removed, wholly or partially, from the mixture, the index of the effluent would have changed in a direction governed by the index of the selectively removed hydrocarbons. Thus, any change in refractive index of a gasoline (free from unsaturates) when passed through silica gel according to the condition outlined above must be solely due to the adsorption and removal of aromatics and olefins.

15. Silica gel removes the dyes, inhibitors, and the part of the lead tetraethyl* from the gasolines. However, when these constituents are added back to the extracted gasoline in their original concentrations, it is found that they exert no influence (in those concentrations) upon the refractive index of the gasoline base stock to 0.0001 unit.

* Extreme caution should be exercised in handling the spent silica gel and in regenerating it. The adsorbed lead tetraethyl is extremely toxic and suitable precautions should be exercised to avoid physical contact with the used gel.

16. The silica gel used in this work was Davison Chemical Corporation, Baltimore, Maryland, No. 659528-2000, 28-200 mesh, stabilized at 650° F. When not in use the gel should be kept in a moisture proof container. The used gel may be reactivated by washing several times with hot water or steam to remove the hydrocarbons, and then heating at 300° C for 24 hours.

III. METHOD

17. (a) Determine the refractive index of the unknown in a thermostatically controlled refractometer capable of giving readings accurate to 0.0002 refractive index units. (The well-known Abbe type is satisfactorily provided it is standardized at appropriate intervals).

(b) Arrange the apparatus shown in Plate 6 so that delivery from the siphon empties into the small channel leading to the split prisms of the refractometer. The apparatus should be mounted separately from the refractometer in order that the prisms may be wiped dry between readings.

(c) Add about 40 cc of the sample to the reservoir of the adsorption tube in the assembly shown in Plate 6, 6a, 6b, and 6c and allow the liquid to filter through the column.

(d) Record the refractive index of each delivery of filtrate from the siphon cup.

(e) Using the lowest constant refractive index as that of the base stock substitute, the values n_x and n_b in the formula $\frac{n_x - n_b}{1.4918 - n_b}$ locate the resulting value on the curve shown in Plate 4 (or a similar curve prepared by the analyst from known mixtures) from which the weight percentage of aromatics may be read directly.

(f) If volume percent is required it may be obtained by finding the correct ratio of volume percent/weight percent on the curve shown in Plate 13 corresponding to the refractive index of the base stock, and multiplying the weight percent by that ratio.

18. The work done in this report was carried out at 25° C*. The refractometer was thermally controlled by circulating water from a bath controlled to ± 0.1° C. An Abbe type refractometer with a compensating drum accurate to .0001 unit, was used with a small 7.5 watt incandescent lamp as a light source. When refractometers without compensating drums are used, the Sodium D line is most readily available. Since the refractometer used in this work was calibrated for the Na_D line, the curves given in this report are valid for that wavelength. These conditions, however, are purely arbitrary and were only chosen for convenience. The important consideration is that whatever set of conditions are used to construct the curve from known mixtures, the same set must prevail when using that curve for the analysis of an unknown mixture.

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* This temperature was used because the high humidity sometimes occurring in the Washington, D. C. area causes fogging of the prisms at 20°C.

IV. VERIFICATION OF METHOD

19. Tests were run using known samples prepared from aromatic-free base stocks varying in refractive index from 1.3676 to 1.4245. The aromatic blending stocks used consisted of pure aromatic hydrocarbons and mixtures of the hydrocarbons as given in the tables. All aromatic percentages were read off the curve on Plate 4, and the results are shwon in Table II. Table III shows the results of analyses of several commercial blends of gasolines. The composition of the base stocks and the aromatic fraction are not known.

V. DISCUSSION

20. It is well known from the classic laws of refraction that the refractive index of each component of an ideal solution contributes directly to the index of the mixture according to the concentration of each component, so that if a refractive index-concentration curve is plotted a straight line will result. It is seen in Plate 1 that the base stock aromatic solutions are very nearly ideal up to about 30% aromatics inasmuch as the nA curves approximate straight lines. Now, if we assume for the moment that the mixtures dealt with in Plate 1 are ideal at all concentrations, the curves would appear as shown in Plate 5 where the curves have been extended to the 100% aromatic ordinate meeting at the common point $n_a = 1.4918$ which is the refractive index of the aromatic blending stock used in the mixtures. Considering any one of these curves shown on Plate 5 we find that if from any point (n_x, X) on the curve, a line is extended perpendicularly to the na and nb axes that we define two similar triangles A and B. From the geometry we see that:

$$\frac{n_x - n_b}{(n_a - n_b)-(n_x - n_b)} = \frac{x}{100 - x}$$

or, on rearranging

$$(100 - x)\ (n_x - n_b) = x(n_a - n_b) - x\ (n_x - n_b)$$

and

$$100\ (n_x - n_b) - x\ (nx - nb) = x\ (n_a - n_b) - x\ (n_x - n_b)$$

it is seen that the second and fourth terms cancel each other giving

$$x = \frac{n_x - n_b}{n_a - n_b} \times 100$$

which is the function derived experimentally.

Actually, the curves shown in Plate 1 do not approach the value 1.4918 via a straight line. If the curves of Plate 1 are extended along straight lines in the direction of the first two points of each curve, it will be found that they converge not at 1.4918 but at a point on the 100% aromatic ordinate approximately equal to 1.4700. Now, by reason of the fact that the curves of Plate 1 are very nearly straight lines at low concentrations and that they converge at a point on the

100% axis when extended, the geometrical argument presented above still holds at low concentrations in the actual case as well as in the theoretical. (It is suggested that the difference between 1.4918 and the theoretical value of convergence 1.4700 is due to either association or resonance of the aromatic molecules at high concentrations. If these two phenomena played no part at high concentrations, i.e., the solutions were ideal, or even in the pure aromatic hydrocarbon the value would approximate the latter value). When this value ($n_a = 1.4700$) is used in the function $\frac{n_x - n_b}{n_a - n_b}$, the resulting curves shown in Plate 4 is a 45° angle as predicted from the geometrical argument. When 1.4918 is used as n_a the curve is somewhat flatter due to the larger factor in the denominator of the function making $\frac{n_x - n_b}{n_a - n_b}$ not equal to but directly proportional to the aromaticity. The value of the refractive index of the blending stock is perhaps less convenient to use but it is easier and more accurately determined.

VI. ANALYSIS OF AROMATICS IN HYDROCARBON MIXTURES CONTAINING OLEFINS

21. Up to this point the preceding discussion has been confined to a review of the general scheme of the analysis as applied to saturated stocks only, together with theoretical and experimental proof. By reason of the fact that silica gel removes not only aromatics but also olefins, both being somewhat polar, it is apparent that the function Δn is dependent upon two independent variables, the amount of aromatics present and the concentration of olefins. It is obvious then that silica gel is unsuitable as an adsorbent for aromatic analysis when olefins are present.*

22. If silica gel allowed the olefins to filter through with the rest of the paraffinic-naphthenic base stock, removing only aromatics, then obviously the presence of olefins would not interfere and Δn would be dependent only on the aromaticity. The presence of olefins in the base stock could not interfere with the argument presented in the first part of this report since the effect on n_D of all fractions except the aromatic fraction cancel out in the function Δn_D. Thus, the problem of adapting the method to the analysis of aromatics in the presence of olefins reduces itself to finding an adsorbent that removes aromatics only, allowing olefins, naphthenes and paraffins to pass through unaffected.

23. Adsorption of aromatics and olefins by an adsorbent is, apparently, dependent upon two factors; first, the polarity of the aromatic or olefinic molecule, and second, the surface energy of the adsorbent. Since aromatic molecules are more polar than olefinic molecules by reason of their greater unsaturation, aromatic hydrocarbons are, in general, more strongly adsorbed by a given adsorbent.(3)

Activated charcoal designated as Special Adsorbent Carbon "A" has a surface energy sufficient to adsorb aromatics but has very little affinity for olefins. That is, the material quickly becomes saturated with olefins long before aromatics begin to pass. Plate 8 depicts the comparison

* 1% unsaturates in the mixture is projected as about .22% error in the aromatic analysis when silica gel is used as the adsorbent.

of SiO_2 and Carbon "A" on a blend containing 72% isooctane, 8.0% diisobutylene and 20.0% aromatics* by volume. Here, using the Carbon "A", the base stock plateau is clearly established and corresponds to the refractive index of the isooctane-diisobutylene mixture. The only plateau resulting from the SiO_2 extraction corresponds to the refractive index of the isooctane alone. Plate 9 shows the course of the carbon extraction when the blend contains 8.33% of a mixture of pentene-1 and penetene-2, both of which have refractive indices lower than isooctane, causing the curve to fall to the plateau rather than rise to it as was the case when diisobutylene was under consideration.

24. Plate 10 compared SiO_2 and Carbon "A" on the course of the adsorption of an unsaturated mixture, the base stock being a mixture of cyclohexane and methyl-cyclohexane. It is evident that naphthenes do not interfere with the analysis.

25. When no unsaturates are present in the fuel, either silica gel or the Carbon "A" may be used to extract the aromatics. In this case silica gel is the better adsorbent of the two since it has a greater affinity for aromatics. This fact is borne out in Plate 11. In view of the decreased activity of Carbon "A" over SiO_2, it is necessary to dilute highly aromatic samples (greater than 20%) with some known amounts of an aromatic-free base stock in order to obtain a recognizable plateau on the curve, after which the aromaticity of the original sample may be easily calculated.

Plate 12 illustrates the base stock plateau of a typical aviation gasoline, with the same aromaticity as that shown in Plate 11 except that it contains 8.33% olefins. It is interesting and instructive to compare Plates 11 and 12 with respect to the two adsorbents on aromatic gasolines, one containing olefins and the other being olefin-free. The excellent result obtained by Carbon "A" in either case is contrasted by the marked failure of silica gel to tolerate unsaturates in the analysis.

26. The procedure for aromatic analysis of gasolines containing olefins follows that described in Part III of this report with one alteration. The silica gel adsorbent is replaced with Special Adsorbent Carbon "A" and sieved to 60 - 100 mesh size. In the event the gasoline contains aromatics in such quantity that the carbon becomes saturated before a constant base stock refractive index is obtainable, the sample must be diluted with an aromatic-free paraffinic base stock, isooctane, or some other paraffinic hydrocarbon or mixture in the gasoline range. A dilution by half cuts the aromaticity of most gasolines to the range suitable for the capacity of the adsorbent.

* 1,3,2,1 ratio of benzene, toluene, xylene and cumene, respectively.

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TABLE I

Referred from paragraph #15 showing the non-specificity of SiO_2 gel in adsorbing typical paraffin and naphthene hydrocarbons.

Hydrocarbon	% in Mixture	n^{25}
n-hexane	25.76	1.3731
iso-octane (2,2,4-trimethyl pentane)	30.63	1.3891
neo-hexane	24.28	1.3675
cyclohexane	12.88	1.4237
methyl cyclohexane	6.44	1.4205
mixture before SiO_2 percolation	99.99	1.3858
mixture after SiO_2 percolation		1.3858
n-heptane	24	1.3855
iso-octane (2,2,4-trimethyl pentane)	24	1.3889
cyclohexane	24	1.4237
triptane (2,2,3-trimethylbutane)	28	1.3869
mixture before SiO_2 percolation	100	1.3959
mixture after SiO_2 percolation		1.3959

TABLE II

Analysis of Blends of Aromatics with Hydrocarbons
and Aromatic free Gasolines

Sample No.	Components Base	Components Aromatics	Prepared Wt % Aromatics	$N_{25°C}$	$(\frac{\Delta n}{Na - Nb})_{25°C} \times 10^3$	Det'n. Wt. % Aromatics	Difference, percentage determined minus percentage prepared	n_b
6	100 O.N.+	Benzene	24.8	1.4095	200	24.5	-0.3	1.3889
8	"	"	25.9	1.4107	212	25.8	-0.1	
17	"	A.B.S.*	13.4	1.4002	110	13.6	+0.2	
18	"	"	28.6	1.4133	237	28.7	+0.1	
19	91 O.N.++	"	4.9	1.3930	39.8	4.9	0.0	1.3889
20	"	"	1.3	1.3900	10.7	1.3	0.0	
21	"	"	8.5	1.3958	68.0	8.4	-0.1	
15	A.S.T.M. Naphtha	A.B.S.	8.62	1.3929	69.0	8.6	-0.02	1.3856
11	"	"	4.96	1.3898	39.7	4.9	-0.06	
16	"	"	14.78	1.3982	119.0	14.8	+0.02	
10	"	"	21.6	1.4044	178.0	21.9	+0.3	
7	Cyclohexane	"	5.52	1.4273	40.4	5.0	-0.52	1.4245
12	"	"	3.32	1.4261	22.5	3.0	-0.32	
13	"	"	12.03	1.4310	95.8	11.8	-0.23	
14	"	"	20.63	1.4355	163.5	20.2	-0.43	
26	100 O.N.	Toluene	13.33	1.4003	107.7	13.2	-0.13	1.3893
27	"	"	27.11	1.4118	220.3	27.2	+0.09	

(Continued)

Na = 1.4918

+ Conforming to Army - Navy Specification AN-VV-F-781, Current Delivery to NAS, Anacostia, D.C.

* Aromatic Blending Stock, Benzene 12.5%, Toluene 50%, Xylene 37.5% by volume.

++ Conforming to Army - Navy Specification AN-VV-F-776, Current Delivery to NAS, Anacostia, D.C.

Sample No.	Components Base	Aromatics	Prepared Wt. % Aromatics	N25°C	$\left(\frac{\Delta n}{Na - Nb}\right)$ 25°C x 10^3	Det'n. Wt. % Aromatics	Difference, percentage determined minus percentage prepared	nb
28	100 O.N.	Xylene	6.14	1.3947	52.8	6.5	+0.36	
30	"	"	3.70	1.3927	33.2	4.1	+0.40	
31	"	"	2.47	1.3915	21.5	2.6	+0.13	
32	Neohexane	Benzene	25.28	1.3928	202.8	25.2**	-0.08	1.3676
33	"	Toluene	24.91	1.3938	210.9	26.1	+1.19	
34	"	Xylene	24.90	1.3939	210.9	26.1	+1.20	
35	"	A.B.S.	6.5	1.3742	53.1	6.6	+0.1	
36	"	"	12.9	1.3814	111.1	13.6	+0.7	
37	"	"	19.0	1.3873	158.6	19.5	+0.5	
38	"	"	24.9	1.3931	205.3	25.4	+0.5	
39	Socony Vacuum 100 Octane[1].	MXAB***	13.0	1.3995	104	12.9	-0.1	1.3888
40			8.8	1.3960	70	8.7	-0.1	
41			19.9	1.4056	163	20.0	+0.1	
42			4.5	1.3930	38	4.7	+0.2	
43			28.5	1.4132	237	28.5	0.0	

**The rather wide variations with this series are atributed to fractionation of the blends due to rapid evaporation of the neo-hexane base in the refractometer. This possibly explains the close agreement of the benzene blend with the theoretical value, the high values for toluene and xylene, and the intermediate values of the aromatic base stock blends. These last contain benzene, which in boiling point and vapor pressure is closer to neohexane than toluene or xylene.

***Mixed Aromatic Blending Stock

Benzene	10%	Ethyl Benzene	5%
Toluene	40	n-propylbenzene	2
Xylene	30	Cumene	1.8
Tertiary Butyl Benzene	5	Di isopropylbenzene	1.2
Pseudo cumene	5		

1. 100 O.N. gasoline conforming to AN-VV-F-781

TABLE III

Analysis of Commercial Aviation Fuels

No.	Gasoline	25°C n_b	25°C n_x	$n \times 10^3$	$\frac{n}{1.4918-n_b} \times 10^3$	Wt. %	Vol. %	% by Vendor*
1	Shell NEI 100 Oct.	1.3898	1.4100	20.2	198.0	24.1	20.4	20
2	80% 2 pass Houdry #545765	1.3844	1.4058	21.4	199	24.2	20.2	20
3	60% Houdry #543572	1.3876	1.3969	9.3	89	11.0	9.0	9
4	Power Plant Fuel #558	1.3900	1.3905			Negligible		
5	Palembang 100 Oct. 20% Arom. P.D. 2173	1.3860	1.4070	21.0	198.5	24.2	20.3	20
6	Palembang	1.3862	1.3965	10.3	97.5	12.1	10.16	10

* In the majority of these reported values, it is not stated whether the percentages are by weight or by volume.

TABLE IV

Analysis for Aromatics in Several Unsaturated Blends

Components			Prepared % Aromatics (Vol. %)	% Olefin Present	% Aromatics Found (Vol. %)
Base	Aromatics	Olefin			
Isooctane	1:3:2:1 *	diisobutylene	20.0	8.0	19.9
Isooctane	1:3:2:1	pentene-1 pentene-2	16.67	8.33	16.65
Cyclohexane Me-cyclohexane	Benzene	diisobutylene	18%	10%	17.6
100 Octane base stock	1:3:2:1	diisobutylene	16.67	8.33	16.65
Isooctane and 100 octane base	1:3:2:1	diisobutylene and pentene-2	12.0	20.0	12.7 **
Cooperative testing Sample B circulated by Section IX, Committee A, A.S.T.M. D-2			24	2.0	23.4
Isooctane and 100 Octane base	1:3:2:1	pentene-2	21.35	15.0	21.6 **

* 1:3:2:1 parts of benzene, toluene, xylene and cumene, respectively.
** Mixtures prepared by other members of section, the composition of the mixtures being unknown to the analyst.

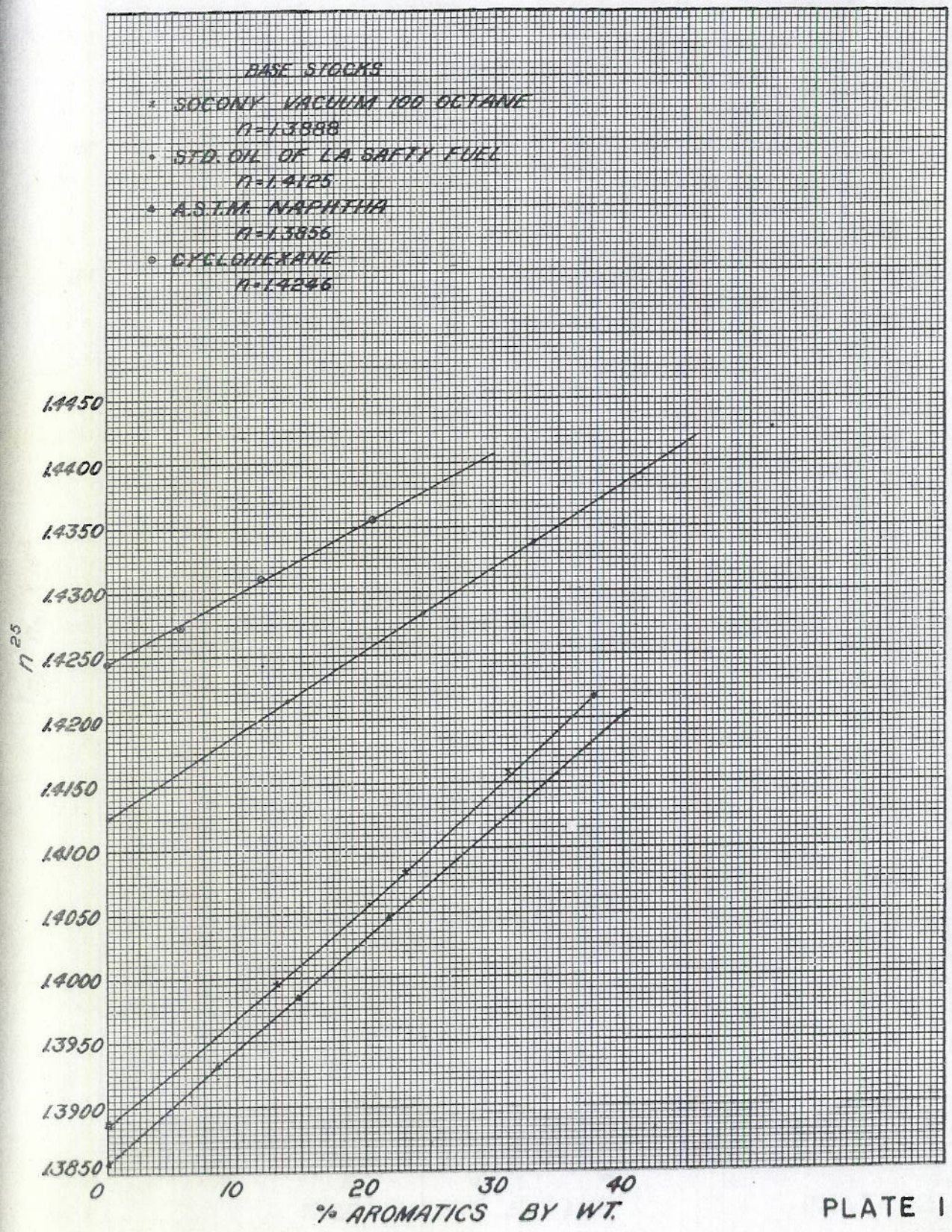

BASE STOCKS
× SOCONY VACUUM 100 OCTANE
n=1.3888
• STD. OIL OF LA. SAFTY FUEL
n=1.4125
• A.S.T.M. NAPHTHA
n=1.3856
○ CYCLOHEXANE
n=1.4246
1.4450
1.4400
1.4350
1.4300
1.4250
1.4200
1.4150
1.4100
1.4050
1.4000
1.3950
1.3900
1.3850
n^{25}
0
10
20
30
40
% AROMATICS BY WT.

PLATE I

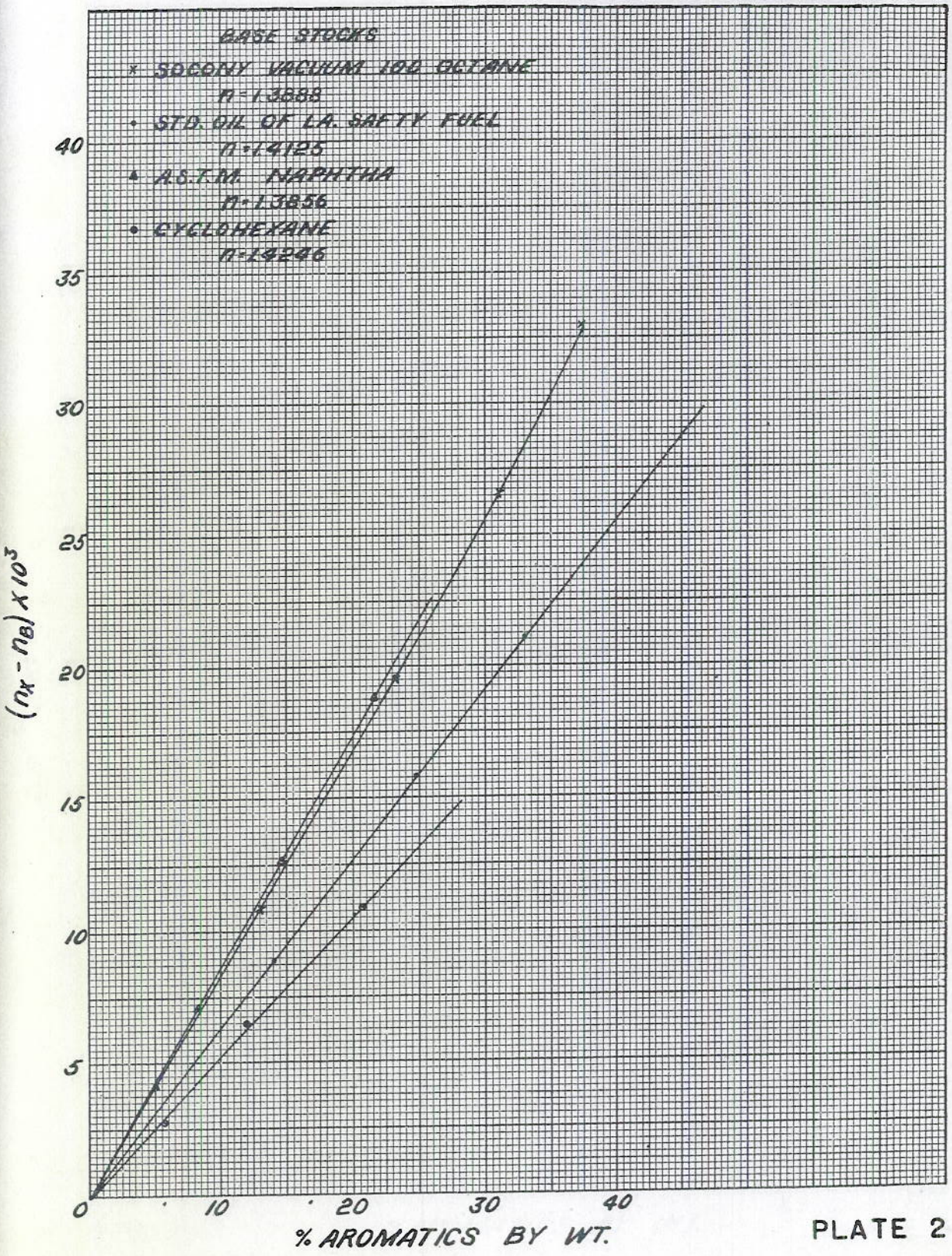

BASE STOCKS
× SOCONY VACUUM 100 OCTANE
n=1.3888
• STD. OIL OF LA. SAFTY FUEL
n=1.4125
▲ A.S.T.M. NAPHTHA
n=1.3856
• CYCLOHEXANE
n=1.4246
40
35
30
25
20
15
10
5
0
10
20
30
40
$(n_x - n_B) \times 10^3$
% AROMATICS BY WT.

PLATE 2

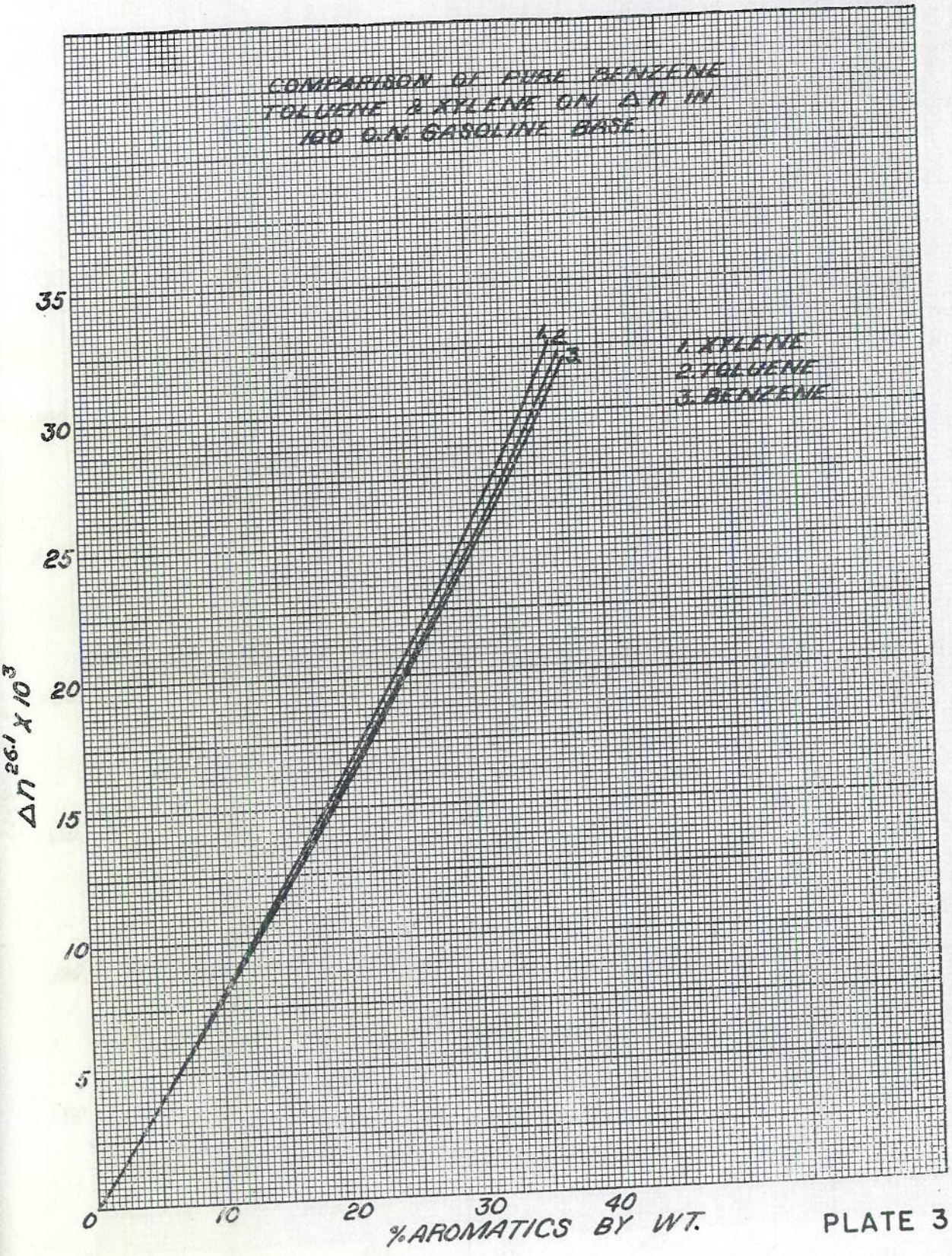

COMPARISON OF EVAL BENZENE TOLUENE & XYLENE ON Δn IN 100 O.N. GASOLINE BASE.
1. XYLENE
2. TOLUENE
3. BENZENE
$\Delta n^{26.1} \times 10^3$
35
30
25
20
15
10
5
0
10
20
30
40
% AROMATICS BY WT.

PLATE 3

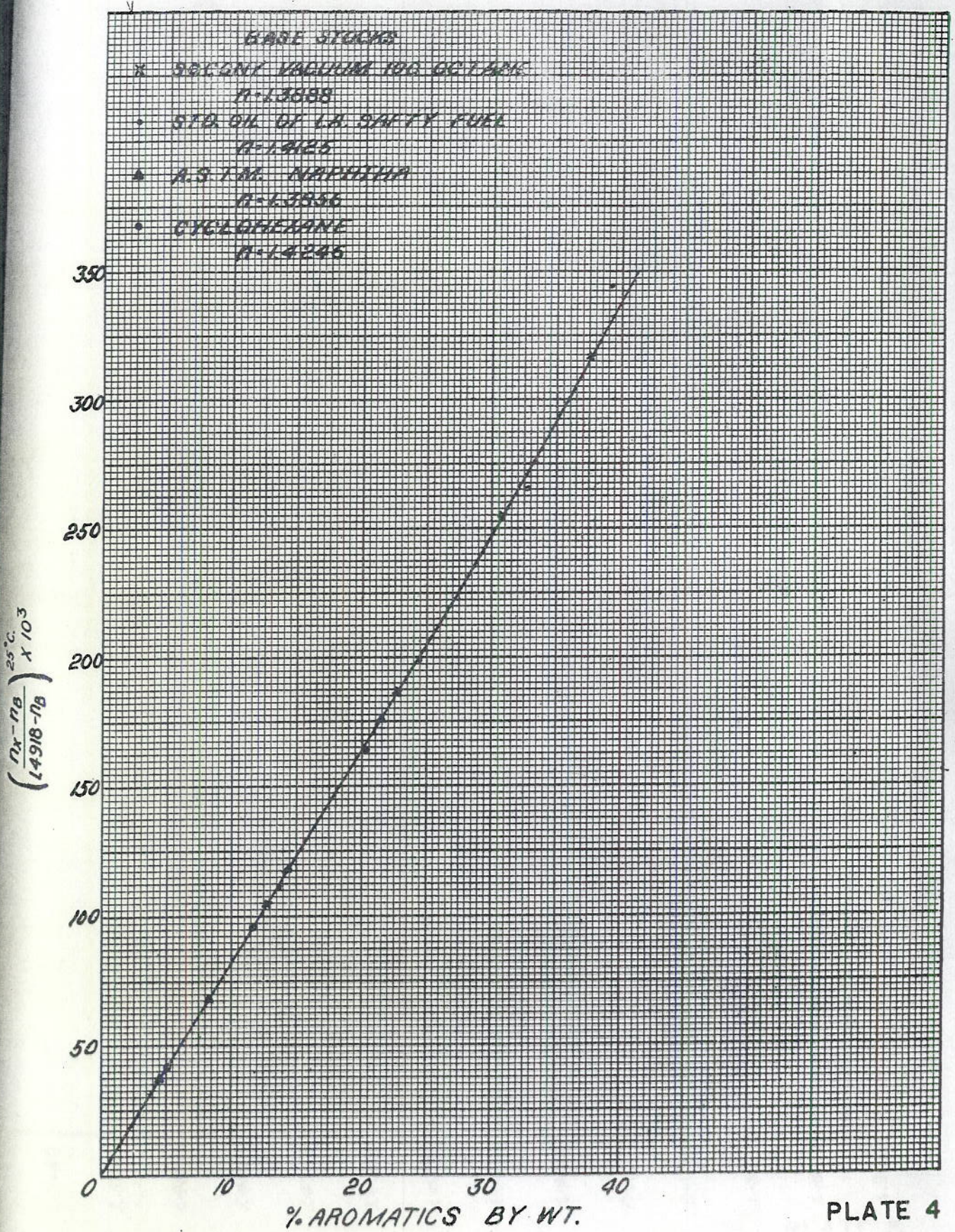

BASE STOCKS
× SOCONY VACUUM 100 OCTANE n-1.3888
• STD. OIL OF LA. SAFETY FUEL n-1.3925
▲ A.S.T.M. NAPHTHA n-1.3856
• CYCLOHEXANE n-1.4246
350
300
250
200
150
100
50
0
10
20
30
40
% AROMATICS BY WT.
$\left(\frac{n_x - n_B}{1.4918 - n_B}\right)^{25°C.} \times 10^3$

PLATE 4

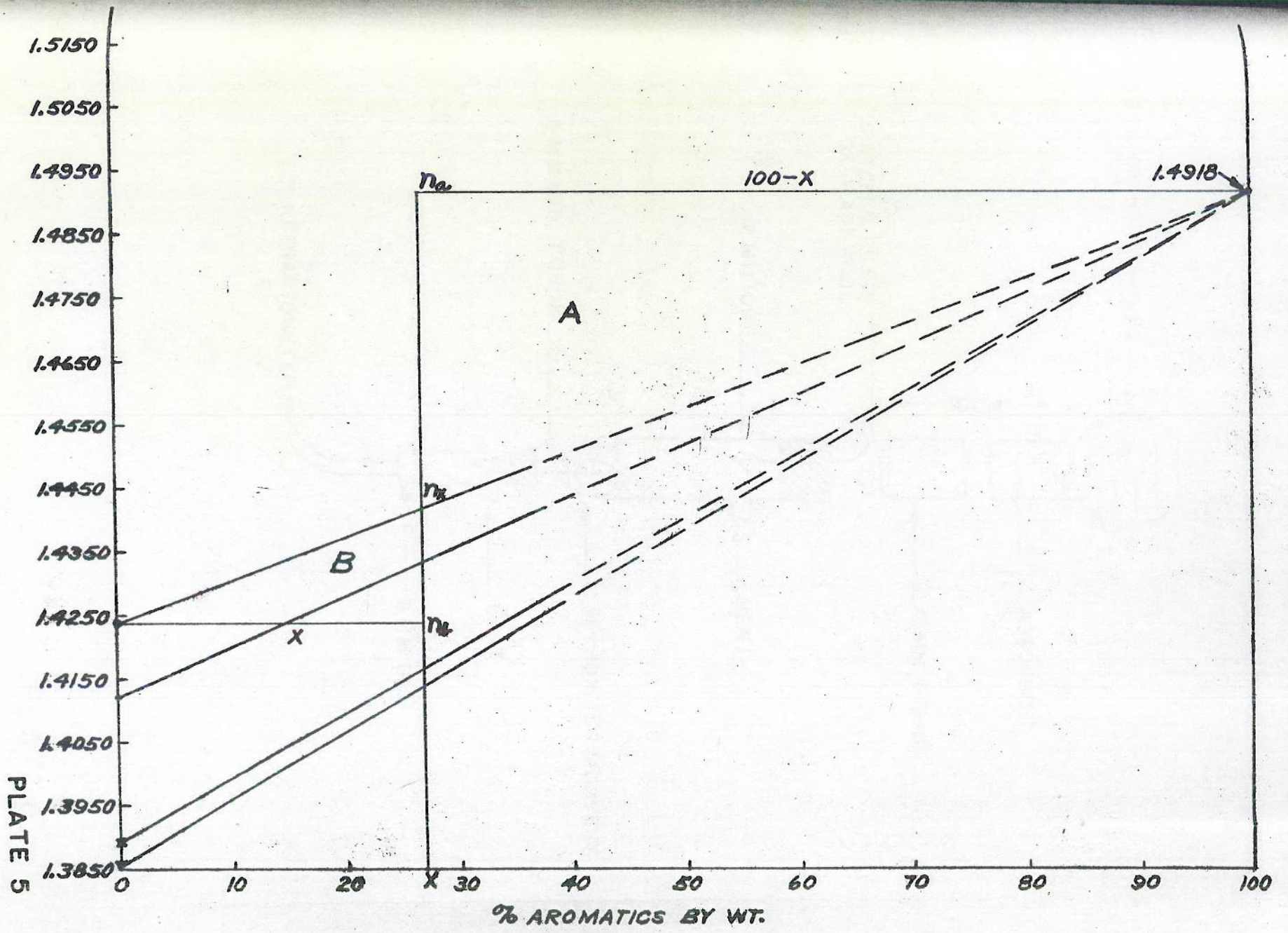

1.5150
1.5050
1.4950
1.4850
1.4750
1.4650
1.4550
1.4450
1.4350
1.4250
1.4150
1.4050
1.3950
1.3850
n_d
100-X
1.4918
A
B
n_s
n_d
X
0
10
20
X
30
40
50
60
70
80
90
100
% AROMATICS BY WT.

PLATE 5

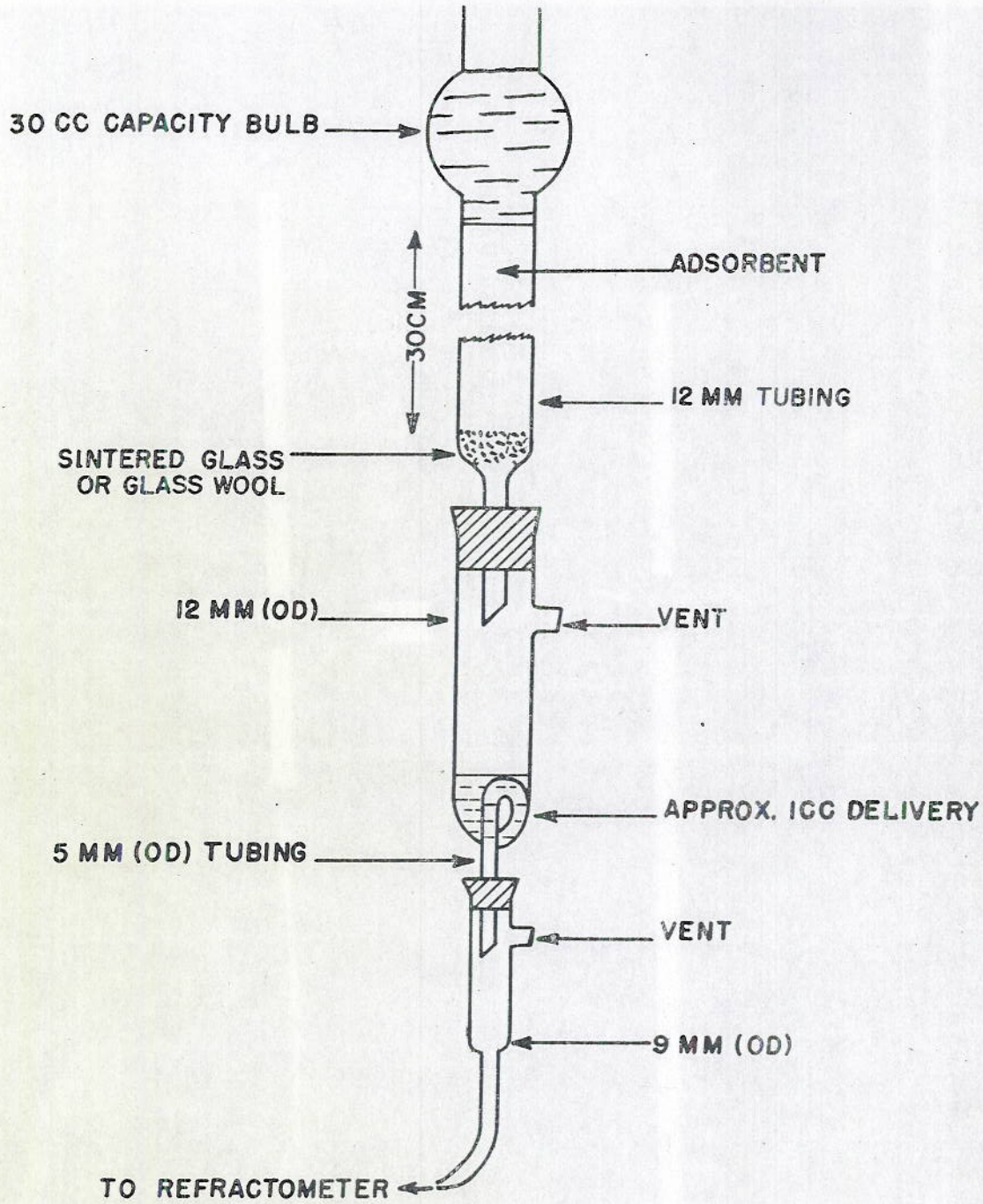

30 CC CAPACITY BULB
ADSORBENT
30CM
12 MM TUBING
SINTERED GLASS
OR GLASS WOOL
12 MM (OD)
VENT
APPROX. ICC DELIVERY
5 MM (OD) TUBING
VENT
9 MM (OD)
TO REFRACTOMETER

PLATE 6

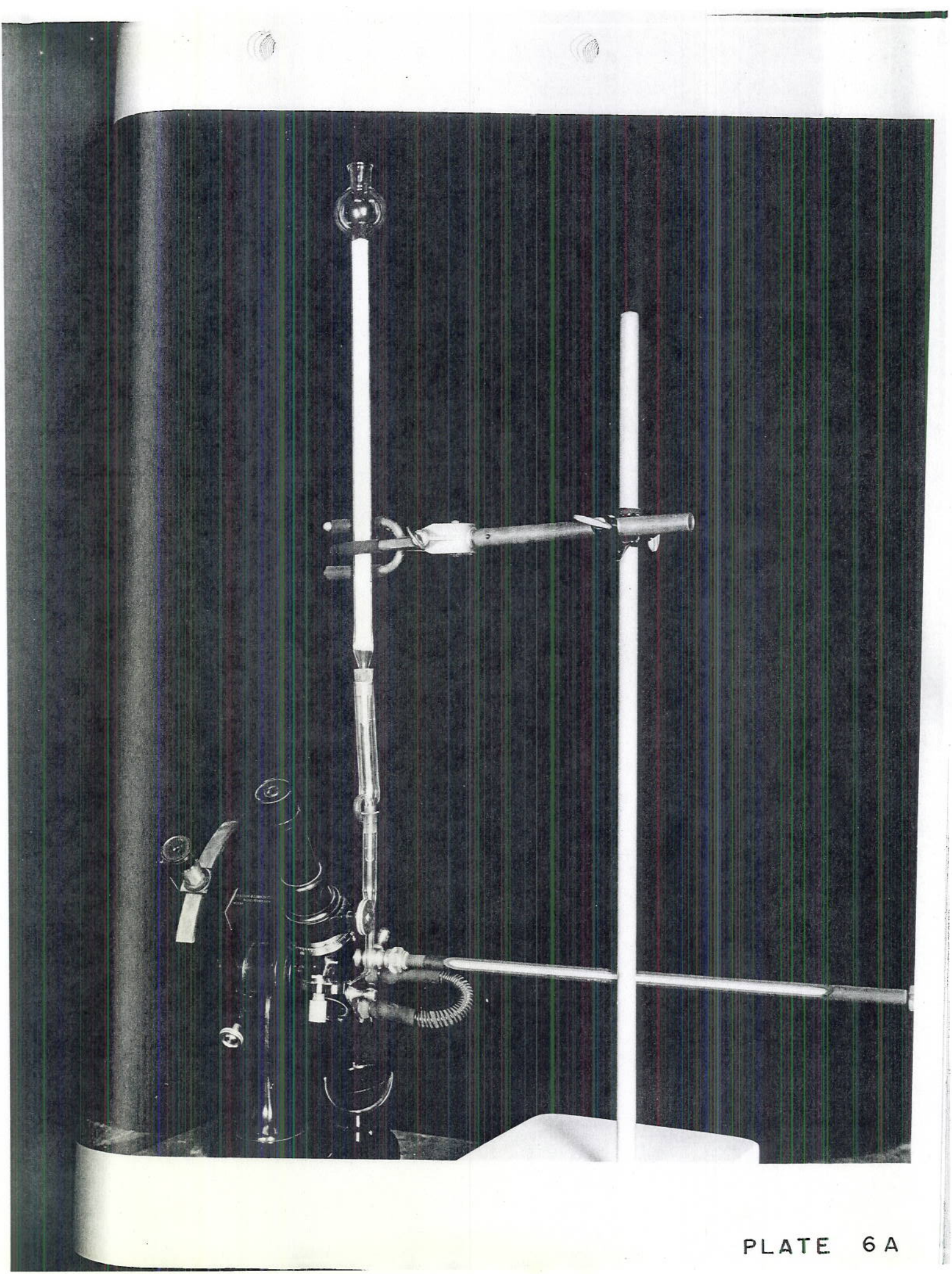


PLATE 6A

PLATE 6 B

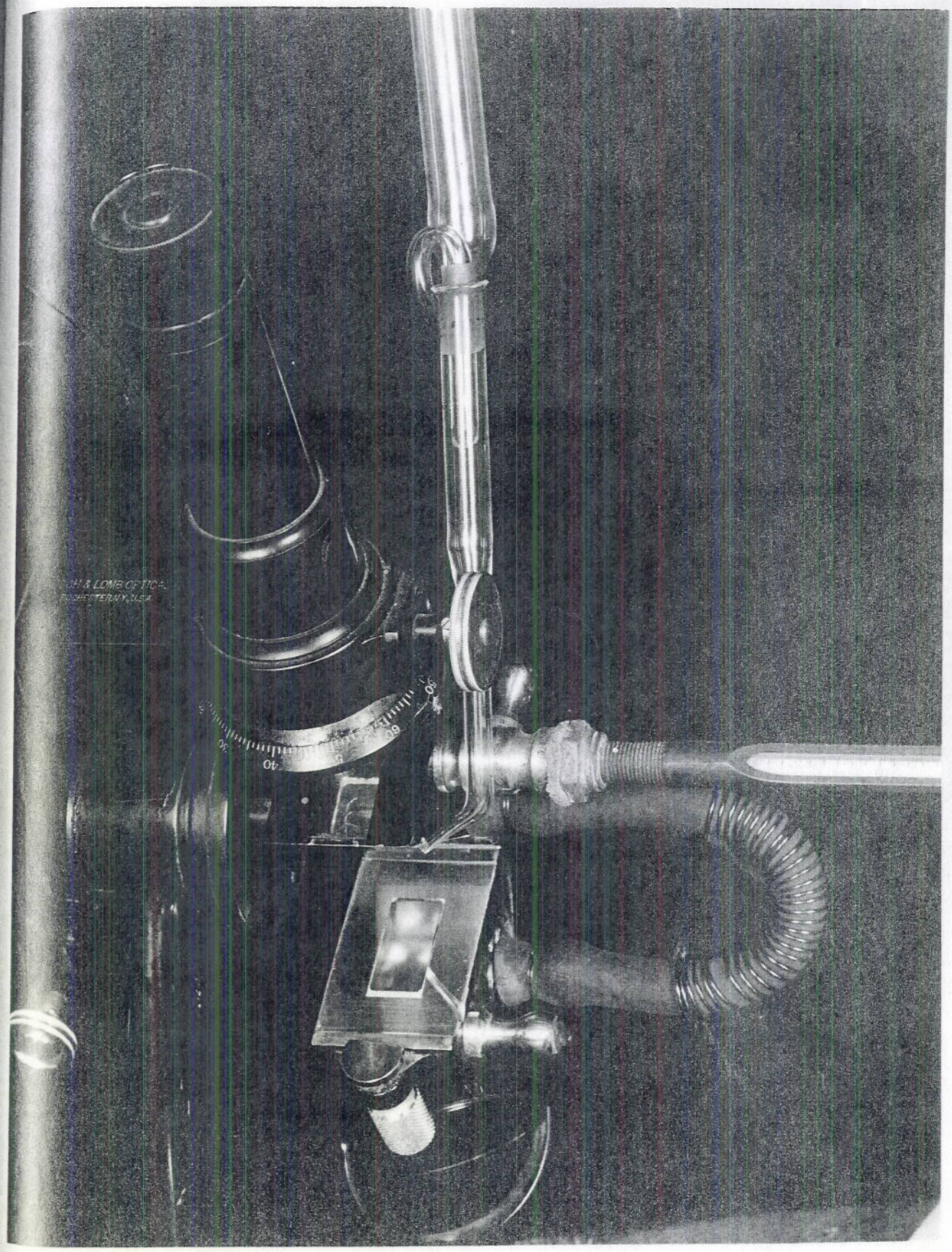


PLATE 6C

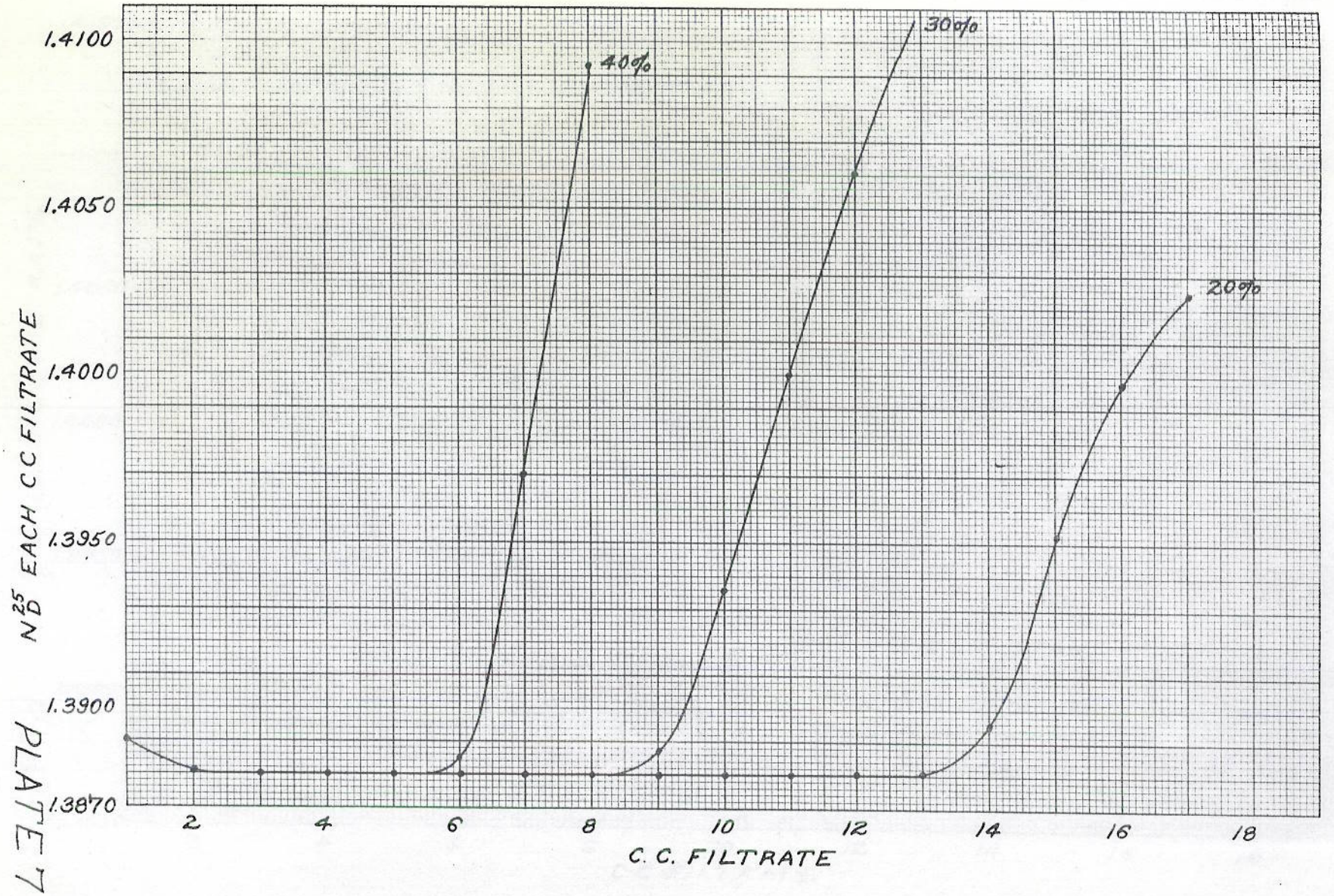


PLATE 7
N_D^{25} EACH C C FILTRATE
1.4100
1.4050
1.4000
1.3950
1.3900
1.3870
2
4
6
8
10
12
14
16
18
C. C. FILTRATE
40%
30%
20%

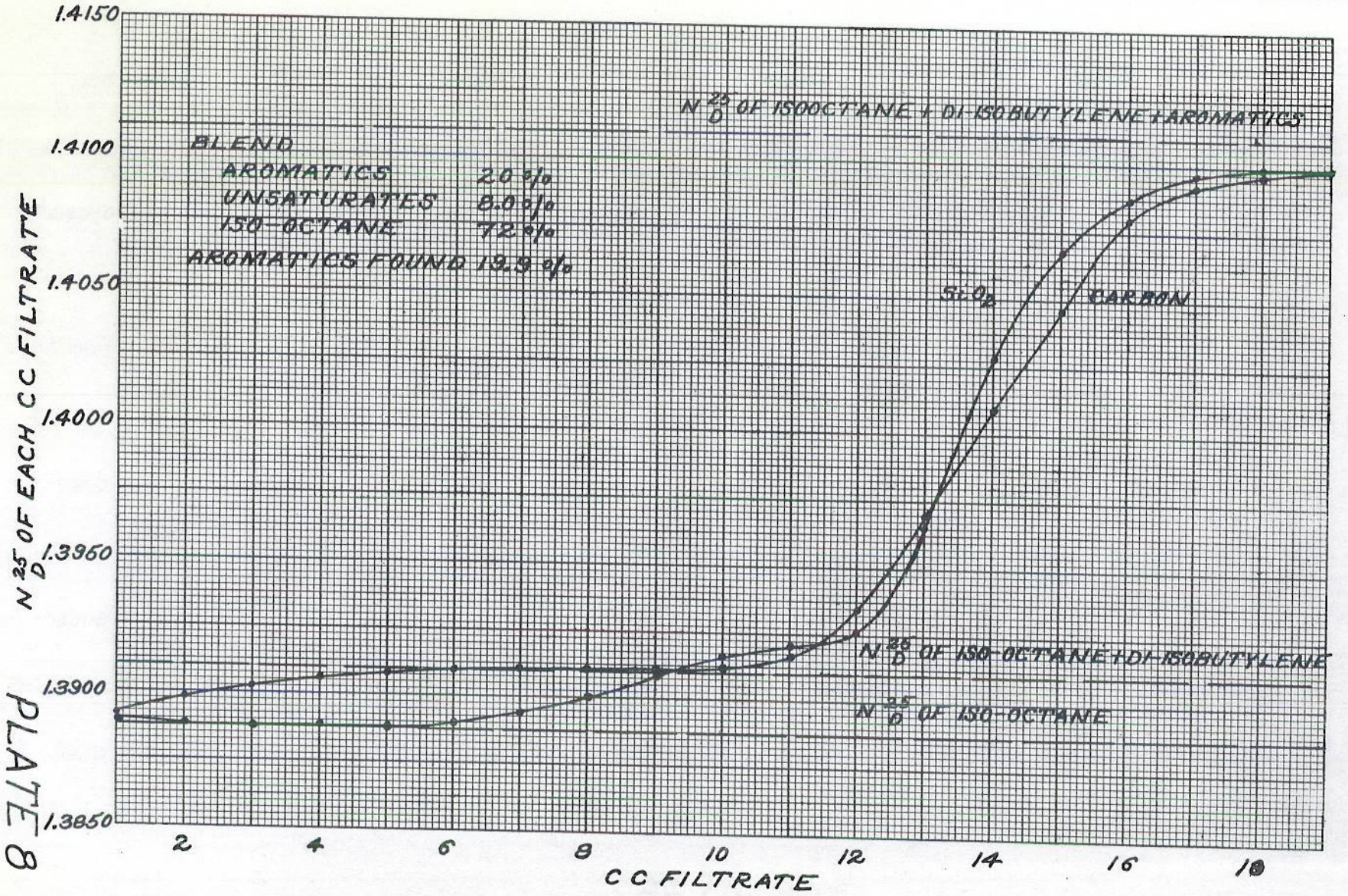
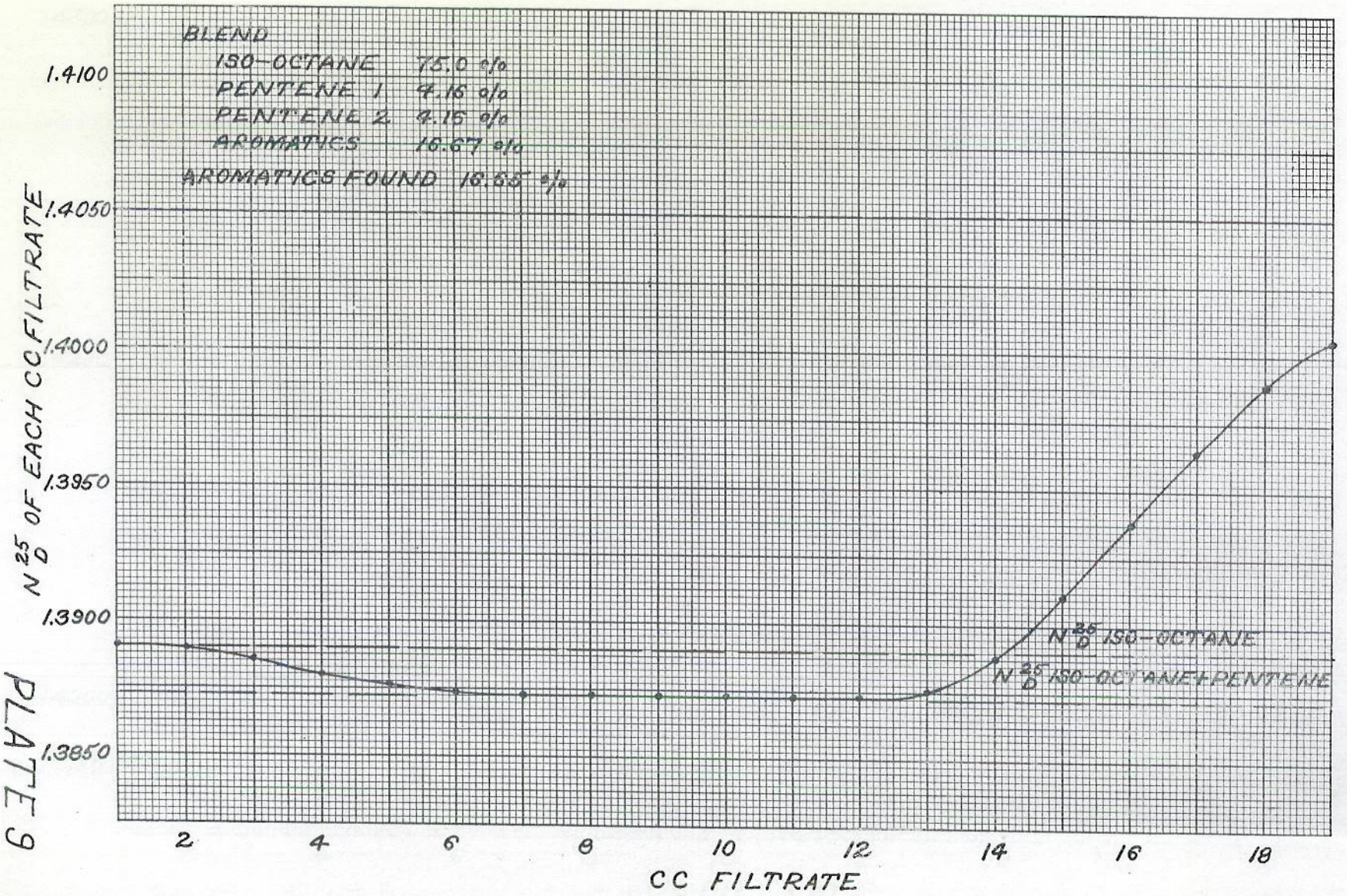
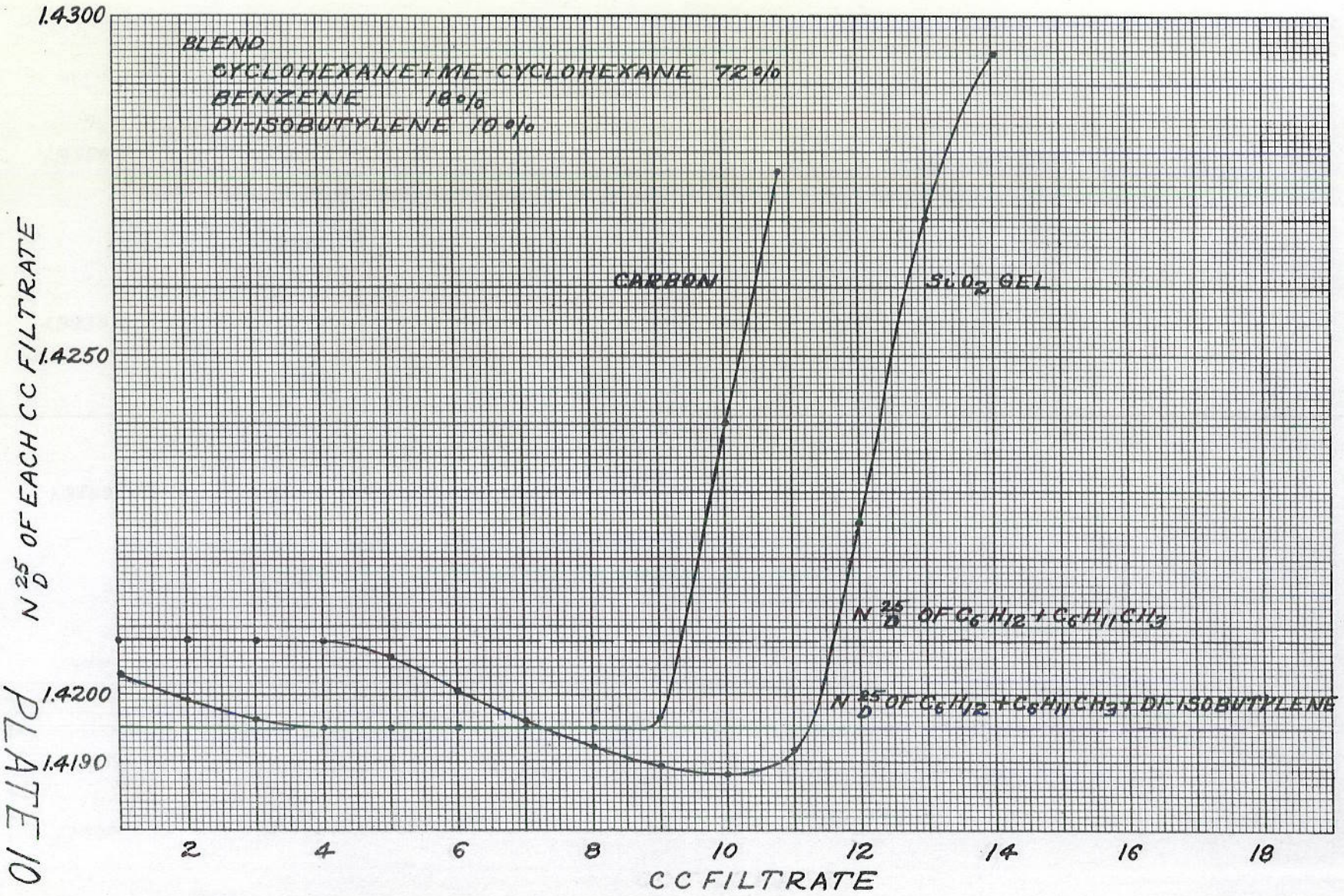


PLATE 8
N^{25}_D OF EACH CC FILTRATE
1.4150
1.4100
1.4050
1.4000
1.3960
1.3900
1.3850
2
4
6
8
10
12
14
16
18
CC FILTRATE
BLEND
AROMATICS 20 %
UNSATURATES 8.0 %
ISO-OCTANE 72 %
AROMATICS FOUND 19.9 %
N^{25}_D OF ISOOCTANE + DI-ISOBUTYLENE + AROMATICS
SiO_2
CARBON
N^{25}_D OF ISO-OCTANE + DI-ISOBUTYLENE
N^{25}_D OF ISO-OCTANE

PLATE 9


BLEND
ISO-OCTANE 75.0 o/o
PENTENE 1 4.16 o/o
PENTENE 2 4.15 o/o
AROMATICS 16.67 o/o
AROMATICS FOUND 16.65 o/o
1.4100
1.4050
1.4000
1.3950
1.3900
1.3850
N_D^{25} OF EACH CC FILTRATE
2
4
6
8
10
12
14
16
18
CC FILTRATE
N_D^{25} ISO-OCTANE
N_D^{25} ISO-OCTANE + PENTENE


BLEND
CYCLOHEXANE + ME-CYCLOHEXANE 72 o/o
BENZENE 18 o/o
DI-ISOBUTYLENE 10 o/o
CARBON
SiO_2 GEL
N_D^{25} OF $C_6H_{12} + C_6H_{11}CH_3$
N_D^{25} OF $C_6H_{12} + C_8H_{11}CH_3$ + DI-ISOBUTYLENE
1.4300
1.4250
1.4200
1.4190
N_D^{25} OF EACH CC FILTRATE
PLATE 10
2
4
6
8
10
12
14
16
18
CC FILTRATE

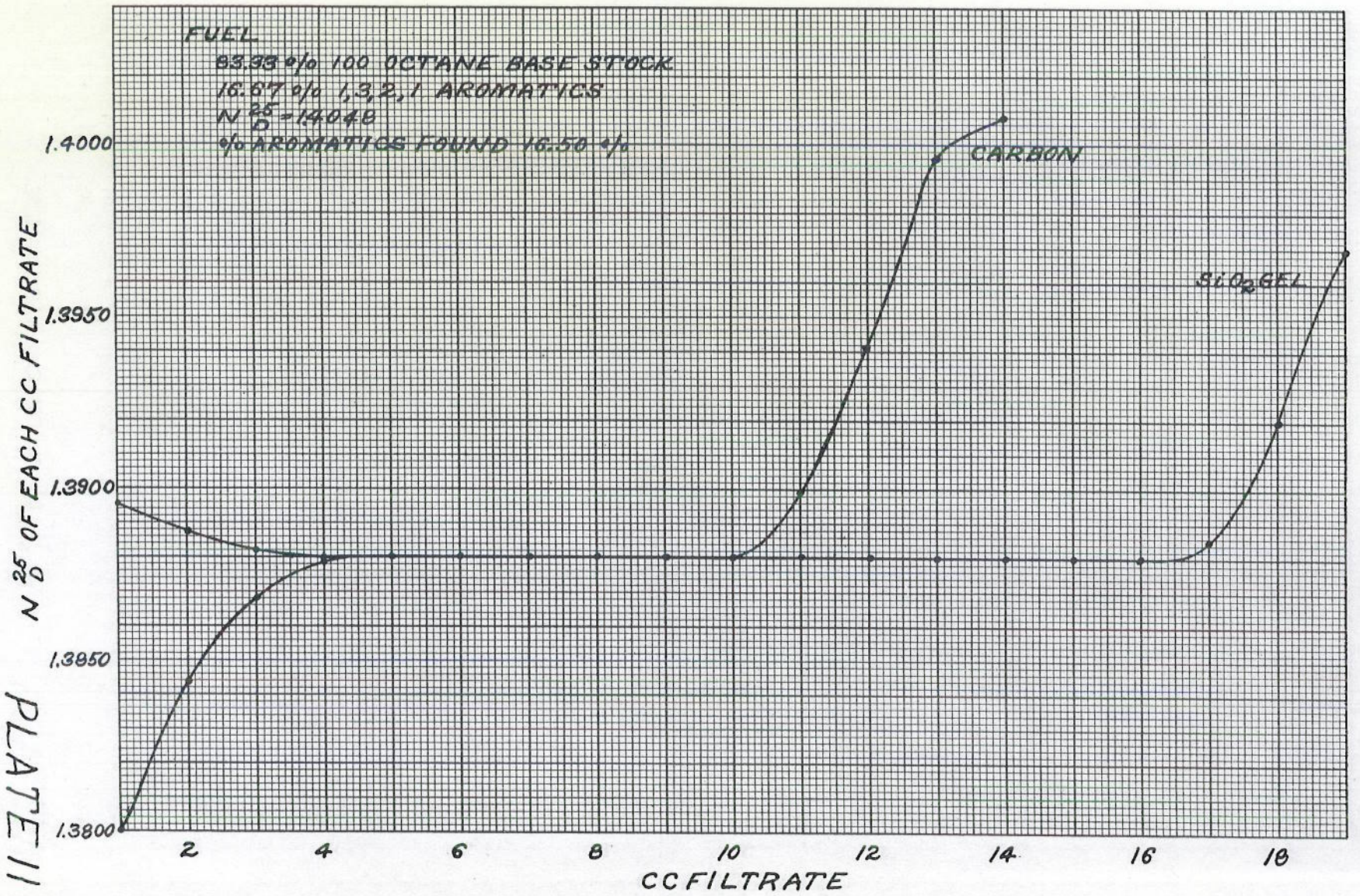
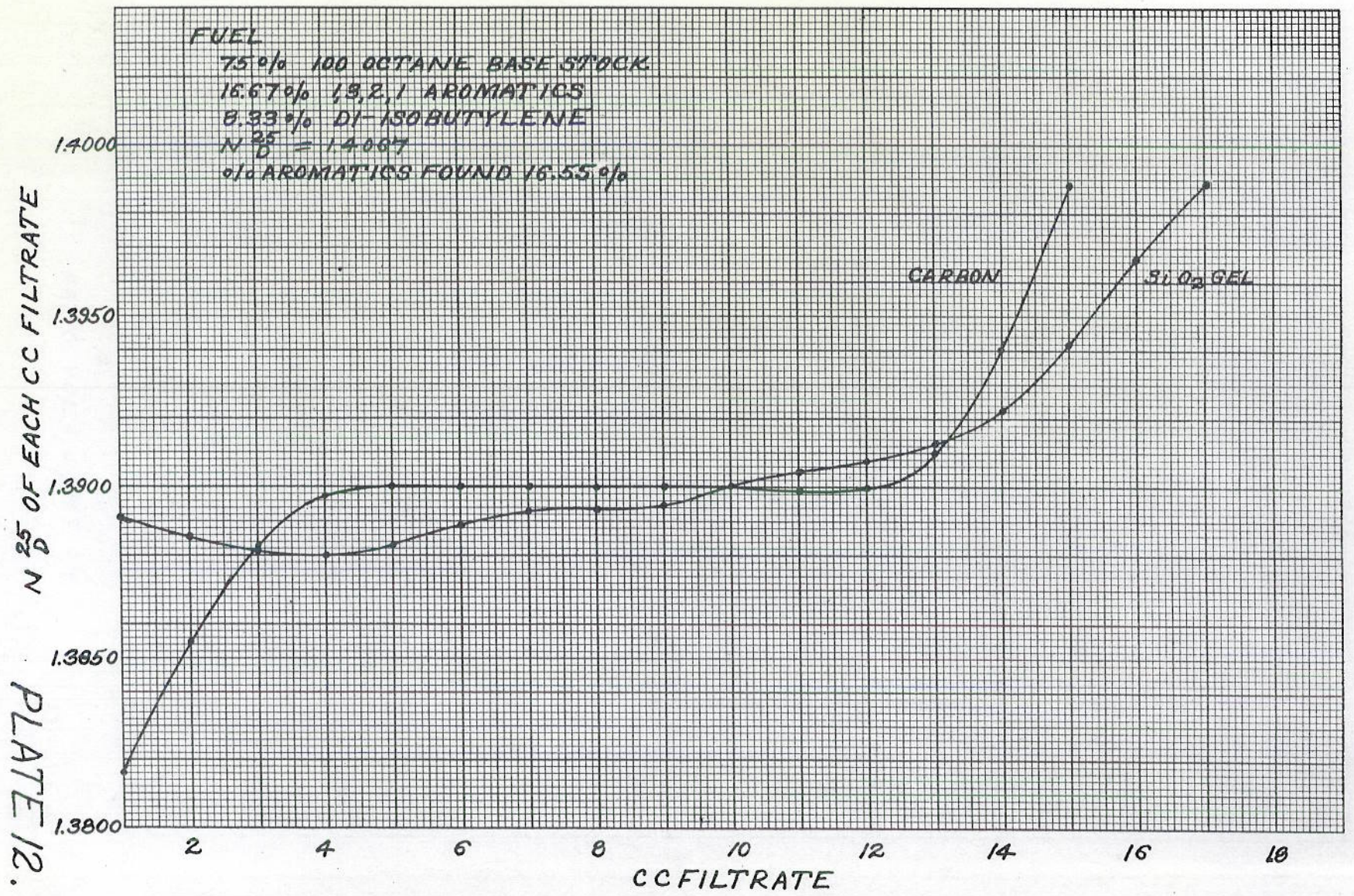

FUEL
83.33 o/o 100 OCTANE BASE STOCK
16.67 o/o 1,3,2,1 AROMATICS
N_D^{25} = 1.4048
o/o AROMATICS FOUND 16.50 o/o
CARBON
SiO_2 GEL
PLATE 11
N_D^{25} OF EACH CC FILTRATE
1.4000
1.3950
1.3900
1.3850
1.3800
2
4
6
8
10
12
14
16
18
CC FILTRATE

PLATE 12.


FUEL
75 o/o 100 OCTANE BASE STOCK
16.67 o/o 1,3,2,1 AROMATICS
8.33 o/o DI-ISOBUTYLENE
N_D^{25} = 1.4067
o/o AROMATICS FOUND 16.55 o/o
CARBON
SiO_2 GEL
1.4000
1.3950
1.3900
1.3850
1.3800
N_D^{25} OF EACH CC FILTRATE
2
4
6
8
10
12
14
16
18
CC FILTRATE

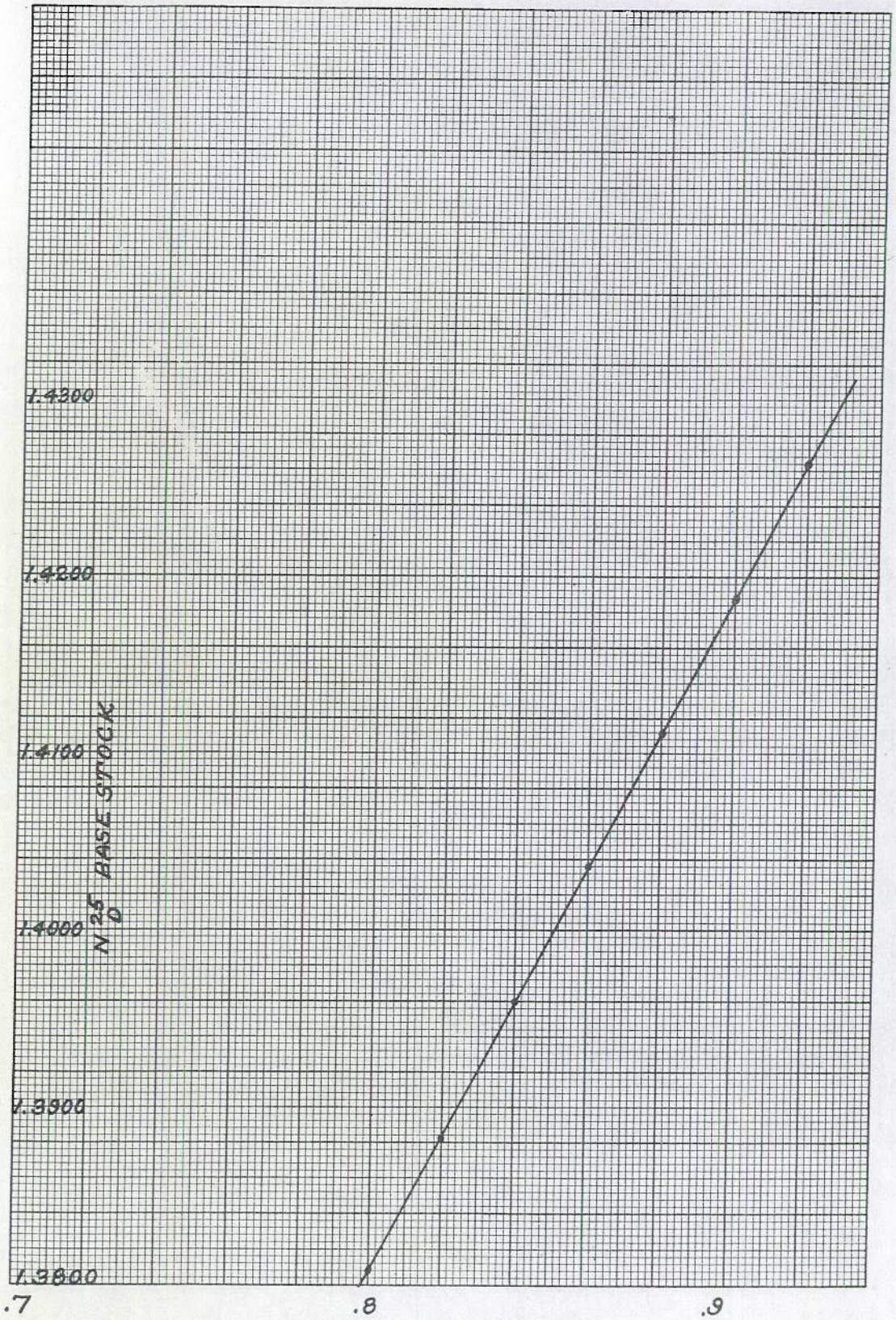

1.4300
1.4200
1.4100
1.4000
1.3900
1.3800
N 25 BASE STOCK
.7
.8
.9
RATIO VOL. o/o / WT. o/o

PLATE 13