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A Method for the Separation and Analysis of Aromatic Fractions of Aviation Gasoline

NAVAL RESEARCH LABORATORY

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NAVY DEPARTMENT

Report On

A Method for the Separation and Analysis of Aromatic Fractions of Aviation Gasoline.

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
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ABSTRACT

A method has been developed for separating the benzene, toluene and "higher aromatic" fractions of aviation gasoline in order that analysis for the content of these hydrocarbons may be effected. This separation is accomplished by distillation of a 200 ml charge through a 600 mm Hempel type column, packed with glass beads, at a rate of 4 ml per minute. The efficiency of the separation is such that aromatic constituents can be determined with an accuracy of ± 1%. The advantages of the method are:

1. Simple apparatus, available to all laboratories.
2. Simple technique: no especial skill is required for performing the distillation operation.
3. Speed: with a high throughput of 4 ml per minute the aromatic fractions can be segregated in a time comparable to that needed for a standard A.S.T.M. distillation of gasoline.

Data, description of apparatus and technique, drawing and photograph of distillation assembly are given in the report.

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I. INTRODUCTION

(A) Authorization

1. This work was authorized by Bureau of Aeronautics Project Order 91/43.

(B) Statement of Problem

2. This report consists of a method for determining the amounts of benzene, toluene and higher aromatics present in aircraft engine fuel.

3. The advantages of utilizing aromatics to increase the available amount of high octane gasoline and to obtain better rich mixture characteristics are generally realized.

4. The deleterious effects of high aromatic content on self-sealing tanks, hose, and other rubber parts of the fuel system and on protective aircraft finishes are equally well known. Benzene performs moor poorly in aircraft engines than do certain of the higher homologs; moreover, large amounts of benzene in gasoline cause undue rise in the freezing point. It is therefore, desirable to limit the benzene content of aircraft fuel to 5 or 6 percent by volume. Because in the future it may be necessary to control the content of other aromatics than benzene, it was felt that a method should be devised which would be satisfactory not only for benzene but for all aromatics boiling in the aviation gasoline range.

5. The method described herein adequately determines the amount of benzene and other aromatics present in aircraft engine fuel and is therefore presented for incorporation in the proposed Army-Navy fuel specifications for determination of the aromatic content.

(C) Known Facts Bearing on the Problem

6. It is virtually impossible to separate pure aromatics from gasolines by distillation. Even when very efficient columns of 75 - 125 theoretical plates are employed, aromatics begin to distill well below their normal boiling point due to the formation of azeotropic mixtures with other hydrocarbons present in the gasoline. The degree of this "spread" of the boiling point varies both with the fractionating equipment used and with the composition of the gasoline. With apparatus common to most laboratories, aromatics would be expected to distill over both below and above their normal boiling points.

(D) Practical Considerations

7. From the foregoing facts, it is obvious that the precise determination of individual aromatics in a gasoline is impossible in the ordinary laboratory. Even under the best conditions the time required would be too great for control purposes.

8. The obvious approach in overcoming this difficulty is to obtain small "cuts" or fractions of restricted boiling range containing a high percentage of the desired aromatic.

9. Distillation apparatus for this purpose must be simple, readily available and capable of operation by relatively unskilled personnel. It should also be designed to take full advantage of any compensating errors due to boiling point spread.

10. It is proposed to separate and estimate the amount of three aromatic types: benzene, toluene and higher aromatics. Xylenes and cumene, which are the principal common higher boiling aromatics, boil so closely together as to be virtually inseparable and are therefore grouped as "higher aromatics."

11. Each of these three groups should be determined with an overall accuracy of 1%. The total error for the whole gasoline should not then exceed 3%. If the proposed A.S.T.M. sulfuric-phosphoric acid mixture is used for aromatic determination, the distillation procedure should have a maximum error of 0.75% for each fraction, which would give a total maximum error of 1%. (Maximum error of analysis would be 1% for the fraction or 0.25% for the whole gasoline if the aromatic content of the fuel did not exceed 25%).

12. In order to insure reproducible results in different laboratories, both equipment and procedure must be standardized. Following below is a summarization of the apparatus and technique used in this investigation.

II. APPARATUS

(A) Still Pot

13. A 250 ml round bottom, short neck flask was used. This was found adequate for a 200 ml charge and has the advantages of low holdup and better heat control than a larger pot. A small piece of porous tile was added to prevent bumping.

(B) Condenser

14. The condenser was a 400 mm Liebig type with the tip bent downward and inward to direct the distillate against the wall of the receiver. The condenser was maintained at 20° C, or less, at all times.

(C) Thermometer

15. An A.S.T.M. standard low distillation thermometer calibrated in 1° C or 2° F served admirably.

(D) Receivers

16. Glass stoppered 100 ml graduates were used since they are more accurately read than larger ones and virtually all samples are of less than 100 ml.

(E) Distilling Columns Investigated:

17. Glinsky, 300 mm in length.

18. Rod and Disc column, 440 mm. long, 15 disc.

19. Hempel columns of the following types:

(a) 300, 450, and 600 mm x 27 mm, packed with glass beads of 6 mm diameter.
(b) 320, and 450 mm x 27 mm, packed with #14 and #18 jack chain.
(c) 400 m x 27 mm, packed with 5 mm lengths of 5 mm O.D. glass tubing.
(d) 400 mm x 20 and 22 mm, packed with 1/4" Monel Lessing rings.
(e) 300 mm x 13 mm, packed with 6 mm glass beads.

20. All Hempel columns had the following features in common:

(a) The expanded portion of the glass tube was extended approximately 80 mm above the top of the packing.

(b) A 150 mm long, 6 mm I.D. delivery tube was placed 25 mm above the packing at an angle of 70° with the long axis of the column.

(c) The top of the column was closed with a short cork carrying the A.S.T.M. thermometer so placed that the bulb occupied the space between the top of the packing and the opening of the delivery tube.

(d) The packing was supported by indentations in the glass tube.

(e) Immediately below the indentations the tube was constricted to a 16 mm I.D. portion 60 mm long for insertion in the still pot. (In the case of the 13 mm column, the tube was merely extended for 60 mm.). The bottom of the tube was beveled at a 60° angle.

(f) All columns, except where so specified, were enclosed in an air jacket of approximately 20 mm greater diameter glass tube, held in place by slotted bored corks.

(g) Heat was supplied by a "Glas-Col" heating mantle. The standard A.S.T.M. electric heater or a bunsen burner should, however, be acceptable.

(h) The condenser and still pot were attached to the column with sound corks of appropriate size.

III. PROCEDURE

(A) Distillation

21. The still pot was charged with a 200 cc sample of the gasoline to be analyzed and a boiling chip was added.

22. With the apparatus assembled and water flowing through the condenser, the following procedure was followed:

(a) Heat was so applied that approximately 10 minutes elapsed before the first drop of distillate appeared at the tip of the condenser. This was taken as the initial boiling point. The rate of heating was so adjusted that a throughput of 4 cc per minute (unless otherwise noted) was maintained throughout the distillation.

(b) Four fractions of distillate were collected and measured. Receivers were changed at 55° C, 95° C, and 123° C. The fraction I.B.P.-55° C(forerun) was analyzed as a check on the method but would be rejected as part of a routine distillation. The 55° - 95° C fraction was analyzed and the aromatic content designated as benzene. The aromatic content of the 95° - 123° fraction was called toluene. When the temperature reached 123° heating was discontinued and the overflow distillate was collected in a 100 ml graduate. Upon cooling and allowing sufficient time for drainage of the column, the residue in the still pot was added to this graduate and the total volume taken as "residue". The aromatic content of this fraction was designated as "higher aromatics".

(B) Analysis of Products for Aromatics

23. The Naval Research Laboratory Refraction Index method was used throughout. However, either the tentative A.S.T.M. H_2SO_4 - P_2O_5 adsorption method or the aniline point procedure proposed by the U. S. Army Materials Laboratory, Wright Field, should give equivalent results.

IV. EXPERIMENTAL RESULTS

(A) 24. Distillations of various gasolines were carried out using the columns specified in II.

(B) Gasolines Distilled

25. Several types were investigated as follows:

(a) S1 + 1 Aviation Fuel

(1) As manufactured, containing 12.6% cumene by volume.
(2) As a base stock after removal of aromatics by silica gel.
(3) Various admixtures of aromatics were used with this base.

(b) Aromatic blends based upon a fuel of 80% isooctane, 10% isopentane and 10% neohexane.

(c) Houdry two pass aviation gasoline.

(d) Hydroform gasoline.

(e) Palembang (East Indies) gasoline.

(f) Aromatic-fuel base stocks of c, d, and e, with aromatics reblended in amounts indicated by the distillation of the whole gasoline. In this way the accuracy of the original distillation was checked.

(C) Tabular Results of Distillations

26. These data are found in Table I, Appendix A.

V. DISCUSSION

(A) Effectiveness of Various Columns

27. The 300 mm Glinsky, 450 mm rod and disc column, 300 and 450 glass bead packed columns were so ineffective in preventing the spread of the boiling range of benzene as to be totally unsuited for its estimation.

28. The 600 mm Hempel column, packed with 6 mm glass beads gives an adequate separation of aromatics from all gasolines tried. It was superior to any other column investigated, more markedly in some cases than in others.

29. The 320 mm jack chain packed column gives fairly adequate, though poorer, separation than the 600 mm glass bead column.

30. Strangely enough, a 450 jack chain column is less effective for isooctane blends than the 320 mm column. Benzene values are far too low.

31. The 450 mm Hempel column packed with 5 mm x 5 mm O.D. glass tubes also falls down for the same gasolines as does the 450 mm jack chain column, above.

32. The proposed Army column, (400 mm in length x 27 mm I.D.) packed with 1/4" Lessing rings) is generally inferior to the 600 mm glass bead column and the 320 jack chain column. Even while operating at the recommended rate of 1 - 1.5 cc/min, it is less effective than either of the other columns operating at 4 cc/min. Much time is saved by the feasibility of a fast distillation rate. At 4 cc/min the Lessing ring column is even less efficient.

33. The 600 mm glass bead packed Hempel column is excellent for concentrating benzene within the proper cut and is also superior in rejecting toluene and higher aromatics when there is no benzene present.

(B) Jacketing

34. The use of an air jacket of glass tubing has many advantages over unjacketed columns and certain advantages over other more complex or opaque, insulating materials.

(a) The effect of drafts upon the column are virtually eliminated enabling an easier and more even control of distillation rate.

(b) Flooding in a long column is eliminated up to 4 cc/min.

(c) The state of reflux is visible.

(d) The jacket is mechanically simple.

(C) Limits of Fractions for Each Aromatic or Group

35. Experiment has shown that a range of 55-95° C for the benzene fraction is considerably better for the estimation of benzene than the 60° - 95° C fraction which has been advocated. Benzene begins to distill at approximately 52° C (depending upon the gasoline) but does not distill in appreciable quantities until 55° C is reached. When the cut is made at 55° C the forerun may be safely rejected.

The limits of the toluene fraction (95°-123° C) are believed to represent a median of accuracy for different gasolines and are, therefore, quite acceptable.

(D) Reproducibility and Reliability

36. Duplicate runs have indicated that with a practiced operator, results are reproducible within the accuracy of the analytical method employed.

37. When results from the distillation of aromatic gasolines were checked by reblending the indicated amount of aromatics to the aromatic free base stock, very close agreement was obtained. This is concrete evidence of reliability.

VI. THEORETICAL CONSIDERATIONS

(A) Effect of Column Efficiency on Separation

38. The efficiencies of the better columns were determined for the system benzene-carbon tetrachloride, utilizing the data of Rosanoff and Easley[1]. These values are given in Table II, Appendix A.

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1. M. A. Rosanoff and C. W. Easley, J.A.C.S. 31, 953 (1909)

39. It should be understood that these values represent as nearly as possible the true operating efficiency of the various columns under actual distillation conditions. No attempt was made to obtain the maximum (and misleading) efficiencies of these packings under total reflux. All efficiencies would, undoubtedly, be raised by the use of a reflux head, but would not be truly representative of the effective separation obtained under actual gasoline analysis. All packings probably would not be affected to the same degree by total or increased reflux, so that such values would be doubly misleading.

40. Higher efficiencies were obtained at the start of each distillation (T = o) due to natural reflux resulting from raising the temperature of the cold packing.

41. Under conditions of the experiments, glass beads have a higher inherent reflux than the other packings and so utilize a greater percentage of their maximum efficiency. This is the principal reason why the efficiency of glass beads does not fall off so rapidly with increasing throughput.

VII. CONCLUSIONS

(A) Method

42. It is believed that a practical method has been developed for the separation of benzene, toluene, and higher aromatic fractions of aircraft engine fuel so that the analysis of these fractions for aromatic content may be accomplished by recognized analytical methods.

VII. RECOMMENDATIONS

43. It is recommended that the following apparatus and procedure be used for the separation by distillation of the aromatic fraction of aviation fuel where analysis for aromatics is necessary in the control of the quality of military gasoline.

(A) Apparatus

44. Hempel Column - The column shall consist of a glass tube of approximately 740 mm overall length consisting of an expanded portion 27 mm internal diameter and 680 mm in length to contain the packing and thermometer, and a narrow tube of 16 mm I.D. and 60 mm in length for insertion in the still pot. Suitable indentations shall be made in the glass at the junction of the narrow and expanded portions of the column to retain the packing. Fifty mm from the top of the column shall be placed a 6 mm I.D. delivery tube 150 mm long, set at an angle of 70° to the long axis of the column. The expanded portion of the column shall be filled with 6 mm glass beads to a height 25 mm below the delivery tube. The column shall be closed with a cork carrying a thermometer so placed that the bulb of the thermometer is accomodated in the space between the top of the packing and the opening of the delivery tube. The portion

of the column containing the glass bead packing shall be encased in a jacket consisting of a glass tube approximately 20 mm larger in diameter than the column itself and approximately 600 mm in length, held in place by bored slotted corks of appropriate size.

45. Condenser - The condenser shall be of the Liebig type with a jacketed length of approximately 400 mm and with the tip bent downward and inward so that the distillate is directed to the wall of the receiver. The condenser shall be supplied with cooling water of a temperature no higher than 20° C.

46. Thermometer - The thermometer shall be standard A.S.T.M. Low Distillation, or equivalent, graduated in 1° C or 2° F.

47. Still Pot - The still pot shall consist of a 250 ml round bottom, short neck flask attached to the column with a sound cork of appropriate size. (If desired, a female 24/40 Standard taper ground glass joint may be used for this connection in which event the constricted portion of the Hempel column shall be replaced with a corresponding male joint.) A small chip of porous tile, or equivalent, may be added to promote even boiling.

48. The still pot shall be heated by open burner or electric heating devices of such capacity and so controlled as to enable the operator to attain and maintain the distillation rate indicated below under "procedure". The pot should be appropriately protected from drafts.

49. Receivers - The receivers shall be 100 ml glass stoppered graduates, graduated in 1 ml.

(B) Procedure

50. With all in readiness, heat shall be applied at such a rate that the first drop of distillate appears at the tip of the condenser in not less than 5 minutes nor more than 10 minutes. Heat input shallthen be so adjusted that distillate is collected at a rate of 4 ml $\pm$ 0.5 ml per minute. When the temperature reaches 55° C, the first receiver shall be removed and the fraction distilling between 55° C and 95° C shall be collected as the benzene cut. Similarly, the toluene cut shall be taken between 95° and 123° C. The residue shall be regarded as containing the higher aromatics. This residue is collected by adding the cooled bottoms in the pot to any distillate above 123° C.

51. These three fractions shall be analyzed by the A.S.T.M. sulfuric-phosphoric acid method or the Naval Research Laboratory refractive index method, the differential aniline point method, or any other method capable of an accuracy of $\pm$ 1%.

TABLE I

FRACTIONAL ANALYSIS OF GASOLINE FOR AROMATIC TYPES

Packing Type	Column Type I.D. mm.	Column Type Length mils.	Air Jacket	Rate c.c/min.	Gasoline	Fraction Limits I.B.P.-55° 55-95	Fraction Limits I.B.P.-60° 60-95	% Benzene Found	% Benzene Prepared	% Toluene Found	% Aromatic Residue Found	Total Aromatics Found	Total Aromatics Prepared	Error %	% Aromatics in Forerun
6 mm. Glass Beads	27	300	No	3	S1 + 1*		x	0.96	0.0						
"	"	"	"	0.75-1.	"		x	0.78	0.0						
"	"	"	Yes	4	"		x	0.84	0.0						0.00
"	13	"	No	4	"		x	0.80	0.0						
"	"	"	"	3.5	"		x	1.25	0.0						
#14 Jack Chain	27	"	"	4	"		x	0.63	0.0						
"	"	"	"	3	"		x	0.94	0.0						0.18
6 mm. Glass Beads	"	450	Yes	4	"		x	0.74	0.0						0.00
"	"	600	"	4	"		x	0.79	0.0						0.00
Lessing Rings	20	400	No	1.1	"		x	0.71	0.0	1.73	8.80	11.21	12.6	1.39	0.05
6 mm. Glass Beads	27	600	Yes	4	"	x		0.85	0.0	1.43	9.32	11.60	12.6	1.00	0.00
#18 Jack Chain	"	320	"	4	"	x		0.82	0.0	1.82	8.84	11.48	12.6	1.12	0.04
"	"	"	"	4	"	x		0.92	0.0	1.60	8.98	11.50	12.6	1.10	0.00
#14 Jack Chain	27	300	No	4	#1 + 10% Toluene		x	0.28	0.0						0.08
6 mm. Glass Beads	"	"	"	4	"		x	0.19	0.0						0.00
"	"	450	Yes	4	"		x	0.36	0.0						0.00
"	"	600	"	4	"		x	0.15	0.0						0.00
Lessing Rings	22	400	No	1.1	"	x		0.08	0.0	9.22	0.17	9.47	10.0	0.53	0.02
6 mm. Glass Beads	27	600	Yes	4	"	x		0.14	0.0	8.94	0.14	9.23	10.0	0.77	0.00
#18 Jack Chain	"	320	"	4	"	x		0.13	0.0	8.97	0.32	9.42	10.0	0.58	0.20
Olinsky, 300 mm.	22	300	No	4	"	x		1.13	0.0						0.06
#18 Jack Chain	27	450	Yes	4	"	x		0.00	0.0	8.95	0.47	9.42	10.0	0.58	0.00
6 mm. Glass Beads	27	300	No	4	#2 + 10% Toluene		x	0.61	0.0						0.00
"	"	450	Yes	4	"		x	0.93	0.0						0.00
"	"	600	"	4	"		x	0.35	0.0						0.00
6 mm. Glass Beads	27	300	No	4	#2 + 5% Benzene		x	3.55	5.0						0.71
"	"	450	Yes	4	"		x	3.30	5.0						1.10
"	"	600	"	4	"		x	4.20	5.0						0.00
Lessing Rings	22	400	No	1.1	"	x		3.93	5.0	0.14	0.00	4.07	5.0	0.93	0.43
"	"	"	"	4	"	x		3.35	5.0						0.85
6 mm. Glass Beads	27	600	Yes	4	"	x		4.58	5.0	0.00	0.00	4.58	5.0	0.42	0.05
#18 Jack Chain	"	320	"	4	"	x		4.25	5.0						0.17
"	"	"	"	4	"	x		4.17	5.0						0.37
"	"	450	"	4	"	x		4.40	5.0						0.08
5x5 mm. O.D. Glass Tubes	"	"	"	4	"	x		4.43	5.0						0.11
6 mm. Glass Beads	27	300	No	4	#1 + 5% Benzene		x	3.64	5.0						0.71
"	"	450	Yes	4	"		x	3.63	5.0						0.29
Lessing Rings	22	400	No	4	"		x	2.36	5.0						0.75
"	"	"	"	1.4	"		x	2.60	5.0						0.73
"	"	"	"	1	"	x		3.15	5.0						0.21
"	"	"	"	1.1	"	x		3.38	5.0	1.05	0.05	4.48	5.0	0.52	0.28
15 Dec. Rod and Disc	"	440	"	2	"	x		2.98	5.0						0.61
Olinsky	"	300	"	4	"	x		2.61	5.0						0.16
#18 Jack Chain	27	450	Yes	4	"	x		3.84	5.0						0.12
5x5 Glass Tubes	"	"	"	4	"	x		3.38	5.0						0.21
6 mm. Glass Beads	27	300	No	4	#1 + 15% 1:1:1		x	3.01	5.0						0.64
6 mm. Glass Beads	27	300	No	4	#1 + 20% 2:1:1		x	5.91	10.0						0.63
"	"	"	Yes	4	"		x	5.78	10.0						0.77
"	"	450	"	4	"		x	7.11	10.0						0.76
"	"	600	"	4	"		x	9.40	10.0						0.25
"	"	"	No	1.2	"		x	9.84	10.0						0.19
Lessing Rings	22	400	"	1.5	"		x	6.45	10.0	6.56	4.28	19.29	20.0	0.71	0.30
6 mm. Glass Beads	27	600	Yes	4	"	x		9.00	10.0	5.12	4.70	18.82	20.0	1.18	0.13
5x5 Glass Tubes	"	450	"	4	"	x		3.60	10.0	5.70	4.62	18.90	20.0	1.10	0.13
#18 Jack Chain	"	"	"	4	"	x		7.92	10.0	5.92	5.33	19.07	20.0	0.97	0.09

TABLE I (continued)

Packing Type	Column Type I.D. m.m.	Length m.m.	Air Jacket	Rate c.c./min.	Gasoline	Fraction Limits I.B.P.-55° 55-95	I.B.P.-60° 60-95	% Benzene Found	% Benzene Prepared	% Toluene Found	% Aromatic Residue Found	Total Aromatics Found	Total Aromatics Prepared	Error %	% Aromatics in Forerun
6 mm. Glass Beads	27	600	Yes	4	#2 + 20% 2:1:1		x	9.73	10.0						0.13
Lessing Rings	22	400	No	1.25	"		x	8.85	10.0	4.70	5.34	18.90	20.0	1.10	0.52
"	"	"	"	4	"		x	8.10	10.0	4.88	5.20	18.18	20.0	1.82	1.20
6 mm. Glass Beads	27	600	Yes	4	"	x		9.40	10.0	4.35	4.41	18.16	20.0	1.84	0.09
#18 Jack Chain	"	320	"	4	"	x		9.32	10.0	4.64	3.93	17.99	20.0	2.01	0.29
"	"	450	"	4	"	x		9.66	10.0	4.83	5.78	20.27	20.0	0.27	0.05
5x5 Glass Tubes	"	"	"	4	"	x		10.44	10.0	4.30	5.47	20.21	20.0	0.21	0.00
6 mm. Glass Beads	27	600	Yes	4	#2 + 7% Benzene		x	6.10	7.0						0.42
Lessing Rings	22	400	No	1	"	x		5.66	7.0	0.03	0.00	5.70	7.0	1.30	1.01
#18 Jack Chain	27	320	Yes	4	"	x		5.88	7.0	0.38	0.00	6.26	7.0	0.74	0.77
6 mm. Glass Beads	27	600	Yes	4	#2 + 5% Benzene, 7% Toluene, 7% Xylene	x		5.14	5.0	6.40	7.58	19.12	19.0	0.12	0.00
"	"	"	"	4	(1) [redacted] Hydroform	x		0.69	unknown	0.62	7.55	8.86	9.2	0.34	0.00
"	"	"	"	4	(2) Palembang - 20% Aromatic	x		2.06	"	2.24	14.12	18.42	20.2	1.78	0.00
"	"	"	"	4	(3) 80% Houdry 2 Pass	x		2.18	"	7.07	14.40	23.65	24.2	0.55	0.11
6 mm. Glass Beads	27	600	Yes	4	A(1) Base + 4.6% Xylene, 4.6% Cumene	x		0.00	0.0	0.41	8.02	8.43	9.2	0.77	0.00
"	"	"	"	4	B(2) Base + 2% Benzene, 2% Toluene 8% Xylene, 8% Cumene	x		2.18	2.0	2.35	14.50	19.10	20.0	0.90	0.00
"	"	"	"	4	C(3) Base + 2.5% Benzene, 7% Toluene 7.35% Xylene, 7.35% Cumene	x		2.87	2.5	7.12	13.90	23.89	24.2	0.31	0.05

* Aviation gasoline containing 12.6% Cumene by volume.

#1-Synthetic blend: 80% 2,2,4-trimethyl pentane, 10% methexane, 10% isopentane

#2-81 + 1 gasoline with aromatics removed by SiO_2

1:1:1 - Benzene:toluene:cumene

2:1:1 - Benzene:toluene:cumene

Fraction limits as follows: Benzene, 60° - 95° C (55° - 95° C); Toluene 95° - 123° C; higher aromatics, above 123° C.

TABLE 2

Column Efficiencies as Determined for the System Benzene-Carbon Tetrachloride

Column Packing	Column Length, mm	Column I.D.mm	Distillation Rate, cc/min	Elapsed* Time min.	Total Operating Plates	Column Operating Plates ‡	H.E.T.P. cm	Comments
Glass tubing 5 mm O.D. x 5 mm long; not fire polished	450	27	4	0	5.3	4.3	10.6	Air jacket
	"	"	"	5	3.0	2.0	22.5	
6 mm Glass Beads	600	27	4	0	7.5	6.5	9.2	Air jacket
	"	"	"	5	4.5	3.5	17.1	
1/4" Lessing Rings	400	22	1.5	0	4.0	3.0	13.3	No air jacket
	"	"	"	5	3.0	2.0	20.0	
	"	"	3.0	10	2.6	1.6	25.0	
1/4" Lessing Rings	400	22	1.25	0	4.3	3.3	12.3	No air jacket
	"	"	1.5	5	3.0	2.0	20.0	
	"	"	4	10	2.2	1.2	34.2	
#18 Jack Chain	300	27	4	0	4.5	3.5	8.6	Air jacket
	"	"	4	5	2.5	1.5	20.0	

* From first drop of distillate collected

‡ still pot assumed = 1 plate

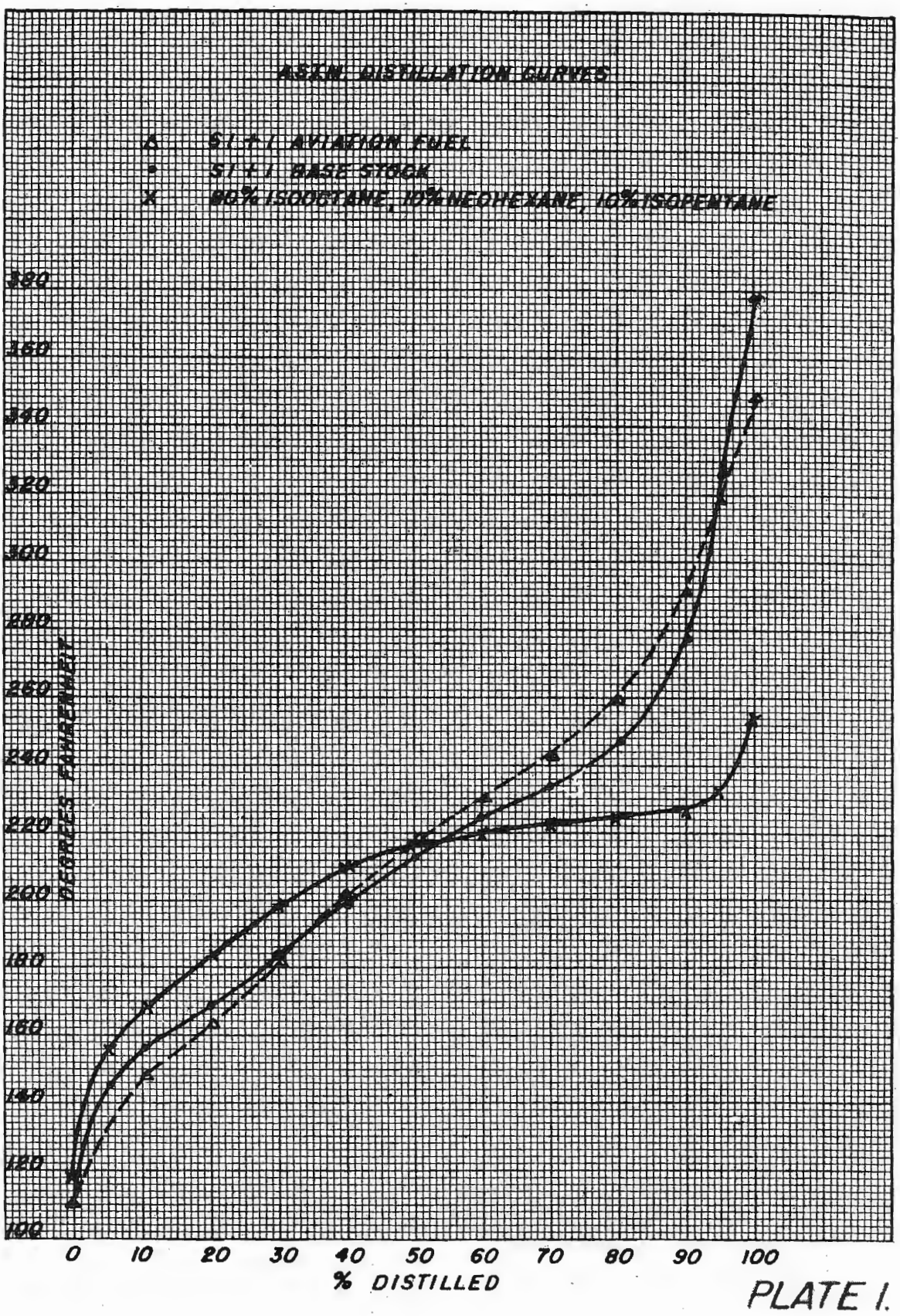
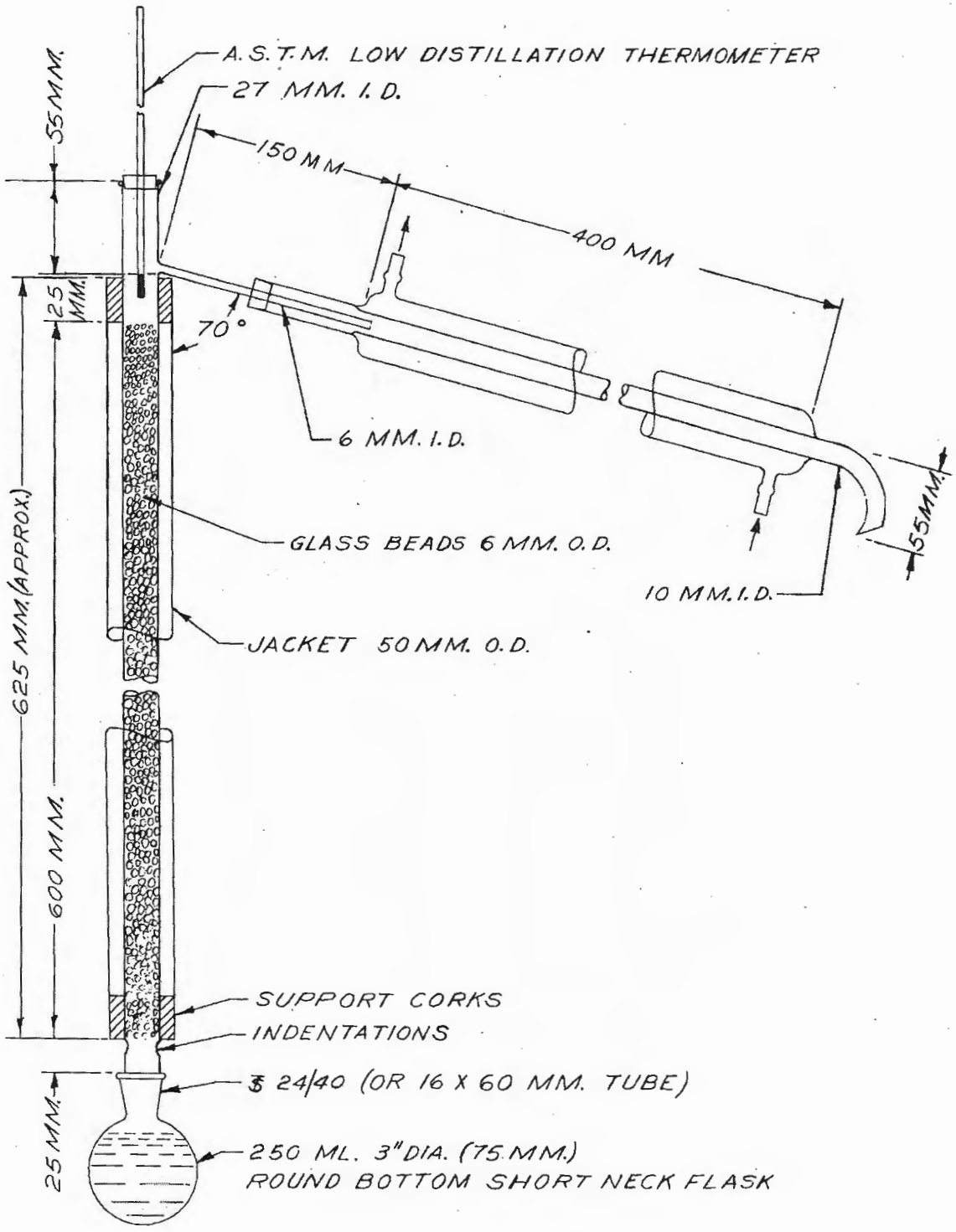

ASTM DISTILLATION CURVES
S1 + 1 AVIATION FUEL
S1 + 1 BASE STOCK
80% ISOOCTANE, 10% NEOHEXANE, 10% ISOPENTANE
DEGREES FAHRENHEIT
100
120
140
160
180
200
220
240
260
280
300
320
340
360
0
10
20
30
40
50
60
70
80
90
100
% DISTILLED

PLATE I.



DISTILLATION APPARATUS FOR SEPARATING
AROMATIC FRACTIONS OF AVIATION FUEL

PLATE 2

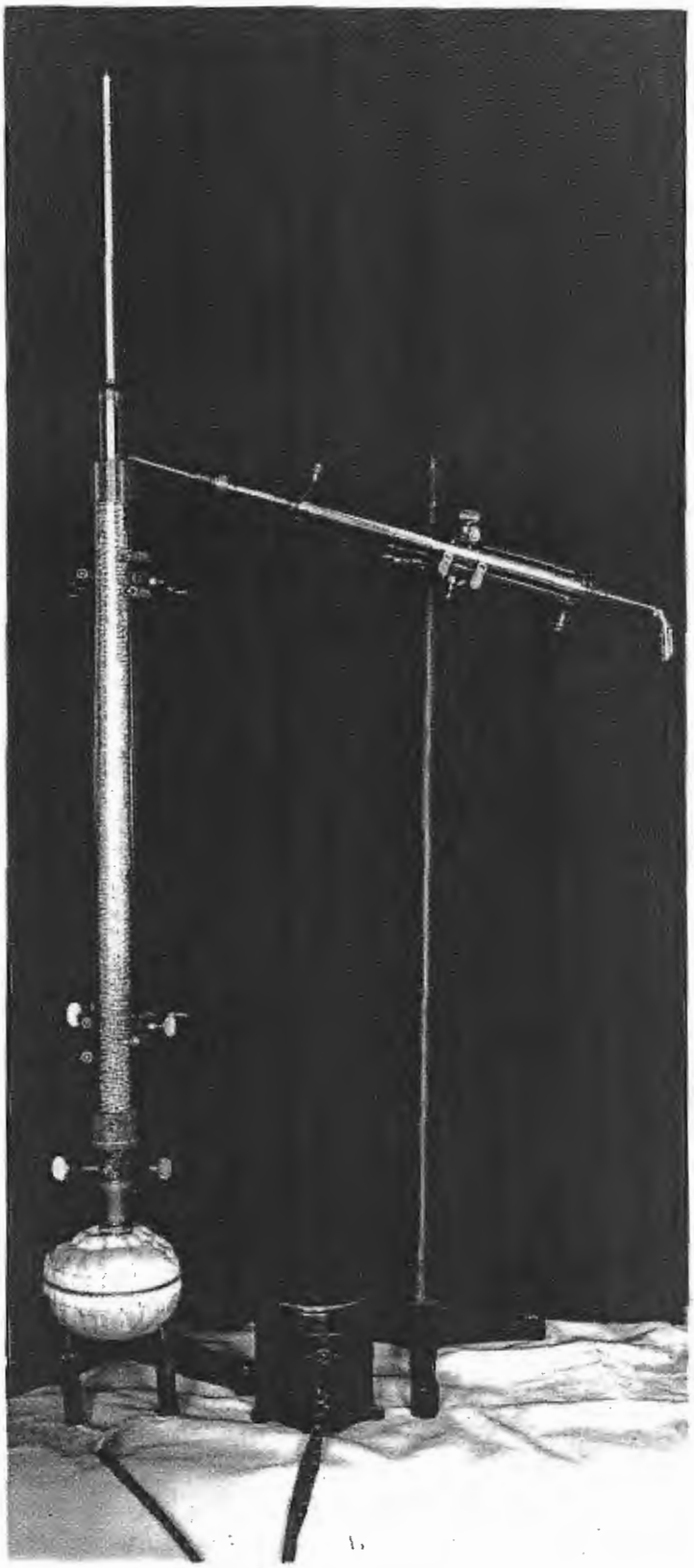


PLATE 3