DETERMINATION OF IGNITION CHARACTERISTICS OF HYDRAULIC FLUIDS

PART II

FLAMMABILITY REFERENCE SCALE

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SUMMARY

A need exists for a means to determine the flammabilities of fluids by some simple test method that can be readily conducted in any laboratory. Methods such as determination of the flash point, fire point, spontaneous ignition temperature and the spray flammability limit, are inconsistent and do not represent a true evaluation of the flammabilities of the fluids. Also, other simpler methods, such as the various wick tests, fail to provide a true evaluation of flammability. The flame-length scale was the first step toward the development of a useable method in that it would clearly discriminate between the flammable and nonflammable fluids. The per cent nonflammable scale was developed as a useable scale for determining the relative flammabilities of hydraulic fluids and lubricating oils. The latter scale covers a range of flammabilities from fluids more flammable than aviation gasoline down to a level which is considered nonflammable as determined by full-scale simulated flight conditions and simulated crash conditions.

INTRODUCTION

This work is a continuation of the work accomplished for Part I of this report,[1] Recommendation 4 of which stated that, "Further study be applied to the development of a simple and standardized testing procedure, not requiring the use of an aircraft engine, but equivalent to practical aircraft conditions, by which any laboratory could test, qualitatively, the ignitability or flammability of hydraulic or other aircraft fluids." The equipment used in simulating crash conditions in Part I of this report was revised, simplified and adapted to the determination of the flammability reference numbers of fluids. The flammability reference numbers of the test fluids, to be of any practical value, had to be in agreement with their relative flammabilities as established by exposure of the fluids to the conditions existing in an operating aircraft power plant.

DESCRIPTION OF TEST EQUIPMENT

The equipment used in conducting these tests consisted essentially of an air-operated, hydraulic cylinder for discharging fluids into the atmosphere, a source of ignition and a scale for measuring flame length. Fig. 1 shows the general arrangement of the apparatus for determining the flammability ratings of fluids.

A high-pressure air cylinder with a capacity of approximately 210 cubic inches is used as a source of power for operating the hydraulic cylinder. This air cylinder is equipped with a filler valve, a pressure gauge (0-1,000 psi) and an outlet for connecting 1/2-inch copper tubing. Copper tubing, 11 1/2 inches long and 1/2 inch o.d., is used for connecting the air cylinder with the other components. A quick opening valve, lever operated, is located just below the hydraulic cylinder assembly. A hole, 0.070-inch diameter, was drilled in the nipple between the quick opening valve and the hydraulic cylinder assembly to serve as a bleed to atmosphere. This hole permits the escape of air when the pistons are depressed manually and also prevents creeping of the pistons in case of a minute leak in the quick opening valve.

[1] J. J. Gassmann, "Determination of Ignition Characteristics of Hydraulic Fluids — Part I — Simulated Flight and Crash Conditions," Technical Development Report No 64, April 1951.

Please note that with the exception of the standard hydraulic fluids, the test fluids are either of a development nature or are primarily intended for other purposes and have been tested here only for the purpose of obtaining information.

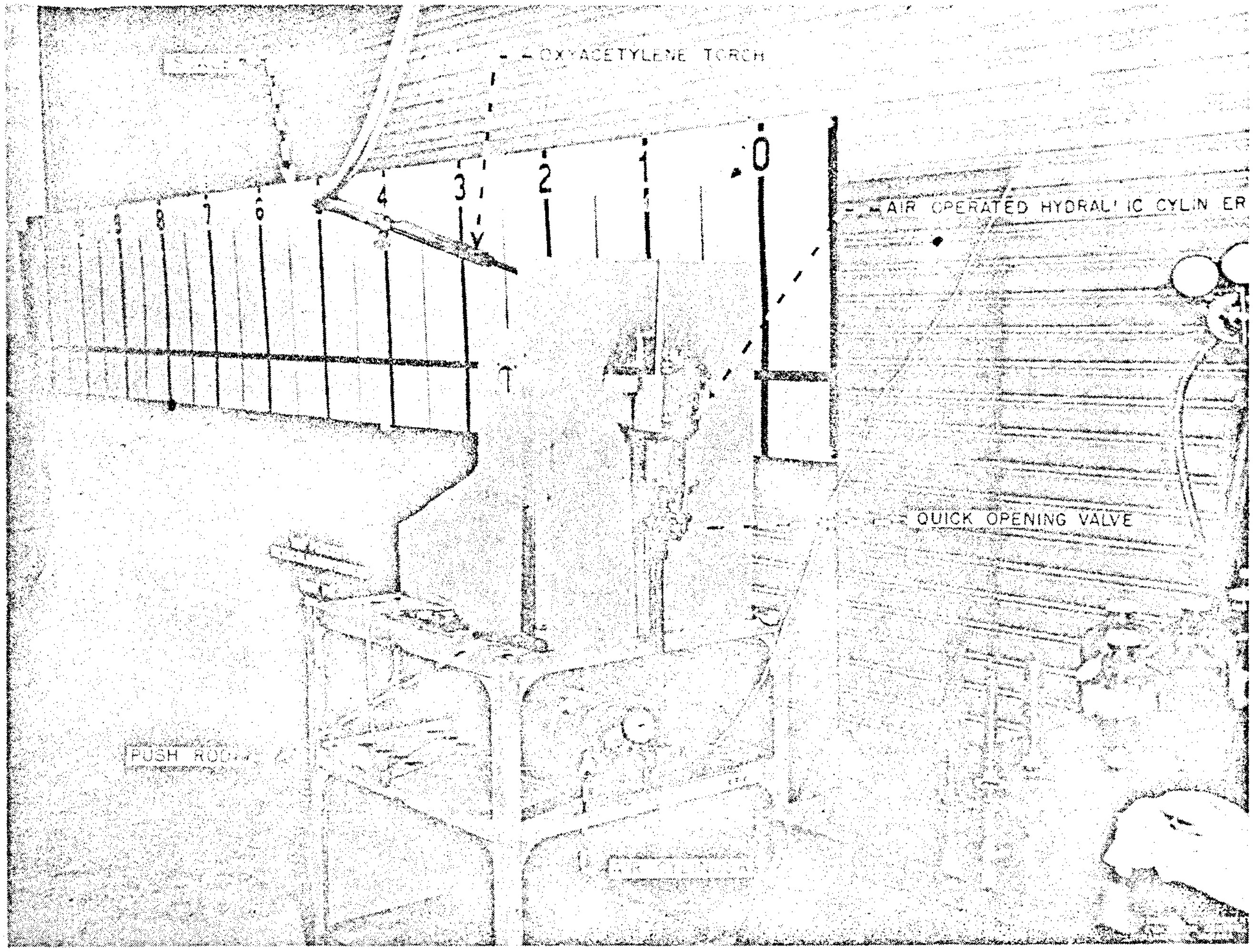


Fig. 1 Apparatus Used in Determining the Relative Flammabilities of Hydraulic Fluids and Lubricating Oils

The air-operated, hydraulic cylinder assembly, shown detailed in Fig. 2, has a capacity of 10 cc. The operating air piston has an area ten times that of the hydraulic piston, thus effecting a hydraulic pressure of ten times that of the operating air pressure. The orifice of 0.040-inch diameter directs the fluid stream horizontally past an ignition source. A thermometer well is located in the hydraulic cylinder block so that the temperature of the block, and hence that of the test fluid, can be determined.

The ignition source comprises the largest practical oxy-acetylene flame that can be produced by a Smith torch B-67 tip. The tip is located so that the flame is directed vertically downward over the center line of the fluid stream, the end of the tip being 5 1/2 inches in front of, and 1 5/16 inches above, the orifice. A scale 11 feet long is mounted parallel to the hydraulic fluid stream. This scale is used for measuring the length of the resulting test flames beginning at the ignition source.

During the tests, fresh-air masks were worn by the operator and observers since many of the fluids used were of questionable toxicity.

TEST PROCEDURE

Operation of Equipment

The procedure followed in operating the test equipment is:

1. Remove filler plug at head of hydraulic cylinder and force piston to bottom of stroke using a suitable push rod.
2. Fill cylinder with 10 cc of test fluid.
3. Replace filler plug and secure.
4. Fill air bottle to desired air pressure.
5. Ignite oxy-acetylene torch and adjust flame to largest practical for tip used.

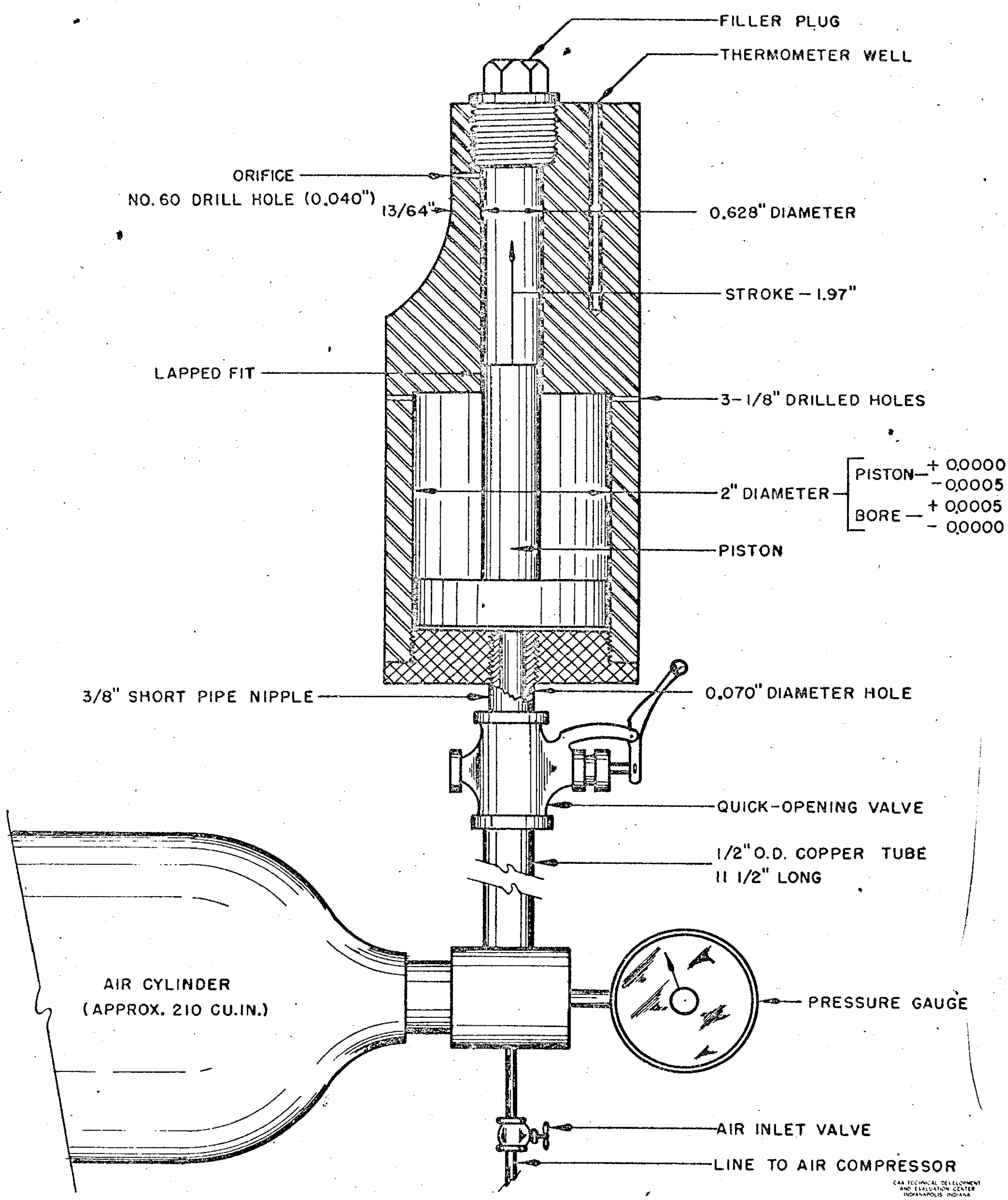
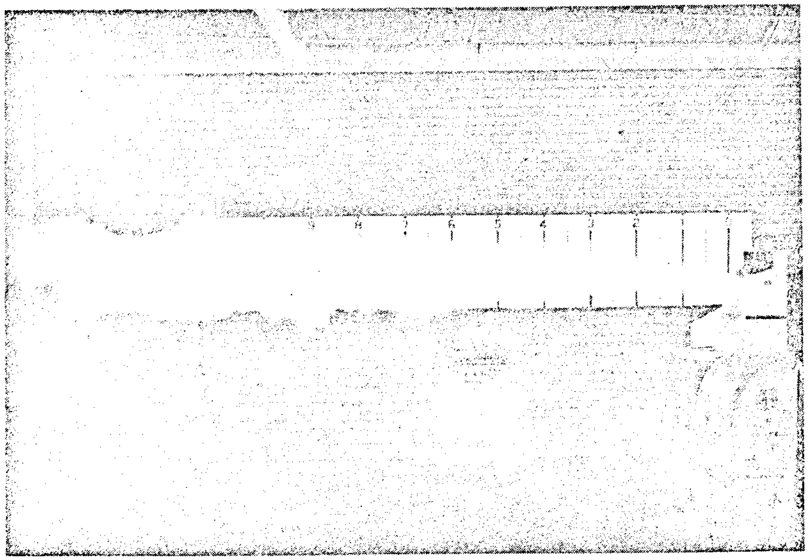
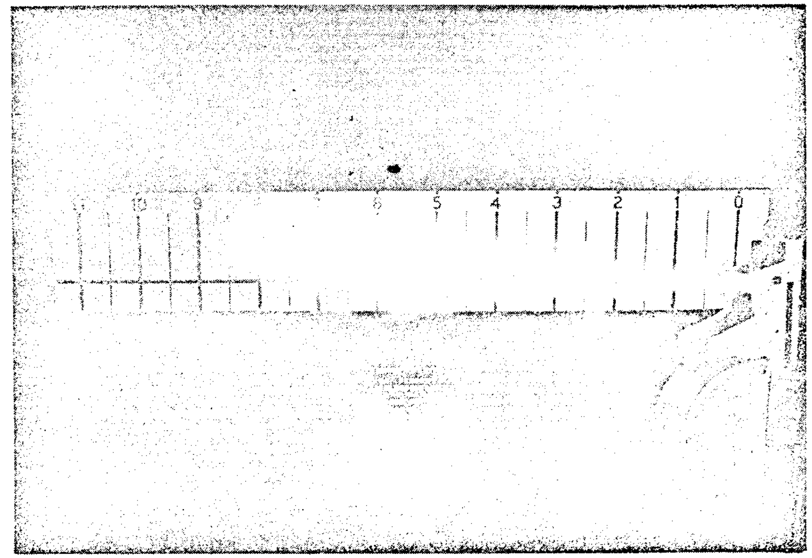


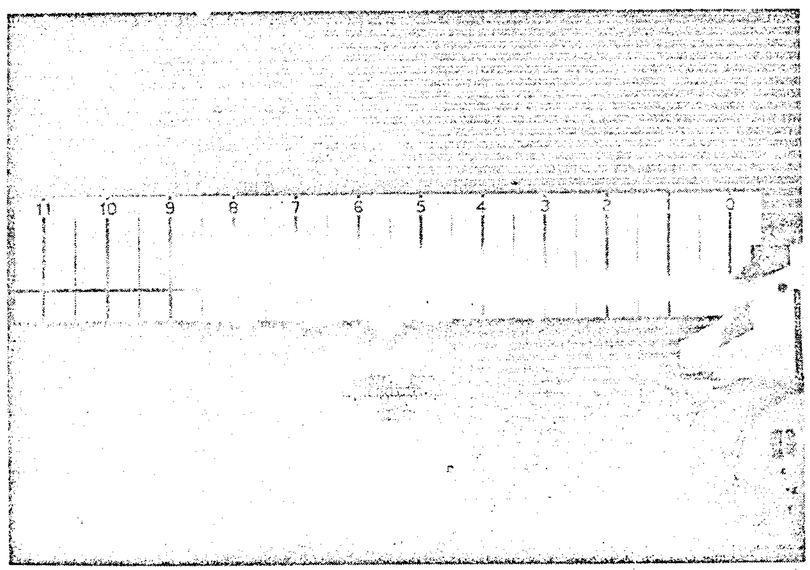
Fig. 2 Sketch of the Air-Operated Hydraulic Cylinder Assembly



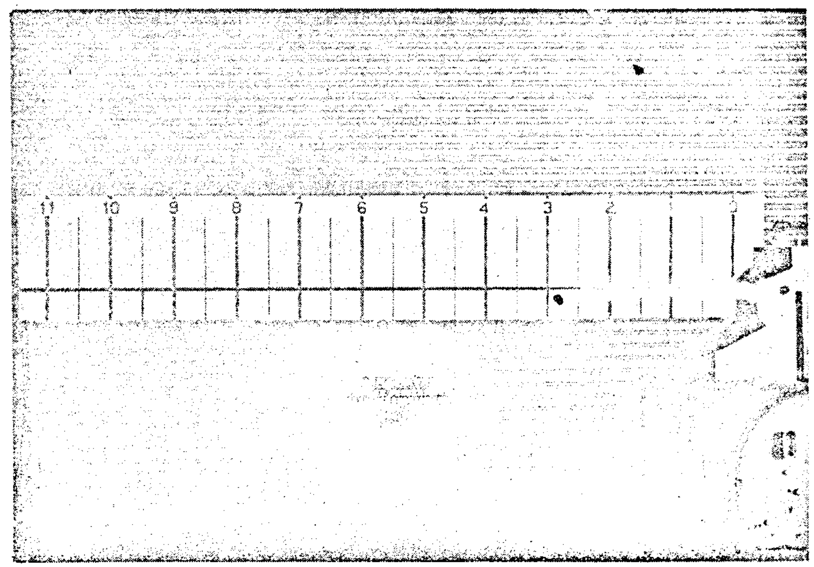
(A) Pure Fluid Sample "S"



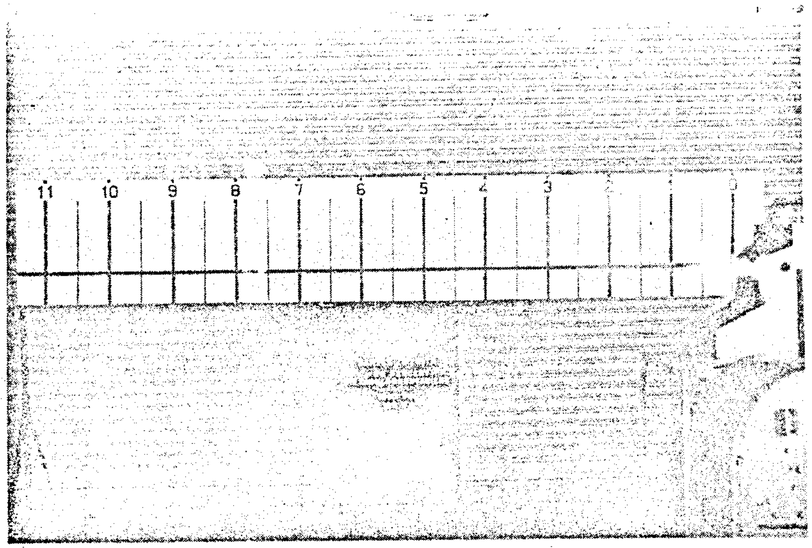
(B) Fluid Sample "S" with 52% Hexachlorobutadiene



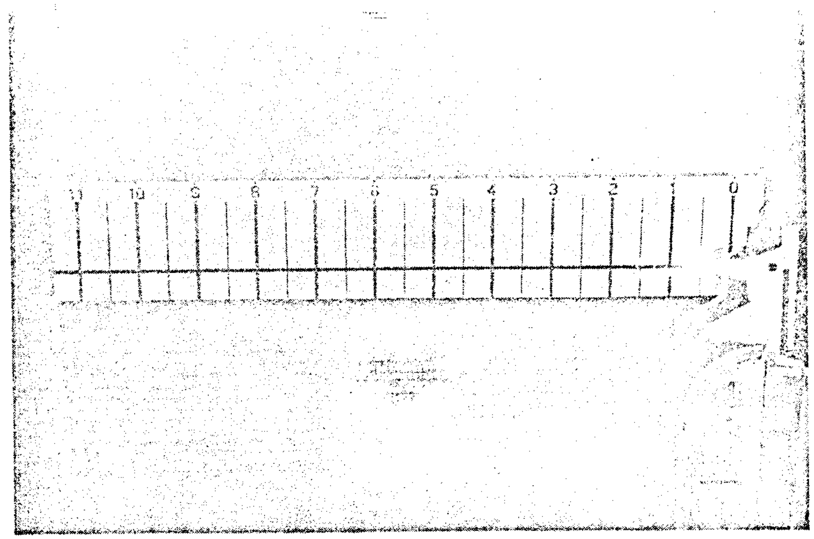
(C) Fluid Sample "S" with 54% Hexachlorobutadiene



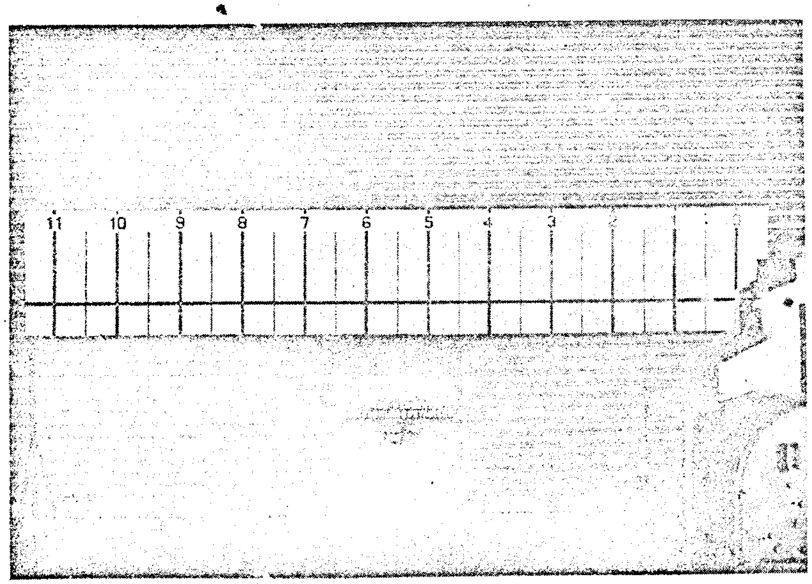
(D) Fluid Sample "S" with 55% Hexachlorobutadiene



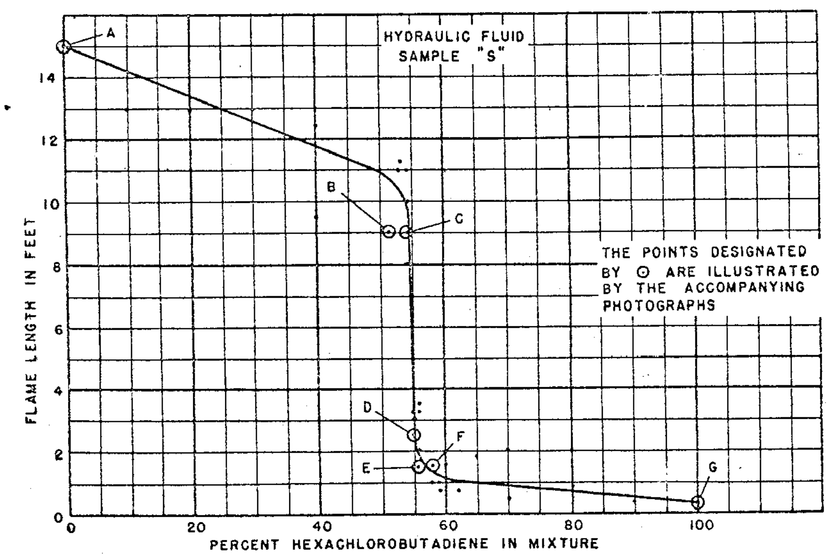
(E) Fluid Sample "S" with 56% Hexachlorobutadiene



(F) Fluid Sample "S" with 58% Hexachlorobutadiene



(G) Pure Hexachlorobutadiene



(H) Typical Per Cent Hexachlorobutadiene-Flame Length Curve

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Fig. 3 Development of a Typical Per Cent Hexachlorobutadiene-Flame Length Curve, Including Photographs from which the Data Were Obtained

6. Check temperature of test fluid.
7. When desired temperature is reached, open the quick opening valve and observe results.

A slow rise of cylinder and test fluid temperature is caused by close proximity to the torch flame. With experience, the operator can determine the best procedure to use for obtaining proper cylinder and fluid temperatures, that is, whether to extinguish the torch flame between runs.

Determination of Relative Flammabilities by the Flame-Length Method

In determining the relative flammability of a fluid by the flame-length method, temperature of the fluid did not prove to be important. The fluids were discharged at a pressure of 3,000 psi; therefore, the air cylinder was charged to a pressure of 300 psi prior to each test. The results were tabulated and expressed as large fire, small fire or no fire.

Determination of Relative Flammabilities by the Per Cent Nonflammable Method

In determining the relative flammability of a fluid by the per cent nonflammable method, a more complex procedure was required. It was first necessary to select a fluid that was nonflammable and generally miscible with petroleum oils, the latest developed hydraulic fluids and compounds proposed for future use as oils or hydraulic fluids. Fluids such as water, hexachloropropene, perfluoro amines, tricresylphosphate and hexachlorobutadiene were investigated. Hexachlorobutadiene was selected because it was nonflammable, miscible with the greatest number of fluids in question and capable of giving the greatest spread in results.

Fluid temperature at the time of discharge was important. A temperature of 120°F was selected as being a reasonable operating temperature. The fluid was discharged at a pressure of 1,000 psi; therefore, the air cylinder was charged to a pressure of 100 psi prior to each test.

The flammability reference number of a fluid was determined by the per cent hexachlorobutadiene that had to be added to the fluid in order to produce a sharp decrease in flame length. This was accomplished in the following manner:

1. A 10 cc sample was prepared. This sample was made up of fluid to be tested and a selected percentage of hexachlorobutadiene.
2. The sample was shaken in a test tube, by hand, and then subjected to the flame test previously described. Since the fluids are necessarily miscible with hexachlorobutadiene, the amount of shaking is not critical as long as the fluids appear mixed.
3. The resulting flame length was noted.
4. This result was plotted as flame length versus per cent hexachlorobutadiene. See Fig. 3H. These four steps were repeated, using a different percentage of hexachlorobutadiene for each test, until a pronounced sharp drop in the curve appeared. This portion of the curve, corresponding to the per cent of hexachlorobutadiene required to produce it, designated the flammability reference number of the particular fluid.

RESULTS AND DISCUSSION

Flame-Length Method

In order to illustrate the principle involved in the flame-length method of determining relative flammability, only a partial list is shown in this report. The fluids selected and the flame length each produced are listed in Table I.

TABLE I

Fluid	Flame Length (feet)
Santicizer 140	15
Tricresylphosphate	15
366 base stock	15
Trioctylphosphate	13
Gasoline (100 octane)	11
Formulation No. 9	4
Hydrolube	less than 6 inches

These results indicate that the first five fluids are flammable, Formulation No. 9 much less flammable and Hydrolube nonflammable. It is an established fact that gasoline is more flammable than light oil and certainly more flammable than tricresylphosphate. However, the flame-length method indicated gasoline to be somewhat less flammable than either of the other two fluids. Obviously, this method does not give true relative flammability. A scale based on such a method can only differentiate between flammable and nonflammable fluids, and, therefore, was abandoned.

Per Cent Nonflammable Method

The principle involved in determining the relative flammability of a fluid by the per cent nonflammable method can best be illustrated by the representative curve shown in Fig. 3H. This curve was developed by plotting percentages of hexachlorobutadiene in fluid S (by volume) against the flame lengths produced by subjecting each such mixture to the flame test previously described. Fig. 3A is a photo of a flame test of pure sample S (zero per cent hexachlorobutadiene) and is shown as point A on the curve. The other six photos show flames from mixtures containing increasing percentages of hexachlorobutadiene, the last one being of 100 per cent hexachlorobutadiene and shown as point G on the curve. Close inspection of this curve will indicate that the flame length decreased gradually to point C corresponding to 54 per cent hexachlorobutadiene. Point D corresponding to 55 per cent of hexachlorobutadiene resulted in a sudden, decided, decrease in flame length. Points corresponding to 56 per cent of hexachlorobutadiene and up to 100 per cent continued to show additional slight reduction in flame length. Since 55 corresponded to the per cent of hexachlorobutadiene required to produce the sharp decrease in flame length, it was the number used to designate the relative flammability of fluid sample S on this scale.

Fluids such as hexachlorobutadiene and Hydrolube, which produce flame lengths of less than six inches, have flammability reference numbers of zero on this scale. Pure Formulation No. 9 produces a 4-foot flame. When it is mixed with hexachlorobutadiene, there is no sharp decrease of flame length as the percentage of hexachlorobutadiene is increased. The flame length decreases gradually until 40 per cent hexachlorobutadiene has been added at which point the flame is less than one foot long. It has been estimated, therefore, that Formulation No. 9 has a flammability reference number of less than 30, but it was not possible to place Formulation No. 9 accurately on this scale. Generally, this scale is not adaptable to fluids which produce flames less than ten feet in length.

Another shortcoming of this scale is its limitation to fluids that are miscible with hexachlorobutadiene. For example, the relative flammability of the Cook Electric 909 fluid cannot be determined by this method since it is a water-soluble fluid and will not mix with hexachlorobutadiene. Table II lists a number of fluids with their flammability reference numbers as determined by this method, in addition to the flash points, the fire points, the spontaneous ignition temperatures and the spray flammability limits as determined by others. A study of Table II will serve to illustrate that no pattern of true flammability is evidenced by any method mentioned in this report other than the per cent nonflammable method. Fig. 4 shows

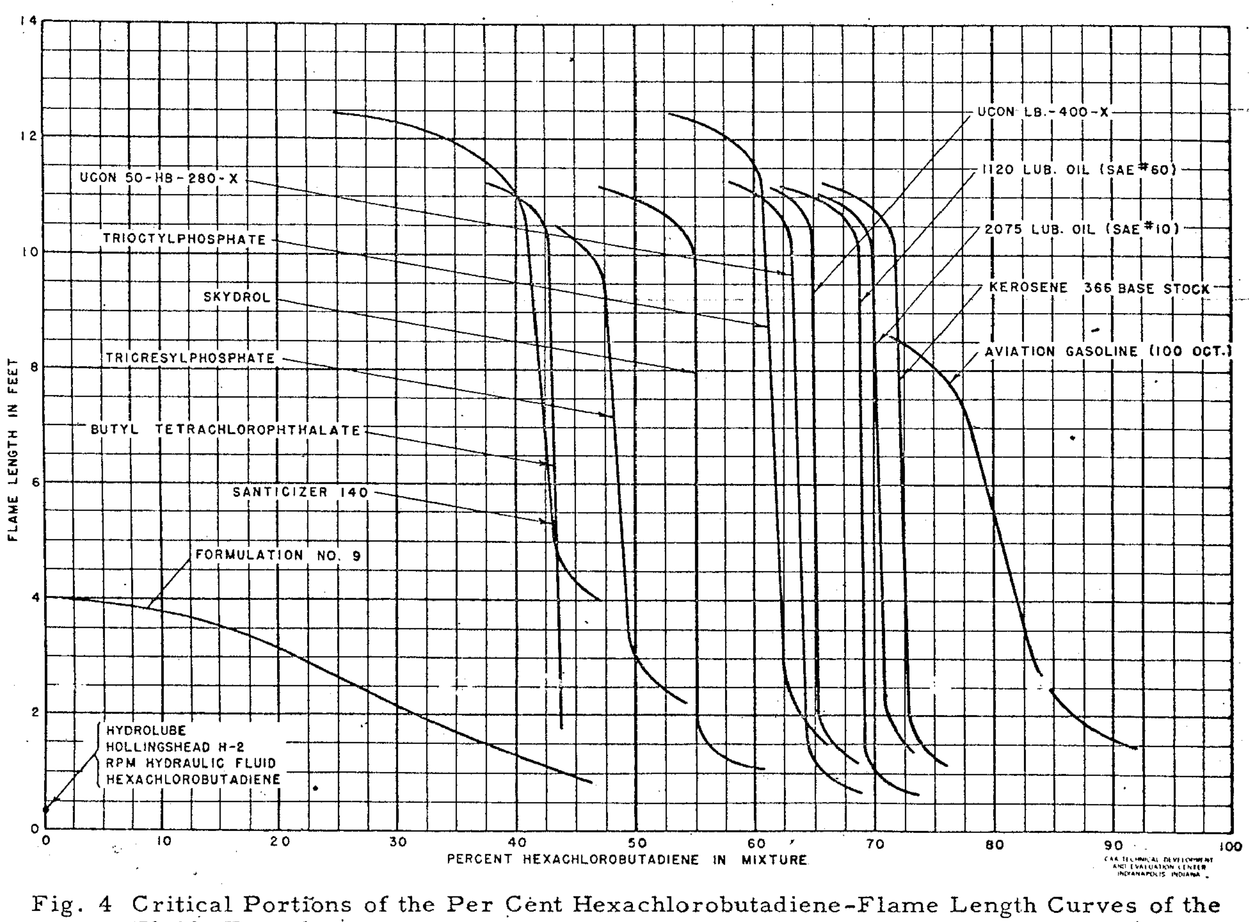

Fig. 4 Critical Portions of the Per Cent Hexachlorobutadiene-Flame Length Curves of the Fluids Tested

TABLE II

Flammability Characteristics Of Fluids

Fluid	Supplier	Flash Point °F	Fire Point °F	Spontaneous Ignition Temp. °F **	Spray Flammability Limit** % Oxygen	Flammability Reference No.
Aviation gasoline (100 oct.)		12**		1295	12	80
366 base stock	Standard Oil Dev. Co.	215*	220*	500	12	72
Kerosene	The Texas Co.	130*				72
Lub. oil 2075 (SAE No. 10)	The Texas Co.	340*	380*			70
Lub. oil 1120 (SAE No. 60)	The Texas Co.	480*	620*			69
Ucon LB-400-X	Carbide & Carbon Chem. Corp.			752	54	65
Ucon 50-HB-280-X	Carbide & Carbon Chem. Corp.	500*	600*	743	43	64
Trioctylphosphate	Standard Oil Dev. Co.	380**	465**	680	13	61
Skydrol	(Monsanto Chemical Co.) (Douglas Aircraft Co.)	360*	470*	>1300*	25	55
Tricresylphosphate	Monsanto Chemical Co.	500**	685**	1170	19	48
Butyl Tetrachlorophthalate	Commercial Solvents Corp.					44
Santicizer 140	Monsanto Chemical Co.					42
Formulation No. 9	Monsanto Chemical Co.					<30
Hexachlorobutadiene	Standard Oil Dev. Co.	None*	None*	>1000	77	0
Hydrolube				885	67	0
Hollingshead H-2	Hollingshead Research Div.					0
RPM Hydraulic fluid	California Research Corp.					0
Perfluorotriethylamine	Minnesota Mining & Mfg. Co.					0
Perfluorodiethylpropylamine	Minnesota Mining & Mfg. Co.					0
Hexachloropropene	Dow Chemical Co.					0

* Manufacturers' data.

** From "Flammability of the Higher Boiling Liquids and Their Mists" by M. V. Sullivan, J. K. Wolfe and W. A. Zisman.

the critical portions of the per cent hexachlorobutadiene-flame length curves which determined the relative flammability numbers of the fluids listed in Table II.

CONCLUSIONS

1. The per cent nonflammable method based on hexachlorobutadiene is a means for determining the relative flammabilities of most fluids intended for use as aircraft lubricating oils or hydraulic fluids. Relative flammabilities as determined by this scale correlate satisfactorily with results obtained under simulated flight and crash conditions.
2. The flashpoint, fire point, spontaneous ignition temperature, spray flammability limit and flame-length methods are not suitable for determining the relative flammabilities of the fluids tested.

RECOMMENDATIONS

It is recommended that:

1. Work on the development of a flammability scale be continued so that all fluids can be rated, possibly employing such methods as addition of an emulsifying agent or ultrasonic vibration to facilitate in mixing fluids which are normally noncompatible.
2. The use of fluids other than hexachlorobutadiene as the nonflammable portion be investigated.
3. Cognizance be given to the possibility of adding sufficient hexachlorobutadiene to an existing less flammable fluid to form a useable nonflammable hydraulic fluid.
4. This equipment be used in determining the amount of "snuffing" agent required to produce a nonflammable "snuffer"-type fluid. A "snuffer"-type fluid is a fluid obtained by mixing a nonflammable additive with a flammable fluid in order to reduce its flammability.

ACKNOWLEDGMENT

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