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AF TECHNICAL REPORT NO. 5872

ATI No. 137139
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FIRE EXTINGUISHING AGENTS FOR ROCKETS FUELS

(This report supersedes AF Technical Report No. 5872, Fire Extinguishing Agents For Jet Fuels, September, 1951. The Change from "Jet Fuels" to "Rocket Fuels" in the title also governs throughout the report.)

ZARA D. WELCH
HAROLD ROSENBERG
EARL T. McBEE

PURDUE UNIVERSITY

SEPTEMBER 1951

WRIGHT AIR DEVELOPMENT CENTER

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Purdue University, Research Foundation, Lafayette, Ind.

Fire Extinguishing Agents for Rocket Fuels - and Appendix

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Zara D. Welch
Harold Rosenberg
Earl T. McBee

Purdue University

September 1951

Equipment Laboratory
Contract No. AF 33(038)-10959
E. O. No. 664-739

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

McGregor & Werner, Inc.
Dayton, O. 100, 18 June 52

FOREWORD

The investigation covered in this report was conducted by Purdue Research Foundation and The Department of Chemistry, Purdue University under the research and development project identified by Contract No. AF 33(038)-10959 and Expenditure Order No. 664-739, Development of Fire Extinguishing Agents. It was administered under the direction of the Equipment Laboratory, Weapons Component Division, Wright Air Development Center, Air Research and Development Command, Mr. R. R. Stasiak acting as project engineer. The research and testing described herein was carried out by Dr. Harold Rosenberg under the general supervision of Dr. Zara D. Welch. Dr. Earl T. McBee served as director of the project.

Included among those who cooperated in the study were: Dr. O. R. Pierce, C. D. Caldwell, H. F. Eckhardt, W. Eldridge, V. A. Fauver, W. E. Fish, S. J. Gottlieb, J. V. Hession, J. W. Johnson and W. J. Wheeler, all of Purdue University.

ABSTRACT

Results of the testing of the effectiveness of certain fire extinguishing agents in reducing the flammability of rocket fuel-air mixtures are described. Information is given on experiments conducted to determine the reactivity of fluorine with these fire-retarding materials. These tests were carried out in order to ascertain the suitability of the latter compounds for extinguishing fluorine fires. Significant features of the apparatae employed and procedures followed are pictured and discussed. On the basis of the results obtained in the case of four out of six fuels tested, it is concluded that 1,2-dibromotetrafluoroethane is the most effective extinguishing agent of the compounds tested for combatting rocket fuel fires. Results of the fluorine-extinguisher reactivity tests indicate that it is unlikely that any of the extinguishers tested could be used successfully in fighting fires involving fluorine.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDING GENERAL:

Harry E. McCabe
1st Lt USAF
for GORDON A. BLAKE
Brigadier General, USAF
Chief, Weapons Components Division

TABLE OF CONTENTS

	Page
FOREWORD	ii
ABSTRACT	iii
INTRODUCTION	1
SECTION I - NON-FLUORINE FUELS	3
Equipment	3
Original Apparatus	3
Modified Apparatus I	6
Modified Apparatus II	10
Test Materials	13
Jet Fuels	13
Hydrogen	13
Ammonia	13
Methanol	13
Ethanol	13
Nitromethane	14
Hydrazine	14
Furfuryl Alcohol	14
Aniline	14
Fire Extinguishers	14
Carbon Dioxide	14
Methyl Bromide	15
Bromochloromethane	15
Dibromodifluoromethane	15
1,2-Dibromotetrafluoroethane	15
Extinguisher Tests	16
Hydrogen	16
Ammonia	23
Methanol	28
Ethanol	35
Nitromethane	35

Page

Hydrazine - 49

Furfuryl Alcohol - - - - - - - - - - - - - - - - 49

Aniline - 50

Summary of Test Results - - - - - - - - - - - - - 50

SECTION II - FLUORINE - - - - - - - - - - - - - - - - - - 57

Equipment - 57

Fluorine-Extinguisher Reactivity Apparatus - - - - - - - - - - - - - - - - - - - 57

Modified Reactivity Apparatus - - - - - - - - - 62

Test Materials - - - - - - - - - - - - - - - - - - 65

Fuel - 65

Fluorine - - - - - - - - - - - - - - - - - - 65

Nitrogen - - - - - - - - - - - - - - - - - - 65

Fire Extinguishers - - - - - - - - - - - - - - - 65

Bromotrifluoromethane - - - - - - - - - - - 65

Reactivity Tests - - - - - - - - - - - - - - - - - 65

BIBLIOGRAPHY - 68

APPENDIX - 69

LIST OF ILLUSTRATIONS

SECTION I - NON-FLUORINE FUELS

Figure		Page
1	Apparatus for the Determination of Flammability Limits at Various Temperatures (Diagram) - - - - - -	4
2	Apparatus for the Determination of Flammability Limits at Various Temperatures (Photograph) - - - - -	4a
3	Modified Pumping System for High-Temperature Combustion Apparatus - - - - - - - - - - - - - - - - -	7
4	Modified Manifold and Gas Measuring System for High-Temperature Combustion Apparatus - - - - - - - - - -	8
5	Remodified Manifold and Trap - - - - - - - - - - - -	11
6	Remodified High-Temperature Combustion Apparatus (Side-View) -	12
7	Flammable Area for Mixtures of Hydrogen, Carbon Dioxide and Air - - - - - - - - - - - - - - - - - - -	17
8	Flammable Area for Mixtures of Hydrogen, Methyl Bromide and Air - - - - - - - - - - - - - - - - - - -	18
9	Flammable Area for Mixtures of Hydrogen, Bromochloromethane and Air - - - - - - - - - - - - - - - - -	19
10	Flammable Area for Mixtures of Hydrogen, Dibromodifluoromethane and Air - - - - - - - - - - - - - - -	20
11	Flammable Area for Mixtures of Hydrogen, 1,2-Dibromotetrafluoroethane and Air - - - - - - - - - - - -	21
12	Flammable Areas for Mixtures of Hydrogen, Extinguishers and Air - - - - - - - - - - - - - - - - - -	22
13	Flammable Area for Mixtures of Ammonia, Carbon Dioxide and Air - - - - - - - - - - - - - - - - - - -	25
14	Flammable Area for Mixtures of Ammonia, Methyl Bromide and Air - - - - - - - - - - - - - - - - - - -	26
15	Flammable Areas for Mixtures of Ammonia, Extinguishers and Air - - - - - - - - - - - - - - - - - - -	27
16	Flammable Area for Mixtures of Methanol, Carbon Dioxide and Air - - - - - - - - - - - - - - - - - - -	29

Figure		Page
17	Flammable Area for Mixtures of Methanol, Methyl Bromide and Air - - - - - - - - - - - - - - -	30
18	Flammable Area for Mixtures of Methanol, Bromochloromethane and Air - - - - - - - - - - - - -	31
19	Flammable Area for Mixtures of Methanol, Dibromodifluoromethane and Air - - - - - - - - - -	32
20	Flammable Area for Mixtures of Methanol, 1,2-Dibromotetrafluoroethane and Air - - - - - - -	33
21	Flammable Areas for Mixtures of Methanol, Extinguishers and Air - - - - - - - - - - - - - - -	34
22	Flammable Area for Mixtures of Ethanol, Carbon Dioxide and Air - - - - - - - - - - - - - - -	36
23	Flammable Area for Mixtures of Ethanol, Methyl Bromide and Air - - - - - - - - - - - - - - -	37
24	Flammable Area for Mixtures of Ethanol, Bromochloromethane and Air - - - - - - - - - - - - -	38
25	Flammable Area for Mixtures of Ethanol, Dibromodifluoromethane and Air - - - - - - - - - -	39
26	Flammable Area for Mixtures of Ethanol, 1,2-Dibromotetrafluoroethane and Air - - - - - - - - - -	40
27	Flammable Areas for Mixtures of Ethanol, Extinguishers and Air - - - - - - - - - - - - - - -	41
28	Flammable Area for Mixtures of Nitromethane, Carbon Dioxide and Air - - - - - - - - - - - - - - -	43
29	Flammable Area for Mixtures of Nitromethane, Methyl Bromide and Air - - - - - - - - - - - - - - -	44
30	Flammable Area for Mixtures of Nitromethane, Bromochloromethane and Air - - - - - - - - - - - - -	45
31	Flammable Area for Mixtures of Nitromethane, Dibromodifluoromethane and Air - - - - - - - - - - - - -	46
32	Flammable Area for Mixtures of Nitromethane, 1,2-Dibromotetrafluoroethane and Air - - - - - - -	47
33	Flammable Areas for Mixtures of Nitromethane, Extinguishers and Air - - - - - - - - - - - - - - -	48

Figure		Page
34	Flammable Area for Mixtures of Aniline, Carbon Dioxide and Air - - - - - - - - - - - - - - -	51
35	Flammable Area for Mixtures of Aniline, Methyl Bromide and Air - - - - - - - - - - - - - - -	52
36	Flammable Area for Mixtures of Aniline, Bromochloromethane and Air - - - - - - - - - - - - -	53
37	Flammable Area for Mixtures of Aniline, Dibromodifluoromethane and Air - - - - - - - - - - -	54
38	Flammable Area for Mixtures of Aniline, 1,2-Dibromotetrafluoroethane and Air - - - - - - - -	55
39	Flammable Areas for Mixtures of Aniline, Extinguishers and Air - - - - - - - - - - - - - - - -	56
	SECTION II - FLUORINE	
40	Apparatus for the Determination of Reactivity of Fluorine with Extinguishers - - - - - - - - - -	58
41	Fluorine-Extinguisher Reactivity Apparatus - - - -	59
42	Detailed Photograph of Fluorine-Extinguisher Reactivity Apparatus - - - - - - - - - - - - - - -	60
43	Modified Fluorine Reactivity Apparatus for Use with High-Boiling Extinguishers - - - - - - - - - -	63
44	Detailed Photograph of Modified Fluorine-Extinguisher Reactivity Apparatus - - - - - - - - - -	64

INDEX OF TABLES

Table		Page
I	Summary of Compounds Evaluated as Fire Extinguishing Agents for Hydrogen Fires - - - - - -	16
II	Summary of Compounds Evaluated as Fire Extinguishing Agents for Ammonia Fires - - - - - -	28
III	Summary of Compounds Evaluated as Fire Extinguishing Agents for Methanol Fires - - - - - -	35
IV	Summary of Compounds Evaluated as Fire Extinguishing Agents for Ethanol Fires - - - - - -	42
V	Summary of Compounds Evaluated as Fire Extinguishing Agents for Nitromethane Fires - - - -	42
VI	Summary of Compounds Evaluated as Fire Extinguishing Agents for Aniline Fires - - - - - -	50
VII	Summary of Compounds Tested for Reactivity with Fluorine - - - - - - - - - - - - - - - - - -	66

INTRODUCTION

As a result of the rapid development of the jet propelled aircraft, the problem of applying safety measures against fires in the those aircraft arose quite suddenly. The need for a fire extinguishing agent(s) for combatting jet fuel fires was recognized early by the USAF and has been the subject of at least one research project to date.

Studies and investigations carried out at Purdue University during the years 1947-1950 (in cooperation with the Army Engineers Research and Development Laboratories) led to the development of new fire retarding agents for use in fighting class "B" and class "C" fires. Previously considerable work was done at the U.S. Bureau of Mines in determining the flammable limits of gases and fuels. This work included a study of the effects of certain inert materials upon these limits. The procedure used at the Bureau of Mines was modified in the study at Purdue to rate compounds in order of their flame extinction characteristics. A laboratory screening test of compounds for their fire inhibiting properties was set up by determining the limits of flammability of mixtures of fuel (n-heptane), air and the proposed extinguishing agent. The peak in the curve obtained by plotting data concerning the flammability of mixtures was considered as a measure of the effectiveness of the test compound as a fire retarding agent. This hypothesis was later shown to be valid by field tests conducted at Fort Belvoir.

As a result of this research at Purdue, the Air Forces became interested in the applicability of the results obtained therein to the problem of combatting jet fuel fires. A contract was negotiated by the Air Materiel Command and Purdue University for conducting investigations of the effectiveness of certain extinguishing agents in reducing the flammability of mixtures of air and specified jet fuels. The materials to be tested, with the exception of

carbon dioxide, were all halogen-containing compounds and included several of the agents found to be most effective in the earlier Purdue investigation.

A second phase of this research project was concerned with determining the suitability of the aforementioned halogen compounds for extinguishing fluorine fires. Fluorine was classed as a fuel with regard to this investigation. However, if actually used as a component of a jet combustion system, fluorine theoretically would be the oxidizing agent for reaction with a hydrocarbon or other organic fuel.

SECTION I - NON-FLUORINE FUELS

Equipment

The studies which were conducted to determine the flammable areas of the non-fluorine fuels with air and extinguishers were, in general, carried out in order of decreasing volatility of the fuels.

Original Apparatus

The apparatus initially used in this research program was one utilized previously in the earlier Purdue investigations[1]. It was reconditioned and minor modifications were made to permit handling of some less volatile materials. It proved adequate, however, only for studies carried out at room temperature and up to temperatures in the vicinity of 100°C. Thus the only fuels studied in this apparatus were hydrogen, ammonia, methanol and ethanol. A diagram of the apparatus is shown in Fig. 1 and a photograph in Fig. 2.

A pyrex combustion tube (A) of 51 mm inside diameter and 120 cm long was placed in a constant temperature bath (P). The bath was constructed of one-sixteenth inch sheet copper and was lagged with 1.5 inches of magnesia (not shown). For elevated temperatures P was filled with oil which was heated by the 750-watt nichrome wire immersion heaters (not shown). The rubber stopper (B), held on by atmospheric pressure, sealed the upper end of A and served as a relief valve in case of an explosion within the tube. The lower end of A was connected by means of 8 mm Pyrex tubing (C) to the gas mixing system. The upper end of A was connected to the gas mixing system by means of E. The gas mixing system consisted of the mercury piston (G) and the one-way check valves (F). Thus, when the mercury rose and fell in G, the gas mixture in A was circulated and thoroughly blended into a homogeneous mixture. Relay (J) and solenoids (I_1 and I_2) controlled the pump action in G by regulating the flow of compressed air into the mercury reservoir (H).

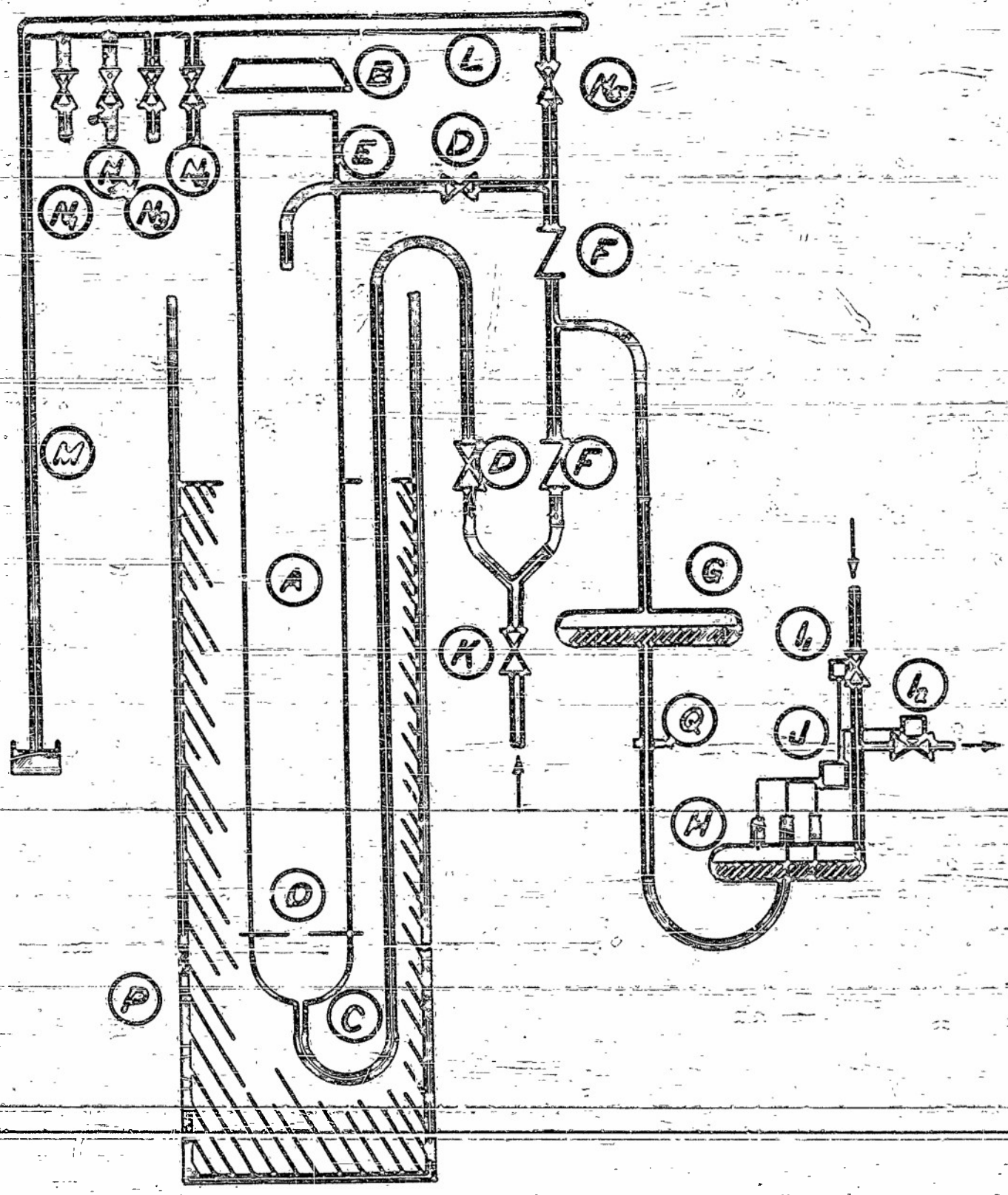

FIG. 1 APPARATUS FOR THE DETERMINATION OF FLAMMABILITY LIMITS AT VARIOUS TEMPERATURES

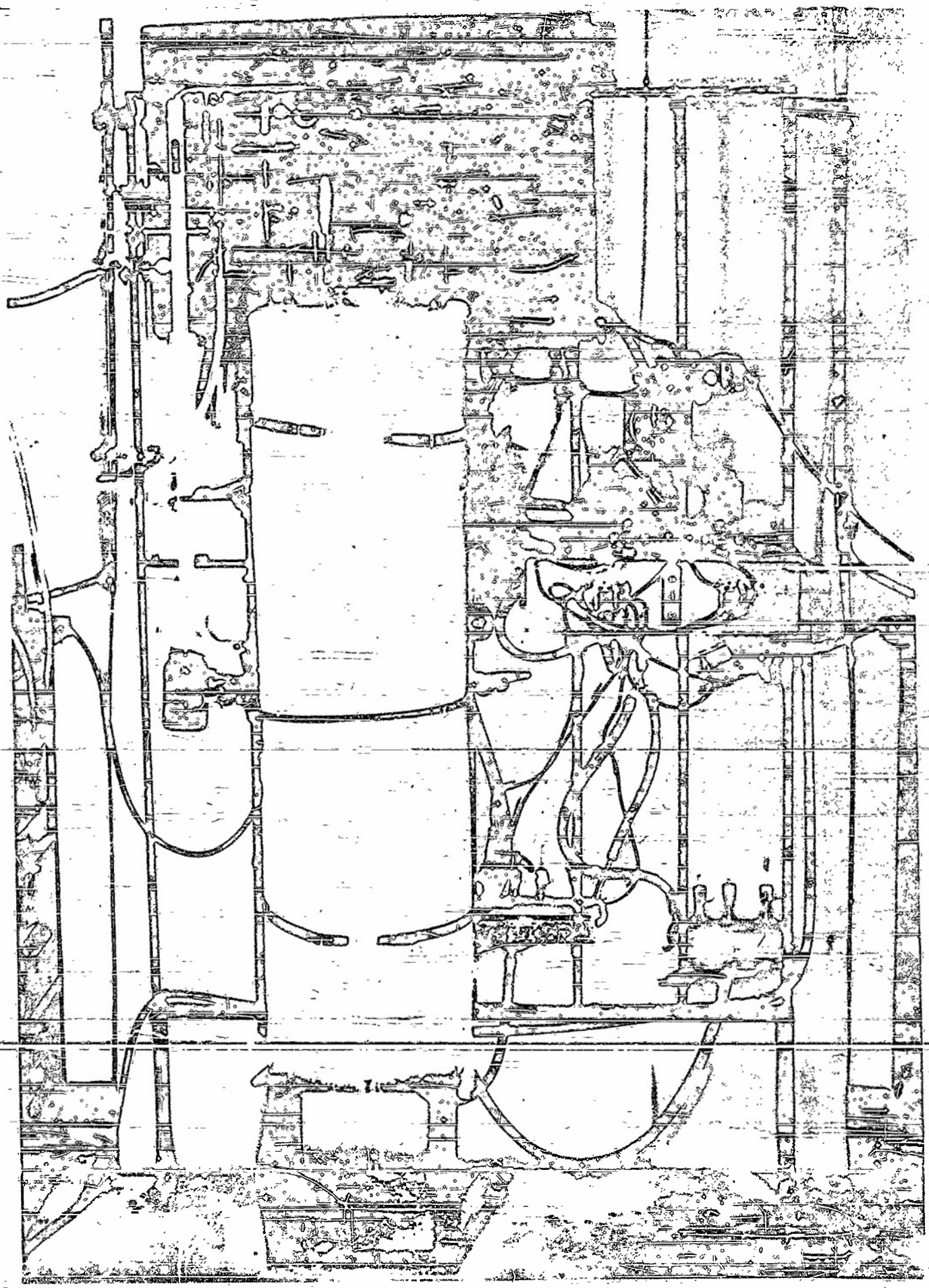

Fig. 2 Apparatus for the Detmn. of Flammability Limits at Various Temperatures.

Tube (A) was connected to the manifold (L) through stopcocks (D and N_5). In practice, two combustion tubes were placed in the bath, the second tube (A') being connected to L through stopcock (D') (not shown). The pressure in A was determined by means of manometer (M), consisting of a meter stick and a mercury well. A vacuum pump, dry air, fuel and extinguisher supplies were connected to L through stopcocks (N_1), (N_2), (N_3) and (N_4), respectively. The ignition electrodes (O) were made of 24 gauge platinum wire and were connected to the high voltage terminals of a Model-T Ford induction coil (not shown). The electrodes were adjusted to provide a spark gap of 6 mm.

Since in general the vapor pressure of the test materials was too low at room temperature to permit the desired composition, it was found advantageous to carry out the experiments leading to the determination of flammable areas at a pressure of 400 mm mercury.

The apparatus (Fig. 1) was operated as follows: Tube (A) was evacuated by means of the vacuum pump by closing and opening the appropriate stopcocks. Fuel and extinguishers were introduced in order of increasing volatility. Dry air was then introduced in sufficient quantity to produce the required total pressure. The gaseous composition was calculated from the partial pressure of each component as noted on the manometer (M). Clamp (Q) was opened and the pump (G) allowed to operate until thorough mixing had occurred. The mixing time was determined by several preliminary runs and usually was for a period of 10-15 minutes. After mixing, the mixture was fired, and a positive result was recorded if the flame traveled the whole length of tube (A). Before the next run the system was flushed with air by opening stopcock (K).

Modified Apparatus I

When nitromethane was used as the fuel in the studies, difficulty was encountered in the form of fuel condensation on the walls of the manifold and in the mercury pumping system. Tests showed that this obstacle could not be overcome satisfactorily by heating these parts. Consequently, it was found necessary to redesign and reconstruct the apparatus described above; the design of the combustion tubes was altered only slightly. The initial and most important change made in the apparatus was in the gas mixing or pumping system. A diagram of the modified pumping system is shown in Fig. 3. A three and one-half inch Alnico magnet mounted on a brass slide was allowed to pass on brass guides along the walls of the two combustion tubes. The magnet was raised and lowered through the oil bath by means of a drive pulley attached to an eccentric. The eccentric was turned by a one-eight hp motor at the rate of 12 rpm. Mixing was effected by means of slider discs (Fig. 3) which were raised and lowered inside tubes by the magnet. Each slider was constructed of two perforated aluminum discs connected by a thin strip of iron. By means of this modification in the pumping system the mixing time for a single flammability test was reduced from ten minutes (or greater) to two minutes.

The manifold and gas measuring system were redesigned so as to form, in the main, a compact unit immediately above the bath. A cross-sectional diagram of the modified manifold and gas measuring system is shown in Fig. 4. The modified pumping system, illustrated in Fig. 3, was omitted in order to show the aforementioned parts in greater detail. The two combustion tubes were similar in design to those used in the unmodified apparatus. They differed, however, in having only one inlet near the top of each tube which was used for evacuation and introduction of fuel, air

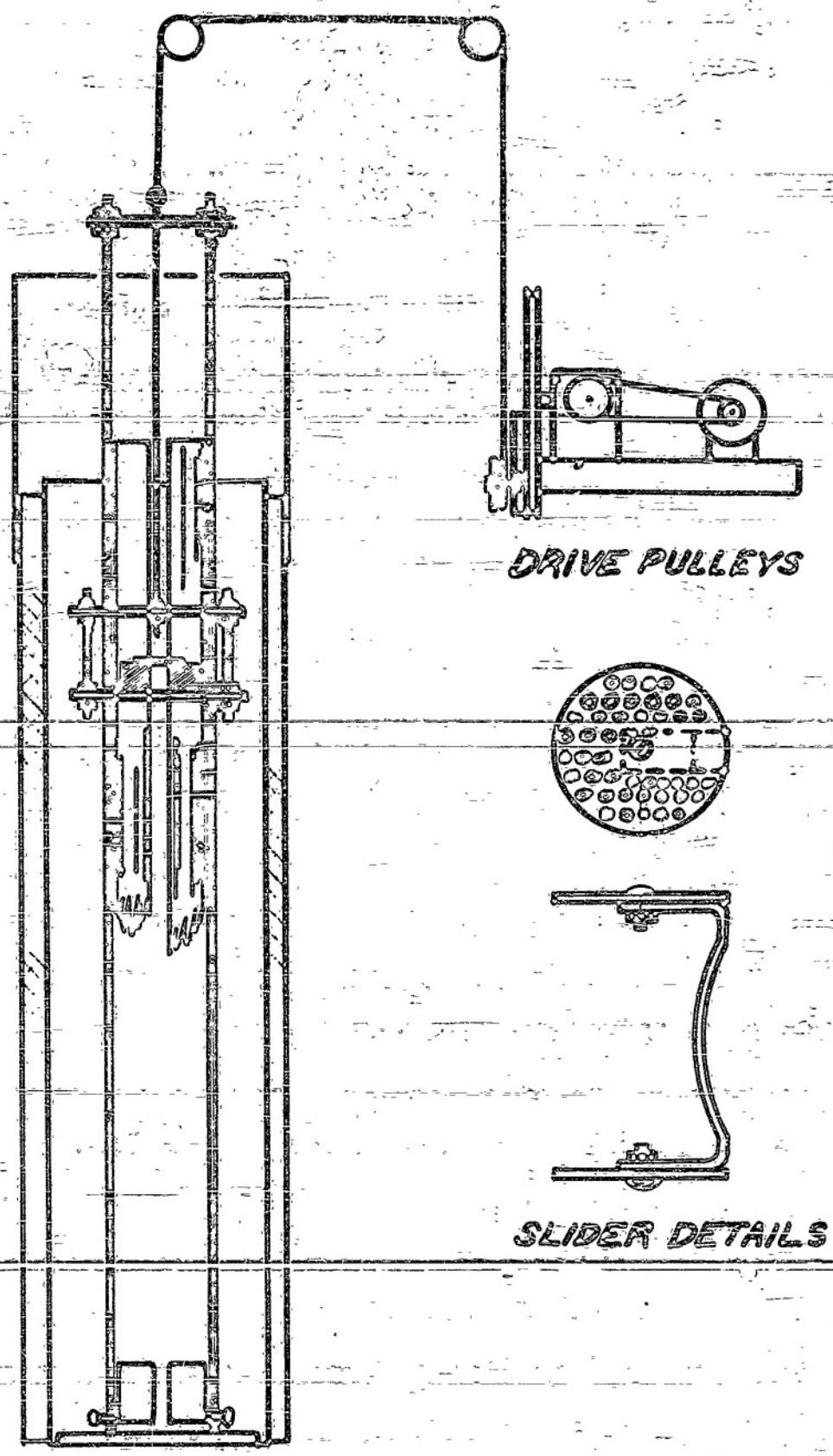

Fig. 3 MODIFIED PUMPING SYSTEM
FOR HIGH-TEMPERATURE COMBUSTION APPARATUS

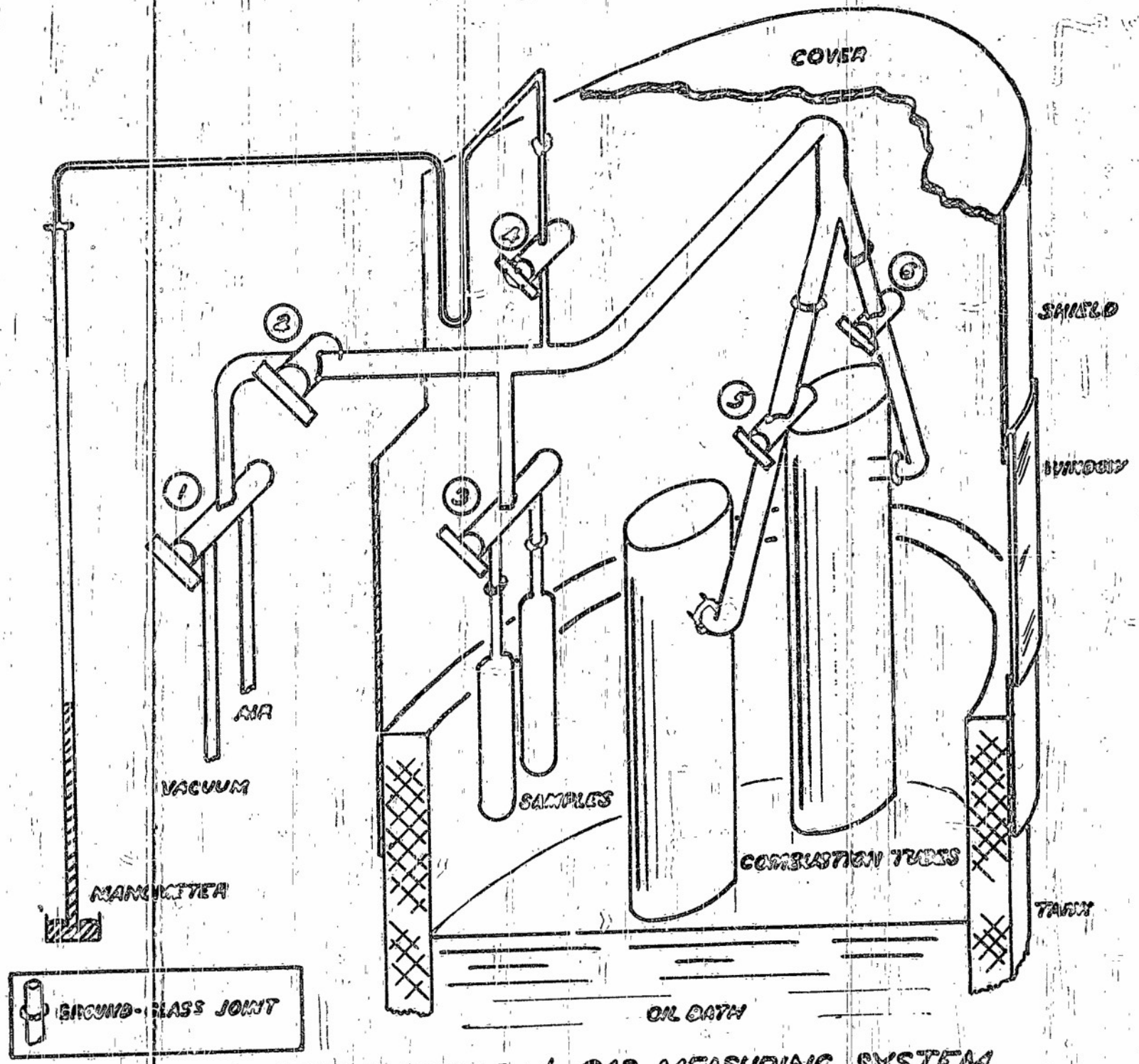

Fig. 1. MODIFIED MANIFOLD & GAS MEASURING SYSTEM FOR HIGH-TEMPERATURE COMBUSTION APPARATUS

and extinguisher. Rubber stoppers (not shown) were used to seal the upper ends of the tubes. The electrodes in the tubes and the ignition system were the same as in the former apparatus.

The combustion tubes were connected to the manifold through stopcocks (5) and (6) by means of 8 mm Pyrex glass tubing. The fuel and test extinguisher contained in sample tubes were introduced by means of opening and closing stopcock (3) appropriately. The vacuum pump and the dry air source were connected to the manifold through stopcocks (1) and (2). The manometer, used to measure the pressures in the combustion tubes, was attached to the manifold through stopcock (4) by means of capillary tubing. The constant temperature bath, in which the combustion tubes are immersed, was heated by one 500-watt steel immersion heater.

The combustion tubes, manifold, and fuel and extinguisher samples were enclosed in a metal shield directly above the bath. These parts were kept warm by means of a heat lamp (not shown) placed in a circular aperture in the shield. The shield was fitted with a metal cover and with a "Pyralin" window for observation purposes. The capillary tubing and trap extending through the shield cover and connecting the manometer to the manifold were also heated by lamps.

The modified apparatus was operated as follows: The combustion tubes were evacuated by the vacuum pump by opening and closing appropriate stopcocks. Fuel, extinguisher and dry air were introduced in order of increasing vapor pressure. The pressure in the tube was determined from the manometer by opening stopcock (4) only for very brief intervals. This was done in order to prevent fuel condensation in the unheated manometer. The gases were then mixed by means of the sliding disc pumping system for a minimum period of two minutes. The mixtures were fired and a positive result recorded according to the usual standards.

Modified Apparatus II

As the work with the high boiling fuels progressed, it was found that the manifold and trap were not heated sufficiently by the enclosed shield - lamp system to prevent condensation of fuels having a boiling point above 110°C. As a result it was found necessary to modify these parts of the apparatus once again in order to overcome the difficulty.

The modifications made in the apparatus were those involving heating of the manifold and trap. In place of the metal shield and heat lamps, the manifold and trap were each wrapped with asbestos cord. Then nichrome wire was wrapped in the folds of the cord around each part (i.e., the manifold and trap). The two ends of each of the wire heaters were each connected by means of electric wire cord to a 7.5 amp variac (Powerstat). In this manner the temperature of both the manifold and trap could be readily controlled to prevent condensation in these parts. A photograph of the remodified manifold and trap is shown in detail in Fig. 5.

The design of the manifold was also altered slightly in order to bring the fuel and extinguisher sample tubes into a position not directly above the bath. This was done in order to facilitate heating of the fuel sample by means of an electrical wire heater (not shown).

It was found necessary to construct the manifold and trap from Vycor tubing for the studies with furfuryl alcohol and aniline. At the temperature required to maintain these fuels in the vapor state, the temperature of the wire was high enough to soften the Pyrex tubing.

A photograph (side view) of the entire high-temperature combustion apparatus, equipped with the Vycor manifold and trap, is shown in Fig. 6. A second apparatus, identical with the one pictured in the afore-mentioned photograph, was built and utilized during the last phase of the investigation.

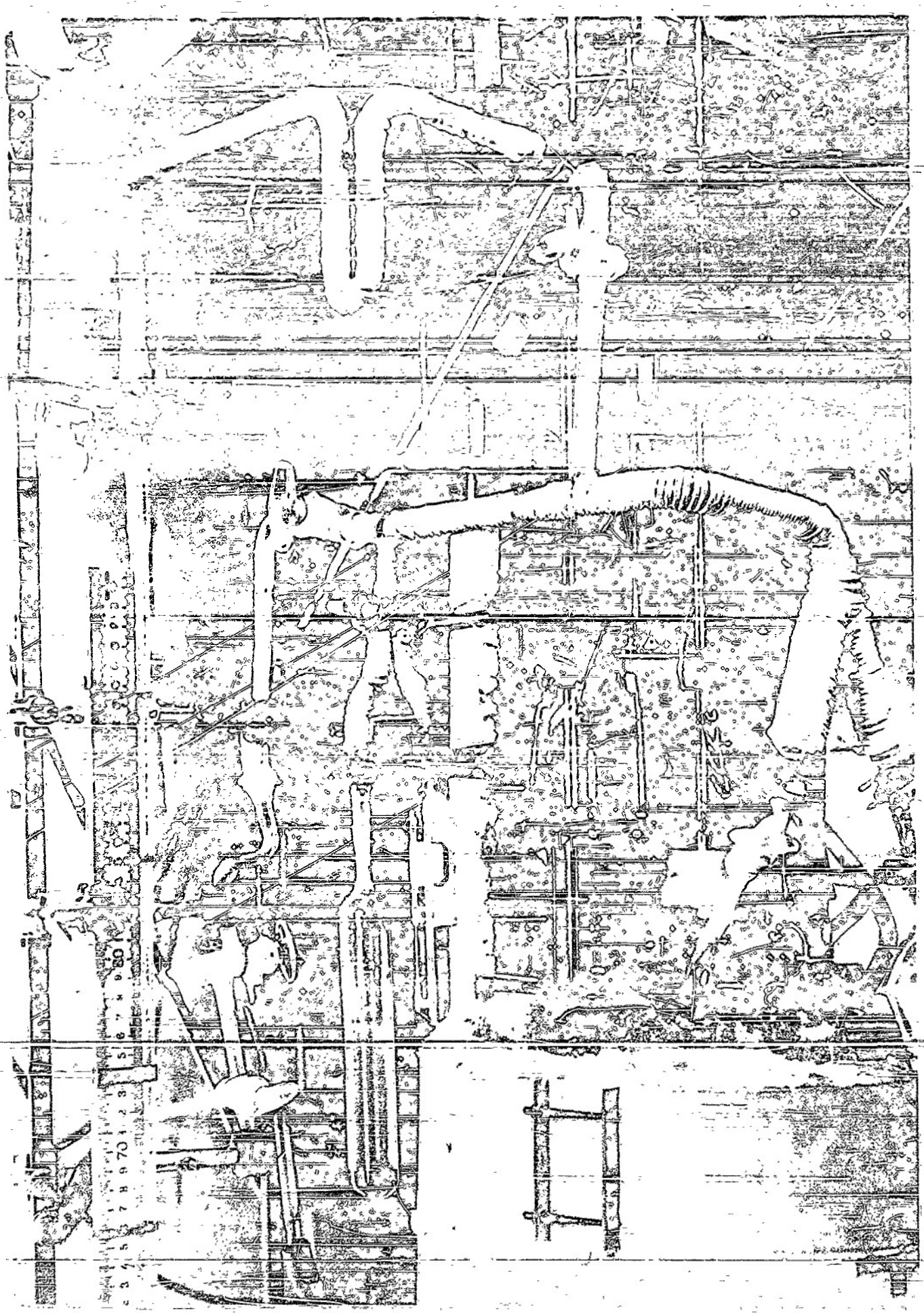

Fig. 5 Remodified Manifold and Trap

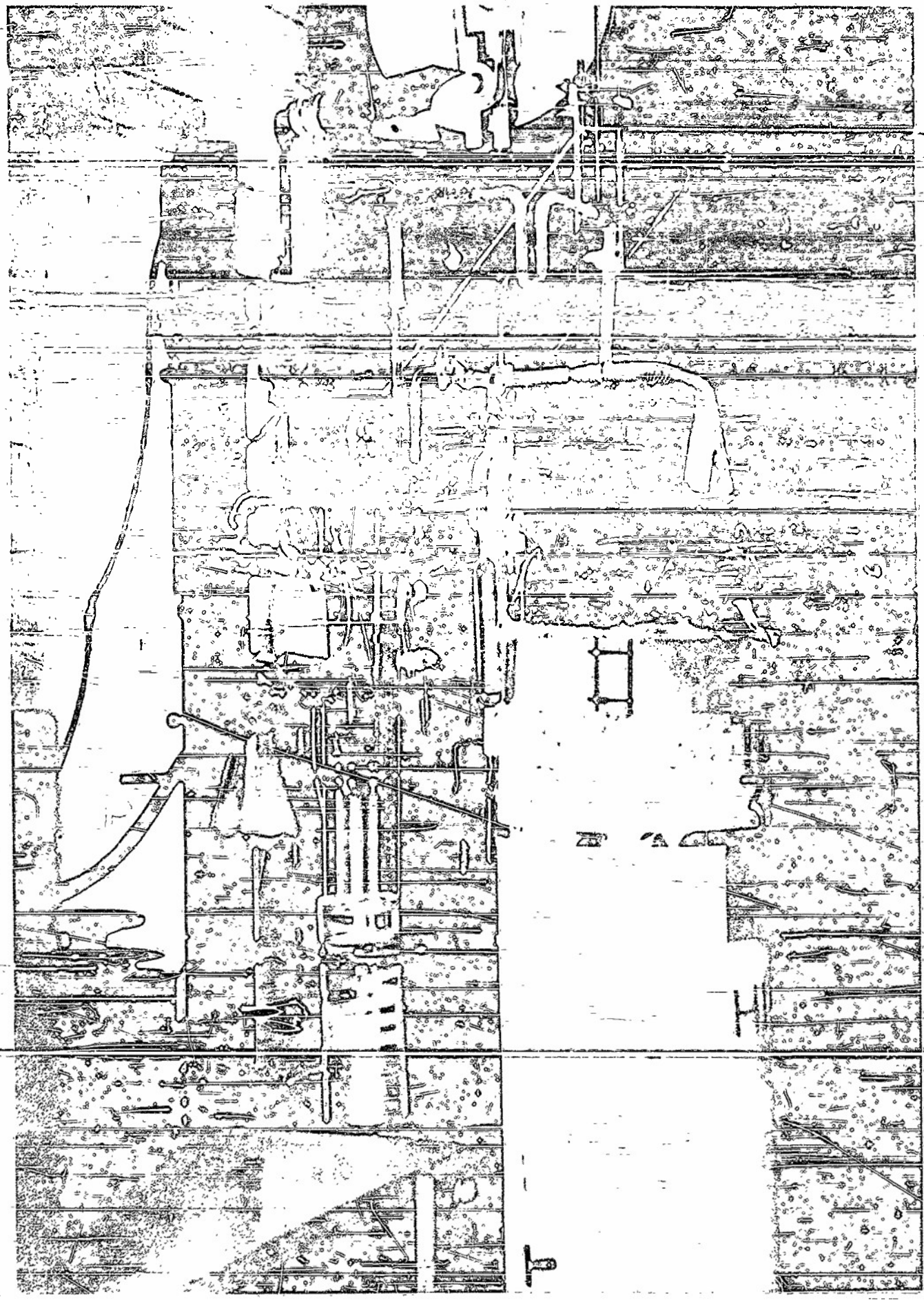

Fig. 6 Remodified High-Temperature Combustion Apparatus (Side View)

Test Materials

During the course of this investigation compounds of high purity were used in the tests. Whenever possible materials known to be commercially available were obtained from appropriate vendors. Other compounds were synthesized at Purdue by the most expedient procedure described in the literature. Brief descriptions and sources of the materials used on the project are presented on the following pages.

Jet Fuels

Hydrogen (H_2)

This colorless, odorless gas, b.p. -252.8°C, is highly flammable in air or oxygen. It was obtained from the Linde Air Products Company and was used without further purification.

Ammonia (NH_3)

Ammonia (b.p. -33.4°C) is a colorless gas possessing a strong odor. It is readily compressed in iron cylinders as liquid ammonia. A cylinder of the latter was obtained from E.I. DuPont de Nemours and Company and used without additional purification.

Methanol (CH_3OH)

Methyl alcohol, or methanol, is a colorless liquid boiling at 64.7°C. This compound was obtained from Carbide and Carbon Chemicals Corporation and was purified by rectification.

Ethanol (C_2H_5OH)

Ethanol, or ethyl alcohol, is a colorless liquid having a boiling point of 78.5°C. Commercial grade alcohol was obtained from Commercial Solvents Corporation and was made absolute by treatment with magnesium and rectification.

Nitromethane (CH_3NO_2)

This compound (b.p. 101-101.5°C) is a colorless liquid and has a somewhat pleasant odor. It was obtained from Commercial Solvents Corporation and was purified by rectification through a column packed with glass helices.

Hydrazine (NH_2NH_2)

Hydrazine in the pure state is a colorless liquid (or white crystalline solid) having a boiling point of 113.5°C and a melting point of 1.4°C. A sample of the compound having a purity of 98% or greater was obtained from the Mathieson Chemical Corporation. In view of the possible hazards involved in the rectification of hydrazine, this material was used without further purification.

Furfuryl Alcohol ($C_5H_6O_2$)

This slightly yellowish or straw-colored liquid (b.p. 170-171°C) was prepared from furfural and formaldehyde by the "crossed" Cannizzaro reaction.

$$C_4H_3O{\cdot}CHO + HCHO + NaOH \rightarrow C_4H_3O{\cdot}CH_2OH + HCOONa$$

The method used was based on a procedure described in the literature by Berkenheim and Dankova[2]. The product was purified by rectification through a Widmer column. In addition, some furfuryl alcohol was obtained from the Eastman Kodak Company.

Aniline ($C_6H_5NH_2$)

Aniline is a colorless, oily liquid which boils at 184.4°C and darkens on standing and exposure to sunlight. The compound was obtained from the Mallinckrodt Chemical Works and was purified by rectification through a Widmer column.

Fire Extinguishing Agents

Carbon Dioxide (CO_2)

This colorless and odorless gas (b.p. -78.5°C subl.) is extensively used as a fire extinguishing agent. It is non-toxic and non-corrosive but

is considered less effective than methyl bromide (the base criterion for USAF fire extinguishers). In addition, being a high pressure gas it requires heavy containers and distribution systems. A large cylinder of the material was obtained from Liquid Carbonic, Inc., Indianapolis.

Methyl Bromide (CH_3Br)

Methyl bromide (b.p. 4.5°C) is a colorless gas at room temperature and atmospheric pressure. Although it is one of the most effective fire-retarding agents available, its toxicity and corrosiveness make it undesirable for extensive use, particularly in aircraft. The methyl bromide was obtained from the Paragon Division, Matheson Company and was used without further purification.

Bromochloromethane (CH_2BrCl)

This compound was obtained from the Eastman Kodak Company and used without purification. It is a colorless liquid, b.p. 68-69°C, and, in general, is considered as effective as, and less toxic than, methyl bromide as a fire extinguishing agent.

Dibromodifluoromethane (CF_2Br_2)

Dibromodifluoromethane is a colorless liquid boiling at 24.5°C. It was obtained from the Dow Chemical Company and used without further purification. This compound was the most effective of thirty-one compounds found to be superior to methyl bromide in the earlier Purdue studies[1].

1,2-Dibromotetrafluoroethane (CF_2BrCF_2Br)

This material was supplied by the laboratories of the Civil Aeronautics Administration, Indianapolis. It is a colorless liquid (b.p. 46.4°C) and was rectified by distillation through a Widmer column before using. This compound also rated high on the list of extinguishing agents found to be more effective than methyl bromide in the previous Purdue investigation[1].

Extinguisher Tests

Hydrogen

The first fuel studied on this project for charting of flammable areas with a test extinguisher and air was hydrogen. A plot was made of the percent fuel (by volume) vs. percent extinguisher (by volume) in each case. These curves are shown in Figs. 7-11. A plot of the five flammable areas illustrating their relationship to each other is presented in Fig. 12. The results indicating the effectiveness of the test extinguishers in reducing the flammability of mixtures of air and hydrogen are summarized in Table I. The compounds are arranged in order of decreasing effectiveness on a volume basis. On the basis of these tests, methyl bromide is the most effective extinguisher of the compounds studied for combatting hydrogen fires.

Table I

Summary of Compounds Evaluated as Fire Extinguishing Agents for Hydrogen Fires (Temperature = 26°C)

Compound Formula	Compound Name	Peak in Flammability Curve, %	Extinguisher, cm³*	Order of Effectiveness Vol. Basis	Order of Effectiveness Wt. Basis
CH_3Br	Methyl bromide	15.5	65.7	1	1
CF_2BrCF_2Br	1,2-Dibromotetrafluoroethane	17.3	171.5	2	3
CH_2BrCl	Bromochloromethane	31.0	180.0	3	4
CF_2Br_2	Dibromodifluoromethane	32.0	223.0	4	5
CO_2	Carbon dioxide	52.5	103.0	5	2

* These values were obtained by calculations assuming 100 liters of gaseous mixture at 0°C and one atmosphere of pressure.

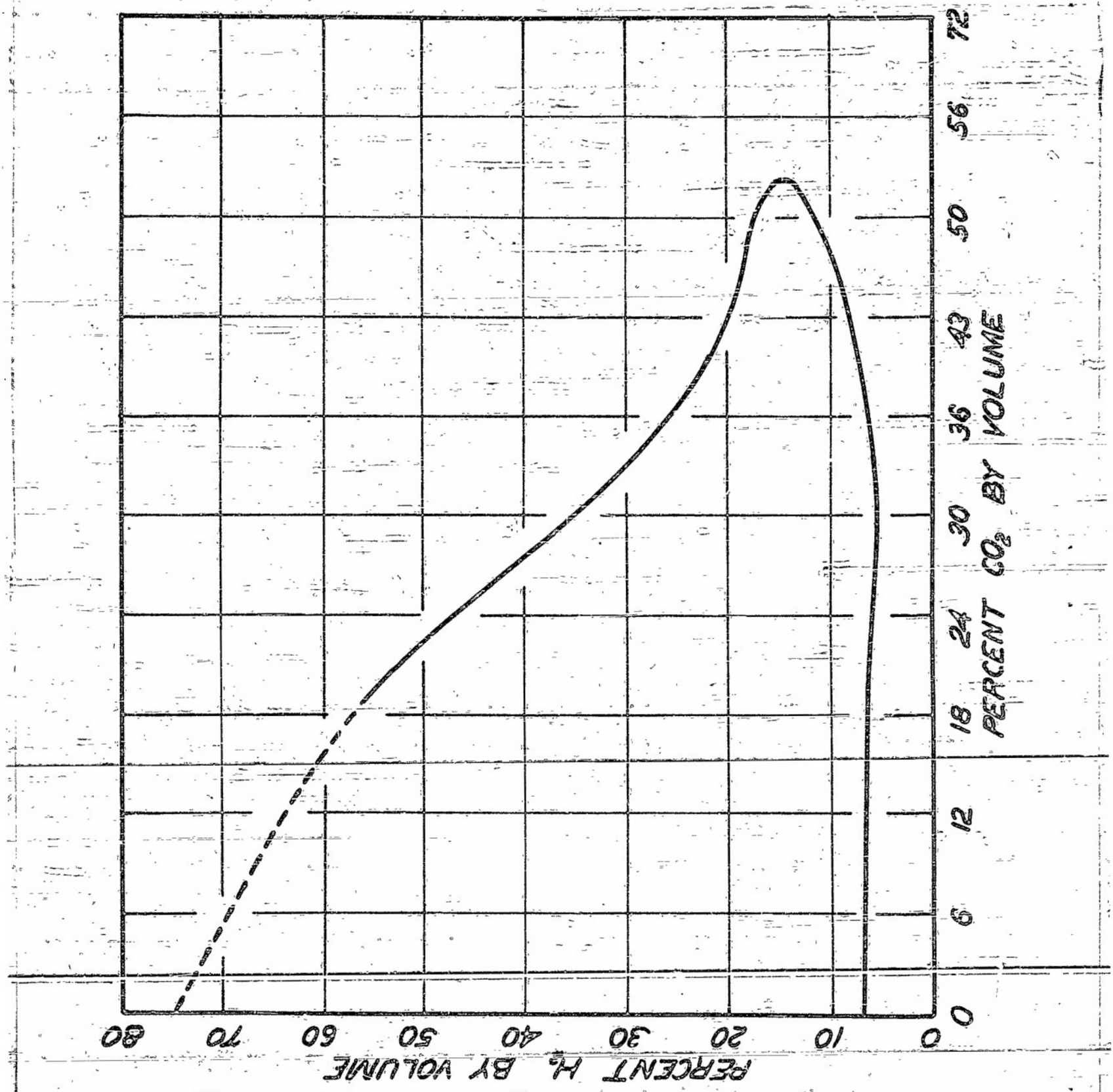

Fig. 7 Flammable Area for Mixtures of Hydrogen, Carbon Dioxide and Air

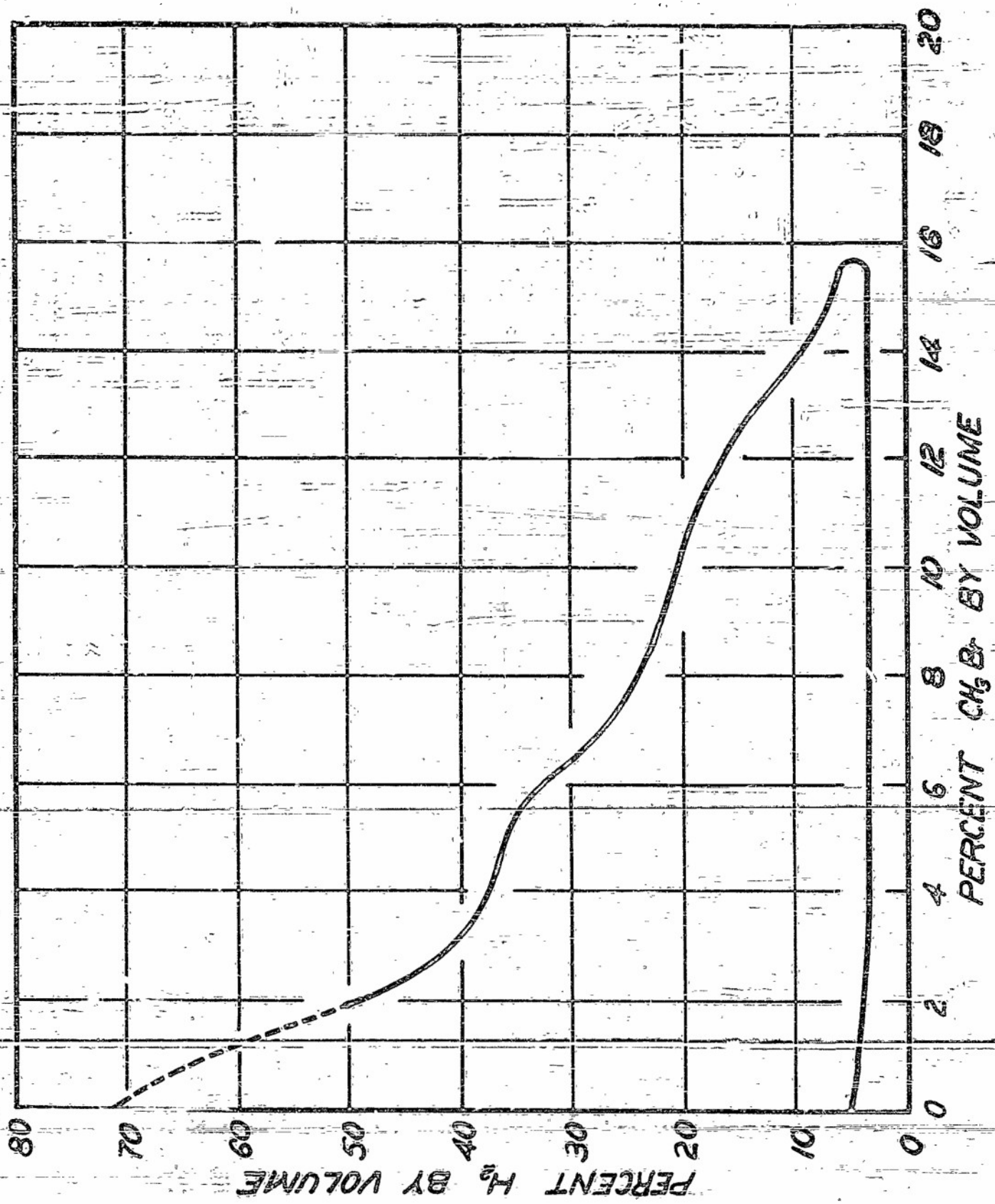

Fig. 8 Flammable Area for Mixtures of Hydrogen, Methyl Bromide and Air

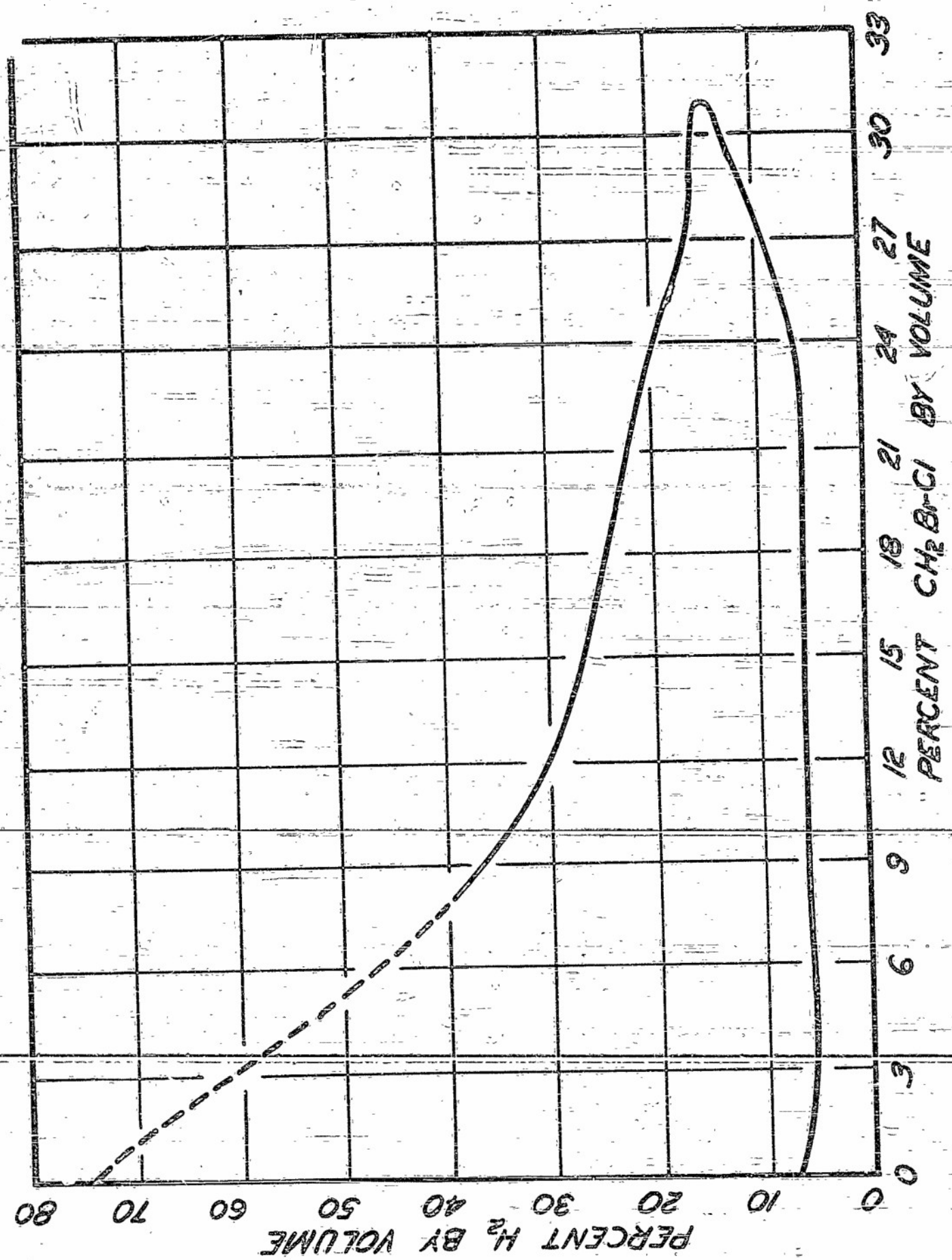

Fig. 9 Flammable Area for Mixtures of Hydrogen, Bromochloromethane and Air

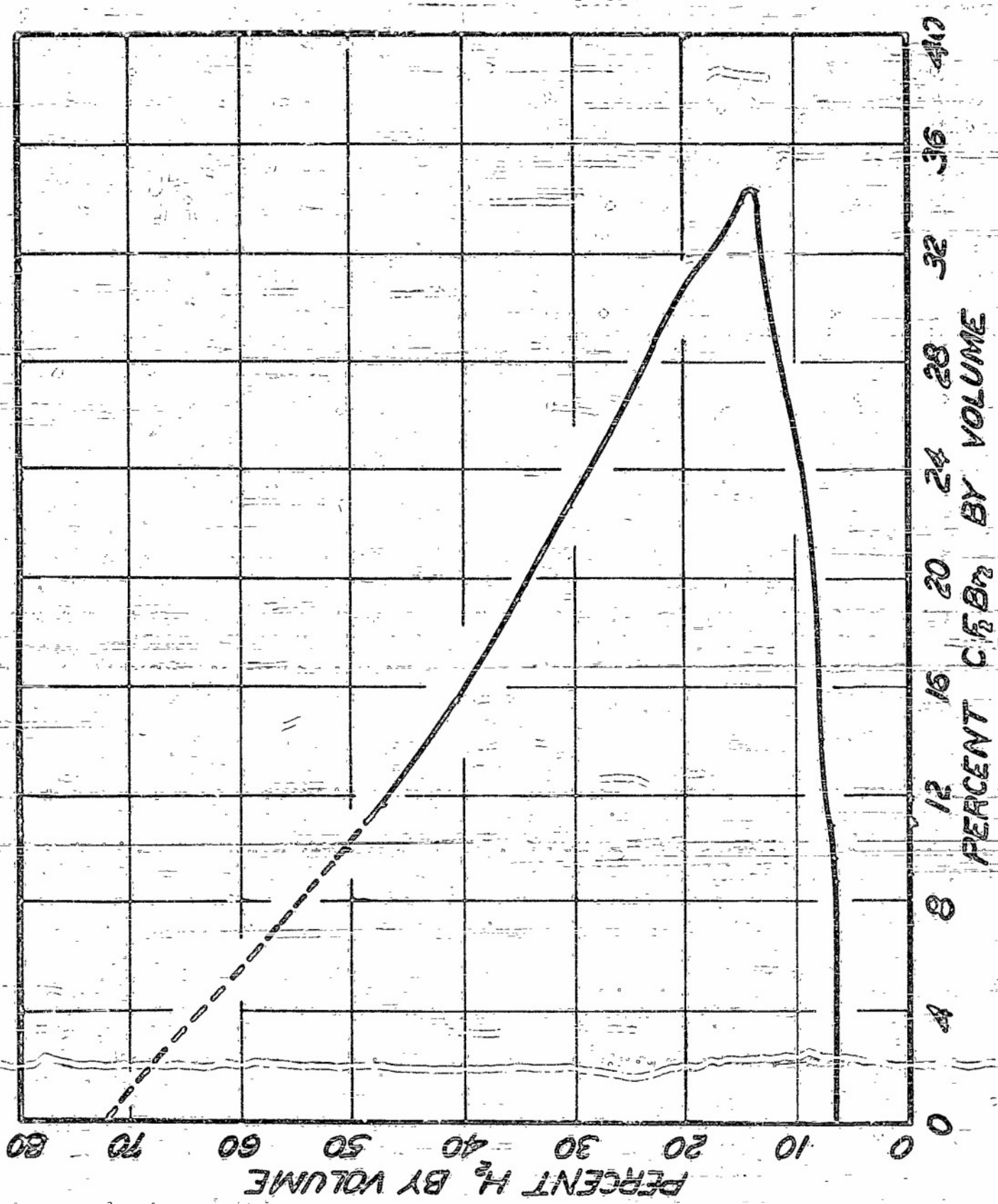

Fig. 10 Flammable Area for Mixtures of Hydrogen, Dibromodiflucromethane and Air

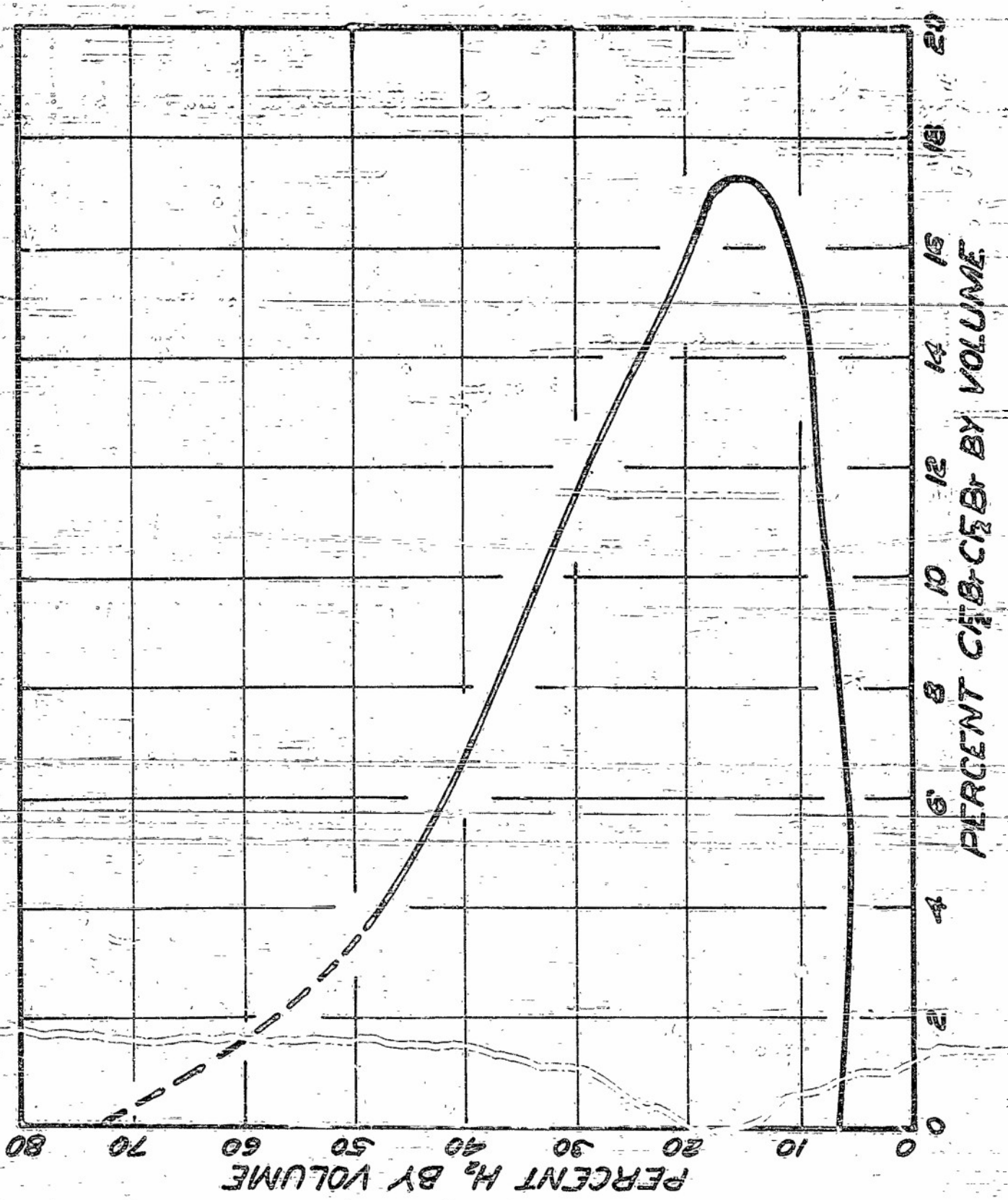

Fig. 11 Flammable Area for Mixtures of Hydrogen, 1.2-Dibromotetrafluoroethane and Air

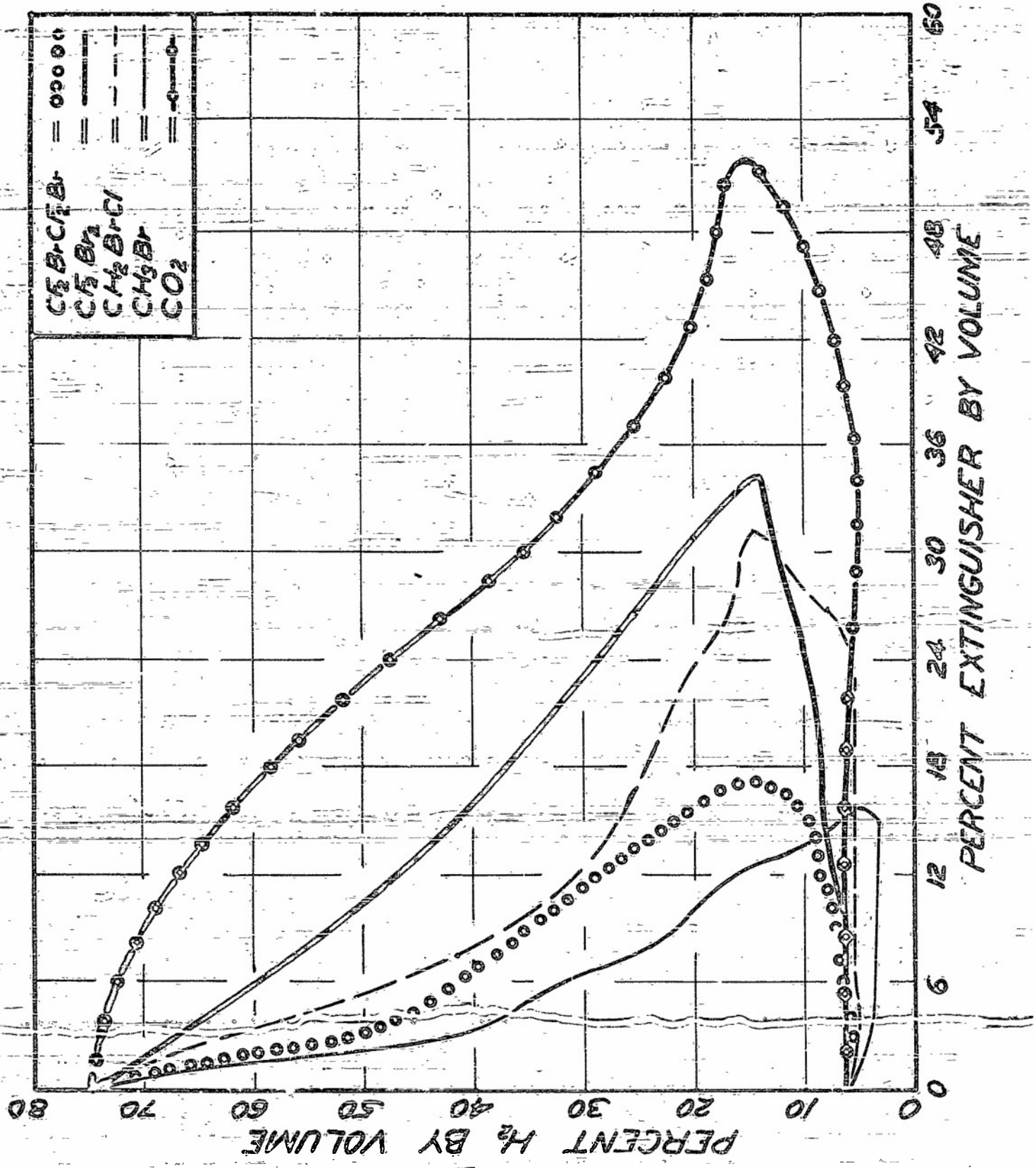

Fig. 12 Flammable Areas for Mixtures of Hydrogen, Extinguishers and Air

In Table I, a comparison is also made between the weight effectiveness and the volume effectiveness of each of the test compounds as a fire extinguishing agent. Although the method used for the determination of the flame inhibition properties of fire extinguishers is based upon the volume percentage of the agent in a mixture of vapors, the weight effectiveness is significant from a economic standpoint. This results from the fact that these materials are sold on a weight basis. Furthermore, in aircraft the weight of material required for fire protection is always an important consideration.

The following equation was used in determining the weight of halogen compound (or carbon dioxide) equivalent to the volume percentage of the extinguisher at the peak in the flammability curve.

$$\text{Gm, Extinguisher} = \frac{100 \text{ liters}}{22.4 \text{ liters}} \times \text{Mol. Wt. of Extinguisher} \times \text{Vol. of extinguisher at peak}$$

It will be noticed that some compounds which have a lower flammability peak are found to be less effective on a weight basis than others with a higher flammability peak and vice versa.

Thus on a weight basis methyl bromide also was found to be the most effective of the five compounds tested with hydrogen. However, carbon dioxide which was the poorest of the group on a volume basis was found to rank second in weight effectiveness.

Ammonia

Ammonia was the fuel next studied after hydrogen. By means of plots of their flammable areas with ammonia and air, each of the fire-retarding materials was evaluated in the same manner as described for hydrogen. The flammable area for mixtures of ammonia, carbon dioxide and air is shown in

Fig. 13 while that for mixtures of ammonia, methyl bromide and air is given in Fig. 14. In Fig. 15, the two flammable areas are shown on one plot for comparison.

When ammonia was tested using bromochloromethane as the fire-retarding agent, it was found that combustion failed to occur at any concentration within the flammable range of the fuel even when the lowest concentration of extinguisher experimentally measurable was employed. Similar results were obtained in the testing of ammonia with dibromodifluoromethane and 1,2-dibromotetrafluoroethane, respectively. By analogy to certain similar observations recorded in the literature[3] and from some experimental evidence, it is believed that the anhydrous ammonia reacts with each of the three halogen-containing extinguishers (as well as with methyl bromide). White solid deposits which are either addition complexes of ammonia or inorganic salts of amines and ammonium halides were found on the walls of the tubes and on the electrodes during ammonia runs. If ammonia and the organic halide react under the conditions of the test prior to ignition of the mixture, an explanation may then be offered for the non-combustibility of the afore-mentioned fuel, air and halogen extinguisher mixtures.

The results obtained from the study of ammonia with all of the test extinguishers are summarized in Table II. As in the case of hydrogen, the compounds are arranged in order of decreasing effectiveness on a volume basis. Thus 1,2-dibromotetrafluoroethane, dibromodifluoromethane and bromochloromethane were found equally to be the most effective extinguishing agents for fires involving ammonia.

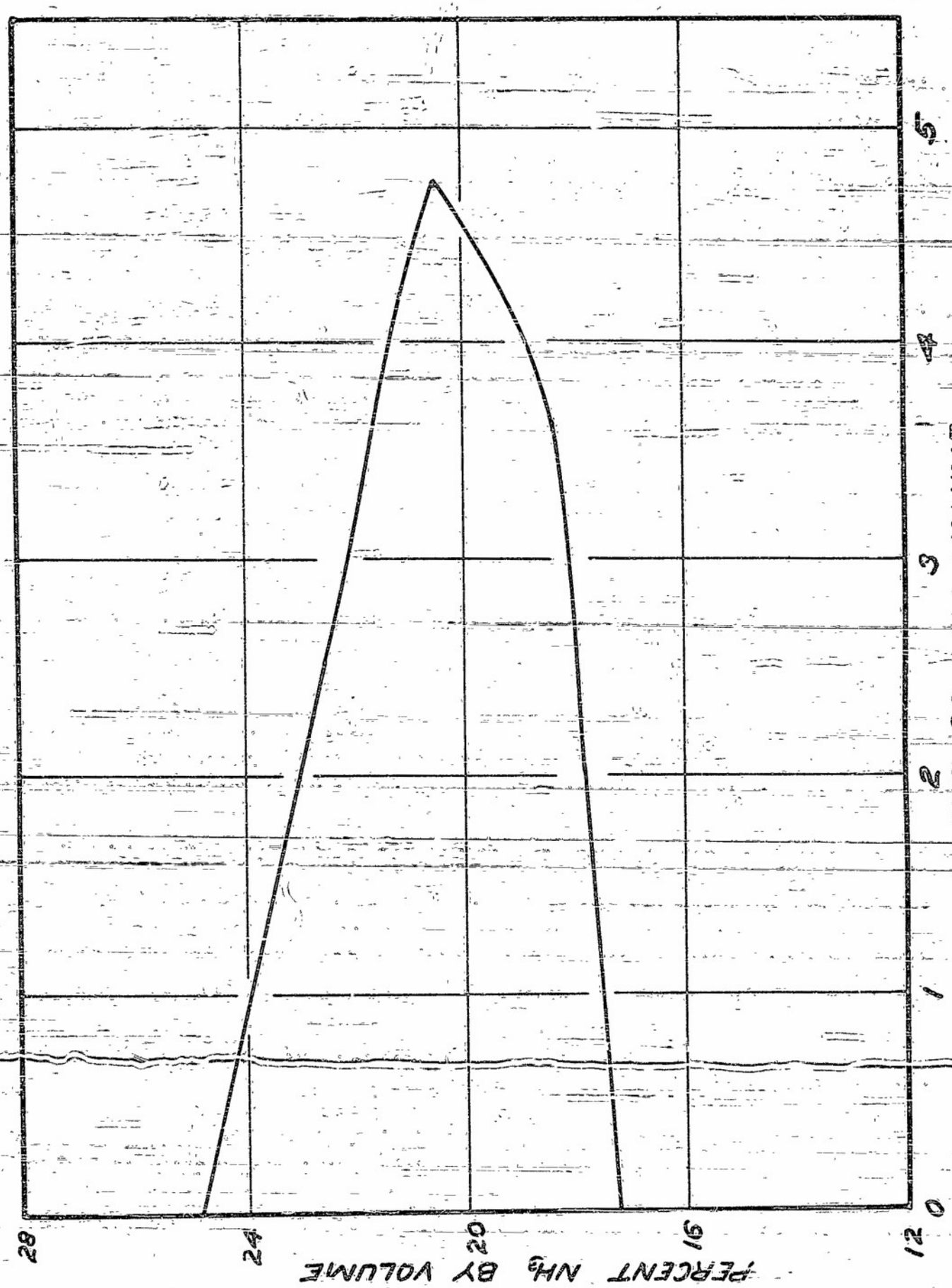

Fig. 13 Flammable Area for Mixtures of Ammonia, Carbon Dioxide and Air

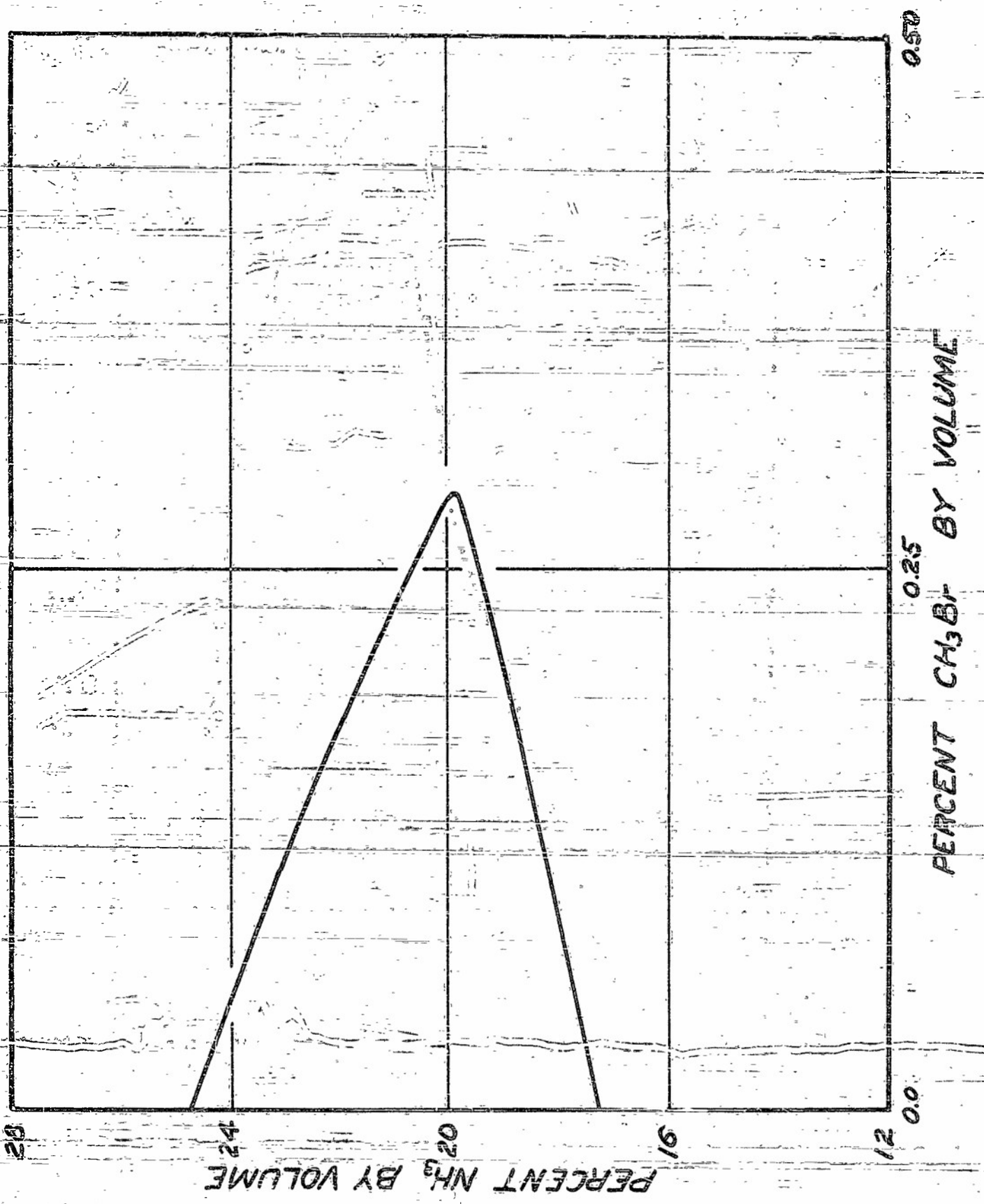

Fig. 14 Flammable Area for Mixtures of Ammonia, Methyl Bromide and Air

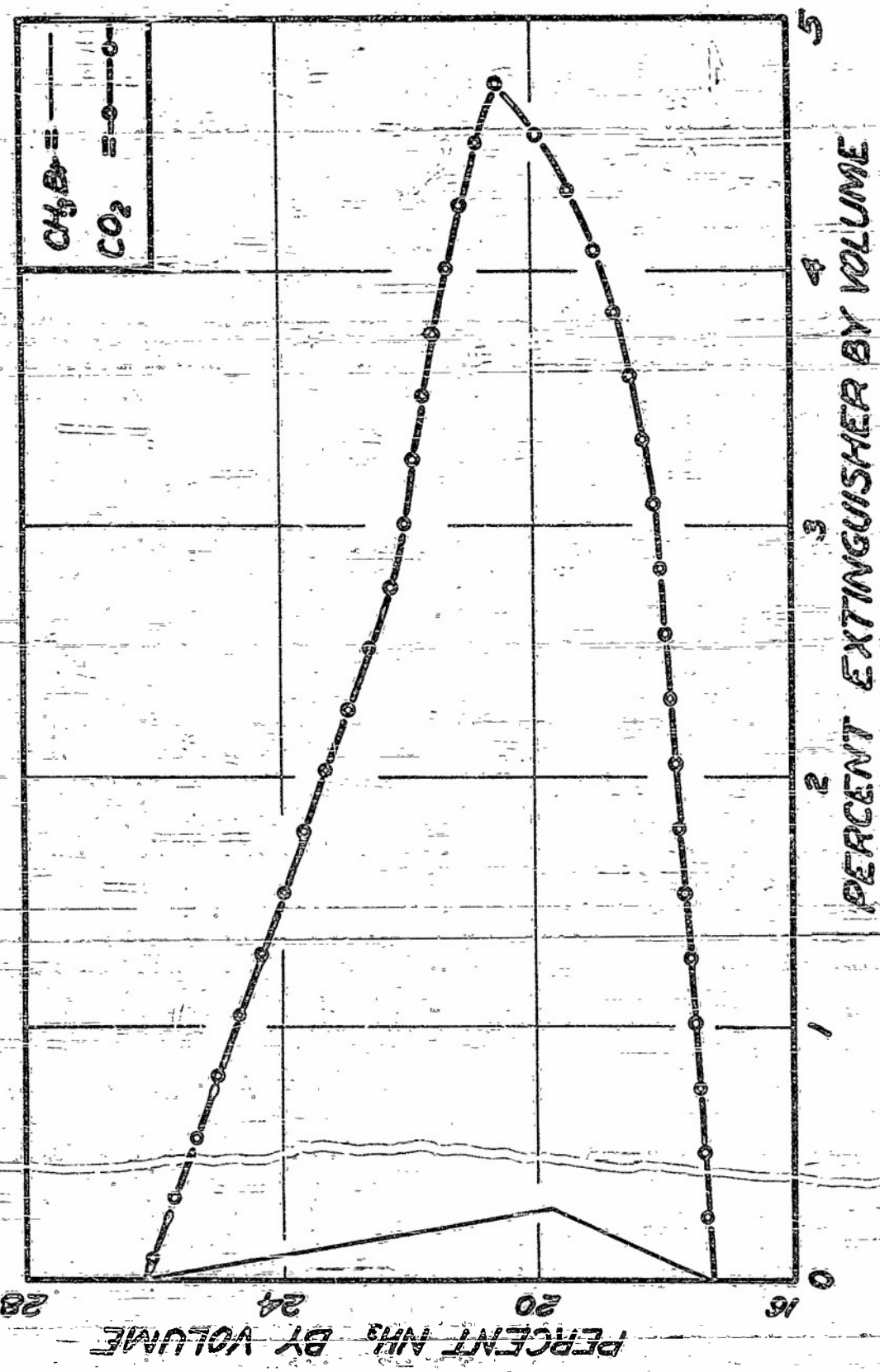

Fig. 15 Flammable Areas for Mixtures of Ammonia, Extinguishers and Air

Table II

Summary of Compounds Evaluated as Fire Extinguishing Agents for Ammonia Fires
(Temperature = 26°C)

Compound Formula	Compound Name	Peak in Flammability Curve, %	Extinguisher, gm*	Order of Effectiveness Vol. Basis	Order of Effectiveness Wt. Basis
CF_2BrCF_2Br	1,2-Dibromotetrafluoroethane	< 0.25	—	1	1
CF_2Br_2	Dibromodifluoromethane	< 0.25	—	1	1
CH_2BrCl	Bromochloromethane	< 0.25	—	1	1
CH_3Br	Methyl bromide	0.3	1.27	2	2
CO_2	Carbon dioxide	4.7	9.24	3	3

* These values were obtained by calculations assuming 100 liters of gaseous mixture at 0°C and one atmosphere of pressure.

Methanol

In the testing of methanol with extinguishing agents, 1,2-dibromotetrafluoroethane proved to be the most effective compound when evaluated on a volume basis. However, from the standpoint of weight effectiveness it ranked fourth, carbon dioxide being first. The results of the various tests with methanol as the fuel are presented in Table III. The flammable areas for each of the extinguishers and the fuel are shown in Figs. 16-20. Figure 21 is a plot showing the relationship of each the flammable areas to one another.

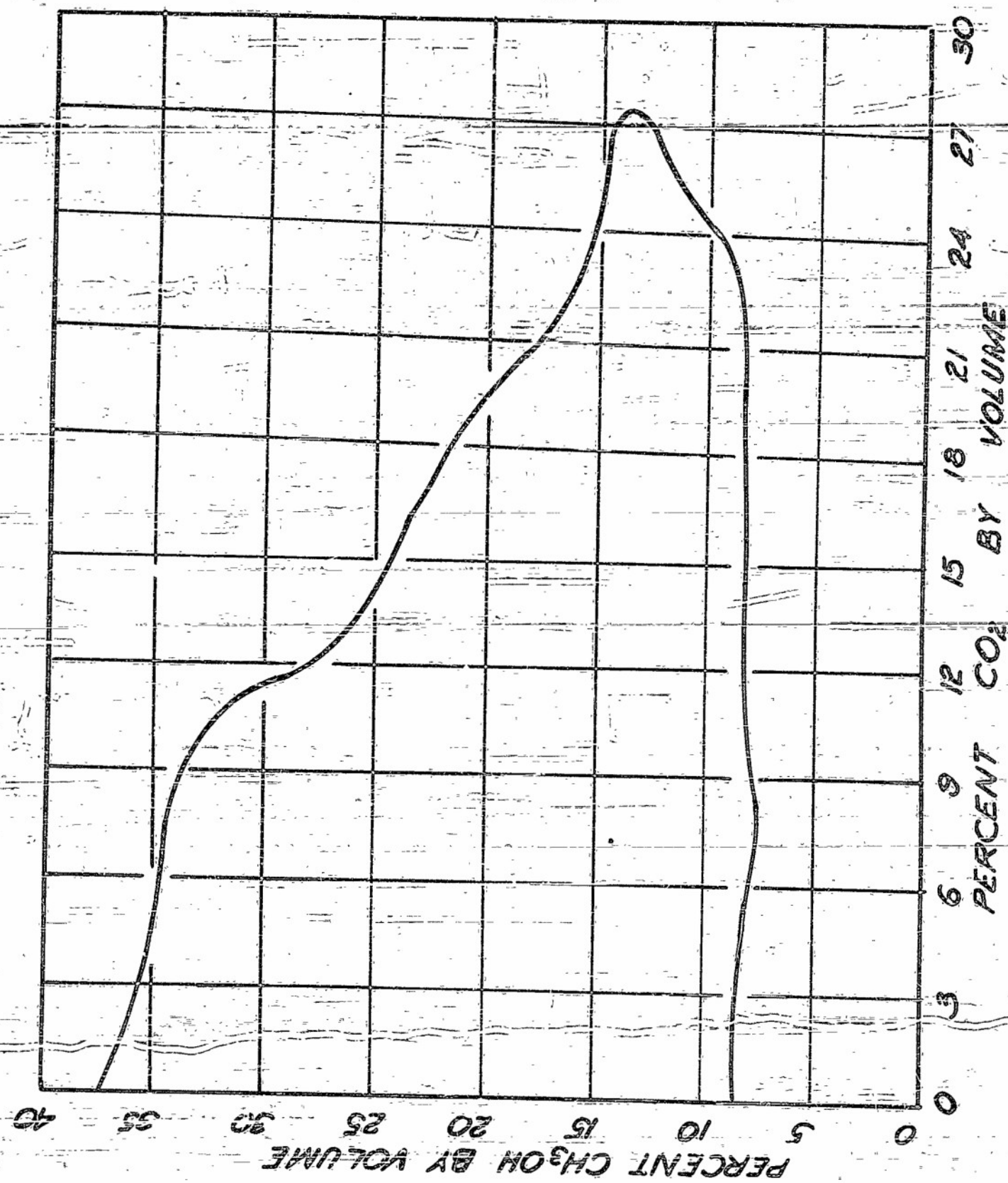

Fig. 16 Flammable Area for Mixtures of Methanol, Carbon Dioxide and Air

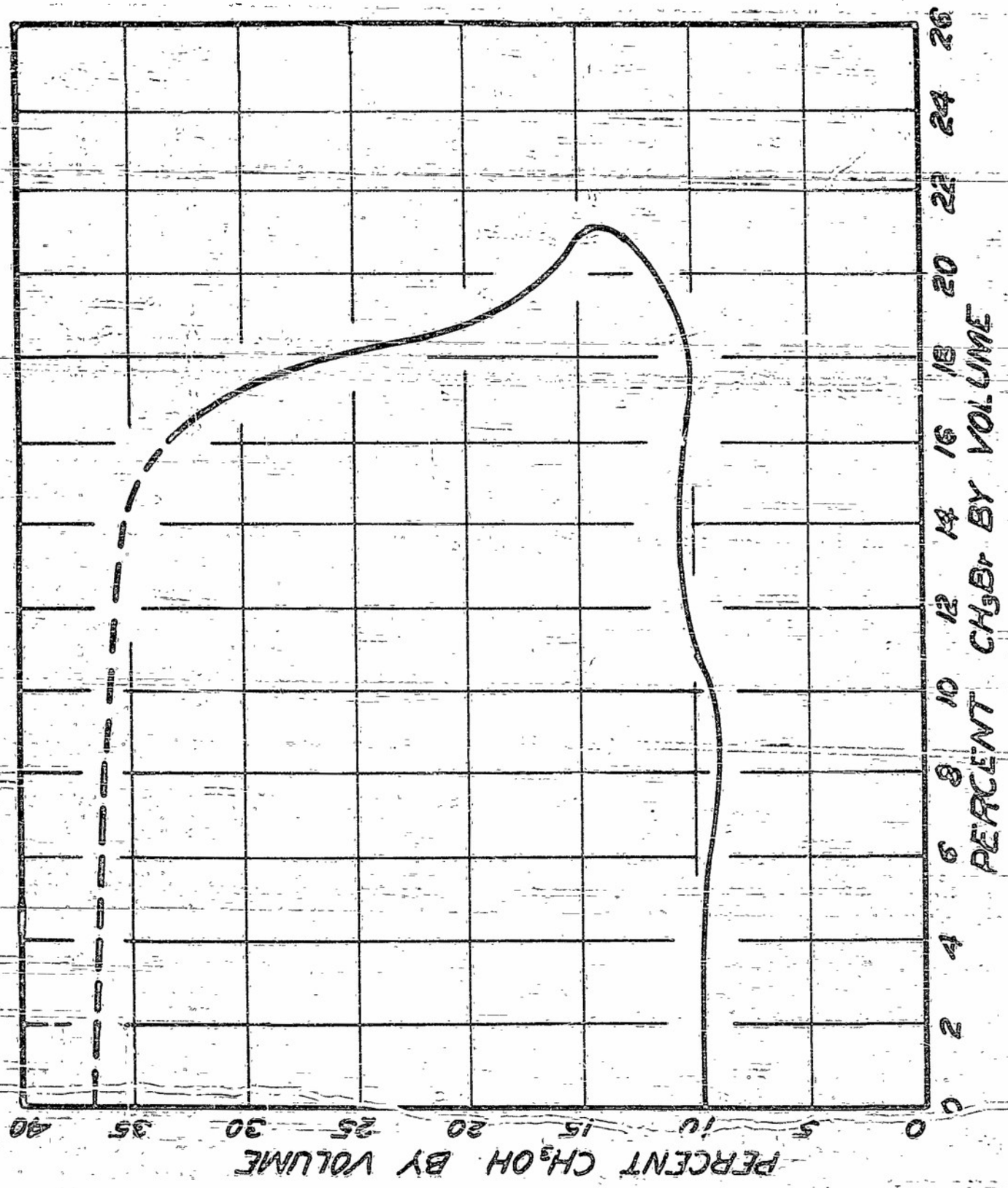

Fig. 17 Flammable Area for Mixtures of Methanol, Methyl Bromide and Air

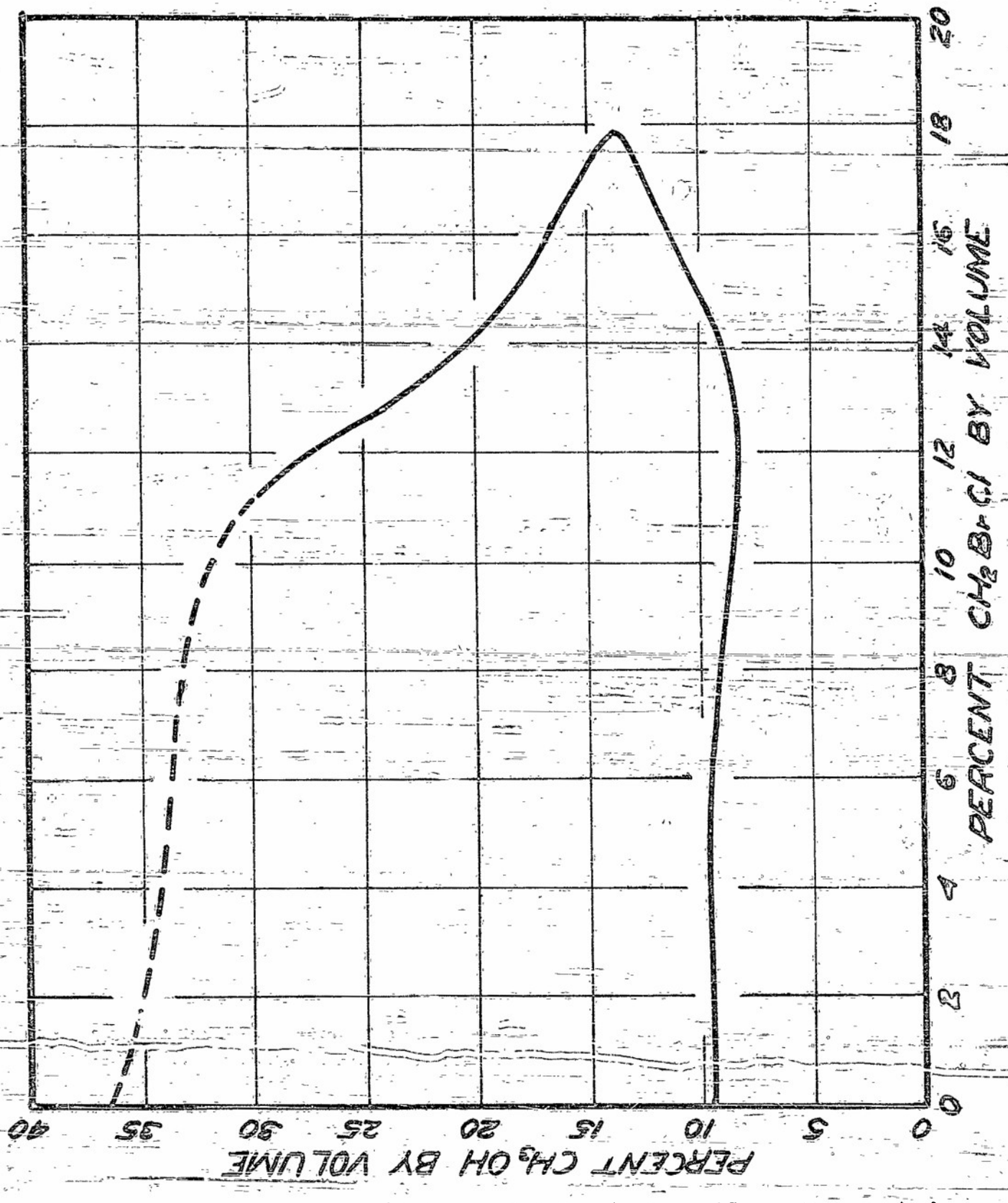

Fig. 18 Flammable Area for Mixtures of Methanol, Bromochloromethane and Air

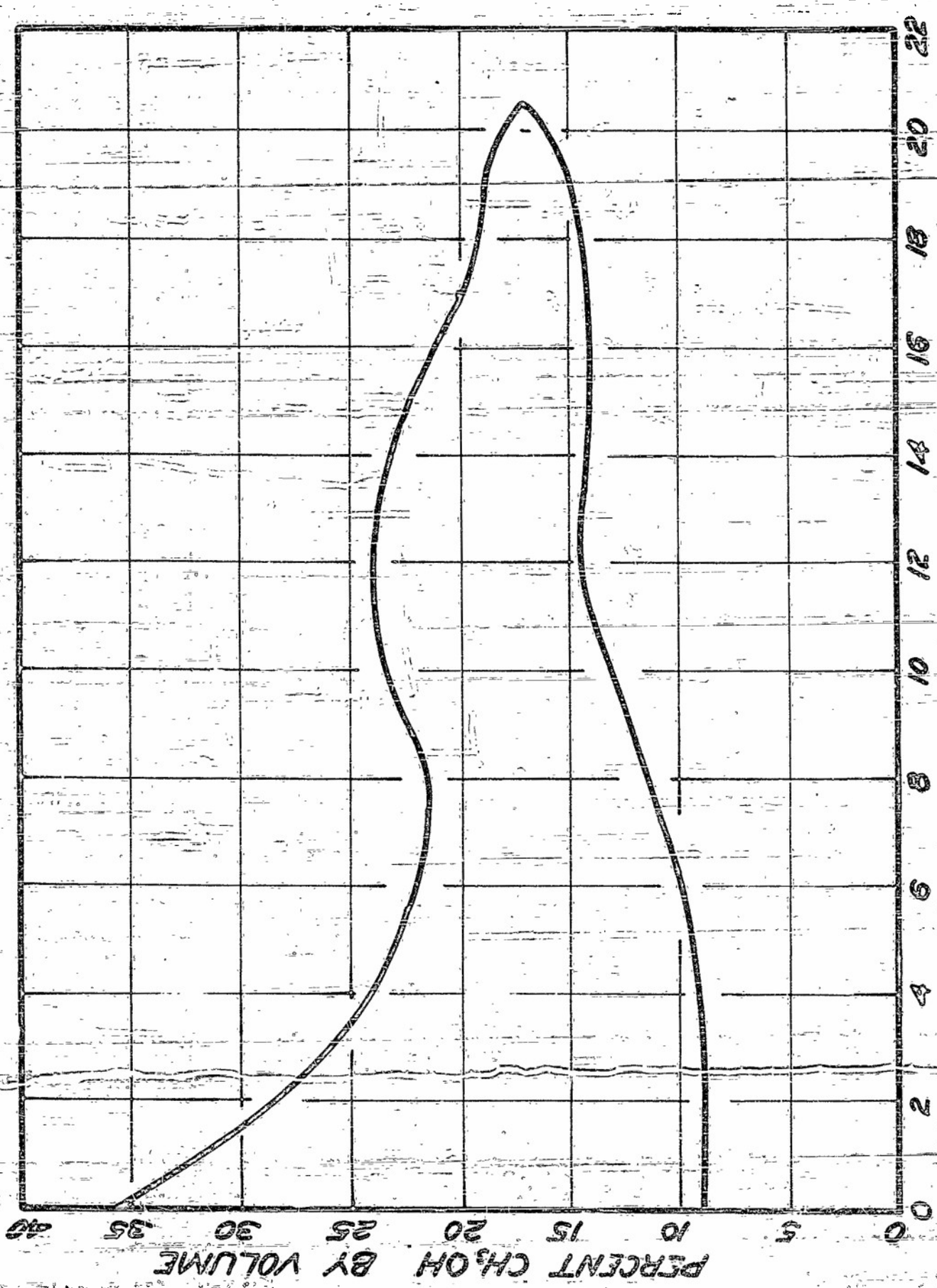

Fig. 19 Flammable Area for Mixtures of Methanol, Dibromodifluoromethane and Air

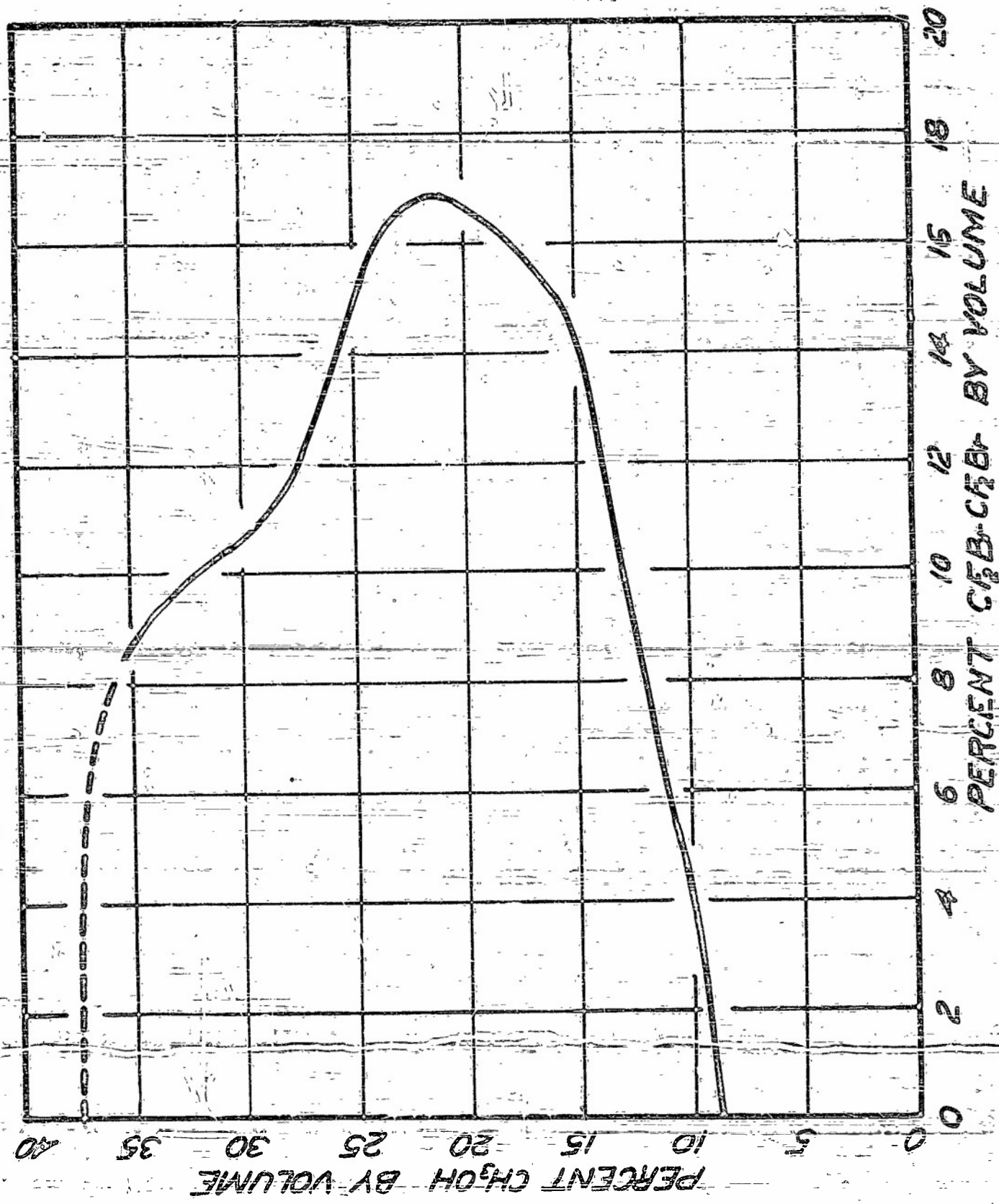

Fig. 20 Flammable Area for Mixtures of Methanol, 1,2-Dibromotetrafluoroethane and Air

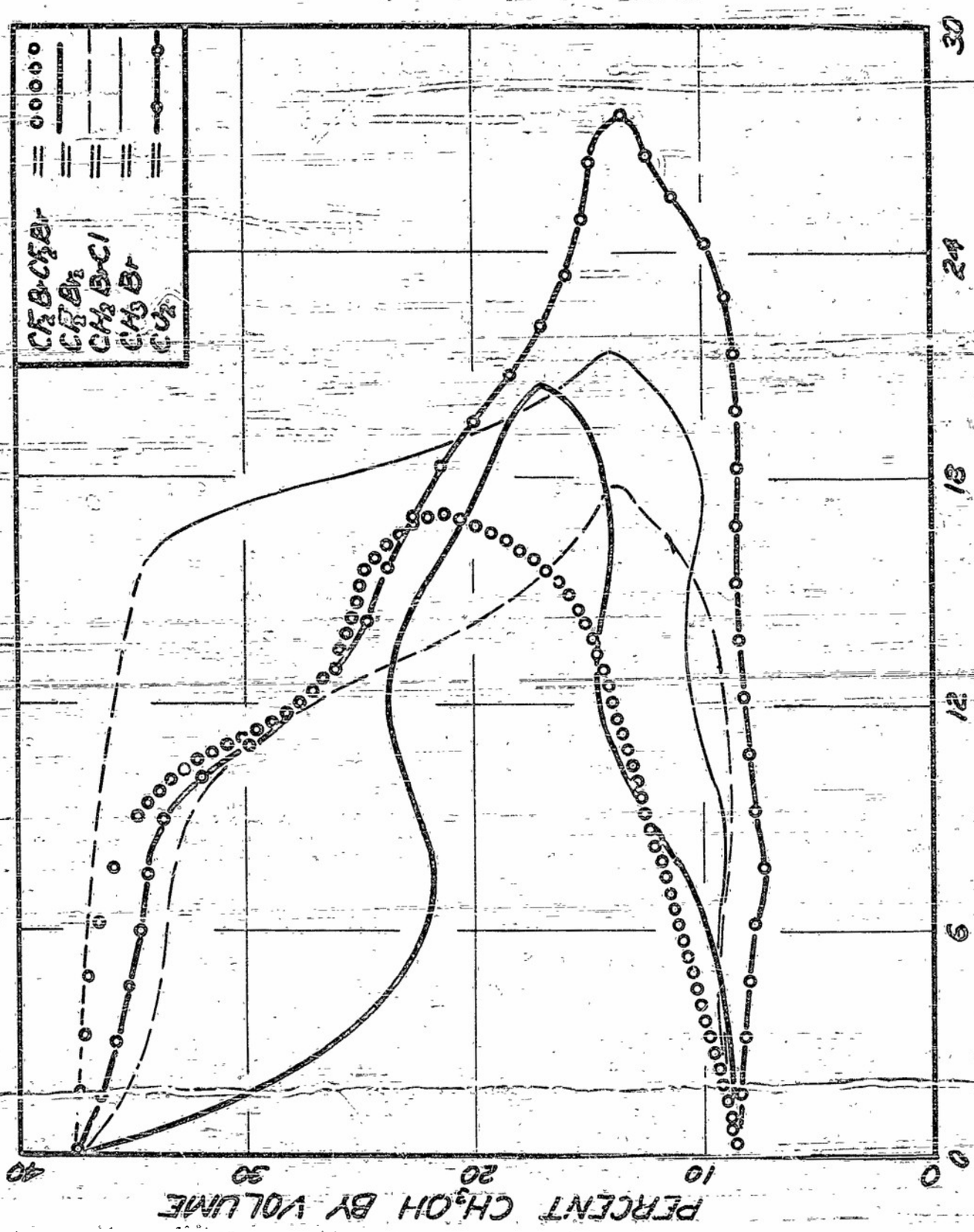

Fig. 21 Flammable Areas for Mixtures of Methanol, Extinguishers and Air

Table III

Summary of Compounds Evaluated as Fire Extinguishing Agents for Methanol Fires (Temperature = 26°C)

Compound Formula	Compound Name	Peak in Flammability Curve, %	Extinguisher, gm*	Order of Effectiveness Vol. Basis	Order of Effectiveness Wt. Basis
CF_2BrCF_2Br	1,2-Dibromotetrafluoroethane	16.8	166.2	1	4
CH_2BrCl	Bromochloromethane	17.9	104.0	2	3
CF_2Br_2	Dibromodifluoromethane	20.6	193.2	3	5
CH_3Br	Methyl bromide	21.0	89.1	4	2
CO_2	Carbon dioxide	27.5	54	5	1

* These values were obtained by calculations assuming 100 liters of gaseous mixture at 0°C and one atmosphere of pressure.

Ethanol

1,2-Dibromotetrafluoroethane was found to be the most effective (on a volume basis) of the fire-retarding materials tested with ethanol. Although the poorest in volume effectiveness, carbon dioxide was again found to be the most effective from the standpoint of weight. The results of the tests with ethanol, air and extinguishers are summarized in Table IV.

Plots of the flammable areas of mixtures of ethanol, air and extinguishers are shown in Figs. 22-27, Fig. 27 being a graph of all five of the fuel-extinguisher curves together.

Nitromethane

Of the five extinguishing agents tested with nitromethane, 1,2-dibromotetrafluoroethane proved to be the most effective on both a volume and weight basis. Table V presents the results of the test with nitromethane, air and extinguishers. In Figs. 28-32 are presented the flammable areas for mixtures of nitromethane and air with each of the test extinguishing materials. A

Fig. 22 Flammable Area for Mixtures of Ethanol, Carbon Dioxide and Air

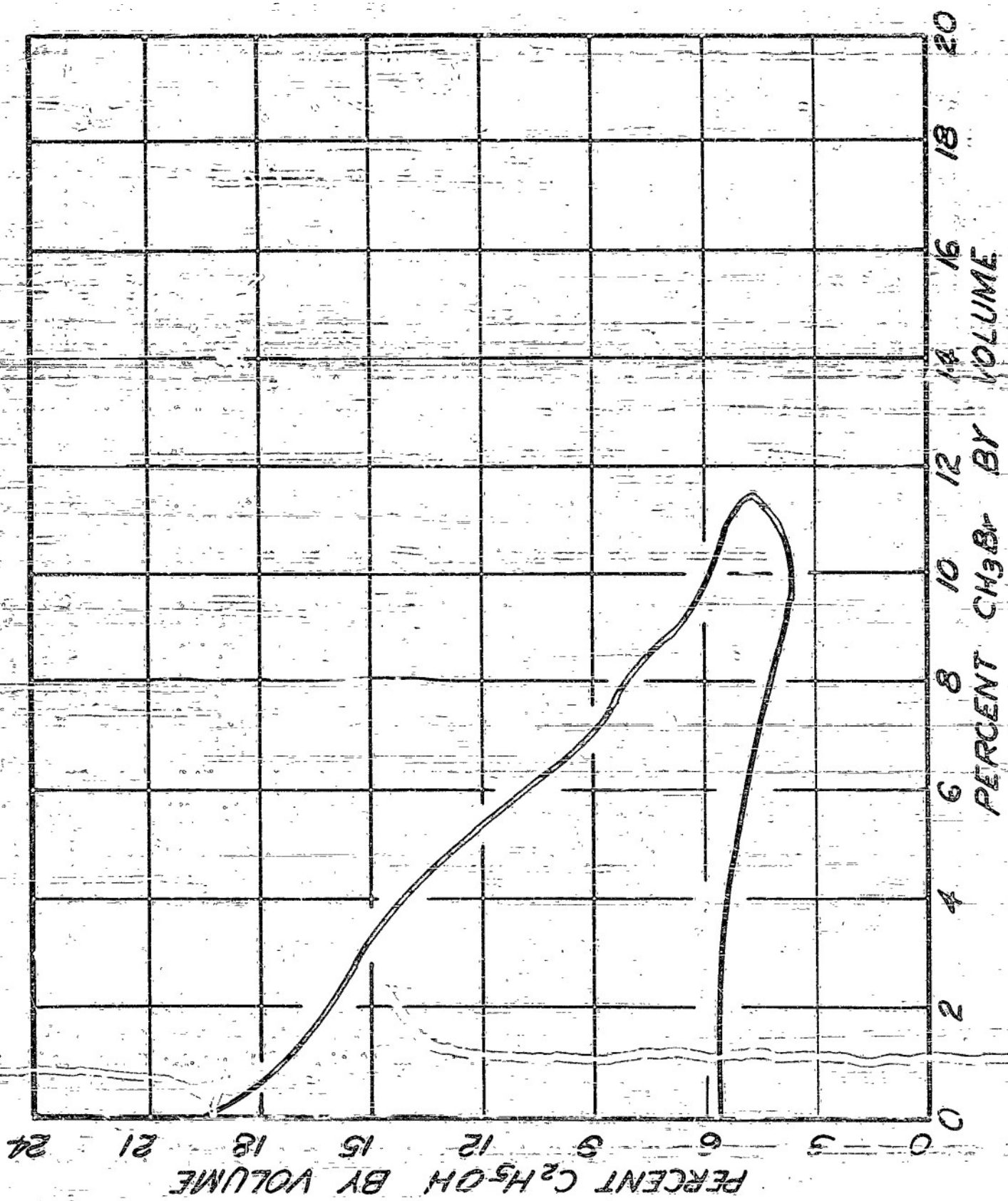

Fig. 23 Flammable Area for Mixtures of Ethanol, Methyl Bromide and Air

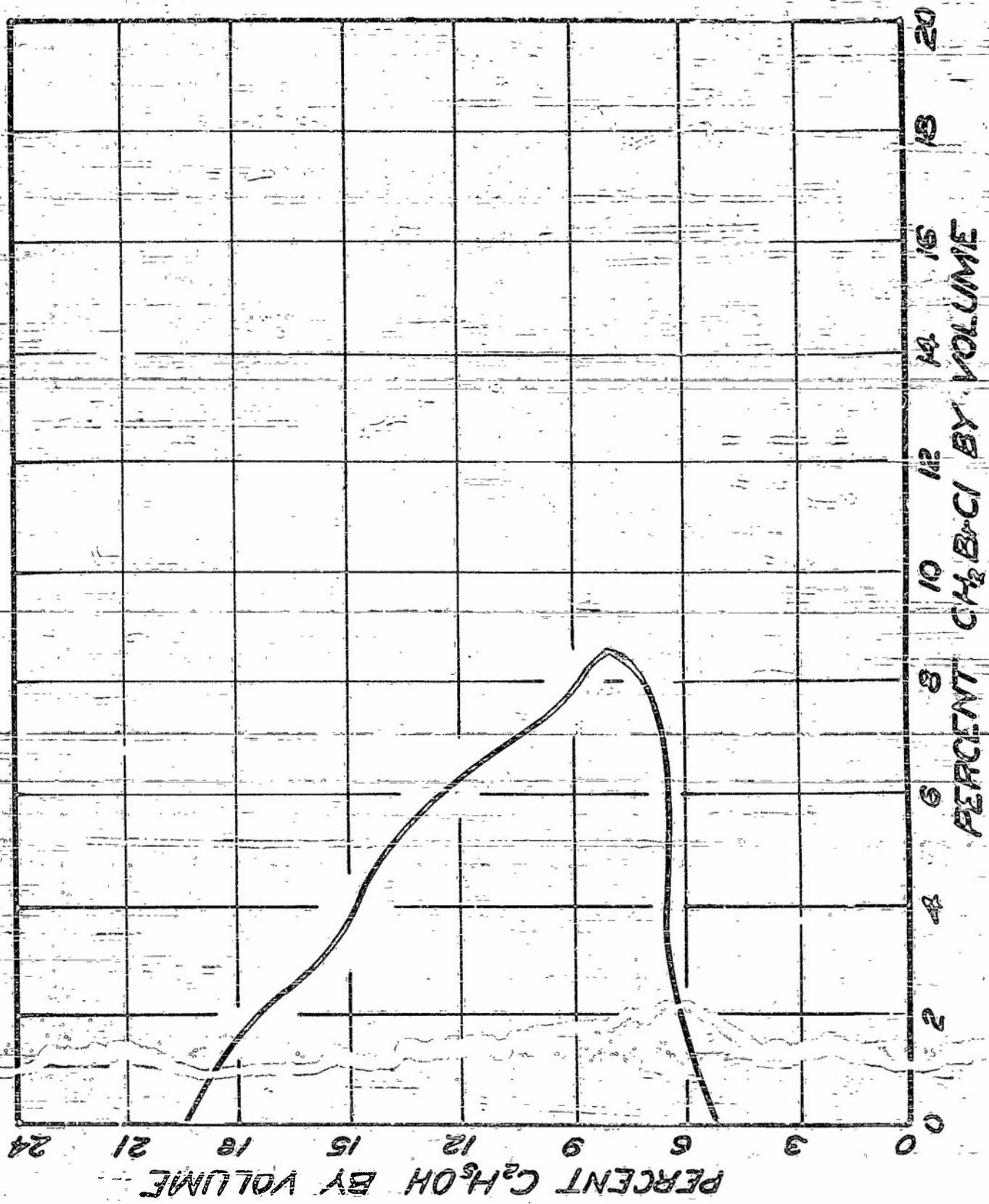

Fig. 24 Flammable Area for Mixtures of Ethanol, Bromochloromethane and Air

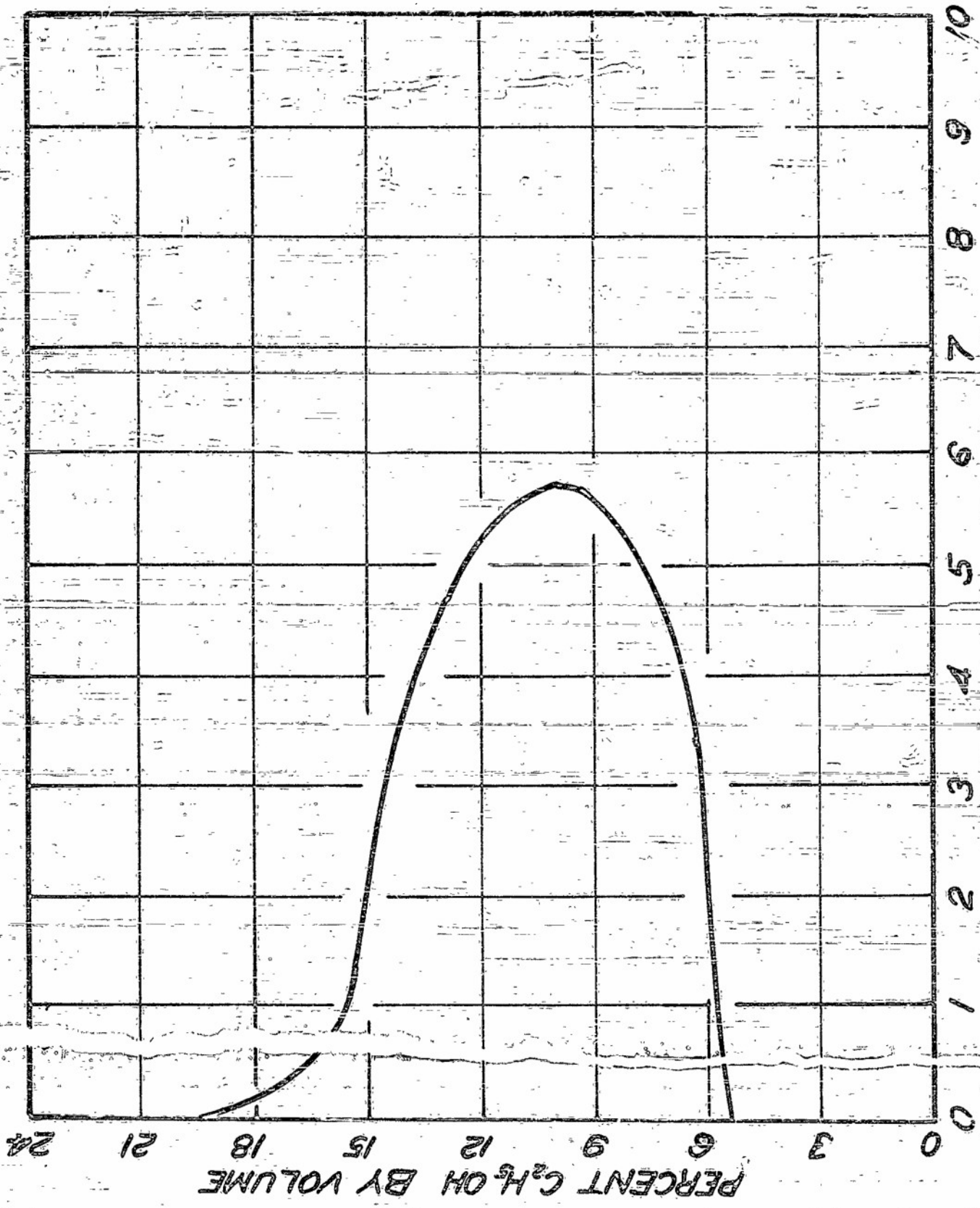

Fig 25 Flammable Area for Mixtures of Ethanol, Dibromodifluoromethane and Air

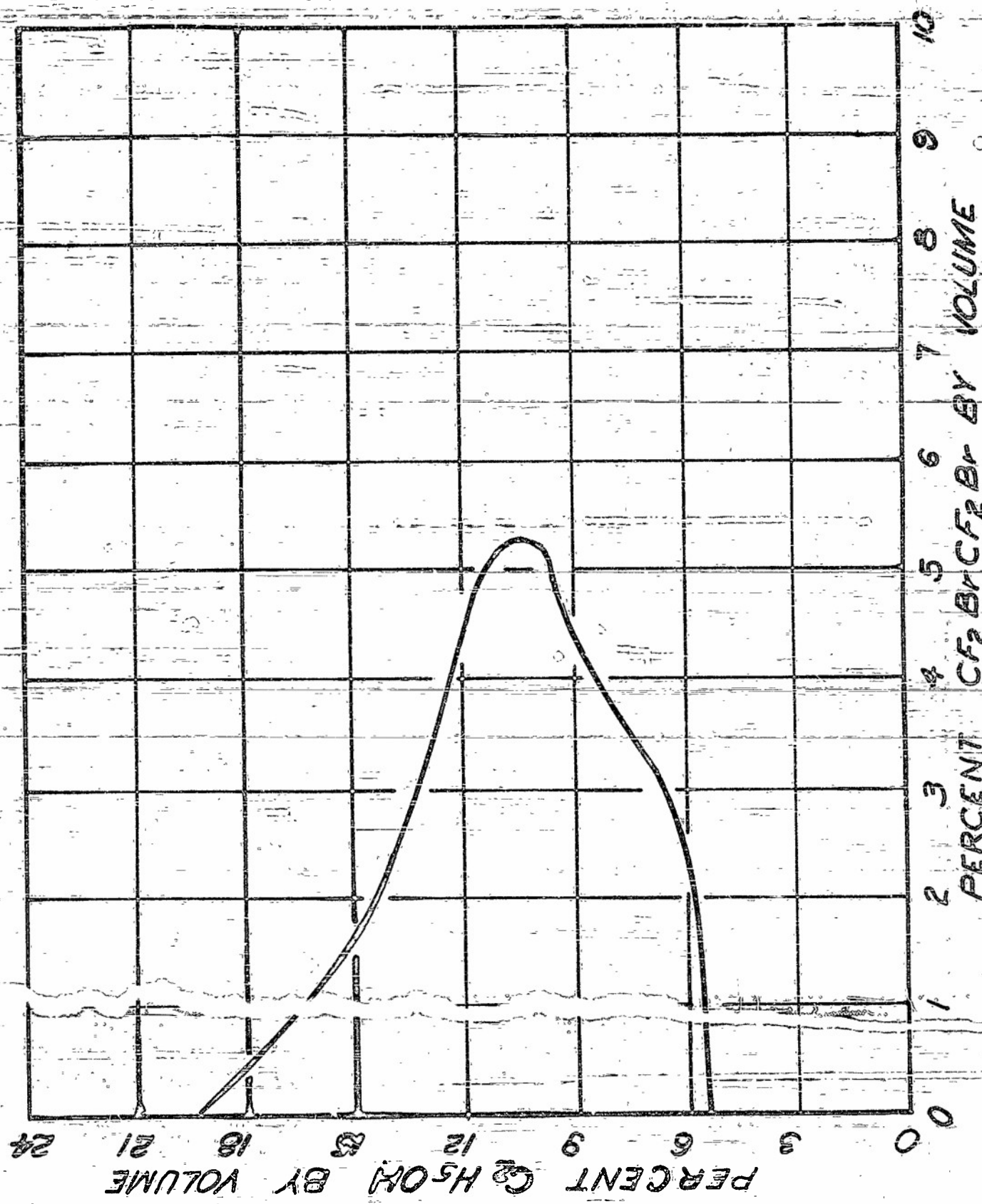

Fig. 26 Flammable Area for Mixtures of Ethanol, 1.2-Dibromotetrafluoroethane and Air

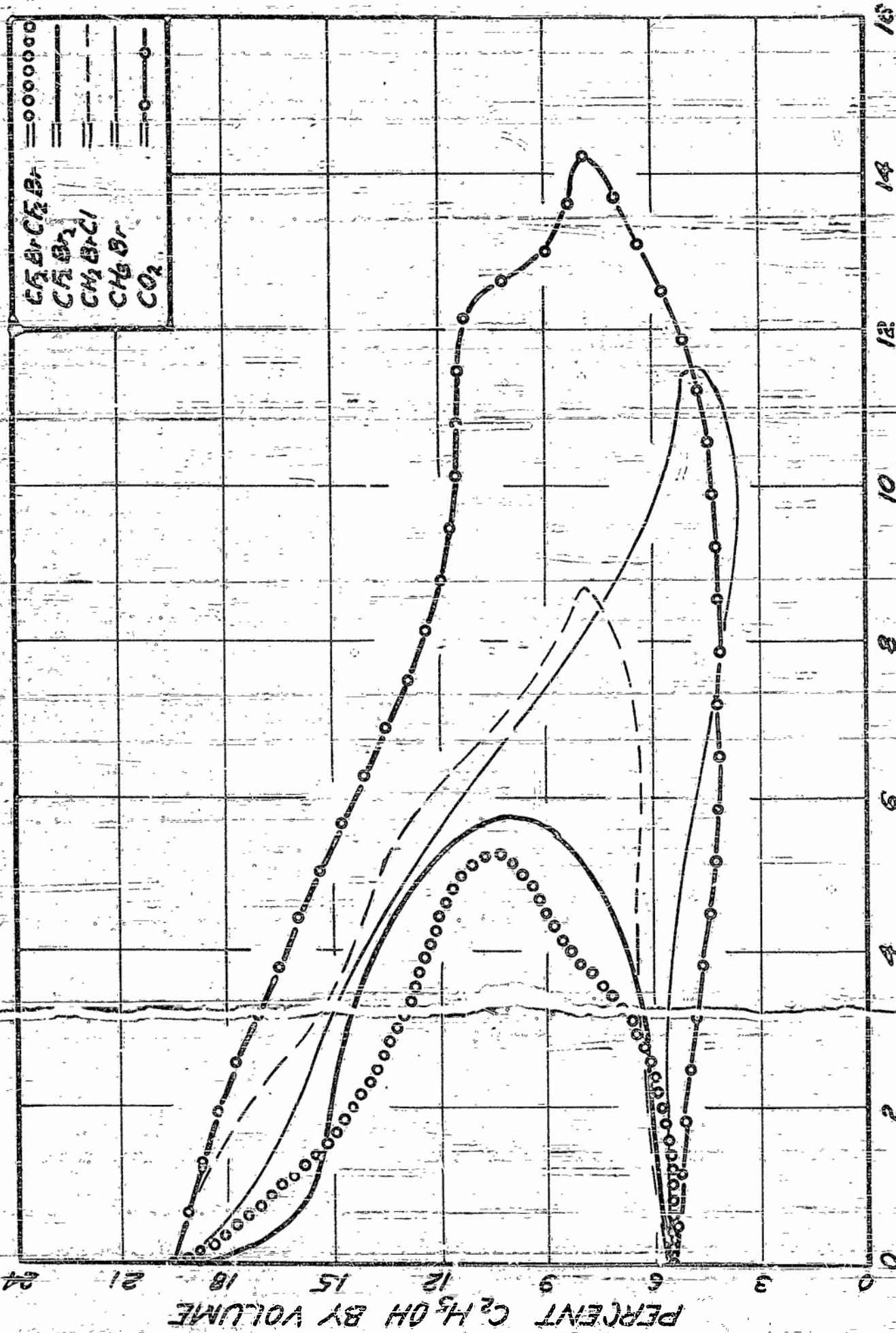

Fig. 27 Flammable Areas for Mixtures of Ethanol, Extinguishers and Air

Table IV

Summary of Compounds Evaluated as Fire Extinguishing Agents for Ethanol Fires (Temperature = 130°C)

Compound Formula	Compound Name	Peak in Flammability Curve, %	Extinguisher, gm*	Order of Effectiveness Vol. Basis	Order of Effectiveness Wt. Basis
CF_2BrCF_2Br	1,2-Dibromo-tetrafluoro-ethane	5.3	52.5	1	4
CF_2Br_2	Dibromodi-fluoromethane	5.8	54.4	2	5
CH_2BrCl	Bromochloro-methane	9.7	50.5	3	3
CH_3Br	Methyl bromide	11.4	48.4	4	2
CO_2	Carbon dioxide	14.1	27.7	5	1

* These values were obtained by calculations assuming 100 liters of gaseous mixture at 0°C and one atmosphere of pressure.

plot of all five flammable areas is given in Fig. 33.

Table V

Summary of Compounds Evaluated as Fire Extinguishing Agents for Nitromethane Fires (Temperature = 150°C)

Compound Formula	Compound Name	Peak in Flammability Curve, %	Extinguisher, gm*	Order of Effectiveness Vol. Basis	Order of Effectiveness Wt. Basis
CF_2BrCF_2Br	1,2-Dibromo-tetrafluoro-ethane	4.2	41.6	1	1
CF_2Br_2	Dibromodi-fluoromethane	8.6	80.7	2	5
CH_2BrCl	Bromochloro-methane	12.4	72.0	3	3
CH_3Br	Methyl bromide	18.9	80.2	4	4
CO_2	Carbon dioxide	21.7	42.6	5	2

* These values were obtained by calculations assuming 100 liters of gaseous mixture at 0°C and one atmosphere pressure.

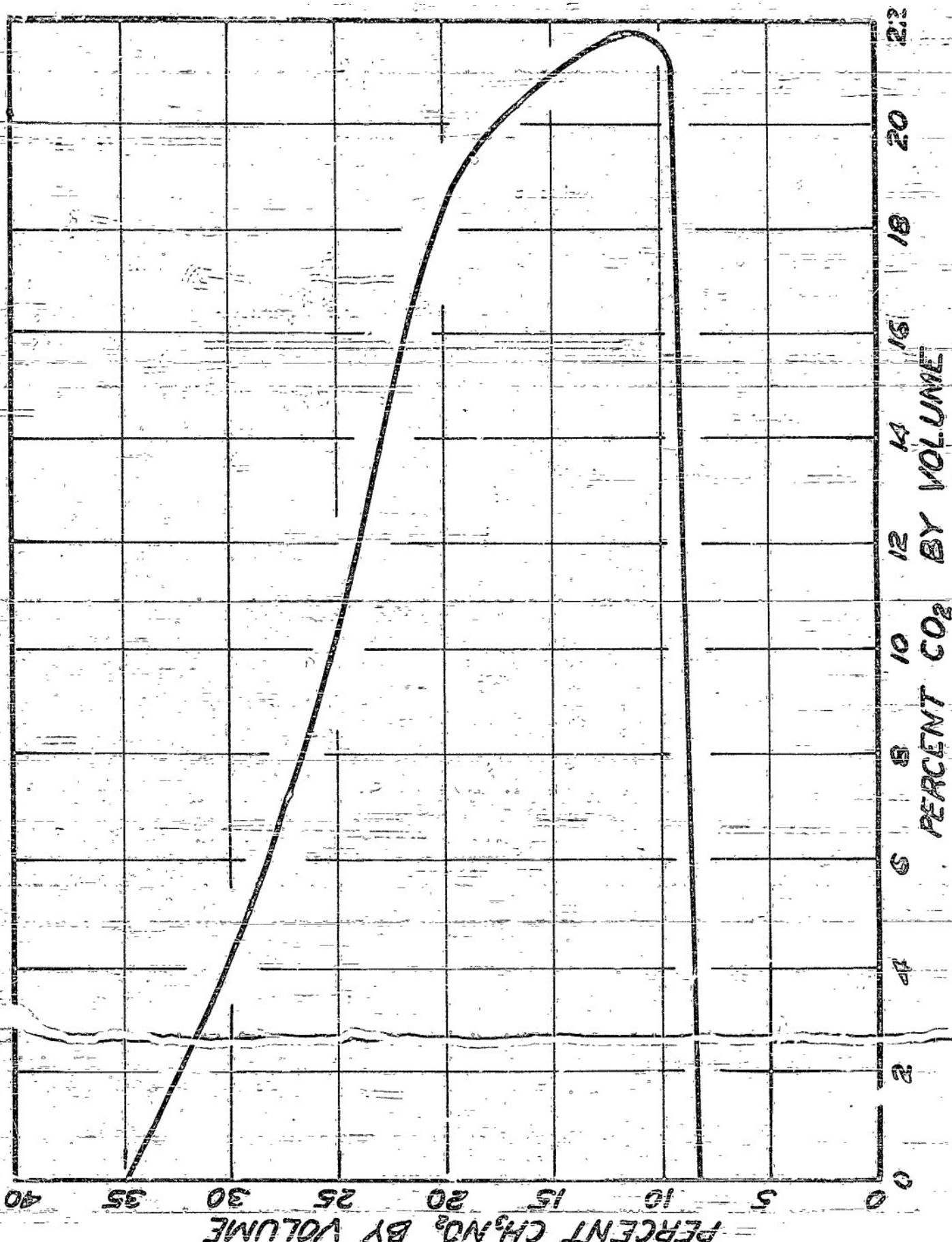

Fig. 28 Flammable Area for Mixtures of Nitromethane, Carbon Dioxide and Air

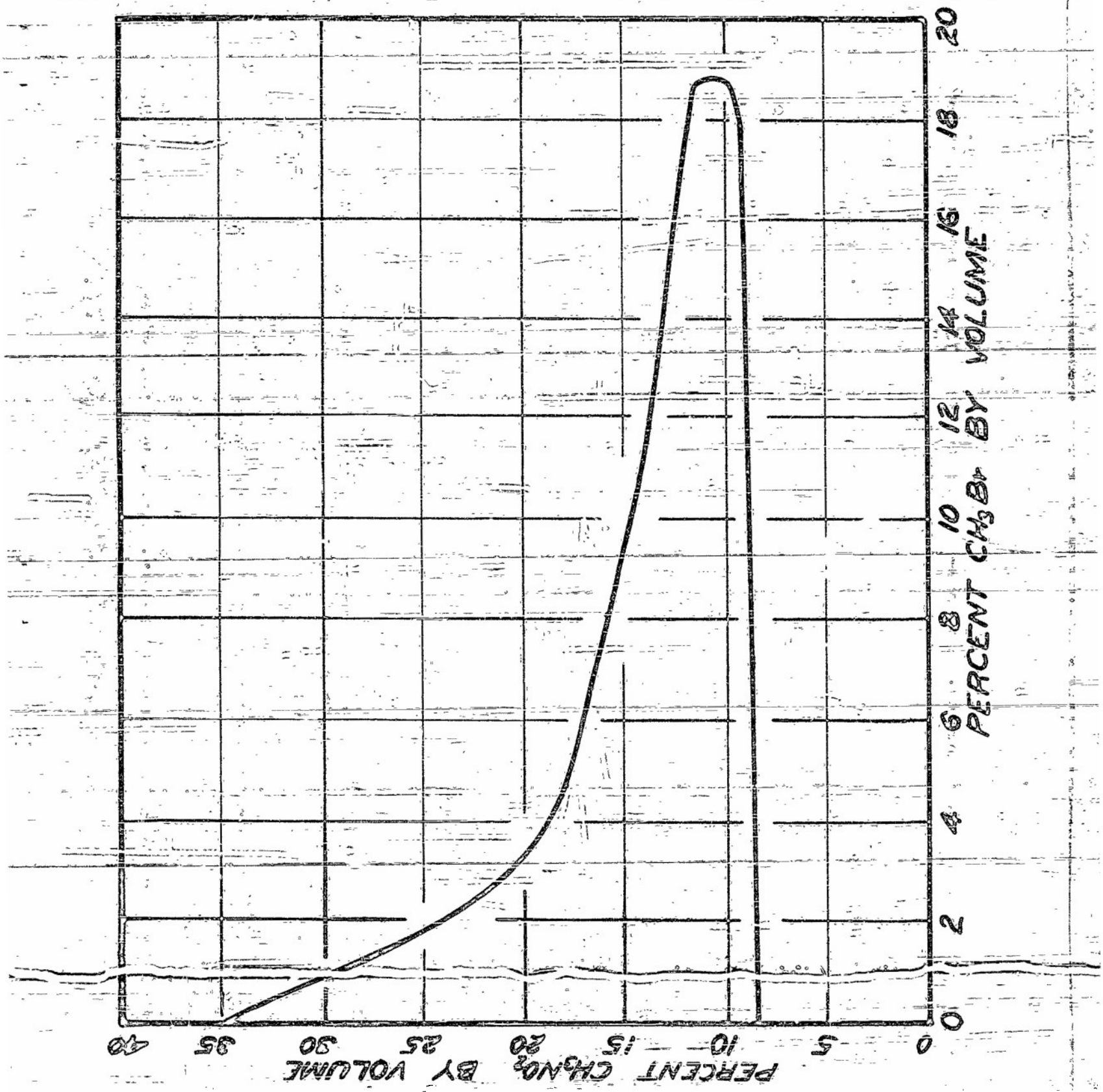

Fig. 29 Flammable Area for Mixtures of Nitromethane, Methyl Bromide and Air

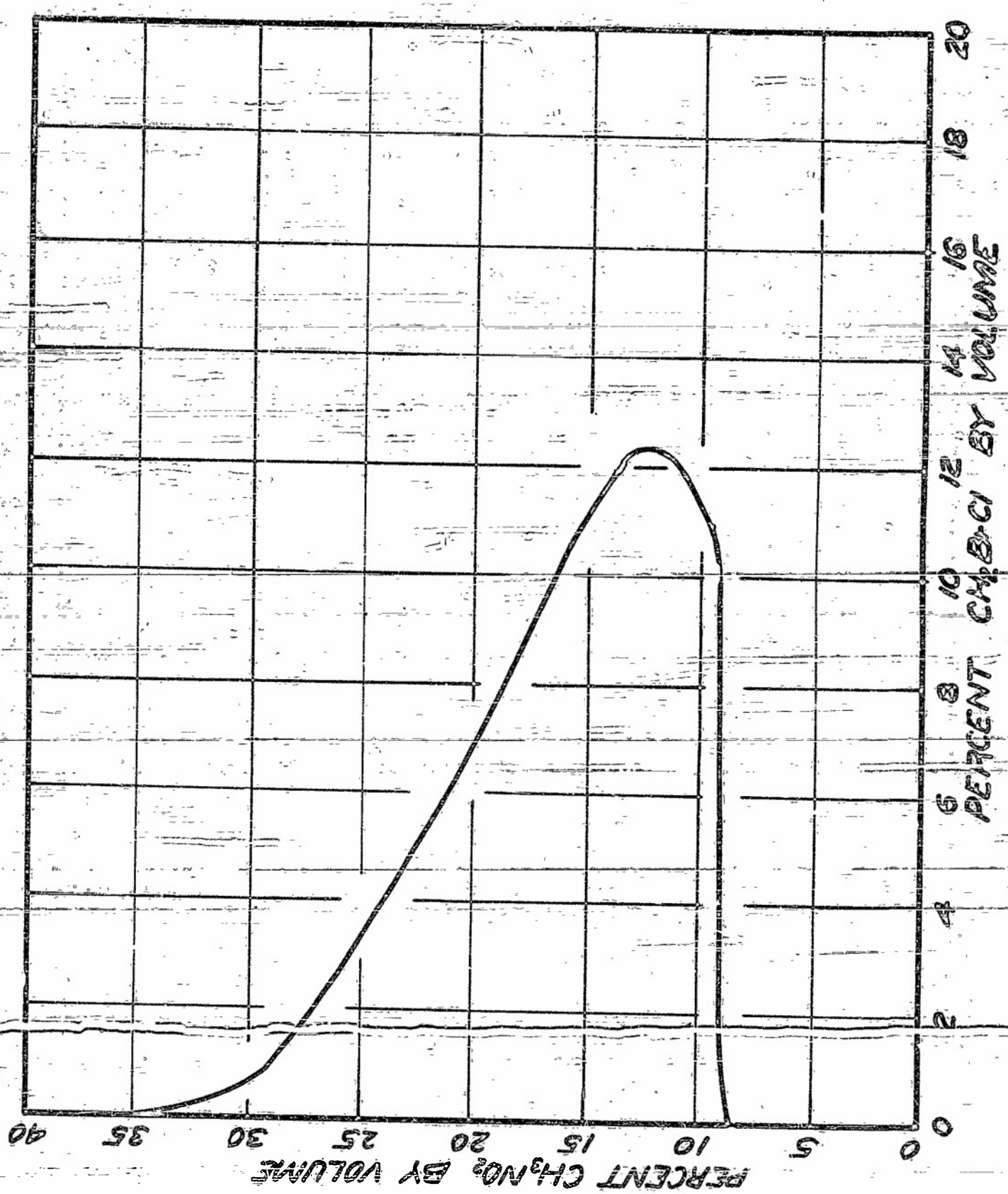

Fig. 30 Flammable Area for Mixtures of Nitromethane, Bromochloromethane and Air

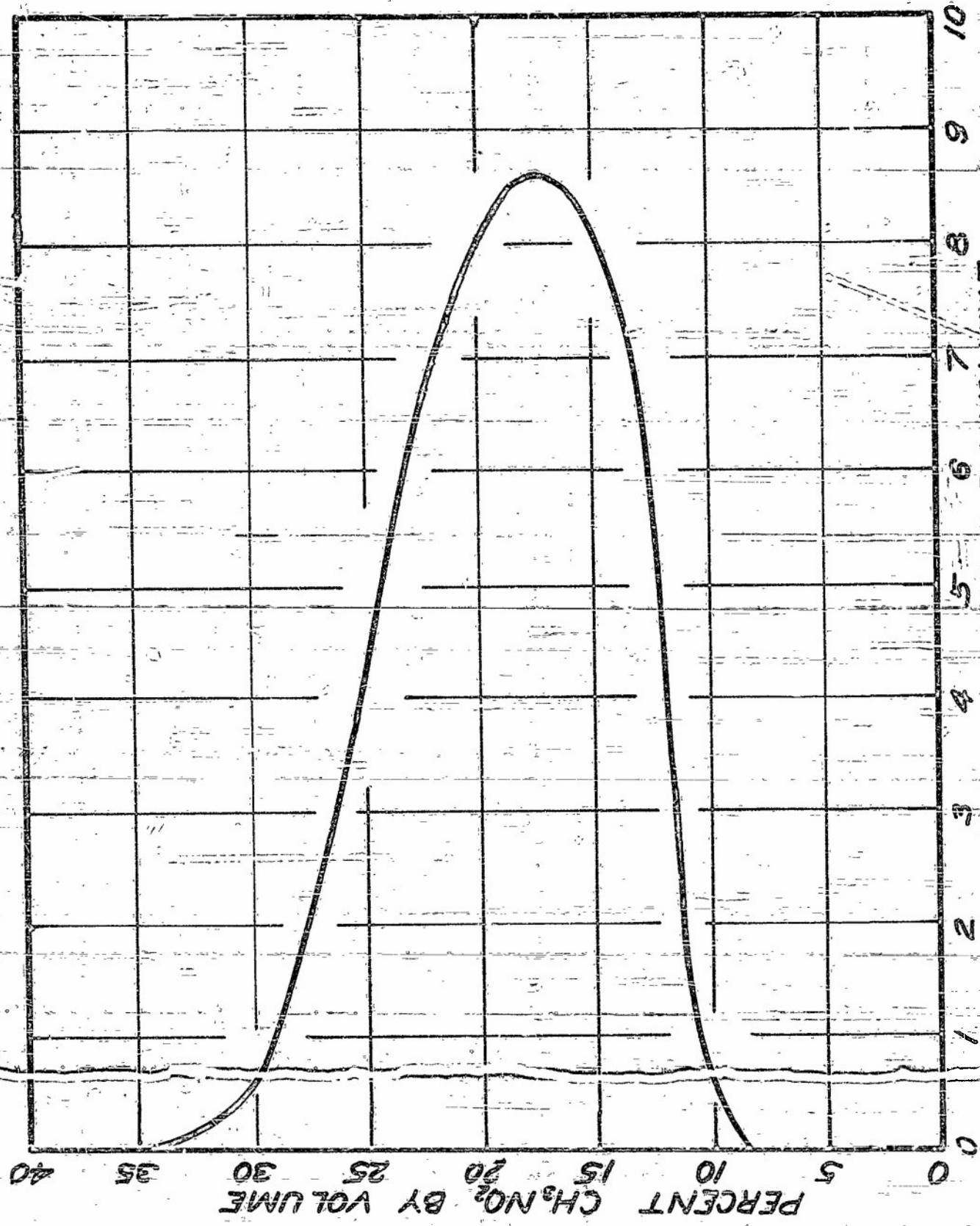

Fig. 31 Flammable Area for Mixtures of Nitromethane, Dibromodifluoromethane and Air

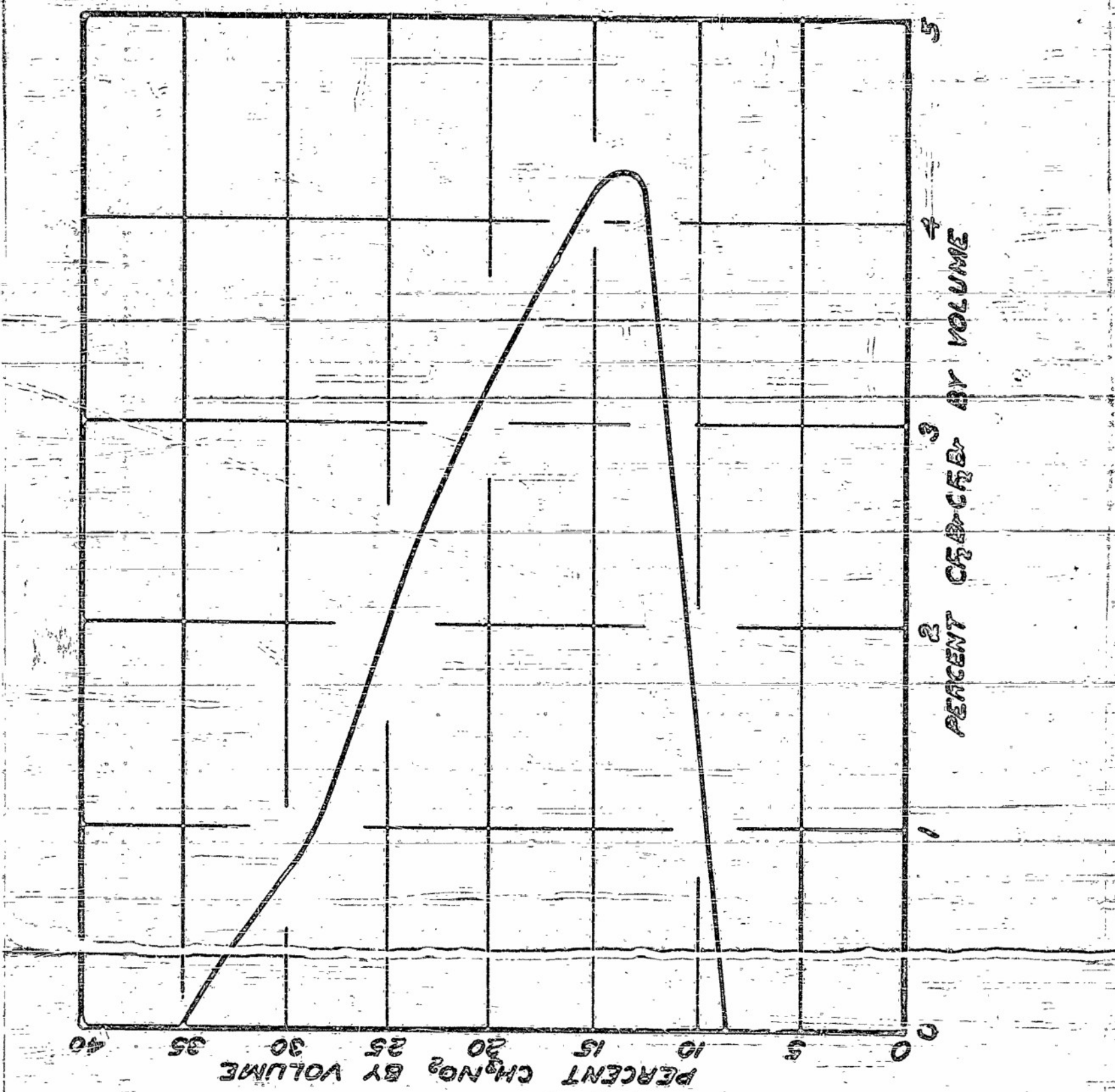

Fig. 32 Flammable Area for Mixtures of Nitromethane, 1,2-Dibromotetrafluoroethane and Air

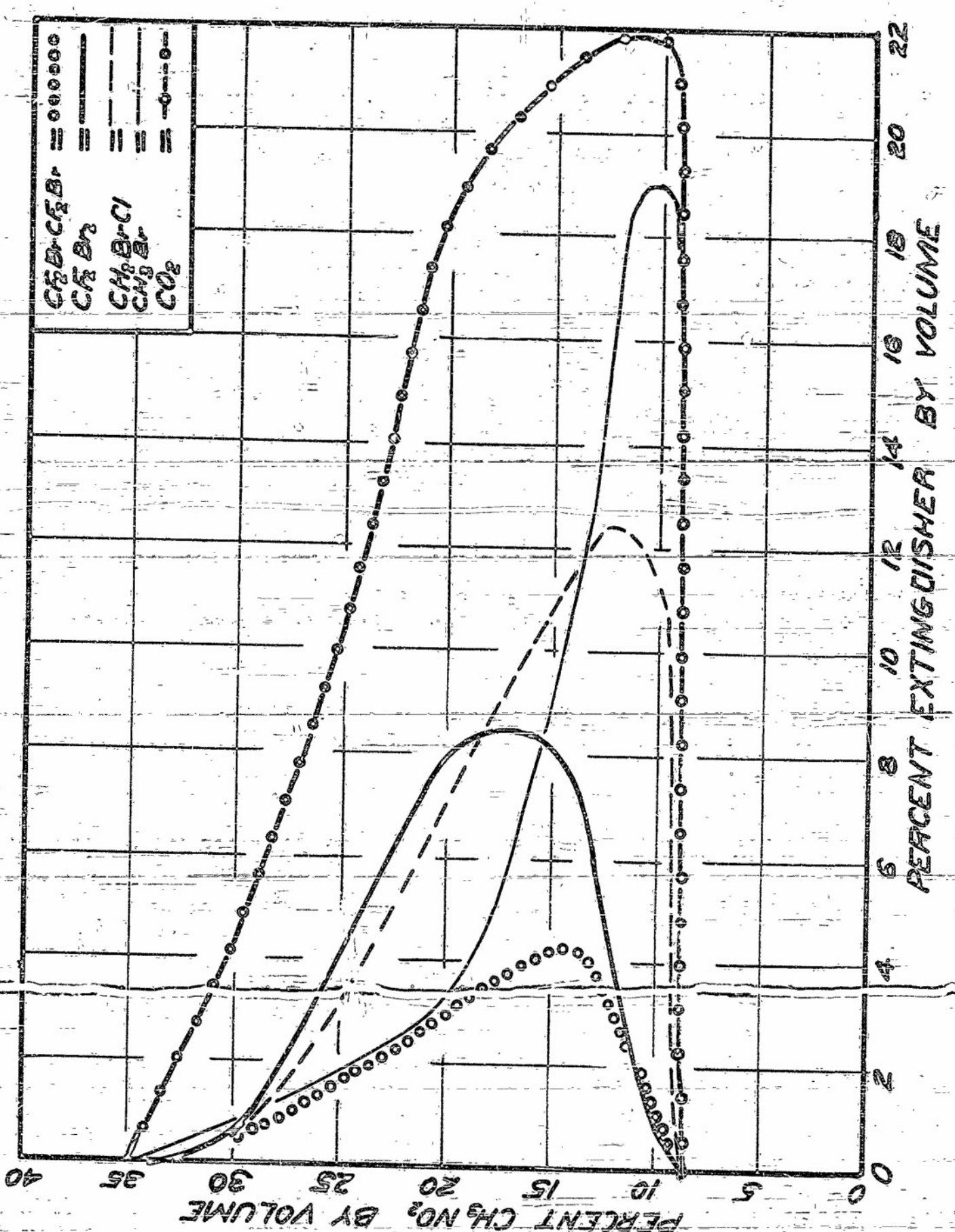

Fig. 33 Flammable Areas for Mixtures of Nitromethane, Extinguishers and Air

Hydrazine

Although special precautions were taken to insure the safety of the workers when testing hydrazine as a fuel, it was found that all such measures were actually unwarranted. A recent report[4] in the literature described a violent explosion incurred by workers at the Bureau of Mines while determining the flammable limits of hydrazine in air. A minor explosion resulting from the ignition of a hydrazine-air mixture was reported still earlier by Bamford[5].

According to the former report[4], the flammable limits of hydrazine in air at atmospheric pressure are 4.67 and 100 percent. However, when hydrazine was tested in this investigation in the range of 5-60% by volume, no combustion was obtained in any of the trials. Since these tests were conducted at 200°C (and 400 mm), it might be concluded that thermal decomposition of the fuel occurred prior to ignition of the mixtures, thus leading to erroneous conclusions with regard to concentrations percent. A bath temperature of 200°C was found desirable in order to maintain the hydrazine in the vapor state throughout the course of an individual run.

Furfuryl Alcohol

When the preliminary tests with furfuryl alcohol were carried out in an effort to obtain the flammable limits of this fuel, rapid dehydration and polymerization of the fuel was found to occur. It is known[6] that furfuryl alcohol dehydrates in an intermolecular manner and polymerizes when heated above its boiling point (169.5°C). Since bath temperatures in the neighborhood of 200°C (and still higher manifold temperatures) were required for its testing in the apparatus used, it was found necessary to discontinue the work on this compound.

Aniline

In the testing of aniline, bromochloromethane was found to be the most effective extinguishing agent when considered on the usual volume basis. From the weight standpoint, carbon dioxide proved to be the most desirable agent for use in combatting aniline fires. The flammable areas of each of the extinguisher compounds with aniline and air are shown in Figs. 34-38. In Fig. 39 is presented a plot of the five areas together. The results of the aniline-extinguisher tests are given in Table VI.

Table VI

Summary of Compounds Evaluated as Fire Extinguishing Agents for Aniline Fires (Temperature = 200°C)

Compound Formula	Compound Name	Peak in Flammability Curve, %	Extinguisher, gm*	Order of Effectiveness Vol. Basis	Order of Effectiveness Wt. Basis
CH_2BrCl	Bromochloromethane	1.8	10.5	1	3
CH_3Br	Methyl bromide	1.9	18.05	2	2
CO_2	Carbon dioxide	2.1	4.13	3	1
CF_2BrCF_2Br	1,2-dibromotetrafluoroethane	2.2	30.0	4	4
CF_2Br_2	Dibromodifluoromethane	3.2	21.8	5	5

* These values were obtained by calculations assuming 100 liters of gaseous mixture at 0°C and one atmosphere of pressure.

Summary of Test Results

From the tables presented in the preceding pages, it may be concluded that 1,2-dibromotetrafluoroethane is probably the most effective over-all extinguishing agent for combatting jet fuel fires. This conclusion is drawn primarily from the fact that in the case of four out of the six fuels successfully tested, 1,2-dibromotetrafluoroethane was found to be the most effective

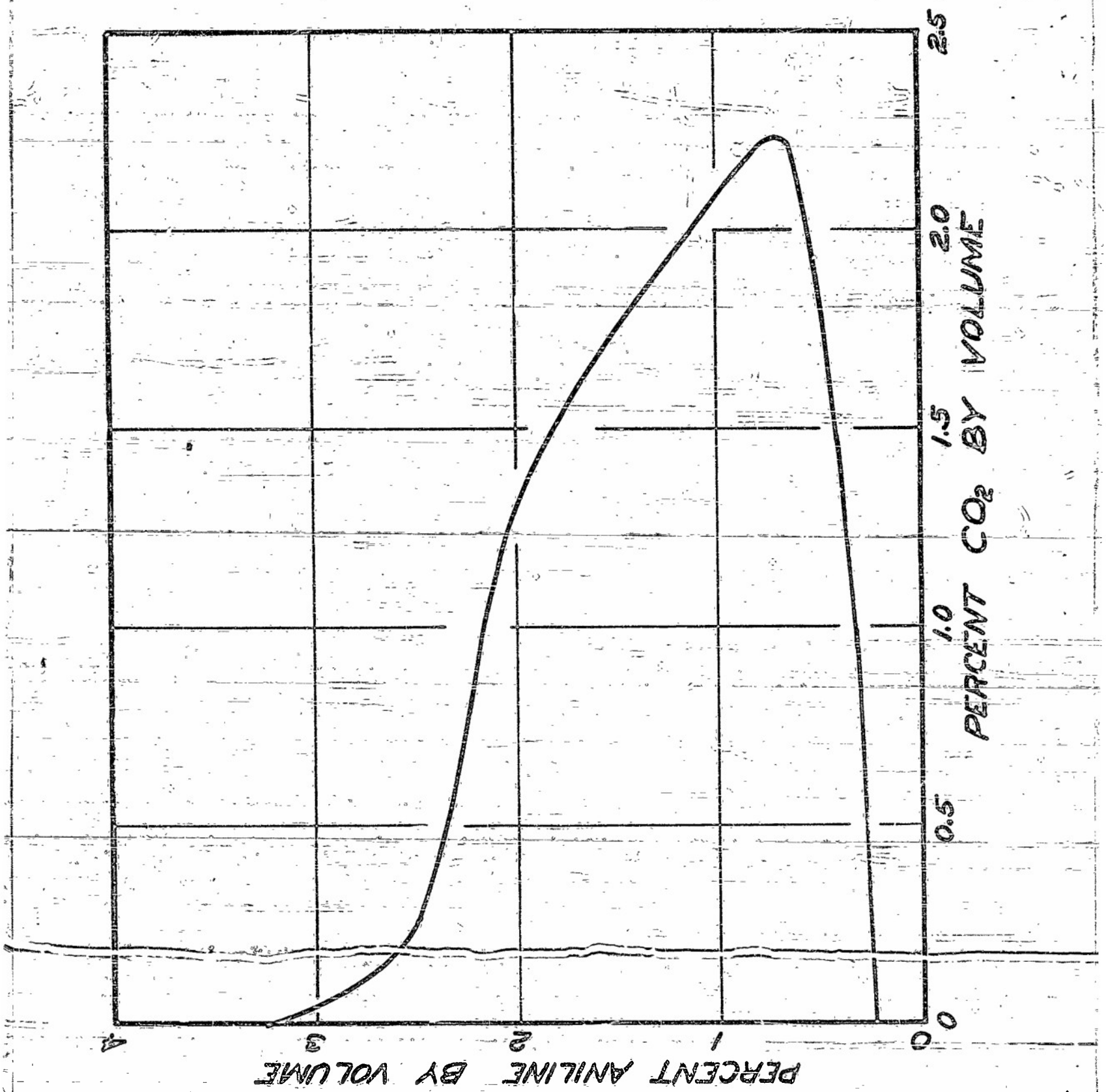

Fig 34 Flammable Area for Mixtures of Aniline, Carbon Dioxide and Air

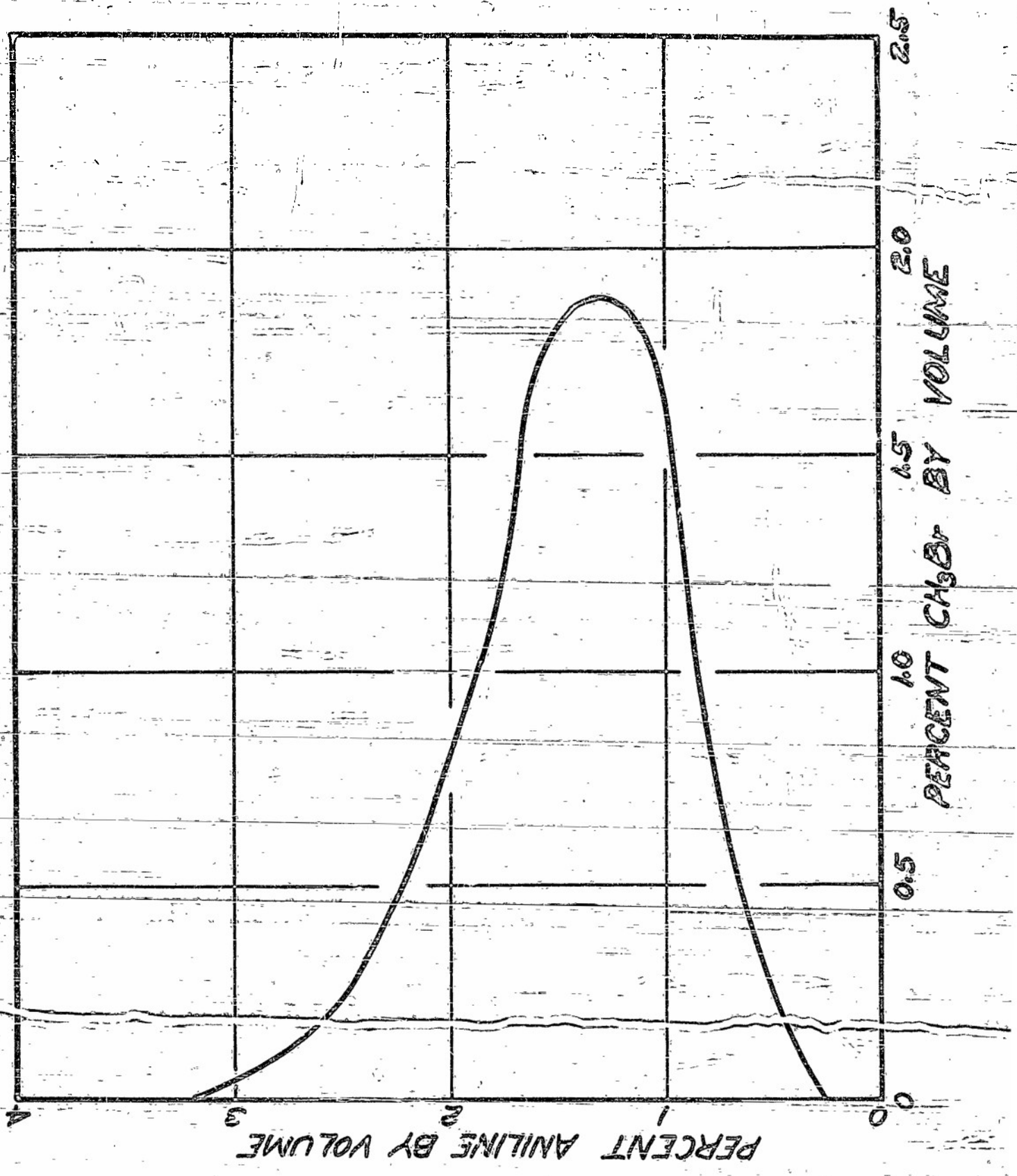

Fig. 35 Flammable Area for Mixtures of Aniline, Methyl Bromide and Air

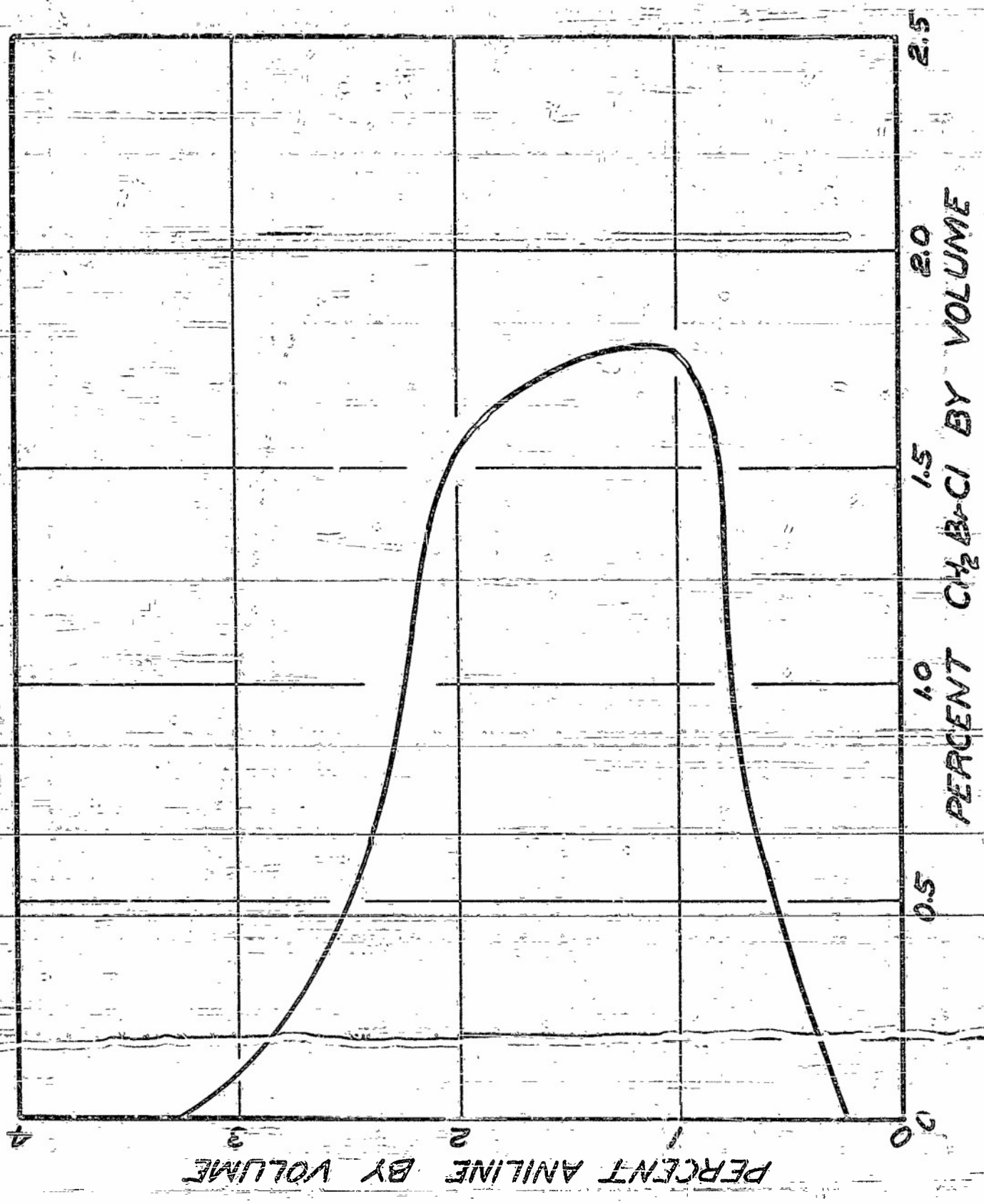

Fig. 36 Flammable Area for Mixtures of Aniline, Bromochloromethane and Air

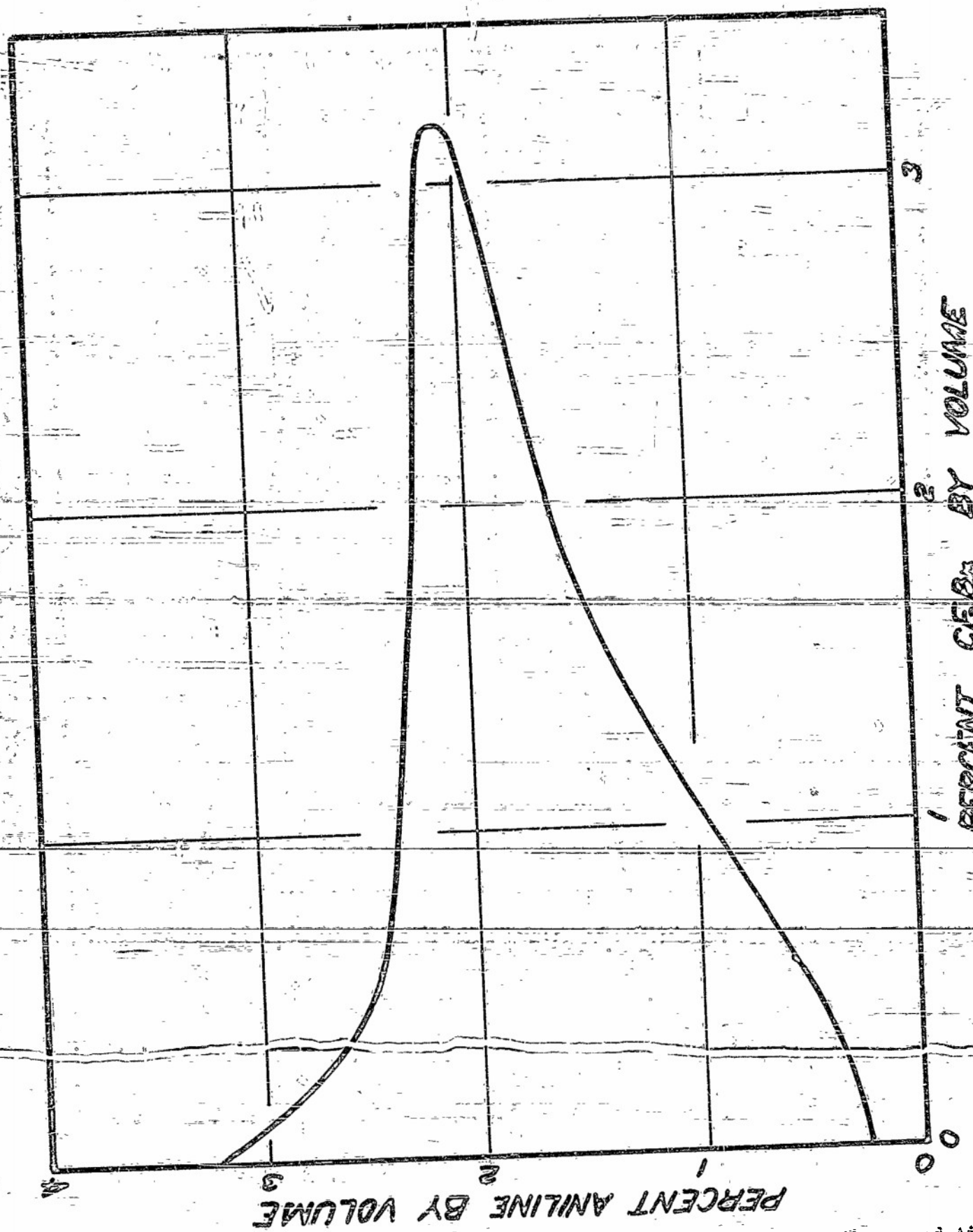

Fig. 37 Flammable Area for Mixtures of Aniline, Dibromodifluoromethane and Air

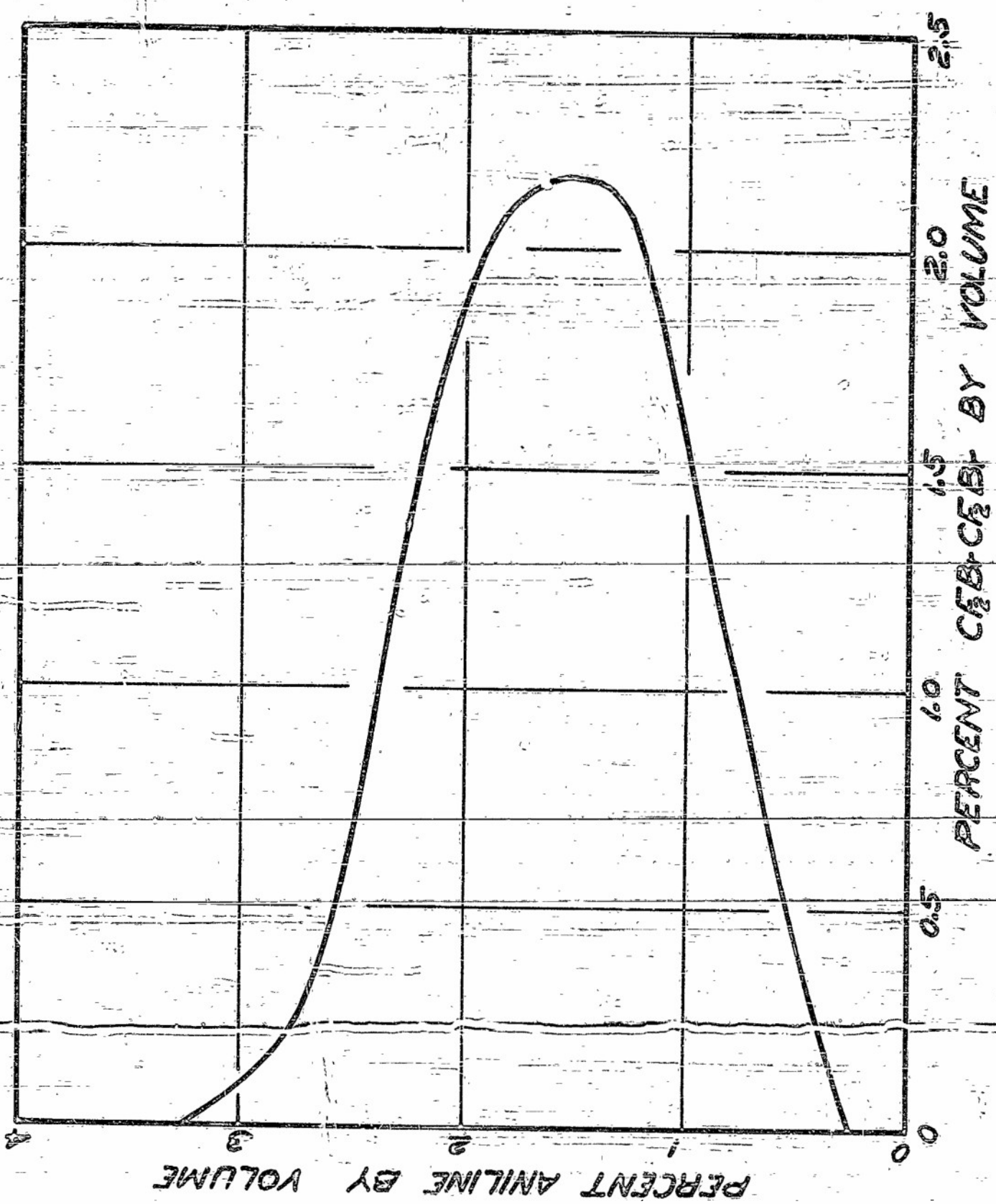

Fig. 38 Flammable Area for Mixtures of Aniline, 1,2-Dibromotetrafluoroethane and Air

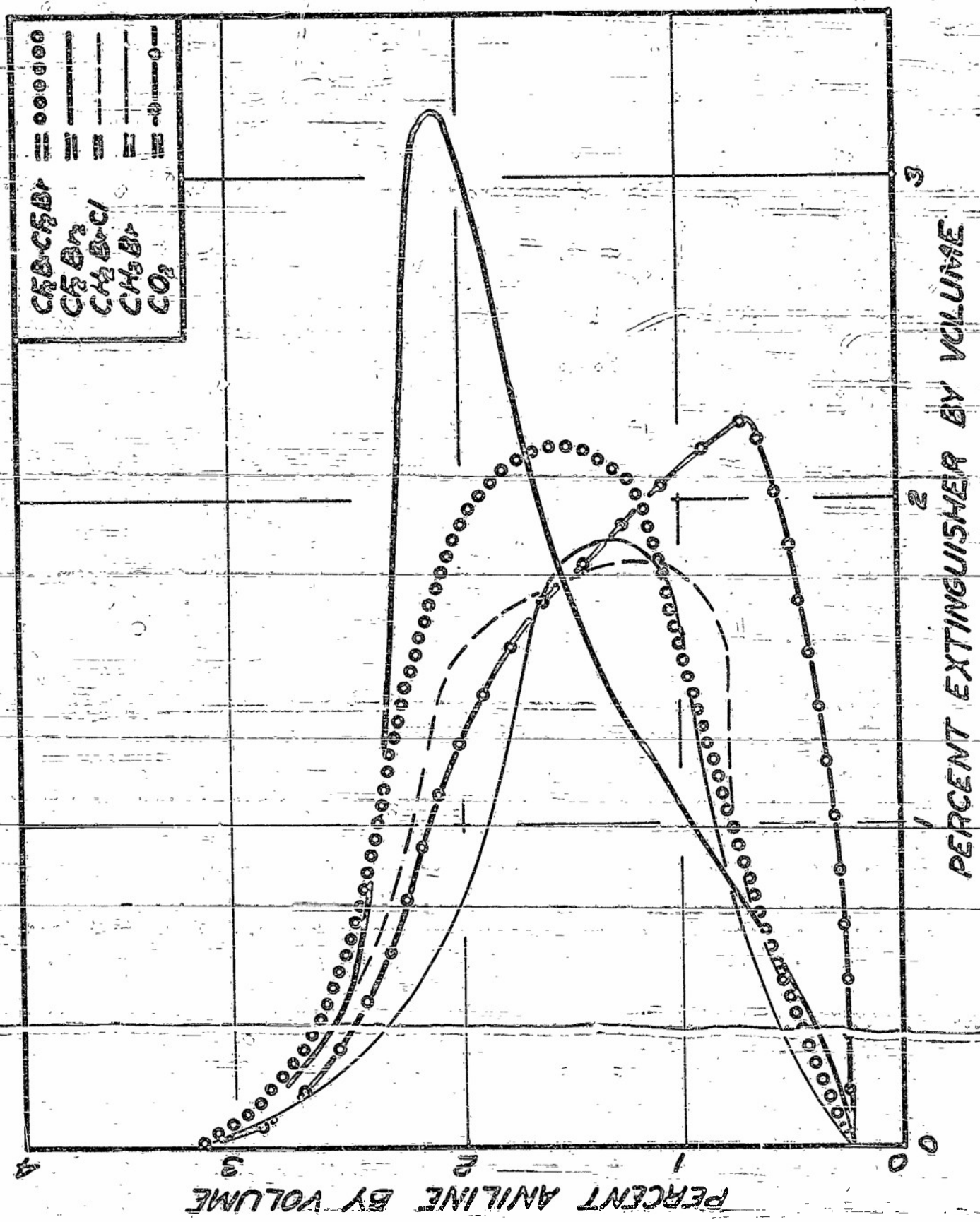

Fig. 39 Flammable Areas for Mixtures of Aniline, Extinguishers and Air

extinguisher on a volume basis. The compound ranked a close second in the case of the fifth fuel and was only fourth best in the testing of the last fuel.

SECTION II - FLUORINE

Equipment

Fluorine - Extinguisher Reactivity Apparatus

When the problem of determining the applicability of fire-retarding agents against fluorine fires was considered early in the investigation, it was believed that a material reacting with fluorine at room temperature would be unsuitable for use as an extinguishing agent in fires involving fluorine. Consequently, it was decided that studies should first be conducted to determine the concentration of fluorine, in admixture with nitrogen, required for reaction with the test agent before attempting further evaluation of the effectiveness of an extinguisher against fluorine fires. Since it was recognized that special techniques and apparatus would be required, the methods of handling fluorine were reviewed with the idea of applying known techniques to the problem of determining reactivity of fluorine with extinguishing agents. This resulted in measuring reactivity by mixing fluorine, nitrogen and the test agent in a nickel tube packed with copper gauze. A diagram of the entire apparatus is presented in Fig. 40 and a photograph of the same is shown in Fig. 41. A more detailed photograph of the fluorine, nitrogen and extinguisher supplies and equipment for their measurement is shown in Fig. 42. A description of the apparatus is as follows:

The nickel reaction or combustion tube (8) was constructed from nickel pipe of 30 mm inside diameter and was 124 cm long. An inlet 51 cm from the bottom of the tube was connected by means of one-quarter inch copper tubing to the extinguisher supply (1). The flow of the fire-retarding

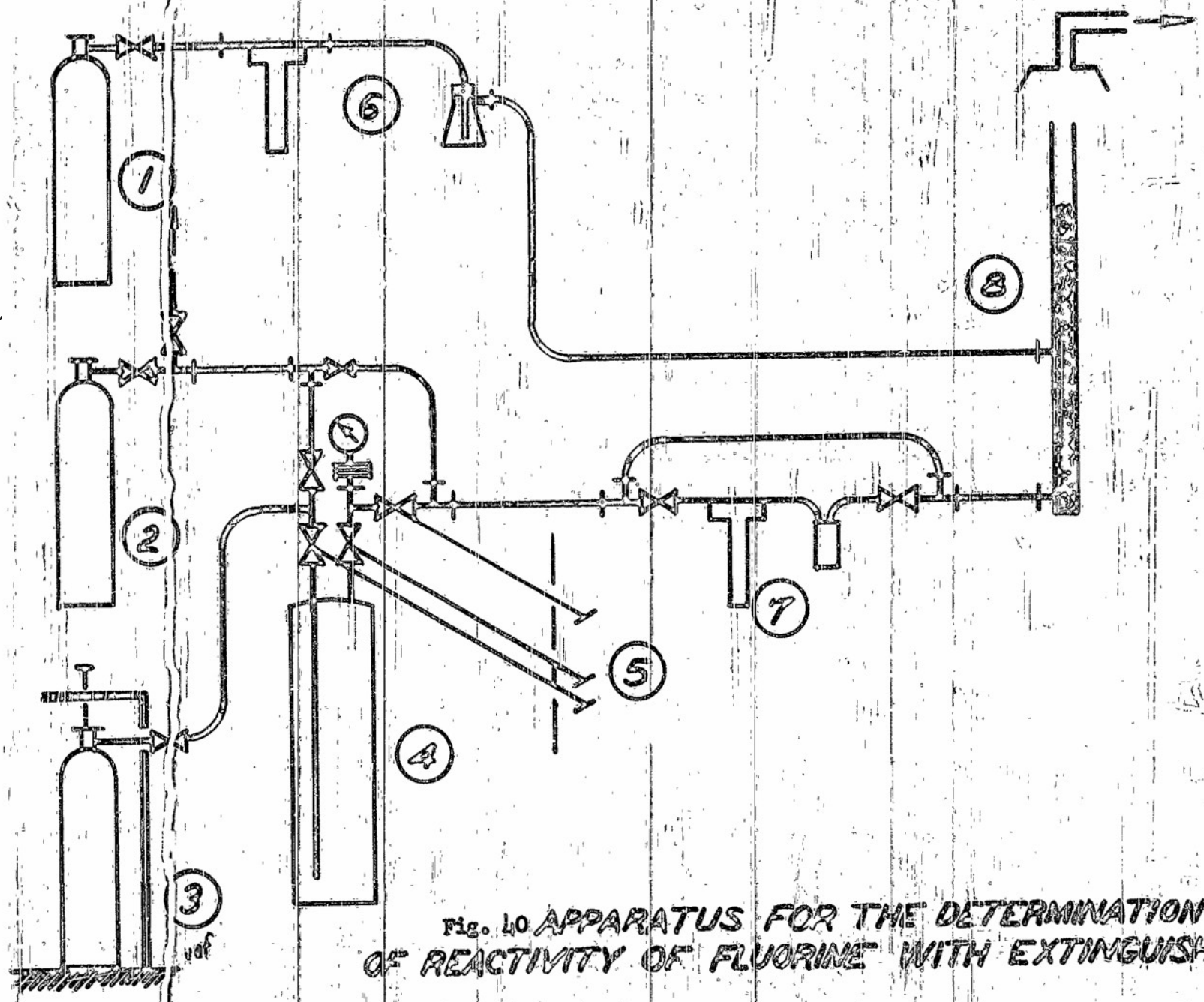

Fig. 40 APPARATUS FOR THE DETERMINATION OF REACTIVITY OF FLUORINE WITH EXTINGUISHERS

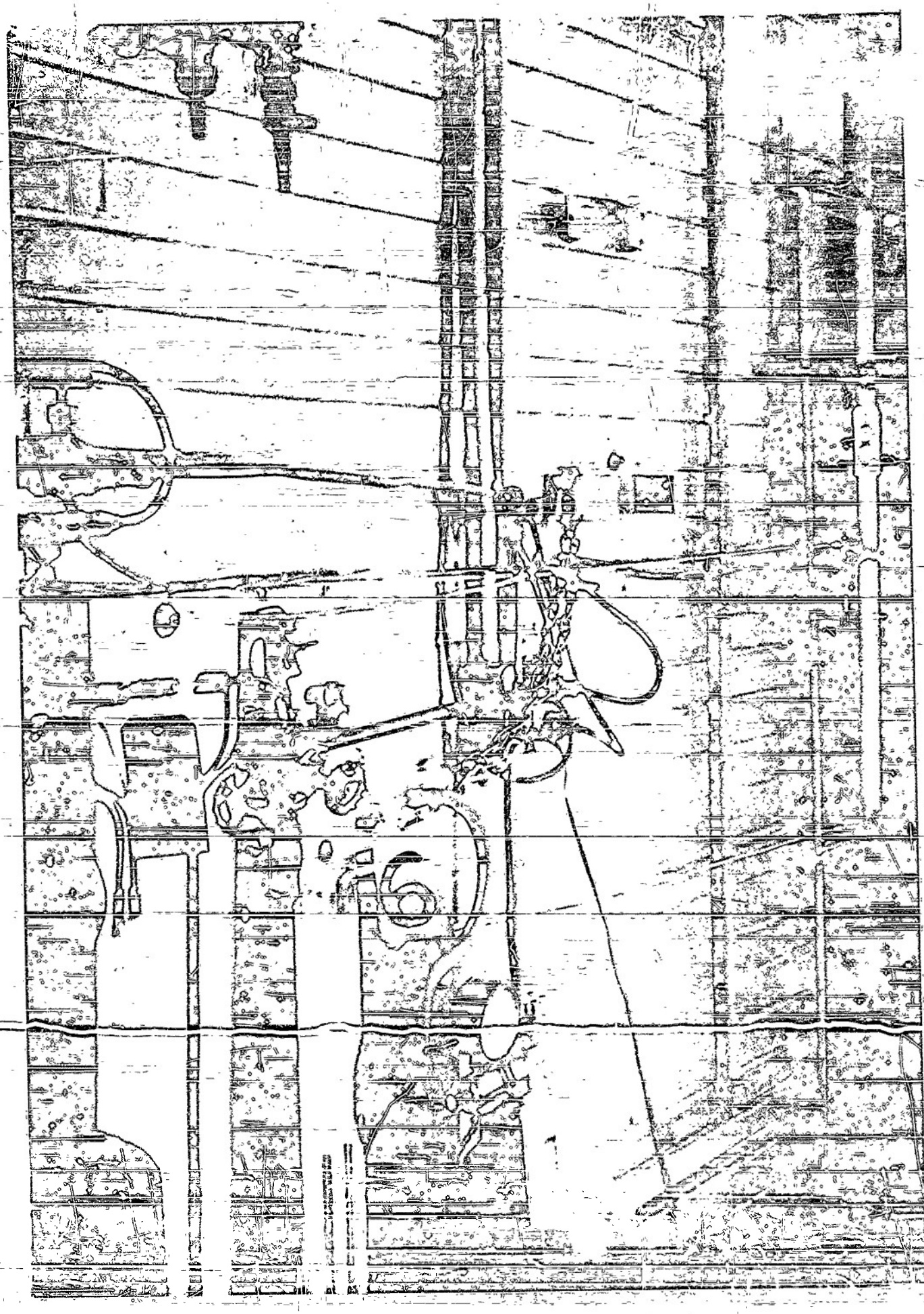

Fig. 41 Fluorine-Extinguisher Reactivity Apparatus

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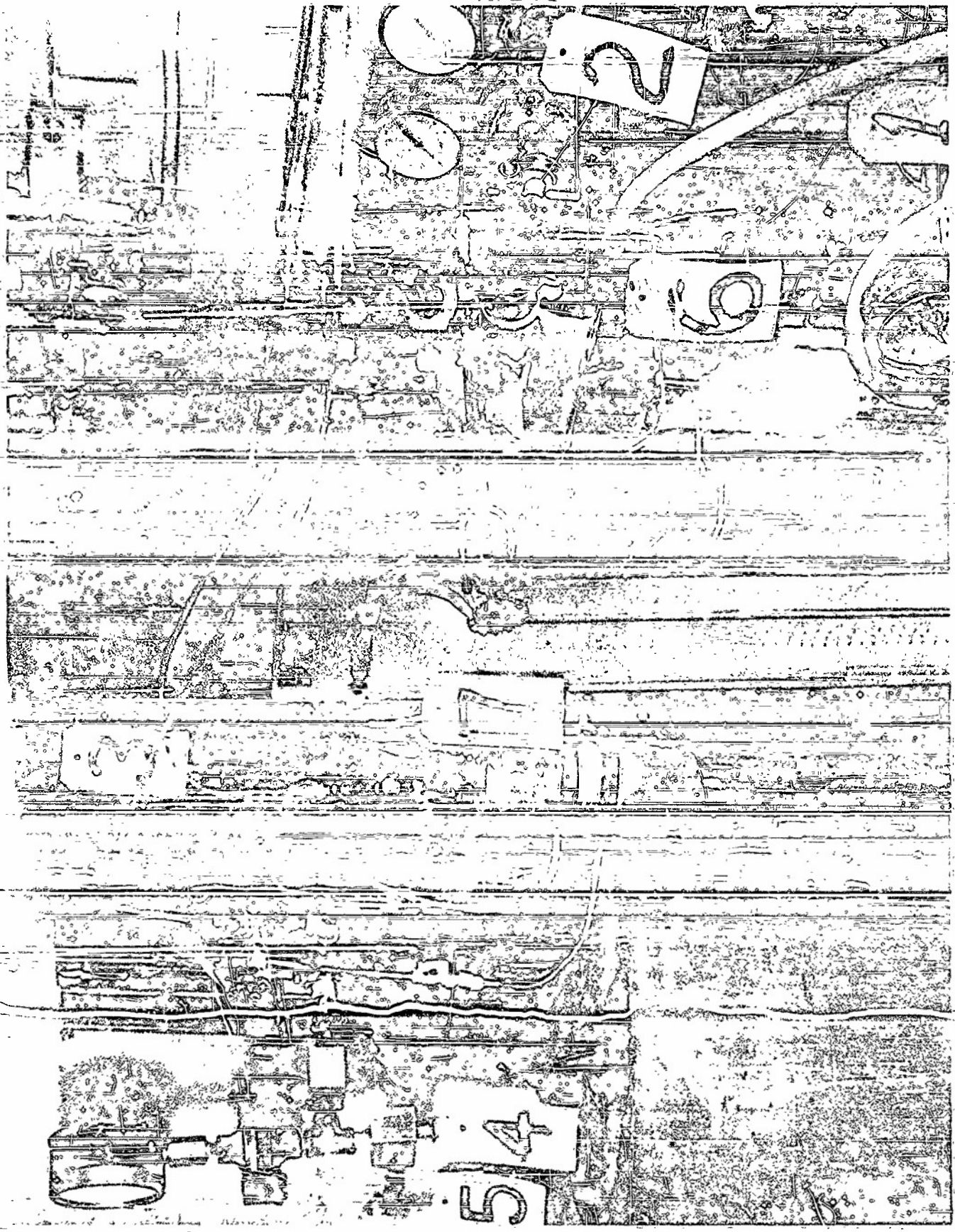

Fig. 42 Recovery Equipment of Fluorine

material to the reactor was determined by a mercury flowmeter (6) which was protected by a Pyrex glass trap. An inlet 5 cm above the bottom of the reaction tube was connected by one-quarter inch copper tubing to an iron storage tank (4), 6 ft in height and of 5.1 cu ft capacity. The tank was charged with a fluorine-nitrogen mixture, under a pressure of 100 lbs/sq in. and containing 12.3% (approx.) fluorine, from nitrogen (2) and fluorine (3) cylinders.

The flow rate of the fluorine-nitrogen mixture was determined by means of a flowmeter (7) constructed from one-quarter inch copper tubing and connected by brass fittings. To permit observation of the liquid level in the flowmeter, a section of one of the flowmeter legs was replaced by a length of 8 mm Pyrex glass tubing. The glass was connected to the copper by means of Tygon tubing. The liquid used to measure the flow rate was perfluro-1-methylnapthalene, a compound inert to fluorine. The constriction in the upper portion of the meter was effected by means of a small copper disc with a small hole in its center and held in place by brass fittings. This meter was calibrated with a wet test meter, using nitrogen, and was protected by a nickel trap.

The apparatus was operated in the following manner: Storage tank (4) and reactor tube (8) were flushed out with nitrogen by opening and closing the appropriate needle valves. Fluorine was introduced into the tank after the inlet and outlet valves were opened by remote control from behind a steel barrier (5). The free halogen was not permitted to flow through flowmeter and trap, however. It was passed through a one-quarter inch copper tubing shunt by closing the two valves on each end of the flowmeter. The point at which the storage tank was completely filled with fluorine was indicated by the combustion of a wooden splint placed at the top of the

reactor (8). Nitrogen was then bled into the tank until the desired pressure was indicated on a silver diaphragm gauge.

After reflushing the reactor tube with nitrogen, the extinguisher was introduced. The gaseous flow rate was determined by pressure difference as noted on the flowmeter (6). The diluted fluorine was then admitted by opening the outlet valves on the storage tank by remote control (5). Observation of reaction effects at the top of the tube (8), as well as of pressure differences on the flowmeter (7), was made through a small hole in the steel barrier. A positive result was indicated by the appearance of visible gaseous products at the top of the combustion tube. In the case of the bromine containing extinguishers, the reddish vapors of bromine were, in general, observed as a result of the reaction.

Modified Reactivity Apparatus

Due to the relative non-volatility of 1,2-dibromotetrafluoroethane (b.p. 46°C) and bromochloromethane (b.p. 68-69°C), it was found necessary to slightly modify the afore-mentioned apparatus and procedure to permit testing of these higher boiling compounds.

The modification in the apparatus is shown by diagram in Fig. 43 and by photograph (in part) in Fig. 44. The numbers used in the diagram of the original apparatus (Fig. 40) were retained in Figs. 43 and 44 to prevent confusion in the description. A stream of nitrogen obtained through a three-way connection from the nitrogen cylinder (2) was introduced into a 250-ml Pyrex glass bubbler containing the extinguisher (1). The rate of flow of gas into and out of the bubbler was controlled by stopcocks on the inlet and outlet stems of the vessel. The mixed vapors from the bubbler were passed through a flowmeter (6) and trap into the reactor tube (8) in the usual manner. The flow rate of the extinguisher was determined from the loss in weight of the extinguisher after passage of the nitrogen through the bubbler.

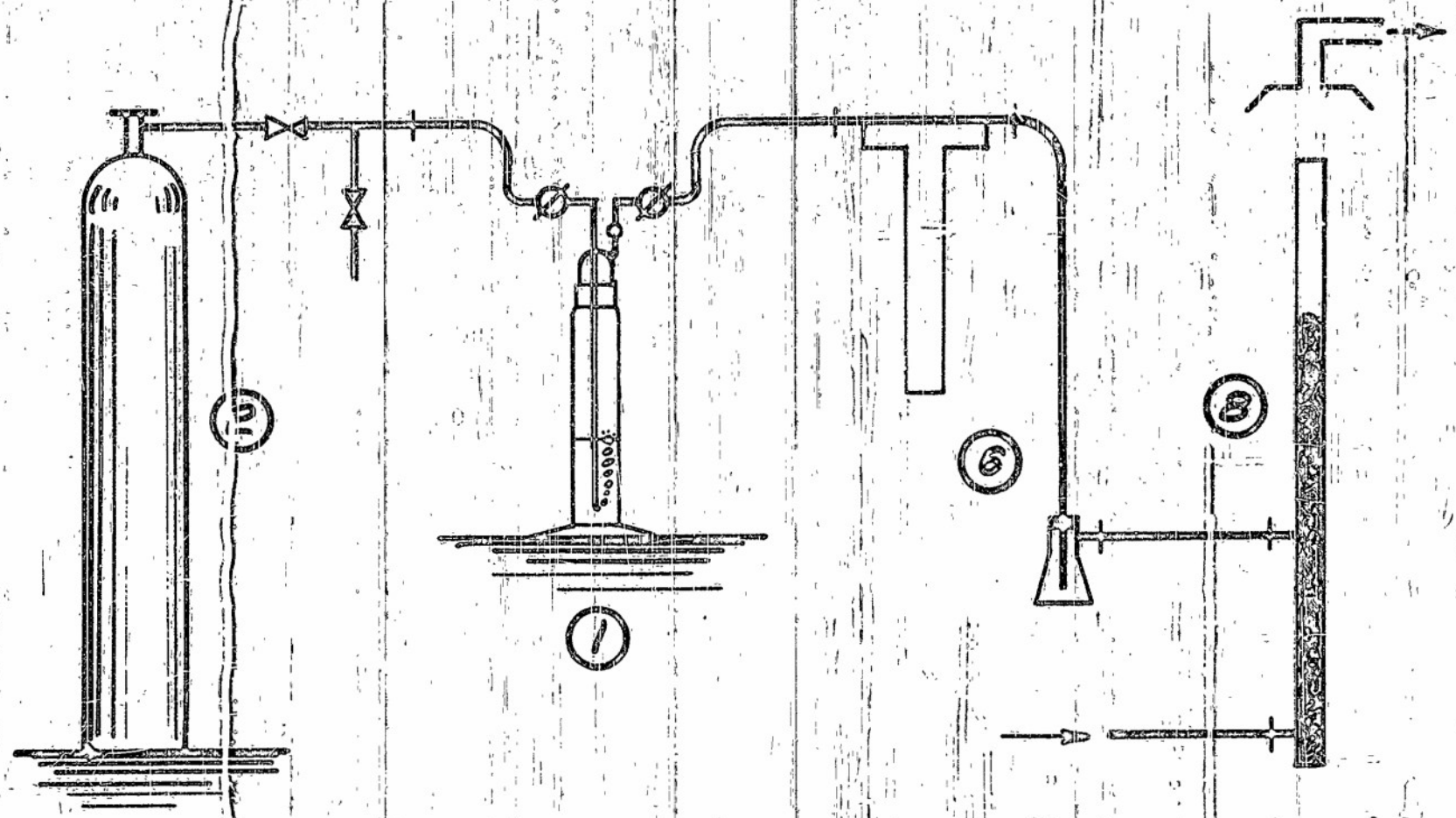

Fig. 43 MODIFIED FLUORINE REACTIVITY APPARATUS FOR USE WITH HIGH-BOILING EXTINGUISHERS

Fig. 14 Detailed [illegible] of [illegible] fied Fluo- [illegible] guisher Reactivity Apparatus

Test Materials

Fuel

Fluorine (F_2)

Elementary fluorine is a light yellow gas having a boiling point of -188.3°C and a characteristic odor. It was obtained in a (6 lb) cylinder from the Pennsylvania Salt Manufacturing Company.

Nitrogen (N_2)

Nitrogen, a colorless and odorless gas, boils at -195.8°C. It was obtained from Linde Air Products Company and was used without further drying or purification.

Fire Extinguishers

The fire-retarding agents used in the reactivity tests with fluorine were the same as those used with the non-fluorine fuels as described in Section I. However, at the request of the Army Engineers, bromotrifluoromethane was added to the list of materials to be tested with fluorine.

Bromotrifluoromethane (CF_3Br)

This compound (b.p. -60°C) is a colorless and nearly odorless gas. It was obtained from the Army Engineers Research and Development Laboratories, Fort Belvoir, Virginia.

Reactivity Tests

When fluorine, mixed with nitrogen, was allow to react with the various fire-retarding compounds described above, it was found that reaction occurred in all concentrations or not at all. The results of these tests are summarized in Table VII.

Table VII

Summary of Compounds Tested for Reactivity with Fluorine
(Temperature = 25°C)

Extinguishing Agent Formula	Extinguishing Agent Name	B.P., °C	Reactivity with Fluorine
CO_2	Carbon dioxide	subl. -78.5	-
CH_3Br	Methyl bromide	4.5	+
CH_2BrCl	Bromochloromethane	68-69	+
CF_2Br_2	Dibromodifluoromethane	24.5	+
CF_2BrCF_2Br	1,2-Dibromotetrafluoroethane	46.4	+
CF_3	Bromotrifluoromethane	-60.0	+

Five of the six extinguishing agents reacted with fluorine in all concentrations although to widely varying degrees. Methyl bromide and dibromodifluoromethane, under the conditions of the test, reacted most vigorously with fluorine. 1,2-Dibromotetrafluoroethane and bromotrifluoroethane and bromotrifluoromethane were found to be the least reactive. Carbon dioxide, the sixth extinguisher, failed to react with fluorine in an concentration.

As a basis for these tests, as described earlier in this report, it was presupposed that any material which will react with fluorine at room temperature will be unsuitable for use as an extinguishing agent in fires involving fluorine. Since all of the fire-retarding agents tested, except carbon dioxide, react with fluorine at room temperature, it is quite unlikely that any of them could be used to extinguish fluorine fires. These compounds should, therefore, be eliminated from further consideration as extinguishing agents for this type of fire.

In consideration, then, of the one material which failed to react with fluorine at room temperature, namely carbon dioxide, the following must

be taken into account. Although fluorine does not react with carbon dioxide under test conditions, it is very possible that at high-temperatures, such as would exist in fluorine fires, reaction will take place. This hypothesis could not be confirmed because of lack of suitable high-temperature laboratory equipment for use with fluorine. Furthermore, although it is possible that at room temperature carbon dioxide (similar to nitrogen) acts as an inert diluent with fluorine, at high-temperature this effect would probably be negligible or entirely absent.

It appears highly improbable, therefore, that any of the compounds tested can be used successfully for combatting fires involving fluorine.

BIBLIOGRAPHY

1. McBee, E. T., Welch, Z. D., et al. Fire Extinguishing Agents. Final Report on Contract No. W-44-009eng-507, Army Engineers Research and Development Laboratories, June 1950. pp. 1-32.

2. Berkenheim, A. M. and Dankova, T. F. Synthesis of Piperylene from Furfural. Journal of General Chemistry of USSR. Vol. 9. May 1939. pp. 924-31. (Russian); Chemical Abstracts. Vol. 34. January 1940. p. 568.

3. Petrenko-Krichenko, P. and Opotsky, V. The Laws of Periodicity I. The Activity of Organic Halides. Berichte der Deutschen Chemischen Gesellschaft. Vol. 59B. September 1926. pp. 1231-40. (German).

4. Scott, F. E., Burns, J. J. and Lewis, B. Explosive Properties of Hydrazine. Report of Investigation No. 4460, United States Bureau of Mines. May 1949. pp. 1-18.

5. Damford, C. H. Some New Observations on Hydrazine. Transactions of the Faraday Society. Vol. 35. October 1939. pp. 1239-45.

6. Dunlop, A. P. and Peters, F. N. The Nature of Furfuryl Alcohol. Industrial Engineering Chemistry. Vol. 34. July 1942. pp. 814-17.

APPENDIX

Tables 1-30

The data and results of the tests conducted to determine the flammability of mixtures of fuel, extinguisher and air are presented here in tabular form. Although not specified in the tables, all tests were carried out at a pressure of 400 mm Hg. A "+" indicates that the mixture burned, i.e. the flame was propagated through the entire length of the tube. A "-" indicates that the mixture did not burn or that if the mixture was ignited, the flame did not travel to the top of the tube.

Tables 31-36

In these tables the data and results of the testing carried out to determine the reactivity of fluorine-nitrogen mixtures with extinguishers are given. The tests were in all cases conducted at room temperature and atmospheric pressure. A "+" indicates a positively observed reaction, i.e. gaseous products were visible at the top of the reaction tube; a "-" indicates non-reaction or the absence of visible products.

Table 1

Flammability of Mixtures of Hydrogen, Carbon Dioxide and Air
(Temperature = 28°C)

Volume Percent H_2	Volume Percent CO_2	Result
10.0	20.0	+
8.0	10.0	+
8.0	20.0	+
5.0	10.0	-
6.0	20.0	-
12.0	30.0	+
12.0	40.0	+
8.0	30.0	+
12.0	40.0	+
12.0	50.0	+
12.0	70.0	-
15.0	70.0	-
15.0	60.0	-
20.0	60.0	-
16.0	50.0	+
20.0	50.0	-
15.0	56.0	-
11.0	50.0	-
18.0	50.0	-
15.0	53.0	-
20.0	45.0	-
25.0	36.0	-
15.0	52.0	-
18.0	43.0	+
15.0	52.0	+
26.0	30.0	+
16.0	52.0	-
14.0	52.0	-
17.0	30.0	+
22.0	30.0	+
7.0	30.0	+
36.0	30.0	-
6.0	30.0	+
10.0	40.0	+
34.0	30.0	+
8.0	40.0	+
30.0	20.0	+
7.0	40.0	-
32.0	20.0	+
6.0	20.0	-
60.0	20.0	-
5.0	30.0	-
55.0	20.0	-
6.0	10.0	+
19.0	45.0	+

Table 2

Flammability of Mixtures of Hydrogen, Methyl Bromide and Air
(Temperature = 28°C)

Volume Percent H_2	Volume Percent CH_3Br	Result
5.5	4.0	+
4.5	4.0	+
5.5	8.0	+
4.0	4.0	+
5.0	11.0	+
3.0	4.0	-
4.0	11.0	+
4.0	1.0	-
3.0	11.0	-
5.0	1.0	+
4.0	15.0	+
75.0	2.0	-
4.0	20.0	-
3.0	15.0	-
5.0	20.0	-
74.0	5.0	-
6.0	20.0	-
5.0	17.0	-
5.0	16.0	-
5.0	15.0	+
7.0	16.0	-
9.0	15.0	-
10.0	14.0	-
11.0	13.0	+
15.0	13.0	-
15.0	12.0	+
20.0	12.0	-
25.0	10.0	-
30.0	9.0	-
25.0	9.0	-
20.0	10.0	+
20.0	11.0	-
25.0	9.0	-
25.0	8.0	
25.0	7.0	+
31.5	5.0	+
30.0	6.0	+
30.0	7.0	-
35.0	5.0	+
35.0	6.0	-
40.0	8.0	-
40.0	7.0	-

Table 2 (Cont'd)

Flammability of Mixtures of Hydrogen, Methyl Bromide and Air
(Temperature = 28°C)

Volume Percent H_2	Volume Percent CH_3Br	Result
40.0	6.0	-
40.0	5.0	-
40.0	4.5	-
50.0	4.0	-
40.0	4.0	-
50.0	3.0	-
40.0	3.0	+
50.0	2.5	-
60.0	2.5	-
50.0	1.5	+

(Tests were discontinued above 60% hydrogen because of the violence of the explosion.)

Table 3

Flammability of Mixtures of Hydrogen, Bromochloromethane and Air
(Temperature = 28°C)

Volume Percent H_2	Volume Percent CH_2BrCl	Result
6.0	1.0	-
6.5	1.0	-
7.5	3.0	+
8.0	4.0	+
8.0	5.0	+
7.5	4.0	+
8.0	6.0	+
7.0	4.0	+
8.0	7.0	+
6.0	4.0	+
8.0	8.0	+
5.0	4.0	+
4.0	4.0	-
8.0	10.0	+
8.0	12.0	+
5.0	8.0	-
9.0	14.0	+
5.0	8.0	-
10.0	16.0	+
8.0	20.0	+
8.0	2.0	-
8.0	24.0	+
8.0	30.0	-
7.0	20.0	+
8.0	28.0	-
5.0	20.0	-
8.0	26.0	+
8.0	2.0	+
8.0	27.0	-
10.0	27.0	+
10.0	28.0	-
12.0	29.0	+
6.0	3.0	+
12.0	30.0	-
6.0	8.0	+
[illegible]	[illegible]	-
6.0	2.0	+
18.0	30.0	-
15.0	29.0	+
6.0	1.0	-
14.0	30.0	+
16.0	30.0	-
7.0	1.0	+
14.0	31.0	-
17.0	28.0	-

Table 3 (Cont'd.)

Flammability of Mixtures of Hydrogen, Bromochloromethane and Air
(Temperature = 28°C)

Volume Percent		Result
H_2	CH_2BrCl	
16.0	28.0	-
17.0	24.0	+
25.0	16.0	+
21.0	22.0	+
27.0	16.0	-
22.0	22.0	-
35.0	9.0	+
37.0	6.0	+
36.0	9.0	+
38.0	6.0	+
37.0	9.0	-
39.0	6.0	+

Table 4

Flammability of Mixtures of Hydrogen, Dibromodifluoromethane and Air
(Temperature = 28°C)

Volume Percent		Result
H_2	CF_2Br_2	
5.0	8.0	-
5.0	20.0	-
6.0	8.0	-
6.0	20.0	-
7.0	8.0	+
8.0	20.0	-
7.0	10.0	+
10.0	15.0	+
7.0	12.0	-
12.0	18.0	+
11.0	18.0	+
15.0	20.0	+
10.0	18.0	+
9.0	18.0	+
15.0	21.0	+
8.0	18.0	-
18.0	22.0	+
10.0	20.0	+
22.0	22.0	+
15.0	22.0	+
25.0	22.0	+
38.0	14.0	+
14.0	34.0	+
38.0	16.0	+
14.0	35.0	-
33.0	18.0	-
45.0	12.0	+
50.0	12.0	-
8.0	2.0	+
15.0	32.0	+
10.0	22.0	+
9.0	22.0	+
27.0	22.0	+
8.0	22.0	-
30.0	[illegible]	
12.0	30.0	-
35.0	22.0	-
13.0	30.0	+
34.0	22.0	-
15.0	33.0	+
33.0	22.0	-
20.0	35.0	-
31.0	27.0	+
25.0	30.0	-

Table 4 (Cont'd.)

Flammability of Mixtures of Hydrogen, Dibromodifluoromethane and Air
(Temperature = 28°C)

Volume Percent		Result
H_2	CF_2Br_2	
32.0	22.0	-
24.0	30.0	-
14.0	33.0	+
18.0	34.0	-
13.0	33.0	-
23.0	30.0	-
22.0	30.0	-
17.0	34.0	-
15.0	30.0	+
34.0	34.0	-

Table 5

Flammability of Mixtures of Hydrogen, Dibromotetrafluoroethane and Air
(Temperature = 22°C)

Volume Percent H_2	Volume Percent CF_2BrCF_2Br	Result
10.0	20.0	-
7.0	12.0	-
15.0	20.0	-
8.0	12.0	-
20.0	20.0	-
15.0	12.0	+
15.0	16.0	+
30.0	20.0	-
15.0	16.0	-
10.0	12.0	+
25.0	16.0	-
10.0	16.0	-
30.0	12.0	-
20.0	16.0	-
15.0	17.0	+
25.0	12.0	+
15.0	18.0	-
17.0	16.0	+
16.0	17.0	+
17.0	17.0	+
15.0	17.0	+
19.0	16.0	+
28.0	12.0	+
18.0	17.0	-
12.0	17.0	-
15.0	17.5	-
40.0	8.0	-
17.0	18.0	-
38.0	8.0	-
13.0	18.0	-
35.0	8.0	+
11.0	16.0	+
9.0	12.0	+
50.0	4.0	-
8.0	12.0	-
48.0	4.0	-
8.0	4.0	+
46.0	4.0	+
7.0	4.0	+
6.0	4.0	+
5.0	4.0	-

Table 6

Flammability of Mixtures of Ammonia, Carbon Dioxide and Air
(Temperature = 28°C)

Volume Percent NH_3	Volume Percent CO_2	Result
17.0	0.0	-
17.25	0.0	+
17.25	0.25	-
17.5	0.25	+
17.25	0.5	-
17.5	0.5	+
17.25	0.75	-
17.5	0.75	+
17.25	1.0	-
17.5	1.0	+
17.5	1.25	-
17.75	1.25	+
17.5	1.5	-
17.75	1.5	+
17.75	1.75	-
18.0	1.75	+
17.75	2.0	-
18.0	2.0	+
17.75	2.25	-
18.0	2.25	+
17.75	2.5	-
18.0	2.5	+
17.75	2.75	-
18.0	2.75	+
18.0	3.0	-
18.25	3.0	+
18.0	3.25	-
18.25	3.25	+
18.0	3.5	-
18.25	3.5	+
18.25	3.75	-
18.5	3.75	+
18.75	4.0	-
19.0	4.0	+
19.25	4.25	-
19.5	4.25	+
19.75	4.5	-
20.0	4.5	+
20.25	4.75	-
20.5	4.75	+
20.25	5.0	-
20.5	5.0	-
20.75	5.0	-
20.75	4.75	-

Table 6 (Cont'd.)

Flammability of Mixtures of Ammonia, Carbon Dioxide and Air
(Temperature = 28°C)

Volume Percent NH_3	Volume Percent CO_2	Result
20.5	4.5	◇
20.75	4.5	—
21.0	4.25	◇
21.25	4.25	—
21.25	4.0	◇
21.5	4.0	—
21.5	3.75	—
21.75	3.75	—
21.5	3.5	◇
21.75	3.5	—
21.75	3.25	◇
22.0	3.25	—
22.0	3.0	◇
22.75	3.0	—
22.25	2.75	◇
22.5	2.75	—
22.5	2.5	◇
22.75	2.5	—
22.75	2.25	◇
23.0	2.25	—
23.0	2.0	◇
23.25	2.0	—
23.25	1.75	◇
23.5	1.75	—
23.25	1.5	◇
23.5	1.5	—
23.5	1.25	◇
23.75	1.25	—
23.75	1.0	◇
24.0	1.0	—
24.0	0.75	◇
24.25	0.75	—
24.25	0.5	◇
24.5	0.5	—
24.5	0.25	◇
24.75	0.25	—
24.75	0.0	◇
25.0	0.0	—

Table 7

Flammability of Mixtures of Ammonia, Methyl Bromide and Air
(Temperature = 25°C)

Volume Percent		Result
NH_3	CH_3Br	
17.0	0.0	-
17.25	0.0	+
17.25	0.25	-
17.5	0.25	-
17.75	0.25	-
18.0	0.25	-
18.25	0.25	-
18.75	0.25	-
19.0	0.25	-
19.25	0.25	-
19.5	0.25	+
19.75	0.25	+
20.0	0.25	+
20.25	0.25	+
20.5	0.25	+
20.75	0.25	-
21.0	0.25	-
21.25	0.25	-
22.0	0.25	-
22.25	0.25	-
22.5	0.25	-
22.75	0.25	-
23.0	0.25	-
23.25	0.25	-
23.5	0.25	-
23.75	0.25	-
24.0	0.25	-
24.25	0.25	-
24.5	0.25	-
24.75	0.25	-
17.25	0.5	-
17.5	0.5	-
17.75	0.5	-
18.0	0.5	-
18.25	0.5	-
18.5	0.5	-
18.75	0.5	-
19.0	0.5	-
19.25	0.5	-
19.5	0.5	-
19.75	0.5	-
20.0	0.5	-
20.25	0.5	-
20.5	0.5	-

Table 7 (Cont'd.)

Flammability of Mixtures of Ammonia, Methyl Bromide and Air
(Temperature = 28°C)

Volume Percent		Result
NH_3	CH_3Br	
20.75	0.5	-
21.0	0.5	-
21.25	0.5	-
21.5	0.5	-
21.75	0.5	-
22.0	0.5	-
22.25	0.5	-
22.5	0.5	-
22.75	0.5	-
23.0	0.5	-
23.25	0.5	-
23.5	0.5	-
23.75	0.5	-
24.0	0.5	-
24.25	0.5	-
24.5	0.5	-
24.75	0.5	-
24.75	0.0	+
25.0	0.0	-

Table 8

Flammability of Mixtures of Ammonia, Bromochloromethane and Air
(Temperature = 28°C)

Volume Percent		Result
NH_3	CH_2BrCl	
17.0	0.0	-
17.25	0.0	+
17.25	0.25	-
17.5	0.25	-
17.75	0.25	-
18.0	0.25	-
18.25	0.25	-
18.5	0.25	-
18.75	0.25	-
19.0	0.25	-
19.25	0.25	-
19.5	0.25	-
19.75	0.25	-
20.0	0.25	-
20.25	0.25	-
20.5	0.25	-
20.75	0.25	-
21.0	0.25	-
21.25	0.25	-
21.5	0.25	-
21.75	0.25	-
22.0	0.25	-
22.25	0.25	-
22.5	0.25	-
22.75	0.25	-
23.0	0.25	-
23.25	0.25	-
23.5	0.25	-
23.75	0.25	-
24.0	0.25	-
24.25	0.25	-
24.5	0.25	-
24.75	0.25	-
24.75	0.0	+
25.0	0.0	-

Table 9

Flammability of Mixtures of Ammonia, Dibromodifluoromethane and Air
(Temperature = 28°C)

Volume Percent NH_3	Volume Percent CF_2Br_2	Result
17.0	0.0	-
17.25	0.0	+
17.25	0.25	-
17.5	0.25	-
17.75	0.25	-
18.0	0.25	-
18.25	0.25	-
18.5	0.25	-
18.75	0.25	-
19.0	0.25	-
19.25	0.25	-
19.5	0.25	-
19.75	0.25	-
20.0	0.25	-
20.25	0.25	-
20.5	0.25	-
20.75	0.25	-
21.0	0.25	-
21.25	0.25	-
21.5	0.25	-
21.75	0.25	-
22.0	0.25	-
22.25	0.25	-
22.5	0.25	-
22.75	0.25	-
23.0	0.25	-
23.25	0.25	-
23.5	0.25	-
23.75	0.25	-
24.0	0.25	-
24.25	0.25	-
24.5	0.25	-
24.75	0.25	-
24.75	0.0	+
25.0	0.0	-

Table 10

Flammability of Mixtures of Ammonia, 1,2-Dibromotetrafluoroethane and Air

(Temperature = 28°C)

Volume Percent NH_3	Volume Percent CF_2BrCF_2Br	Result
17.0	0.0	-
17.25	0.0	+
17.25	0.25	-
17.5	0.25	-
17.75	0.25	-
18.0	0.25	-
18.25	0.25	-
18.5	0.25	-
18.75	0.25	-
19.0	0.25	-
19.25	0.25	-
19.5	0.25	-
19.75	0.25	-
20.0	0.25	-
20.25	0.25	-
20.5	0.25	-
20.75	0.25	-
21.0	0.75	-
21.25	0.25	-
21.5	0.25	-
21.75	0.25	-
22.0	0.25	-
22.25	0.25	-
22.5	0.25	-
22.75	0.25	-
23.0	0.25	-
23.25	0.25	-
23.5	0.25	-
23.75	0.25	-
24.0	0.25	-
24.25	0.25	-
24.5	0.25	-
24.25	0.25	-
24.75	0.0	+
25.0	0.0	-

Table 11

Flammability of Mixtures of Methanol, Carbon Dioxide and Air
(Temperature = 28°C)

Volume Percent		Result
CH_3OH	CO_2	
8.0	0.0	-
9.0	0.0	+
8.0	4.0	-
9.0	4.0	+
8.0	8.0	+
9.0	8.0	+
7.0	8.0	-
7.0	10.0	-
8.0	10.0	-
8.0	12.0	-
9.0	10.0	+
10.0	10.0	+
10.0	12.0	+
10.0	13.0	+
9.0	12.0	+
9.0	14.0	+
8.0	14.0	-
8.0	16.0	-
9.0	15.0	+
9.0	16.0	-
10.0	15.5	+
10.0	16.0	+
10.0	17.0	+
11.0	17.0	+
9.0	20.0	+
10.0	20.0	+
9.0	22.0	+
10.0	22.0	+
8.0	20.0	-
8.0	22.0	-
8.0	24.0	-
9.0	24.0	-
10.0	23.0	+
10.0	24.0	+
12.0	25.0	+
12.0	26.0	-
13.0	25.5	+
13.0	25.0	+
13.0	26.0	+
13.0	27.0	+
14.0	26.0	+
13.0	28.0	-
13.0	30.0	-
13.0	27.5	+

Table II (Cont'd.)

Flammability of Mixtures of Methanol, Carbond Dioxide and Air
(Temperature = 28°C)

Volume Percent		Result
CH_3OH	CO_2	
13.0	28.0	-
16.0	27.0	-
15.0	20.0	+
17.0	20.0	+
20.0	20.0	-
20.0	22.0	-
18.0	22.0	-
19.0	22.0	-
17.0	22.0	-
17.0	24.0	-
15.0	22.0	+
16.0	22.0	+
19.0	20.0	+
25.0	15.0	-
25.0	16.0	-
20.0	16.0	+
22.0	16.0	+
23.0	16.0	+
23.0	17.0	-
27.0	12.0	+
27.0	13.0	-
30.0	7.0	+
30.0	8.0	+
30.0	9.0	+
30.0	10.0	+
32.0	5.0	+
34.0	5.0	+
35.0	6.0	-
35.5	6.0	-
32.0	9.0	+
32.0	10.0	+
36.0	0.0	+
37.0	0.0	+
15.0	37.0	-
30.0	0.0	+

Table 12

Flammability of Mixtures of Methanol, Methyl Bromide and Air
(Temperature = 28°C)

Volume Percent		Result
CH_3OH	CH_3Br	
10.0	0.0	+
9.0	0.0	-
9.0	2.0	-
10.0	2.0	+
10.0	4.0	+
9.5	12.0	-
10.5	10.0	+
10.5	12.0	+
10.0	10.0	-
10.0	12.0	-
10.0	14.0	-
10.5	14.0	+
10.0	18.0	+
9.5	18.0	-
12.5	22.0	-
15.0	22.0	-
12.5	20.0	+
10.0	22.0	-
13.0	20.0	-
14.0	20.0	+
11.5	20.0	-
14.5	20.0	+
13.5	21.5	-
13.5	21.0	+
15.0	20.0	+
16.5	20.0	-
13.5	22.0	-
27.5	18.0	+
29.0	18.0	-
30.0	15.0	+
32.5	15.0	+

(Curve discontinued due to non-volatility of methanol at 28°C

above 32.5%.)

Table 13

Flammability of Mixtures of Methanol, Bromochloromethane and Air
(Temperature = 28°C)

Volume Percent CH_3OH	Volume Percent CH_2BrCl	Result
9.0	0.0	-
10.0	0.0	+
10.0	6.0	+
9.0	6.0	-
10.0	10.0	+
12.0	10.0	+
9.0	10.0	+
9.0	14.0	+
8.0	10.0	-
8.0	14.0	-
10.0	16.0	-
12.5	18.0	-
10.0	16.0	-
12.5	16.0	+
12.0	16.0	+
15.0	16.0	+
11.0	16.0	-
17.0	16.0	-
14.0	16.5	-
14.0	17.0	+
14.0	17.0	+
14.0	18.0	-
17.0	15.0	+
17.0	14.0	+
17.5	12.0	+
20.0	12.0	+
22.5	11.0	+
25.0	11.0	+
22.5	12.0	+
25.0	12.0	+
20.0	13.0	+
20.0	14.0	+
22.5	13.0	-
25.0	13.0	+
29.0	11.0	-
29.0	12.0	-

(Curve discontinued due to non-volatility of methanol at 28°C.)

Table 14

Flammability of Mixtures of Methanol, Dibromodifluoromethane and Air
(Temperature = 28°C)

Volume Percent CH_3OH	Volume Percent CF_2Br_2	Result
9.0	8.0	-
10.0	8.0	-
11.0	8.0	-
12.0	8.0	+
12.0	10.0	-
13.0	10.0	-
12.0	9.0	-
13.0	9.0	+
14.0	9.0	+
14.0	9.5	+
14.0	10.0	+
14.0	10.5	+
17.0	10.5	+
17.0	11.5	+
17.0	13.0	+
15.0	13.0	+
13.0	11.5	-
13.0	13.0	-
15.0	14.0	+
15.0	16.0	+
15.0	17.0	+
15.0	18.0	+
14.0	16.0	-
25.0	16.0	-
22.5	16.0	-
22.5	17.0	-
17.5	17.0	+
17.5	18.0	+
17.5	20.0	+
17.5	22.0	-
16.5	20.0	+
18.5	20.0	-
22.5	15.0	-
22.5	16.0	-
22.5	14.0	+
22.0	12.0	-
25.0	12.0	-
25.0	9.0	-
30.0	8.0	-
22.5	4.0	+
22.5	8.0	-
22.5	10.0	+
22.5	14.0	+
20.0	6.0	+
25.0	5.0	-
30.0	2.0	-
35.0	2.0	-

Table 15

Flammability of Mixtures of Methanol, 1,2-Dibromotetrafluoroethane and Air

(Temperature = 28°C)

Volume Percent CH_3OH	Volume Percent $CBrF_2CBrF_2$	Result
7.0	0.0	-
8.0	0.0	-
10.0	0.0	+
9.0	0.0	+
8.0	4.0	-
9.0	4.0	-
10.0	3.0	+
10.0	4.0	-
10.0	5.0	-
10.0	6.0	-
12.0	6.0	+
13.0	6.0	+
12.0	7.0	+
12.0	8.0	-
14.0	10.0	+
14.0	11.0	+
15.0	11.5	+
15.0	12.0	+
14.0	13.0	-
15.0	13.0	+
15.0	14.0	+
16.0	14.0	+
15.0	15.0	-
16.0	15.0	+
17.0	16.0	-
18.0	16.0	-
21.0	17.0	-
22.0	17.0	-
20.0	16.5	+
20.0	17.5	-
16.5	20.0	+
16.5	22.0	+
23.0	17.0	-
23.0	18.0	-
27.0	15.0	-
27.0	16.0	-
25.0	14.0	+
30.0	14.0	-
27.0	13.0	-
28.0	13.0	-
27.0	12.0	+
28.0	12.0	-
27.0	11.0	+
28.0	11.0	+

Table 15 (Cont'd.)

Flammability of Mixtures of Methanol, 1,2-Dibromotetrafluoroethane and Air

(Temperature = 28°C)

Volume Percent		Result
CH_3OH	$CBrF_2CBrF_2$	
30.0	10.0	+
30.0	11.0	-
35.0	8.0	+
35.0	10.0	-
30.0	7.0	+
30.0	8.0	+
32.0	6.0	+
35.0	6.0	+

(Tests discontinued because of non-volatility of methanol.)

Table 16

Flammability of Mixtures of Ethanol, Carbon Dioxide and Air
(Temperature = 130°C)

Volume Percent		Result
C_2H_5OH	CO_2	
5.0	4.0	+
6.0	4.0	+
4.0	4.0	-
5.0	4.0	+
4.0	8.0	-
5.0	8.0	+
5.0	12.0	-
6.0	12.0	+
6.0	16.0	-
7.0	16.0	-
6.0	14.0	-
7.0	14.0	-
8.0	13.0	+
8.0	14.0	+
9.0	15.0	-
9.0	16.0	-
9.0	14.0	-
9.0	14.5	-
9.0	13.0	-
9.0	14.0	-
9.0	12.0	+
10.0	12.0	+
12.0	11.0	-
12.0	12.0	-
12.0	9.0	-
12.0	10.0	-
11.0	8.0	+
12.0	8.0	+
11.0	10.0	+
11.0	12.5	+
14.0	7.0	-
14.0	8.0	-
15.0	5.0	+
16.0	5.0	-
16.0	3.0	+
17.0	3.0	+
6.0	13.0	+
7.0	13.0	+

Table 16 (Cont'd.)

Flammability of Mixtures of Ethanol, Carbon Dioxide and Air
(Temperature = 130°C)

Volume Percent		Result
C_2H_5OH	CH_3Br	
13.0	5.0	-
15.0	2.0	+
15.0	3.0	+
16.0	3.0	-
16.0	4.0	-

Table 17

Flammability of Mixtures of Ethanol, Methyl Bromide, and Air
(Temperature = 130°C)

Volume Percent		Result
C_2H_5OH	CH_3Br	
7.0	4.0	+
7.0	6.0	+
8.0	6.0	+
6.0	6.0	+
6.0	8.0	+
5.0	8.0	+
4.0	8.0	-
3.0	12.0	+
5.0	12.0	-
6.0	12.0	-
6.0	14.0	-
5.0	6.0	+
4.0	4.0	-
4.0	6.0	-
5.0	4.0	-
6.0	4.0	+
5.0	10.0	+
4.0	12.0	-
4.0	10.0	+
4.0	11.0	-
5.0	11.0	+
6.0	11.0	-
6.0	10.0	-
6.0	11.0	-
6.0	9.0	+
7.0	9.0	-
8.0	9.0	-
8.0	7.0	+
8.0	8.0	+
8.0	9.0	-
8.0	10.0	-
12.0	8.0	-
12.0	9.0	-
12.0	7.0	-
13.0	7.0	-
10.0	7.0	-
10.0	8.0	-
9.0	7.0	-
9.0	8.0	-
9.0	5.0	+
9.0	6.0	+
10.0	6.0	+
10.0	6.5	+
13.0	6.0	+
12.0	6.0	-
12.0	5.0	+

Table 18

Flammability of Mixtures of Ethanol, Dichloromethane and Air
(Temperature = 130°C)

Volume Percent		Results
C_2H_5OH	CH_2Cl_2	
5.0	0.0	+
6.0	0.0	+
5.5	0.0	+
5.5	4.0	-
6.0	4.0	-
6.0	8.0	-
7.0	4.0	+
7.0	8.0	+
7.0	12.0	-
8.0	12.0	-
9.0	12.0	-
9.0	11.0	-
10.0	11.0	-
8.0	10.0	-
10.0	10.0	-
9.0	10.0	-
9.0	10.5	-
9.0	9.5	-
9.0	10.0	-
7.0	9.0	-
8.0	10.0	-
9.0	10.0	-
8.0	9.0	-
8.0	9.0	-
8.0	9.0	-
7.0	8.0	+
6.0	8.0	-
8.0	9.0	-
7.0	9.0	-
9.0	9.5	-
9.0	8.5	-
9.0	9.0	-
7.0	8.0	+
8.0	8.0	+
7.0	8.5	-
8.0	8.5	+
8.0	8.5	+
8.0	9.0	-
9.0	8.0	-
9.0	8.5	-
9.0	6.0	+
10.0	6.0	+
11.0	6.0	+
12.0	6.0	+
13.0	6.0	-

Table 18 (Cont'd.)

Flammability of Mixtures of Ethanol, Bromochloromethane and Air
(Temperature = 130°C)

Volume Percent		Result
C_2H_5OH	CH_2BrCl	
16.0	4.0	-
17.0	4.0	-
14.0	4.0	+
15.0	4.0	-
18.0	0.0	+
19.0	0.0	+
16.0	2.0	+
17.0	2.0	+

Table 19

Flammability of Mixtures of Ethanol, Dibromodifluoromethane and Air
(Temperature = 130°C)

Volume Percent		Result
C_2H_5OH	CF_2Br_2	
5.0	4.0	-
6.0	6.0	-
7.0	8.0	-
8.0	8.0	-
9.0	8.0	-
8.0	7.0	-
6.0	6.0	-
7.0	6.0	-
8.0	6.0	-
6.0	4.0	-
6.0	5.0	-
5.0	4.0	-
6.0	4.0	-
7.0	4.0	+
7.0	5.0	-
8.0	5.0	+
9.0	5.5	+
10.0	5.0	+
11.0	5.0	+
9.0	6.0	-
9.0	6.5	-
11.0	6.0	-
10.0	5.0	+
10.0	5.5	+
10.0	6.0	-
12.0	5.0	-
13.0	4.0	+
7.0	4.0	+
6.0	0.0	+
8.0	3.0	+
8.0	3.0	+
11.0	5.0	+
12.0	5.0	+
13.0	5.0	-
14.0	5.0	-
12.0	3.0	+
12.0	3.0	+
14.0	1.0	+
14.0	2.0	+
16.0	1.0	-
16.0	2.0	-
14.0	2.0	+
15.0	2.0	+
13.0	3.0	+
14.0	3.0	+
15.0	3.0	-

Table 19 (Cont'd)

Flammability of Mixtures of Ethanol, Dibromodifluoromethane and Air
(Temperature = 130°C)

Volume Percent		Result
C_2H_5OH	CF_2Br_2	
15.0	4.0	-
18.0	0.0	+
19.0	0.0	+
20.0	0.0	+
9.0	5.5	+
10.0	5.5	+
6.0	4.0	-
7.0	4.0	+
10.0	6.0	-
10.0	8.0	-

Table 20

Flammability of Mixtures of Ethanol, 1, 2-Dibromotetrafluoroethane and Air
(Temperature = 130°C)

Volume Percent		Result
C_2H_5OH	CF_2BrCF_2Br	
5.0	4.0	-
6.0	4.0	-
7.0	4.0	-
7.0	6.0	-
8.0	4.0	-
8.0	6.0	-
9.0	4.0	+
9.0	6.0	-
10.0	6.0	-
10.0	8.0	-
11.0	6.0	-
12.0	6.0	-
11.0	5.0	+
10.0	5.0	+
10.0	5.5	-
12.0	5.0	-
13.0	5.0	-
12.0	3.0	+
13.0	3.0	+
15.0	2.0	-
15.0	3.0	-
19.0	0.0	+
20.0	0.0	-
7.0	2.0	+
8.0	2.0	+
6.0	3.0	-
7.0	3.0	+
9.0	4.0	+
9.0	5.0	-

Table 21

Flammability of Mixtures of Nitromethane, Carbon Dioxide and Air
(Temperature = 150°C)

Volume Percent CH_3NO_2	Volume Percent CO_2	Result
8.0	0.0	-
8.5	0.0	+
8.0	1.0	-
8.5	1.0	+
8.0	2.0	-
8.5	2.0	+
8.5	3.0	-
9.0	3.0	+
8.5	4.0	-
9.0	4.0	+
8.5	5.0	-
9.0	5.0	+
8.5	6.0	-
9.0	6.0	+
8.5	7.0	-
9.0	7.0	+
8.5	8.0	-
9.0	8.0	+
8.5	9.0	-
9.0	9.0	+
8.5	10.0	-
9.0	10.0	+
8.5	11.0	-
9.0	11.0	+
8.5	12.0	-
9.0	12.0	+
8.5	13.0	-
9.0	13.0	+
8.5	14.0	-
9.0	14.0	+
8.5	15.0	-
9.0	15.0	+
8.5	16.0	-
9.0	16.0	+
8.5	17.0	-
9.0	17.0	+
9.0	18.0	-
9.5	18.0	+
9.0	19.0	-
9.5	19.0	+
9.0	20.0	-
9.5	20.0	+
9.0	21.0	-
9.5	21.0	+
10.0	22.0	-

Table 21 (Cont'd)

Flammability of Mixtures of Nitromethane, Carbon Dioxide and Air
(Temperature = 150°C)

Volume Percent CH_3NO_2	Volume Percent CO_2	Result
12.5	22.0	-
15.0	22.0	-
14.5	21.0	+
15.0	21.0	-
17.0	20.0	+
17.5	20.0	-
18.5	19.0	+
19.0	19.0	-
20.0	18.0	+
20.5	18.0	-
21.0	17.0	+
21.5	17.0	-
21.5	16.0	+
22.0	16.0	-
22.0	15.0	+
22.5	15.0	-
22.5	14.0	+
23.0	14.0	-
23.0	13.0	+
23.5	13.0	-
23.5	12.0	+
24.0	12.0	-
24.0	11.0	+
24.5	11.0	-
24.5	10.0	+
25.0	10.0	-
25.5	9.0	+
26.0	9.0	-
26.5	8.0	+
27.0	8.0	-
27.5	7.0	+
28.0	7.0	-
28.0	6.0	+
28.5	6.0	-
28.5	5.0	+
29.0	5.0	-
29.5	4.0	+
30.0	4.0	-
31.0	3.0	+
31.5	3.0	-
32.0	2.0	+
32.5	2.0	-
33.0	1.0	+
33.5	1.0	-
34.0	0.0	+
36.0	0.0	-

Table 22

Flammability of Mixtures of Nitromethane, Methyl Bromide and Air
(Temperature = 150°C)

Volume Percent CH_3NO_2	Volume Percent CH_3Br	Result
8.0	0.0	-
8.5	0.0	+
8.0	1.0	-
8.5	1.0	+
8.5	2.0	-
9.0	2.0	+
8.5	3.0	-
9.0	3.0	+
8.5	4.0	-
9.0	4.0	+
8.5	5.0	-
9.0	5.0	+
8.5	6.0	-
9.0	6.0	+
8.5	7.0	-
9.0	7.0	+
8.5	8.0	-
9.0	8.0	+
8.5	9.0	-
9.0	9.0	+
8.5	10.0	-
9.0	10.0	+
8.5	11.0	-
9.0	11.0	+
8.5	12.0	-
9.0	12.0	+
9.0	13.0	-
9.5	13.0	+
9.0	14.0	-
9.5	14.0	+
9.0	15.0	-
9.5	15.0	+
9.0	16.0	-
9.5	16.0	+
9.0	17.0	-
9.5	17.0	+
9.0	18.0	-
9.5	18.0	+
9.0	18.5	-
9.5	18.5	+
11.0	19.0	-
9.5	20.0	-
10.5	20.0	-
11.5	20.0	-
11.5	18.5	+
12.0	18.5	-
11.5	18.0	+

Table 22 (Cont'd.)

Flammability of Mixtures of Nitromethane, Methyl Bromide and Air
(Temperature = 150°C)

Volume Percent		Result
CH_3NO_2	CH_3Br	
12.0	18.0	-
12.0	17.0	+
12.5	17.0	-
12.0	16.0	+
12.5	16.0	-
12.5	15.0	+
13.0	15.0	-
12.5	14.0	+
13.0	14.0	-
13.0	13.0	+
13.5	13.0	-
13.5	12.0	+
14.0	12.0	-
14.0	11.0	+
14.5	11.0	-
14.0	10.0	+
14.5	10.0	-
15.0	9.0	+
15.5	9.0	-
15.5	8.0	+
16.0	8.0	-
16.0	7.0	+
16.5	7.0	-
17.0	6.0	+
17.5	6.0	-
17.0	5.0	+
17.5	5.0	-
18.0	4.0	+
18.5	4.0	-
20.5	3.0	+
21.0	3.0	-
24.0	2.0	+
24.5	2.0	-
29.5	1.0	+
30.0	1.0	-
35.0	0.0	+
36.0	0.0	-

Table 23

Flammability of Mixtures of Nitromethane, Bromochloromethane and Air
(Temperature = 150°C)

Volume Percent		Result
CH_3NO_2	CH_2BrCl	
8.0	0.0	-
8.5	0.0	+
8.5	0.5	-
9.0	0.5	+
8.5	1.0	-
9.0	1.0	+
9.0	1.5	-
9.5	1.5	+
9.0	2.0	-
9.5	2.0	+
9.0	2.5	-
9.5	2.5	+
9.0	3.0	-
9.5	3.0	+
9.0	3.5	-
9.5	3.5	+
9.0	4.0	-
9.5	4.0	+
9.0	4.5	-
9.5	4.5	+
9.0	5.0	-
9.5	5.0	+
9.0	5.5	-
9.5	5.5	+
9.0	6.0	-
9.5	6.0	+
9.0	6.5	-
9.5	6.5	+
9.0	7.0	-
9.5	7.0	+
9.0	7.5	-
9.5	7.5	+
9.0	8.0	-
9.5	8.0	+
9.0	8.5	-
9.5	8.5	+
9.0	9.0	-
9.5	9.0	+
9.0	9.5	-
9.5	9.5	+
9.0	10.0	-
9.5	10.0	+
9.0	10.5	-
9.5	10.5	+
9.5	11.0	-
10.0	11.0	+
10.0	11.5	-
10.5	11.5	+

Table 23 (Cont'd.)

Flammability of Mixtures of Nitromethane, Bromochloromethane and Air
(Temperature - 150°C)

Volume Percent CH_3NO_2	Volume Percent CH_2BrCl	Result
11.0	12.0	-
11.5	12.0	+
13.5	12.0	+
14.0	12.0	-
14.0	11.5	+
14.5	11.5	-
15.5	11.0	+
16.0	11.0	-
16.0	10.5	+
16.5	10.5	-
16.0	10.0	+
16.5	10.0	-
16.5	9.5	+
17.0	9.5	-
17.5	9.0	+
18.0	9.0	-
18.0	8.5	+
18.5	8.5	-
18.0	8.0	+
18.5	8.0	-
19.0	7.5	+
19.5	7.5	-
19.5	7.0	+
20.0	7.0	-
20.0	6.5	+
20.5	6.5	-
21.0	6.0	+
21.5	6.0	-
21.5	5.5	+
22.0	5.5	-
22.0	5.0	+
22.5	5.0	-
23.0	4.5	+
23.5	4.5	-
24.0	4.0	+
24.5	4.0	-
24.5	3.5	+
25.0	3.5	-
25.5	3.0	+
26.0	3.0	-
26.0	2.5	+
26.5	2.5	-
27.0	2.0	+
27.5	2.0	-
27.5	1.5	+

Table 23 (Cont'd.)

Flammability of Mixtures of Nitromethane, Bromochloromethane and Air
(Temperature = 150°C)

Volume Percent		Result
CH_3NO_2	CH_2BrCl	
28.0	1.5	-
28.5	1.0	+
29.0	1.0	-
30.0	0.5	+
30.5	0.5	-
35.0	0.0	+
36.0	0.0	-

Table 24

Flammability of Mixtures of Nitromethane, Dibromodifluoromethane and Air
(Temperature = 150°C)

Volume Percent CH_3NO_2	Volume Percent CF_2Br_2	Result
8.0	0.0	-
8.5	0.0	+
9.5	0.5	-
10.0	0.5	+
10.0	1.0	-
10.5	1.0	+
10.5	1.5	-
11.0	1.0	+
10.5	2.0	-
11.0	2.0	+
11.0	2.5	-
11.5	2.5	+
11.0	3.0	-
11.5	3.0	+
11.5	3.5	-
12.0	3.5	+
11.5	4.0	-
12.0	4.0	+
12.0	4.5	-
12.5	4.5	+
12.0	5.0	-
12.5	5.0	+
12.0	5.5	-
12.5	5.5	+
12.0	6.0	-
12.5	6.0	+
12.5	6.5	-
13.0	6.5	+
13.0	7.0	-
13.5	7.0	+
13.5	7.5	-
14.0	7.5	+
13.5	8.0	-
14.0	8.0	+
14.0	8.5	-
14.5	8.5	+
14.0	9.0	-
14.5	9.0	+
14.5	9.5	-
15.0	9.5	+

Table 24 (Cont'd.)

Flammability of Mixtures of Nitromethane, Dibromodifluoromethane and Air
(Temperature = 150°C)

Volume Percent CH_3NO_2	Volume Percent CF_2Br_2	Result
14.5	10.0	-
15.0	10.0	+
15.0	10.5	-
15.5	10.5	+
15.5	11.0	-
16.0	11.0	+
16.0	11.5	-
16.5	11.5	+
16.0	12.0	-
16.5	12.0	+
16.5	12.5	+
16.5	14.5	+
17.0	11.5	+
17.5	11.5	-
17.0	11.0	+
17.5	11.0	-
17.5	10.5	+
18.5	10.5	-
18.0	10.0	+
18.5	10.0	-
18.5	9.5	+
19.0	9.5	-
19.0	9.0	+
19.5	9.0	-
20.0	8.5	+
20.5	8.5	-
20.5	8.0	+
21.0	8.0	-
21.0	7.5	+
21.5	7.5	-
22.0	7.0	+
22.5	7.0	-
22.5	6.5	+
23.0	6.5	-
23.0	6.0	+
23.5	6.5	-
23.5	5.5	+
24.0	5.5	-
24.0	5.0	+
24.5	5.0	-

Table [illegible] (Cont'd.)

Flammability of Mixtures of Nitromethane, Dibromodifluoromethane and Air

(Temperature = 150°C)

Volume Percent CH_3NO_2	Volume Percent CF_2Br_2	Result
24.5	4.5	+
25.0	4.5	-
25.0	4.0	+
25.5	4.0	-
25.5	3.5	+
26.0	3.5	-
26.0	3.0	+
26.5	3.0	-
27.0	2.5	+
27.5	2.5	-
27.5	2.0	+
28.0	2.0	-
28.0	1.5	+
28.5	1.5	-
29.0	1.0	+
29.5	1.0	-
30.0	0.5	+
30.5	0.5	-
35.0	0.0	+
36.0	0.0	-

Table 25

Flammability of Mixtures of Nitromethane, 1,2-Dibromotetrafluoroethane and Air

(Temperature = 150°C)

Volume Percent		Result
CH_3NO_2	CF_2BrCF_2Br	
8.0	0.0	-
8.5	0.0	+
9.0	0.5	-
9.5	0.5	+
9.0	1.0	-
9.5	1.0	+
10.0	1.5	-
10.5	1.5	+
10.0	2.0	-
11.0	2.0	+
11.5	2.5	-
12.0	2.5	+
11.5	3.0	-
12.0	3.0	+
12.0	3.5	-
12.5	3.5	+
12.0	4.0	-
12.5	4.0	+
13.5	4.25	+
14.0	4.25	-
13.0	4.5	-
15.0	4.5	-
15.5	4.0	+
16.0	4.0	-
18.0	3.5	+
19.0	3.5	-
21.0	3.0	+
21.5	3.0	-
22.0	2.5	+
25.0	2.0	+
26.0	2.0	-
27.0	1.5	+
28.0	1.0	+
29.0	1.0	-
32.0	0.5	+
35.0	0.0	+
36.0	0.0	-

Flammability of Mixtures of Aniline, Carbon Dioxide and Air
(Temperature = 200°C)

Volume Percent $C_6H_5NH_2$	Volume Percent CO_2	Result
0.0	0.0	-
0.25	0.0	+
0.0	0.25	-
0.25	0.25	+
0.0	0.5	-
0.25	0.5	+
0.25	0.75	-
0.5	0.75	+
0.25	1.0	-
0.5	1.0	+
0.25	1.25	-
0.5	1.25	+
0.25	1.5	-
0.5	1.5	+
0.25	1.75	-
0.5	1.75	+
0.5	2.0	-
0.75	2.0	+
0.5	2.25	-
0.75	2.25	-
1.0	2.25	-
1.25	2.25	-
1.0	2.0	+
1.25	2.0	-
1.25	1.75	+
1.5	1.75	-
1.75	1.5	+
2.0	1.5	-
2.0	1.25	+
2.25	1.25	-
2.0	1.0	+
2.25	1.0	-
2.25	0.75	+
2.5	0.75	-
2.25	0.5	+
2.5	0.5	-
2.25	0.25	+
2.5	0.25	-
3.25	0.0	+
3.5	0.0	-

Table 27

Flammability of Mixtures of Aniline, Methyl Bromide and Air
(Temperature = 200°C)

Volume Percent		Results
$C_6H_5NH_2$	CH_3Br	
0.0	0.0	-
0.25	0.0	+
0.5	0.25	-
0.75	0.25	+
0.5	0.5	-
0.75	0.5	+
0.75	0.75	-
1.0	0.75	+
0.75	1.0	-
1.0	1.0	+
0.75	1.25	-
1.0	1.25	+
0.75	1.5	-
1.0	1.5	+
1.0	1.75	-
1.25	1.75	+
1.25	2.0	-
1.5	2.0	-
1.5	1.75	+
1.75	1.75	-
1.5	1.5	+
1.75	1.5	-
1.75	1.25	+
2.0	1.25	-
1.75	1.0	+
2.0	1.0	-
2.0	0.75	+
2.25	0.75	-
2.25	0.5	+
2.5	0.5	-
2.25	0.25	+
2.5	0.25	-
3.25	0.0	+
3.5	0.0	-

Table 22

Flammability of Mixtures of Aniline, Bromochloromethane and Air
(Temperature - 200°F)

Volume Percent		Result
$C_6H_5NH_2$	CH_2BrCl	
0.0	0.0	-
0.25	0.0	+
0.25	0.25	-
0.5	0.25	+
0.5	0.5	-
0.75	0.5	+
0.5	0.75	-
0.75	0.75	+
0.75	1.0	-
1.0	1.0	+
0.75	1.25	-
1.0	1.25	+
0.75	1.5	-
1.0	1.5	+
0.75	1.75	-
1.0	1.75	+
1.0	2.0	-
1.25	2.0	-
1.5	2.0	-
1.25	1.75	+
1.5	1.75	-
2.0	1.5	+
2.25	1.5	-
2.0	1.25	+
2.25	1.25	-
2.0	1.0	+
2.25	1.0	-
2.25	0.75	+
2.5	0.75	-
2.25	0.5	+
2.5	0.5	-
2.5	0.25	+
2.75	0.25	-
3.25	0.0	+
3.5	0.0	-

Table 29

Flammability of Mixtures of Aniline, Dibromodifluoromethane and Air
(Temperature - 200°C)

Volume Percent $C_6H_5NH_2$	Volume Percent CF_2Br_2	Result
0.0	0.0	-
0.25	0.0	+
0.25	0.25	-
0.5	0.25	+
0.25	0.5	-
0.5	0.5	+
0.5	0.75	-
0.75	0.75	+
0.75	1.0	-
1.0	1.0	+
1.0	1.25	-
1.25	1.25	+
1.25	1.5	-
1.5	1.5	+
1.5	1.75	-
1.75	1.75	+
1.5	2.0	-
1.75	2.0	+
1.5	2.25	-
1.75	2.25	+
1.75	2.5	-
2.0	2.5	+
1.75	2.75	-
2.0	2.75	+
1.75	3.0	-
2.0	3.0	+
2.0	3.25	-
2.25	3.25	-
2.25	3.0	-
2.25	2.75	-
2.25	2.5	-
2.25	2.25	-
2.25	2.0	-
2.25	1.75	+
2.5	1.75	-
2.25	1.5	+
2.5	1.5	-
2.25	1.25	+
2.5	1.25	-
2.25	1.0	+
2.5	1.0	-
2.25	0.75	+
2.5	0.75	-
2.25	0.5	+
2.5	0.5	-
2.75	0.25	+

Table 29 (Cont'd.)

Flammability of Mixtures of Aniline, Dibromodifluoromethane and Air
(Temperature = 200°C)

Volume Percent		Result
$C_6H_5NH_2$	CBr_2F_2	
3.0	0.25	-
3.05	0.0	+
3.11	0.0	-

Table 50

Flammability of Mixtures of Aniline, 1,2-Dibromotetrafluoroethane and Air

(Temperature = 200°C)

Volume Percent $C_6H_5NH_2$	Volume Percent CF_2BrCF_2Br	Result
0.0	0.0	-
0.25	0.0	+
0.25	0.25	-
0.5	0.25	+
0.5	0.5	-
0.75	0.5	+
0.5	0.75	-
0.75	0.75	+
0.5	1.0	-
0.75	1.0	+
0.75	1.25	-
1.0	1.25	+
1.0	1.5	-
1.25	1.5	+
1.0	1.75	-
1.25	1.75	+
1.0	2.0	-
1.25	2.0	+
1.25	2.25	-
1.5	2.25	-
1.75	2.25	-
1.75	2.0	+
2.0	2.0	-
2.0	1.75	+
2.25	1.75	-
2.0	1.5	+
2.25	1.5	-
2.25	1.25	+
2.5	1.25	-
2.25	1.0	+
2.5	1.0	-
2.25	0.75	+
2.5	0.75	-
2.5	0.5	+
2.75	0.5	-
2.5	0.25	+
2.75	0.25	-
3.25	0.0	+
3.5	0.0	-

Table 31

Reactivity of Mixtures of Fluorine, Nitrogen and Carbon Dioxide
(Temperature = 25°C)

Rate of Flow, Liters/Min. F_2	CO_2	Ratio $F_2 : CO_2$	Result
1.51	0.20	7.55 : 1	-
1.51	0.31	4.87 : 1	-
1.51	0.46	3.28 : 1	-
0.62	0.25	2.48 : 1	-
1.51	0.65	2.32 : 1	-
1.51	0.78	1.94 : 1	-
1.51	0.90	1.68 : 1	-
1.51	1.05	1.44 : 1	-
1.51	1.27	1.19 : 1	-
1.51	1.32	1.14 : 1	-
1.51	1.40	1.08 : 1	-
1.51	1.49	1.01 : 1	-
1.51	1.52	0.99 : 1	-
0.62	0.76	0.82 : 1	-
0.62	1.59	0.39 : 1	-
0.62	2.10	0.30 : 1	-
0.62	2.51	0.25 : 1	-
0.62	2.84	0.22 : 1	-
0.62	3.13	0.20 : 1	-
0.62	3.27	0.19 : 1	-
0.62	3.81	0.16 : 1	-
0.62	4.12	0.15 : 1	-
0.62	4.40	0.14 : 1	-
0.62	4.70	0.13 : 1	-
0.62	4.97	0.12 : 1	-

Table 32

Reactivity of Mixtures of Fluorine, Nitrogen and Methyl Bromide
(Temperature = 25°C)

Rate of Flow, Liters/Min. F_2	CH_3Br	Ratio $F_2 : CH_3Br$	Result
0.62	0.22	2.82 : 1	+
0.62	0.63	0.97 : 1	+
0.62	1.08	0.57 : 1	+
0.62	1.27	0.49 : 1	+
0.62	1.42	0.43 : 1	+
0.62	1.72	0.36 : 1	+
0.62	1.94	0.32 : 1	+
0.62	2.06	0.30 : 1	+
0.62	2.19	0.28 : 1	+
0.62	2.43	0.26 : 1	+
0.62	2.61	0.24 : 1	+
0.62	2.70	0.23 : 1	+

Table 34

Reactivity of Mixtures of Fluorine, Nitrogen and Bromodifluoromethane
(Temperature = 25°C)

Rate of Flow, Liters/Min. F_2	CF_2Br_2	Ratio $F_2:CF_2Br_2$	Result
1.51	0.38	4.32 : 1	+
1.51	0.51	2.86 : 1	+
1.51	0.63	2.40 : 1	+
1.51	0.85	1.78 : 1	+
1.51	0.94	1.61 : 1	+
1.51	1.06	1.42 : 1	+
1.51	1.17	1.35 : 1	+
1.51	1.28	1.18 : 1	+
1.51	1.36	1.12 : 1	+
1.51	1.45	1.03 : 1	+
1.51	1.57	0.96 : 1	+
1.51	1.73	0.87 : 1	+
1.51	1.98	0.76 : 1	+

Table 35

Reactivity of Mixtures of Fluorine, Nitrogen and 1,2-Dibromotetrafluoroethane
(Temperature = 28°C)

Rate of Flow, Liters/Min. F_2	CF_2BrCF_2Br	Ratio $F_2:CF_2BrCF_2Br$	Result
1.51	0.24	6.29 : 1	+
1.51	0.35	4.32 : 1	+
1.51	0.42	3.59 : 1	+
1.51	0.49	3.06 : 1	+
1.51	0.56	2.70 : 1	+
1.51	0.62	2.42 : 1	+
1.51	0.68	2.21 : 1	+
1.51	0.73	2.04 : 1	+
1.51	0.77	1.96 : 1	+
1.51	0.84	1.80 : 1	+
1.51	0.91	1.66 : 1	+
1.51	0.98	1.53 : 1	+
1.51	1.08	1.40 : 1	+
1.51	1.15	1.31 : 1	+

Table 36

Reactivity of Mixtures of Fluorine, Nitrogen and Bromotrifluoromethane
(Temperature = 25°C)

Rate of Flow, Liters/Min. F_2	CF_3Br	Ratio $F_2:CF_3Br$	Result
1.51	0.32	4.72 : 1	+
1.51	0.66	2.29 : 1	+
1.51	1.02	1.48 : 1	+
1.51	1.21	1.25 : 1	+
1.51	1.43	1.06 : 1	+
1.51	1.66	0.91 : 1	+
1.51	1.89	0.80 : 1	+
1.51	2.05	0.74 : 1	+
1.51	2.14	0.71 : 1	+
1.51	2.25	0.68 : 1	+
1.51	2.39	0.63 : 1	+
1.51	2.47	0.61 : 1	+
1.51	2.60	0.58 : 1	+
1.51	2.76	0.55 : 1	+
1.51	2.89	0.52 : 1	+
1.51	3.03	0.50 : 1	+
1.51	3.19	0.47 : 1	+
1.51	3.47	0.44 : 1	+
1.51	3.80	0.40 : 1	+
1.51	4.01	0.38 : 1	+
1.51	4.26	0.35 : 1	+
1.51	4.54	0.33 : 1	+
1.51	4.72	0.32 : 1	+

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