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A PORTABLE WATER-SPRAY FIRE EXTINGUISHER FOR SUBMARINE USE

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ABSTRACT

A portable first-aid fire extinguisher has been designed, developed, and tested at NRL for use on most fires likely to be encountered aboard submarines. The extinguisher uses water, improved by the addition of a wetting agent, as an extinguishant; compressed air, which is stored in the same compartment as the water, supplies the operating force. To insure low electrical conductivity and high fire-extinguishing efficiency, the water is broken up by a special nozzle into a spray of optimum drop size. This form was slightly more effective than a solid stream and much more effective than streams approaching a broad mist. The addition of a 0.1-percent wetting agent to the water reduced the amount of liquid required to extinguish the test fires by one-third without appreciably increasing electrical conductivity.

Cotton waste was used as fuel for tests on deep-seated fires, while a shallow pool of diesel oil represented the flammable liquid tests and a deep tub of vigorously boiling hydrogenated vegetable oil was used for the fat fire test.

The low electrical conductivity of the emitted spray was demonstrated by measuring the current flowing through it when directed against a copper plate charged to potentials up to 950 volts. At a distance greater than 4 inches the current in all cases was less than 1 ma which is below the minimum that can be felt.

PROBLEM STATUS

This is an interim report; work is continuing.

AUTHORIZATION

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INTRODUCTION

In submarines, and in the interior spaces of surface vessels as well, the difficulties of fire fighting are aggravated by a lack of control over ventilation. For example, when a submarine is surface cruising, fresh air is drawn down access hatches to ventilate the ship and to provide a new supply for the engines. As a result, the large quantities of air, which pass through several compartments, produce strong air currents in the vessel. On the other hand, a snorkeling submarine receives its engine induction air through hull valves in the engine room, and fresh air is circulated by a ventilating system which permits some control of air currents. On a fully submerged submarine, ventilation is obviously limited to the recirculation of air without an opportunity to vent foul air overboard. Thus, fire fighting aboard a submarine must be done under circumstances dictated by the manner of operating the vessel. This situation is in sharp contrast to fighting land fires where the first act is to clear away products of combustion by providing proper ventilation. Fire fighting aboard submarines is further complicated by the operational necessity of stowing several kinds of supplies in the same spaces. This deprives the damage-control party of the advantage of segregation which permits the use of the most appropriate fire-fighting technique. Since combustibles are often stored adjacent to electrical conductors or other electrical equipment, accidental sparking constitutes a real danger.

Satisfactory fire extinguishers for submarine use must not contribute any substantial amount of toxic materials, whether they be inherent in the extinguishant or a result of its breakdown in the fire, and the extinguisher must also be able to quickly stop smoking and smoldering. It is also desirable to obtain a single type of extinguisher that can be used on all kinds of combustibles without regard to the presence of electrical equipment.

Extinguishers Now in Use

Fire-fighting equipment presently used aboard submarines consists of hoses connected to salt-water trim lines and small (usually 15 pound) portable carbon dioxide extinguishers. Since carbon dioxide extinguishes fire primarily by excluding the air rather than by cooling the combustibles, it is effective only as long as it forms a blanket around the combustible, and reignition either from heat in the fuel or from heated surroundings will result if the blanket is broken too soon. The lack of complete control over ventilation makes maintenance of a blanket difficult where the carbon dioxide is applied directly to the fire, and it likewise interferes with flooding a compartment with the extinquishing gas. This problem is particularly noticeable in the newer style ventilation system in which the open space of the submarine (instead of actual ducts) is used as air return lines. Water is better suited than carbon dioxide for the extinguishment of deep-seated fires such as those in cotton, paper, wood, burlap, and charred wood. Damage-control water lines, however, generally contain salt water, and its improper application can result in damage to equipment and danger to personnel when electrical equipment is involved.

Vaporizing Liquid Extinguishers

Several new fire extinguishants have been proposed in recent years. Many of them are effective, but each has one or more drawbacks that prohibit its recommendation for general use, especially in enclosed spaces. Chlorobromomethane (CB, CBM), which was developed in Germany during World War II and afterward brought into this country, is a considerably more effective extinguishant than carbon tetrachloride, but it is likewise inherently toxic and produces toxic breakdown products in a fire (1). Thus, it cannot be safely used without adequate ventilation. Methyl bromide, a gaseous agent, also is efficient but it, too, has a high inherent toxicity which is only partly destroyed by decomposition in a fire.

More recently, attention has turned toward organofluorine compounds. Some fluorinated compounds containing at least one atom of bromine were found to be exceptionally effective extinguishants. Some of these, notably dibromodifluoromethane and monobromotrifluoromethane, can be obtained commercially in adequate quantity, and their use on a large scale is contemplated. The studies made so far show them to be relatively nontoxic in themselves (2,3, and 4), but they are known to partly break down at flame temperatures and some corrosive and toxic products are to be expected. Further study of their physiological effects after contact with burning or hot materials is needed before their use in unventilated spaces can be unqualifiedly recommended.

The fire-extinguishing effectiveness of several perfluorocarbons (fluorine and carbon only) and some brominated hydrocarbons has been determined and reported (5). It was apparent that the presence of bromine in the compounds was necessary for high efficiency, and that the perfluorocarbons which were comparably effective on a volumetric basis owed their effectiveness to high density and the consequent greater mass concentration of vapor that could be obtained. Some perfluorocarbons were subjected to heat to determine if their reputed thermal stability extended over the range of temperature that might be encountered in a fire. Of the materials tested, only tetrafluoromethane appeared reasonably stable over the range of 900^0 to 1800^0 F, and this compound, owing to its low molecular weight and vapor density, is the least effective perfluorocarbon extinguishant. The other perfluorocarbons under consideration had a much higher vapor density, showed a low but appreciable breakdown at 900^0 F, and at 1800^0 F gave up about 85 percent of their fluorine probably as fluorine and hydrofluoric acid. In contradistinction to the physiological inertness of the original compound, the released fluorine or hydrofluoric acids are expected to be intolerably irritating and toxic.

Dry Chemical Powder Extinguishers

Powdered anhydrous sodium bicarbonate, treated to render it noncaking, is used as a fire extinguishant, particularly on burning liquids. It is also advertised as useful around electrical equipment. Studies (6), however, have shown that it is capable of conducting electricity if exposed long enough to air having a relative humidity in excess of 70 percent. Its use, therefore, is accompanied by a serious cleanup problem. The powder is relatively ineffective on deep-seated fires in solid combustibles. It is thus apparent that the dry-powder type of extinguisher cannot be considered for use as a general purpose extinguisher aboard submarines.

Water as an Extinguishant

No new types of extinguishants suitable for general use appear to be forthcoming in the near future. The use of halogenated hydrocarbons (volatilizing liquid extinguishants), carbon dioxide, and dry powder appears to be too limited in scope. On the other hand, the efficiency of water as a fire extinguishant has been greatly increased through the introduction of new application methods (particularly as a spray or fog) and through the use of chemical additives.

When wetting agents are added to water, its efficiency is increased against Class A fires, and this technique is finding wide acceptance in the field. The use of these agents generally increases the effectiveness of water from one and one half to two times. When some of the agents are mixed with water, the resulting solution can be driven against the surface of a pool of oil with enough force to emulsify the surface and thus make the oil noncombustible for a short time, at least.

Problem of Electrical Shock

Contrary to popular belief, water can be applied to energized electrical equipment under some circumstances without danger of shock to the person holding the water applicator. For example, Appel and Bono (7) pointed out that a person holding a fog nozzle in his bare hands and directing a salt-water spray against a target 6 feet away will feel no shock even though the target is charged to 27,000 volts. They also stated that certain fog nozzles can be safely used to direct a spray against a conductor charged to 120,000 volts at a distance of only 6 feet. When water was broken up into a spray and directed against a conductor that was charged to 250,000 volts and located 10 feet away, the current was just barely enough to be felt by an operator (8). Similar results have been reported by the British Admiralty (9).

The present problem is to determine the size and type of dispenser, the application method, and the chemical additives that will make water suitable for extinguishing all types of fires likely to be encountered aboard submarines. Consequently, a series of tests was made to ascertain how the effectiveness of water as an extinguishant will vary with the addition of wetting agents and changes in drop size and velocity. Tests were also made to determine the extent of danger for a fire fighter who directs such a spray against live electrical equipment.

EXPERIMENTAL PROCEDURE AND RESULTS

Design of Extinguisher

It was decided, on the basis of past experience, that the so-called "2-1/2 gallon" commercial fire extinguisher was the largest unit that would be portable in crowded spaces. (This extinguisher is only slightly bulkier and substantially lighter than the commonly used 15-pound-size carbon dioxide unit.) The extinguisher used in the tests (Figs. 1 and 2) was adapted from a commercial soda acid model; it measured 23-1/2 inches high, 7 inches in diameter, and weighed 29 pounds when ready for use. The extinguishant was carried out through a central tube (5/16-inch id) reaching nearly to the bottom of the container. An external short length of flexible metallic hose connected the tube to a trigger valve and the nozzle.

Compressed air in the space above the water was used to expel the extinguishant. When an initial charge of 7 liters of liquid and an air pressure of 150 psig were employed, a residual pressure of 50 psig remained at the completion of the discharge.

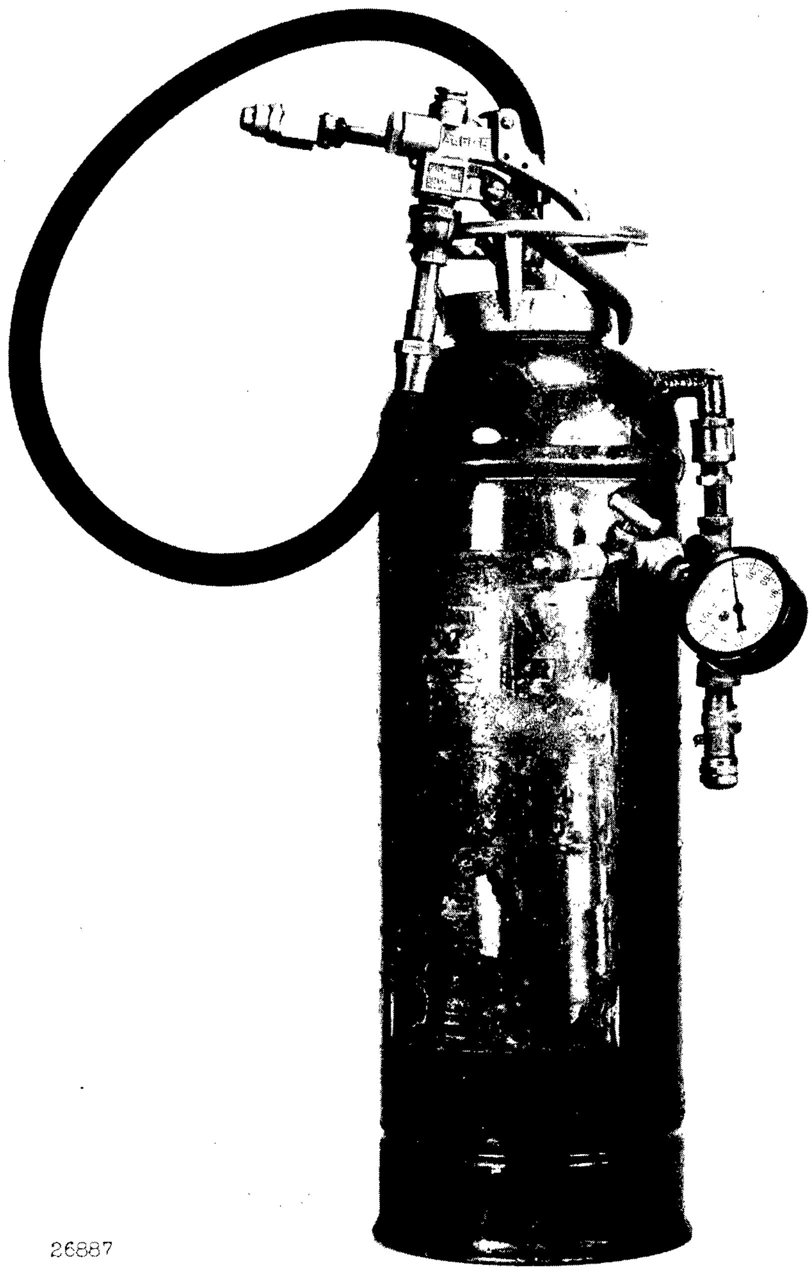

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Fig. 1 - Fire extinguisher used in all tests

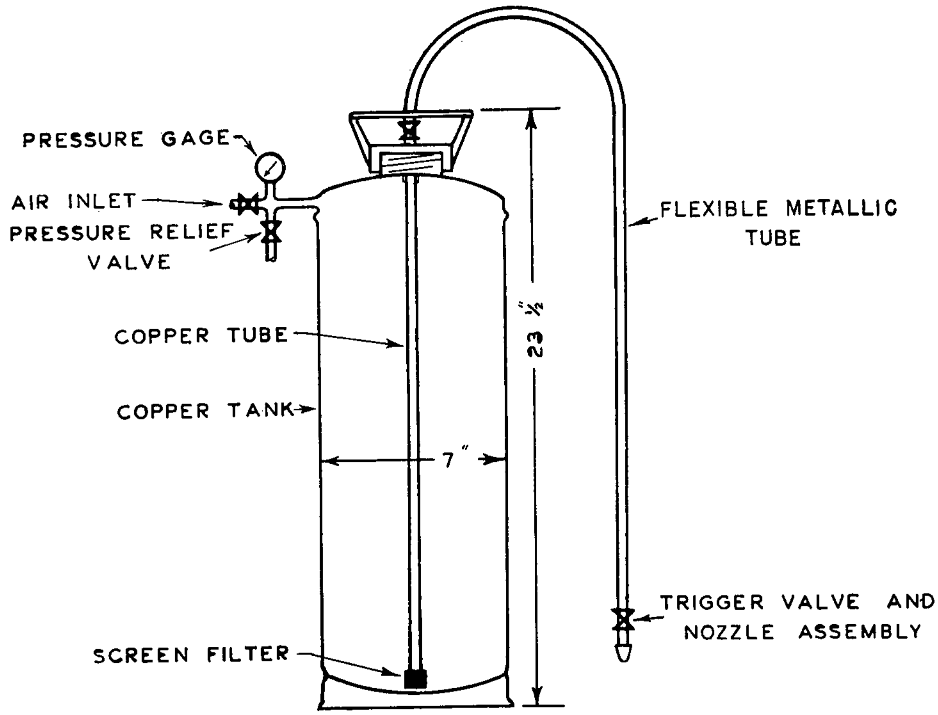


Fig. 2 - Diagram of extinguisher

The four nozzles, designated A through D, used in these tests were constructed so that the pattern of the issuing streams ranged from a narrow solid stream to a broad mist; all, however, discharged water at essentially the same volumetric rate. Nozzle A was a straight tube used to produce a solid stream; B, C, and D had inserts which aided in breaking the stream into a spray. The principal dimensions of the most effective nozzle, B, are given in Fig. 3.

The quantity of water discharged during various periods of time under the same starting pressure (150 psig) was determined for each of the four nozzles. The closeness of the results is shown in Fig. 4.

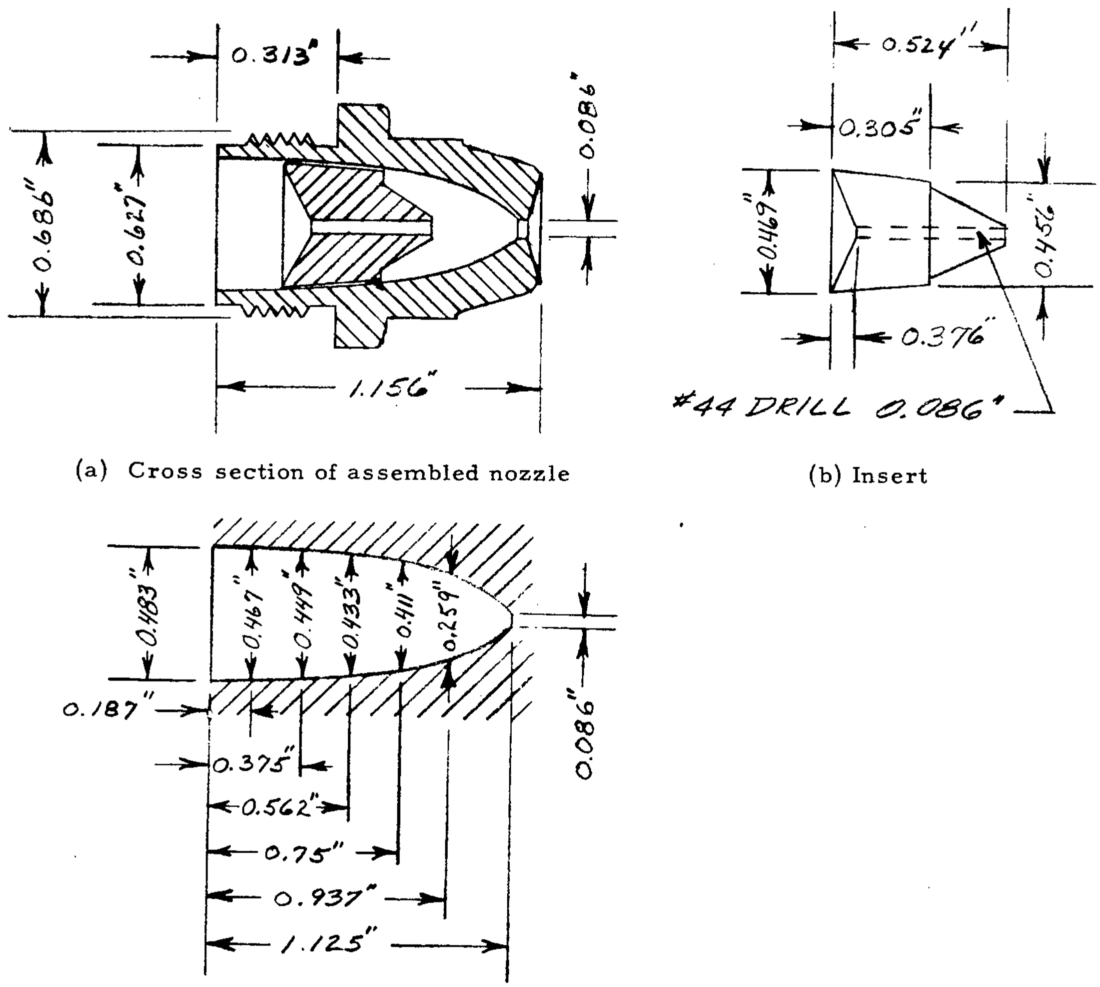
The pattern of the stream of liquid as it leaves Nozzle B is shown in Fig. 5. At a horizontal distance of 6 feet the stream was approximately 10 inches in diameter. When the nozzle was mounted 3 feet above the ground and aimed horizontally, the range was 24 feet, but when it was aimed for maximum distance, the range was 30 feet. These distances are more than adequate for fire fighting in situations where the use of a first-aid extinguisher is appropriate.

Class A Combustibles

All tests in this series were patterned after the procedure recommended by the Underwriters' Laboratories.* An aluminum sheet, 2 × 4 feet, was evenly covered with two

*According to their specifications, fires involving ordinary solid combustibles such as paper, wood, cloth, etc., are designated Class A; fires involving oils, greases, and fats are designated Class B; and those involving combustible materials surrounding or adjacent to electrical conductors are designated Class C.

pounds of cotton waste fluffed up so that no portions were wadded or packed. One hundred cc of gasoline were sprinkled over the cotton because it was important to ignite the entire surface practically at once. The extinguisher was placed so that the nozzle could be held about four feet away from, and three feet above, the sheet. The trigger and nozzle were held in the operator's hand and directed, at his discretion, to produce the most rapid extinguishment of the fire. Application of the extinguishant was started after a 30-second preburn, and extinguishment was considered complete when all smoldering ceased. (Since smoke and gases in a closed space are as hazardous as flames, tests were timed to complete extinction, rather than to the disappearance of visible flames and glowing spots.)



(a) Cross section of assembled nozzle

(b) Insert

(c) Cavity in body of nozzle

Fig. 3 - Diagram of Nozzle B

The tests were carried out in an isolated compartment of a building especially constructed so that there were no drafts to influence the fire. The progress of the extinguishment was observed through windows and glazed doors, and the extinguisher was manipulated by an operator whose hands and arms were thrust through suitable holes in one of the doors.

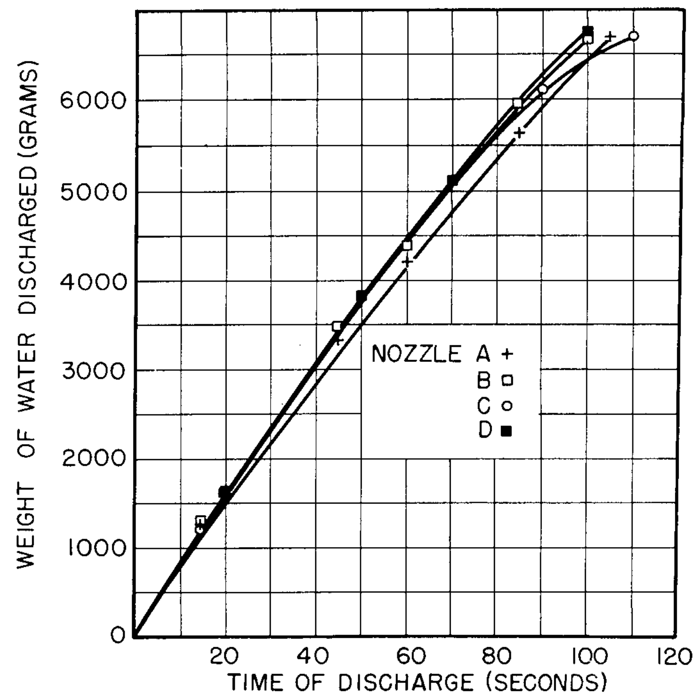


Fig. 4 - Comparison between discharges of nozzles

Fig. 5 - A 1-microsecond exposure of emergent stream from Nozzle B

In spite of efforts to standardize experimental conditions, there was considerable variation between repeated runs, and it was necessary to test each combination of nozzle and fluid several times to give statistical significance to the data. The results of a set of like tests are presented in Table 1 as the range of time and the average time required for extinguishment and the average amount of water used.

In all tests, the extinguisher was operated in the same manner, i.e., it was charged with 7 liters of fluid and pressurized to 150 psig. The only controllable variables were the spray pattern (through interchange of nozzles) and the kind of fluid (plain water or water with various amounts of wetting agent* added).

*Igepal, extra high concentration, manufactured by General Dyestuff Corporation

TABLE 1
Extinguishing Efficiency of Various Nozzles when a 0.1-Percent Solution of Wetting Agent was Used on Class A Combustibles

Nozzle	Number of Tests	Extinguishment Time (sec)			Average Amount of Fluid Required for Extinguishment (gm)
		Min	Max	Avg	
A	13	35	67	45	3240
B	15	29	42	36	2630
C	10	75	107	92	6030
D	6	Extinguisher exhausted without extinguishment			

The effect of variation in the spray pattern was determined by using a 0.1-percent wetting agent in water as the extinguishing medium. The pattern produced by Nozzle B was the most effective (Table 1).

According to the manufacturer, the economically maximum effectiveness of the wetting agent is reached at a concentration just below 0.1 percent. This claim was verified by extinguishing the standard Class A fire using several different concentrations of agent in water (Table 2). The same nozzle was used for each test.

TABLE 2
Extinguishment of Class A Combustible when Nozzle B was Used with Various Concentrations of Wetting Agent

Wetting Agent (%)	Number of Tests	Extinguishment Time (sec)			Average Amount of Fluid Required for Extinguishment (gm)
		Min	Max	Avg	
0.0	10	38	72	56	4140
0.1	15	29	42	36	2630
0.2	12	31	44	35	2630
0.5	12	31	45	36	2740

The first addition of wetting agent produced a marked reduction in time and amount of water required for extinguishment. This was to be expected since plain water did no more than wet the surface of the fuel before draining away, whereas the treated water immediately soaked into the fuel and extinguished internal smoldering with little runoff. Additions of wetting agent greater than 0.1 percent produce no substantial increase in extinguishing effectiveness.

Class B Combustibles

The extinguisher was tested on diesel fuel as a typical petroleum product likely to be encountered on practically every naval vessel. A sheet-iron fuel tray, 36 × 36 × 4 inches, and the same extinguisher used in the Class A tests was employed during this investigation. Since Nozzle B proved to be so satisfactory in the Class A tests, it was considered advisable to use the same nozzle exclusively on all other classes of fire in this series.

As a fuel for the Class B fires, six quarts of diesel oil (a layer approximately 1/4 inch thick) were floated on a 2 to 3 inch layer of water, and to serve as a fire starter, 100 cc of automotive gasoline were carefully poured on the surface of the oil. Within 90 seconds after ignition of the gasoline, the oil layer was burning and boiling vigorously. Following a 90-second preburn, the operator attacked the fire from a distance of 10 feet. After the initial momentary flare-up, the operator was able to move in close and apply the spray with a back and forth motion that drove the flames to the edge of the fuel and consequent extinguishment. The cooling and perhaps the emulsification of oil near the surface was sufficient to prevent reignition. As a result, little trouble was experienced with the fire flashing back behind the point of impact.

The additional effectiveness contributed by a small amount of wetting agent was again demonstrated by running two series of tests, one with plain water and one with water containing 0.1-percent wetting agent. The results given in Table 3 show that the agent doubles the effectiveness of the spray.

TABLE 3
Influence of Wetting Agent on Extinguishment
of Class B Combustible

Wetting Agent (%)	Number of Tests	Extinguishment Time (sec)			Average Amount of Fluid Required for Extinguishment (gm)
		Min	Max	Avg	
0.0	5	53	68	60	4480
0.1	6	9	40	26	2100

An opportunity was presented, in connection with another problem, to examine the effectiveness of the extinguisher on another Class B combustible, i.e., cooking fat. Although no exhaustive study was made on this type of fire, the qualitative results indicate another field of application for the extinguisher.

The test equipment included a round sheet-iron tank (8 inches high and 11 inches in diameter) which was supported near the rim so that fire could be applied underneath. A portable oil burner was placed on the ground near the tank and aimed so that most of the flame was beneath the tank.

Each test was made on a fresh charge of two gallons of cooking fat (hydrogenated vegetable oil) which filled the tank to within 3 inches of the top. Heat was applied to the tank until the fat reached its self-ignition temperature (692°F). The fat was allowed to burn for about two minutes, and then the spray was applied from the extinguisher equipped with Nozzle B.

Short bursts of 0.1-percent Igepal spray quickly extinguished the fire, and only a small amount of fat was spattered.

However, when spray was applied immediately after extinguishment or when it was applied too steadily while the fat was still burning, the liquid spattered vigorously and sometimes boiled and frothed until the tank was entirely empty. The same tests made with plain water resulted in similar effects except that the spattering was much more pronounced in the early stages of extinguishment.

For comparison, similar fires involving cooking fats were instantly extinguished with carbon dioxide from a regular 15-pound extinguisher, but spontaneous reignition occurred within 5 to 10 seconds, and it was necessary to apply more of the extinguishant. This alternate extinguishment and spontaneous reignition could be repeated as many as five times before permanent extinguishment was accomplished. The use of carbon dioxide on these fires produced irritating and noisome fumes, but they were not present when water was employed.

Electrical Conductivity of Water Spray

When the water spray from an extinguisher is directed against live electrical conductors, the operator is subjected to a certain amount of danger. To determine this hazard, it was necessary to measure the flow of current through the spray between the nozzle and a charged metal plate (Figs. 6 and 7). Since 710 volts dc and 440 volts ac are the maximum lighting and power voltages encountered on submarines, the plate was charged with these potentials. Additional tests were made at 950 volts dc in order to determine the proper safety factor necessary in translating the laboratory tests to operational conditions.

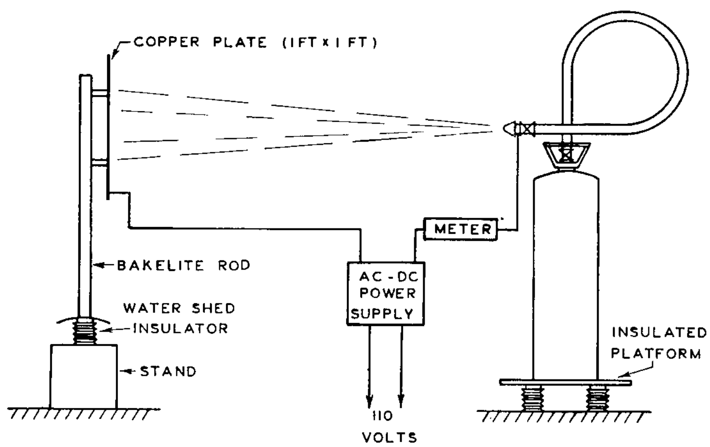


Fig. 6 - Diagram of conductivity test setup

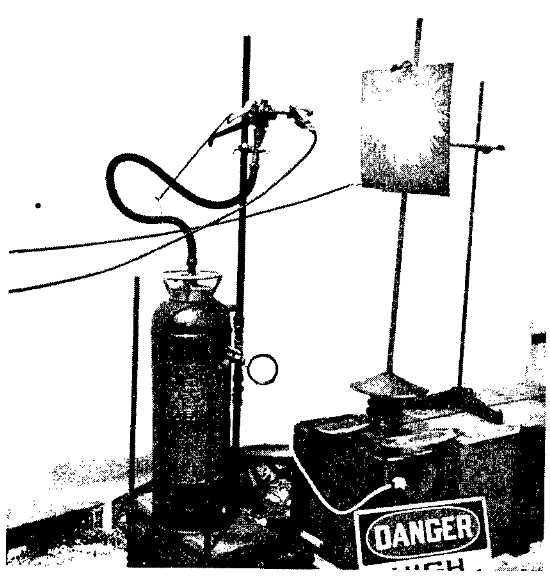


Fig. 7 - Conductivity test setup

The test equipment consisted of a 12-inch-square metal plate mounted on insulators, an insulated stand for the extinguisher and nozzle, and dc and ac power supplies which were provided with interchangeable micro and milliammeters. Where only low currents were encountered, meters capable of indicating current as low as 1 microampere were used. For higher currents, meters sensitive to approximately 0.02 milliampere were employed.

The nozzle was mounted at a selected distance from the plate and aimed to give a horizontal discharge. The electrical system was energized, and then the extinguisher valve was held open continuously until the extinguisher was completely discharged. Thus, all variations in spray pattern and drop size that might be encountered in service were tested. The maximum current flow was recorded for each test. For successive tests, the nozzle-to-plate distance was increased in steps to the distance at which current flow was 1 microampere or less. The fluid in the extinguisher was tap water to which a 0.1-percent addition of Igepal had been made. The current flow through the spray is shown in Figs. 8 and 9 as a function of distance for all four types of nozzles.

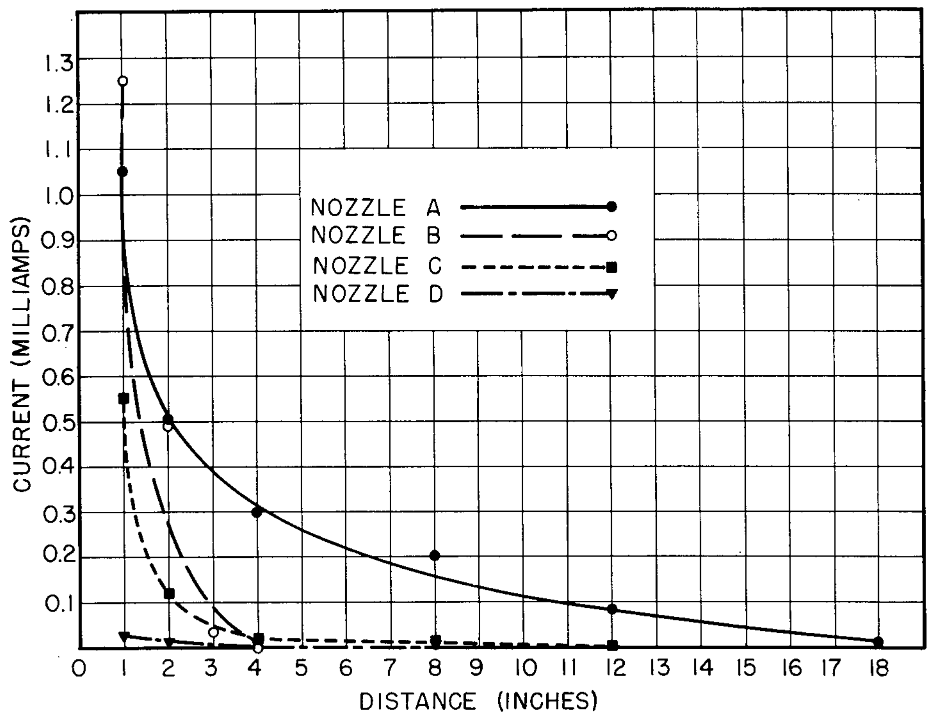


Fig. 8 - Electrical current through spray vs. distance between nozzle and plate at 710 volts dc

Two additional conductivity tests were run with Nozzle B, but this time one test employed plain tap water as the extinguishant and the other used a 0.5-percent solution of Igepal (Fig. 10).

When Nozzles A, B, and C were used in the foregoing tests, the current flowing through the extinguisher spray was affected very little by changes in the distance between the nozzle and the plate provided this distance exceeded 3 or 4 inches. When the distance was less than 3 or 4 inches, shortening the gap produced a rapid rise in current.

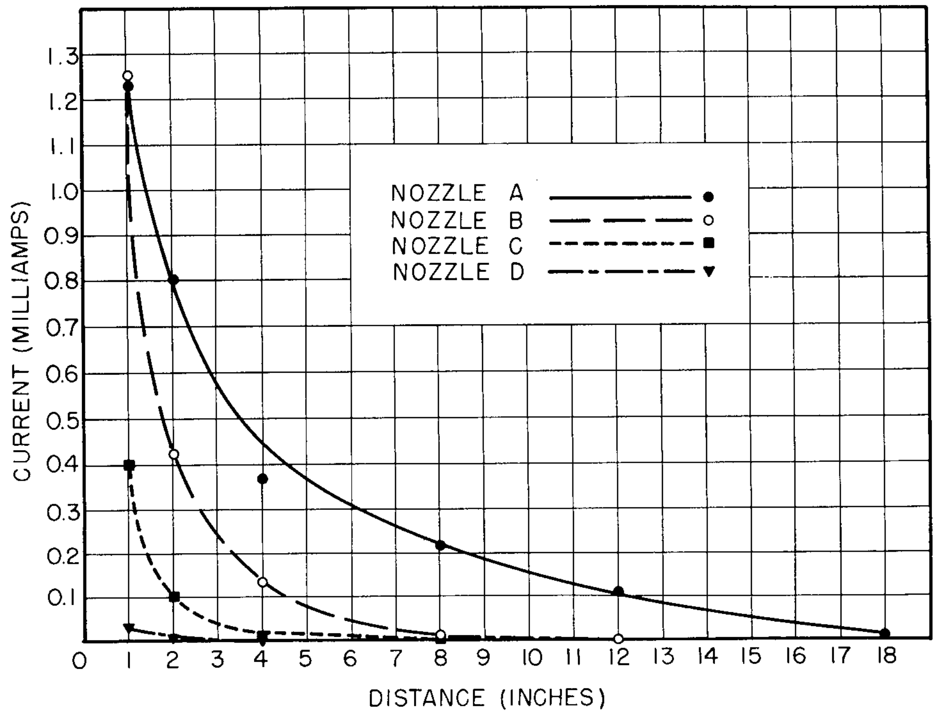


Fig. 9 - Electrical current through spray vs. distance between nozzle and plate at 940 volts dc

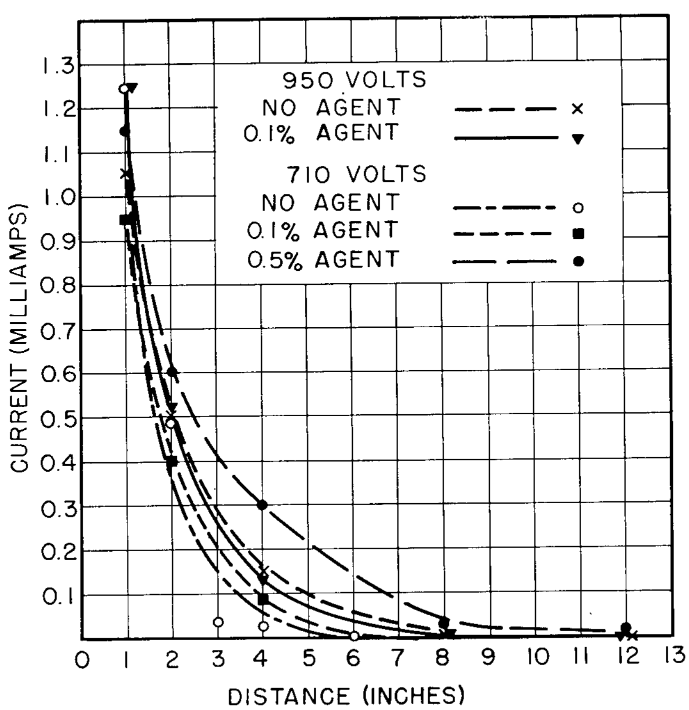


Fig. 10 - Influence of wetting agent on conductivity of spray. All tests were made with Nozzle B.

Arcing and Tracking Produced by Extinguishant

When the extinguishing fluid is used against a live electrical control panel, there is some chance of arcing and tracking. This possibility was explored with the aid of a simulated section of a switchboard composed of copper bars mounted, at various distances apart, on a sheet of phenolic plastic. One long copper bar mounted along the bottom edge of the panel was common to all tests. Above and parallel to it, bars 3 inches long were mounted on the panel 1/2, 1, 2, 4, and 8 inches above the long bar in a manner so that none was interposed between the long bar and another short bar (Fig. 11). Power-supply connections were arranged so that the long bar and any one of the short ones could be energized while the remaining bars were unenergized. The extinguisher was set up with Nozzle B 12 inches from the vertical panel, and operation of the extinguisher drenched the panel and caused a steady sheet of liquid to flow between the bars.

When the extinguishant was applied to the panel, the current rose promptly to maximum and fluctuated slightly as long as the liquid was running over the panel. Cessation of flow caused the current to drop off quickly, and within 30 seconds it was only a small fraction of the maximum. The maximum current observed in each test was recorded. Test conditions were somewhat more severe than would be encountered in actual practice, i.e., the panel was charged to 940 volts and the extinguishant was a 0.5-percent solution of Igepal. It was felt that a single set of test conditions would be adequate and that effects obtained under less severe conditions could be estimated by using these as a basis. The results of these tests and similar tests in which water was used as the extinguishant are given in Table 4 and Fig. 12.

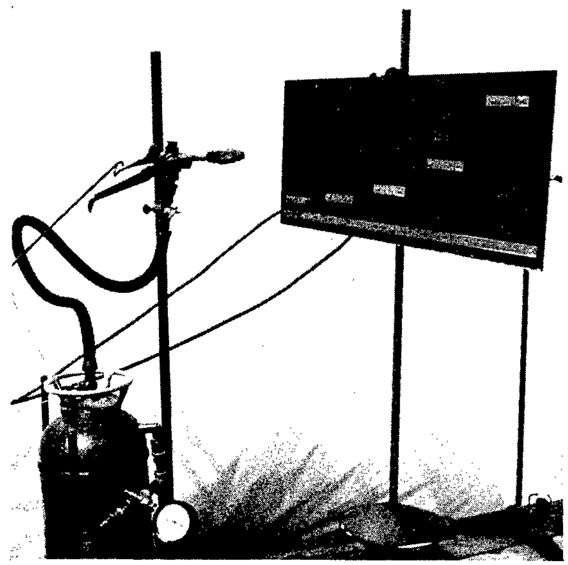


Fig. 11 - Arcing and tracking test setup

TABLE 4
Electrical Conductance between Energized Bars on Simulated Switchboard Wetted with Extinguishant

Distance between Conductors (in.)	Current (ma)	
	Solution of 0.5% Igepal in Water	Tap Water
1/2	25	35
1	21	20
2	18	12
4	10	8
8	8	2

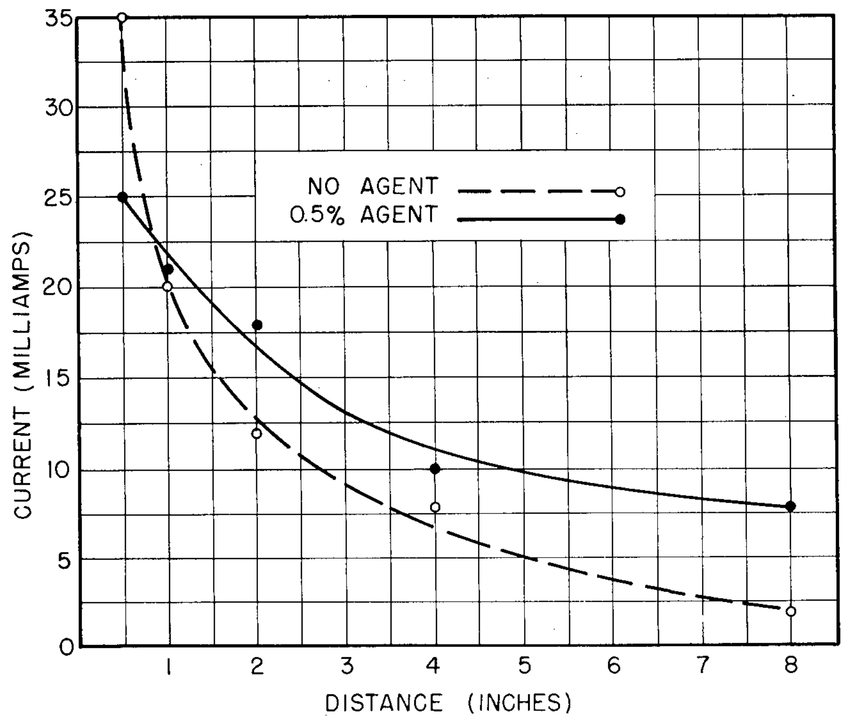


Fig. 12 - Current flow over face of simulated switchboard

SUMMARY AND DISCUSSION

A portable first-aid fire extinguisher, which uses water improved by the addition of a wetting agent, has been developed and demonstrated at NRL for use under conditions likely to be encountered aboard submarines. The operating force is supplied by compressed air contained in the same tank that holds the extinguishant. The extinguisher was tested on solid and liquid combustibles, and the hazard of its use on electrical equipment was also evaluated.

In extinguishing standard laboratory test fires in solid fuel, it was found that the best method of applying the extinguishant was through the use of a stream of coarse droplets. This form was slightly more effective than a solid stream and much more effective than streams approaching a broad mist. The addition of a wetting agent to water reduced the amount of liquid required to extinguish the test fires by one-third.

Because the cotton waste employed in these tests as a fuel resisted wetting and penetration by the extinguishant, its use imposes as severe a task on the extinguishant as any material likely to be found aboard ship. Cotton waste, however, is approximately matched by bedding and baled cloth. The extinguisher should be notably more effective on fires in loosely packed combustibles.

The same extinguisher, nozzle, and wetting agent that were the most effective on burning solids were also effective on a burning pool of diesel oil. Tests on these fires show that the extinguisher would be eminently suited to the extinguishment of fires involving oil which, though small in amount, is spread over a relatively large area, such as could be the result of leakage in fuel lines. Even deeper pools of burning oil could be extinguished provided the extinguishant was applied before the body of oil had sustained much rise in temperature.

Fires involving cooking fats were also satisfactorily extinguished, but it was necessary to take suitable precautions against spattering caused by an excessive use of the extinguishant.

The measurement of electric current flowing from a charged conductor through the stream of extinguishant to the nozzle showed the hazard of electric shock to be surprisingly low, even when potentials as high as 950 volts were used. It is generally accepted that a current of at least 1 milliampere must pass through the human body to be felt, that 5 to 10 milliamperes are required to cause loss of muscular control, while 30 is likely to be fatal. In none of the tests did the current between conductor and nozzle reach 1 milliampere when the nozzle was held 4 or more inches away. As this distance was decreased below 3 or 4 inches, however, the current began to rise rapidly. This safe distance might be insured by equipping the nozzle with a nonconducting fender. In the actual use of the equipment, the current would be divided between the apparatus and the operator; therefore, the foregoing values are the maximum to which the operator could be subjected.

Although tests made to determine the amount of current flowing over the face of a simulated live-front switchboard are not intended to be applied proportionally to a full-scale switchboard, they should give some idea of the current flow that might be expected. Certainly, the amounts of current measured in the tests could be increased many hundredfold without overloading even a low-capacity power or lighting circuit. Probably more consideration should be given to the possible malfunction of relays and other components that require only about an ampere or less for operation. Quantitative information can be obtained only by tests on a full-scale switchboard.

The results of this investigation indicate that a spray-type first-aid fire extinguisher should have a wide field of usefulness and in many cases could replace the more limited types now in use. With the exception of the wetting agent, which constitutes only a small portion of the extinguishant, all materials necessary to recharge the extinguisher, i.e., water and compressed air, are readily available aboard ship and no special tools or equipment are required in the process.

This investigation should be augmented by tests on full-scale counterparts that represent the compartments and equipment of naval vessels.

* * *

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