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Study of the Ignition Inhibiting Properties of Compressed Air Foam

Daniel Madrzykowski

U.S. DEPARTMENT OF COMMERCE
Nationl Institute of Standards and Technology
(Formerly National Bureau of Standards)
Center for Fire Research
Gaithersburg, MD 20899

October 1988

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ABSTRACT

This report describes an initial step to quantify the effectiveness of water-based compressed air foam (CAF) generated with a synthetic hydrocarbon-based surfactant. Two series of tests were conducted with the synthetic hydrocarbon surfactant based CAF: ignition retardation tests and mass retention tests. The ignition delaying capability of the foam was twice that of water when protecting a T1-11 plywood surface irradiated from an external source in the range of 15 kW/m^2 to 60 kW/m^2. The mass retention test, conducted on T1-11 plywood siding, exhibited an initial retention efficiency for the foam of approximately 20 times the efficiency of water. This type of foam may have potential for improving performance of fixed fire suppression systems, such as residential sprinkler systems. Further study is recommended to generalize the results of these tests and to quantify the extinguishing capabilities of the CAF relative to water.

Key Words: compressed air foam (CAF); foam; foam generator; ignition inhibiting; mass retention; residential sprinkler systems; retention efficiency; surfactants.

1.0 INTRODUCTION

Two recent developments in foam technology have stimulated the interests of firefighters and fire agencies across the country and around the world. The first technological breakthrough was the development and use of the compressed air foam system (CAFS) by the Texas Forest Service in 1977. This type of foam generator creates mechanical foam by injecting compressed air into a solution of water and foaming agent while it is being pumped through a hose. Dependent on the foaming agent and the CAFS's capabilities, the water-foaming agent solution may be expanded up to 50 times the original volume [1]. While this system is effective for increasing the amount of fire fighting material available from a limited water supply, it did not alleviate the problem of carrying large quantities of foaming agent. At that time, commercially available foaming agents had to be mixed at concentrations of 3 to 6 percent or 3 to 6 gallons of foaming agent for every 100 gallons of water.

The second development was a new type of synthetic hydrocarbon surfactant foaming agent that was introduced in Canada in 1985. The recommended concentration for foaming solutions with this agent is 0.3 to 0.7 percent, reducing the amount of the agent required by a factor of 10. Currently four foaming agents of this type are commercially available and qualified under the United States Department of Agriculture interim requirements for wildland fire foam [2].

The Bureau of Land Management (BLM), the U.S. Forest Service (USFS), the Texas Forest Service and a few municipal and state fire agencies have combined the advantages of these recent developments and have built CAFS units to generate synthetic hydrocarbon-based foam (Figure 1). Operational experiments have been conducted on both the CAFS and the foaming agents by the BLM and the USFS [1]. Initial firefighter testimonials indicate that the foam is superior to water in a variety of forest fire fighting situations as well as in structure protection.[3]

It seems that this new generation foam may have potential uses in other fire suppression systems, such as improving the performance of residential sprinkler systems, and especially in self-contained systems which have a fixed water supply held in a tank. These systems are used primarily in areas with low domestic water supply pressures. This study was undertaken as an initial step in evaluating that potential.

This report describes an initial step in an effort to evaluate the capabilities of CAF for use in residential sprinkler systems. This study was limited to the ignition inhibiting properties of CAF although other factors need to be evaluated to fully assess CAF's capabilities for use in residential sprinkler systems. Two types of tests were conducted; an ignition inhibiting test and a mass retention test. In both cases a vertically oriented sample was used to simulate foam application to a wall.

2.0 EXPERIMENTAL APPROACH

2.1 Foam Generating Apparatus

To enable the study of the synthetic hydrocarbon surfactant foam (hereafter referred to as the foam) a laboratory scale foam generator was constructed, since a field operational CAFS unit is not suited to the laboratory environment. After several iterations, the design of the foam generator evolved into a unit similar to a Water Expansion System (WES), a predecessor of CAFS. The components of the foam generator are; a pressure vessel, a compressed gas cylinder, flow meters, a mixing tee, an improver (mixing device) and hose (Figure 2). An improver was required since the natural turbulence in the hose of the lab foam apparatus was insufficient to produce the same quality of foam used in the field. The improver is similar to the one built by Fry and French in 1951 [4] (Figure 3). When used in conjunction with a 12 m (40 ft) length of 5 mm (3/16 inch) diameter tubing, it provides foam representative of that used in the field with an expansion capability up to 20.

2.2 Test Methods

Since the performance of the foam is dependent on its characteristics, the following characteristics were fixed in this study:

- A 0.3% foaming agent concentration was used in all of the tests. This is within the manufacturer's recommended range for ground application.

- Only one brand of foaming agent was used. It is representative of the commercially available foaming agents of this type.

- A foam expansion of 14 ± 1 was used for all of the tests.

- All of the tests were performed on 152 mm (6 inch) square specimens of T1-11 siding material (conditioned to constant moisture content at a temperature of 23 ± 2 °C (74 ± 4 °F) and a relative humidity of 50 ± 10%). T1-11 is a textural exterior plywood, which is composed of southern pine and phenolic adhesives.

2.3 Ignition Retardation Test

The ignition retardation tests were performed on the Lateral Ignition and Flame Spread Test (LIFT) apparatus [5]. The key component of this device is a gas fired radiant panel (Figure 4). Prior to testing, the apparatus was calibrated as specified in "New Concepts for Measuring Flame Spread Properties" [5]. This test was performed by exposing a vertically-oriented sample to constant and nearly uniform irradiation from the radiant panel and recording the time until piloted ignition. This test simulates a wall exposure situation. The heat flux from the radiant panel was varied from 60 kW/m^2 down to a flux where ignition would not occur. Testing in this fashion yields a curve of time to ignition versus the heat flux. To find a basis on which to gauge the foam's performance, 4 treated samples were tested at each flux level. The treatments are as listed below:

1. Untreated T1-11

2. T1-11, test surface sprayed with approximately 9 ml (3 fl. oz.) of water.

3. T1-11, test surface sprayed with approximately 9 ml (3 fl. oz.) of water and 0.3% foaming agent (unfoamed).

4. T1-11, test surface covered with a 6 mm (1/4 in.) blanket of foam. The 6 mm (1/4 in.) thick foam cover contains approximately the same amount of water as in treatments 2 and 3.

The quantity of water to be used was determined empirically by observing the amount of water the T1-11 surface would hold without dripping, when oriented in a vertical position. At 9 ml, no dripping from the sample occurred. It should be noted that the samples were treated in a horizontal position and then immediately (under 10 seconds) oriented vertically and positioned in the LIFT apparatus (Figure 4). A set of the treated samples was tested at the following heat flux levels; 60, 50, 41, 30, 25, 20 and 15 kW/m^2. The time to ignition was recorded for each sample.

2.4 Mass Retention Test

The scenario represented by this experiment is that of foam application to a wall. A vertically oriented T1-11 sample, of known mass, was subjected to a constant flow rate stream of water applied to its textured surface for a fixed amount of time. Immediately after the application period, the sample was weighed to determine the amount of water which remained with the sample. With a new sample placed in position, the test was repeated for a longer period of time. This cycle was repeated until the sample's change in weight was negligible. The test sequence was then repeated applying foam to the sample instead of water. This experiment provides an indicator as to the efficiency of application of foam to a vertical surface.

3.0 RESULTS AND DISCUSSION

3.1 Ignition Retardation Test

The ignition retardation tests were performed over a heat flux range which represents heat flux exposures associated with a developing room fire, 15 kW/m^2 (panel temperature ≈ 440 °C (830 °F)), up through a fully developed room fire, 60 kW/m^2 (panel temperature ≈ 740 °C (1370 °F)). The results are shown in Figure 5.

To study the overall effectiveness of the various treatments, relative comparisions of ignition times were made. Using the ratio of ignition times (water/untreated), at the same radiant flux, Figure 6 exhibits the effectiveness of water in delaying ignition of the Tl-11 plywood siding. At low radiant flux exposure, the water increased the time to ignition by about 20 percent. At higher radiant flux exposures the time to ignition was doubled. The reasons for the difference in behavior at low and high incident radiant flux are unknown.

The effectiveness of the foam, and the unaerated water-foaming agent solution were determined relative to the ignition times for the water treated plywood siding. Figure 7 shows the relative performance of the unaerated water-foaming agent solution compared with water as the ratio of ignition times (water+/water). The data show considerable scatter. The average of the entire data set is approximately 1. This means that on the average there is no increase in the ignition delay for unaerated water-foaming agent solution over that provided by plain water treatment. It may be significant that there was a decrease in ignition time for the unaerated water-foaming agent solution compared to plain water at the lowest radiant flux exposure measured (15 kW/m^2). In the two measurements performed, the plywood siding treated with the unaerated water-foaming agent solution ignited in half the time required for the water treated siding. The reasons for this behavior are not clearly understood. As unaerated water-foaming agent solutions may be used in the field, this detrimental performance with regard to ignition retardation should be investigated further.

Figure 8 shows the relative performance of the foam compared with water, as the ratio of ignition times (water/foam). The average of the entire data set is approximately 2. This indicates that on the average, the foam treatment yielded ignition delay times twice as long as the delay provided by the water treatment. It should be noted that the layer of foam used in these tests was thin (6 mm) to enable the direct comparision of the foam relative to water on a mass basis. In practice, the foam is applied liberally, yielding a thicker coating of foam than those used in the ignition inhibiting tests. A thicker coating of foam, with a similar expansion ratio, on a surface means more water mass is retained by the surface, possibly furthering the foam's capability to inhibit ignition. The amount of foam or water that could be retained by a sample in a specific time period was investigated in mass retention tests.

3.2 Mass Retention Test

The mass retention test was performed with a water mass flow rate of 760 grams per minute (gpm) and a foam flow rate of 190 gpm. The water application rate was set at 760 gpm, which was the lowest value capable of delivering a steady water stream from the unit. This meant that the mass flow rate of water being applied to the sample was 4 times the mass flow rate of the foam. The initial measurements were performed after 5 seconds of application time. The plot for water in Figure 9 represents the averages of the three water tests, with the exception of the 60 second water test for which only one trial was conducted. Since measurements were only taken at two time periods for the foam, the data points are shown without a curve fit. The initial fraction of water mass retained by the sample, after 5 seconds of application, was 0.045. This was determined by dividing the average mass gain by the mass applied (the product of flow rate and time) {2.9g/[(1/12 min)(760 g/min)]}. The initial percentage of foam retained by the sample was calculated in the same way and yielded 0.88 {14g/[(1/12 min)(190 g/min)]}. This represents an initial retention efficiency for foam approximately 20 times greater than plain water. Prior to the initial measurement at 5 seconds the foam treated sample had reached its virtual steady state weight. The foam applied after the initial coating of the sample simply sheared off, leaving a residual foam layer approximately 12 mm (1/2 in.) to 19 mm (3/4 in.) thick on the sample. After 60 seconds of application time, the water sample still yielded a slight weight gain. The water weight gain after 60 seconds was 72% of the weight gain of the foam treated sample at 5 seconds (Figure 9).

4.0 CONCLUSIONS

A 6 mm (1/4 inch) thick layer of foam exhibited an ignition-inhibiting capability twice that of an equal mass of water for T1-11 plywood siding irradiated from an external source. The synthetic hydrocarbon surfactant-based CAF displayed a retention efficiency approximately 20 times the efficiency of water on the test samples. Considering the results of both the tests, water in the form of foam should be more efficient than plain water at retarding the ignition of combustibles in room fires. Foam could be beneficial for use in residential sprinkler systems, especially residential sprinkler systems that draw on a small, tank held water supply.

5.0 RECOMMENDATIONS FOR FURTHER STUDY

To evaluate fully the potential use of this technology in residential sprinkler systems, the direct extinguishing capabilities of the foam relative to water spray must be studied. Further testing must be performed on different materials to generalize the results of the ignition inhibition tests, mass retention tests and any future fire extinguishment tests. In addition, understanding of the basic physical processes involved in the action of the foam for ignition inhibition and fire extinguishment should be addressed to determine the generality of findings and to allow optimal use of the agent.

6.0 ACKNOWLEDGEMENTS

Appreciation is extended to David Evans, Margaret Harkleroad, Roy McLane, Gary Roadarmel, David Stroup and Bob Vettori of the Center for Fire Research and to Ron Rochna and Paul Schlobohm of the Bureau of Land Management for their assistance in the performing of this study. Appreciation is also extended to Ed Wall, Roger Lanahan and Tom Smith of the U.S. Fire Administration for their support of this project.

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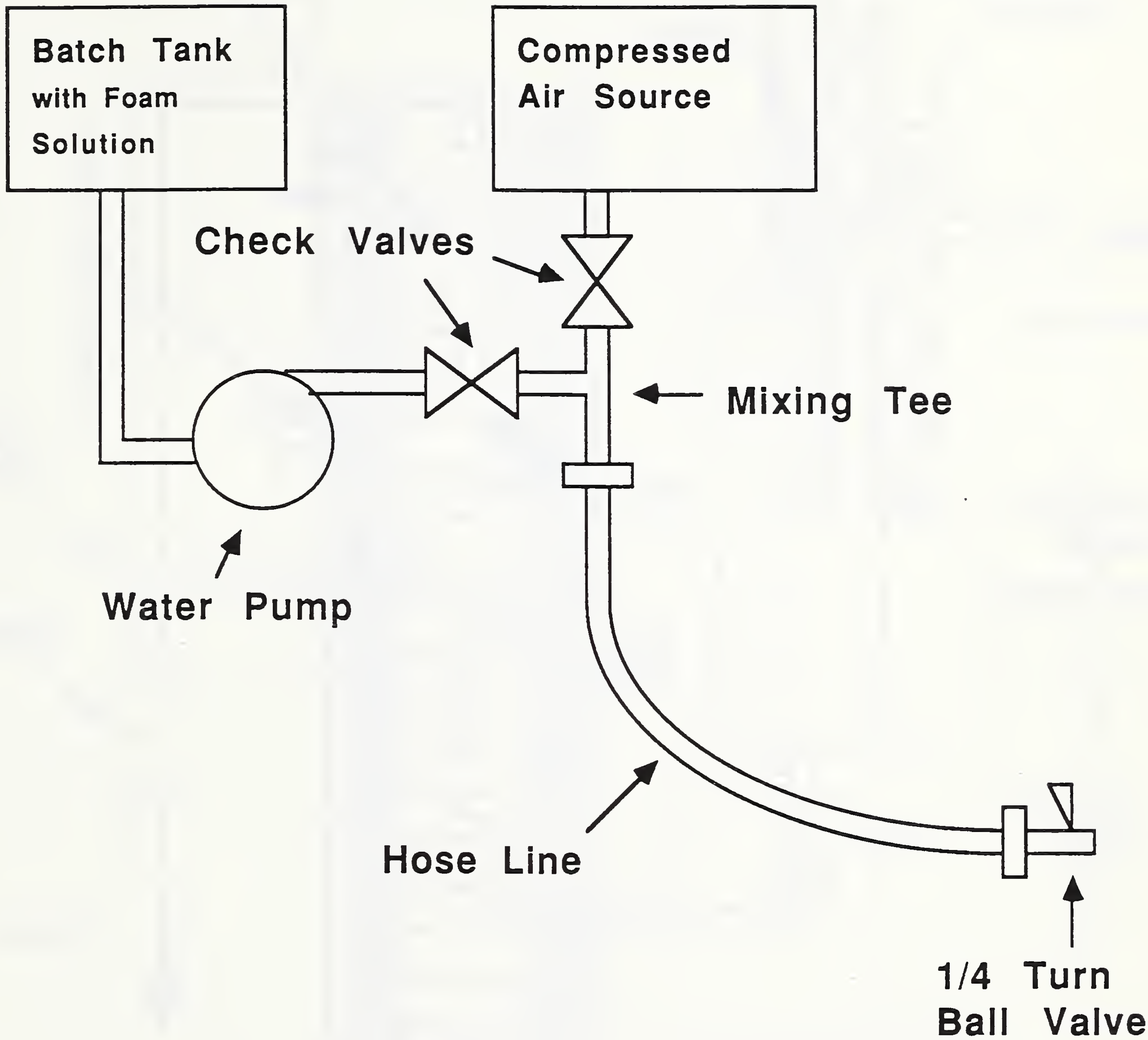


FIGURE 1. BASIC COMPRESSED AIR FOAM SYSTEM

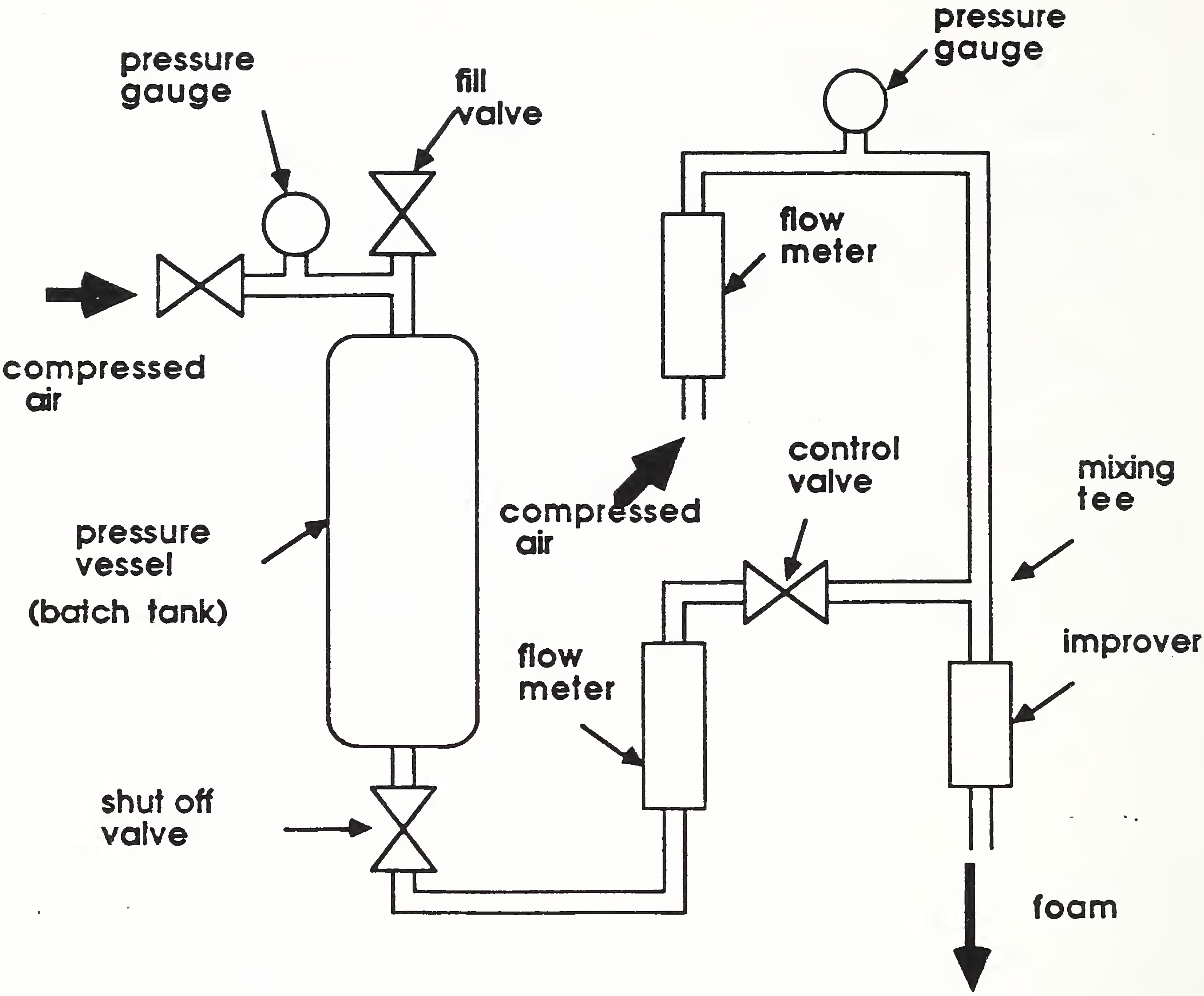


Figure 2. Laboratory foam generator

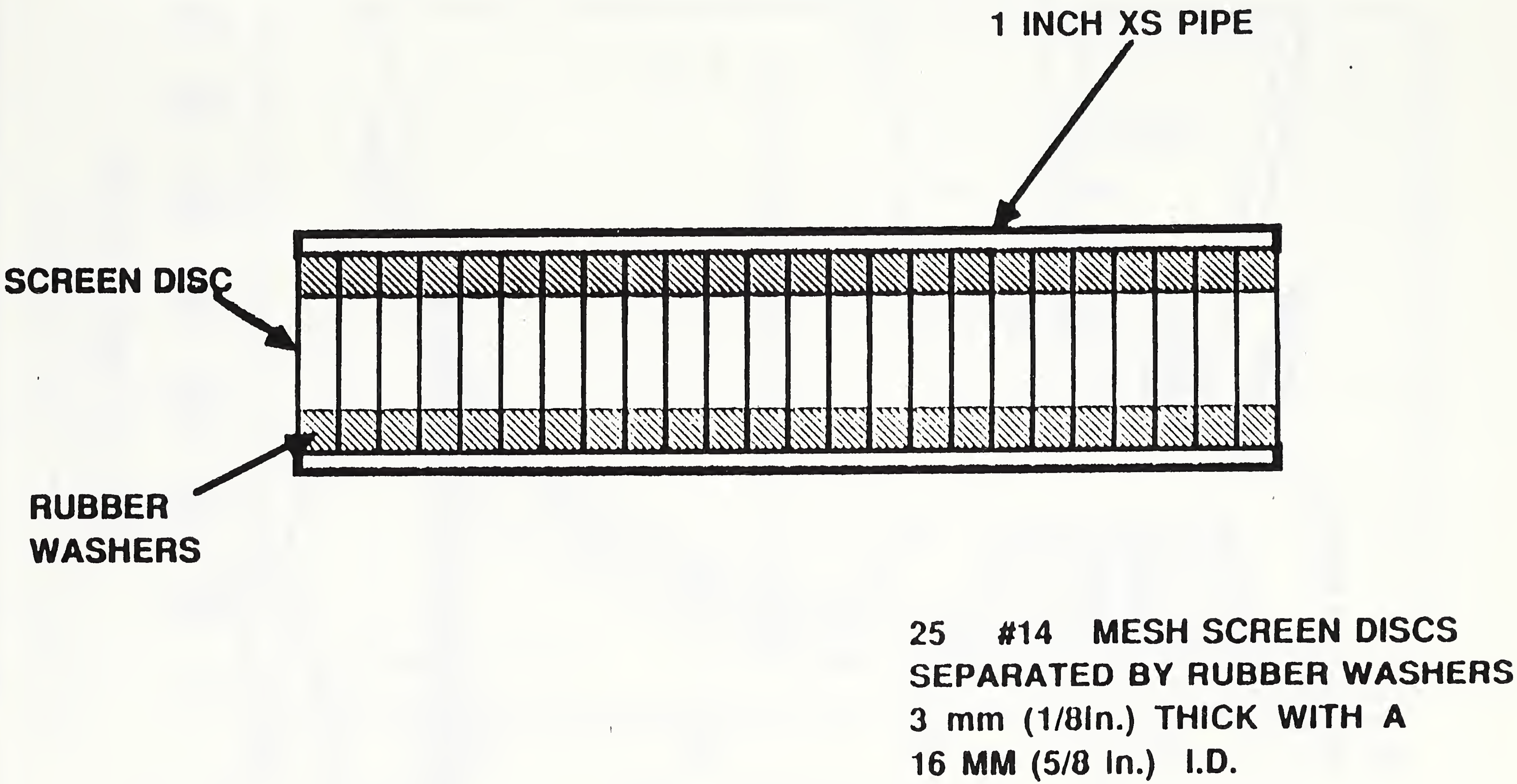
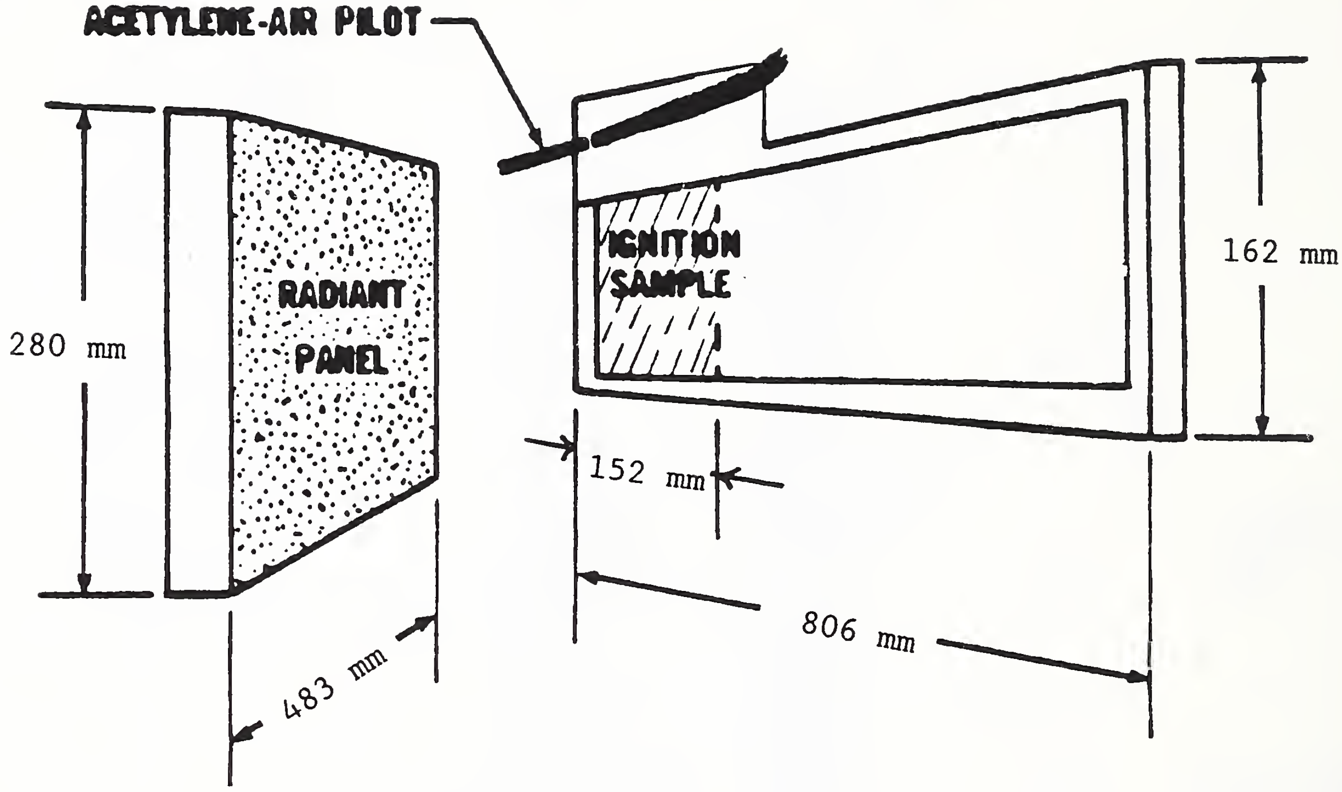
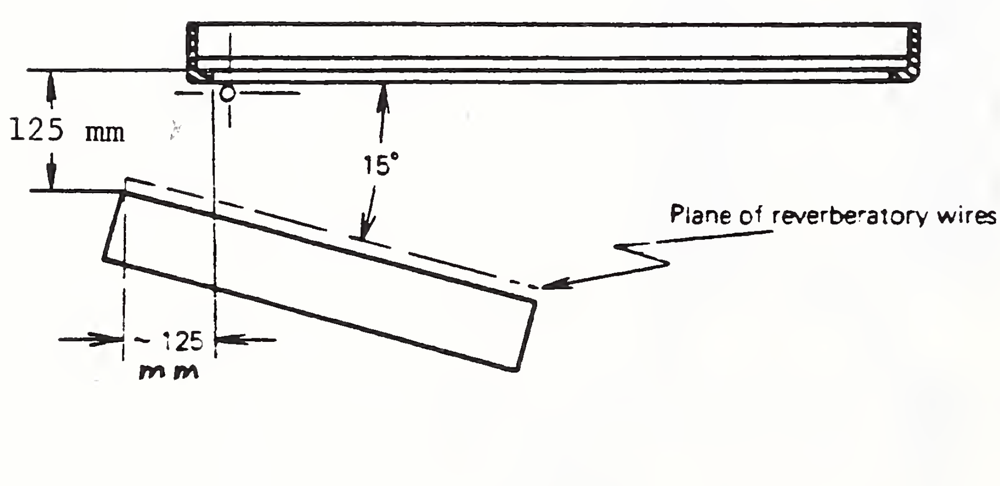


FIGURE 3. SCHEMATIC OF IMPROVER



Schematic of Apparatus with Ignition Specimen



Plan View of Specimen - Panel Arrangement

FIGURE 4. SIDE VIEW AND PLAN VIEW OF RADIANT PANEL AND SPECIMEN ARRANGEMENT

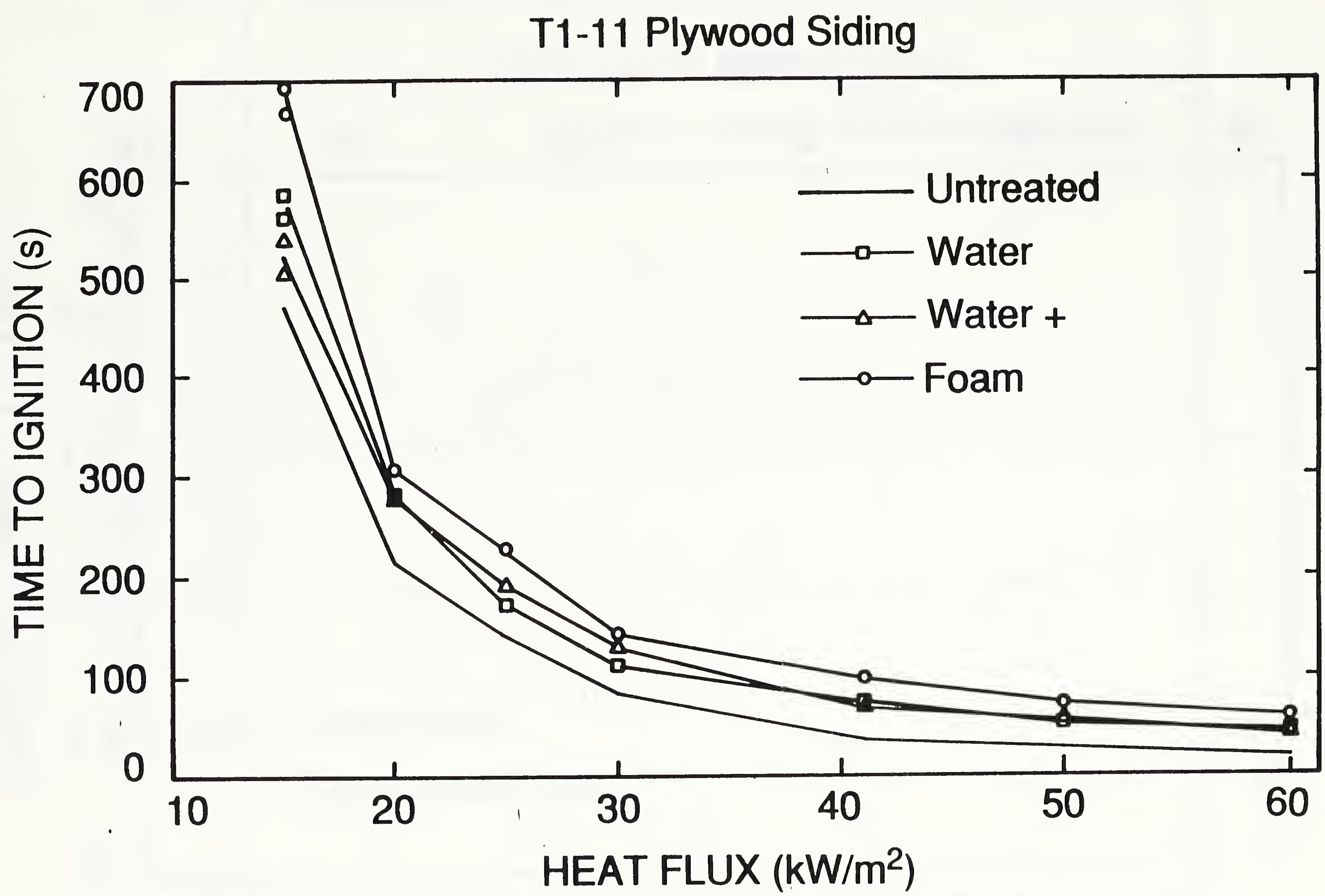


FIGURE 5. TIME TO IGNITION CURVES FOR T1-11 PLYWOOD SIDING

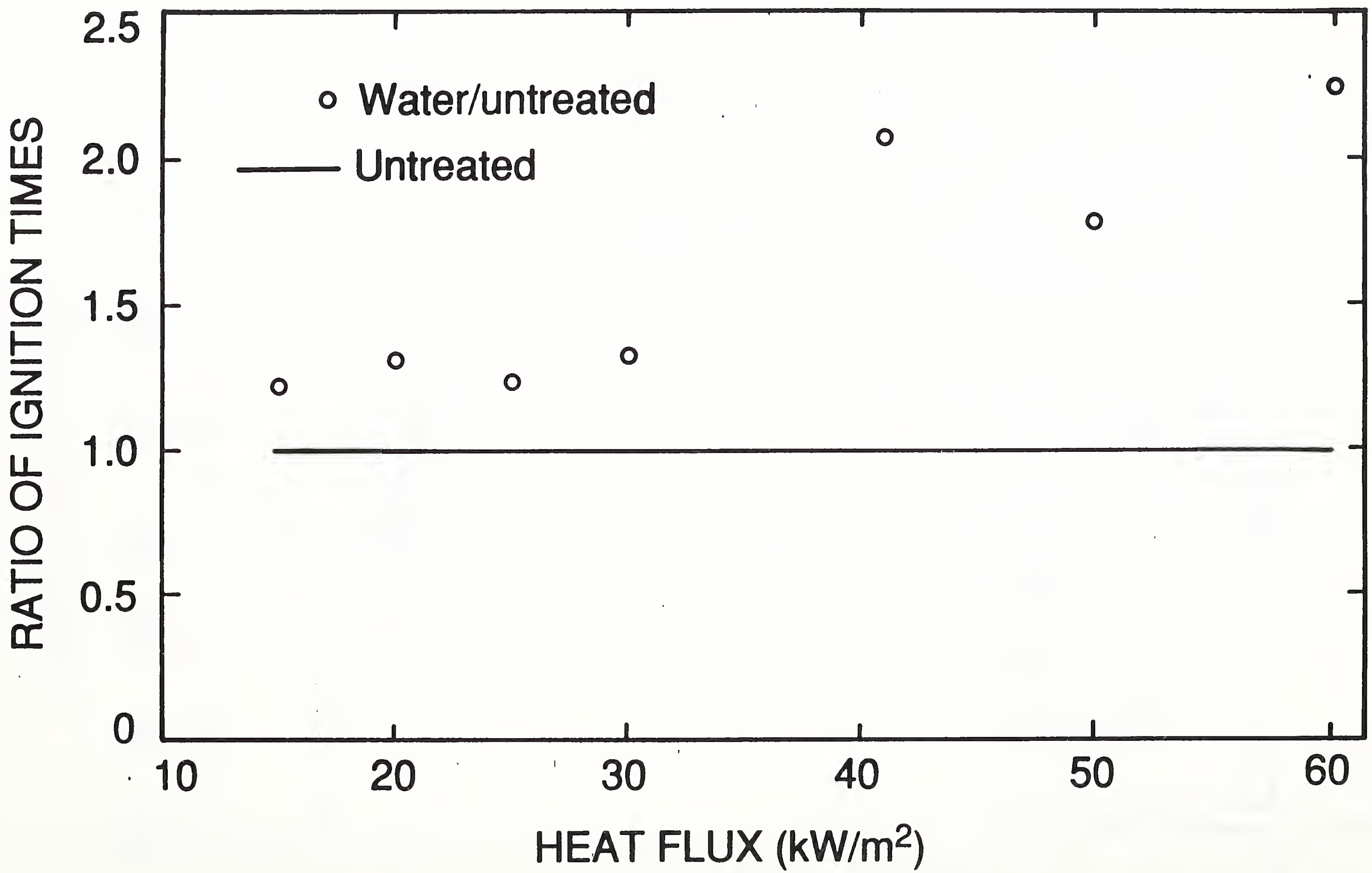


FIGURE 6. EFFECTIVENESS OF WATER IN DELAYING IGNITION OF T1-11 PLYWOOD SIDING

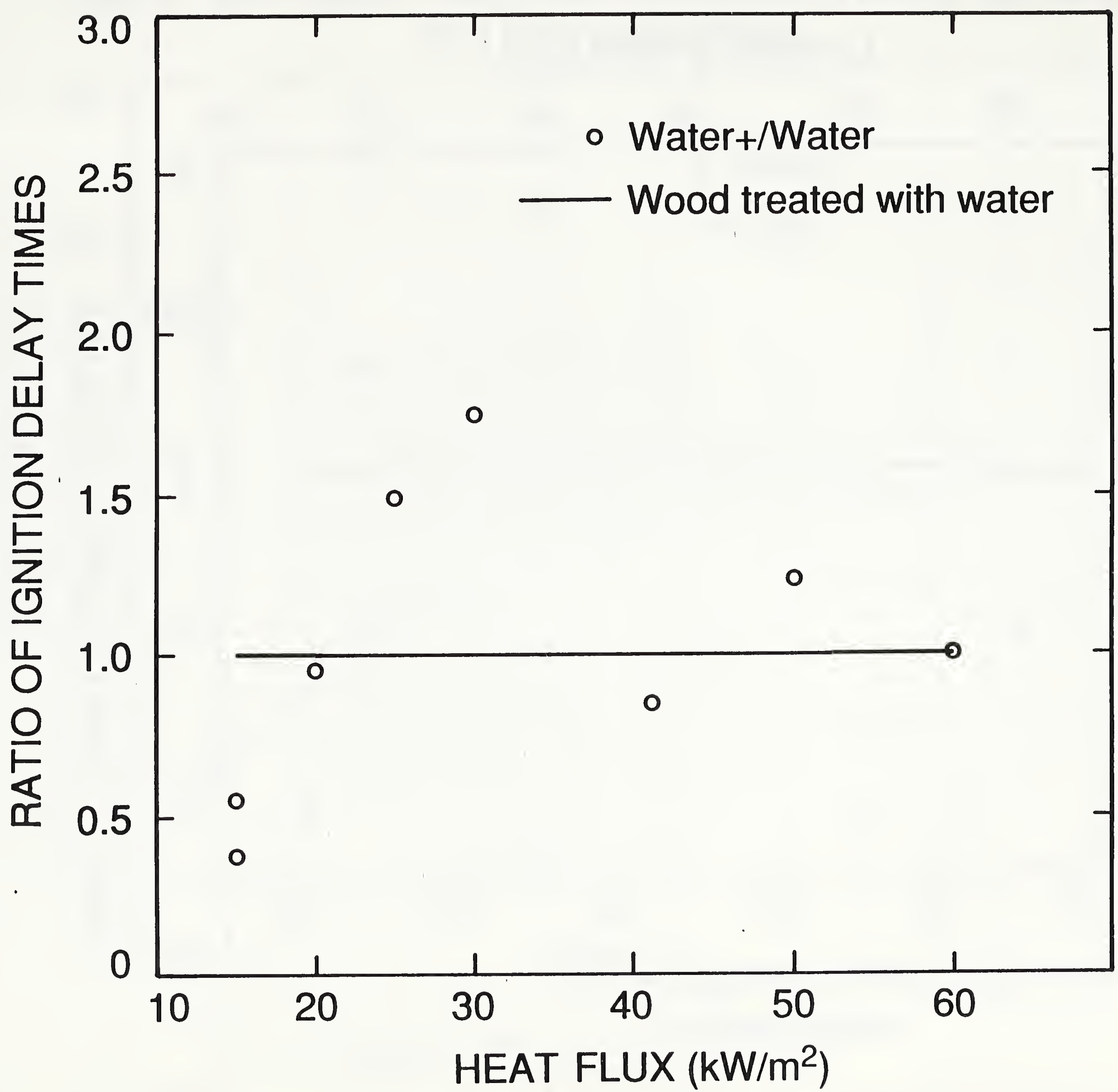


FIGURE 7. EFFECTIVENESS OF UNAERATED WATER-FOAMING AGENT SOLUTION RELATIVE TO PLAIN WATER IN DELAYING IGNITION OF T1-11 PLYWOOD SIDING

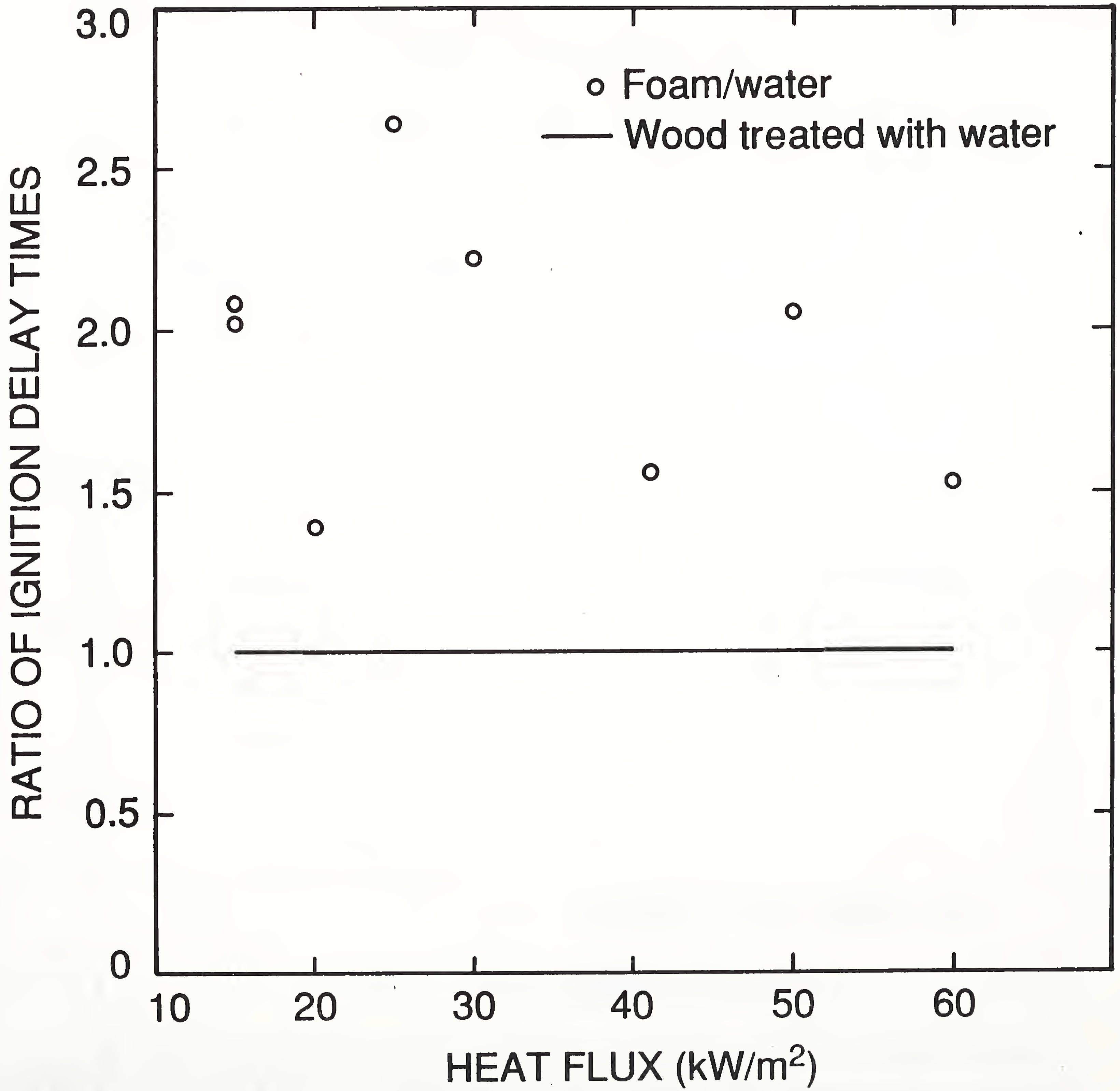


FIGURE 8. EFFECTIVENESS OF FOAM RELATIVE TO PLAIN WATER IN DELAYING IGNITION OF T1-11 PLYWOOD SIDING

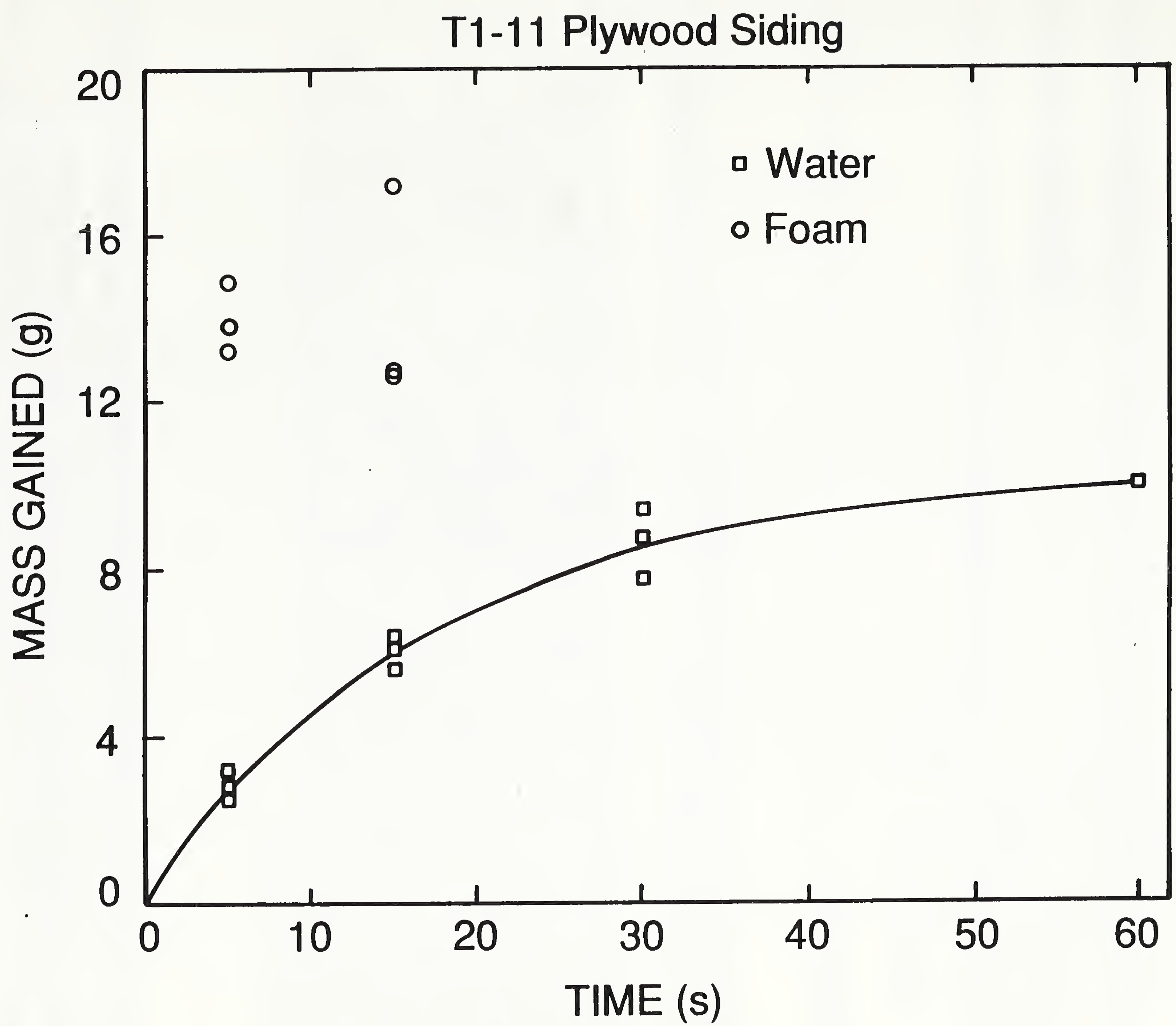


FIGURE 9. MASS RETENTION TEST RESULTS

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This report describes an initial step to quantify the effectiveness of water-based compressed air foam (CAF) generated with a synthetic hydrocarbon-based surfactant. Two series of tests were conducted with the synthetic hydrocarbon surfactant based CAF: ignition retardation tests and mass retention tests. The ignition delaying capability of the foam was twice that of water when protecting a T1-11 plywood surface irradiated from an external source in the range of 15 kW/m^2 to 60 kW/m^2. The mass retention test, conducted on T1-11 plywood siding, exhibited an initial retention efficiency for the foam of approximately 20 times the efficiency of water. This type of foam may have potential for improving performance of fixed fire suppression systems, such as residential sprinkler systems. Further study is recommended to generalize the results of these tests and to quantify the extinguishing capabilities of the CAF relative to water.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

compressed air foam (CAF); foam; foam generators; ignition; mass retention; residential building; sprinkler systems; retention efficiency; surfactants

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