Severe Laboratory Fire Test for Fire Fighting Foams

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A small-scale laboratory fire test has been developed to replace costly and air-polluting large-scale field fire tests that are used to evaluate reliability of fire fighting foam formulations.

FIRE FIGHTING foams are employed extensively in the suppression of Class B pool fires. Historically, reliability has been established and maintained through extinguishment tests. Because such fires are complex and much remains to be understood about their behavior, faith in results has tended to increase with the size of the test fire. Certification of agents by government and independent testing laboratories and quality conformance by the manufacturers have been based on test size, generally ranging from 28 ft^2 to 100 ft^2.

Inherent problems of this approach are (1) the notorious amount of smoke produced, which is causing air pollution control agencies to restrict such fires; (2) the costly amount of fuel, labor, and the agent itself; and (3) the large experimental error due to environmental conditions, operator techniques, and variability in application equipment.

Our objective has been to develop test procedures and equipment that minimize the problems of pollution, cost, and uncontrolled variables in tests suitable for quality control, certification, and the evaluation of new foam formulations.

The approach focused on reduced-scale modeling of large pool fires in which the hostile environment of the accidental fires could be generated in a modest laboratory sized burn. In scope, the study examined the importance of (1) the type, geometry, and amount of the fuels; (2) atmospheric parameters, such as the available air and its motion; and (3) environmental factors, such as substrates and structures that control the configuration of the fuel and serve as heat sources and sinks.

CURRENT FIRE TESTS

We are concerned with hot tests and the three general kinds of information they provide about foam — the ability to control and extinguish a fire, the ability to seal in vapor and prevent reignition, and stability in the presence of contiguous flames. Some currently used shallow and deep pool tests of various sizes are in accordance with standards set forth by various regulatory agencies. All have several of the weaknesses that we propose to eliminate, i.e., expensive, polluting, highly dependent on operator or environment, not reproducible, not realistic.

BURNING RATE

Normally, the burning rate equals the rate of fuel evaporation, which, in turn, provides the challenge to the foam's ability to seal the fuel surface. Ideally, this challenge should remain constant in standard fire tests or be a controlled variable in development research. Table 1 shows that, with free-burning pool fires, the burning rate varies considerably; therefore, it appears desirable to exercise positive control over this parameter. Burning rates for fuels that burn with luminous flames generally increase with pool size up to diameters of about 3 or 4 ft at which point radiative feedback from the flames becomes essentially constant.[1] This feedback is also sensitive to the plane geometry of the fire, which, in turn, is strongly dependent on the environment, particularly the wind.

Fires in the 1- to 2-ft range can be forced to burn at the large fire rate by augmenting the heat feedback from the combustion zone. This combination of a modest size fire and an auxiliary heater provides a simple laboratory size fire that can meet the burning rate stability requirements needed in the foam tests. The evaporation rate or burning rate should be measured prior to the application of foam in order to document the fire condition that was suppressed.

TABLE 1. *Examples of Pool Fire Burning Rate Data (lbs ft^{-2} min^{-1})*

	Data source							
Fuel	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Diesel				0.2 - 0.33				0.3
Ethanol					0.15			0.3
Gasoline	1.17	1.16		0.9				1.17
Hexane					0.44		0.98	1.0
JP4		1.1			0.20			1.1
JP5	0.74	1.0	1.1 - 1.3	0.22 - 0.24	0.12			1.0
Methanol			0.3 - 0.35		0.14 - 0.17	0.16	0.28	0.3
Naphtha								
Benzene				0.74 - 0.82			1.05	1.0
Toluene				0.47 - 0.5				0.5
Naval distillate				0.2 - 0.34				0.3
Acetone					0.22			0.4

1 = Cass, 25-ft by 35-ft pool
2 = Dr. Fu, 2-ft to 8-ft diameter pool
3 = Camp Parks, 10 ft diameter pool
4 = Alvares, 2-ft diameter pool
5 = Sealed compartment, 1.5-ft to 3-ft diameter pool
6 = Blackshear
7 = Burgess
8 = Values used in computations.

HEAT FLUX

The radiation field generated by a fire interacts with the foam both during the exinguishment and burnback tests. In the first case, one of the extinguishing mechanisms involves terminating the energy feedback from the combustion zone to the fuel by foam that absorbs and scatters the radiant energy. For small diameter fires in which the flames become relatively transparent, the radiant intensity will fall below the large fire value even if it were possible to maintain the view factor unchanged. In Reference 1, the simulated radiation field applied to the foam was used at intensities up to 5.4 Btu ft^{-2} s^{-1}. Therefore, values corresponding to real fire environments can be achieved if required for burnback tests.

FUEL TYPE

The selection of a test fuel involves a compromise because no single choice is ideal in all respects. Besides the impact on the fire characteristics, the fuel type affects the foam directly in several ways. First, the temperature, temperature distribution, and heat capacity determine the amount of foam required to cool the fuel to a temperature at which a foam blanket can form. Second, to form a stable foam blanket, the fuel surface must be cooled below the boiling point of water; therefore, the difficulty in sealing the vapors and the susceptibility to secondary foam formation depend on the fuel's evaporation rate at 212° F. Third, the foam spreading capability depends on the surface tension and the interfacial tension between the foam and the hot fuel. In some instances, a polar fuel may be needed for testing special foams formulated to protect such hazards.

Homogeneous fuels are the most attractive from the standpoint of reproducibility and stability because the composition, boiling point, and rate of evaporation per unit of energy feedback remain constant. However, gasoline was selected for the initial investigation to provide a basis for comparision to the existing tests, but a versatile test apparatus should permit foam tests as a function of the fuel.

FUEL GEOMETRY AND SIZE

For pools without a freeboard to collect heat that can be transmitted to the fuel, the burning rates should be independent of the modest geometrical changes in going from a circle to a square or rectangle. However, when large freeboards are present, the additional energy feedback can substantially enhance the burning rate, particularly in corners. From this standpoint, circular symmetry is preferable. The preferable geometry from the standpoint of foam application depends on the pattern employed to meet the needs of a particular foam property test. For example, in foam spreading tests, a rectangle would provide a longer spread-distance-to-fuel ratio than a square or circle, particularly when the agent is applied along one of the narrow sides. On the other hand, a rectangular or square pool with hot freeboards could be more difficult for the foam blanket to seal vapor tight than a circular counterpart. Similarly, the rectangular geometry could provide a long burnback-distance-to-fuel ratio as developed in Reference 11. In summary, geometrical effect appears to be minor; however, in foam spreads and burnback measurements, the rectangle was chosen for its convenience.

Foam application becomes a problem with very small fires; therefore, this factor appears to control size in the coverage, control, and extinguishment tests. These foam spread and burnback tests set a minimum size in the 1 to 2 ft^2 range.

ENVIRONMENTAL PARAMETERS

Two groups of parameters acting on the fire characteristics are (1) the amount and motion of the air and (2) heat sources and sinks. For example, a large freeboard can control air motion, serve as a heat sink at the start of the fire, and become a heat source after the metal heats.

An intuitive assessment made us choose to include the option of heating the freeboard, but to ignore simulating air motion. Air motion is a major difference between the larger test fires and the laboratory simulation.

FOAM PRODUCTION AND APPLICATION

The guiding philosophy is to minimize the effects of the generating equipment and the application techniques. Variables that are readily controlled during foam production include the agent, concentration, and expansion ratio. To a lesser degree, some control can be exercised over bubble size and uniformity. These variables are of concern because they control properties that are vital to foam performance but are difficult to control or measure during the brief foam formation process, i.e., fluidity, viscosity, and stability or drainage rate. Precise concentration control can be achieved by using a premixed solution, and a uniform water temperature and purity contribute to reproducible physical properties.

The foam application variables of concern are the application rate, pattern, and density. Test application rates frequently match the specific ap-

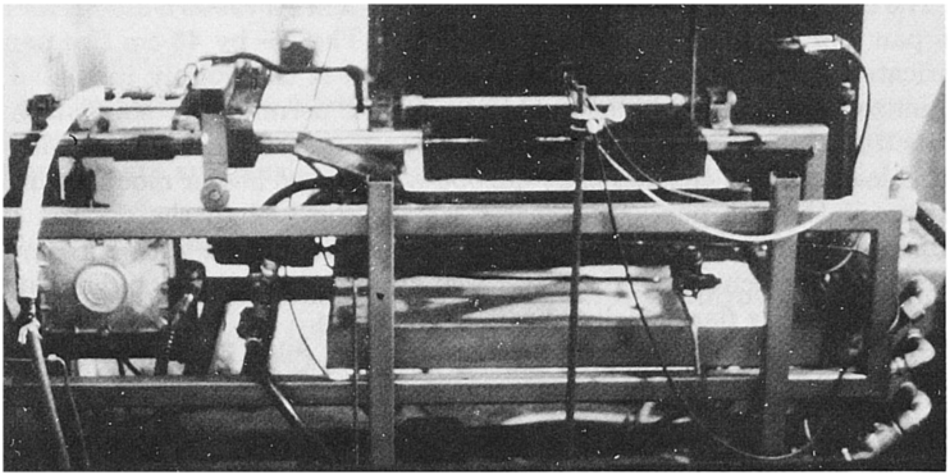

Figure 1. Laboratory test stand.

plication rates recommended for foam suppression of real tank fires, e.g., 0.06 gpm ft^{-2}. If only the size factor were involved, all test areas would be covered in the same time interval. However, coverage, control, and extinguishment times depend on the mode and pattern of application. Three general patterns are employed in the surface mode of application — total flooding as with built-in sprinkler systems; incremental coverage as is commonly achieved with a handline; and single point application as is employed in portable towers, fixed outlets, and also in subsurface injection. Total flooding and incremental patterns can achieve total coverage in a specified time, irrespective of the foam's flow properties. Coverage with the single point application, however, is very sensitive to foam fluidity, and it is very difficult to estimate performance in a 100-ft diameter tank from a 1-ft diameter fire test. Consequently, for testing such foam properties as the critical application density for extinguishment or control, sealability, and burnback resistance, either the total flooding or incremental patterns are preferable. The latter was chosen as the most practical for a small-scale application.

Application densities are usually specified in terms of application time at a specific application rate. Consequently, the rate control usually determined the accuracy of this measurement. Since the application density markedly affects all of the evaluation parameters, it is important to ensure either reliable rate measurements or an independent determination of total foam applied.

APPARATUS

The apparatus can be broken down into three main sections — the test stand, which includes the fire pan; the foam generator; and the control console, which provides power and contains monitoring instruments.

TEST STAND

The test stand is constructed of Unistrut® and serves as a mount for the fire pan and auxiliary equipment (Figure 1). The 15- by 45-cm fire pan is fabricated from light gage stainless steel and is thoroughly insulated to minimize heat losses. A removable freeboard permits the simulation of either a shallow pool or a tank fire. The specific burning rate is monitored with a load cell and controlled by a 2,000-watt calrod heater mounted in the bottom of the fire pan. This heater warms the fuel to the desired test temperature prior to ignition. Evaporation is controlled with a remotely operated lid, which fits into a water seal around the fuel pan and exhausts vapors through a flare stack for safe combustion.

Remotely activated electric igniters and gas pilot lights provide safe, positive ignition for the flare stack and ignite the entire pan when the lid is opened.

The foam applicator is mounted on a mobile carriage, which can traverse the length of the pan at a predetermined speed for the incremental mode of application. A stepping motor drives the carriage, which, in turn, is controlled by an indexer on the control console. Fixed point application is simulated by stopping the carriage at the front edge of the fire pan.

THE FOAM GENERATOR

The foam generator is a laboratory type similar to that shown in Figure 2. It consists of air regulators, airflow controller and rotometer, a flow meter and needle valve for liquid flow control, and a mixing chamber. The generator produces foam of similar quality to that produced by a National 2-gpm test nozzle.

By adjusting the liquid flow, we can carefully control foam application rate. The desired expansion ratio is achieved by adjusting the airflow.

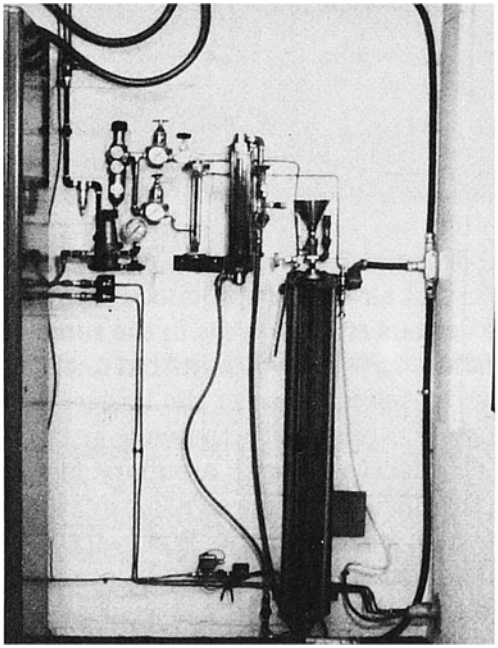

Figure 2. Foam generator.

CONTROL CONSOLE

The control console allows operation of the test stand from outside the fire room for the sake of safety and comfort. It provides and controls all power outputs and receives all input signals (Figure 3).

EXPERIMENTAL RESULTS

So far, the apparatus has been used only for fire control and extinguishment tests without the freeboard panel extensions. These current tests are concerned with two factors — establishing the laboratory fire intensity required to challenge the foam to the same degree as the conventional test fires and determining the reproducibility of the laboratory tests.

In the simulation test, the agent served as the yardstick for the comparison of the laboratory burner fires and the 50- and 100-ft^2 pool fires.

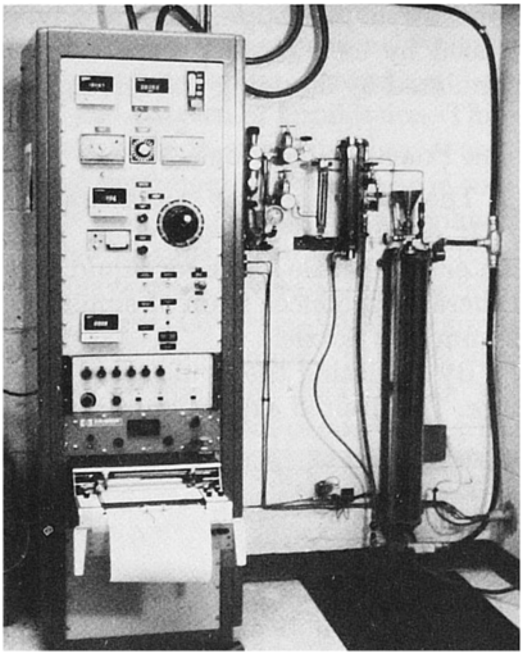

Figure 3. Control console.

Premixed foam with the same physical properties (i.e., expansion ratio and drainage rate) was applied to all three fires at a rate that produced the same theoretical application density over the various surface areas in the same interval of time. The burning rate of the laboratory fire was adjusted until the control times and extinguishment times matched those of the larger fires. In all cases, the temperature of the gasoline was essentially the same, namely, the boiling point, but the evaporation rate increased with auxiliary power. For example, without auxiliary power, the burning rate was 8.2 g m^{-2} s^{-1} or about 12 percent of the large pool specific burning rate. With auxiliary power, the burning rate followed the exponential relationship

$$\ln R_b = (8.1 \times 10^{-4})\, P + 2.1$$

where R_b is in g m^{-2} s^{-1}, and the power, P, is in watts. A similar expression was obtained for the fire intensity indicated by the radiation field and measured with the radiometer, i.e.,

$$\ln H = (2.6 \times 10^{-4})\, P + 2$$

where H is in Btu s^{-1} m^{-2}. With the maximum auxiliary heating rate of 1.9 kW, it was impossible to extinguish the fires unless the power was drastically reduced during the foam application. For example, in tests with fluoroprotein liquids in a 3 percent concentration applied at a rate of 0.261 ml min^{-1} cm^{-2} (0.06 gpm ft^{-2}), the 100-ft^2 OF-555c tests were satisfactorily reproduced by reducing the auxiliary power to 830 watts at the start of foam application and to zero at the 95 percent control time. Figure 4 shows a typical

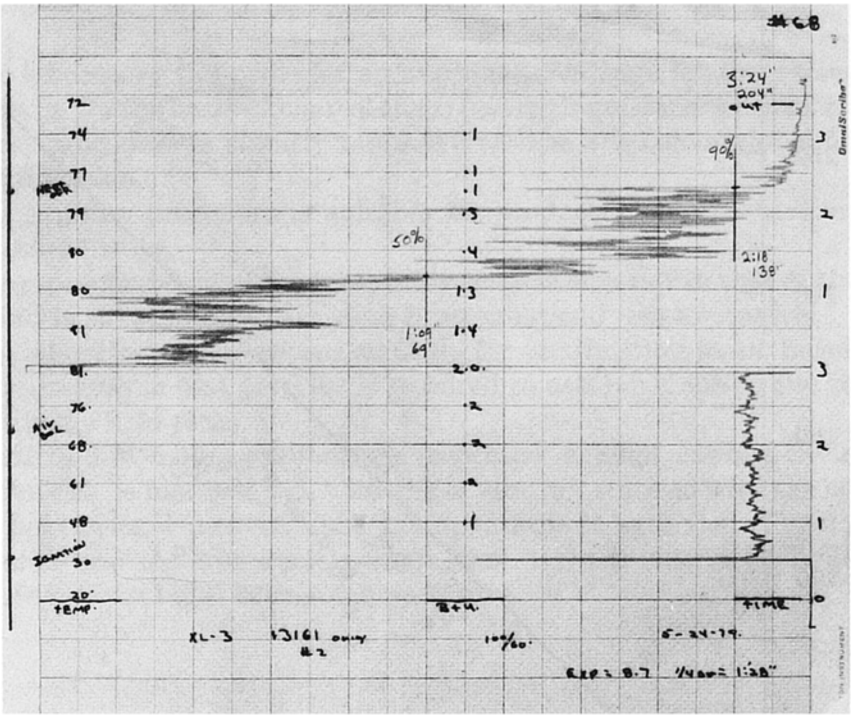

Figure 4. Typical radiometer record made during an extinguishment test.

radiometer record of an extinguishment test. After a 3-min heat-up period, the gasoline reached the maximum evaporation rate, the lid was opened, vapors were ignited, auxiliary power was reduced, and foam was applied. Fire knockdown and contol are defined as the points where 50 percent and 90 percent, respectively, of the original fire intensities are recorded by the radiometer.

Figure 5 shows a correlation of control times observed when the same series of nineteen foam samples were tested on the laboratory fire and on a 50-ft^2 test fire in the field. Laboratory test control times are plotted horizontally, and field test values, vertically. Equal control times by both tests correspond to the 45-degree line. Since eighteen of the points fall below the line, the laboratory test was slightly more severe than the field tests. A visual correlation through the scatter points (dotted line) indicates control times about 35 percent longer for the heating cycle employed with the laboratory apparatus. The dashed line in Figure 5 is the regression line obtained by a least squares fit to the scatterplot. Because of the modest number of samples, the few extreme points play a significant role in the computer correlation coefficient, which obviously cannot be applied at small values of X.

This scatter in the correlation appears to be largely due to the variability of the conventional field test in which weather conditions and human judgment played larger roles. Also, the observed parameters are slightly different in the two tests. For example, in the 50-ft^2 test, control was measured

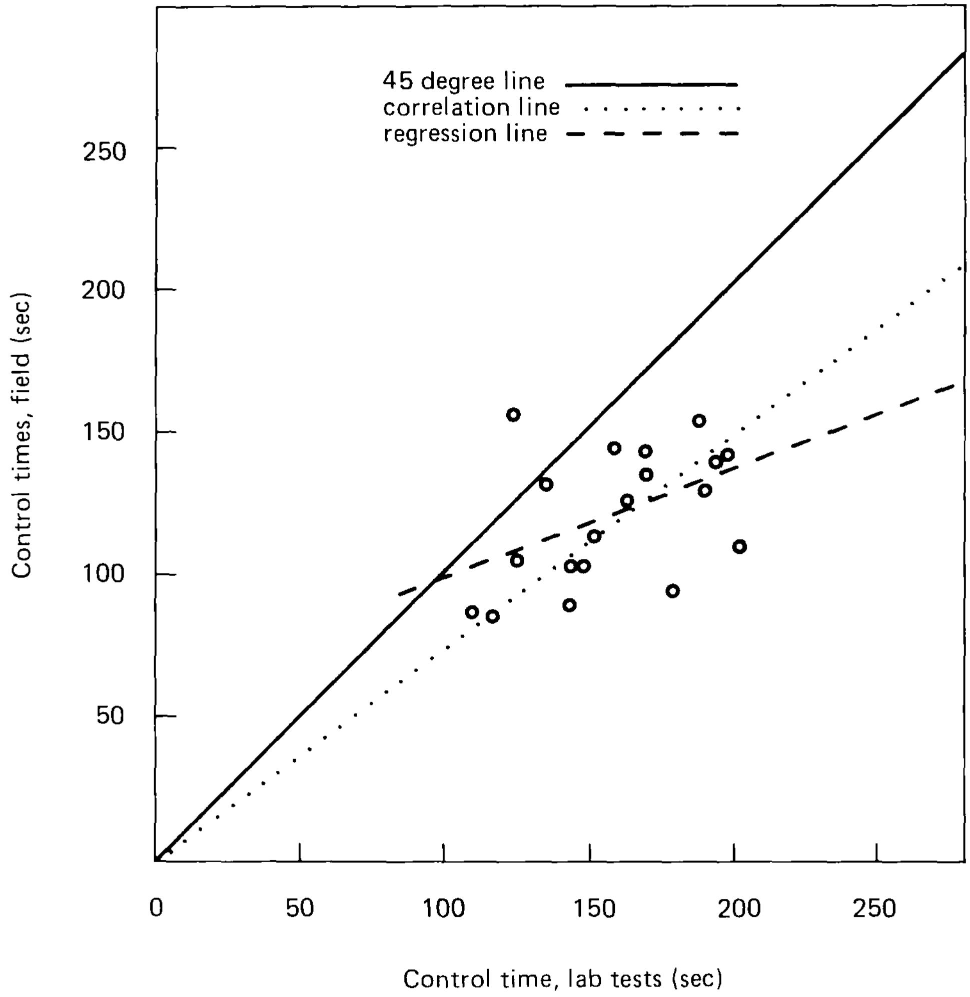

Figure 5. Correlation of control times observed in laboratory and field tests.

by an estimate of the percentage (90 percent) of the fuel area that was covered by the foam blanket. In the fire modeling laboratory, however, 90 percent control represented the time at which only 10 percent of the original thermal radiation intensity remained.

Reproducibility of the laboratory tests was checked with a series of production foam batches in which two tests were performed on each batch and both time to control and time to extinguish were recorded. A statistical test of sixteen pairs of control times and fourteen pairs of extinguishment times showed no significant difference between the means of the replicate values. While both agreements were satisfactory, the extinguishment tests were somewhat more reproducible than the control times, e.g., the average difference between control times was about 6 percent compared to 3 percent for the corresponding average in extinguishment times. In both cases, the reproducibility was substantially better than for the field tests.

CONCLUSIONS

The laboratory fire provides an adequate challenge for fire extinguishment tests. On the basis of control times and extinguishment times, the current test procedure is slightly more severe than the conventional 50- and 100-ft^2 fire tests.

The existing procedure is suitable for production control and product development tests.

The reproducibility of the laboratory tests is superior to that of the field tests and is substantially less time consuming and less expensive.

The laboratory tests appear suitable for certification tests; however, a slight reduction in test severity is required to achieve a one to one correlation with the field tests.

Prediction of foam requirements to protect against various envisioned pool fires can be made as well with the laboratory tests as with the conventional field tests. However, until the apparatus is extended to tests with freeboards and the burnback modification, its use should be limited to measuring control and extinguishment time.

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