A NOVEL DEVICE FOR DISSEMINATING FIRE EXTINGUISHING AGENTS - II

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ABSTRACT

It **is** generally believed that, because of its ability to absorb large quantities of heat, a mist of water droplets would be an excellent fire-extinguishing agent. **A** device has been constructed to disseminate a high volume of fine droplets of a liquid agent (water) in such a way as to make the liquid droplets permeate an enclosure. This device is capable of dispersing a water mist throughout a volume. Thus, the water mist can act as a three-dimensional agent, much like gaseous agents.

The device consists of two equally pressurized cylinders, fast-acting solenoid valves, a mixing chamber, and the necessary hardware to complete the system. One cylinder contains a vaporizable liquid, such as CO_2, and the second cylinder contains a liquid agent, such as water or water-based solution pressurized with CO_2 or nitrogen. Upon activation of the solenoid valves, two liquid streams (CO_2 and water/water-based solution.) are directed into a mixing chamber, such as a vortex mixer. The two streams are blended intimately in the chamber. Upon exiting the mixer into a nozzle, the vaporizable liquid flash evaporates and expands throughout the volume of an enclosure. This expanding gas carries droplets of the liquid agent with it as it permeates the volume. The droplets of liquid act as the principal fire-extinguishing agent. The high aerodynamic drag of the small droplets is an advantage, for they are swept along by the expanding gas as it moves throughout an enclosure. The main purpose of the vaporizable liquid is to carry the liquid fire-extinguishing agent and not to extinguish a fire. Limiting the amount will allow use of the vaporizable agent in small enough quantities that it does not exceed the Environmental Protection Agency's (EPA) "No Observed Adverse Affects Level" (NOAEL).

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BACKGROUND

It is generally believed that, because of its ability to absorb large quantities of heat, a mist of water droplets would be an excellent fire extinguishing agent. However, a mist has two distinct disadvantages.

The first disadvantage is the fact that a water mist is a streaming agent. For it to work effectively, the location of the fire must be known ahead of time in order to orient the system with the location in mind. The other alternative is to manually direct the mist toward the fire; however, this requires operator interaction after the fire starts, which defeats the purpose of an automatic fire extinguishing system. In either case, to achieve maximum efficiency of the water mist, the location of the fire must he known, either before or during the event. If there is the possibility of **a** fire in multiple locations in a given area, then either multiple streaming agents or **a** three-dimensional agent is needed.

When discharged, a three-dimensional agent will flood the enclosure it is in. With this flooding effect, it is more likely the agent will reach **a** fire that is not directly in front of the discharging nozzle. Gaseous agents such as Halon 1301 and carbon dioxide (CO_2) are good three-dimensional agents. However, the ozone-depletion problems associated with Halon **1301** are well known. Using CO_2, the concentration needed to extinguish a fire is too high to consider it **as a** viable fire extinguishing agent in locations that are considered occupied.

The second disadvantage of **a** water mist is the size of the particles. The most effective mist is one that has very small water particles. With smaller particles, the ratio of the surface area to the volume of each droplet is greater. This larger ratio increases the heat-transfer rate from the flame zone to the water droplets. Increasing the heat-transfer rate reduces the flame temperature faster, which in turn extinguishes the fire with less water.

However, the disadvantage of **a** fine mist of water droplets is the ability to spray the mist. Water droplets are not very aerodynamic, and the smaller the particles, the less mass they have. Nonaero-dynamic, low-mass droplets make it difficult to propel a fine mist of water very far. This requires the designer of the fire extinguishing system not only to know where the location of the fire is but also to locate the system close to the anticipated flame zone.

Some problems associated with fine mist may be overcome by using high concentrations of certain salts in water instead of pure water as the fire-extinguishing agent. Using **a** 60-weight % potassium acetate or potassium lactate solution in water allows for use of larger droplets, since there is a relatively small amount of water to be evaporated. The residual salt particles can act as effective fire extinguishing powders, enhancing the effectiveness of water as **a** fire extinguishing agent.

INTRODUCTION

A device capable of making and dispersing a water mist throughout a volume has been constructed. Therefore, the water mist can act as a three-dimensional agent, much like gaseous agents. The purpose of this device is to disseminate fine droplets of water in such **a** way as to make the droplets permeate an enclosure.

The device consists of two equally pressurized cylinders, fast-acting solenoid valves, **a** mixing chamber, and the necessary hardware to complete the system. One cylinder contains a vaporizable liquid, such as FE25 or CO_2, and the second cylinder contains a liquid agent such as water or a water-based solution. The cylinder containing the water is pressurized with CO_2 or nitrogen. Upon activation of the solenoid valves, two liquid streams (CO_2 and water/water-based solution) are directed into a static mixing chamber, such as **a** vortex mixer. The two streams are blended intimately in the chamber. Upon exiting the mixer into a nozzle, the vaporizable liquid flash evaporates and expands throughout the volume of the enclosure. This expanding gas carries droplets of the liquid agent with it as it permeates the volume. The droplets of liquid act as the principal fire extinguishing agent.

The vaporizable liquid (in the gaseous state) can contribute to the fire extinguishing process; however, its main purpose is to act as a carrier for the liquid fire extinguishing agent. This limits the amount of vaporizable agent required to the amount needed for dissemination. This will allow use of the vaporizable agent in small enough quantities that it does not exceed the "No Observed Adverse Effects Level" (NOAEL). The high aerodynamic drag of the small droplets is an advantage as they are swept along by the expanding gas as it moves throughout an enclosure.

DESCRIPTION OF DEVICE

An illustration of the device is shown in Figure 1. For the purpose of experimentation, the device consists of two sections: a stationary section that is permanently connected to the experimental chamber and a removable section.

The removable section consists of two modified 15-lb fire extinguishers. The standard head and valve assembly is removed from the bottles. It is replaced with a modified system that consists of a gate valve, an overpressure disk for safety reasons, and a union for quickly disconnecting the cylinders from the stationary portion of the system for refilling purposes.

The valving system on both cylinders is identical. Directly out of the cylinders is a I-in diameter stainless steel nipple. This nipple leads into a 1-in stainless steel tee. In the other two sections of the tee are another I-in nipple and a stainless steel plug. The plug is modified to receive a copper burst disk that will rupture if there is an overpressure in the cylinder. The disk used is a standard disk from a 15-lb CO_2 fire extinguisher. The 1-in nipple leads into a cast-iron gate valve. The gate valve is used to seal the cylinder after it is filled, yet it does not restrict the flow when in the fully open position. Following the gate valve are two reducers that reduce the diameter from 1 in to ***3/4*** in and then to 1/2 in. A 1/2-in nipple follows the reducers and leads into the male end of **a** disconnect union. This union is used to simplify disassembling the system after each experiment in order to refill the cylinders.

The stationary portion of the system starts at the female end of the union. Following the female end of the union is a fast-acting solenoid valve. The solenoid valve is followed by a 1/2-in flexible hydraulic hose. The hydraulic hoses from both the cylinders lead into a mixing chamber.

The initial configuration of the system is described above; however, future experiments include the investigation of mixing chambers with diameters larger than 1/2 in. This will require modifications of the system beyond the gate valve.

MIXING CHAMBER

The static (motionless) mixer is the location where the two liquids (CO_2 and water) are mixed. Both liquid CO_2 and water enter the mixing chamber as two distinct streams. Within the chamber, the two streams are intimately mixed to produce a homogeneous mixture. This homogeneous mixture then exits the mixing chamber into a nozzle, where the CO_2 flash vaporizes, creating a fine mist of water throughout the CO_2 gas.

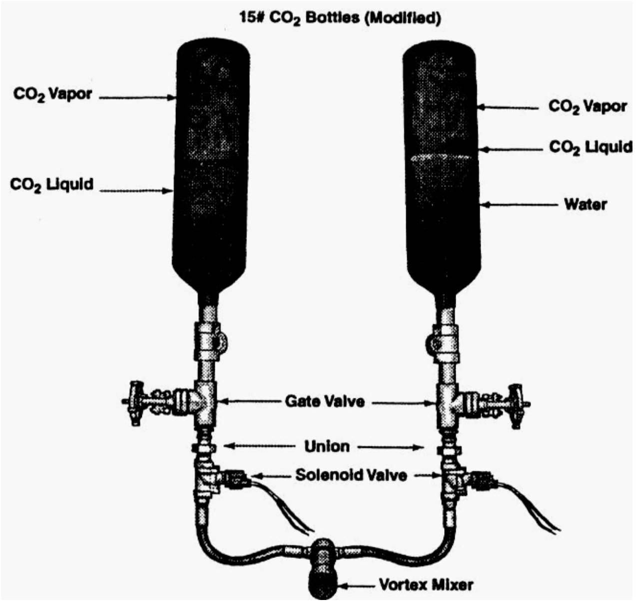

Figure 1. Illustration of Experimental Device.

Various static mixers will be utilized to determine the characteristics of each chamber. One device to be utilized is an interfacial surface generator **(ISG)** motionless mixer available from Ross Engineering. This is an in-line mixer that consists of individual mixing elements enclosed in a housing. Four holes are bored in each element to allow for the flow, and the ends of the elements are machined to create a tetrahedral chamber between two elements. Within the tetrahedral chamber, the exit holes of one element are in **a** linear array 90 deg from the linear array of the entrance holes of the adjoining element. This operation of the mixer is illustrated in Figure 2.

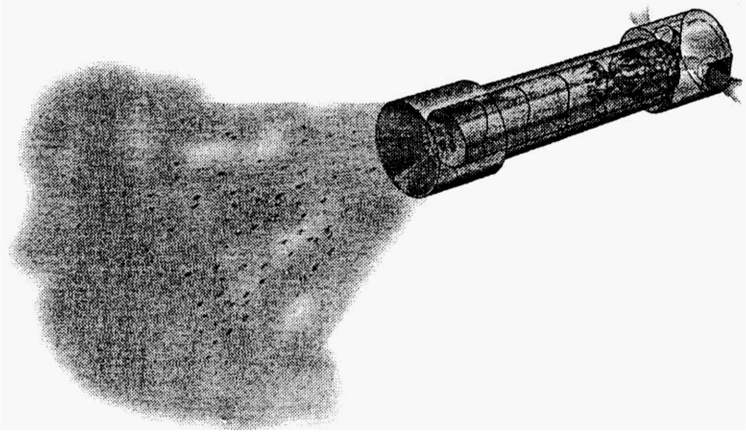

Figure 2. Operation of the Static Mixer.

This particular mixer offers mathematically predictable layer generation. The layer generation is the number of layers created at the exit side of an element. As an example, this device has two inlet streams entering four holes in the first element. Exiting the first element will be eight layers. Now, eight layers are entering four holes in the second element. At the exit of the second element will be **32** layers.

The number of layers emerging from an element is calculated based on the formula*

$$L = N\,(4)^E$$

where

L = number of layers created
N = number of initial input streams (two for this device)
E = number of elements

The number of elements in the array will be varied in order to determine how the number of layers created affects the output of the device. As a starting point, five elements will be used, which will yield 2048 layers:

$$L = 2*(4)^5 = 2048 \text{ layers}$$

These mixers are available in various diameters. As stated previously the initial installation will have five 1/2-in-diameter elements. Variations of the mixing chamber will include changing the number of elements and using different diameter elements.

Other mixing chambers are commercially available. Motionless mixers other than the **ISG** mixer will be investigated to determine their effectiveness with this device.

CONCEPT OF DEVICE

The concept of the device is to store liquid CO_2 and water (or a water-based material) in separate cylinders. When the fire extinguishing agent is needed, liquid water and liquid CO_2 are mixed in the mixing chamber. Upon exiting the chamber, the CO_2 flash evaporates and fills the enclosure as it normally would when released into an enclosure. However, the liquid mixture also contains water or a water-based liquid. As a result of the flash vaporization of the CO_2, a fine mist of the water/water-based liquid is created. The large aerodynamic drag associated with a fine mist of water will now be a benefit. Typically, the large aerodynamic drag of a water mist is a disadvantage because it is hard to propel very far. However, in this case, the CO_2 is expanding and filling the enclosure at the same time the fine mist is being created. **As** a result of the large aerodynamic drag, the CO_2 will carry the water mist with it as it expands throughout the enclosure.

To accomplish this objective, one cylinder is filled with CO_2. This cylinder is inverted as shown in Figure 1, in order for the liquid CO_2 to exit the cylinder through the valving system and into the mixing chamber. The water/water-based solution is added to the second cylinder. After the water is added, the cylinder is pressurized with CO_2. This cylinder is also inverted in order for the water/water-based solution, which is denser than CO_2, to exit the cylinder.

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*Literature: Ross Engineering, Inc., 32 Westgate Blvd., Savannah, **GA.**

DATA COLLECTION

Various parameters of the device will be modified to determine the optimum configuration. For these various parameters, extensive data will be collected for comparison of the different configurations. The data collected will include the droplet size, the droplet distribution with respect to location and time, the concentration of CO_2 in the enclosure, etc.

To collect these data, several tools will be used. The first data collection tool is a set of conventional drying tubes. Drying tubes will be placed throughout the enclosure to measure the quantitative amount of water at a given location. A schematic of the drying tube setup is shown in Figure **3.**

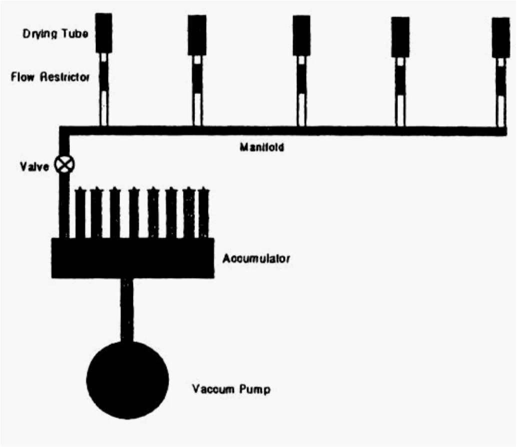

Figure **3.** Drying Tube Schematic.

The drying tubes will collect data from five locations within the enclosure. At each location, there will be 9 drying tubes, for a total of **45** drying tubes per experiment, which will allow for the determination of water concentration at five locations at nine different time intervals. This will indicate the concentration of water immediately after discharge of the cylinders and at interval times following the discharge of the cylinders.

The setup consists of a drying tube filled with an absorbent material and porous plugs. The weight **of** the drying tube is measured prior to the experiment. Following the drying tube is **a** calibrated flow restricter. The flow restricter limits the flow of air to a manageable amount with respect to the vacuum pump, which is further downstream of the flow. Tubing is connected to the flow restricter, which leads into a manifold. Nine of these drying tube setups lead into a single manifold. At the beginning of the manifold is a solenoid valve. This valve starts or stops the airflow to the nine drying tubes.

A single manifold contains five drying tubes. These drying tubes are located at five separate data collection stations within the enclosure. This manifold system with drying tubes is repeated nine times. This yields **45** drying tubes, which means 9 drying tubes at each of five locations. The nine manifolds are connected to a central accumulator that is connected to a vacuum pump.

To obtain the data, the vacuum pump is constantly running during an experiment. After discharge of the system, the individual valves for the manifolds are opened and closed at predetermined times. Based on the time a given valve is open and the flow rate, the volume of air traveling through the drying tube is calculated. The drying tube is weighed after the experiment and compared to its weight prior **to** the experiment to determine how much water was absorbed. With this information, the weight of water droplets in the air can be calculated. This enables air sampling for water concentration at five different locations at nine different times. With this information, a direct comparison of the water concentration can he plotted as a function of time and as a function of location.

To determine droplet size, microscope slides will be utilized. The slides will be coated with a thin layer of silicon grease to help collect the water droplets. **A** device to expose these slides for a given amount of time and then cover them is being redesigned and constructed. It is intended to he used for future experiments. Droplet sizes have not been measured in any of the experiments described in this paper.

DISCHARGE RATES TO EXTINGUISH FIRES IN THE DESIRED TIME FRAME

The weight of water droplets per volume to extinguish a fire has been estimated using many assump-tions. **A** conservative (high) estimate would be about *500* mg of liquid water per liter of air.

In the crew compartment of a generic military vehicle, 7 Ibs of Halon 1301 are discharged to give an average concentration of 7% Halon 1301 in air. This allows for the loss of agent due to the normal losses from the compartment. **A** 7% concentration is equivalent to 469 mg of Halon 1301 per liter of air. This is approximately the weight of water required per liter. Therefore, approximately 7 lbs of water would be required. This is equivalent to 3.2 liters.

If a low freezing point solution, such as a 60-weight % potassium acetate in water solution, is used instead of neat water, considerable **less** agent will be required. Prior work has indicated that sprays of a 60-weight % solution of potassium acetate in water or a 60-weight % solution of potassium lactate in water is 10 to 20 x more effective than neat water at extinguishing JP-8 pan fares [1]. Both solutions have a freezing point of approximately -60 °C. It is quite possible that as little as 1 liter of solution would be required.

With these data, it is conceivable that only 2 liters of liquid **(1** liter of solution and 1 liter of liquid CO_2) would **be** required to flow through the mixer. Current regulations require an extinguishment time of 250 ms in an occupied compartment. It takes 7 Ibs of Halon 1301 approximately 110 ms to discharge through its nozzle. To determine the required ISG mixer size for turbulent flow that will accommodate this flow rate, the following formula? is used:

$$\Delta p = \frac{1.2\text{x}10^{-1} Q^2 (\text{spgr}) \mu^{0.055}}{D^4}$$

[†] Literature, Ross Engineering, Inc., 32 Westgate Blvd., Savannah, **GA** 31405-1475.

where

Ap = pressure drop across one element
Q = volumetric flow rate (gallons/minute)
spgr = specific gravity
μ= absolute viscosity
D = inside diameter of mixer housing (inches)

With CO_2, approximately 740 psi vapor pressure is available at room temperature. Using a five-element, 3-in **ISG** mixer with CO_2, a flow rate of 1194 liters/min can be obtained. This correlates to 19.9 liters/sec or 50.2 ms to discharge a liter. Therefore, 2 liters can be discharged through a 3-in mixer in 100.4 ms. This leaves approximately 150 ms to extinguish the fire and still be within the 250-ms required time frame.

EXPERIMENTAL SETUP

The device illustrated in Figure 1 is mounted on the inside wall of a test chamber. Rough dimensions of the test chamber are 13.6 ft x 13.6 ft x 10.6 ft. The nozzle as shown is 27 1/2 in above the floor of the test chamber. There are five locations where the drying tubes are located in order to measure the concentration of water in the air. **All** of these locations are at the same height above the floor as the nozzle. The locations are illustrated in Figure 4.

EXPERIMENTAL RESULTS

Initial experiments have been performed to test the system. All **of** the initial experiments have been performed with a 1/2-in mixer. This mixer was used instead of the 3-in mixer outlined in an effort to characterize the system and various parameters. **A** system with the 3-in mixer is being designed in order to achieve the desired discharge times.

For the initial tests, both **of** the fire extinguishing bottles were filled with 15-lb of CO_2. Upon activation of the solenoid valves, the two bottles discharged. The time required to discharge the bottles was approximately 45 sec. This was using the system as described with the 1/2-in diameter **ISG** mixer with five elements present.

The temperature **of** the CO_2 was also measured as it exited the nozzle. The minimum temperature was -65 "C. **As** expected with this temperature, it is possible the water could freeze at some point, creating a temporary blockage in the system. For this reason, experiments with a low freezing point, water-based material are also planned.

One experiment has been performed with 8 Ibs of CO_2 in one cylinder and 1 gal of water in the other. The second cylinder was pressurized with 2 Ibs of CO_2. In this experiment, the vacuum was opened to draw from the first set of drying tubes, one tube at each of the five locations, **for** the first 10 sec after the solenoids were opened. After 10 sec, the vacuum line was closed and simultaneously opened **for** the second set of drying tubes. This process was continued until all 9 sets of drying tubes were opened for 10 sec and then closed. Measurements of the drying tube setup gave a flow rate through each tube of approximately 6200 cm^3/min. For 10 sec, this gives a total flow of approximately 1 liter of air.

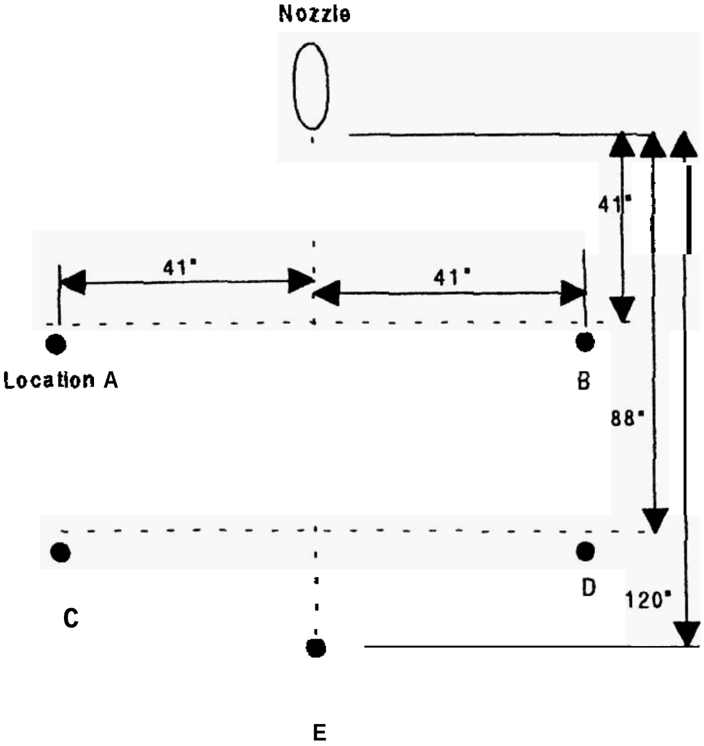

Figure 4. Drying Tube Locations.

A preliminary evaluation of the data indicates that, from 0 to 10 sec, there was little or no increase of the water in the air. From 20 to 40 sec, drying tubes three and four, the concentration of water in the air increased and then it dropped off after 40 sec. During the highest concentrations, there were approximately 37 mg of water **per** liter of air. This is well below the desired result, but, for a first experiment, it shows promise.

Carbon dioxide was also measured during this test. Concentrations peaked at ***6%.*** Based on calculations, if 10 lbs of CO_2 were evenly distributed throughout the chamber, the concentration would equal 2.2%. This indicates that the CO_2 is not being distributed throughout the chamber uniformly. **A** possible cause for this could be because of the extremely low temperatures reached when the CO_2 discharges. This could cause the CO_2 to settle quicker than it normally would and not fill the upper areas of the chamber.

If 1 gal of water was distributed uniformly as mist droplets in the chamber, the water concentration would be only 78 mg of water per liter. This is not sufficient to extinguish a pan fire, as was demonstrated when a fire involving 15 cm^3 of cyclohexane was placed in the chamber, out of the discharge path of the extinguishing system. When 1 gal of a 60-weight % potassium lactate solution was used in place of water, a similar pan fire was extinguished. Since the density of this solution was 1.34 g/cm^3, a uniform distribution would give 104 mg of solution per liter.

FUTURE WORK

Future work will entail determining the most effective configuration. This will require experimenting with different mixing chambers. The 1/2-in diameter **ISG** will be used. Work is currently underway to implement the 3-in mixer in order to discharge the system in the desired time. The number of mixing elements will also be varied to determine how the number of layers created affects the dispersion of the water mist.

Various commercial static mixers are available. Different mixers will be investigated to determine their ability to create a mixture suitable for use with this device. Nozzle design will also be investigated to determine how the nozzle affects the output of the water mist.

Other parameters of the device will also be varied to determine the optimum configuration. Gases other than CO_2 will be investigated to determine their ability to pressurize the water/water-based solution. A possible gas for this purpose is nitrogen. Vaporizable liquids other than CO_2 **for** use as the propelling agent will also be investigated. One possible vaporizable liquid is FE25 due to its favorable normal boiling point, approximately that of Halon 1301.

After the preliminary investigation of mixing chambers, nozzle designs, various gases, etc., telltale fires will be created throughout the enclosure and the system will be discharged. The device's ability to extinguish the telltale fires will be noted. This will be repeated with the configurations that looked promising, based on the data collection from the investigation of the system parameters.

REFERENCE

1. Finnerty, **A.** E., R. L. McGill, and W. A. Slack, "Water-Based Halon Replacement Sprays," ARLTR-1138, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, July 1996.