UPDATE ON WATER AS A THREE-DIMENSIONAL FIRE-EXTINGUISHING AGENT

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BACKGROUND

The US Army is investigating alternatives to Halon 1301 for use in automatic fire-extinguishing systems (AFES) on board tactical vehicles. In general, a fully automatic system is installed in normally occupied spaces, such as crew compartments, and an automatic and/or manual system is used to combat engine compartment fires.

Any alternative to Halon 1301 must he acceptable from both environmental and toxicity standpoints. The most common fire-extinguishing agent, water, meets this requirement. Because of its high specific heat and high latent heat of vaporization, a mist of water droplets should be an excellent fire-extinguishing agent. However, there are two distinct disadvantages to the use of a water mist as a fire-extinguishing agent.

The first disadvantage is that a water mist is a streaming agent, that is, its flow is directional. It normally flows in a direction until it encounters a surface on which it condenses or the velocity of the mist particles is reduced to approximately zero due to the high aerodynamic drag associated with small particles in air. In order for a mist to function effectively as an extinguishing agent, the location of the fire should be known ahead of time so that the mist generator can be properly oriented. An alternative is to detect the fire and then aim the mist in the proper direction. In either case, in order to use the mist efficiently, the location of the fire should he known, either before or during the event. If there is the possibility of a fire in multiple locations in a given space, multiple mist generators are required.

The second disadvantage of a water mist is the problem of droplet size. The most efficient mists are those with small droplets, since small droplets can completely evaporate in the flame zone, maximizing the heat-absorbing ability of the water. Removing heat from a flame reduces its temperature and leads to flame extinguishment. However, small droplets have high aerodynamic drag. Low-mass droplets are difficult to propel any distance. Devices that generate small particles of water should be located close to the anticipated flame zone.

The disadvantages associated with water mists would he overcome if water can he made to act as a three-dimensional (3-D) agent. **A** 3-D agent would permeate an enclosure. Therefore, the agent could reach a fire, even if the fire is not directly in front of the discharge point. In addition, the agent would flow around obstacles in its path. The agent would encounter any fire in the enclosure.

INTRODUCTION

A device that is capable of making and dispersing a water mist throughout an enclosure has been designed and constructed. The device can disseminate fine droplets of water in such a way as to make the droplets permeate a space. Therefore, the water can act as a 3-D fire-extinguishing agent.

The device consists of two equally pressurized bottles. fast-acting solenoid valves, a mixing chamber leading to a nozzle, and the necessary hardware to complete the system. One pressurized bottle contains a vaporizable liquid, such as CO_2 or FE-13 (trifluoromethane). The second pressurized bottle contains a liquid fire-extinguishing agent such as water or a water-based solution. Upon activating (opening) the solenoid valves. two liquid streams (liquid CO_2 and liquid water) are directed into a static mixing chamber. The two streams are blended intimately in the chamber. Upon exiting the mixer through the nozzle, the vaporizable liquid flash evaporates and expands throughout the volume of the enclosure. This expanding gas carries droplets of the liquid fire-extinguishing agent with it as it permeates the volume. The high aerodynamic drag of the small droplets is an advantage as they are swept along by the expanding gas as it moves throughout the volume. The droplets of liquid act as the principal fire-extinguishing agent. An illustration of the device is presented in Figure 1.

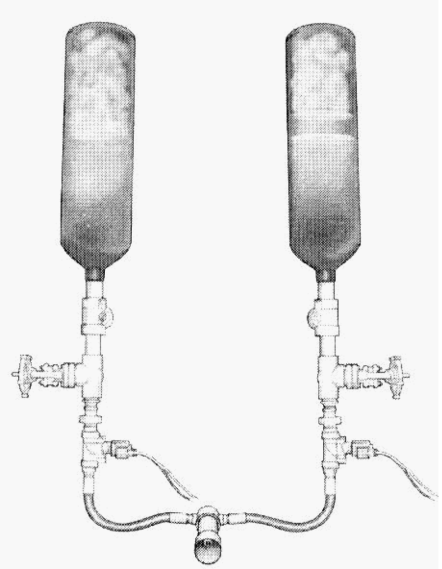

Figure 1. Experimental device.

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, and this will allow use of the vaporizable agent in small enough quantities so as not to exceed the maximum concentration allowed by the Environmental Protection Agency (EPA) or the Army Surgeon General for use in occupied compartments.

DESCRIPTION OF DEVICE

The experimental device consists of two main sections: a stationary section that is permanently connected to the experimental enclosure and a removable section. In the initial version (No. 1) of the system. the removable section consisted of two modified CO_2 fire extinguishers. The standard head and valve assemblies were removed from the bottles. Each bottle then received a gate valve connected to the bottle, an overpressure disc for safety reasons, and a quick disconnect union. The union was used to connect/disconnect the bottle assembly to the stationary portion of the system. The bottles were easily removed from the system for refilling, then returned to the system for an experiment. The valving and plumbing of both cylinders were identical. One end of a 1 in diameter stainless steel nipple was screwed into a steel pressure bottle. The other end of the nipple screwed into a 1 in stainless steel tee. In another section of the tee was a stainless steel plug, modified to hold a copper burst disc. Since the burst disc had been removed from a CO_2 fire extinguisher, it had the proper pressure rating to protect the cylinders. The last section of the tee contained another 1 in stainless steel nipple. **A** cast iron gage valve was attached to this nipple. The gate valve was used to seal the cylinder after it was filled. In the fully opened position, the valve had a full 1 in opening, which offered no restriction to flow.

Following the gate valve were reducers to bring the diameter down to 0.5 in. **A** *0.5* in nipple followed and connected to a quick-disconnect union. The union facilitated assembly and disassembly of the system to refill cylinders. The stationary portion of the system starts at the lower half of the union, which is attached to a solenoid valve with a 0.5 in opening. On the other side of the valve was a 0.5 in diameter flexible hydraulic hose. The flexible hoses, one from each cylinder assembly, were attached to a mixing chamber. The exit of the chamber had a nozzle that delivered the water-mist fire-extinguishing agent to the enclosure. This system is illustrated in Figure 1.

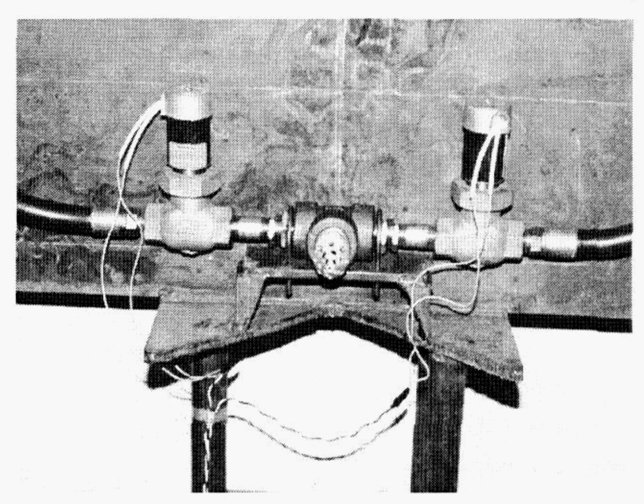

Figure 2. Configuration with larger plumbing and **FAASV** nozzle.

A later version (No. 2) of the device used *1* in diameter plumbing from the outlet of the solenoid valve with 1 in hydraulic tubing to a 1.5 in tee. The plumbing from the two bottles connected to the two inlets of the tee. **A** nozzle, of the type used on the M992 **FAASV** Halon 1301 system was attached to the outlet of the tee. The threads of the nozzle had to be modified to connect to the tee. Version No. 2 is shown in Figure 2.

MIXING CHAMBER

The static motionless mixer was the location where the two liquids (liquid CO_2 and liquid water) were mixed. Both streams entered the mixing chamber. Within the chamber, the two streams were intimately mixed to produce a virtually homogeneous mixture. The mixture exited the mixing chamber. into a nozzle, where the CO_2 flash vaporized and created a fine mist of water throughout the CO_2 gas.

In mixer version No. 1, an interfacial surface generator (ISG) motionless mixer from Ross Engineering was utilized. This in-line mixer consisted of individual mixing units enclosed in a housing. Four holes were bored into each element to allow for flow, while the ends of the elements were machined to create a tetrahedral chamber between any two elements. Within the tetrahedral chamber, the exit holes of one element were in a linear array 90 deg from the linear array of the entrance holes of the next element. **A** schematic of the elements of the mixer is presented in Figure 3.

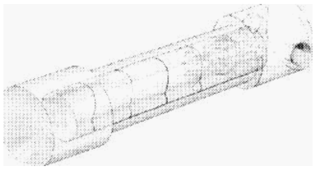

Figure 3. Mixing chamber.

ISG mixers are available in up to 3 in diameter models. The mixer that was used in version No. 1 was a 0.5 **in** diameter. five-element unit. This type mixer offers mathematically predictable layer generation. The materials mixed form multiple layers of each liquid. **As** an example, this device has two inlet streams entering four holes in the first element. Exiting the first element are eight layers. The eight layers enter four holes in the second element. There are 32 layers that exit the second element, etc. With five elements present, 2048 layers of CO_2 and water are theoretically created.

COLLECTION OF DATA

Certain data must be collected and analyzed to determine how well the fire-extinguishing device is functioning. Data have been collected on droplet size, droplet distribution in an enclosure with respect to location and time, Concentration of CO_2 in the enclosure, and the ability of the device to actually extinguish fires.

The first data collection tool used was **a** set of arrays of conventional drying tubes. Each tube contained water-absorbing material and **a** porous plug. Each tube. with contents. is weighed prior to an experiment. The inlet of each tube is sealed with a rubber plug. The outlet of each tube is connected to a flow restrictor. The outlet of the flow restrictor is connected to a vacuum line. which connects to a manifold. There are five drying tubes connected to ***a*** manifold. At the end of the manifold is a solenoid valve leading to a vacuum source. Nine manifolds are connected to a total of 45 drying tubes. Upon activation of a solenoid valve, a vacuum is applied to 5 drying tubes. each in an array at **a** specified location in the experimental enclosure.

To obtain data on the weight of liquid agent per unit volume of air in the enclosure the rubber seal is removed from each of the 45 tubes. The vacuum pump is constantly running during an experiment. After discharge of the fire-extinguishing agent. individual solenoid valves are opened and closed. The time is computer controlled. Based on the time a given solenoid valve is open and the flow rate through a restrictor, the volume of air that traveled through a given tube is calculated, Each tube is weighed after the experiment and the gain in weight is equated with the amount of water or water-based liquid in that particular volume of air. Water concentration can be calculated at five locations at nine different times.

Optical microscopy was employed to determine droplet size. Microscope slides were coated with a very thin layer of silicone grease. Nine slides were placed into slots in a carrousel. The slides were covered by **a** disc with one opening. This disc could rotate so that the opening could be over a particular microscope slide or over **a** blank space between slides (Figure 4). The position of the opening in the disc was programmed using a computer-controlled stepping motor, which turned the disc.

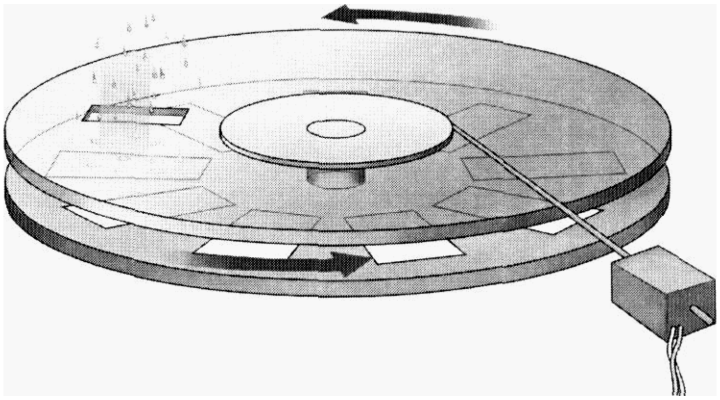

Figure 4. Carousel.

The slides collected droplets that fell from the air after activation of the fire-extinguishing device. The computer was programmed so that a given slide collected droplets for 10 sec in 10 sec intervals.

For droplet sizes to he calculated, the microscope slide had to be photographed; however, it was found that water droplets evaporated too quickly. Therefore, a new method was developed to determine the droplet size. A piece of double-sided tape was placed on a microscope slide, and a dusting of 10x confectioners sugar was placed on the tape. Silicon grease was not used. When water droplets collected on the slide, the sugar dissolved in the water. The water would then evaporate and the sugar would recrystallize and leave a distinctive footprint of the original droplet.

When water-based solutions containing high concentrations of salt, such as a 60 wt.% potassium lactate, 40 wt.% water solution were used, the droplets did not evaporate rapidly. They were collected on microscope slides that had the thin layer of silicon grease.

RESULTS

Large Chamber

Initial experiments were performed in a chamber whose volume was approximately 48.3 m^3. The experiments utilized the five-element, 0.5-in diameter ISG mixer. Each of the two pressure bottles was originally 15-lb CO_2 fire-extinguisher bottles. The first phase of experiments was aimed at characterizing the capabilities of the system. The device and mixing chamber previously shown in Figures 1 and 2, respectively, were used in this chamber.

The first experiment involved both pressure bottles, each containing 15 lbs of CO_2. The two solenoid valves were activated simultaneously. A thermocouple was placed at the exit nozzle of the device.

The discharge of the CO_2 required 45 sec. The temperature of the thermocouple dropped to -65 "C. Water vapor condensed out of the air and froze the vortex mixer. It was concluded that the liquid CO_2 was evaporating in the mixer. This caused an excessively long discharge time and the low temperature observed with the thermocouple and the ice formation on the vortex mixer.

In a following experiment, 8 lbs of CO_2 were put into one pressure bottle. One gallon of distilled water was placed in the second bottle. Two pounds of CO_2 were added to this bottle to pressurize the water to the same value as the liquid CO_2 in the first bottle. Upon activation of the two solenoids, CO_2 and water mist were injected into the enclosure. CO_2 concentration was measured by continuously withdrawing gas from the enclosure into a nondispersive infrared CO_2 analyzer.

Concentration of CO_2 peaked at 6%, the maximum value the analyzer could measure. Calculations indicated that a uniform concentration of CO_2 in the 48.3 m^3 enclosure would give a 2.2% CO_2 concentration. It is assumed that the cold CO_2 gas settled out low in the chamber.

The drying tube collectors were utilized for this experiment, and vacuum was applied to five tubes (each at a different location) for 10 sec starting with the electrical signal to the solenoid valves of the pressure bottles. After 10 sec, the vacuum was removed from these tubes and switched to the second set of five tubes for 10 sec. This process was repeated until **all** nine sets had been activated for 10 sec of vacuum.

A calculation indicated that 1 gallon of water, in the form of a mist in the chamber. would give an average concentration of 78 mg of water/liter. The highest concentration of water in the air (eliminating drying tubes that had been hit by direct discharge of water) was 37 mg/liter. Examination of the chamber after the experiment showed that much of the water was condensed on surfaces facing the discharge nozzle of the device.

Vapor **was** observed (by video) coming from the nozzle during the entire timed portion of the event (112 sec). The direction of the vapors changed repeatedly during the discharge. likely caused by the intermittent freezing and thawing of water in the channels of the vortex mixer.

Water droplets were collected on sugar-coated microscope slides. The slides were on the carousel. While the carousel did not function properly during this experiment, some water droplets were collected. Figure 5 is a representative sample of the water droplets on a slide.

It has been estimated that approximately 500 mg of water mist/liter of air in a chamber would be required to extinguish **a** hydrocarbon fire. An average water mist of only 78 mg/liter would not be sufficient.

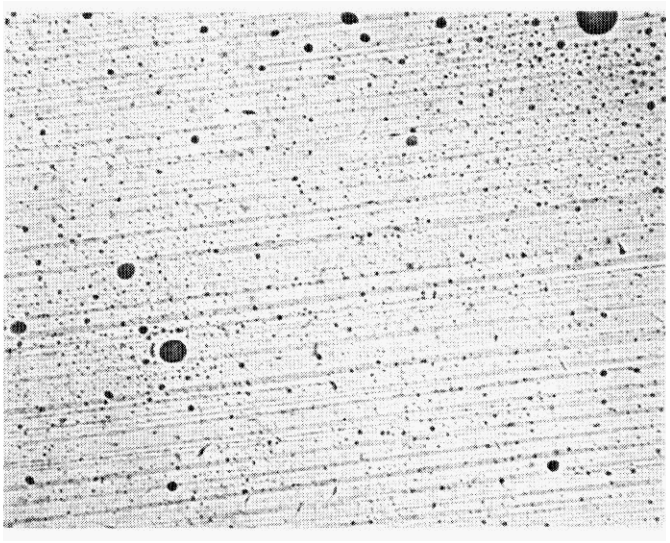

Figure 5. Representative sample of water droplets on microscope slide.

An experiment was conducted using 10 lbs of CO_2 in one bottle and 1 gallon of water with 3 lbs of CO_2 in the second bottle, with the mixing elements removed from the mixing chamber. A 3 5/8 in diameter container, 7/8 in high. with 15 ml of burning cyclohexane **was** placed out of the direct path of the discharge. When the 1 gallon of water was discharged, the pan fire was not extinguished.

In the next experiment, 1 gallon of a 60 wt.% potassium lactate, 40 wt.% water solution was used in place of neat water. **In** this experiment the pan fire of cyclohexane was extinguished. Taking into consideration the 1.34 specific gravity of the solution. **a** uniform mist would give only approximately 104 mg of solution/liter of air in the chamber. The same volume of potassium lactate solution was more effective than water.

Small Chamber

The experimental apparatus was installed in a bay whose volume was approximately 23.2 m’. The hydraulic hoses were changed *to 1* in from the 0.5 in diameter hoses formerly used, The mixing chamber used was a standard 1.5 in plumbing tee. The two hydraulic hoses (one from each pressure bottle) feed into the two inlets of the tee. The outlet of the tee had a nozzle of the type used on the M992 FAASV vehicles Halon 1301 fire-extinguishing system (Figure 2). The nozzles are shown in Figure 6. One gallon of water was used along with the CO_2. The two pans of burning cyclohexane used were out of the direct line of the CO_2 propelled water mist. Upon activation of the two solenoids, both fires were extinguished. A dense fog was observed in the chamber. The simple mixing chamber and nozzle combination appear to be very much superior to the complex mixer and nozzle used previously.

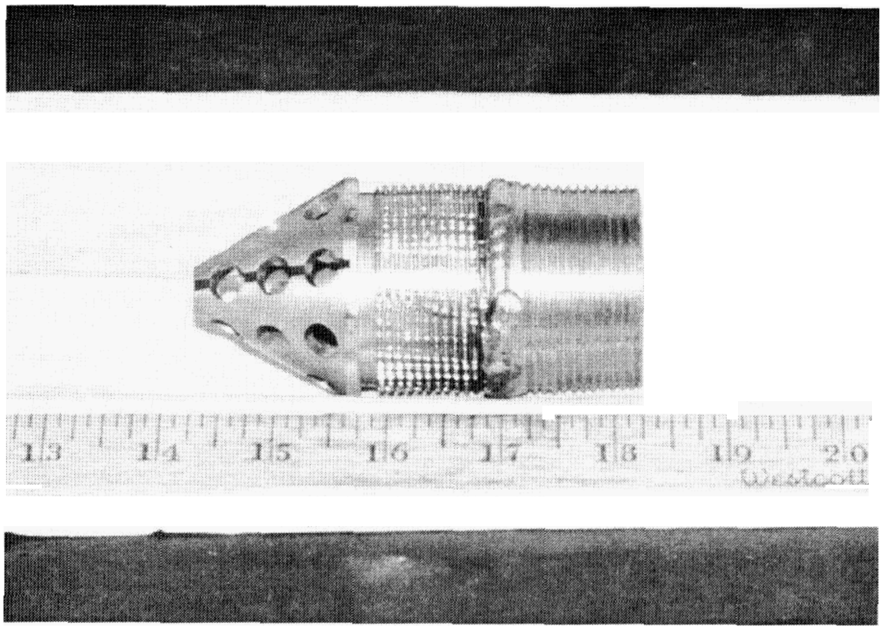

Figure *6*. FAASV nozzle modified.

All four subsequent experiments using 1 gallon of the potassium lactate solution extinguished the pan fires. The fires, even with the pans placed behind the apparatus, gave fire-out times as low as 132 msec. There appears to be uniform coverage of the enclosure by the mist.

Pictures of the microscope slides taken in these experiments have been scanned and histograms constructed by a computer program. The histograms show that most of the droplets of the potassium lactate solution are in the 1-2 µm size range. This is consistent with the uniform distribution in the bay. These very small droplets can be carried along by the expanding CO_2 gas, giving excellent distribution of the fire-extinguishing agent (the liquid droplets) throughout the enclosure.

CONCLUSIONS

The five-element, 0.5-in diameter vortex mixer was not suitable for use with liquid CO_2. The liquid evaporated in the mixer, freezing water that then blocked the channels in the elements.

A simple, large diameter (1.5 in) tee mixer with opposed flow inlets and a perforated nozzle outlet is quite satisfactory. Flow is rapid and very small (1-2 µm) droplets are formed.

A 60 wt.% potassium lactate, 40 wt.% water solution is superior to water as the fire extinguishing agent.

The device does allow for the expanding boiling gas to carry liquid fire-extinguishing droplets to all portions of an enclosure.

FUTURE WORK

The device will be constructed using US Army fire extinguishing equipment. Pressure bottles and 24-volt solenoid valves used in combat vehicles will be used. The 1.5 in tee mixer and FAASV perforated nozzle will be retained. When the system has been demonstrated capable of extinguishing fire in a test chamber. it will be delivered to TARDEC for testing in the crew compartment of combat vehicles.

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