EXAMINATION OF AN ALTERNATIVE DELIVERY METHOD FOR A SUSTAINABLE CLEAN AGENT IN A TOTAL FLOODING FIRE SUPPRESSION SYSTEM

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ABSTRACT

This paper describes results from testing a unique, patent pending approach to delivering a sustainable clean agent through a piping distribution network for a total flooding or local application fire protection system. Currently approved methods for applying most halocarbon clean agents consist of either a gas and/or liquid stored in high pressure cylinders that is propelled to a discharge nozzle or device(s) by an additional high pressure gas; typically nitrogen.

Due to the distinctive physical properties of the halon alternative FK-5-1-12, commercially known as 3M™ Novec™ 1230 Fire Protection Fluid, the use of pumps was investigated as a potential alternative delivery method in lieu of pressurized cylinders. Conclusive proof exists that this fire protection fluid can be pumped; delivering FK-5-1-12 using typical clean extinguishing agent fire suppression hardware and nozzles. This concept has been recently validated during nozzle distribution fire tests conducted in both 100 m^3 and 29 m^3 test enclosures as tested against international test standards [1, 2].

INTRODUCTION

Current Halon replacement systems utilize a network of pressurized cylinders that are designed and installed in accordance with the National Fire Protection Association’s (NFPA) Standard 2001, *Standard on Clean Agent Fire Extinguishing Systems*. In order for a product to be accepted as a “clean agent,” it must be electrically nonconductive, volatile, or gaseous fire extinguishant that doesn’t leave a residue after it evaporates. These characteristics make clean agents ideal for protecting high value assets, electrical equipment, mission critical devices, guidance systems, turbines or telecommunications equipment.

With the exception of FK-5-1-12, virtually all of the available clean agents are stored at elevated pressures in order for the agent to remain in liquid form. For a majority of the fire extinguishing agents listed in NFPA 2001, the cylinders are filled with the fire extinguishing agent of choice and then super pressurized to 25 or 42 bar (360 or 600 psig). When the system is activated, the additional pressure from the nitrogen propels the fire extinguishing agent out of a dip tube in the high pressure cylinder into the piping distribution system. Once this system is discharged, the system is no longer operative and cannot be easily or quickly returned to an active state until trained technicians service it.

The ability to store FK-5-1-12 in a sealed *"non pressurized"* container is, in itself, unique for a clean agent. The research described in this paper explored the possibility of using the non-pressurized liquid storage container as a supply source of FK-5-1-12 for a pump that, in turn, can deliver the fire protection liquid to a nozzle(s) in the hazard area.

Positive test results would prove the concept of eliminating the requirement to use high pressure cylinders with the inherent safety of handling and recharging requirements that, by necessity, require the cylinders to be removed from the installation, taken to a recharging facility, recharged, returned and reinstalled. All this requires time and results in increased costs by using temporary cylinders to keep the system from being "out of service" and requires a significant amount of labor along with the safety concerns of handling highly pressurized gases by personnel.

In addition to the above concerns, the ability to deliver agent to a nozzle at a consistent and steady nozzle pressure without the high to low pressure transition of a pressurized gas or liquid during delivery, is considered to be of significant value for agent disbursement, extinguishment times as well as maintaining concentration levels for prolonged time periods. A pump has the added benefit of allowing very long concentration hold times to be achieved at low flow, a feature not available from a pressurized cylinder.

Further, because FK-5-1-12 can be stored in standard non-pressurized containers, personnel on site can do refilling quickly, and the special hazard protection system is restored to a system ready state very quickly without the need to remove or reinstall any cylinders or associated equipment.

Finally, a pumped clean agent liquid would provide greater design flexibility to have sustained discharge, cycling discharge, remote location of the delivery equipment as well as ease of retrofit to any existing Halon, HFC-227ea, CO_2 or Inert gas systems. This concept holds considerable merit.

OBJECTIVES

Phase 1

Initial pumping system design targets of 76 L/min at 10 bar [~20 gpm at ~150 psi] and 0.08 L/min at 6.9 bar [~0.2 gpm at 100 psi] were selected as the upper and lower boundaries respectively for testing as these were initially thought to be the limits for a pump based system. Also taken into consideration were average discharge nozzle pressures for cylinder systems of no less than 5.2 bar [75 psi]. Three pumps were tested to simulate both a smooth continuous and pulsing discharge/suction flow condition within a closed loop test setup.

Initial research revolved around engineering a closed loop test system that would provide adequate suction capability, as this was suspected to be critical. Data acquisition equipment was obtained and installed for monitoring and recording conditions within the piping system. Three separate piping systems were assembled. Each pump was plumbed to its respective piping system during each test series to monitor discharge pressure, flow rates and suction characteristics.

Phase 2

Pending successful tests from Phase 1, additional efforts were put forth to test the concept using standardized fire test protocols described in International Standard 14520-1 Annex C and Underwriters Laboratories 2166, Standard on Halocarbon Clean Agent Extinguishing System Units.

TEST EQUIPMENT

Data Acquisition Equipment

Pressures developed on the suction and discharge sides of the pumps, motor amperage draw, flow rate and temperatures were recorded with a computer controlled analog-to-digital converter. The converter system is a 133MHz Pentium based Toshiba computer system running LabTech Notebook data collection software. A parallel port cable is used as an interface to control an Omega OMB-Daqbook 100 analog-to-digital converter. A three slot expansion chassis containing a DBK-13 digital input board and two DBK-19 thermocouple input boards were daisy chained to the Daqbook 100.

Two calibrated Ashcroft pressure gauges having display ranges of 30" Hg to 30 psig and 0-300 psig were used to monitor pressures in the piping systems. Four electronic pressure transducers were used to measure and record the pressures developed during the test series. All four pressure transducers were purchased from Omega Engineering. Table 1 provides the model numbers and respective pressure ranges.

Temperatures were measured using Omega Type K, thermocouples. Stainless steel thermocouple probes, having a 1/8" stainless steel diameter and an exposed tip, were affixed to the piping using Swagelock fittings. Type K wire thermocouples were used to measure the temperature of the FK-5-1-12 in the tank and ambient air temperature.

ID	Model Number	Pressure Range
1	PX242-150G5V	0-10 bar (0-150 psig)
2	PX242-250G5V	0-17 bar (0-250 psig)
3	PX303-300G5V	0-21 bar (0-300 psig)
4	PX243A-15BG5V	± 15 psig

Table 1: Pressure Transducers Utilized

Additional equipment used included a Data Industrial digital flow meter that produced a 4-20 mA signal based on a programmable flow range between 0 and 303 L/min (0-80 gpm) and a Dwyer rotameter. The calibration of the digital output flow meter was verified in the laboratory by discharging into a metal drum that was resting on a large load cell. The mass of FK-5-1-12 gained in the drum was compared to the flow meter readings and validated during a specified time period. The rotameter had a range from 0-38 L/min (0-60 gph) based on water and was calibrated by measuring the time it took to fill a known volume within a 1000mL (0.3 gallon) graduated beaker.

Phase 1 - Pumps and Piping Distribution System

The lab was set up with adequate electrical supply power to allow testing of various design's of pumps and motors up to 7.5 HP. A liquid test loop and tank with a capacity up to 379 L (100 gallons) was used as the source and return point of the fluid, via flexible suction and discharge hoses with all associated fittings and instrumentation necessary to attempt pumping and, if successful, document the specific and peculiar characteristics of pumping this fluid.

Tests were performed using two closed loop piping arrangements. These systems provided the ability to adjust and monitor the flow rate while limiting the amount of fire extinguishing agent emitted into the atmosphere. FK-5-1-12 was transferred to a 379 L (100 gallons) tank whereby a 1.8 m (6 ft.) long by 5 cm (2 inch) diameter flexible suction hose was connected to the intake side of Pump 1. Rigid piping was affixed to the discharge side of the Pump 1 (centrifugal pump) in order to accommodate a flow meter and metering valve. The rigid piping had a diameter of 3.8 cm (1.5 inch) and approximately 1.2 m (4 ft.) in length, returning back to the 378.5 L (100 gallons) tank via another 1.8 m (6 ft.) long by 5 cm (2 inch) diameter flexible hose.

A 38 L (10 gallon) tank was used to hold a smaller quantity of FK-5-1-12 for the second and third pumping systems. Pump 2 (compressed gas diaphragm pump) utilized tubing having a nominal 1.2 cm (½ inch) inside diameter connected both to the suction and discharge ports of the pump to the tank. A valve attached to the top of the tank, controlled backpressure on the discharge side of Pump 2. Pump 3 (gear pump) utilized the same diameter tubing on the suction side of the pump as Pump 2. However, 6 mm ($^1/_4$ inch) diameter tubing was used to connect the discharge port to a rotameter and nozzle. Flow rates for Pumps 2 and 3 were determined by using a known calibrated volume measured during a specified time period.

Phase 2 – Full-Scale Test Enclosures

Two fire test enclosures and piping schemes were utilized for this phase. Extinguishing agent was delivered during the tests conducted in the 100 m^3 (16 ft x 16 ft x 14 ft) enclosure using Pump 1 (centrifugal) described previously. The same suction arrangement was used as the previous phase however, 13.3 m of 3.8 cm (43 ½ feet of 1.5 inch) pipe was connected to the end of the rigid piping on the discharge side of the pump. The elevation of the nozzle in this room was approximately 4 m (13 feet) from floor level.

The discharge piping used to deliver FK-5-1-12 into the 29 m^3 (32' x 32'x 1') enclosure consisted of a mix of 3.8 and 2.4 cm (1.5 and 1 inch) diameter pipe. The first 7.3 m (24 ft) of pipe after the pump, had a 3.8 cm (1.5 inch) diameter before it was reduced down and flowed through 5 m (16 ft) of 2.5 cm (1 inch) diameter pipe. Once installed, the nozzle was approximately 28 cm (11 inches) from floor level in the smaller enclosure, simulating common subfloor clean agent systems.

TEST METHODOLOGY & PROCEDURE

Phase 1 Methodology

A recirculation system allowing for a continuous stable pump operation was used allowing collection of necessary system data with minimal loss of FK-5-1-12 for Phase 1 of testing. The associated supply and discharge system was designed and engineered to provide the best suction characteristics because of concerns about the FK-5-1-12 vapor pressure. Discharge pressures to 21 bar (300 psig) were targeted and system design components were selected based on this assumption. Considering the discharge piping system must be capable of generating a discharge nozzle pressure near 5.2 bar (75 psig), the piping distribution system was designed to minimize pressure drop due to friction loss.

During the smooth flow pump tests the procedure was as follows.

- Start the computer and verify signal readings are accurate. Record 60 seconds of data.
- At "Time" = –50 seconds, the video camera was turned on.
- The pump was turned on after 60 seconds of baseline data or at T = 0 seconds.
- The pressure of the discharge side was adjusted using the metering valve until the desired value was observed on the Ashcroft pressure gauge.
- During the test, visual readings of the flow rate, suction and discharge pressures were manually recorded along with any additional observations. These manual recordings were for comparison with data recorded by the electronic instrumentation.
- The metering valve is either left in place until the duration of the test is complete or adjusted accordingly.
- When the objectives of the test were reached, the test was terminated and all equipment was turned off.

During the pulsing flow pump tests the procedure was as follows.

- Start the computer and verify signal readings are accurate. Record 60 seconds of data.
- At "Time" = –50 seconds, the video camera was turned on.
- The pump was turned on after 60 seconds of baseline data or at T = 0 seconds.
- The pump is adjusted until the desired discharge pressure is reached.
- The pump is manually cycled in an on/off pattern during the test duration.
- Manual measurements were made of the volume of liquid flow during each specified time period. This recorded time for the specified volume was later used to compute the flow rate.
- The pump and other equipment are turned off after test objectives were achieved.

Phase 2 Methodology

In order to select and accurately size a pump for a given application, the desired flow rate and discharge pressure must be known. Table 2 provides a summary of the ideal design considerations for selecting the properly sized pump for testing during this phase. The required flow rate for a pump can be determined by using the minimum design extinguishing concentration to determine the quantity of agent necessary to be delivered within the required 10 second discharge time.

In order to achieve the desired 4.5% [V/V] design concentration of FK-5-1-12 in the two test enclosures, the discharge time was adjusted accordingly to fit 10 second agent quantity requirements. As shown in the last column of Table 2, the discharge time was increased from between 14 to 17 seconds and decreased to 4 or 5 seconds for the respective enclosures based on the total nozzle orifice opening. This discharge time modification was necessary to compensate for the testing of only one pump and not two individual properly sized pumps.

It is also necessary to point out that the discharge time started at the moment of liquid appearing at the nozzle. Given a pipe length of 13.3 m (43 ½ feet) in length for the pipe arrangement for the 100 m^3 enclosure, the pump obviously operated slightly longer than the nozzle discharge times.

Table 2: Extinguishing Concentrations and Discharge Times

Enclosure Size [m^3]	Desired Design Concentration [V/V]	Agent Required [kg (lbm)]	Desired Nozzle Pressure [bar (psi)]	Flow Rate for 10 Second Discharge [kg/s (gpm)]	Required Discharge Time [seconds]
100	4.5	65.5 (144.5)	6.2 (90)	6.6 (66.7)	14-17
29	4.5	19 (42)	6.2 (90)	1.9 (19.3)	4-5

In all other aspects of these tests, the test protocol for heptane can fire tests outlined in International Standard 14520-1 (C.6.3) was followed. As a summary, the steps were as follows.

- Fill cans with heptane and place in remote corners of enclosure and behind baffle.
- Start data acquisition system and video cameras
- Ignite all cans and allow a 30 second pre-burn.
- Activate pump and begin agent flow – start discharge time at moment liquid appears at nozzle
- Stop pump at end of pre-determined discharge time and evaluate if cans are extinguished within 30 second period
- Ventilate enclosure

RESULTS & DISCUSSION

Phase 1 Results

Observations made during this test phase indicate that FK-5-1-12 can be pumped in a closed loop system using three different pump types resulting in both a smooth and pulsing flow regime. Interestingly, more than 53,000 liters (14,000 gallons) have been pumped through the test pumps and piping systems to date. It is important to note that the suction sides of the pumps described below were in a flooded state at the start of each test.

Pump 1

Adjustments to the metering valve while operating Pump 1 allowed the discharge pressure to be varied from as low as 7 bar (100 psi) up to 19.3 bar (280 psi) with respective flow rates between 190 and 19 L/min (50 gpm and 5 gpm). The pressure and flow performance for the test system arrangement using Pump 1 are summarized in Figure 1.

Figure 2 displays the results of a test where the pump was allowed to operate for over an hour after being set for a constant discharge pressure of 19.3 bar (280 psi). The resulting flow remained relatively constant near 30 L/min (8 gpm). The slight decline in discharge pressure and flow rate is attributed to the increasing temperature of the liquid agent being circulated within the test loop and the high accuracy of the flow meter used that was able to pick up such differences.

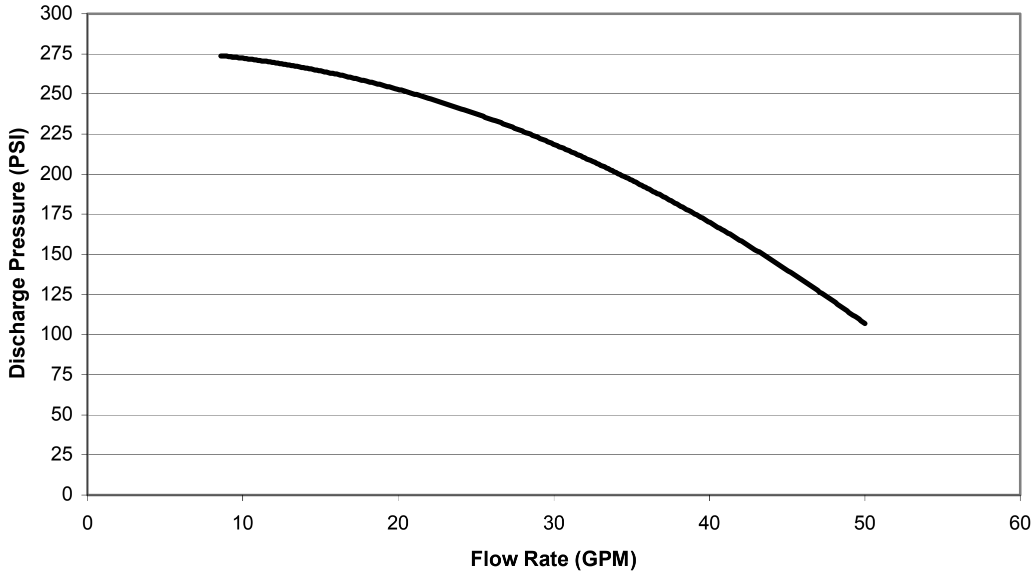

Figure 1: Pump 1 (centrifugal) - Performance Chart

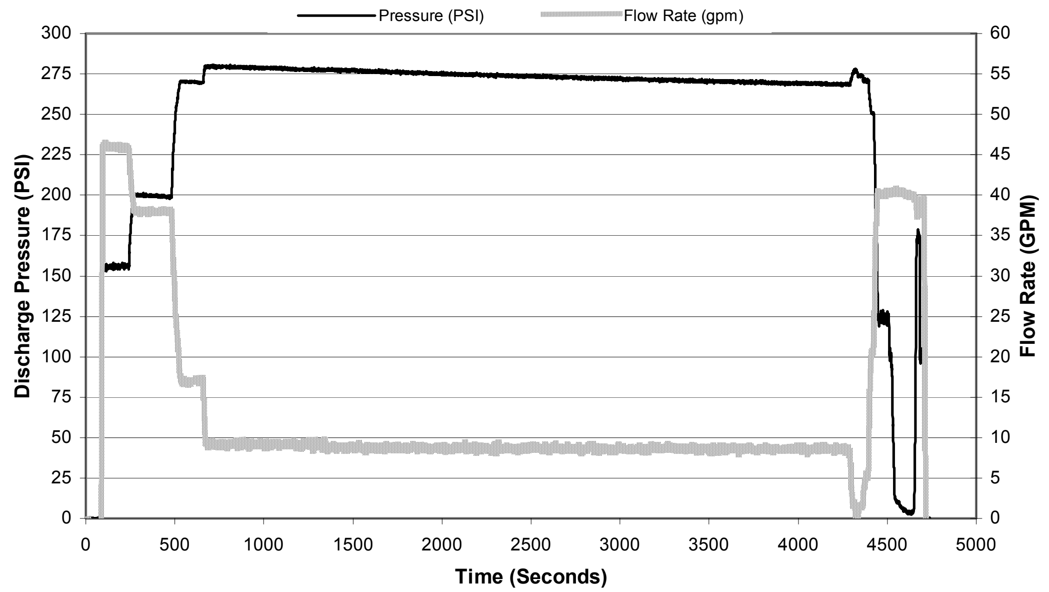

Figure 2: Pump 1 (centrifugal) - Constant Orifice

Figure 3 displays the discharge pressures measured during a cycled discharge test. During this particular test, a constant discharge pressure of 17 bar (250 psi) was established using the metering valve while the pump was operating. Once the operating pump system reached the desired pressure of 17 bar (250 psi), the pump controller was turned off for approximately 15 seconds and then on for approximately 15 seconds. This cycle was repeated until sufficient data was collected.

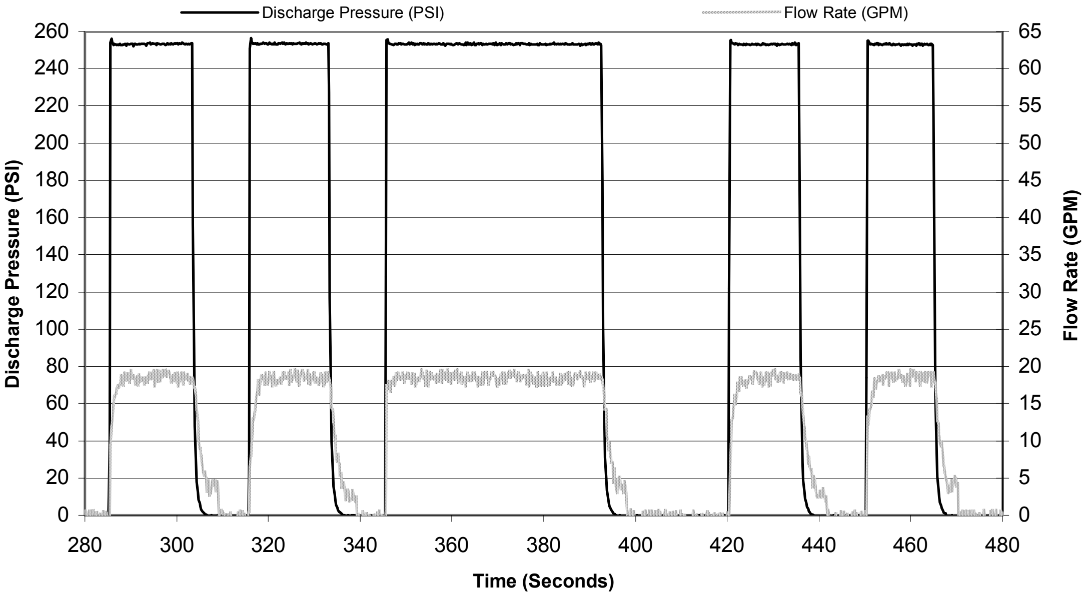

Figure 3: Pump 1 (centrifugal) – Cycled Discharge Test

Figure 4 reveals that the desired discharge pressure of 17 bar (250 psi) can be achieved in less than 1 second when measured at a distance of 1.2 m (4 feet) away from the pump.

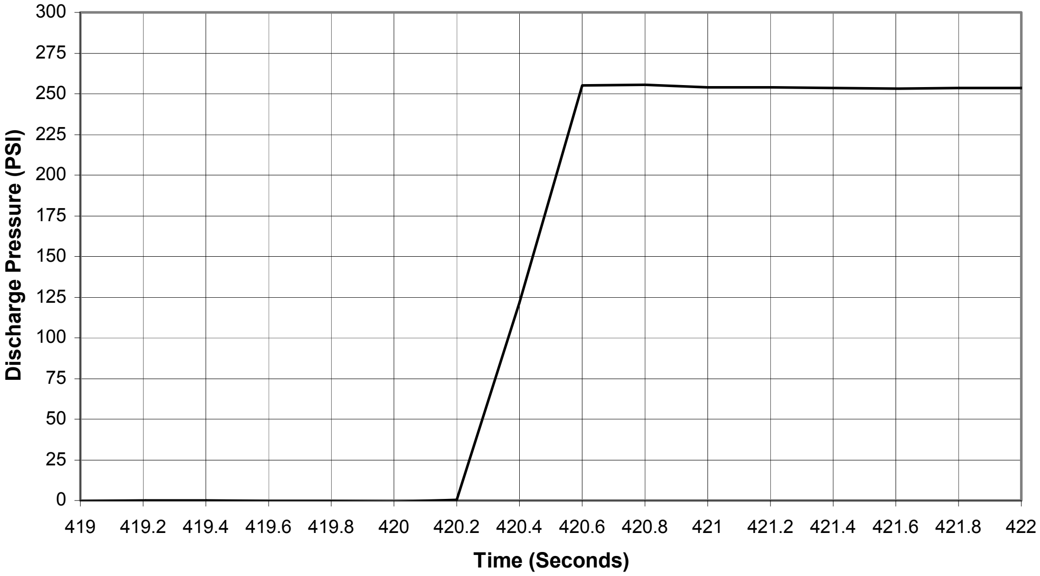

Figure 4: Pump 1 (centrifugal) – Cycled Discharge Test, Time Scale Closeup

Pump 2

Observations during tests utilizing Pump 2 (compressed gas diaphragm pump) demonstrate that FK-5-1-12 is capable of being pumped in a pulsing flow condition. Although this test arrangement did not provide the precision to "dial" in a desired discharge pressure as in the Pump 1 system, discharge pressures were measured between 0.3 and 2.4 bar (5 and 35 psi) with resulting flow rates in the range 20 and 4.9 L/min (5.3 to 1.3 gpm). Figure 5 shows the performance curve for Pump 2 operating with two distinct inlet supply air pressures. Tests were not performed with Pump 2 to determine the time required to reach a pre-defined discharge pressure nor were discharge periods greater than 10 minutes tested.

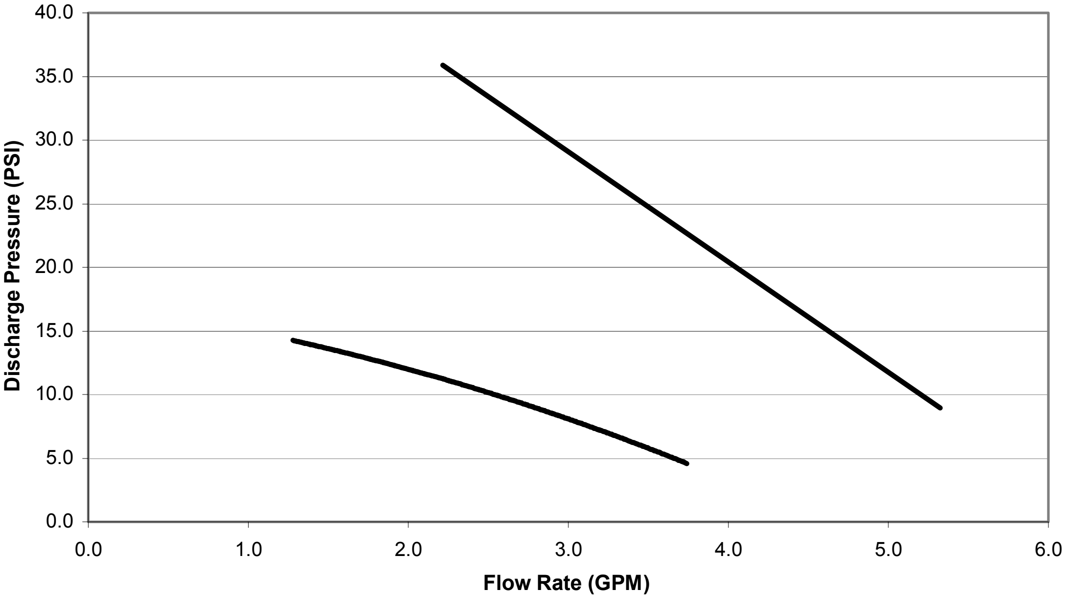

Figure 5: Pump 2 (compressed gas diaphragm pump) – Performance Curves

Pump 3

Results from Pump 3 (gear pump) provide an exciting insight and verification of a new potential use for small or local application markets. Flow rates ranging from 0.5 to 1.1 L/min (0.13 to 0.3 gpm) within a discharge pressure range of 0.3 to 11 bar (5 to 160 psi) were measured during this test series. By varying the nozzle and pump operating conditions, three separate performance curves were developed. These curves can be found below in Figure 6.

It is important to note that the curves in Figure 6 merely represent some of the flow and pressure capabilities of this single nozzle arrangement. A multiple nozzle arrangement would affect the flow rate and corresponding pressure and/or pump size. The small size of the system components provides a great deal of flexibility in system design and overall operation allowing each system to be designed for the specific application.

Phase 2 Results

The most promising results of this research, is reporting the successful extinguishment of all heptane can fires during several fire tests in both full-scale test enclosures. Several discharge nozzles were examined during this testing phase with total orifice openings ranging from 96.8 to 161 mm^2 (0.15 to 0.25 in^2). In order to accelerate the extinguishing agent out of the nozzle and assist in a change from liquid to gas, smaller than normal nozzle hole sizes were used when compared with currently available nozzles for use in pressurized cylinder systems.

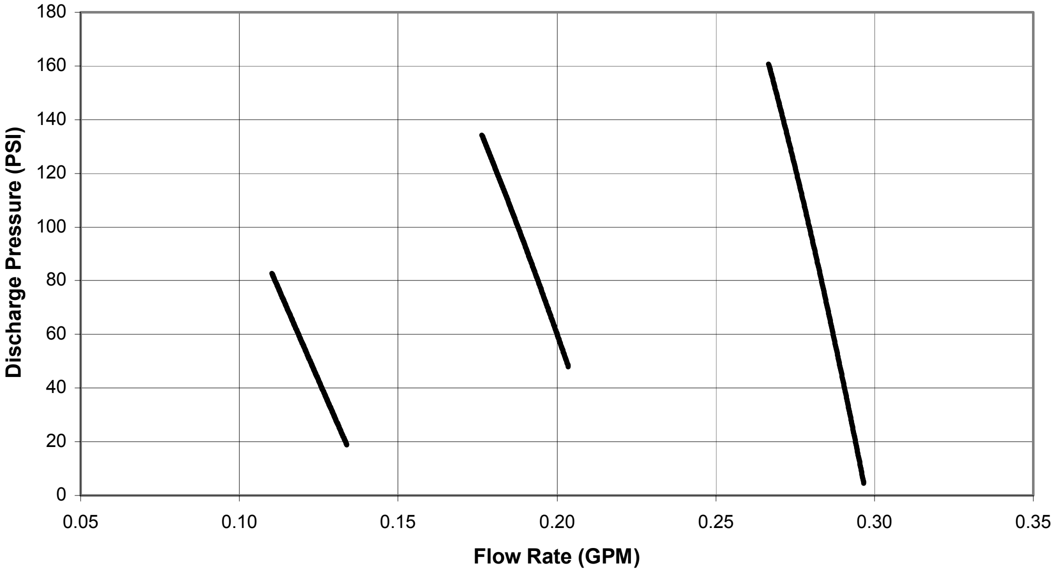

Figure 6: Pump 3 (gear) – Performance Curve

The first nozzle tested had 48 holes arranged in a 360° pattern. The large quantity of holes were needed in order to allow enough FK-5-1-12 to pass thereby, 16 of the holes had a larger diameter opening and the remaining 32 holes were smaller in diameter. Although the first discharge using this nozzle extinguished all of the fires, the long discharge time made this a less than desirable choice due to the 10 second discharge requirement in the approvals test method. Figure 7 shows that the discharge time exceeded 20 seconds. Also as expected, the discharge pressure at the nozzle did not follow the decaying pressure plot that is associated with typical pressurized cylinder discharges.

Besides monitoring the various system pressures, the flow rate of FK-5-1-12 was recorded throughout the tests. The flow rate measurements plotted in the following figures provide a point of reference from when the pump was turned on. The initial surge in flow is indicative of the piping network filling with extinguishing agent. When the fluid reaches the nozzle and the flow is restricted, the flow decreases and the nozzle pressure begins to rise.

Consequently, the sudden drop in nozzle pressure designates the point at which the pump is turned off. At nearly the same instant the pump is turned off, the ¼ turn discharge valve is closed stopping the flow of FK-5-1-12 through the flow meter. During some of the tests, the valve was closed a second or two after the pump was turned off (Figure 7). This ultimately allowed a small amount of FK-5-1-12 to continue flowing into the piping network past the flow meter suggesting that the flow continued to the nozzle when in fact the liquid discharge did stop. The remaining fluid in the pipe was then recaptured using another smaller pump and put back into the test tank.

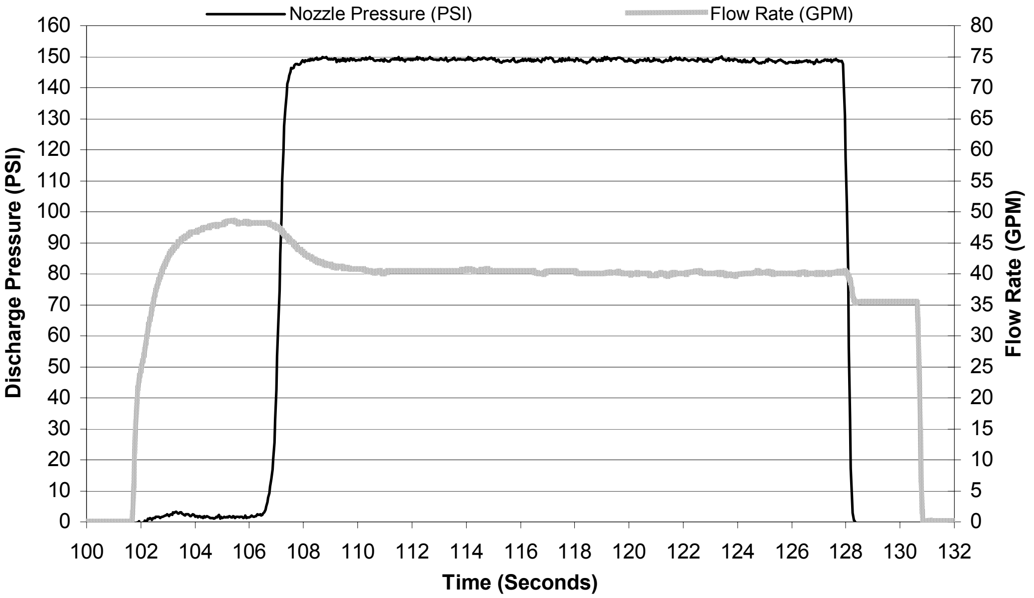

Figure 7: Nozzle Distribution Verification Test (#41) - 100 m^3 Enclosure - Nozzle Orifice 0.177 in^2

After a number of tests using this hybrid nozzle, the decision was made to examine a more traditional discharge nozzle. Therefore an aluminum nozzle having sixteen holes of 3.2 mm ($^1/_8$ inch) diameter each was selected for the next test. This nozzle arrangement also proved effective at extinguishing all of the fires in the 100 m^3 enclosure using a 14 second liquid agent discharge. The fires were extinguished within the 30 second time period identified in the test standard, immediately following end of liquid discharge. A plot of the nozzle pressure can be seen in Figure 8.

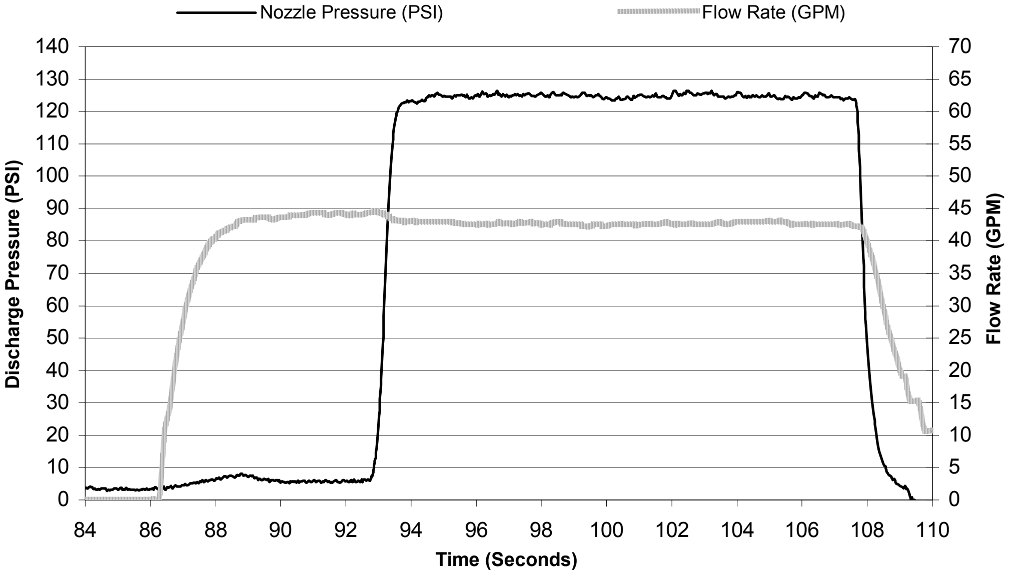

Figure 8: Nozzle Distribution Verification Test (#45) - 100 m^3 Enclosure - Nozzle Orifice 0.196 in^2

In order to provide a contrast of the nozzle pressures, a plot from a typical 24 bar (360 psi) pressurized cylinder discharge test has been overlaid onto the pressure chart from a test conducted within the 29 m^3 subfloor enclosure using a pump (Figure 9). As discussed in a previous section, discharge times during fire tests with the pump were shortened below the standard 10 seconds in order to accommodate for the pump being oversized for this enclosure. The nozzles are both attached to nominal 2.5 cm (1 inch) NPT piping. The nozzle orifice for the pump system was 75.5 mm^2 (0.117 in^2) while the orifice for the nozzle used in the cylinder discharge test was 150 mm^2 (0.2323 in^2). All of the fires in both tests were extinguished. Only the flow rate for the system utilizing a pump is included in the chart because the mass loss rate was not recorded for the cylinder based system nor was flow rate recorded.

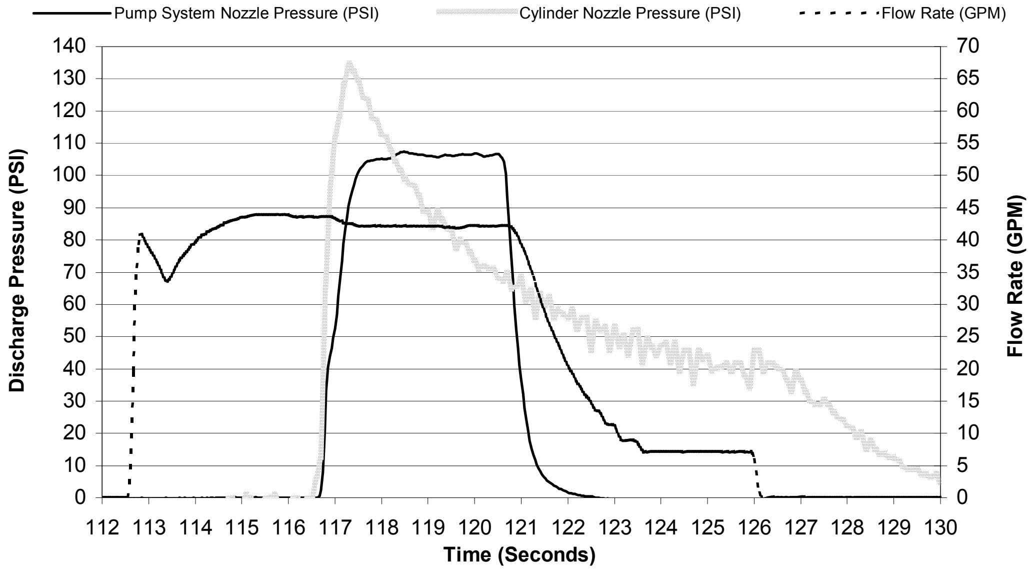

Figure 9: Nozzle Distribution Verification Test (#47) - 29 m^3 Enclosure

CONCLUSIONS

This study proves the concept of pumping FK-5-1-12 is a technically viable substitute to high-pressure gas cylinders for clean agent fire protection systems. FK-5-1-12 does not behave like a “typical” clean agent gas nor is it as easy to pump as water. The ability to pump FK-5-1-12 requires careful evaluation of the pump type, pump internal configuration, internal pump materials, storage container and ancillary piping arrangement based upon the application.

The applications for a clean agent utilizing a pump include, but are not limited to, systems where agent is required to be stored remotely from the hazard area, locations where the inertion of flammable atmospheres is necessary and where mission critical equipment needs to remain online. Small, self contained portable systems could be installed directly inside of electrical equipment enclosures as an alternative to protecting the entire room volume and pumps can easily be programmed for cycled (on/off, on/off) discharge periods or interact with combustible gas detectors. Pumping FK-5-1-12 provides the ability to deliver agent to a nozzle at a consistent and steady pressure without the high to low pressure transition present with a pressurized gas or liquid during delivery. This fact is considered to be of significant additional value for agent disbursement, extinguishment times and maintaining concentration levels for prolonged time periods.

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1) *International Standard 14520-1:2000E Annex C*, International Standards Organization, 2000.
2) *UL 2166, Halocarbon Clean Agent Extinguishing System Units,* Underwriters Laboratories