Considerations for Achieving Extinguishing Concentrations

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Halon alternative agents are utilized to protect very high value assets or functions. These systems are installed at relatively large expense and are often additional fire protection over and above the requirements of building or fire codes. The primary measure of success of a system is fire extinguishment. To insure fire extinguishment the concentration developed in the protected enclosure(s) must exceed the extinguishing concentration for the particular agent used and particular hazard protected. This paper will examine some of the considerations necessary to insure that the design concentration is achieved and the fire extinguished.

The actual concentration delivered to an enclosure may vary from the design concentration for many reasons, even for systems that are properly designed, installed and maintained. This variation may result in the delivered concentration being higher, **or** lower, then the design concentration, depending on the system. The paper will examine some of these factors and attempt to quantify their impact on achieving the design concentration.

The paper assumes that the proper extinguishing concentration has been chosen for the hazard being protected, that a minimum of a **20%** safety factor over the extinguishing concentration is being used for the design concentration, and that the systems have been properly designed, installed and maintained. If any of these assumptions are not true, the system cannot be expected to function properly, and a fire may not be extinguished.

The example calculations done in the paper are for the halocarbon agents, most often FM-200™. Qualitatively, the analysis holds for all of the halocarbon agents, but the calculated numbers may vary. For the inert gasses, the analysis would also be similar

Factors Resulting in Higher Concentrations being Delivered

There are several factors within the standard design practice that can result in **the** delivered concentration actually exceeding the design concentration. The factors addressed are: agent quantity calculation is conservative, non-fixed material in the enclosure is not accounted for, enclosure temperature, and elevation above sea level.

Agent Quantity Calculation

The equation used to calculate the quantity of agent required to protect an enclosure is provided in the National Fire Protection Associations (NFPA) Standard on Clean Agent Fire Extinguishing Systems (NFPA **2001).** This equation is assumed to be conservative (a greater design concentration is actually achieved then is specified). The equation for the halocarbon agents is:

$$W = \frac{V}{S}\left(\frac{C}{100 - C}\right) \qquad (1)$$

W weight of agent, lbs
V net volume of enclosure, ft^3
S specific vapor volume, ft^3/lb
C design concentration, %.

The enclosure must "leak" the entire volume of agent, as a gas, that is added. If the enclosure did not leak, significant over-pressure would occur (about 1 psi for a **7%** design concentration) potentially causing damage to the enclosure. This leakage takes place both during the system discharge, and after the discharge as the enclosure warms up. When agent begins to be discharged, it flash vaporizes cooling the enclosure and causing the enclosure to develop a momentary sub ambient pressure condition. As the discharge continues, and more agent vaporizes, the increase in the quantity of gas in the enclosure causes it to pressurize. This pressurization of the enclosure continues after the discharge is complete as the gas in the enclosure absorbs heat from the walls and objects and warms back up.

The concentration of the agent in the gas that is leaked from the enclosure fluctuates during the discharge and is unknown. The equation assumes that the entire volume of gas leaked is at the final design concentration. Test measurements indicate that this assumption is conservative and less agent is actually leaked.

The tests consisted of discharges of FM-200™ into three separate enclosures **(426 ft^3, 427 ft^3, 1024 ft^3)** from a single cylinder. The design concentration was varied from about **3.5%** to 7%. The average actual measured concentration is plotted with the design concentration in Figure **1.** The measured concentration consistently exceeds the design concentration. At a design concentration of **6.9%** the measured concentration was 7.1%, an increase of about 3%.

The equation assumes that there is not a preferential leak of agent from the enclosure during the discharge. A preferential leak may occur if a nozzle jet is pointed at an opening in the enclosure or if ceiling tiles were to come loose near a nozzle during the discharge.

The gas leaking from the enclosure in these situations would be very rich in agent and the delivered concentration may actually be lower then the design concentration.

Non-fixed Material in the Enclosure

The equation above includes an enclosure volume term. The enclosure volume is taken as the net volume, which is the gross enclosure volume minus fixed structures impervious to the clean agent. In general, the room will also contain a significant amount of material that is not fixed and cannot be subtracted from the gross volume. The volume occupied by this material will result in an effective decrease in the enclosure volume and an effective increase in the delivered concentration.

An estimate of this effect can be calculated. If the floor loading of this material is estimated to be 20 lbs/ft^2, and the density of the material is estimated at 50 lbs/ft^3, and the enclosure has a 10 foot ceiling height (these numbers nominally represent a typical computer room) then the volume occupied by the material is 0.4 ft^3/ft^2. The delivered concentration would be **4%** higher then the design concentration because of this effect.

The material in the room is not fixed and cannot be relied upon to be present. The enclosure volume, and hence the amount of clean agent, cannot be reduced yb this amount. However, in most cases, the delivered concentration will exceed the design concentration.

Conservative Design Basis - Enclosure Temperature and Elevation Above Sea Level

The temperature used to determine the specific vapor volume, from Equation **2,** should be the lowest temperature expected in the enclosure.

$$S = k_1 + k_2 T \qquad (2)$$

k_1, k_2 least square fit constants
T enclosure temperature, °F

For instance, if the temperature used in the equation is 60 °F, but the actual temperature during the discharge **is 70** °F, the resulting delivered concentration would be expected to be 2% higher then the design concentration.

NFPA 2001 also includes an Atmospheric Correction Factor for elevations that differ from sea level. At elevations above sea level, less agent is required to achieve a specified design concentration then at sea level. The correction factors listed are in steps of 1000 feet of elevation. The conservative use of the correction factor would be to round to the lower elevation above sea level. For instance, if the actual elevation is 4500 feet, and the correction factor used is for 4000 feet, the delivered concentration would be expected to be about 2% higher then the design concentration.

Factors Resulting in Lower Concentrations being Delivered

There are several factors within the standard design practice that can result in the delivered concentration being less the design concentration. The factors addressed are: agent vapor left in the cylinder and piping and nitrogen dilution of the delivered concentration in the enclosure.

Agent Vapor Left in Cylinder and Piping

After the discharge some agent vapor will remain in the cylinder and piping. The quantity of agent left is a worst case when the cylinder is at minimum fill density with the maximum pipe volume allowed. For the halocarbon agents, this is generally a fill density of 30 lbs/ft^3 and a percent in pipe of 80% (pipe volume is 80% of the liquid agent volume). At the end of liquid discharge, the maximum possible agent vapor left is **6%** of the initial fill quantity. The calculation is based on the ideal gas law with agent vapor pressure of 50 psi and temperature of 50 °F.

The majority of this agent vapor is discharged during the gas blow down of the cylinder and piping. When the pressure inside of the cylinder has reached atmospheric, the maximum amount of agent that can be left as vapor is 2%.

Nitrogen Dilution of the Delivered Concentration

The halocarbon agents are delivered from cylinders that have been super-pressurized with nitrogen to **360** psig. This nitrogen may cause the concentration in the enclosure to be diluted if it is delivered as a large slug after the liquid agent has been delivered. Again, the worst case is when the cylinder is at the minimum fill density with the maximum amount of pipe.

Assuming the entire cylinder and pipe volume is filled with nitrogen at 200 psig and **30 °F** (conservative compared to actual pressures and temperatures), the maximum amount of dilution of the concentration is 2%.

Factors Resulting in Lower or Higher Concentrations being Delivered

Some factors can change the distribution of the agent amongst the nozzles of a pipe network. This may affect the delivered concentration if the nozzles are in separate enclosures. The factors addressed are: small diameter pipe and nozzles and repeated tee splits.

Small Pipe and Nozzles

There can be considerable variability in the inside diameter of small pipe. For instance, **3/8** inch pipe has a nominal inside diameter of 0.493 inches. The pipe specification calls for an outside diameter of 0.675 inches and a minimum wall thickness of **0.80** (compared to a nominal of 0.91 inches) resulting in a possible inside diameter of 0.515 inches. The cross sectional flow area can vary by 9% between the nominal pipe diameter and the largest possible inside diameter.

Measurements made on 6 pieces of **3/8** inch pipe yielded an average inside diameter of 0.489 inches (with an extreme of **0.480** inches). The average measured inside diameter would have **3%** less flow area then the nominal.

The tolerance on drilling the orifices for a nozzle is generally plus of minus 0.001 inches. For an **8** port **3/8** inch nozzle, this tolerance in the drilled orifice could result in a **3%** variability in the nozzle **flow** area.

The potential effects on system performance can be illustrated with an example. The system in Figure 2 is meant to be a balanced 50:50 split at the tee. Both runs of pipe are 20 feet of **3/8** inch. The run to one side is made of pipe at the extreme end of inside diameter (0.515 inches) and the run to the other side is made of pipe of the measured inside diameter **(0.489** inches). This system was calculated using listed software. There was a 7% shift in mass being delivered, from **18.0** lbs from each nozzle to **16.8** lbs from the side with the smaller inside diameter pipe and 19.2 lbs from the side with the larger inside diameter.

The calculation for the system shown in Figure 2, using the inside diameters indicated, may not be the worst case relative to these effects, but is very highly pessimised. Actual variability in the agent delivered from **3/8** inch pipe would generally not be this large. *Also,* these effects drop off very rapidly for larger diameter pipes.

Repeated Tee Splits

Repeated tee splits could also result in the delivered concentration being **less** then the design concentration. The system in Figure **3** is an example. **A** split ratio, for instance 70:30, does not change significantly relative to the quantity of agent being delivered to the tee. **If** 100 lbs of agent is delivered to the tee then 70 Ibs goes out one branch and **30** lbs out the other branch. If only 95 lbs are delivered to the tee, then **66.5** lbs goes out one branch and **28.5** Ibs out the other branch.

If each branch in Figure 3 allowed only 99% of the expected mass of agent to continue to the next tee, the nozzles on the far end of the pipe network would receive less agent then expected. If, as in Figure 3, one of these nozzles is in a separate enclosure, the delivered concentration for this enclosure would be less then the design concentration.

The split ratio at a tee is determined by flow calculation software when the system is designed. The software is tested to very stringent limits in the listing and approval protocols. An individual nozzle is allowed to be over predicted by a maximum of 5%, or under-predicted by a maximum of 10%. The actual installation in the field will also affect the split ratio (for instance, by variability in pipe inside diameter). Individual tee splits can be expected to vary somewhat from design.

The system shown in Figure 3 is vulnerable to errors in the split ratios because the agent for the final nozzle in the separate enclosure must pass through 7 tee splits. The system design in Figure 4 would be far less vulnerable, as the agent for the final nozzle must only pass through 3 tee splits. An even less vulnerable design would be a completely separate supply for the separate enclosure.

Conclusions

For systems that are properly designed, installed and maintained, the delivered concentration can vary from the design concentration for the reasons identified in this paper. Other reasons that were not included, but could also affect the delivered concentration, are: cylinder leakage, non-homogeneous dispersion and mixing of the agent, and variability in internal pipe roughness.

Two types of systems were identified that are more vulnerable to factors that could result in delivered concentrations being less (or more) then design concentrations. These are systems that utilize small pipe diameters (3/8 inch) and systems with multiple tee splits. Design practice can minimize the potential effects.

The variation does not appear to be more then a few percent for most systems designs and adequate agent should be delivered to provide effective fire extinguishment.

Figure [illegible] Measured Concentration versus Design Concentration

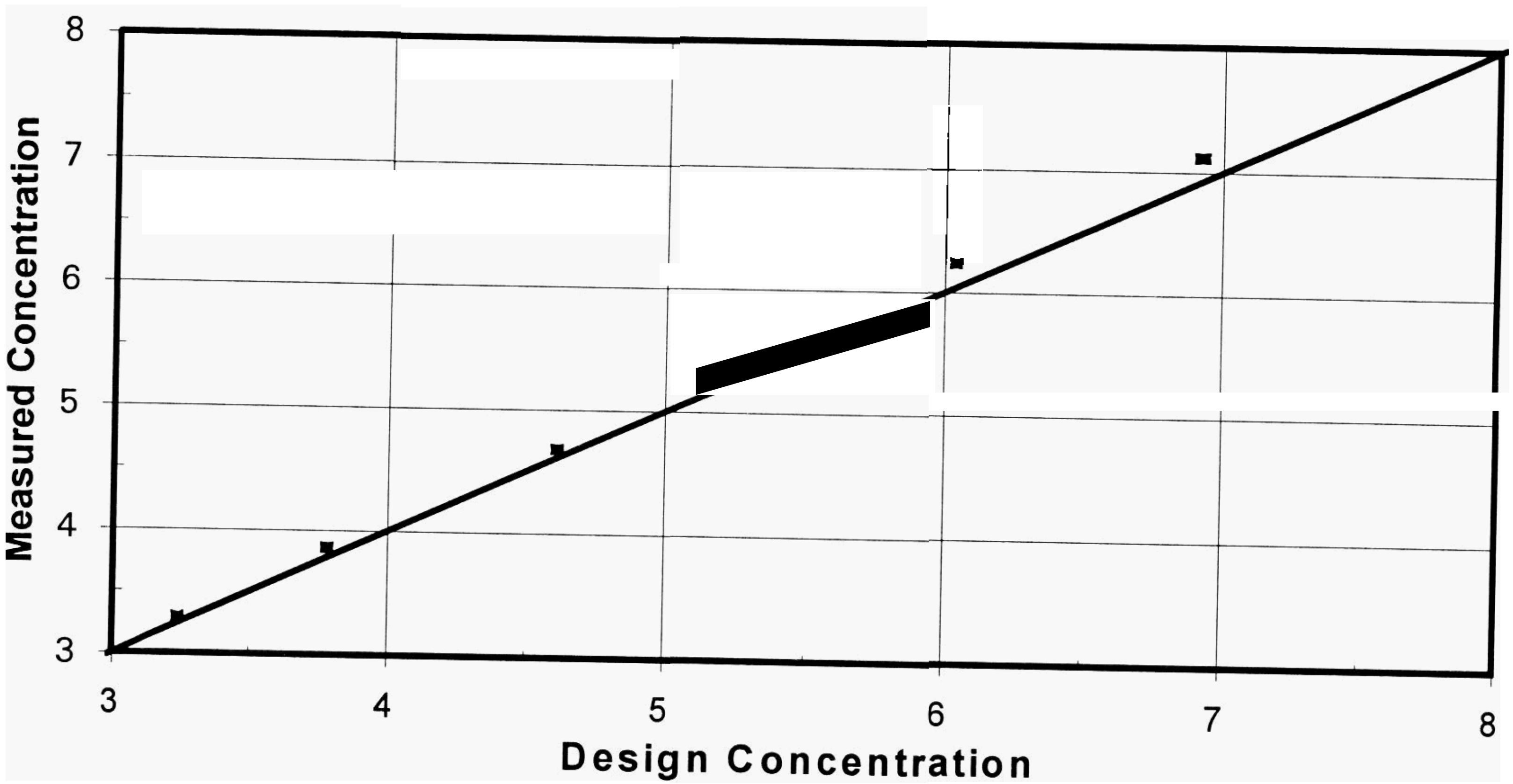

Figure 2. Example system utilizing 3/8 inch pipe.

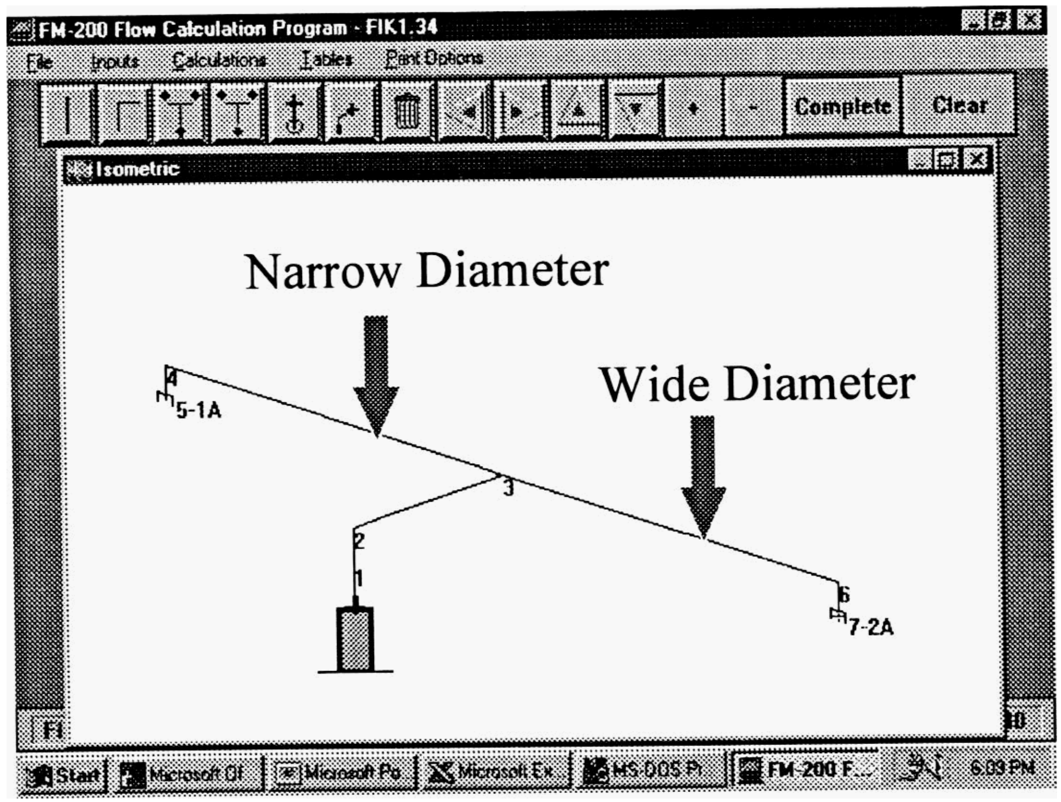

Figure 3. System requiring 7 tee splits.

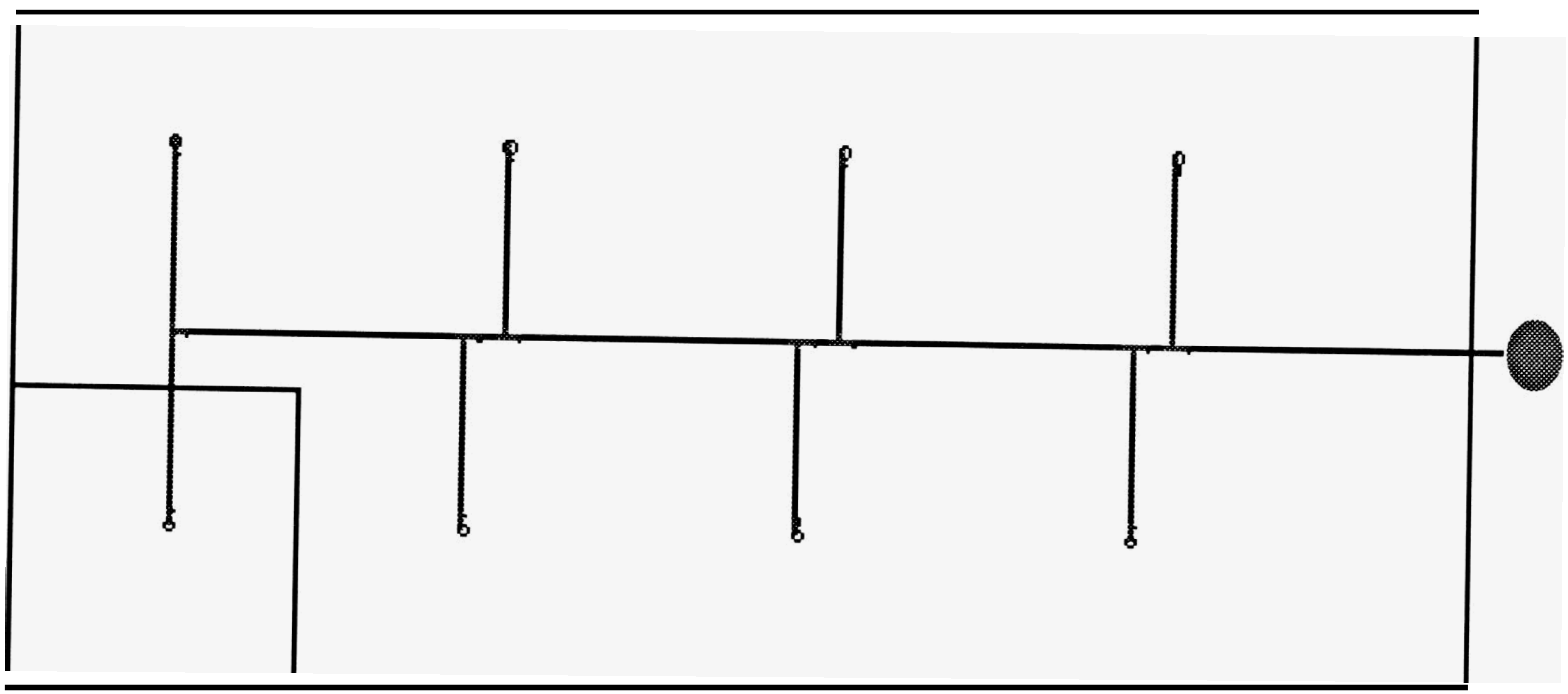

Figure 4. System requiring 3 tee splits.