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FEASIBILITY STUDY ON USING GAS PROTECTION SYSTEM WITH FM-200 IN HONG KONG

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ABSTRACT

The properties of the clean agent FM-200 will be reviewed and its extinguishing mechanism will be studied. The benefits of using gas protection system with FM-200 will be compared with Halon 1301 on the environmental impacts and also the health effect. In order to achieve a better performance in using FM-200 as a fire extinguishing agent in a particular application, the design concentration of FM-200 with respect to a particular fuel is an important parameter in the system design. The current status of national and international fire protection standard requirements for the protection of Class B fire hazard with FM-200 is studied, along with the determination of the minimum design concentration by the cup burner test.

1. INTRODUCTION

In the past few decades, the use of the fire suppression agent Halon 1301 (CF_3Br) in total flooding applications has prevented the loss of human lives and billions of dollars of equipment. As Halon 1301 has a potential to damage the upper stratospheric ozone, the production of Halon 1301 was halted in advanced countries on January 1, 1994, as agreed in the Montreal Protocol using ozone depleting chemicals. Clean agents substituting Halon 1301 were developed, HFC-227ea (CF_3CHFCF_3, 1,1,1,2,3,3,3-Hepta-fluoropropane), the tradename Fire Master 200 (FM-200®), is one of them.

FM-200 is characterized by high fire suppression efficiency, low toxicity, low electrical conductivity, and long-term storage stability. It produces no corrosive or abrasive residues upon extinguishment. It has been proven to extinguish fires without leaving any residue. The contribution of physical mechanisms to the extinguishment of fires also predominates over the chemical mechanism. It suppresses fires primarily by extracting heat from the flame reaction zone, reducing the flame temperature below which is necessary to maintain sufficiently high reaction rates by a combination of heat of vaporization, heat capacity, and the energy absorbed by the decomposition of the agent. Oxygen depletion plays an important role in reducing flame temperature. The energy absorbed in decomposing the agent by breaking the fluorine bond is quite important, particularly with respect to decomposition production formation [1,2].

In the extinguishment process, small amounts of FM-200 thermally decompose to form the halogen acid HF. HF is the primary decomposition product of interest relative to human safety and equipment damage. High HF concentrations or exposure can result in severe human health problems and corrosion or failure of sensitive electronic equipment. The amount of thermal decomposition and HF produced depends on several primary factors, including discharge time, fire growth rate, agent concentration, enclosure volume and size of the fire [3].

FM-200 does not contain chlorine nor bromine and should not damage the stratospheric ozone. It has zero Ozone Depletion Potential (ODP) which is a measure of the ability of a chemical to deplete stratospheric ozone in comparing with CFC-11 which has an ODP of 1. Based on these several benefits on fire extinguishment and one of the replacement options most similar in system design and function to Halon, FM-200 is recommended for replacing Halon as a fire extinguishing agent [1].

In this paper, the properties and extinguishing mechanisms of FM-200 will be reviewed. The parameters in system design (with reference to environmental aspects and potential health effect) in using FM-200 and Halon 1301 will be compared. The design concentration of FM-200 for Class B fires by cup burner test will also be studied.

2. THE FM-200 SYSTEM

2.1 Fire Extinguishing Mechanisms of FM-200

The extinguishment of fires has traditionally been attributed to three actions: removal of heat, the physical separation of the fuel and the oxidizer, or the removal of the oxidizer. These three mechanisms of fire extinguishment come from the basis "fire triangle" – heat, fuel and oxygen.

In the case of FM-200, the contribution of physical mechanisms to the extinguishment of fires also predominates over the chemical mechanism. It suppresses fires primarily by extracting heat from the flame reaction zone, reducing the flame temperature below which is necessary to maintain sufficiently high reaction rates by a combination of heat of vaporization, heat capacity, and the energy absorbed by the decomposition of the agent. Oxygen depletion plays an important role in reducing flame temperature. The energy absorbed in decomposing the agent by breaking the fluorine bond is quite important, particularly with respect to decomposition production formation [1].

The chemical contribution to flame extinguishment arises from the thermal decomposition of small amounts of FM-200 in the flame which form fluorinated fragments such as CF_3 and CF_2. These will then consume and remove the key combustion chain-propagating species H, O, and to a lesser extent OH radicals. The rates of chain-branching combustion reaction will decrease, the chemical flame is inhibited and the flame propagation is halted [2].

Fire is the physical manifestation of a series of high heat-releasing chemical reactions between fuel and oxygen. While a proportion of the heat is dissipated to the surroundings, sufficient heat must be returned to the fuel for it to vaporize and continue the combustion process. Physically, extinguishing agents act by absorbing heat and disturbing this dynamic energy balance. Introduction of sufficient agent into the fire gases reduces the flame temperature to a limiting value below which flame propagation cannot occur [4].

2.2 Environmental Aspects

Halon 1301 is a more efficient extinguishant despite having poorer heat absorbing qualities than FM-200. This is because in addition to the heat absorption effect, the bromine in Halon 1301 catalyses removal (through recombination) of the flame propagating radicals and so suppresses the fire by chemical means. Halon 1301 produces HBr and HF breakdown products in a fire. However, bromine causes depletion of the ozone layer. The FM-200 extinguishing agent produces HF in greater quantities but no HBr. It has no ozone depletion and the shortest atmospheric lifetime of all HFC alternatives to Halon 1301 and a minimal environmental impact.

2.3 Health Effect

The primary short-term "acute" toxicity effect of the halocarbon agents is cardiac sensitisation. It is a term describing the sudden onset of cardiac arrhythmias in the presence of a concentration of an agent, caused by sensitisation of the heart to epinephrine [1].

The toxicity endpoints used to describe cardiotoxicity and allowable exposure levels are: No Observed Adverse Effect Level (NOAEL) and the Lowest Observed Adverse Effect Level (LOAEL). The NOAEL is the highest concentration of an agent at which no "marked" or adverse effect occurred. The LOAEL is the lowest concentration at which an adverse effect was measured [1].

The use of halocarbon agents in occupied areas is generally subject to the constraint that the design concentration must be less than the NOAEL. A comprehensive toxicological evaluation of FM-200 concluded, brief episode exposure to concentrations of less than 14 % by volume appears to present little or no risk to human health. Typically, FM-200 requires a design concentration of 7 %, which is well below the 9 % of NOAEL on cardiac sensitisation. The NOAEL for Halon 1301 is only 5 % (the same as its design concentration). The LOAEL of FM-200 is greater than 10.5 % but less than 14 % by volume.

2.4 Thermal Decomposition Product

In the extinguishment process, small amounts of FM-200 thermally decompose to form the halogen acid (HF). HF is the primary decomposition product of interest relative to human safety and equipment damage. High HF concentrations or exposure can result in severe human health problems and corrosion or failure of sensitive electronic equipment. Numerous studies have indicated that the amount of HF produced from the extinguishment of Class B fires with FM-200 ranges from two to six times or more the total decomposition products (HF + HBr) formed from extinguishment of the same fire with Halon 1301. Rapid detection and discharge allow for the control and reduction of thermal decomposition products following extinguishment of fires with FM-200 [3].

Table 1: Summary of the environmental aspects between FM-200 and Halon 1301

Agent	Ozone Depletion Potential (ODP)	Global Warming Potential (GWP) [100 yr]	Atmospheric Lifetime (yr)
FM-200	0	2050	31
Halon 1301	16	5800	100

Table 2: Toxicity data for FM-200

	NOAEL	LOAEL
HFC-227ea	9.0 % v/v	>10.5 % v/v

2.5 Replacement of the Existing Halon System

Under the regulations from the Montreal Protocol, it is undoubtedly that Halon system will be phased out in a few years. Hence, companies installing Halon system now would be facing the problem of replacing the extinguishing agent and significantly modifying the system within a few years as the pressure to cease the use of these transitional chemicals intensifies. FM-200, one of the alternative halocarbon agents, has a zero Ozone Depletion Potential (ODP) and an acceptably low Global Warming Potential (GWP), giving it a significant advantage in the marketplace. In particular, FM-200 has a similar toxicity to Halon 1301, and a design concentration of 7 % (compared to 5 % for Halon 1301). Hence, although its use will usually require larger pipework and in particular more storage cylinders, the difference is substantially smaller than with other replacement agents. This has led to the adoption of FM-200 as the extinguishing agent of choice [5].

3. DESIGN CONCENTRATION

The extinguishing or inerting concentrations shall be used in determining the agent design concentration for a particular fuel. The extinguishing concentration for Class B fuels shall be determined by the cup burner test method. The minimum design concentration for a Class B fuel hazard is equal to the extinguishing concentration times a safety factor of 1.3 [6]. The minimum design concentration is a function of the fuel, the agent, and the delivery system. Design concentrations for specific hazards must be determined in accordance with the system manufacturer's approval or listing.

The amount of FM-200 clean agent required to achieve the design concentration can be calculated [1] from the following equation:

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

where W is the weight of agent required (kg), S is the specific volume of the superheated agent vapour (m^3kg^{-1}), V is the net volume of protected space (m^3), C is the design concentration (%), and T is the minimum ambient temperature of the protected space (^oC).

4. EXPERIMENTAL METHODS

The cup burner test has historically been employed to determine the extinguishing concentrations for Class B fires, and served as the basis for establishing the design concentration for clean agent fire extinguishing systems. The cup burner test provides a difficult extinguishing challenge due to the elimination of turbulent air flow past the flame and the high stability of the cup burner flame resulting from flame anchoring effects. A generalized description of the cup burner test procedures may be found in Annex B of the BS ISO 14520-1:2000 Standard on Gaseous Fire-Extinguishing Systems [7].

The principle of the test is that the diffusion flames of fuels burning in a round reservoir (burner as the cup), centrally positioned in a coaxially flowing air stream, are extinguished by addition of a gaseous extinguishant (FM-200) to the air. The components included in the whole set-up are a glass cup, a glass chimney, a diffuser, a mixer, the delivery system, the air supply, the liquid fuel supply and also the extinguishant supply (FM-200). The experiment will be ensured to perform in an enclosure area with good ventilation system. Sufficient safety precautions for the fire laboratory are suggested. Absolutely, the influence to the surroundings and the safety concerns are estimated before starting the experiment.

Table 3: Comparison of the system design between FM-200 and Halon 1301

Similarities	**Differences in using FM-200 in comparing with Halon 1301**
Electrically non-conductive	Higher design concentration
Vaporize readily	More quantity of agent, more cylinders usage
Leave no residue	More thermal decomposition products
Liquefied compressed gases storage	Environmental friendly
Airtight protected enclosure	Larger pipework
Space and weight efficient	Lower health effects

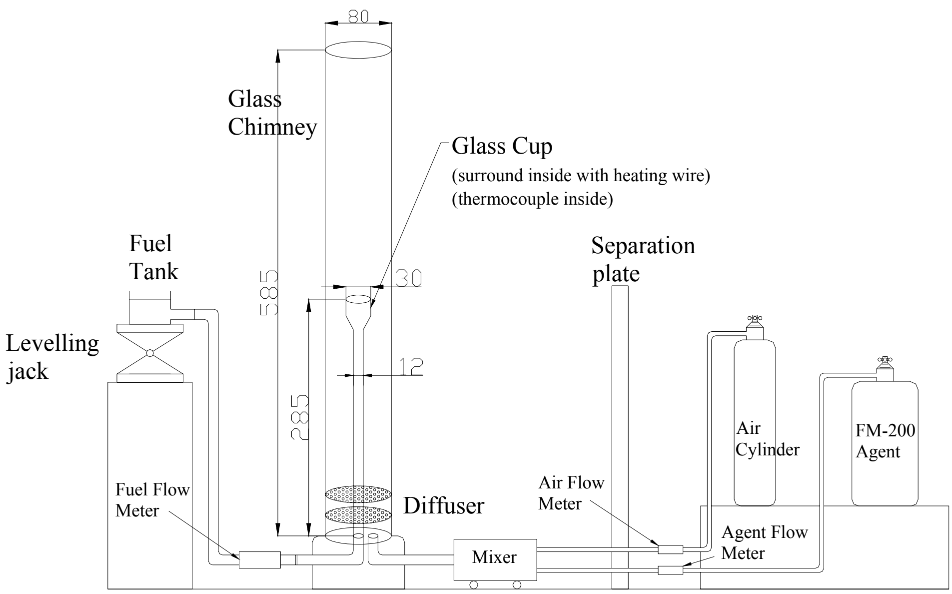

Fig. 1: Designed cup burner test rig

A designed cup burner test rig with reference to the ISO Standards is shown in Fig. 1.

In considering the designed setup of the cup burner test, the ISO standards and NFPA standards are used as references. Although there are several existing results in cup burner test, most of them are performed in North Europe and North America. Because of the different climate when comparing with Hong Kong, the performance of FM-200 may have a different result. The testing environment of the enclosure including the temperature and the humidity are the parameters which may lead to different results in the design concentration of FM-200. Besides, the different sizes in the chimney and the cup are also one of the parameters which may affect the design concentration of FM-200. It is because the size of the chimney acts as the net volume of the enclosure, while the size of the cup acts as the size of the fire source. Therefore, the ratio between the size of the chimney and the cup is an important parameter affecting the design concentration.

Different diameters of chimney are prepared, 80 mm, 60 mm and 40 mm. Also, the different diameters of cup are 30 mm, 25 mm and 20 mm. The chimney and the cup are made of glass which can stand high temperature. The diffuser is made by the upper and lower debris screens with many 2 mm diameter holes. It is located at the bottom of the chimney for mixing well the extinguishing agent before flowing up towards the fire source in the cup. Regarding different design concentrations against different kinds of fuels, several fuels including propane, unleaded gasoline, and alcohol will be used. They will be used to fill in the fuel tank besides the chimney. The fuel level in the fuel tank is equal to the fuel level in the cup so that the fuel level in the cup can be maintained. For the fuel level in the cup will be fluctuated during burning, the levelling jack can be used for adjustment in order to maintain a equal fuel level and also a constant flow of fuel. The mixer is also used to premix the air and the FM-200 before entering the diffuser. The amount of air and FM-200 are pre-calculated by using equation (1). In the measurement, a K-type thermocouple is installed in the cup to measure the temperature of the fire source. Also, some heating wires are installed inside the cup to provide a preheated condition for the fuel. One of the oxygen concentration detection points is located at the top of the chimney in order to measure the remaining oxygen concentration during burning. Another detection point is the supply oxygen concentration in the air supply. Based on equation (2), the design concentration of FM-200 can be calculated. The list of apparatus is shown in Table 4.

The oxygen O_2 sensor has to be calibrated by using the room air as the span gas. Ambient air is almost universally 20.9% O_2 by volume. To calibrate the zero point, nitrogen gas is used free of O_2, the O_2 Calibration Kit Model 801939 provides the zero gas, consisting of a cylinder of pure nitrogen.

Table 4: Specification list of all apparatuses in the cup burner test

Apparatus	Size	Measurement range	Remarks
K-type high temp. flexible wire thermocouple probes	25" L probes with miniconnector 1.6 mm diameter	(-250 to 920 ^{o}C)	0.6 sec time constant 3 sec response time
Direct reading air flow meter with bench mount	150 mm diameter Stainless steel made with valve	(0 to 60 L/min)	± 5 % full-scale accuracy Max. pressure = 14 bar Operating temp. = (-26 to 121 ^{o}C)
Levelling jack	150 × 150 mm^2 plate Max. height = 280 mm Max. load = 60 kg		
Gas mixer	120 mm diameter 350 mm length		2 inlets, 1 outlet Max. pressure = 10 bar
FM-200 agent	10 kg in quantity		Storage in 4.5 kg CO_2 cylinder
Series CA-6200 CA-CALC^{TM} combustion analyser		(0 to 25 % of O_2 conc.)	± 0.3 % accuracy Measurement accurate to 0.1 %

K-type thermocouple   Mixer   Air flow meter   Oxygen analyser

Fig. 2: Pictures of the apparatuses

5. RESULTS AND MEASUREMENT

For Class B fires, the minimum design concentration required is 8%. The enclosure temperature is assumed to be around 20^{o}C. The specific vapour volume can be found from the table given in the ISO Standards. Referring to the dimensions of the chimney, the net enclosure volume can also be calculated. According to equation (1) in determining the total agent quantity, the weight of FM-200 is 1.7 g.

The extinguishing concentration of FM-200 in air for flammable liquids can be determined by this test. An on-line gas analyser is calibrated for the concentration range of the extinguishant-air mixtures being measured. The remaining oxygen concentration in the chimney can be measured with a continuous oxygen analyser. The extinguishant concentration will then be calculated [7] as follows:

$$C = 100\left(1 - \frac{O_2}{O_2(\text{sup})}\right) \qquad (2)$$

where C is the extinguishing concentration (% v/v), O_2 is the oxygen concentration in chimney (% v/v), and O_2(sup) is the oxygen concentration in supply air (% v/v).

One of the limitations of the use of the cup burner test is the variability in the extinguishing concentration as measured by different investigators, due to the lack of standardization of both the cup burner apparatus itself and its operation. In addition, recent experience has shown that a larger scale cup burner apparatus tends to give higher extinguishing concentrations when compared to smaller scale cup burners. While the cup burner test has proven to be a valuable analytical tool as a starting point for establishing the system design concentration for Class B fires, it is only through rigorous full-scale fire testing of the system, conducted by independent approval agencies as a part of a product listing or approval process, that these values can be verified [8].

6. CONCLUSIONS AND FUTURE WORKS

The design concentration is adjusted to a suitable value for different situations such that the amount of FM-200 can be estimated. Obviously, it is suggested that the concentration of the agent can be reduced as much as possible. It saves not only the space provided to agent storage (fewer cylinders required) but also the cost of installation. In summary, the FM-200 gas suppression system actually is worth to adopt in replacing the existing Halon system because of the feasibility usage of FM-200 extinguishing agent.

In the next semester, the cup burner test will be performed. More calibration works and detailed safety precautions will be done before the starting of the test. Different sizes of the glass cup and the glass chimney will be prepared in order to analyse whether there has a ratio relationship as a result of the design concentration of the agent.

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REFERENCES

1. Fire Protection Handbook, 18th edition, Section 6, Chapter 19, National Fire Protection Association, Quincy, MA, USA (1997).
2. M.L. Robin, FM-200®: Theory of fire extinguishment, Great Lakes Chemical Corporation (2001).
3. Understanding the thermal decomposition of FM-200® and the effect on people and equipment, GLK-427-6, Great Lakes Chemical Corporation (1997).
4. FM-200® fire extinguishing agent, KIDDE Fire Protection Ltd. (2000).
5. P. Jennings, Which halon replacement?, Retrotec Europe.
6. BS ISO 14520-9:2000, Gaseous fire-extinguishing systems – Physical properties and system design – Part 9: HFC 227ea extinguishant, British Standards Institution (2000).
7. BS ISO 14520-1:2000, Gaseous fire-extinguishing systems – Physical properties and system design – Part 1: General requirements, Annex B, British Standards Institution (2000).
8. Understanding current fire protection standards and FM-200® performance, GLK-426-6, Great Lakes Chemical Corporation (1997).

Q & A

Q1: The FM200 can be used in computer rooms to protect these expensive equipments. Do we need so expensive systems to protect these fires of low value? Maybe the fire loss is less than the system cost.

Choy: It is necessary to protect important locations with FM200. Other cheaper systems may be used to protect these fires of low value.

Q2: In open areas, how to use FM200 for liquid fires?

Choy: FM200 can be used only in confined rooms.

Q3: How to extend your small-scale fire tests to full-scale tests? The concentration of agent and the effect of ventilation should be considered carefully.

Choy: We used cup burner for liquid fuel fire in our small-scale tests to study the agent concentration for fire extinguishment. According to NFPA test, fuel is assumed to fill all the room, so the agent concentration equation can be deduced by considering the ventilation effect.