A New Particulate Extinguishant for Flammable Liquid Fires

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ABSTRACT

Exfoliated vermiculite was tried first time at the Fire Research Laboratory of the Central Building Research Institute, Roorkee (India) for extinguishment of flammable liquid fires. Five series of experiments were conducted using exfoliated vermiculite as an extinguishant varying petrol layer thickness, preburn time, ullage and size of fire. It was found that 16 cm of exfoliated vermiculite thickness on top of flammable liquid is required for extinguishment of fires. The material was tried upto 5 sq m petrol and kerosene liquid fires using very simple but automatic extinguishment technique. The vermiculite in sealed polyethylene bags was kept immersed in kerosene oil for three years to see the effect of liquid on it. Thus a new particulate extinguishant has been developed for the first time to extinguish any type of flammable liquid fires. An Indian patent for the same was applied on 26th April, 1975 and was granted on 11th February, 1978 (No.143, 818).

INTRODUCTION

During the last 40 years or so almost entire world has experienced a very rapid progress in industrial and scientific areas. Hydrocarbon processing industry can take most of the credit for this rapid industrial progress. A concerted effort in tune with national and international policies on crude oil output was made by the Oil & Natural Gas Commission and others to make the country fairly self sufficient in crude oil production by stepping up exploration of oil fields both in onshore & offshore areas on one hand and refining more crude oil on the other hand. As industrialisation, modernisation and production are getting momentum, the variety, complexity, scale of fire and explosion hazards are increasing.

Conservation of petroleum products and other fuels is as important as their production, as is evident from the international oil crisis of the early seventies when crude prices skyrocketed and almost every country, dependent on oil imports, was forced to spend each year an amount equal to its total foreign exchange reserves. Fire prevention, early suppression and fire loss minimisation gain added importance and therefore place additional responsibilities on the persons engaged in fire prevention, research, development and fire fighting for the immediate and foolproof emergency planning. The paper presents a brief review of fire hazards involved, storage of flammable liquids and work carried out on development of a new extinguishing material in this field at the Fire Research Laboratory of the Central Building Research Institute, Roorkee (India).

OIL PRODUCTION AND CONSUMPTION

Oil & Natural Gas Commission is the major Public Sector Organisation in India dealing with oil/gas exploration both in onshore & offshore areas. As the country is determined to improve standard of living of its population through industrialization its total energy requirement is increasing with a rapid pace. This will inevitably result in a larger number of fires with higher fire losses. Crude Oil, received through a pipe line, is stored in large capacity oil storage tanks at the pumping terminal sites as well as at the receiving end in refineries. The size of such tanks poses serious problem of fire protection. Since crude oil containing volatile hydrocarbons is highly flammable, it is therefore stored in floating roof storage tanks avoiding loss of volatile products. In the event of leakage through the floating roof seal any source of ignition like mechanical friction or even lightning can result in a fire on the peripheral seal of the floating roof. Considering the large size of tanks such fires may not be noticed immediately and in case it spreads more, the roof of tank may collapse setting the entire oil content of the tank on fire. It is even further difficult to fight flammable liquid fires in fixed roof storage tanks.

EXTINGUISHING AGENTS

The specialized fire protection systems which are being used or which can be used alone or in conjunction are :

1. Foam systems
2. Dry powder systems
3. Inerting gas systems &
4. Halogenated hydrocarbon inhibiting systems

One or combination of following mechanisms is associated with each of these.

1. Blanketing
2. Smothering
3. Dilution of flammable vapours either by extinguishing agent or by decomposition products of the agent
4. Cooling, heat absorption either from the flames or from the burning materials
5. Chemical inhibition.

For flammable liquid fires mechanisms 1 & 2 are most widely applicable. Keeping these two criteria in view, a new material (exfoliated vermiculite) was tried for the first time in the Central Building Research Institute, Roorkee which was lighter than flammable liquids.

EXTINGUISHING MATERIAL

Vermiculite is the geological name given to a hydrated laminar mineral comprising aluminium, iron & magnesium silicates, soft and flaky in structure, with the colour ranging from brown to black and resembling mica in appearance. It is found in various parts of India and is obtained by open cast mining method. After removing rock and other impurities, crude mineral is crushed and sorted into various grades. Crude vermiculite consists of thousands of separate laminations per inch thickness of vermiculite and between each flake is a thin layer of water. When heated under controlled conditions to temperatures ranging from 700°C to 1000°C, the flakes exfoliate 7 to 15 times their original volume, due to steam formation forcing laminae apart as steam is driven off. The exfoliated vermiculite consists of accordion like granules containing millions of minute air layers resulting in its high insulation value and very low specific gravity.

Properties

The Chemical composition of vermiculite is

SiO_2	39 – 45 %	MgO	15 – 20 %
Al_2O_3	14 – 20 %	CaO	1 – 2 %
Fe_2O_3– FeO	6 – 11 %	K_2O	4 – 7%
TiO_2	1 – 2 %	Na_2O	0.5 – 1 %
H_2O	5 – 9 %		

Exfoliated vermiculite is incombustible, odourless, non abrasive, rot proof, non irritant, reflective, mouldable, clean to handle and chemically inert. The material is available in different grades with different densities. The sintering temperature of vermiculite is about 1260°C and its melting point is 1315°C. Table 1 shows the approximate particle size, density and its main uses.

TABLE 1

Approx. particle size(mm)	Density Kg/m^3	Main uses
<1.5	128 - 160	Plaster aggregate
<3	88 - 112	Plaster aggregate High temperature insulation
<4.5	72 - 88	High temperature insulation
<6	64 - 80	Concrete aggregate loose fill

EXPERIMENTS

The material was tried for the first time at the Central Building Research Institute, Roorkee for extinguishment of flammable liquid fires in 1973. The concept crystallized after the properties of the material specially the specific gravity, non combustibility and chemical inertness were studied. It was planned to carry out work on exfoliated vermiculite for extinguishment of liquid fires by top surface application as it would not allow fire to continue by stopping feedings of the flammable liquid vapour to combustion zone. The variables selected were :

Vermiculite (a) Volume , (b) Size

Fire (a) Liquid layer thickness, (b) Depth of water (ullage), (c) Size of fire, (d) Preburn time

The following series of experiments were conducted on petrol and kerosene oil fires.

I Series	Depth of petrol layer v/s volume of (exfoliated) vermiculite(preburn time constant, 45 seconds)
II Series	Preburn time v/s volume of exfoliated vermiculite (petrol layer constant)
III Series	Depth of water (ullage) v/s volume of exfoliated vermiculite (Depth of petrol, preburn time & size of vermiculite constant)
IV Series	Size v/s volume of exfoliated vermiculite (depth of petrol & preburn time constant)
V Series	Size of fire v/s volume of vermiculite (Depth of petrol, ullage, preburn time and size of vermiculite constant).

In the I Series of experiments, a mild steel tank of 27.5 cm diameter and 45 cm height was used. Exfoliated vermiculite was applied from another tank with a butterfly valve arrangement as shown in Fig. 1. The liquid level in the tank was always kept constant. Petrol in the tank was ignited manually by a pilot flame and was allowed to burn for 45 seconds, when exfoliated vermiculite was poured from a fixed distance of 150 cm (top surface of the liquid) by operating a butterfly valve. It was concluded that only 6 litre of exfoliated vermiculite was required for 0.1 cm thick layer of petrol. However, if the thickness of petrol layer was increased, 8 litre of vermiculite was found sufficient irrespective of thickness of petrol layer. Results of experiments are shown in table 2.

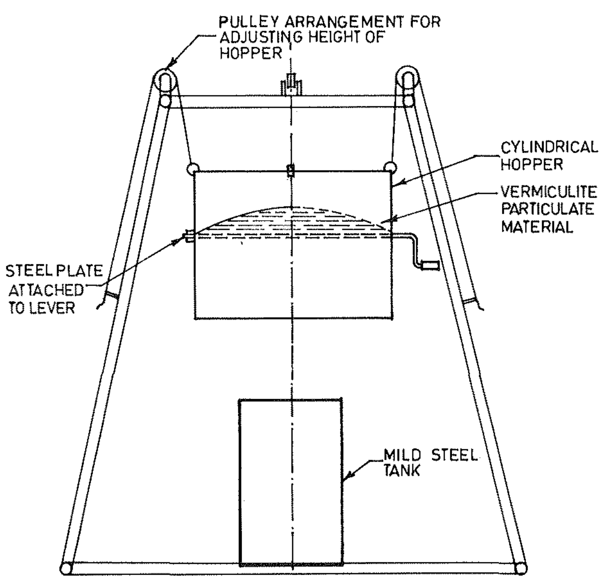

FIGURE 1. Experimental set up

TABLE 2 Depth of petrol v/s volume of exfoliated vermiculite

Sl. No.	Thickness petrol(cm)	Volume petrol (ml)	Preburn time (second)	Volume of Vermiculite (litre)	Time of extinction (second)
1.	0.1	60	45	4	4
	0.1	60	45	6	2
2.	0.2	120	45	4	No extinction
	0.2	120	45	6	Part extinction
	0.2	120	45	8	2
3.	0.3	180	45	8	2
4.	0.4	240	45	8	2
5.	0.5	300	45	8	2
6.	0.6	360	45	8	2
7.	0.7	420	45	8	2
8.	0.8	480	45	8	2
9.	0.9	540	45	8	2
10.	1.0	600	45	8	2
11.	-	1000	45	8	2

Thus it was established that there was no variation in the volume of exfoliated vermiculite required for more than 120 ml of petrol in the tank. Hence for further studies 500 ml of petrol was taken. If 500 ml of petrol is allowed to burn over 35 cm water column in the tank, it takes 7 minutes to extinguish itself.

In the II Series, experiments were carried out to find volume of vermiculite required for different preburn time with a constant water column of 35 cm under petrol layer. Results are shown in table 3. Thus it was established that volume of vermiculite required to extinguish petrol fire also increases with preburn time, but after 55 seconds it becomes constant i.e. 10 litre.

In above two series of experiments depth of water or ullage was kept constant at 35 mm, which might have an effect on extinguishment though many other factors in favour and against were also involved. Hence in the next series of experiments depth of water was also varied and results are reported in table 4. Thus volume of exfoliated vermiculite required to extinguish 500 ml petrol fire in the tank, decreased with ullage to a minimum value of 5 litre.

In all the above experiments exfoliated vermiculite used was of size 4.5 mm as it was assumed that greater the particle size higher will be the capacity to float on the flammable liquid surface due to lower bulk density. In the next series, experiments were conducted to determine best suitable size range. Results are reported in table 5, which lead to the conclusion that efficiency of vermiculite increases with particle size. The bigger particle size is responsible for creating more void area thus rendering blanketing mechanism more effective.

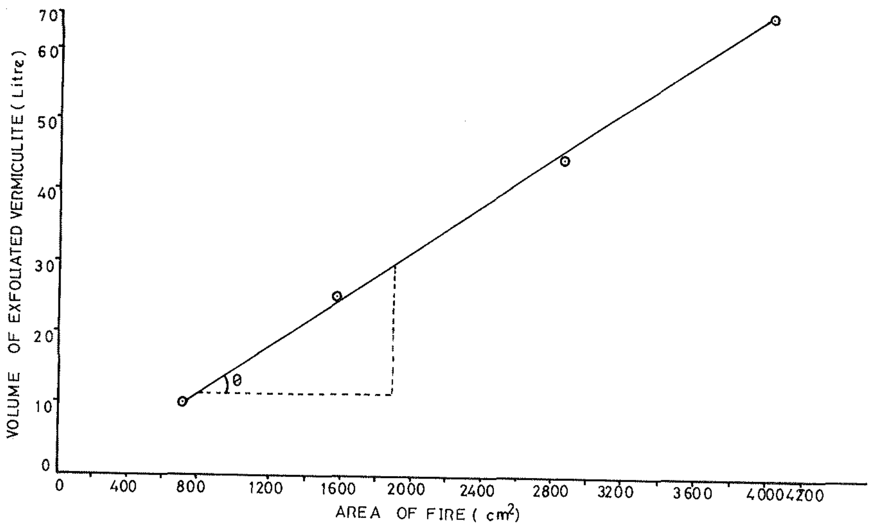

FIGURE 2. Size of fire v/s volume of exfoliated vermiculite

TABLE 3 Volume of exfoliated vermiculite v/s preburn time

S.N.	Preburn time(sec)	Volume of vermiculite(litre)	Remarks
1.	5	4	Extinction
2.	10	4	Extinction
3.	15	5	Partial extinction
4.	15	6	Extinction
5.	20	6	Extinction
6.	25	6	Partial extinction
7.	25	7	Extinction
8.	30	7	Extinction
9.	35	8	Partial extinction
10.	35	8	Extinction
11.	40	8	Extinction
12.	45	8	Extinction
13.	50	8	Partial extinction
14.	50	9	Extinction
15.	55	9	Partial extinction
16.	55	10	Extinction
17.	60	10	Extinction
18.	75	10	Extinction
19.	90	10	Extinction
20.	105	10	Extinction
21.	120	10	Extinction

TABLE 4. Depth of water(ullage) v/s volume of exfoliated vermiculite

Sl.No.	Depth (cm)	Volume of vermiculite(litre)	Remarks
1.(a)	35	8	Extinction
(b)	35	7	Partial extinction
2.(a)	30	7	Extinction
(b)	30	6	Partial extinction
3.(a)	25	6	Extinction
(b)	25	5	Extinction
(c)	25	4	Partial extinction
4.(a)	20	4	Partial extinction
(b)	20	5	Extinction
5.(a)	15	4	Partial extinction
(b)	15	5	Extinction
6.	10	5	Extinction
7.	5	5	Extinction

TABLE 5. Size v/s volume of exfoliated vermiculite

Sl.No.	Size of vermiculite(mm)	Volume of vermiculite(litre)	Remarks
1.(a)	<2.5	11	Partial extinction
(b)	<2.5	12	Extinction
(c)	<2.5	12	Extinction
2.(a)	<4.5 - >2.5	11	Partial extinction
(b)	<4.5 - >2.5	11	Extinction
(c)	<4.5 - >2.5	11	Extinction
3.(a)	>4.5	9	Extinction
(b)	>4.5	8	Extinction
(c)	>4.5	7	Partial extinction

In the next series of experiments effect of size of fire was seen. The results are tabulated in table 6. It is observed from the experiments that 10, 25, 50 and 75 litre of exfoliated vermiculite is required for extinguishment of 30, 45, 60 and 75 cm diameter tank petrol fire respectively. Volume of vermiculite required, is plotted v/s size of fire resulting in a straight line approximately, tangent θ of which gives thickness of exfoliated vermiculite required for complete extinguishment (Fig.2).

DISCUSSIONS & CONCLUSIONS

Fuel, which is used for extinguishing studies, is a single main factor in defining fire or assessing its thermal properties. The most important among liquid fuels is crude oil, which, depending on its

TABLE 6. Size of fire v/s volume of exfoliated vermiculite

S.N.	Volume of petrol(ml)	Dia of tank(cm)	Size of fire/area tank(sq.cm)	Volume vermiculite (litre)	Remarks
1.	1000	30	707	11	Extinction
2.	1000	30	707	10	Extinction
3.	2250	45	1591	30	Extinction
4.	2250	45	1591	25	Extinction
5.	4000	60	2829	60	Extinction
6.	4000	60	2829	50	Extinction
7.	4000	60	2829	45	Extinction
8.	4000	60	2829	40	Partial extinction
9.	6250	75	4420	80	Extinction
10.	6250	75	4420	70	Extinction
11.	6250	75	4420	70	Extinction
12.	6250	75	4420	65	Partial extinction

source has a flash point of - 6°C to 32°C and specific gravity less than 1. Vervalin(1) has given flash point values for various fuels. Wind conditions may also play a significant role. For example, a mild wind may increase the burning rate by fanning the fire while a strong wind may reduce its burning rate by cooling the fire. If the wind turns into a storm, it may even extinguish the fire depending on its speed, diameter of tank and ullage. Blinov & Khudiakov(2) studied the burning rate of various liquid fuels and showed that the burning rate initially decreased while diameter of tank increased then started increasing to become a constant value (Fig. 3). Heat transfer to the fuel surface is also important and have an effect on its burning rate. Yumoto(3) showed that heat transfer from gasoline fire of about 1.2 to 3 m diameter to the fuel surface is about 60% by radiation & 40% by convection, while for hexane fire of 3 m diameter the corresponding values are 70% & 30%.

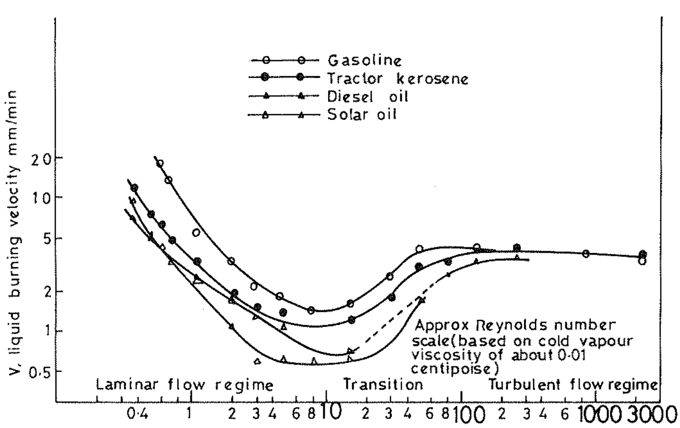

FIGURE 3. Burning rates of various liquid fuels

A new material, exfoliated vermiculite was tried for extinguishment of these types of fire. Five series of experiments were conducted varying the petrol layer thickness, preburn time, depth of water, particle size (exfoliated vermiculite) and size of fire using experimental set up as shown in Fig. 1. It is concluded from the experiments that extinguishing efficiency of exfoliated vermiculite increases with particle size. Further volume of vermiculite required for extinguishment also increases with preburn time to attain a constant value after 55 seconds. It has further been observed that 16 cm thick layer of exfoliated vermiculite is needed for extinguishment of fire. The size of fire does not have any role to play because the material is inert and is not affected by fire. Eklund(4) concluded that pool fires became fully turbulent at about 1 m diameter and flares became optically thick between 1-3 m. He further suggested that test fires could be further scaled down to 1 m diameter without losing radiative characteristics of large fires. Rashbash(5) also conducted fire tests on kerosene oil in 30 cm diameter trays with 3660 g of kerosene floating on water. He estimated the temperature to be in the range of 1200° to 1300°C with emissivity of 0.05 to 0.07

However, the apparatus used was found to be a little cumbersome due to manual operation of damper valve. Hence the set up was modified so that experiments could be conducted without much manual interference. All the experiments were repeated and results were verified by automatic extinguishment using same material with same parameters. The new test set up is shown in fig. 4. Exfoliated vermiculite was kept on a polyethylene sheet in cylindrical containers 22.5 cm in height and of diameter 15 cm more than the diameter of the tanks used for extinguishment studies. The polyethylene sheet was kept on wiremesh which was placed on mild steel stand. Two mild steel flats with a spacing of 5 mm were welded to each of two opposite sides of the stand at a distance of 22.5 cm below wire mesh so that a steel sheet could slide between the grooves for getting desired preburn time. After attaining it, the steel sheet was pulled out causing polyethylene sheet to melt resulting in pouring of exfoliated vermiculite on petrol covering uniformly total surface and extinguishing fire by blanketing mechanism.

Foam also serves the same purpose; in addition it also cools the burning liquid surface. While comparing the quantities of foam with exfoliated vermiculite it was found by Corrie(6) that 1-3 kg of foam is required per sq.m of petrol fire against 13 kg of exfoliated vermiculite. However, exfoliated vermiculite has virtually permanent life, does not deteriorate by radiations and remains unaffected by fuel properties. Further, it does not affect the container and liquid fuel; and can be utilised for extinguishing fires of any type of flammable liquid.

Exfoliated vermiculite filled in sealed polyethylene bags was kept in an environment of petrol vapours for three years without any effect on polyethylene and efficacy of exfoliated vermiculite. Laboratory scale trials on extinguishment of kerosene oil and petrol fires were carried out on 5 sq.m fire with the material. Extinguishment was instantaneous.

Thus an attempt has been made to study various parameters for developing an extinguishing material at the Central Building Research

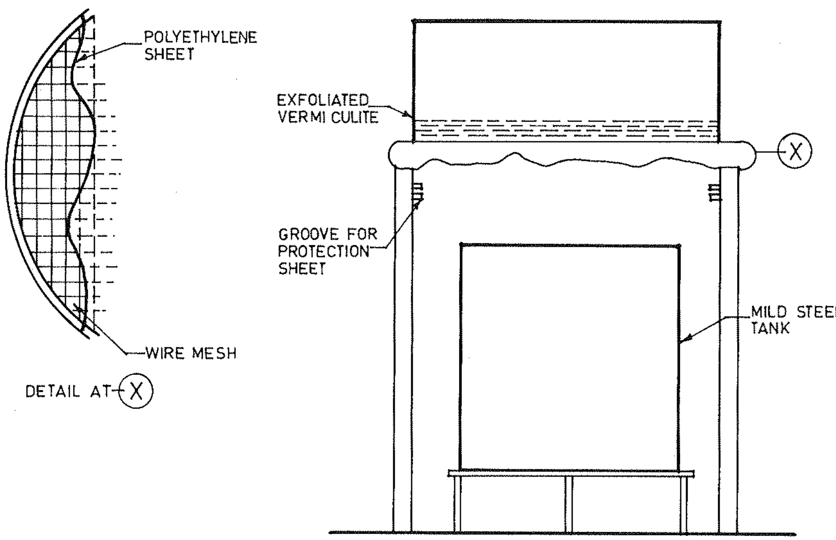

FIGURE 4. Modified experimental set up

Institute, Roorkee (INDIA). The study has resulted in development of a new particulate extinguishing material, which is easily available, is economical, inert, reusable and efficient.

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