

FUELS IN SEWERS: BEHAVIOUR AND COUNTERMEASURES

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(Received May 10, 1988; accepted July 10, 1988)

Summary

A model sewer was constructed to determine the behaviour of fuels spilled into sewers and to test countermeasures for such spills. The model sewer included a head-box containing a concrete pad with a drain which fed into a sewer pipe. Six vapour sensors were mounted at simulated manholes or ports along the sewer and were connected to a computer to provide a continuous record of sewer vapour concentrations.

It was found that vapours in sewers have two distinct origins: the first is vapour formed upon fuel entry into the sewer and the second source is evaporation from the liquid fuel as it is transported with the sewer water. The former vapour moves slowly down the sewer due to the low vapour to liquid friction coefficient.

The use of dispersants on fuel spills in sewers increases both the maximum vapour concentrations observed and the total amount of vapour released. This occurs irrespective of the amount or band of dispersant used. This is thought to be a result of the increased volatilization rate from the small droplets of fuel created by the use of dispersants. The use of fluoroprotein-type foams on fuel spills already in the sewer produces the same result as that of dispersants, primarily because most of the fuel has already evaporated. Foams do however suppress vapour release in tests where significant evaporation has not already occurred.

The use of heavy gases, carbon dioxide in various forms and Halon 1301, was also evaluated. Heavy gases reduce both the maximum concentration and total amount of vapour released. Halon is more effective than carbon dioxide, due to its greater specific gravity. Carbon dioxide released as a gas is more effective than as a solid, dry ice, or as a chemical such as sodium bicarbonate.

The study shows that the use of dispersants on fuel spills in sewers is not recommended as their use results in higher vapour concentrations. The use of dispersants will, in fact, increase the potential for and the magnitude of explosions from fuels spilled into sewers. The use of foams on spills already in sewers produces similar results to that of dispersants and is also not recommended. The use of halon and carbon dioxide results in decreased vapour concentrations in sewers. Carbon dioxide treatment is recommended as a practical and effective countermeasure for fuel vapour explosions in sewers.

1. Introduction

Fuels spilled into sewers can pose a serious explosion threat. In 1986 gasoline explosions in sewers and the subsequent fires caused a 13-block area in Saint

John, New Brunswick, to be evacuated. Fortunately, there were no serious injuries or deaths. Three buildings were destroyed in the subsequent fire. The gasoline came from a leaking underground storage tank [1,2]. Despite the seriousness of such incidents, little work has been done on the countermeasures for fuel vapours in sewer systems. Countermeasures evaluated in this paper include dispersants, foams and heavy gases.

Dispersants have been used for flushing spills into and along sewers. Proponents of this technique have claimed that this reduces the fire potential and offers a safe, convenient means of dealing with spills of flammable or explosive products in an urban environment [3,4]. The hypothesis for such usage is that dispersants would put the majority of the material into the sewer water and thus lower the vapour concentration below the lower flammability limit and below the lower explosive limit. This countermeasure has never been quantitatively examined.

The use of foams in sewer spills has not been well-documented. Foams work by forming stable bubbles (foam) over a vapour source so that the vapour cannot penetrate and thus remains contained. Vapour suppression by foams has been tested and reviewed by a number workers [5–10].

The use of heavy gases to suppress fires or flammable vapours is well-established and is the principle behind many common fire extinguishers and also behind the use of halons in building fire-suppression systems. The use of a heavy gas to specifically control flammable vapours in a sewer system, is not documented in the literature.

The purpose of this study was to examine each of these countermeasures techniques using a model sewer system. The basic criterion used to evaluate the countermeasure is the amount of vapour in the sewer, both in terms of maximum concentration and in terms of the total integral of vapour along the sewer.

2. Experimental techniques and materials

A model sewer was constructed. The basic features of this system are illustrated schematically in Fig. 1 and photographically in Fig. 2. The sewer model consisted of a 104 m length of 3.8 cm diameter pipe, which descended at a slope of 0.0048 to a sump. Water was supplied from a constant head tank through valves, resulting in a uniform flow rate throughout an experimental run. Fuel was introduced at a head box which contained a concrete pad, designed to resemble a street, sloping toward a drain. The drain, in turn, led into the sewer pipe.

Simulated manholes or ports were placed along the sewer pipe at approximately logarithmic intervals (4.5, 9.0, 18.0 m, etc.) starting from the headbox. These served as access ports to sample vapours and to provide vapour space to simulate sewer manholes. Sample probes of HNU photoionizer model PI 101

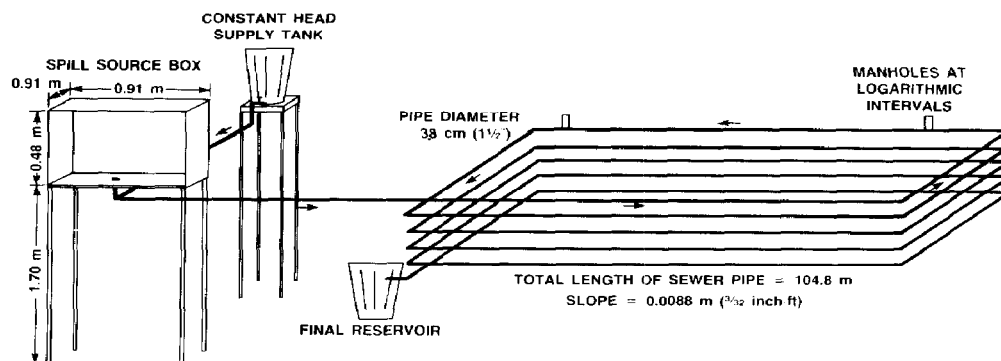


Fig. 1. Schematic of model sewer.



Fig. 2. Photograph of model sewer.

vapour sensors were placed into the manholes at a distance of 10 cm from the sewer pipe.

The HNU sensors were calibrated for measurement of both test fuels, non-leaded automotive gasoline and automotive diesel fuel, using Tedlar bags of known volume [11]. Volumes of fuel necessary to achieve the desired concentration were injected into air-filled bags, and an HNU probe attached to directly sample the mixture. The data from the calibration runs were fitted to a quadratic equation, and this equation was used in a computer program during

actual runs to provide output directly in parts-per-million (ppm) (by volume) of whichever fuel was being tested.

The outputs of the HNU instruments were directly coupled to a Tecmar Labmate analog-to-digital converter which in turn was directly coupled to a Compaq 1 computer. Data were presented on a real-time display and recorded on a floppy disk. Data were later printed on a second computer and analyzed. The computer program was designed to print out vapour concentrations and also sum these concentrations with time to give an integral of vapour appearing at each sensor. These values are summed over all six sensors and presented in this paper as 'total integrals' and represent a measure of the total vapour in the model sewer system.

Three methods of fuel introduction and countermeasures application to the sewer were used. Most experiments involved direct syringe injections of 1 ml of fuel. Countermeasure products were similarly injected at various time intervals after the fuel introduction. In the case of dispersants, a 5% solution of the dispersant in water was injected 10 s after the fuel injection.

The second method consisted of mixing the fuel and treatment solution in a syringe and directly injecting into the sewer. This was performed to measure the effect of treatments when maximum contact and high mixing energy were available. This method was restricted to evaluating dispersants.

The third method consisted of spilling fuel on the concrete in the headbox and then placing the treatment solution up-gradient from the fuel. This represents a situation where a fuel is flushed down the sewer with water, dispersants or foams.

The basic operating conditions of the model sewer are presented in Table 1. test materials were obtained from commercial sources and are listed in Table 2.

Dispersants were applied as 5% solutions in tap water. Foams were applied

TABLE 1

Sewer operating conditions

| Sample points | | Water flow rates* | | |
|---------------|----------------------------|---------------------|-----------------|----------------------|
| Number | Distance from Head-box (m) | Flow volume (l/min) | Flow rate (m/s) | Retention time (min) |
| 1 | 0 | 1 | 0.18 | 10.0 |
| 2 | 4.5 | 2 | 0.22 | 7.5 |
| 3 | 9.0 | 3 | 0.24 | 7.1 |
| 4 | 18.0 | 5 | 0.29 | 6.0 |
| 5 | 51.4 | 10 | 0.34 | 5.1 |
| 6 | 104.0 | | | |

*Water temperature $12 \pm 1^\circ\text{C}$.

TABLE 2

Test products

| Product | Description | Source |
|--------------------|--|---|
| gasoline | non-lead regular gasoline | PetroCan |
| diesel | automotive diesel fuel | PetroCan |
| Biosolve | dispersant sold for land and water fuel spills | Metra Chem Corp. Shrewsbury, Mass. |
| Corexit 9527 | dispersant sold for oil spills on water | Exxon Chemical Houston, Texas |
| Icoshine | dispersant sold for land spills | Illinois Chemical Chicago, Illinois |
| Jansolve | dispersant sold for land spills | Sunshine Chemical West Hartford, Conn. |
| Lestoil | household cleaning liquid | grocery store |
| Sunlight | household cleaning liquid | grocery store |
| Flame-out | vapour suppressing foam | Aaron Fasteners Ottawa, Ontario |
| Aero-foam | vapour suppressing foam | National Foam Lionville, Penn. |
| carbon dioxide | standard gas | Matheson Gas Ottawa, Ont. |
| Dry ice | food grade dry ice | made from gas |
| Halon 1301 | bromotrifluoromethane | Wormald fire Sys. Ottawa, Ont. |
| Sodium Bicarbonate | regular lab grade | Fisher Scientific Ottawa, Ontario |

at the same concentration, but were allowed to expand freely before injection. Gases were admitted from a cylinder through a pressure regulator and a hose to the drain in the head box. Quantities were measured by timing the release and using this data and the pressure and then mass flow measurements made at a later date. The regulators used were Matheson as was the mass flow meter. Solid products, ground dry ice and sodium bicarbonate, were admitted with syringes with large openings.

Gas chromatographic (GC) analyses were performed using a Hewlett-Packard Model 5830A with a 3% SP-2100 (1.8 m, 32 mm) column operated with a temperature ramp of 8°C/min beginning at 40°C and ending at 220°C. Samples were withdrawn from manhole number 5 using a gas-tight syringe and directly injected into the GC. The timing of sample withdrawal was based on the known arrival time of the HNU-detected peaks.

Water flow volumes were measured with calibrated cylinder and stopwatch. Flow volumes were verified before each experimental run. Flow rates were measured by determining the retention time of fluorescein dye.

Water was sampled at taps from locations beneath vapour sampling ports numbers 3 and 5. Analyses were performed using a Horiba Oil-in-water meter

Model OCMA-220; concentrations in the water were too low to be detected (less than 1 mg/l).

3. Behaviour of fuels in sewers

A significant phenomenon observed was that gasoline spilled into the model sewer produced two vapour peaks at sampling ports in the sewer system, whereas diesel produced only one. Figure 3 illustrates the two-peak phenomena for two test runs. This figure is a reconstruction of a computer real-time display. Each display presents the vapour concentrations at each port (manhole). The X-axis is the time scale and each horizontal bar represents the vertical scale of 5000 ppm. Sensor 1, in the head box, does not detect any vapours as the fuel is injected, and the small amount that subsequently escapes is not detected in the large volume of air in the head box. The diagrams show that a sharp peak appears and is followed shortly thereafter by a broader peak. Both peaks flat-

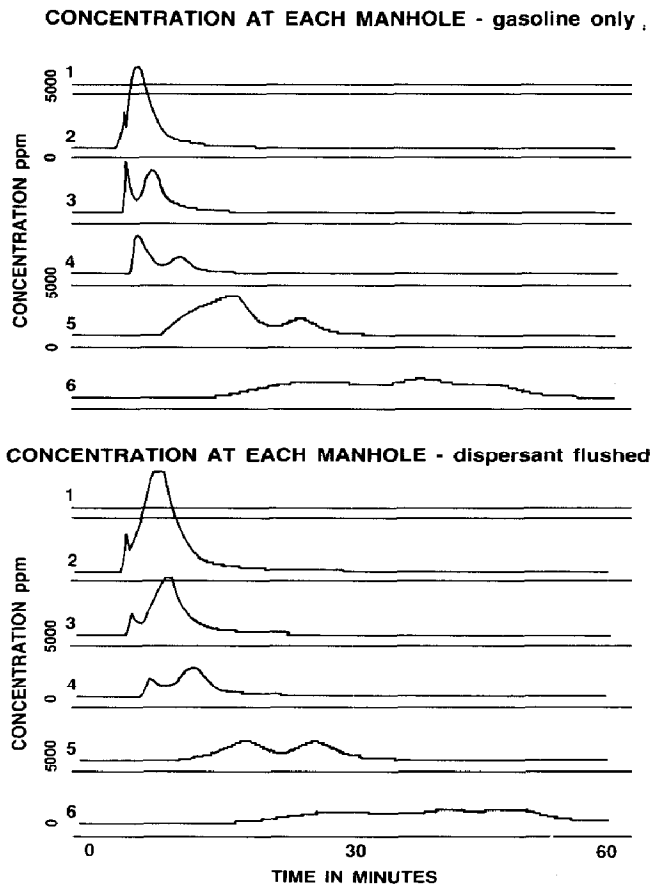


Fig. 3. Real time display of vapour concentrations.

ten out significantly by the time they reach the last sensor (number 6) located 104 m from the head box. The two peaks move at different rates, the second one being slower than the first.

Samples were withdrawn of the air and were analyzed by GC as described above. The results are shown diagrammatically in Fig. 4. It was found that the first vapour peak is formed from gasoline evaporating as it rides on the underlying body of sewer water. This peak moves at approximately the same speed as the sewer water and consists of the higher boiling fractions of the fuel. The second peak originates from fuel evaporating near the entry point and consists of the low boiling point fractions of the fuel. This vapour peak moves slowly through the sewer system, as its only driving force is the weak friction with the underlying sewer water. As can be seen from the gas chromatographic traces in Fig. 4, compounds smaller than toluene are largely removed from vapour peak 1 when dispersants are used.

In a previous paper, we have shown that as the amount of vapour increases in the sewer system, the velocity of its movement decreases [12]. This is an

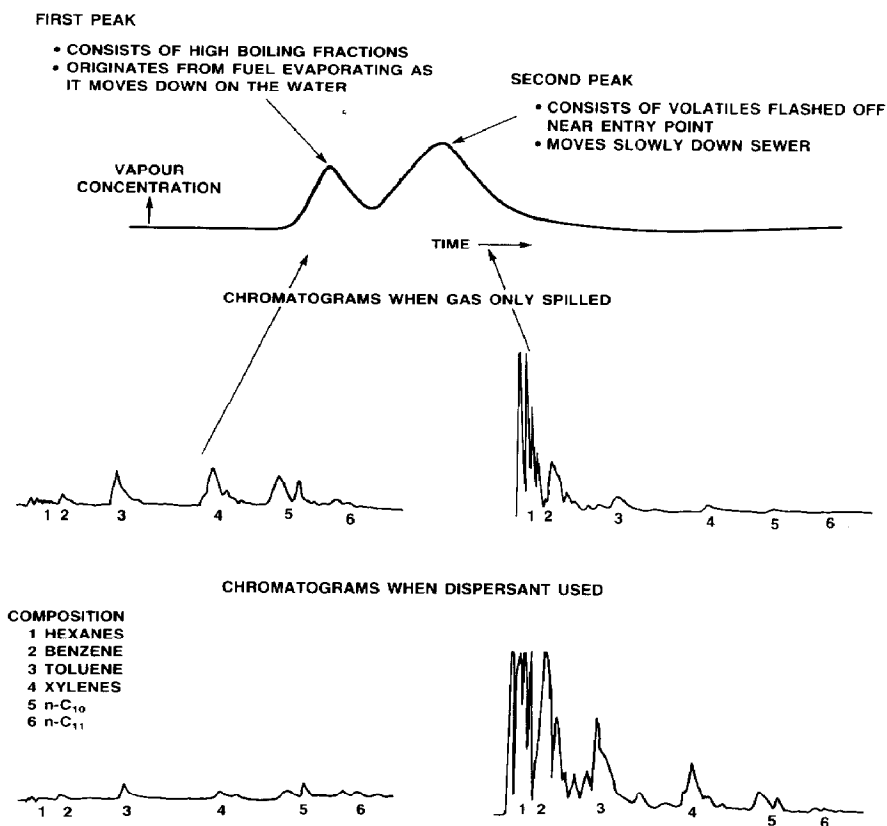


Fig. 4. Origin and composition of vapour peaks in a sewer.

important finding in terms of spill countermeasures, any action which increases vapour content in a sewer also increases vapour exposure time and subsequently explosion potential.

4. Use of dispersants for spill countermeasures

In a previous paper, the present authors describe extensive experimentation on the use of dispersants in sewer systems [12]. The effect of dispersants on fuels already in a sewer system is to increase the volatilization rate of the fuel and thus increase the amount of vapours in every case. This is caused by the action of dispersants on the size of fuel droplets in the water. If a dispersant functions, it produces small fuel droplets in the water and this in turn increases the volatilization rate of the lower-boiling-point fuel components. Dispersants have little actual dispersing effect on these volatile components of fuels such as hexane, benzene, etc. This has been noted by other researchers as well [13,14].

The results of the dispersant treatment of fuels in a sewer system is shown in Figs. 5 and 6 for gasoline and diesel fuel respectively. These figures show that the maximum concentration noted at the manholes is increased in every case through the use of dispersants. Figures 7 and 8 show the effect on the total amount of vapour in the sewers, here represented by the sum of the integrals of vapour appearing at each manhole. The total vapour content in the sewer

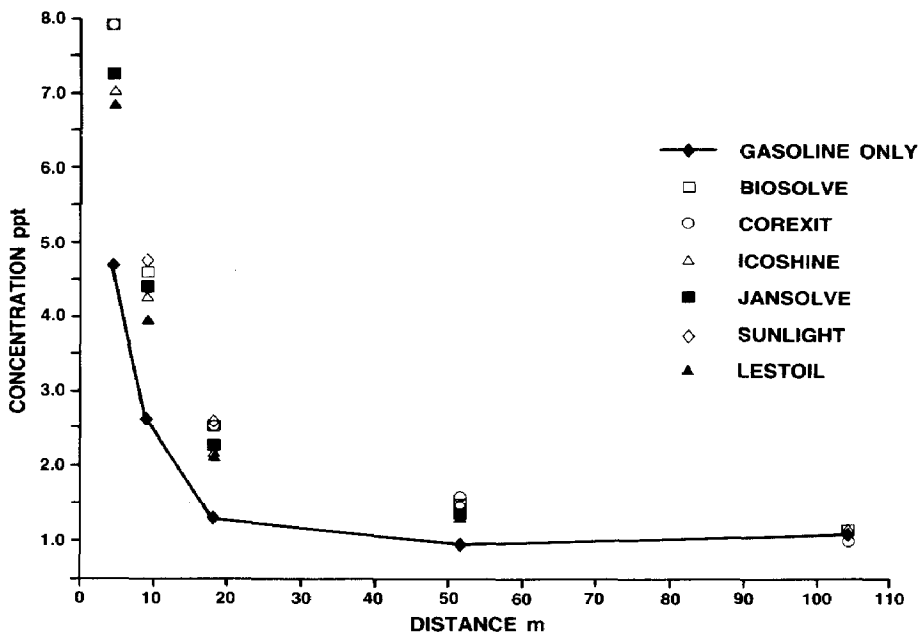


Fig. 5. Peak concentrations at manholes.

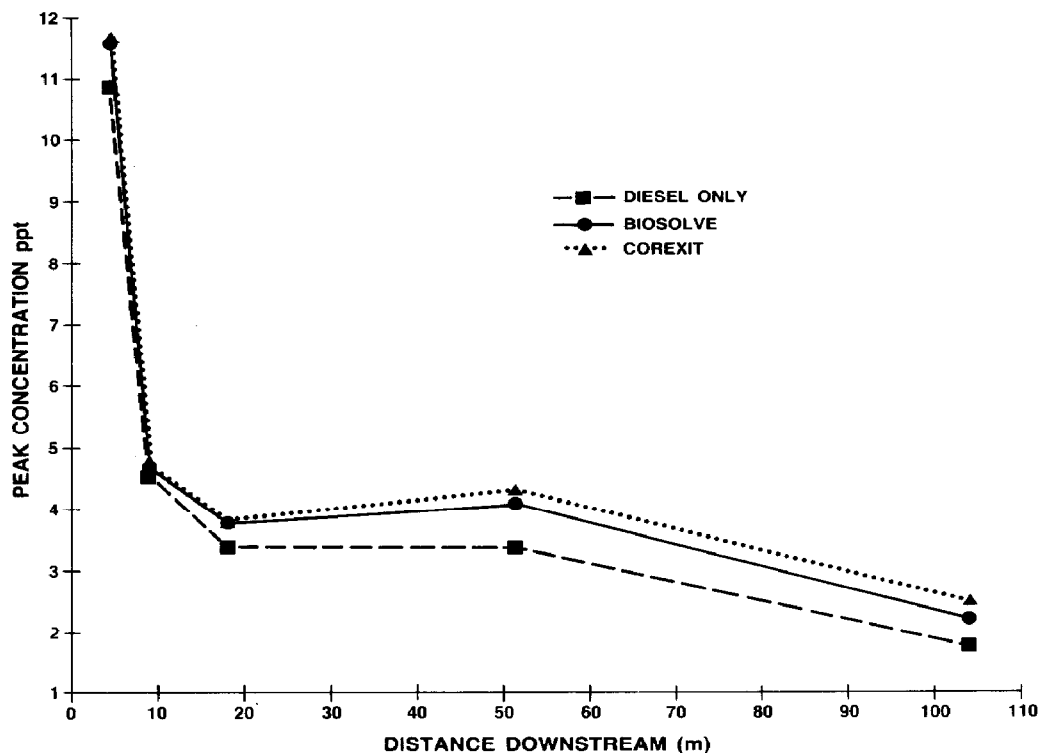


Fig. 6. Peak diesel concentrations at manholes.

system is plotted against the dilution volume which is the amount of dispersant solution used with respect to the volume of fuel spilled. These figures show that dispersant treatment also increases the amount of vapour appearing in the sewer. The flushing of additional volumes of dispersant solution has little beneficial effect. An additional observation is that there is little differentiation between dispersant products. They cause about the same level of vapour increase.

The effect of adding increased energy to the dispersant was also investigated in the previous study [12]. Additional energy increased both the maximum concentration and the total amount of vapour in the sewer system. This is not surprising as the increased energy would make smaller and greater numbers of fuel droplets and thus increase the volatilization from these droplets.

5. Use of foams and heavy gases on fuels in sewers

The effect of foam and heavy gas countermeasures was investigated. Two fluoroprotein vapour-suppressing foams, Flame-outTM and AerO-foamTM, were used as 5% solutions. They were shaken to form stable foams and these were

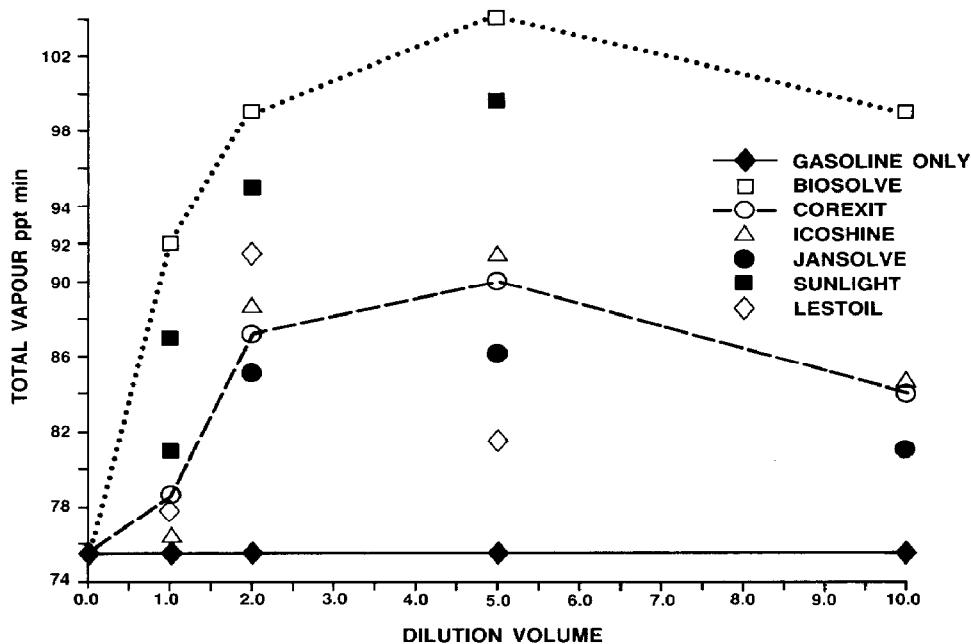


Fig. 7. Total vapour released into sewer.

injected 10 s behind the fuel injection. Gases, Halon 1301 (bromotrifluoromethane) and carbon dioxide were admitted through a plastic tube to be released at the same location as other treatments. Gas releases were timed to provide a measurement of volume. Solid products, sodium bicarbonate and dry ice were admitted using a large syringe at the same location in the drain. The foams were injected in the same quantity as dispersants, generally 1 ml of a 5% solution, unless otherwise specified. Ten grams each of the sodium bicarbonate and ground dry ice were employed.

The effect of these countermeasures on maximum concentrations of gasoline vapour at the various ports is illustrated in Fig. 9. The effect of the low-expansion foams on fuels already in the sewer is the same as that of dispersants, they increase the amount of vapour. It is suspected that this is due to the fact that the foam did not cover the gasoline entirely, that most of the vapour is released before the foam can block further release, and also that the foams' surfactants have a certain amount of dispersing effect. To verify that low expansion foams of this type have the ability to slow evaporation, a series of separate experiments were done. It was found that both foams would suppress the evaporation of gasoline and diesel fuel in static situations and before significant fuel evaporation has taken place.

Figure 9 shows that the two heavy gases carbon dioxide and halon are quite useful in reducing the maximum vapour concentration at the various man-

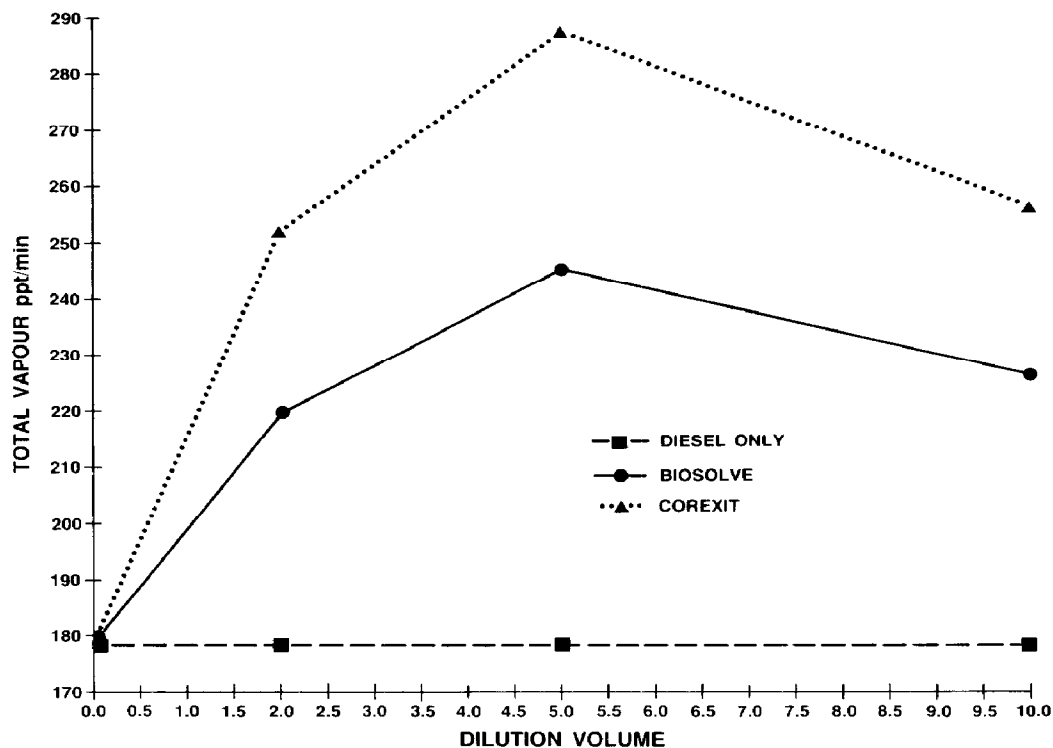


Fig. 8. Total diesel vapour in sewer.

holes. It should be borne in mind when examining Fig. 9, that more halon was admitted than carbon dioxide.

Figure 10 shows the effect of these countermeasures on the total vapour or sum of the integrals at the six sampling ports. These results as well as those in the previous figure are derived from experiments with gasoline. Again, it is demonstrated that foams and dispersants increase the total vapour in the sewer and that carbon dioxide and halon are very effective in reducing the vapour. The mechanism by which these heavy gases remove vapours is thought to be gravity displacement. This is illustrated in Fig. 11 where it is shown that halon is more efficient than carbon dioxide in lowering the total vapour concentration. Halon has a relative vapour density of 5.4 to air compared to that of carbon dioxide which is 1.5 [15]. These are based on dry air having a vapour density of 1.0 kg/m^3 at 20°C , approximately the same temperature used in this study. Additionally, the vapour durations in the sewer are lower for the situation where heavy gases are used, indicating the pumping action.

The model sewer system contains an approximate air volume of 450 l. The amount of gas put in varied from 3 to 12 l for the carbon dioxide and from 10 to 30 l for the halon. If these countermeasures were to be applied in the real world, small amounts could also produce significant effect. For example a car-

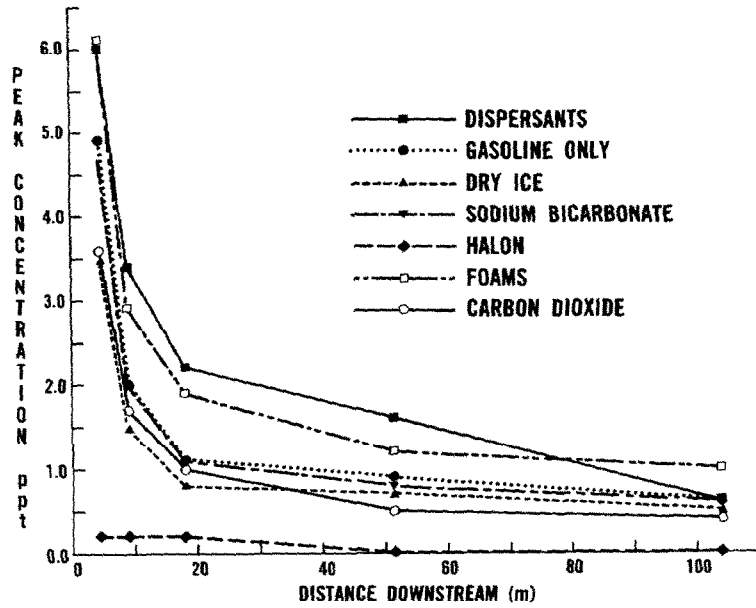


Fig. 9. Effect of countermeasures on peak vapour concentrations.

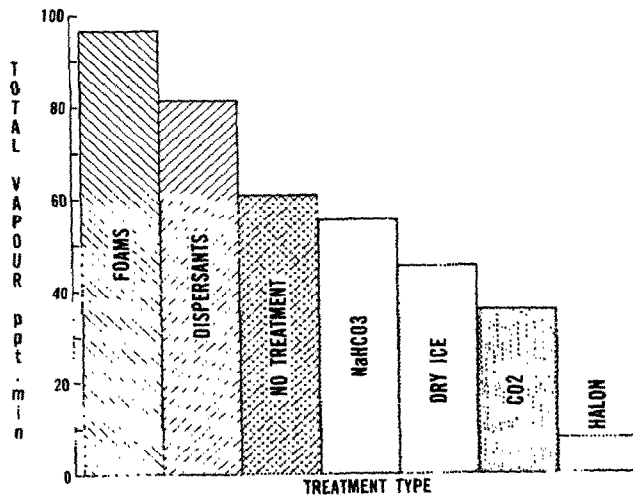


Fig. 10. Total vapour in sewer after treatment.

bon dioxide fire extinguisher often contains 5000 l gas at standard pressure and temperature, this would be sufficient at a similar ratio to that noted above (for example 10 l to 450 l, or 1:45) to treat a sewer pipe of 254 inches diameter (76 cm) for a length of 130 m.

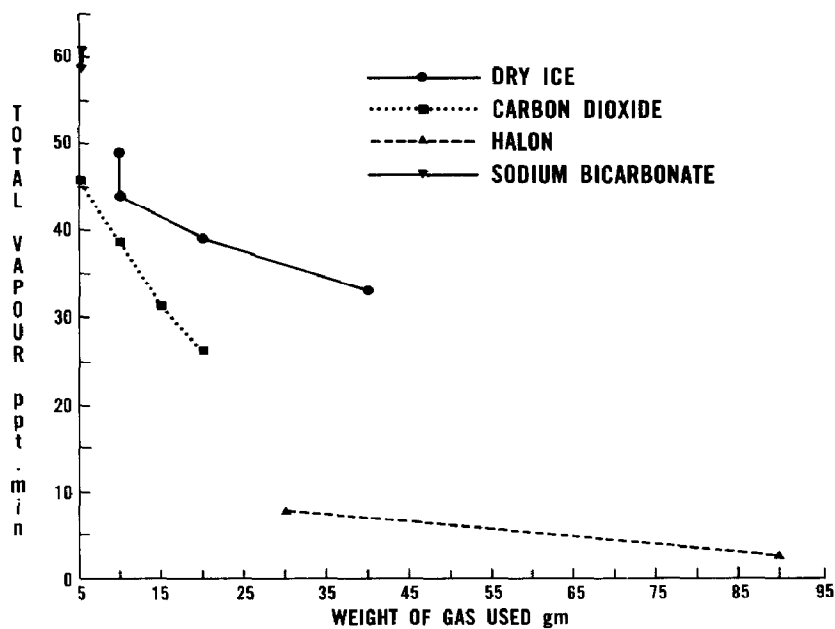


Fig. 11. Effectiveness of heavy gas countermeasures.

6. Conclusions

Fuels evaporate to some extent when spilled into sewers. Lighter components will evaporate near the entry point and the resulting vapours will move slowly down the sewer system. Gasoline contains sufficient volatile components to produce two vapour peaks in the sewer system. The first is a more rapidly moving peak which results from evaporation of fuel riding on the sewer water. The second peak is formed by the slower-moving volatiles resulting from evaporation near the entry point.

Dispersants used on fuel spills in sewers increase the maximum concentrations of the vapour in the sewer as well as the total amount of vapour. Because of the increased amount of vapour, the movement along the sewer is slower than when dispersants were not used. The use of fluoroprotein-type foams on fuel spills in sewers yield the same results as for dispersants. The use of dispersants and low-expansion foams on fuel spills in sewers is not recommended and if used, would result in greater potential for explosions as well as increasing the magnitude of explosions compared to situations where dispersants are not used.

The use of heavy gases such as carbon dioxide or Halon 1301 reduces the maximum vapour concentration and total amount of vapour released into the sewer system. Halon is more effective, because of its greater specific gravity, but because of its expense and concern over its long-term fate in the environ-

ment, is not the wisest choice for spill countermeasures. Carbon dioxide is effective and offers a very practical countermeasure as it is widely available in fire extinguishers.

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