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THE EVALUATION OF AN IMPROVED METHOD OF GAS-FREEING AN AVIATION FUEL STORAGE TANK

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Summary

A new technique is described for the gas-freeing of large storage tanks used for aviation fuel. The technique involves the use of natural and mechanical ventilation, together with an air-driven pump for removal of liquid residues from the irregular bottom of the tank. An assessment was made by gas-freeing a 4500 m^3 (1 M gal) tank in which the atmosphere was monitored using portable flammable gas detectors and checked by the analysis of samples using chromatography. The new technique was much quicker than the traditional method of gas-freeing and was more controlled so that a work schedule could be devised in advance with confidence.

The portable gas detectors were shown to under-estimate gas concentrations; it is thus imperative that the concentration levels at which various inspection and maintenance operations are permitted in tanks should reflect the likely errors of the instrument used to measure concentrations.

Introduction

Aviation fuels are customarily stored in relatively large tanks, either above or below ground, and it is necessary periodically to empty the tanks for inspection and maintenance purposes. The usual interval between inspections is 1 year for tanks which are not epoxy-lined and at less frequent intervals for those which are epoxy-lined. The epoxy-lined tanks are relatively modern, with conical bottoms and centre sumps to avoid fuel puddling problems which can occur with 'flat' bottomed tanks which have welded joints. There are a considerable number of tanks in use which are not epoxy-lined, and these older tanks present considerable difficulties in gas-freeing. Problems arise because the tanks which do not have conical bottoms, may be constructed with lap joints, and the bottom may be irregular, causing pockets of fuel to collect in the low spots, which cannot be removed by the sump pump.

Before any maintenance can be started, all traces of fuel must be removed. Traditionally, the method of doing this has been first of all to ventilate the

tank until the measured concentration of the fuel was less than 50 per cent of the lower explosible limit (l.e.l.). The removal of the flammable vapour was carried out by removing the manhole covers from the tank and allowing natural ventilation, sometimes assisted by air movers, to cause the fuel concentration to decrease to the accepted level. The next step was for an operator to enter the tank, wearing full protective clothing and breathing apparatus, to inspect the tank and to ascertain the quantity of remaining fuel to be removed. After the inspection, operators entered the tank and commenced to sweep the remaining liquid fuel either towards the sump or to adjacent low spots which may have developed after the tank had been constructed. By this action, further vapours were generated which could raise the concentration in the atmosphere to above 50 per cent l.e.l. and the operators then had to withdraw pending further ventilation.

This cyclical procedure led to protracted and uneconomic working, but was essential on safety grounds. When all the liquid had been swept up and the tank was freed from all remaining liquid fuel, sludge, scale, and other arisings, and the gas concentration reduced by ventilation to an acceptable level, the next stage of the maintenance could proceed.

The traditional procedure had the disadvantages of being time-consuming, expensive, with prolonged hazardous conditions, and the duration of the work could not be predicted accurately. An improved method was therefore sought, particularly to obtain greater safety, and more rapid and controlled operations.

An opportunity arose to develop a new procedure for the gas-freeing of a large aviation fuel tank in the U.K., used for the storage of JP-4 aviation fuel; the tank was mounded over so that limited access was only possible from the top. Measurements were made of gas concentrations both by the use of portable gas detectors and by sampling for laboratory analysis, in order to determine what changes took place during the operations.

Description of tank

The tank, shown diagrammatically in Fig. 1, was 32 m in diameter and 5.6 m high (from the tank bottom to the underside of the roof). It was constructed of steel with reinforced concrete protection external to the shell and roof. The roof was supported by columns at 3.3 m centres and the tank was further protected by an earth covering. The capacity of the tank was 4500 m^3 (1 M gal nominal). The lap welded tank bottom was undulating, and pockets of fuel collected in the low spots. The fuel in the low spots could not be withdrawn by the sump pump. The pumping equipment was located on the top of the tank. There were two top access manholes of 0.76 m diameter, and a larger access 1.37 m $\times$ 1.22 m to the floating suction head used in the operation of the tank. The tank was of the conventional protected type and gas-freeing was difficult because of the very limited access and possibilities for ventilation.

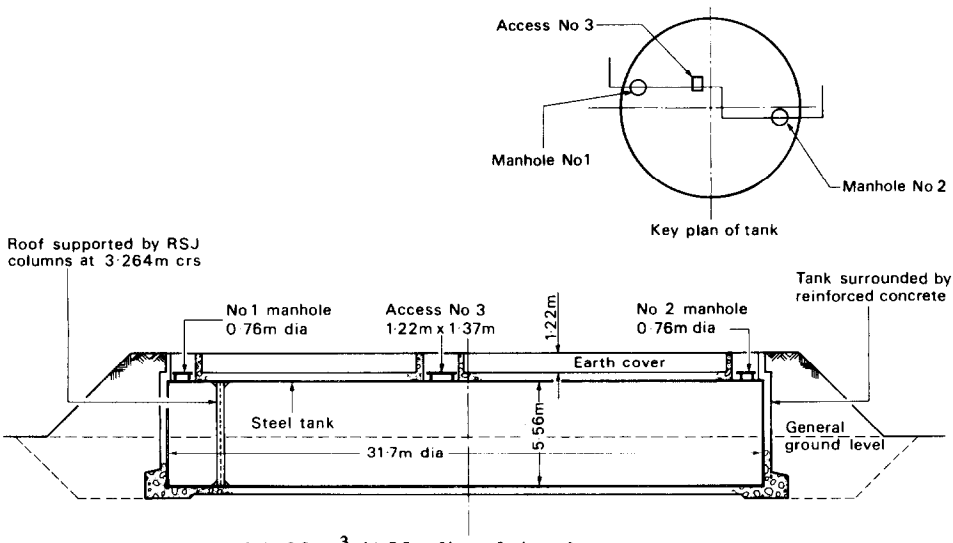

Fig. 1. Cross section of 4500 m^3 (1 M gal) tank (roof support columns not shown).

Objectives of exercise

1. To obtain realistic and factual information in collaboration with DOE/PSA on gas concentrations in the tank during the period of gas-freeing.
2. To determine the time required to reach a 25 per cent l.e.l. reading at the bottom of the tank.
3. To determine the gas concentrations in the tank surrounding the operators during the sweeping up of the pools of fuel.
4. To estimate the quantity of fuel remaining in low spots, after the main pumping operations, and the area and location of the pockets of fuel.
5. To determine the efficiency and effectiveness of the plant and equipment employed for the gas-freeing operation.
6. To compare the readings obtained with portable detectors for flammable gases with laboratory analyses of gas samples taken simultaneously in the tank.

Equipment and apparatus

Two compressed air operated venturi type air movers were used 15 cm diameter, overall length 1.2 m and weighing 14 kg. They induced air through the tank at a rate of 35 m^3/min (1200 ft^3/min). Figure 2 shows one of these in position. Canvas wind sails were also used for ventilation purposes, one as a scoop to deflect the air into the tank (Fig. 3) and the other as an eductor tube with three side flutes (Fig. 4). The tube was 0.75 m in diameter, which fitted into the manhole and extended to within 0.9 m of the tank bottom.

Fig. 2. Compressed air operated venturi air mover (to the left of wind sail air scoop tube).

Residual liquid fuel was removed using a compressed-air operated portable pump of capacity (300 l/min) at 7.6 m suction lift. The weight of the pump was 35 kg, the overall dimensions were height 0.45 m, length 0.56 m, width 0.42 m, permitting it to be lowered through the standard-sized manholes. The suction and delivery hose for the pump were of anti-static rubber, 50 mm in diameter, suitable bonded and earthed (Fig. 5). A diesel driven portable air compressor at 700 kN/m^2 (7 bar) operated the venturi air movers, the portable pump, and the breathing apparatus used by operators within the tank. The atmosphere inside the tank was tested for flammable gas, using three models of portable detectors (designed A, B and C). Types A and B were manually aspirated, and were calibrated for pentane. Type A is shown in Fig. 6, and was designed for use with leaded fuels. Type C was non-as-

Fig. 3. Wind sail air scoop.

pirated and was calibrated by the manufacturers to operate at 50 per cent l.e.l. with JP-4, and gave both audible and visual alarms (Fig. 7).

Detector A was provided with an 8 m long neoprene sampling line which contained a T-piece enabling gases to be sampled for subsequent analysis. Figure 6 shows the method of sampling. The samples were taken and stored in a 1 ml plastics syringe, the needle of which was capped with a silicone rubber disc. All samples were analysed using a gas chromatograph, fitted with a dual flame ionozation detector, with automatic integrating facilities.

Diary of events

Tuesday, 1 July 1975

At 15.40 hours the two 0.76 m diameter manhole covers were removed.

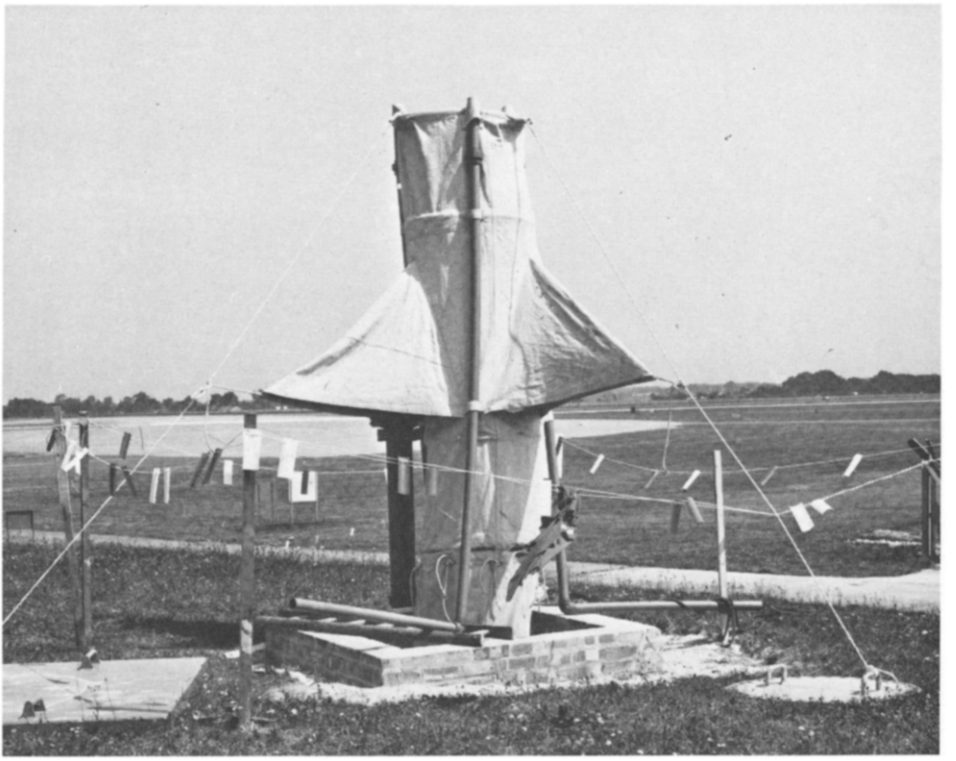

Fig. 4. Wind sail eductor tube.

The readings of portable gas detectors A and B, were off the scale. These observations were taken just inside the tank. Five further observations using the portable detectors were taken during the afternoon, which were again off the scale of the instruments. The wind sails were placed in position at 16.10 hours and then left overnight. The wind and weather conditions throughout the exercise are shown in Appendix A.

Wednesday, 2 July 1975

At 08.30 hours the portable detector readings were still off the scale but the meters reacted less vigorously. The air movers were then installed in place of the wind sails. One air mover was blowing into the tank and the other ejecting.

At 11.00 hours the access cover (no. 3) over the floating suction head was removed and quantities of fuel were observed directly below. A suction pipe was lowered to the tank bottom and the air operated pump connected to the compressed air supply. The delivery pipe was taken to the interceptor pit adjacent to the tank and the fuel was later transferred to a bulk lorry. The pump was removing 90—120 l of fuel per minute with no difficulty, against the suction lift of about 7.6 m. Approximately 14 m^3 of fuel not

Fig. 5. Compressed-air operated portable pump.

removable by the sump pump were removed with the compressed-air pump located at the top of the tank. Four gas concentrations readings were taken during the day, again indicating over 100 per cent of l.e.l. At 16.45 hours the wind sails were again erected, the scoop sail at manhole 2, and the eductor sail at access 3.

Thursday, 3 July 1975

A gas sample and portable detector readings were taken at 08.55 hours 1.9 m below the roof at manhole 1. A summary of the gas sampling and analysis data appears in Table 1. The portable detectors A and B read 30 per cent l.e.l. A second reading was taken at 4.3 m from the top of the tank, the reading, however, was off scale. At 10.25 hours, 1.8 m below the roof, a reading of 70 per cent l.e.l. was observed; at this time the air movers were

Fig. 6. Portable detector 'A' showing sampling method.

operating with 1 blowing and 1 ejecting, and were obviously disturbing the concentrations at the bottom of the tank.

At 10.50 hours a reading of 66 per cent l.e.l. was observed at 4.3 m below the roof. A further sample for chromatographic analysis was also taken.

At 12.00 hours another reading was taken at 4.3 m and was 49 per cent l.e.l. A further gas sample was also taken. At this time the air ejector was fitted with a 15 mm diameter flexible suction hose, extending to within 0.60 m of the tank bottom, operating at access 3.

At 14.45 hours the portable detector reading was 7.5 per cent l.e.l., at a depth of 4.3 m; at this time portable detector C was lowered to the tank bottom and 'alarmed', indicating that the l.e.l. there was above 50 per cent. The wind sails were left in position overnight.

Fig. 7. Type 'C' detector.

Friday, 4 July 1975

Readings on portable detector A were taken at 08.55 hours and were 10 per cent l.e.l., 4 m down.

At 09.50 hours, at 1.8 m from the room at manhole 1, the reading was 9 per cent l.e.l.

At 10.05 hours the reading had risen to 19 per cent l.e.l. and a further sample for chromatographic analysis was taken. By 11.05 hours the reading of the portable detector had risen to 24 per cent l.e.l. 1.8 m down. The reason for this variation in gas concentration was that the air movers were increasing the evaporation rate of the residual liquid fuel, and mixing the atmosphere in the tank.

At 11.20 hours, two operators entered the tank with portable gas detectors B and C.

TABLE 1

Summary of analyses

Sample No.	Date sample taken	Time sample taken	Delay between sampling and analysis	Per cent l.e.l. by chromatography	Detector reading per cent l.e.l.
10	3/7/75	8.55	30.5	34.5	30
11	3/7/75	10.50	94.5	72.9	66
12	3/7/75	12.10	94.5	55.4	49
16	4/7/75	10.50	77.0	22.6	18
17	4/7/75	11.20	94.5	25.3	22
18	4/7/75	12.05	95.5	30.0	28
19	4/7/75	14.15	96.5	16.4	14
20	4/7/75	14.45	96.5	13.2	12

* To nearest half hour.

At 11.50 hours the operators in the tank reported readings of 6 per cent on detector B, and detector C had not alarmed.

At 12.05 hours a further gas sample was taken.

At 14.15 hours, 2 operators re-entered the tank and commenced sweeping the pools of liquid fuel towards the sump. At the same time a further gas sample was taken. Approximately 1.4 m^3 of fuel were withdrawn from the tank by the compressed air driven pump still located at the tank top. The final gas samples were taken at 14.45 hours.

At 15.30 hours, at manhole 1, a reading of 12 per cent l.e.l. was given by portable detector A, sampling at 1.8 m below the roof. At 4.3 m below the roof the reading was 14 per cent. The wind sails were left in position until the morning of Monday, 7 July.

Monday, 7 July 1975

At 08.55 hours at manhole 1, 1.8 and 4.3 m down, the reading of portable detector A was 4 per cent l.e.l., but small pools of fuel still remained in the tank.

At 11.15 hours the operators entered the tank and the compressed-air driven pump was lowered into the tank bottom. A reading of 14 per cent l.e.l. was observed 4.3 m down, using the portable detector A.

At 11.30 hours, at manhole 2, the reading was 9 per cent near the bottom of the tank.

At 12.10 hours the operators emerged from the tank and reported that at all positions within the tank, readings of portable detector B were 4 per cent l.e.l.

Portable detector C gave no response.

Some fuel remained at the tank periphery and amounted to about 140 l.

At this stage it was decided to cease further operations on site until modi-

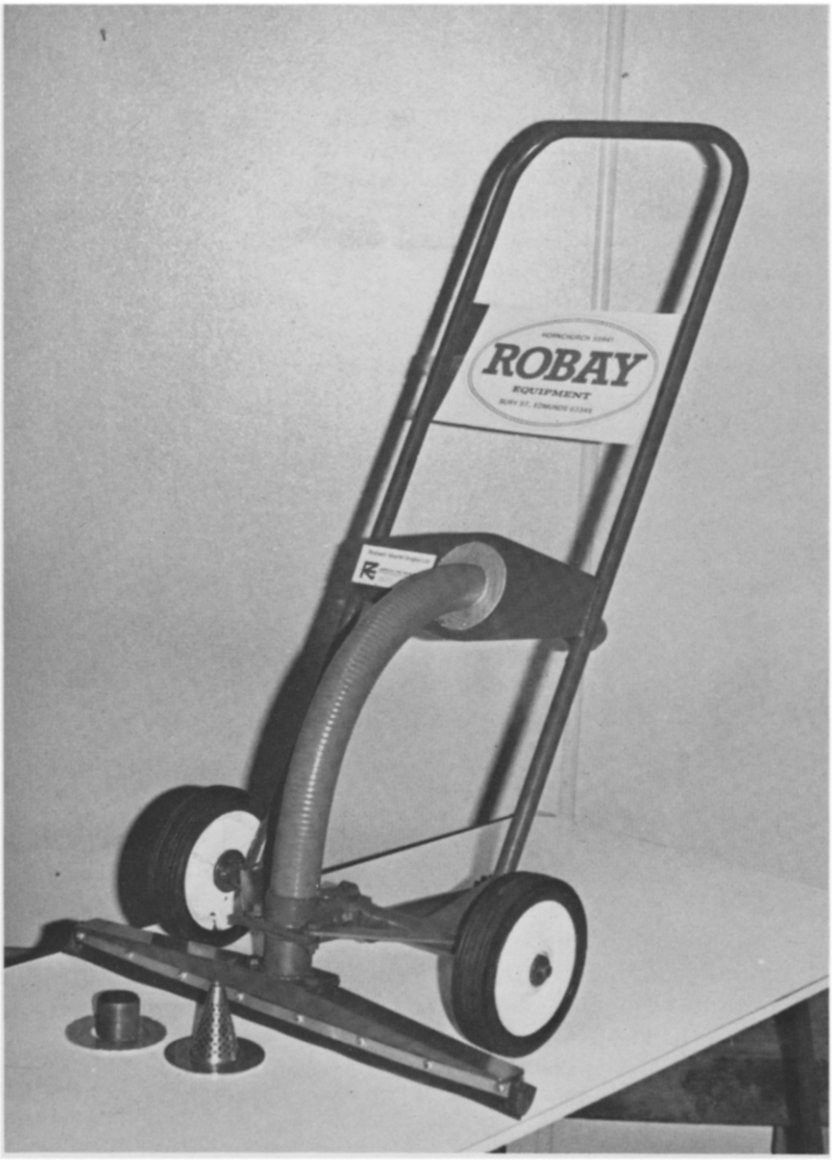

Fig. 8. The 'fish-tail' suction scoop.

fications were made to the suction pipe for the compressed air driven pump, to enable the small quantity of remaining fuel to be removed. A fish-tail suction scoop was subsequently fabricated, incorporating a non-return valve, on a wheeled frame and was attached to the suction pipe to the pump as shown in Fig. 8. This has proved to be the most effective in removing all the remaining unpumpable residue.

Analysis of samples by gas chromatography

1. Method

All samples were analysed using a gas chromatograph, fitted with a dual flame ionization detector. The column used was of stainless steel 1.5 m long, 2.1 mm i.d. packed with 'Porapak Q', with helium carrier gas. Each analysis was temperature programmed at 4° per minute from 30° C to 200° C. An injected volume of 0.5 ml was used throughout. The total area of peaks for each sample was measured using an electronic integrator. The date and time at which the analysis was carried out was noted.

The chromatograph was calibrated using samples from an apparatus designed to generate standard vapour/air mixtures for measuring the l.e.l. of a vapour. This apparatus is described elsewhere [1]. The vapour samples slowly decayed when stored in the plastics syringes, and a number of samples of a vapour/air mixture, within the range of concentrations being considered, were taken and analysed after various periods of storage. In this way inregrator counts for samples analysed several hours after collection could be corrected.

The steps involved in arriving at the vapour concentration were:

a. Run the sample and obtain the total area of the chromatogram.
b. Calculate the delay between collection of the sample and its analysis.
c. Correct the chromatogram area for the delay.
d. Determine the vapour concentration from the corrected chromatogram areas and the calibration data.

2. Results

Eight useful chromatograms were obtained. The results are summarised in Table 1.

The comparison between the readings of portable detector 'a', and the gas concentrations as obtained by chromatography is shown in Fig. 9. The detector tended to underestimate the true concentration as indicated in Fig. 9.

The gas concentrations measured at 2 levels in the tank (4.3 and 1.8 m from the top) during the gas-freeing period, are plotted against time in Fig. 10. Details are also included of the times of major disturbances to the tank atmosphere due to the gas-freeing activity.

Discussion

From the diary of events, and Fig. 10, it may be seen that the gas concentrations within the tank were brought down to below 25 per cent l.e.l. within 2 days. This is a great improvement over the traditional method and was due largely to the use of the compressed-air-driven pump to remove residual fuel and to the employment of the air movers and the wind sails. The reduction in surface area of liquid fuel, and the considerable ventilation of the tank atmosphere combined to reduce gas concentration rapidly.

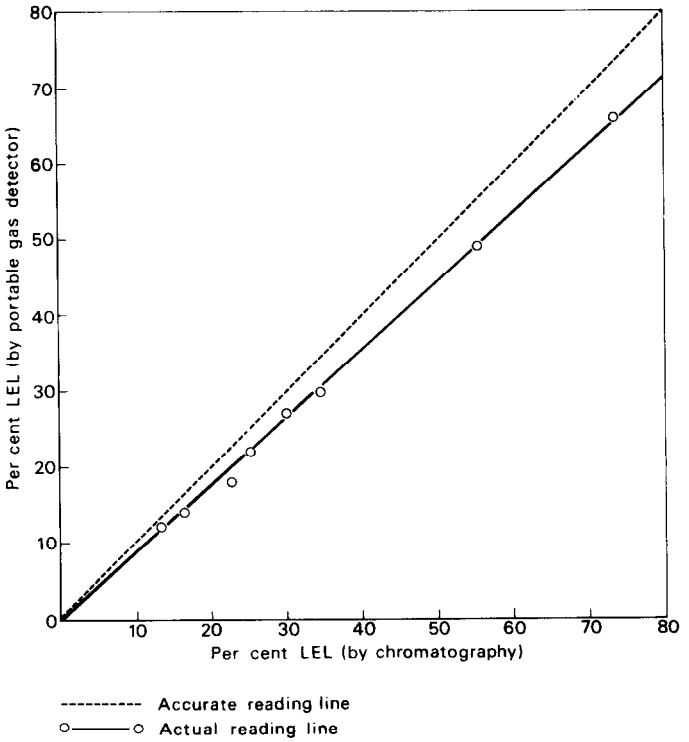

Fig. 9. Comparison of readings obtained with detector A and gas chromatography.

The new technique completed gas-freeing in a much shorter period than the traditional method, with consequent economies in manpower. It will enable work to be planned ahead in a controlled way, and a work schedule to be devised in advance, with confidence.

A considerable improvement in safety is obtained because the concentration of the atmosphere within the tank is between the lower and upper explosible limits for a much shorter time than in the traditional method. In addition, most of the residual fuel can be withdrawn before operators enter the tank for inspection and for final clearing of the puddles. Because a considerable proportion of the residual fuel is removed mechanically by pumping, hazard is minimised, with the attendant savings.

No difficulty was encountered in reducing the vapour concentration in the atmosphere of the tank to below 25 per cent l.e.l. and thus, even if the portable gas detectors have a substantial error, the atmosphere is soon likely to be within accepted limits for inspection and subsequent operations. The tests showed that it was easy to reduce the gas concentration to 4 per cent of the l.e.l. and that it was readily possible to monitor the decreasing concentration down to this level, providing confidence as to the state of the atmosphere within the tank as the gas-freeing proceeded.

Some operators have used water as a means of flotation for removing re-

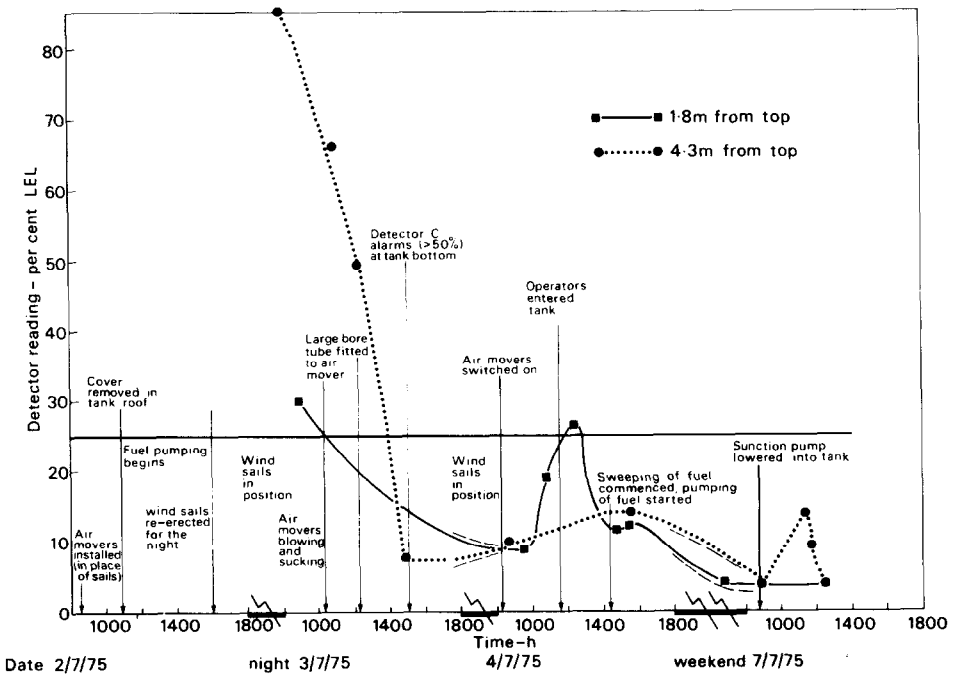

Fig. 10. Detector reading obtained during gas freeing operations.

sidual fuel from the tank, but this method requires the provision of interceptors, and brings in the possibility of water pollution problems. The new method avoids the generation of large volumes of contamined water/fuel and the associated problems of their segregation and disposal. The necessary equipment for the new method is readily portable and is easily manoeuvred on site. In particular, the air-operated pump can be lowered through the standard 0.76 m diameter manhole without difficulty.

Comparison of the readings of the portable detector A with independent gas analysis in the laboratory confirmed that the reading of the detector was consistently low, by about 11 per cent. This means that the instruments underestimate the concentration of vapour being sampled. It is therefore important that the gas concentration levels at which various operations are permitted in tanks should take into account the likely errors of the instrument used to measure concentration in actual installations. Part of the present exercise was to ascertain the time taken to achieve 25 per cent l.e.l., and this level is marked as a horizontal line on Fig. 10. The figure of 25 per cent l.e.l. has now been adopted by various authorities as the maximum permitted before entry to a tank for inspection can take place.

It is important that where the new technique is to be used, adequate preplanning takes place to ensure that the proper procedure is followed and that all legal requirements are met. It is essential to have all necessary equipment actually on site before an operation is started and that staff should be thoroughly trained in the use of the equipment.

Acknowledgement

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Reference

1 P. J. Fardell, The performance of some portable gas detectors with aviation fuel vapours at elevated temperatures. Part 1. Tests with n-hexane, 'Avtag', and 'Civgas' vapours, Fire Research Station, Fire Research Note 938, Borehamwood, 1972.

APPENDIX A

Weather conditions during tests

Date	Time	Temp. (°C)	Windspeed (knots)	Direction	Dew point (°C)
1/7/75	15.58	23	5	N	7
2/7/75	8.55	17	0	N	8
	10.15	19	2	SW	8
	16.30	23	4	SE	8
3/7/75	8.55	17	2	NE	9
	10.25	21	5	E	8
	10.50	22	10	E	8
	12.10	23	9	ESE	9
	16.45	22	9	E	8
4/7/75	8.55	18	8	NE	12
	9.50	19	10	NNE	12
	10.50	20	13	NE	12
	11.30	20	13	NE	12
	12.05	20	13	NE	12
	14.10	21	10	NE	10
	15.30	20	12	NE	10
7/7/75	8.55	18	10	ENE	11
	9.30	19	12	SW	13