



# **Performance of organic vapour filters: Effects of discontinuous and multiple vapour exposures**

Prepared by the **Institute of Occupational Medicine and  
the Health and Safety Laboratory** for the  
Health and Safety Executive 2005

**RESEARCH REPORT 322**



# **Performance of organic vapour filters: Effects of discontinuous and multiple vapour exposures**

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Organic vapour filters are extensively used in respiratory protective equipment (RPE) for providing protection against vapours present in workplace air. The filters, while effective when new, will eventually become overloaded and allow the vapour to breakthrough and expose the wearer to a toxic hazard. There is anecdotal evidence to suggest that RPE wearers may be using filters which have passed their useful service life (i.e. the breakthrough time has been reached). Presently, there is no reliable method of assessing when breakthrough actually occurs in practical usage. Filters may be subject to different patterns of use (e.g. intermittently during the day, or for short periods on different days or different weeks) and may be used to protect against different vapours, simultaneously, or at different times. None of these scenarios are routinely tested as part of the certification process for organic vapour filters which are based on short duration, high concentration challenges.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

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*First published 2005*

ISBN 0 7176 2972 4

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## EXECUTIVE SUMMARY

Organic vapour filters are extensively used in respiratory protective equipment (RPE) for providing protection against vapours present in workplace air. The filters, while effective when new, will eventually become overloaded and allow the vapour to breakthrough and expose the wearer to a toxic hazard. There is anecdotal evidence to suggest that RPE wearers may be using filters which have passed their useful service life (i.e. the breakthrough time has been reached). Presently, there is no reliable method of assessing when breakthrough actually occurs in practical usage. Filters may be subject to different patterns of use (e.g. intermittently during the day, or for short periods on different days or different weeks) and may be used to protect against different vapours, simultaneously, or at different times. None of these scenarios are routinely tested as part of the certification process for organic vapour filters which are based on short duration, high concentration challenges.

### OBJECTIVES

1. To quantify the effect on vapour filter lifetime associated with discontinuous vapour challenges.
2. To investigate the performance of filters in multiple vapour systems.
3. To extend our understanding to include the behaviour of A2 filters.

### MAIN FINDINGS

1. For the agents tested (isopropanol and cyclohexane), discontinuous usage does not have a significant effect on the expected service life of organic vapour filters when compared with continuous use.
2. The results are based upon measurements of filters that were dried prior to use. In practice these filters are not dried and this may lead to shorter lifetimes than those reported here.
3. Breakthrough occurs more rapidly in multiple vapour systems than in single vapour systems.
4. In dual vapour systems, the breakthrough concentration of the first compound can exceed the challenge concentration.
5. Current semi-empirical models do not adequately predict breakthrough characteristics of dual vapour systems but are useful for qualitative understanding of the behaviour of these systems.
6. A2 filters provide improved protection in single and dual vapour systems.

### RECOMMENDATIONS

1. It is understood that HSE is considering whether to introduce recommendations concerning filter service life. Such recommendations, which are based on continuous exposure tests, do not need to be modified in cases where exposure is intermittent or where there are gaps in use of up to one week.
2. All filters should be sealed properly to for transport and storage to prevent ingress of water vapour. More work is necessary to quantify the effects of water vapour on filter performance.
3. It is necessary to take account of reduced breakthrough times caused by the presence of a second (or third, or higher multiple) vapour in any recommendations of filter lifetime.

4. It is necessary to consider the potential effects of sequential use of filters against different vapours in any recommendations produced. One option would be to recommend that filters are not used in this way.
5. More work is desirable on how these filters are actually used in practice. For example information on what vapours, in what combinations, at what levels of challenge concentrations and for how long would be advantageous.
6. More work is required to further develop, refine and validate models of breakthrough time in particular for dual vapour and higher multiple systems, with combinations which are representative of real work environments.

# 1. INTRODUCTION

The health and safety of the wearer of an organic vapour respirator depends on knowledge of the service life of the carbon filter fitted to the respirator under the particular conditions of use in industry. If the lifetime of the filter is overestimated, the wearer could be exposed due to breakthrough of the contaminant through the filter. Anecdotal evidence suggests that filters may be being used for longer periods than appropriate so it is possible that workers are not receiving the required level of protection.

A previous project (Hemingway *et al.*, 2002) has as its aim, assessment of the validity of computational methods, based on adsorption theory, for estimating the service life of vapour respirators used in industry. In this a programme of experiments was conducted in which Class A1 filters were challenged till breakthrough with dry and humid atmospheres containing a single organic vapour at a fixed concentration. Filter lifetimes were compared with those calculated from adsorption theory. The correlation between model predictions and the data obtained was poor.

Data obtained from this project indicated that the lifetimes of Class A1 filters were, as might be expected, highly dependent on the challenge vapour and the challenge concentration. For many of the vapours tested, the results indicate that exposure at 200 ppm results in breakthrough at the limit value in less than 15 hours. It must be expected that in many instances of use, the challenge concentration could be much greater than this, hence resulting in more rapid breakthrough.

In actual usage, most filters would not be exposed to continuous concentrations of single vapours. Rather, exposure would be intermittent and would often be to mixtures of vapours simultaneously. At present, the behaviour of filters under these conditions is poorly understood and work is needed to address this knowledge gap. Even less information is available on higher capacity A2 filters which, according to some manufacturers, are becoming the filter of choice.

The current programme of work extended the previous project into a second phase to consider these additional aspects

- The effect of a discontinuous challenge with a single vapour
- The effect of challenges comprising mixtures of vapours
- The performance of A2 filters

The work, as in Hemingway's earlier study, was carried out as a collaboration between the Institute of Occupational Medicine (IOM) and the Health and Safety Laboratory (HSL). The work programme was devised so that each laboratory concentrated on a specific area. HSL's objective was to determine the lifetime of filters which are intermittently exposed to vapours whereas IOM would determine the lifetimes of the filters when exposed to multiple vapours. Both IOM and HSL carried out testing of A2 class filters.





## **2. OBJECTIVES**

The objective of the work was to quantify the effect on filter lifetime associated with (i) intermittent vapour challenges (ii) challenges comprising two or more vapours and (iii) to extend our understanding to include the behaviour of A2 filters. A secondary objective was to determine to what extent these effects may be explained or incorporated into current or developing models of filter behaviour.



## 3. DESIGN AND METHODS

In this chapter, the methods and design are described. The methodology for the discontinuous (single vapour) challenge experiments (carried out by HSL) are described in Section 3.1. The description of the mixed vapour system methods and development (carried out by IOM) is in Section 3.2

### 3.1 DISCONTINUOUS (SINGLE VAPOUR) CHALLENGES

#### 3.1.1 Introduction

The purpose of the discontinuous (single vapour) challenge work was to reproduce a range of patterns of exposure that represent the types of exposure that might occur in the practical usage of organic vapour filters, to investigate the behaviour of filters under these conditions, and to compare that with behaviour under continuous challenge conditions. Four discontinuous challenge scenarios were investigated and compared with a continuous challenge. All of these experiments were carried out with single vapours. The scenarios were;

1. Breathing: A square wave pattern to simulate exposure as a result of breathing with a period of three seconds on, during which air containing the challenge concentration was drawn through at fixed rate and three seconds off during which no air was passed through the filter.
2. Intermittent: Simulating intermittent usage throughout a shift with a period of two hours on during which air containing the challenge concentration was drawn through at fixed rate and two hours off during which no air was passed through the filter.
3. Shift: Simulating likely exposure during a shift (short term repeat use). Filters were exposed until no greater than 10% breakthrough had occurred, followed by no exposure overnight and continuous exposure the following day.
4. Long Term: Replicating likely long term use of a filter (long term repeat use). Filters were exposed until no greater than 10% breakthrough had occurred, followed by no exposure for seven days, followed by a continuous exposure pattern.

Filter performance against these challenges was compared with performance against a continuous challenge comprising a fixed (within experimental error) vapour challenge concentration. This is the type of challenge commonly used in certification testing for organic vapour filters (eg BS EN 141, 2004). As such it represents a baseline test against which all the other patterns were compared.

#### 3.1.2 Experimental Design

Filters were tested at a flow rate of 40 litres per minute, at a single humidity value (<10%), and against two vapours. The two vapours used were isopropanol and cyclohexane. The target concentration was 200 ppm. A single filter type (Martindale) was used in all cases. Most of the tests were carried out with A1 filters but some additional testing was carried out with A2 filters. In each case, the experimental design required that replicates will be carried out for the breathing, intermittent, shift and long term patterns. No replicates were required for the continuous pattern as data was available from the previous study.

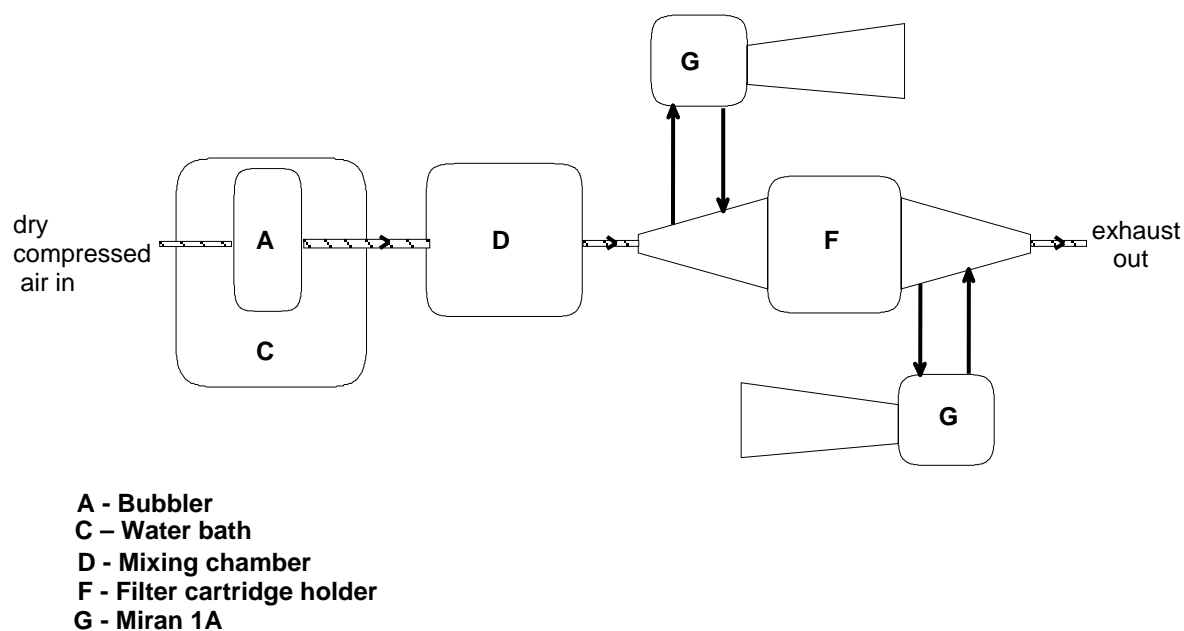
The design is summarised in Table 3.1.

**Table 3.1 Experimental design for the discontinuous exposure study**

Filter Type	Test Vapour	Pattern	Replicates	Total Filters
A1	Isopropanol	Breathing	2	18
		Intermittent	2	
		Shift	2	
	Cyclohexane	Long Term	2	
		Continuous	1	
A2	Isopropanol	Long Term	2	4
		Continuous	2	

### 3.1.3 Methods

The apparatus used to generate standard atmospheres for loading carbon filters, detailed previously (Hemingway *et al.*, 2002), was improved by developing a method based on a bubbler system. Further development of the method included the use and adaptation of timing systems plus appropriate data logging. A schematic diagram is shown in Figure 3.1



F

**Figure 3.1 Filter Test System**

A bubbler system was used to generate a stable vapour concentration. Approximately 230 ml min<sup>-1</sup> of dry air was bubbled through approximately 250 ml of the test solvent in a flask which was kept at a constant temperature in a water bath. The resulting saturated vapour was mixed (diluted) with clean dry air to generate 200 ppm vapour concentration.

An automatic switching system was developed that could divert the airflow through either the filter under test or through an exhaust filter so that the Intermittent and Breathing exposure scenarios could be carried out. For the Shift and Long Term scenarios the equipment was turned off and the filters were kept inside the sealed filter holder between exposures.

In a typical experiment, each filter was weighed and then conditioned by passing low humidity (<10% RH) air through it for at least two hours at  $20 \text{ l min}^{-1}$  for A1P2 filters and four hours for A2P3 filters. The filter was then reweighed to determine the weight loss associated with conditioning.

The filter was then placed into the system and the experiment begun. The challenge concentration monitored and controlled at  $200 \pm 20 \text{ ppm}$  at a temperature of  $20 \pm 2^\circ\text{C}$ , a flow rate of  $40 \text{ l min}^{-1}$  and a relative humidity of less than 10%. A laptop computer using a Picolog ADC-16 analog to digital converter logged the temperature, airflows, vapour concentration upstream and downstream of the filters and pressure drop across the filters. After breakthrough reached 100% the experiment was stopped and the filter removed. The filter was again weighed to determine the gain in weight associated with the exposure.

## **3.2 MIXED VAPOUR SYSTEMS**

### **3.2.1 Introduction**

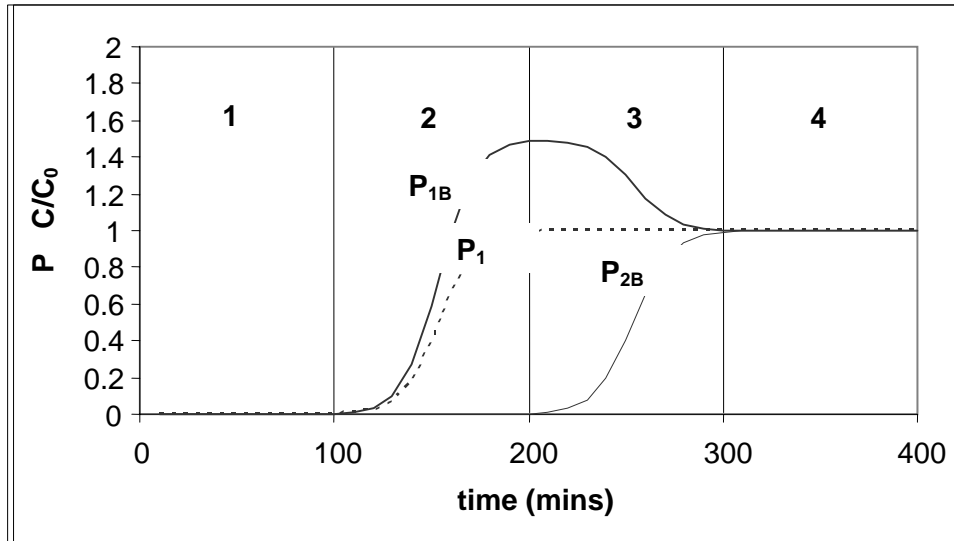
In many cases, users of respirators with organic vapour filters will be exposed to more than one vapour simultaneously, or will be exposed to different vapours at different times. The behaviour of organic vapour filters under these circumstances is not well understood. In this experimental programme we investigated the behaviour of filters in a dual vapour system in which the filter is exposed to two vapours simultaneously. Such systems have been referred to as “binary” systems by other authors (e.g. Yoon and Nelson, 1984).

### **3.2.2 Theoretical background**

In an earlier project (Hemingway *et al.*, 2002), we compared the performance of organic vapour filters against predictions of filter lifetime based on a model devised by Wood (1991) and found poor correlation. Theoretical models to describe the behaviour of organic vapour filters have been reported by several other authors. The most accessible are the semi-empirical models by Yoon and his colleagues (e.g. Yoon and Nelson, 1984, Yoon *et al.*, 1992).

Yoon’s model predicts that the presence of a second vapour in a dual vapour system modifies the performance of organic vapour filters against the first vapour, when compared with the performance against that vapour alone. Two distinct breakthrough curves are discernable. The concentration of the first vapour, which breaks through, usually the more volatile, can rise higher than 100% of the challenge concentration.

This effect was reported by Yoon *et al.* (1991) in an acetone/m-xylene dual vapour system. It is best explained by considering the idealised data as shown in Figure 3.2, which is typical of the data which can be obtained. This shows the breakthrough curves of two compounds ( $P_{1B}$ ,  $P_{2B}$ ) in a dual vapour system as well as the breakthrough curve which would be expected for compound 1 in a single vapour experiment ( $P_1$ ). Compound 1, which is the first vapour to breakthrough, is relatively weakly adsorbed by the activated carbon when compared with compound 2.



**Figure 3.2 Idealised breakthrough curve for dual vapour vapour system**

In period 1 (0-100min) both compounds are being absorbed by the activated carbon. In period 2 at 100 minutes, as the available sites begin to diminish, compound 1 begins to breakthrough. At this point, the downstream concentration of compound 1 will result from the sum of the challenge concentration of compound 1 passing straight through the filter (as no sites are available) plus compound 1, previously adsorbed onto the activated charcoal, being displaced by preferential absorption of compound 2. As this process continues, the downstream concentration of compound 1 rises to become higher than the challenge concentration. At 200 min in period 3, compound 2 starts to break through. Compound 1 in the filter bed continues to be displaced by compound 2 but the rate at which this displacement occurs begins to decrease, as the reservoir of compound 1 in the bed decreases. By the start of period 4, at 300 min all of the available sites in the filter bed have been filled by compound 2, no compound 1 remains in the filter and both chemicals are passing straight through.

In Yoon and Nelson (1984), a model is described which may be used to predict single contaminant breakthrough for specific filters under some conditions. They compared their model with their own experimental data for several organic vapours and against earlier, more general models reported by Wheeler and Mechlenberg. Their model provided better agreement with their experimental data over the entire contaminant breakthrough profile and was much simpler to use. It does however require the derivation of empirical parameters.

From Yoon and Nelson the probability of contaminant breakthrough ( $P$ ) for a single vapour may be expressed as:

$$P = \frac{1}{1 + e^{k'(\tau - t)}} \quad 3.1$$

where

- $k'$  = rate constant
- $\tau$  = time required for 50% breakthrough
- $t$  = time from start of exposure

Using this model  $\tau$  may be calculated from

$$\tau = \frac{W_e}{CF} \quad 3.2$$

where

$$\begin{aligned} W_e &= \text{saturation capacity of the cartridge} \\ C &= \text{contaminant concentration} \\ F &= \text{flow rate} \end{aligned}$$

Both the rate constant  $k'$  and the 50% breakthrough time  $\tau$  are specific to the challenge vapour, its concentration and to the specific filter. This model was extended to dual vapour systems by Yoon *et al.*, (1991,1992). They showed that the probability of contaminant breakthrough of the first compound in a dual vapour system ( $P_{1B}$ ) is given by:

$$P_{1B} = P_1 + A_m(P_1 - P_{2B}) \quad 3.3$$

where

$$\begin{aligned} P_1 &= \text{expected fractional breakthrough of compound 1 in the absence of} \\ &\quad \text{compound 2} \\ P_{2B} &= \text{fractional breakthrough of compound 2} \\ A_m &= \text{maximum fractional excess (of compound 1) derived from the dual vapour} \\ &\quad \text{breakthrough curves from} \end{aligned}$$

$$A_m = \frac{C_m - C_1}{C_1} \quad 3.4$$

where

$$\begin{aligned} C_m &= \text{maximum observed concentration of compound 1} \\ C_1 &= \text{challenge concentration of compound 1} \end{aligned}$$

From Yoon *et al.* (1991) the parameter  $A_m$  may be calculated from the 50% breakthrough times of compound 1 ( $\tau_1$ ) and compound 2 ( $\tau_2$ ) by

$$A_m = D \frac{\tau_1}{\tau_2 - \tau_1} \quad 3.5$$

$\tau_1$  may be derived from the time at which  $P=0.5 C_1$  in a single vapour system or  $P=0.5 C_m$  in a dual vapour system.  $D$  represents the fraction of compound 1 which is eventually displaced by compound 2. The use of this model gives a basis for comparing the expected results for a dual vapour system based on results obtained earlier on single vapour systems, with those obtained in the dual vapour system.



It is however dependant on the empirical derivation of the parameter D which varies depending on the compounds and concentrations. For the acetone/m-xylene dual vapour system reported by Yoon, all challenge combinations resulted in a value of 1 for D. In subsequent work, with multi-vapour systems Yoon *et al.* (1996) reported D values in the range 0.55-0.88.

### 3.2.3 Experimental Design

In the dual vapour system programme, we planned to measure the penetration of five pairs of vapours. For each pair, we planned to carry out two replicates. Filters were to be tested at a flow rate of 40 lmin<sup>-1</sup>, at a single humidity value (<10%), and against two vapours. The target concentration was 200 ppm (for each vapour). A single filter type (Martindale) was used.

Most of the work was carried out with A1 filters but additional work, was carried out with A2 filters as summarised in Table 3.2 below.

**Table 3.2 Dual vapour experiments summary design**

<b>Filter Type</b>	<b>Test Vapour</b>	<b>Replicates</b>	<b>Total Filters</b>
<b>A1</b>	<b>Isopropanol with Toluene</b>	<b>2</b>	<b>10</b>
	<b>Isopropanol with Heptane</b>	<b>2</b>	
	<b>Isopropanol with Cyclohexane</b>	<b>2</b>	
	<b>Toluene with Heptane</b>	<b>2</b>	
	<b>Toluene with Cyclohexane</b>	<b>2</b>	
<b>A2</b>	<b>Toluene with Heptane</b>	<b>2</b>	<b>4</b>
	<b>Toluene with Cyclohexane</b>	<b>2</b>	

### 3.2.4 Methods

For the dual vapour system, two possible options were considered. These were; (i) chemicals mixed in the liquid form and vaporised and (ii) separate injection of two vapours simultaneously.

For the first of these options it is necessary that the two compounds are miscible and non-reactive. Compounds could be mixed in the appropriate proportions to give the target airborne concentration, providing a relatively simple approach. Preliminary testing ruled out the first option due to difficulties in establishing stable concentration at the correct level of the two chemicals and the development work focussed on option two. This method enabled injection and vaporisation of two separate compounds simultaneously maximising the possibility of control of the vapour concentrations. As described in Section 3.1, the syringe pump approach used in the previous work by Hemingway *et al.*, 2002, was replaced by (in this case) a twin bubbler system (one for each chemical).

A method employing two Miran detectors was employed to determine the concentrations of the two vapours. In this method, the Mirans were connected in series and each of the Mirans tuned to one of the vapours. It was necessary to determine that the combinations of vapours could be discriminated by Mirans. This was investigated by tuning a Miran to the first vapour then exposing it to the second vapour at the experimental design concentration and determining the signal level. In practice it was

found for almost all combinations of vapours there was some interference. The interference was minimised in each by selecting the optimum peak. Calibrations were carried out with and without the second vapour present.

The Mirans sequentially measured the challenge and penetrating vapour concentrations. Selection between challenge and penetration was achieved through a solenoid valve arrangement

A valve control system determined when to measure the challenge concentration. After completion of the challenge measurement the control system changed the solenoid valve configuration to measure the penetration concentration after a specified time period to allow the challenge atmosphere to be purged. The system then switched back to challenge mode and the process repeated until 100% breakthrough occurs. Preliminary testing was carried out to determine the time taken to flush out the Mirans. Measurements of pressure drop, temperature and humidity were also taken.

The system was controlled by a PC. The data acquisition and control system comprised a PicoLogger ADC10, a PCI 8255 Digital input/output board (to supply the on/off signal to the solenoid valves), a DC relay board (comprising of 8 SSR's), in conjunction with LabView (6.1) software. LabView was used to control the valves via the relays and to log all the concentration data from of the Mirans, the pressure drop data and the environmental conditions.

A schematic diagram showing the system design is given in Figure 3.3.

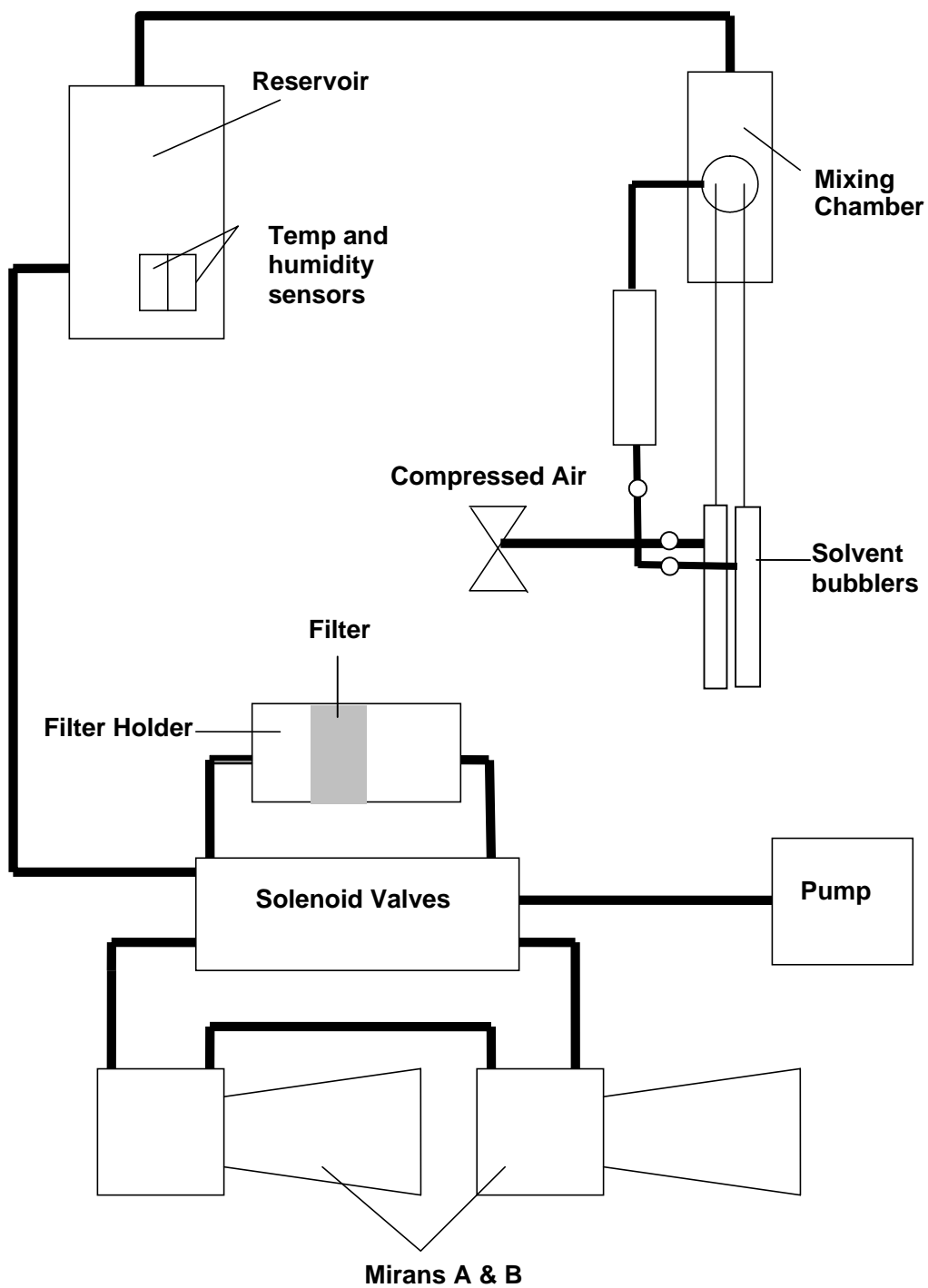


Figure 3.3 Dual Vapour Test System

## 4. RESULTS AND DISCUSSION

### 4.1 DISCONTINUOUS CHALLENGES

#### 4.1.1 Results

The experiments as carried out are summarised in Table 4.1

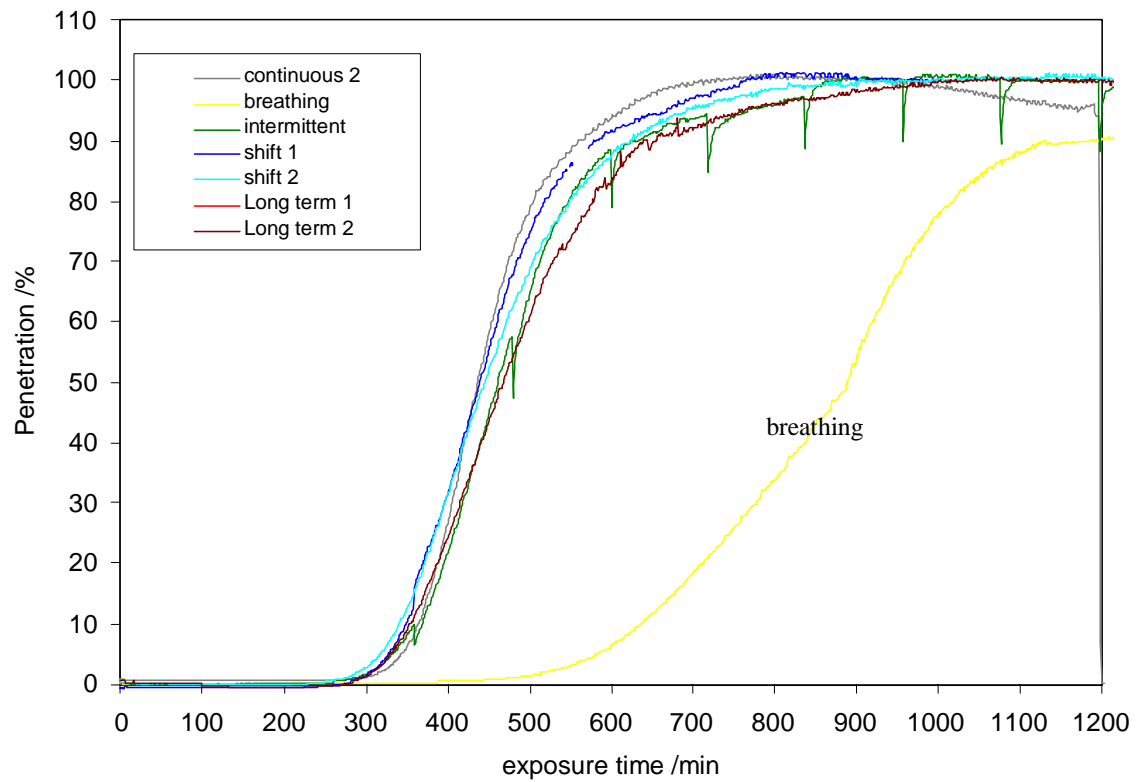
**Table 4.1: Summary of experiments**

Filter type	Vapour	Expt. number	Exposure pattern	Detailed Conditions /comments
A1P2	Iso-propanol	1	Continuous 1	Apparatus not sealed correctly
		2	Continuous 2	Exposure concentration too high after 360 min but results still valid
		3	Breathing	Breathing mechanism failed so some periods of continuous exposure but results still valid
		4	Intermittent	OK
		5	Shift 1	Overnight interval after 400 min exposure during which the filter left connected to the Mirans
		6	Shift 2	Overnight interval after 200 min exposure
		7	Long term 1	One week interval after 362 min exposure
		8	Long term 2	One week interval after 100 min exposure
	Cyclo-hexane	9	Continuous 1	OK
		10	Continuous 2	OK
		11	Breathing	OK
		12	Intermittent 1	Humidity control failed
		13	Intermittent 2	OK
		14	Shift 1	Overnight interval after 242 min exposure
		15	Long term 1	One week interval after 240 min exposure
		16	Long term 2	One week interval after 65 min exposure
		17	Long term 3	One week interval after 80 min exposure
A2P3	Iso-propanol	18	Continuous 1	OK
		19	Continuous 2	OK
		20	Long term	One week interval after 1107 min exposure

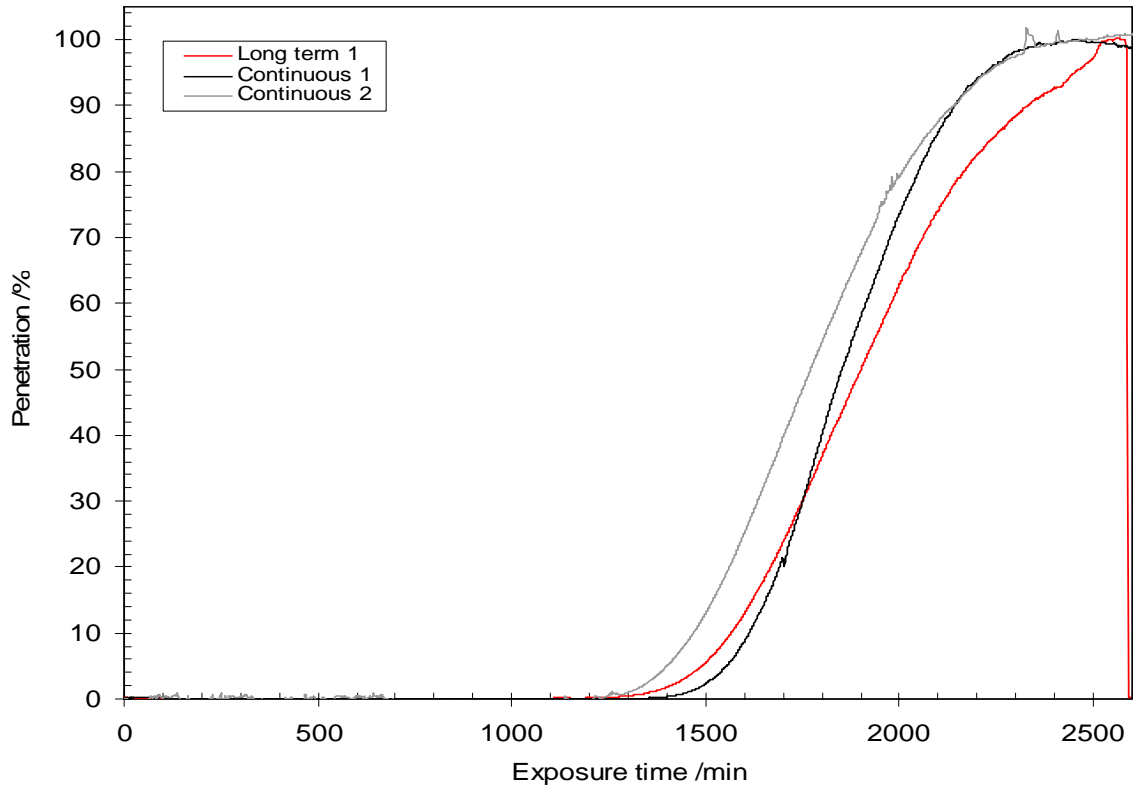
The breakthrough curves collected in these experiments are shown in Figures 4.1 to 4.3. In these figures, the periods during which the filters were not exposed have been removed so that the results can be more easily compared with each other. A summary of all of the results derived from these curves, as well as the other data (temp, RH, pressure drop, mass loss due to drying and mass of solvent absorbed) is given in Appendix 1.

Figure 4.1 shows that all the breakthrough curves for A1P2 filters exposed to isopropanol. The continuous 1 experiment has not been included due to incorrect sealing, causing experimental leakage,

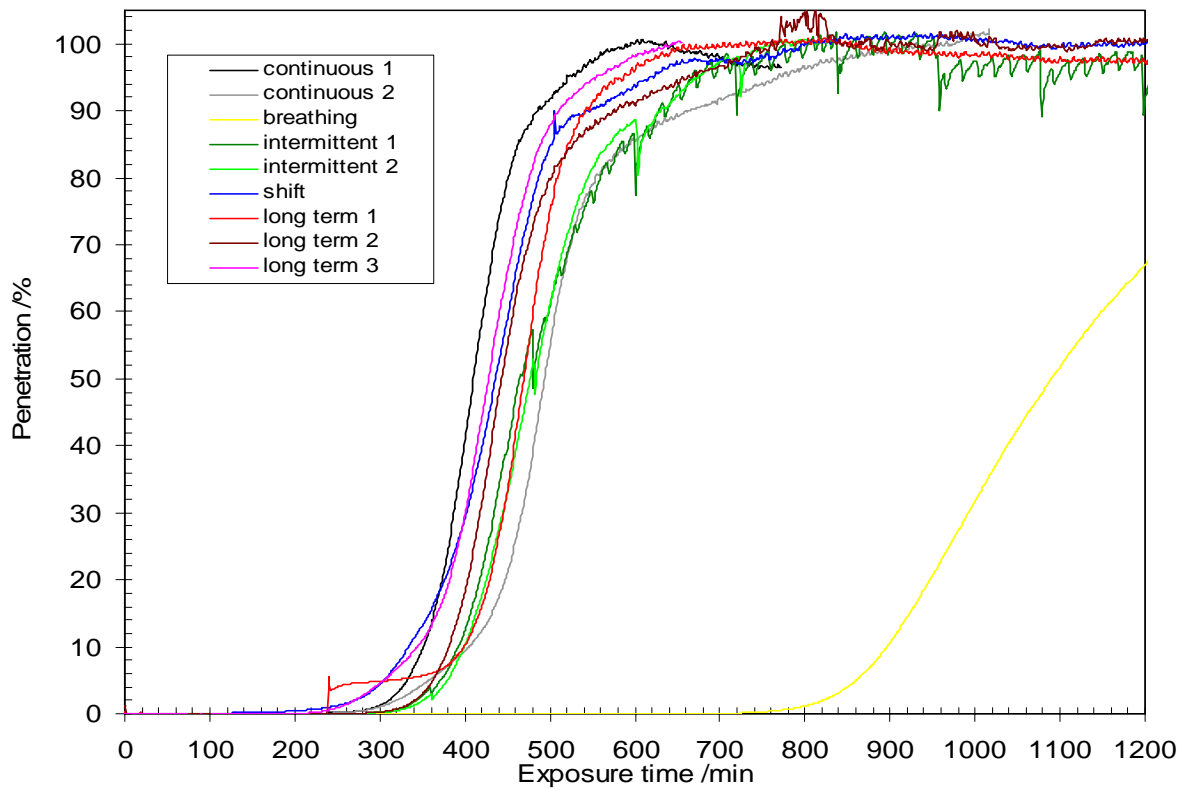
identified in that experiment. Other than the “breathing” scenario, all of the curves are very closely grouped together.



**Figure 4.1: Breakthrough curves for A1P2 filters exposed to isopropanol  
(view in colour)**



**Figure 4.2: Breakthrough curves for A2P3 filters exposed to isopropanol  
(view in colour)**



**Figure 4.3: Breakthrough curves for A1P2 filters exposed to cyclohexane  
(view in colour)**

Figure 4.2 show the breakthrough curves for A2P3 filters exposed to isopropanol. Again, the curves are grouped together apart from the 'breathing' exposure pattern.

Figures 4.3 shows the breakthrough curves for the A1P2 filters exposed to cyclohexane. All of the various intermittent exposure scenarios are grouped together other than the breathing scenario.

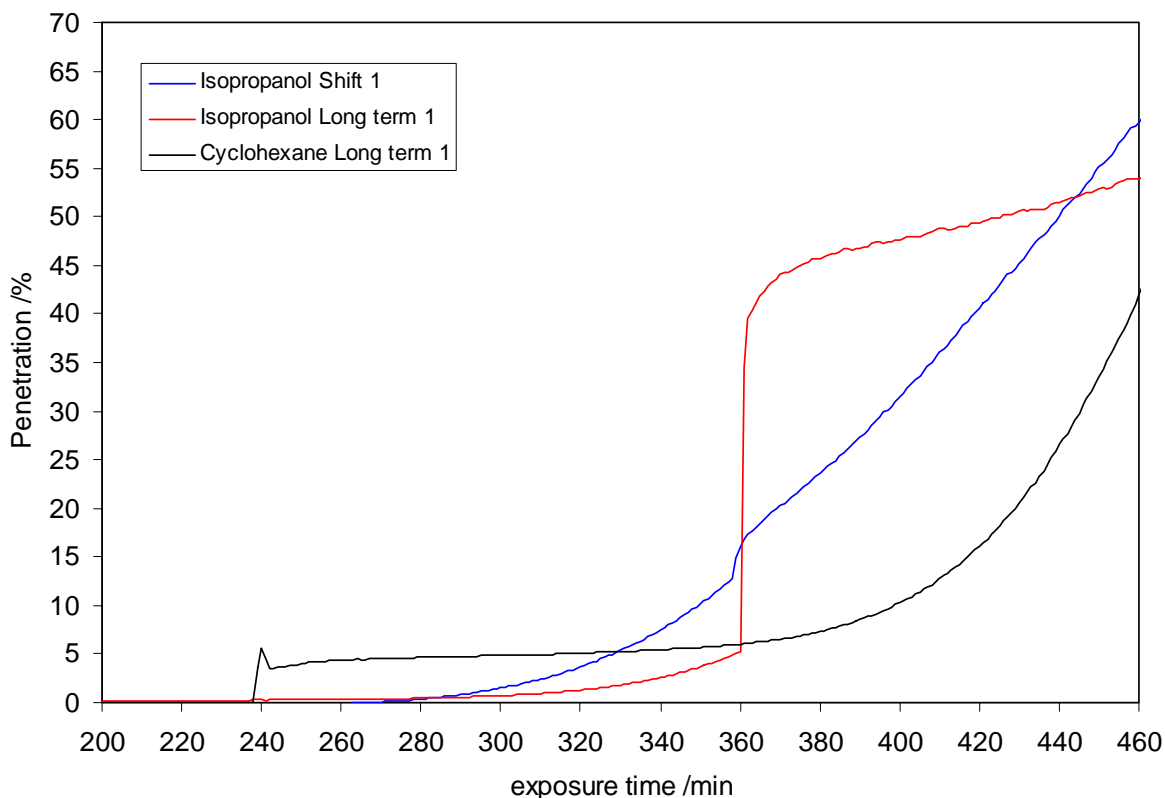
#### **4.1.2 Discussion**

For all of the single vapour experiments the data in Figures 4.1 and 4.3 and Appendix 1 strongly indicate that there is no apparent difference between the results for the continuous and discontinuous scenarios. Nor is there any difference between the various discontinuous scenarios (intermittent, shift and long term). Although the breathing scenario results appear to differ, this is only relates to the way in which the results have been presented. For all of the other discontinuous scenarios, the periods of no exposure have been taken out so that the results could be compared on the same scale. This was not possible for the breathing scenario due to the high switching frequency of this pattern. Had these periods of non-exposure been removed, these curves would also have been aligned with the other discontinuous scenarios.

Although there was little difference in the broad comparison between continuous and discontinuous exposure, there were some differences in detail which were noteworthy. These are expanded below.

##### *Long term and Shift Exposure Scenarios*

Increased breakthrough concentrations, immediately following exposure breaks, were observed in three cases. These were Shift 1 and Long Term 1 exposure scenarios for isopropanol (Fig. 4.1) and Long Term 1 exposure scenario for cyclohexane (Fig. 4.3). These curves are picked out and shown in more detail in Figure 4.4. In each case, the concentration subsequently reverted to that expected for a normal breakthrough curve once exposure was resumed, although the rate at which that happened varied. For example Long Term 1 for isopropanol reverted to a more typical pattern after about 500 min (see Fig. 4.1). None of the other Long Term or Shift scenarios showed any change in their breakthrough pattern. In all of these cases breakthrough had already begun before the exposure was interrupted. In the other Shift and Long Term experiments, exposure was interrupted before breakthrough occurred. Enhanced breakthrough following resumption of exposure was not observed in any of these cases.



**Figure 4.4: Example breakthrough curves for AIP2 filters showing penetration increases after periods of no exposure**

During Shift 1 for isopropanol the Mirans were left connected to the filter during the exposure break (see Fig. 4.5) to observe possible absorption or desorption in the absence of airflow through the filter. Effectively, the downstream part of the circuit would be a sealed system. Any desorption from the filter into this part of the circuit would result in an observed increase in the downstream concentration. No such increase was observed.

These observations suggest that there can be significant diffusion within, but not out of the filter cartridges during periods of no exposure. If a large amount of vapour has been absorbed it will diffuse from the saturated areas on the upstream side of the filter through to the un-saturated areas on the downstream side of the filter. The concentration of vapour on the downstream side will rise as that on the upstream side falls. Consequently, when airflow is switched back on vapour will be absorbed on the upstream side cleaning the airflow, which will then cause the vapour on the downstream side to be desorbed giving a larger downstream concentration. This will continue until the filter further upstream has once again become saturated, vapour will reach the areas downstream, which will stop desorbing, and a more normal breakthrough curve develops. The effect is more noticeable the longer the filter stands (compare Shift 1 with Long Term 1 for isopropanol in Fig. 4.4).

If only a small amount of vapour has been absorbed it will be on the upstream side of the filter. Again diffusion will allow the vapour to spread out but it will not reach the downstream face of the filter. Consequently, when airflow is switched back on the concentration at the downstream face of the filter will remain zero.

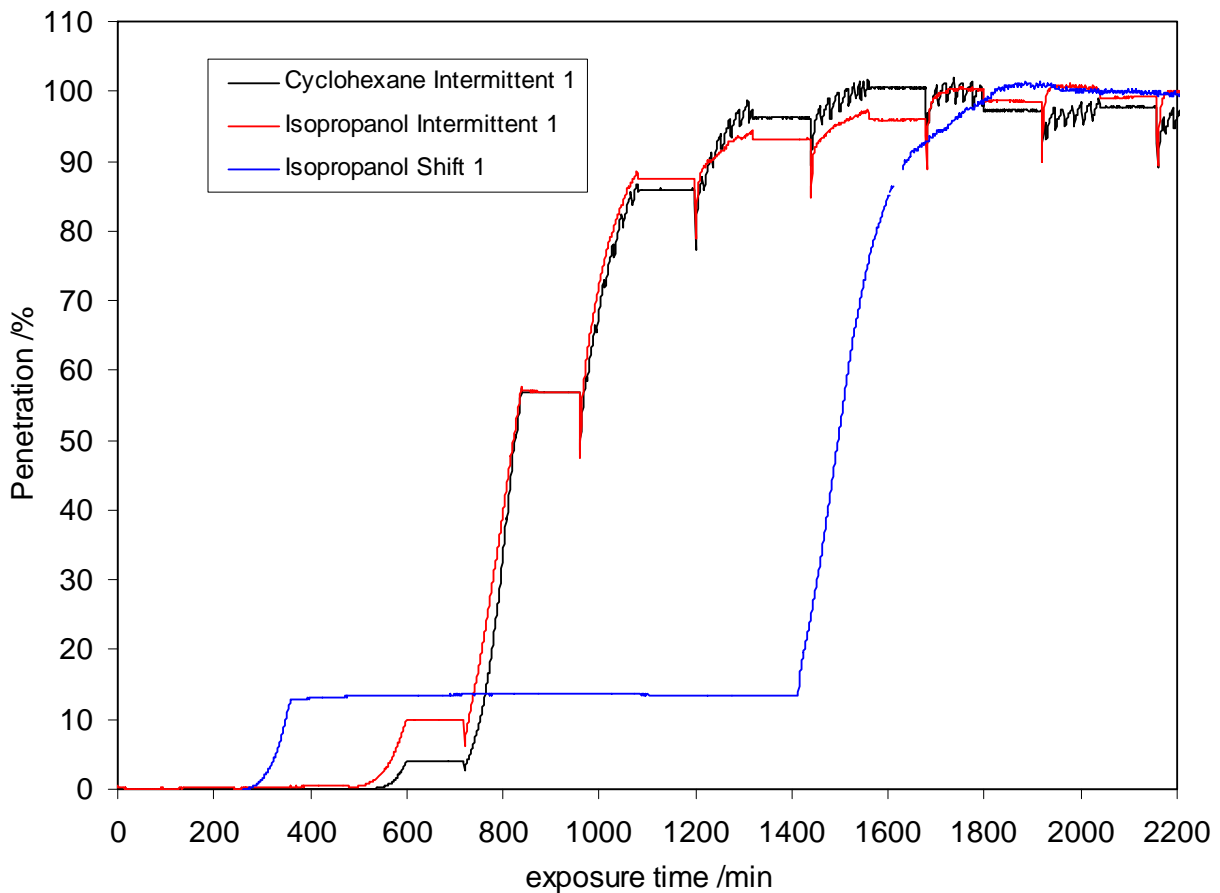
This suggests that gaps in the use of vapour filters are likely to have little effect on the breakthrough time for these filters. However, if breakthrough has already begun then the concentration at the downstream side of the filter may initially be increased.



### *“Intermittent” Exposure Scenario*

None of the intermittent scenarios (two hours on, two hours off) showed an increase in filter penetration after periods of no exposure (Fig 4.5). The periods of two hours during which no exposure occurred were not long enough for diffusion to significantly affect the breakthrough patterns. However, there was a sharp drop in breakthrough vapour concentration just after the exposure breaks which quickly reverted to a more typical breakthrough curve. This was most likely due to the automatic switching unit causing a backpressure during switching that affected the rate of vaporisation in the bubbler unit. The automatic switching unit was not used during other scenarios and these did not show this effect.

There was a small waveform in the breakthrough concentration pattern for the Intermittent 1 scenario for cyclohexane during which the de-humidifier failed (Fig. 4.5). The period of the wave pattern appears to match the times at which the compressor unit, that provided the airflow to the apparatus, switched on and off to top-up its reservoir. The waveform was not present until after 50% breakthrough or in either the upstream concentration or the overall airflow. This suggests that it was a result of absorption and desorption from the saturated filter, possibly as a result of the humidity varying as the compressor activated.



**Figure 4.5: Example breakthrough curves for A1P2 filters showing periods of no exposure**

#### *Average breakthrough times*

Since no differences were observed in the various exposure scenarios (excluding breathing), it is appropriate to summarise these by taking means. These are shown in Table 4.2.

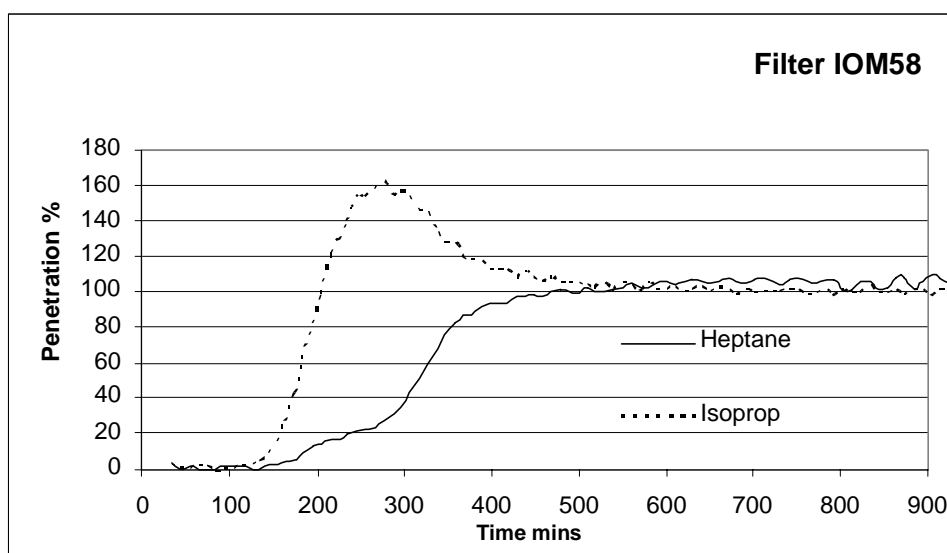
**Table 4.2: Average breakthrough times (concentration of 200ppm and flow rate of 40 l min<sup>-1</sup>).**

Filter type	Compound	Exposure pattern	n	Average time to 10% breakthrough Standard deviations in brackets
A1P2	Isopropanol	Breathing	1	636
		All others	6	357 (9)
	Cyclohexane	Breathing	1	897
		All others	6	371 (27)
A2P3	Isopropanol	All others	3	1553 (53)

## 4.2 DUAL VAPOUR CHALLENGES

### 4.2.1 Results

The breakthrough curves for the dual vapour systems were very distinctive and were different to those obtained for single vapour systems. An example is shown in Figure 4.6 which shows the breakthrough curves for the isopropanol-heptane system. This was typical for all of the dual vapour breakthrough curves although there were differences in detail. The vapours break through separately. In many cases the downstream concentration of the vapour which breaks through first exceeds the challenge concentration before decreasing to fall to that of the challenge concentration. The shape of the breakthrough curve of the second chemical follows an s-shape curve, typical of that seen in single vapour systems.



**Figure 4.6 Isopropanol – heptane system breakthrough curves**

Table 4.3 summarises the main data obtained for the dual vapour systems. For each of these experiments, the summarised data comprises the compounds in the system (chemical A, B), the first compound to break through (compound 1), the maximum height of the peak, expressed as a percentage of the challenge concentration, and the 10 and 50% breakthrough times for each compound.

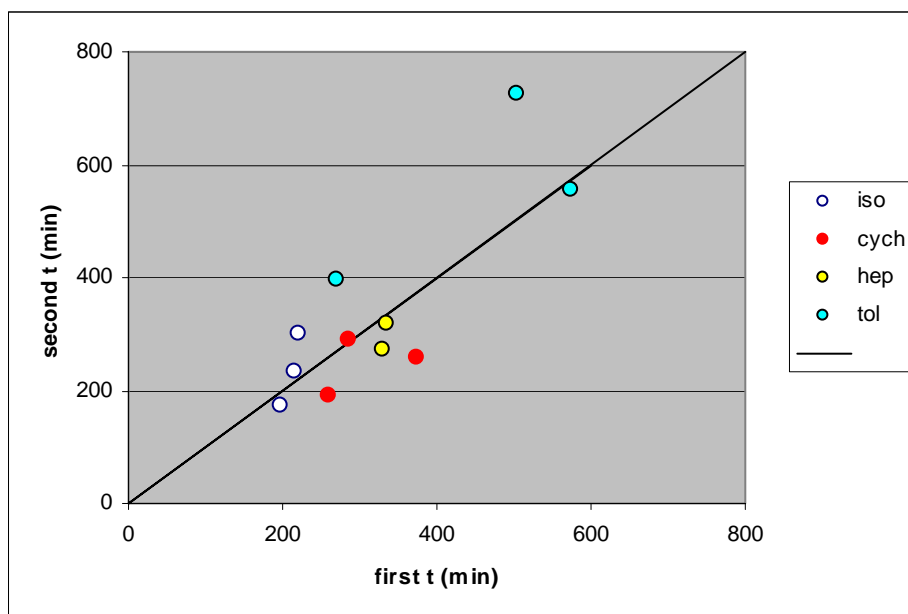
**Table 4.3 Summary data, dual vapour vapour systems**

Filter type	Filter No	Chemical A 200 ppm	Chemical B 200 ppm	Compound 1	Max breakthrough %	10% Time A mins	50% Time A mins	10% Time B mins	50% Time B mins
a1	IOM44	isopropanol	toluene	isopropanol	133	173	221	391	503
a1	IOM42	isopropanol	toluene	isopropanol	133	195	301	544	724
a1	IOM46	isopropanol	heptane	isopropanol	120	136	197	212	334
a1	IOM58	isopropanol	heptane	isopropanol	161	145	175	185	317
a1	IOM04	isopropanol	cyclohexane	isopropanol	113	169	215	202	286
a1	IOM10	isopropanol	cyclohexane	isopropanol	103	193	235	218	289
a1	IOM14	toluene	heptane	heptane	100	233	273	205	238
a1		toluene	heptane						
a1	IOM34	toluene	cyclohexane	cyclohexane	100	240	269	172	260
a1	IOM26	toluene	cyclohexane	cyclohexane	139	331	396	170	190
a2	IOM22	toluene	cyclohexane	cyclohexane	164	469	547	344	373
a2	IOM02	toluene	cyclohexane	cyclohexane	104	407	554	227	257
a2	IOM18	toluene	heptane	heptane	137	496	592	288	317
a2	IOM20	toluene	heptane		112			245	270

#### 4.2.2 Analysis

In general terms the data quality was not good. Figure 4.7 shows the time to 50% breakthrough for each replicate pair of data points. It may be seen that while these are distributed around a line of equality, there is substantial scatter. (The figure shows the line of equality, not the fitted line). As we noted in our earlier study (Hemmingway *et al.*, 2002), a number of factors contributed to this variability but much of it was considered to arise from variability in the filters themselves. The variability in the data and the relatively few numbers of data points meant that the opportunities for formal statistical analysis were limited but this was expected at the outset. Nevertheless the data were of sufficient quality to facilitate improved understanding of the behaviour of filters in dual vapour vapour system and to enable examinations of the issues identified as important namely:

- Comparison between dual vapour systems and single vapour systems
- Comparison of dual vapour systems data with models
- Extrapolation to other systems



**Figure 4.7 Breakthrough times for replicate pairs**

*Comparison between Dual vapour and Single Vapour Systems*

Table 4.4 (Parts A, B) shows the 50% breakthrough time for the A1 cartridges in dual vapour vapour systems in comparison with the breakthrough times for single vapours in current study (Section 4.1). Further comparison with results obtained in an earlier study (Hemingway *et al.*, 2002) is also shown. The table has been split to summarise the data for the compound in the dual vapour system according to whether it was the first or second compound to break through.

**Table 4.4A Comparison between dual vapour (first compound breakthrough) and single vapour systems**

isopropanol		heptane		cyclohexane	
dual <sup>1</sup>	single <sup>1</sup>	dual <sup>1</sup>	single <sup>2</sup>	dual <sup>1</sup>	single <sup>1</sup>
221	502	238	422	269	410
301	462		597	396	495
197	440				465
175	446				477
215	422				436
235	469				470
					444
					428
224	453	238	510	332	453

<sup>1</sup> source current study

<sup>2</sup> source Hemingway *et al.*, 2002

**Table 4.3B Comparison between dual vapour (2nd compound breakthrough) and single vapour systems**

heptane		toluene		cyclohexane	
dual <sup>1</sup>	single <sup>2</sup>	dual <sup>1</sup>	single <sup>2</sup>	dual <sup>1</sup>	single <sup>1</sup>
334	422	503	579	286	410
317	597	724	581	289	495
		273			465
		269			477
		396			436
					470
					444
					428
326	510	433	580	288	453

<sup>1</sup> source current study

<sup>2</sup> source Hemingway *et al.*, 2002

For the first compound breakthrough, comparative data are available for isopropanol heptane and cyclohexane. In all cases there was a significant decrease in breakthrough time for the dual vapour system compared with in the single vapour system. In each case the breakthrough was around half of that for the single vapour system. For isopropanol the (arithmetic) mean 50% breakthrough time in the dual vapour system is 224 minutes, compared with 453 minutes in the single vapour system. Similarly for heptane the 50% breakthrough time was 238 minutes in the dual vapour system compared with 510 minutes in the single vapour system. For cyclohexane the comparative figures were 332 and 453 minutes.

Considering the data for the second breakthrough chemicals, comparative data were available for both the heptane, toluene and cyclohexane. Again, in all systems, the 50% breakthrough times were significantly shorter in the dual vapour system.

For heptane, the 50% breakthrough was 326 minutes in the dual vapour system and 510 minutes in the single vapour system. For toluene, the equivalent figures were 433 and 580 minutes and for cyclohexane the equivalent figures were 288 and 543 minutes.

These results appear to show quite clearly that the presence of a second vapour does lead to a shorter breakthrough time apparently for both of the vapours. This result does need interpreted with some caution however in that some of the filters for the single vapour tests were sourced at different time from those for the dual vapour tests, and that the experiments were carried out in two laboratories for which formal equivalence was not demonstrated. Nevertheless, the shortening of breakthrough times appears in all cases and is partly supported by some models of filter performance (below).

#### *Comparison with Models*

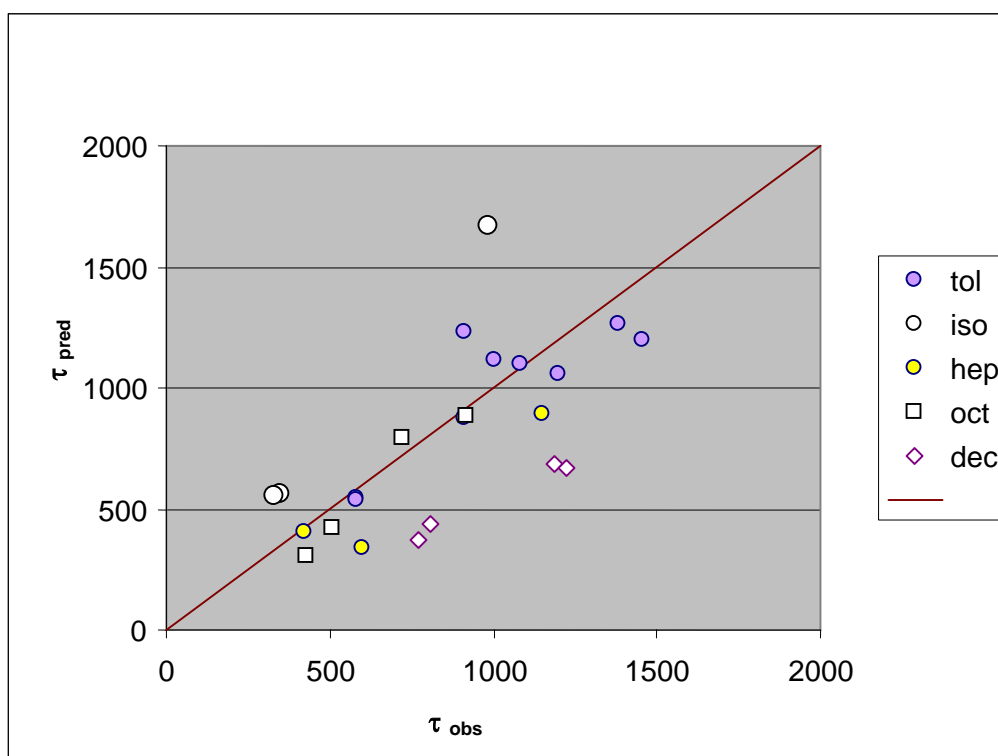
In Section 3 we described the performance model for single and dual vapour systems developed by Yoon and his colleagues. To investigate whether or not this model was applicable to the filters tested, we firstly examined the single vapour filter data from the Hemingway *et al.*; (2002) study.

Equation 3.2 provides a basis of calculation of the 50% breakthrough time ( $\tau$ ) in a single vapour system from the saturation capacity of the cartridge, the challenge concentration and the flow rate. This can also be observed directly from the breakthrough curve. Values for all of these parameters were reported by Hemingway and his colleagues.

Figure 4.8 shows the calculated value of  $\tau$  based on these parameters ( $\tau$  pred) compared with that observed in the breakthrough curves ( $\tau$  obs) for 5 chemicals (toluene, isopropanol, heptane, octane

and decane). In broad terms this graph indicates a measure of agreement between the predicted and observed values of  $\tau$ .

There are however, what appears to be systematic differences for some chemicals. For isopropanol the predicted values are all higher than the observed values by approximately 50%. Similarly the predicted decane values are all lower than the observed values, by about 50%. The predicted and observed values for toluene, heptane and octane are all quite comparable. At this stage we have no explanation for these apparent differences in a single vapour system.



**Figure 4.8 Predicted and Observed Values of  $\tau_1$  for a single vapour system**

In a dual vapour system, Yoon's model predicts that compound 1 will breakthrough faster than the breakthrough time for the same compound in a single vapour system. It also predicts that the breakthrough of compound 2 in a dual vapour system will be the same as the breakthrough of the same compound in a single vapour system. The implication of this is that the compound 2 breakthrough time will be independent of which compound 1 it is paired in the dual vapour system. In this study it can be seen that the breakthrough times for both compound 1 and compound 2 are significantly shorter than those obtained for these as single compounds in the Phase 1 tests. It may also be seen that there was substantial variability in the compound 2 breakthrough, particularly for toluene. Therefore, while the experimental data supports the model (in a qualitative sense) for compound 1 scenarios, it does not support the model for compound 2 scenarios

The model also predicts that, for some combinations at least, that the breakthrough concentration of compound 1 will peak at a level greater than the challenge concentration. This was observed in our data, at least for some combinations.

D, which is the fraction of compound 1 which is eventually displaced by compound 2, is an important factor in relation to the behaviour of those filters in dual vapour systems. Equation 3.5 provided a way of estimating D from the 50% breakthrough times and from the height of the peak in a dual vapour system. Rearranging, this becomes

$$D = \frac{A_m(\tau_2 - \tau_1)}{\tau_1} \quad 4.1$$

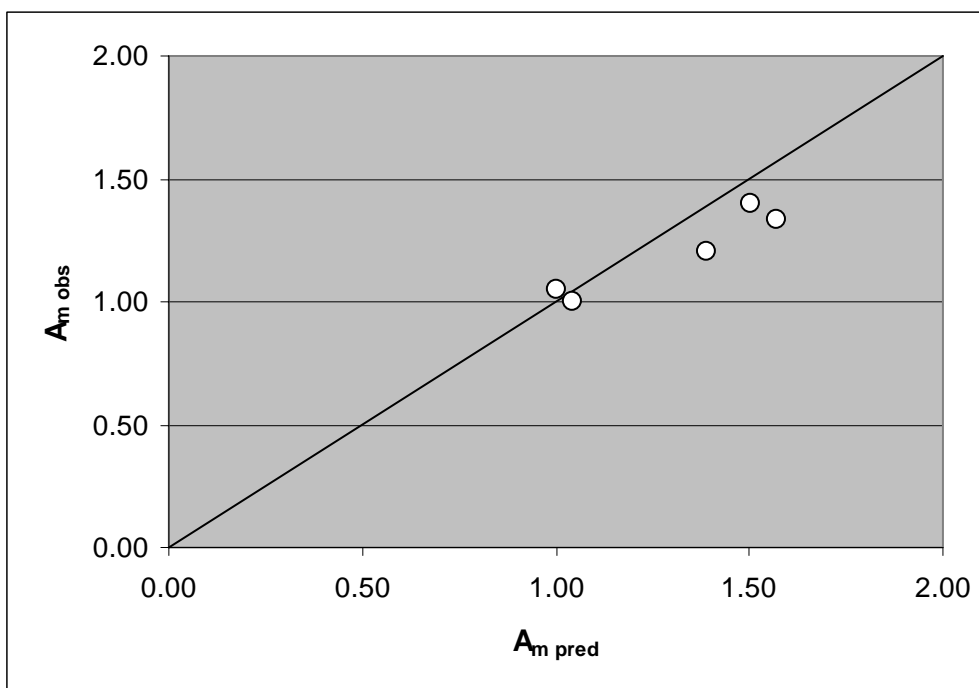
Estimates of  $A_m$ ,  $\tau_1$ , and  $\tau_2$  were calculated from the penetration curves in the dual vapour experiments. Estimates of D were derived from these and these are reproduced below in Table 4.4.

**Table 4.4 Evaluation of the fraction of compound one displaced in dual vapour systems**

Chemical A	Chemical B	1st Breakthrough Compound 1	D
isopropanol	toluene	isopropanol	0.400
isopropanol	toluene	isopropanol	0.400
isopropanol	heptane	isopropanol	0.110
isopropanol	heptane	isopropanol	0.380
isopropanol	hexane	isopropanol	0.040
isopropanol	hexane	isopropanol	0.008
toluene	heptane	heptane	0.000
toluene	heptane		
toluene	hexane	hexane	0.000
toluene	hexane	hexane	0.390
toluene	hexane	hexane	0.260
toluene	hexane	hexane	0.050
toluene	heptane	heptane	0.300
toluene	heptane		

These fractional values, which range from 0.4 down to 0, are generally lower than figures reported by Yoon and his colleagues. However, there is no directly comparable data.

Equation 3.5 provides a way of estimating  $A_m$  (the maximum fractional excess) in a dual vapour system based on the  $\tau$  values derived from single compound systems, provided that values of D are known. Therefore, we used the D values in Table 4.4 to calculate values of  $A_m$  based on  $\tau$  values derived from the Hemingway *et al* (2002) study. These predicted values of  $A_m$  are plotted in Figure 4.9 against the observed values. This shows reasonable agreement (not tested statistically) between the two estimates of  $A_m$ .



**Figure 4.9 Comparison of predicted and observed  $A_m$  values**

It seems from this limited data that the semi-quantitative model of filter performance developed by Yoon and his colleagues does, qualitatively at least help to explain some of the observed behaviour of organic vapour filters in single and dual vapour systems. Furthermore, it gives some basis for evaluating likely behaviour in dual vapour systems from known behaviour in single systems.

However, there are limitations to the applicability of this approach. Firstly, all of the behaviour is not predicted by the model. In particular, the observed breakthrough of compound 2 in a dual vapour system compared to the same vapour in a single vapour system. The reason for this is not known. Secondly, the value of  $D$  is generally unknown and can only be arrived at by experiment. It will vary depending on the filter and the vapour. In the absence of further information a pragmatic (worst case) approach would be to consider that the value of  $D$  should be assumed to be unity unless it has been shown to be otherwise. For some vapour combinations and for some filters,  $D$  has been shown to equal unity. This will tend to maximise the undesirable effects (lower breakthrough time, higher breakthrough peak) in the dual vapour system and so be the basis of a conservative approach.

Finally this approach still requires information about the breakthrough profile ( $\tau$ ,  $k'$ ) in a single vapour system. Again this will be filter and vapour dependent.

Here we have considered exposure in dual vapour systems. Clearly, more complex systems comprising three or more vapours are also possible. Filter behaviour in these systems will be governed by similar mechanisms. The vapours will be preferentially absorbed depending largely on their volatility, with the more strongly absorbing vapour displacing the more weakly absorbing vapour from the charcoal bed.

### 4.3 COMPARISON BETWEEN A1 AND A2 FILTERS

Comparison between A1 and A2 filters were carried out in both single vapour (intermittent) and dual vapour systems. The results are summarised in Table 4.5 below.



**Table 4.5 Breakthrough times for A1 and A2 filters in various system**

Vapour challenge		A1 (n) mins	A2 (n) mins
toluene/cyclohexane system	toluene	286 (2)	551 (2)
	hexane	225 (2)	315 (2)
toluene/heptane system	toluene	273 (1)	592 (2)
	heptane	238 (1)	289 (1)
isopropanol	isopropanol	357 (6)	1553 (3)

In all except for isopropanol, the number of comparison point is rather small. However, in all cases the comparison between A1 and A2 indicated that the larger A2 filters, as might be expected, provided higher capacity and therefore longer life times. The difference was most marked in the single vapour isopropanol case where a 4-fold increase was observed. In the dual vapour systems, the factor ranged from approximately 2 for toluene in all systems, to about 1.5 for heptane and hexane. There is insufficient data to determine whether it is applicable to use these data more widely.

#### 4.4 FILTER MASSES

The average conditioned mass of the A1P2 filters was 108 g although the filters were largely split into two weight groups of about 106 g and 110 g. The average conditioned mass of the A2P3 filters was 333.3 g. The mean initial pressure drop across the filters was 149 Pa for A1P2 filters and 151 Pa for A2P3 filters. The average mass loss of the A1P2 filters during drying was 6.6 g (see Appendix 1). The average mass of solvent absorbed was 7.5 g for isopropanol and 10.8 g for cyclohexane. In practical use, these filters are not dried before use. If a large fraction of the absorption sites in the filter are already occupied by water then it is possible that less vapour can be absorbed and breakthrough may occur sooner than reported here. It is also possible that water will be displaced by the challenge vapour and hence its presence will not affect capacity of breakthrough

#### 4.5 FILTER QUALITY

The previous study showed that 7% of A1P2 filters tested leaked (Hemingway et al; 2002). Leaks observed in the current study were seen to be due to the experiment, rather than the filters. Hence no leaks were observed in the current filters. Combining these results with the earlier results of Hemingway shows an overall percentage of filters with leaks over the two studies of 4%.

## 5. CONCLUSIONS

This program of work has led to improved understanding concerning the behaviour of organic vapour filter filters.

Based on the data obtained, there appears to be little difference in the capacity or time to breakthrough of filters which are intermittently exposed compared with those which are continuously exposed. No difference was found between those filters which were exposed continuously and those in which there were gaps in exposure for up to one week. This was true even in cases where breakthrough had begun during the first exposure period. While there is some evidence of enhanced breakthrough concentrations in filters where breakthrough has already begun, such filters are already beyond their useful life. It is certainly true that gaps of longer than one week may yield different results as could exposure to other solvents. However, from the results obtained there is no evidence to suggest that multiple short usage of a respirator filter over periods of up to a week will result in reduced protection being offered by the filter compared to continuous exposure.

Where exposure is to more than one vapour, the behaviour of organic vapour filters is quite different. The vapours are preferentially absorbed depending largely on their volatility. The more strongly absorbing vapour acts to displace the more weakly absorbing vapour from the charcoal bed. In practice this leads to separate breakthroughs for the two vapours, with the weaker absorber breaking through first. This also leads to more rapid breakthrough of both of the vapours compared with the breakthrough times of single vapours at the same concentration. We found that the time of the first vapour breakthrough in a dual vapour system was about half (actual range 0.46 to 0.74) of that expected in a single vapour system at the same challenge concentration. The second vapour breakthrough time was also reduced by a factor ranging from 0.64 to 0.74.

The reduction in breakthrough time for the first vapour is predicted by the semi-empirical model reported by Yoon and his colleagues. However, Yoon's model does not predict a reduction in breakthrough time for the second vapour, which was also observed.

A second feature of the dual vapour system is that the downstream concentration of the first vapour to breakthrough can rise to levels which are higher than that of the challenge concentration. This occurs when, as the available sites begin to diminish, compound 1 begins to breakthrough. At this point, the downstream concentration of compound 1 will result from the sum of the challenge concentration of compound 1 passing straight through the filter (as no sites are available) plus compound 1, previously adsorbed onto the activated charcoal, being displaced by preferential deposition of compound 2. As this process continues, the downstream concentration of compound 1 rises to be higher than the challenge concentration.

This effect was observed in several of the dual vapour systems. The peak downstream concentrations ranged from 100% to 164% of the challenge concentration. This effect was also predicted by Yoon's model, and showed reasonable agreement with observed values.

Overall the Yoon model gives a basis for explaining, at least qualitatively, the behaviour of dual vapour systems. It provides some basis for extrapolating between single vapour and dual vapour systems. The approach however is descriptive, rather than predictive as it requires experimental data from the actual system under consideration to determine the values of essential parameters. As such it is limited in its application.

Similar principles apply to the behaviour of triple or higher multiple vapour systems.

The reduced breakthrough time in dual vapour systems has important implications for the service life of these filters. It is often (perhaps more often than not) the case that these filters will be used to protect against more than one vapour simultaneously. Examples include paints spraying where typically a mixture of solvents is used. In these cases the likely concentrations of all of the vapours

need to be taken into account in evaluating the service life. Clearly it is necessary to provide protection based on the first breakthrough. Until better models are developed or validated one approach would be to use the sum of all of the likely vapour concentrations (in ppm) as the estimate for the vapour concentration least absorbing vapour. Service life could then be based on that estimate. As with all estimates of this type, this is highly dependant on the estimate of exposure concentration which in many cases will not be known.

One further consequence related to filters being used at two different times against two different vapours. If a filter is exposed to a weakly absorbing vapour, and subsequently to a more absorbing vapour, a worker using the respirator may be exposed to high concentrations of first vapour over a short time, caused by the second vapour preferentially displacing the first vapour from the filter bed. This could happen even though there was no initial breakthrough of the first vapour and subsequently no breakthrough of the second vapour. This may be particularly significant in scenarios where peak exposures are important. An example of this would be in an industrial process in which one solvent is used as part of the process and a second solvent is used as part of the clean up.

This effect would be difficult to prevent. One approach may be recommended that filters are not used to protect against different vapours at different times although how practical this approach would be is open to debate.

## 6. RECOMMENDATIONS

1. It is understood that HSE is considering whether to introduce recommendations concerning filter service life. Such recommendations, which are based on continuous exposure tests, do not need to be modified in cases where exposure is intermittent or where there are gaps in use of up to one week.
2. All filters should be sealed properly to for transport and storage to prevent ingress of water vapour. More work is necessary to quantify the effects of water vapour on filter performance.
3. It is necessary to take account of reduced breakthrough times caused by the presence of a second (or third, or higher multiple) vapour in any recommendations of filter lifetime.
4. It is necessary to consider the potential effects of sequential use of filters against different vapours in any recommendations produced. One option would be to recommend that filters are not used in this way.
5. More work is desirable on how these filters are actually used in practice. For example information on what vapours, in what combinations, at what levels of challenge concentrations and for how long would be advantageous.
6. More work is required to further develop, refine and validate models of breakthrough time in particular for dual vapour and higher multiple systems, with combinations which are representative of real work environments.



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## APPENDIX 1

**Table 1 Results of tests carried out on Martindale A1P2 filter cartridges.**

Vapour	Loading Scenario	%RH	Flowrate (l/min)	Temp (°C)		Final Downstream Conc. (ppm)	Challenge Concentration (ppm)		Initial Pressure Drop (Pa)	Conditioned Mass (g)	Mass Loss During Drying (g)	Mass Solvent Adsorbed (g)	Time to Breakthrough <sup>2</sup> (min)	
				Min <sup>1</sup>	Max <sup>1</sup>		min <sup>1</sup>	max <sup>1</sup>					10%	50%
Isopropanol	Continuous 1	<1.0	40	19.2	20	200	202	208	75 <sup>3</sup>	107.11	5.67	7.92	403 <sup>3</sup>	502 <sup>3</sup>
	Continuous 2	2.3		20.2	23.2	201	208	235	146	105.78	7.65	7.22	365	- <sup>4</sup>
	Breathing	0.1		19.5	19.9	184	194	199	145	105.98	6.95	7.49	636	890
	Intermittent	0.1		19.2	20.0	193	200	203	141	105.99	6.67	7.57	369	462
	Shift 1	0.1		19.3	20.1	191	200	202	147	105.23	5.80	7.43	348	440
	Shift 2	1.4		20.8	21.2	184	189	198	147	110.46	5.80	7.60	344	446
	Long term 1	0.1		19.9	20.5	192	198	202	143	105.94	5.92	7.42	361	422
	Long term 2	1.1		20.8	21.2	175	192	199	170	110.30	5.99	7.72	355	469
Cyclohexane	Continuous 1	1.6	40	19.5	20.5	179	198	226	145	111.03	7.47	10.83	351 <sup>4</sup>	410 <sup>4</sup>
	Continuous 2	0.6		20.3	20.7	185	194	199	/	107.38	7.07	10.37	406 <sup>5</sup>	495 <sup>5</sup>
	Breathing	1.0		20.2	20.6	188	195	200	/	111.95	6.49	11.20	897	1090
	Intermittent 1	1.4-16		19.4	20.2	200	198	202	163	110.63	6.42	11.99	393 <sup>6</sup>	465 <sup>6</sup>
	Intermittent 2	0.9		19.5	20.3	200	201	205	132	105.93	6.31	10.23	399	477
	Shift	1.4		19.9	20.3	191	196	210	138	110.97	6.50	10.97	334	436
	Long term 1	1.3		19.2	20.2	198	195	201	165	110.04	6.80	11.57	399	470
	Long term 2	0.9		20.1	20.5	197	199	203	155	105.98	6.43	10.36	381	444
Long term 3	0.5	19.0	19.8	191	198	207	/	105.79	7.42	10.03	344	428		

1 - Min and Max refer to the mean value ± standard deviation.  
2 - Breakthrough times do not include exposure stoppages.  
3 - Evidence of leak through and around filter.  
4 - High challenge concentration.  
5 - Possible leak upstream of filter.  
6 - High %RH.

**Table 2 Results of tests carried out on Martindale A2P3 filter cartridges.**

Vapour	Loading Scenario	%RH	Flowrate (l/min)	Temp (°C)		Final Downstream Conc. (ppm)	Challenge Concentration (ppm)		Initial Pressure Drop (Pa)	Conditioned Mass (g)	Mass Loss During Drying (g)	Mass Solvent Adsorbed (g)	Time to Breakthrough (min)	
				Min <sup>1</sup>	Max <sup>1</sup>		min <sup>1</sup>	max <sup>1</sup>					10%	50%
Isopropanol	Continuous 1	1.9	40	19.4	20.2	176	191	206	152	329.15	7.42	30.33	1611	1851
	Continuous 2	1.2		20.9	21.3	173	201	205	/	336.62	8.22	30.07	1482	1792
	Long term	1.8		19.7	20.3	181	186	209	149	334.08	7.23	30.06	1566	1901









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ISBN 0-7176-2972-4

