

Effect of tubing type on gas detector sampling systems

Prepared by the **Health and Safety Laboratory**
for the Health and Safety Executive 2008

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Reactive gases are defined as gases which, because of their high chemical activity, are easily sorbed (adsorbed and/or absorbed) by the exposed surfaces of gas detection systems including detector housings, calibration adapters and remote sample draw accessories (tubing). Because of their greater tendency to be depleted from a gas sample by the exposed surfaces of gas detection systems, special care must be taken to ensure accurate monitoring results. The principle danger is that failure to use compatible materials and proper calibration procedures can result in dangerously inaccurate (low) readings and increased response times [1].

Many of the gases monitored by HSL field and laboratory scientists in their normal line of work may be classed as reactive. This investigation was designed to determine the effect of various types of tubing on the response times of the detection systems utilised to monitor a range of reactive gases.

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 2008

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EXECUTIVE SUMMARY

Objectives

This investigation was designed to determine the effect of polytetrafluoroethylene (PTFE), fluorinated ethylene propylene (FEP) and Tygon tubing on the response times of the detection systems utilised to monitor Hydrogen Sulphide (H_2S), Nitrogen Dioxide (NO_2), Nitric Oxide (NO) and Toluene (C_7H_8).

Main Findings

- With the exception of C_7H_8 passing through Tygon tubing, the change in T_{90} as a function of tubing length is comparable within accuracy limits for all gases at each corresponding tubing type and diameter.
- The times taken for H_2S and NO to reach T_{90} , T_{100} and T_{10} are comparable for all corresponding dimensions of PTFE and FEP tubing, but while the time taken to reach T_{10} is comparable for Tygon tubing, the times taken to reach T_{90} and T_{100} are considerably longer for all corresponding dimensions.
- The times taken for NO_2 to reach T_{90} and T_{10} are comparable for all corresponding dimensions of PTFE, FEP and Tygon tubing and to reach T_{100} for all but the largest dimension of Tygon tubing.
- The times taken for C_7H_8 to reach T_{90} and T_{100} through all dimensions of Tygon tubing were greater than one hour.
- The times taken for C_7H_8 to reach T_{90} and T_{10} are comparable for all corresponding diameters of the 2.5 m and 5 m lengths of PTFE and FEP tubing, but the times taken to reach T_{90} in the 10 m lengths of PTFE and FEP tubing are noticeably longer and to reach T_{100} are considerably longer for PTFE tubing than for FEP tubing .
- The times taken for H_2S , NO and NO_2 to reach each level of concentration are reasonably comparable for all corresponding dimensions of PTFE and FEP tubing, but are noticeably longer for all corresponding dimensions of Tygon tubing.
- The times taken for NO_2 to reach each level of concentration are generally noticeably shorter than the times taken by H_2S , NO and C_7H_8 for all corresponding dimensions of PTFE, FEP and Tygon tubing.
- The times taken for C_7H_8 to reach each level of concentration are considerably longer than the times taken by H_2S , NO and NO_2 for all corresponding dimensions of PTFE and FEP tubing.

Recommendations

PTFE and FEP can be used with minimal effect when sampling H_2S , NO and NO_2 . Tygon may be used when sampling H_2S , NO and NO_2 if PTFE and FEP are not available providing the delay time is not an issue, but the tube dimensions must be as small as practically possible without restricting the flow rate of the sampling instrument. Tygon is not suitable for use in sampling C_7H_8 but PTFE and FEP may be used providing the delay time is not an issue.

1 INTRODUCTION

Reactive gases are defined as gases which, because of their high chemical activity, are easily sorbed (adsorbed and/or absorbed) by the exposed surfaces of gas detection systems including detector housings, calibration adapters and remote sample draw accessories (tubing). Because of their greater tendency to be depleted from a gas sample by the exposed surfaces of gas detection systems, special care must be taken to ensure accurate monitoring results. The principle danger is that failure to use compatible materials and proper calibration procedures can result in dangerously inaccurate (low) readings and increased response times [1].

Many of the gases monitored by HSL field and laboratory scientists in their normal line of work may be classed as reactive. This investigation was designed to determine the effect of various types of tubing on the response times of the detection systems utilised to monitor a range of reactive gases.

2 EXPERIMENTAL

2.1 EQUIPMENT

2.1.1 Tubing

The types, lengths and inside diameters (IDs) of tubing considered in this investigation are shown in Table 2.1.

Table 2.1: Tubing types, lengths and inside diameters investigated

Type	Length (m)	Inside Diameter (mm)
PTFE	2.5, 5, 10	3.40, 4.75, 6.35
FEP	2.5, 5, 10	3.40, 4.75, 6.35
Tygon	2.5, 5, 10	3.40, 4.75, 6.35

The properties of each type of tubing are described in [2][3][4][5].

2.1.2 Gases

The gases considered in this investigation, the concentrations used, and the methods of supply are shown in Table 2.2.

Table 2.2: Method of supply and concentration of each gas investigated

Gas/Vapour	Method of Supply & Concentration
Hydrogen Sulphide (H ₂ S)	Cylinder of 100ppm H ₂ S diluted with air to 30ppm via Mass Flow Controller (MFC)
Nitrogen Dioxide (NO ₂)	Cylinder of 5ppm NO ₂ in air
Nitric Oxide (NO)	Cylinder of 25ppm NO in N ₂
Toluene (C ₇ H ₈)	1000ppm (C ₇ H ₈) vapour mixed in air via MFC and B. Braun manufactured 'Perfusor VI' vapour dispenser (liquid syringe injection)

2.1.3 Detector

The same MiniRAE 2000 Portable Volatile Organic Compound (VOC) Monitor PGM-7600, S/N 001165, was used throughout this investigation to maintain a comparable flow rate of each gas through each type and length of tube investigated. The 11.7 eV photo-ionisation detector (PID) lamp was chosen as it has a photon energy high enough to ionise all of the gases investigated, and is the most sensitive (lowest correction factor with respect to the standard calibration gas for PIDs, isobutylene) of all the PID lamps available, as shown in Table 2.3 [6]. The response time of this instrument is less than 1 s and therefore has a negligible effect on the investigation results.

Table 2.3: Ionisation potential of gases and correction factors for PID lamps

Gas/Vapour	Ionisation Potential (eV)	MiniRAE 9.8 eV PID Lamp Correction Factor	MiniRAE 10.6 eV PID Lamp Correction Factor	MiniRAE 11.7 eV PID Lamp Correction Factor
Hydrogen sulphide (H ₂ S)	10.45	No Response	3.30	1.50
Nitrogen Dioxide (NO ₂)	9.75	23.00	16.00	6.00
Nitric Oxide (NO)	9.26	6.00	5.20	2.80
Toluene (C ₇ H ₈)	8.82	0.54	0.50	0.51

2.2 INVESTIGATION PROCEDURE

20 m of each type of tubing was purchased at each inside diameter stated in the previous section prior to the start of these investigations. Each length of tubing was cut into 2.5m 5m and 10m lengths and stored in a secure location when not in use. Fresh tubing was used for each experiment to prevent the possibility of contamination from previous usage.

A mass flow controller (MFC) connected in series with the gas supply was used to regulate the flow rate of the gas to a level greater than the flow rate of the pump on the MiniRAE. One end of the tubing under test was connected to the output of the MFC via a Y connector and the other end was connected to the MiniRAE as shown in Figure 2.1. This allowed the flow rate of the gas through the tubing to be controlled by the internal pump of the MiniRAE.

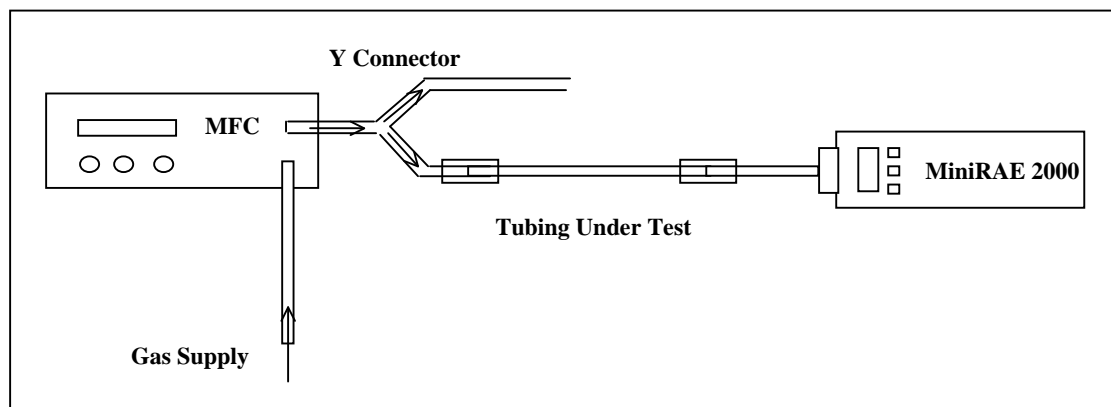


Figure 2.1: Set up of apparatus used in investigation

Each stage of the investigation comprised four exposures of one length of one internal diameter of one type of tubing to one type of gas, the MiniRAE being re-calibrated to the concentration of the applied gas before each stage.

As the MiniRAE begins logging data it assigns the start of the nearest minute on its internal clock, rather than the actual second, to the start of data logging. It was necessary therefore to synchronise the clock in the MiniRAE with an external clock after data logging had begun. This was achieved by exposing the MiniRAE directly to the gas under investigation for one minute immediately prior to each stage of the investigation, the on and off times of the exposure on the external clock being noted. These times were then assigned to the initial rise and fall positions observed in the downloaded data after that stage of the investigation was completed,

and all other times in that stage adjusted accordingly. The one minute exposure duration allowed the clock synchronisation to be performed at two separate times and therefore reduced the uncertainty in the time scales throughout each stage.

Tubing of each type, length and internal diameter listed in Section 2.1.1 was exposed to each of the gases listed in Section 2.1.2. Each of the four exposure times in each stage was at least sufficient to for the concentration detected by the MiniRAE to reach a maximum and become reasonably constant, after which point the gas supply was disconnected from the end of the tubing, allowing the MiniRAE to purge the tubing with air between exposures. This facilitated the removal of any residual absorbance after purging and allowed averages to be taken to attain more consistent results.

The response times for the initial detection of gas (i.e. a noticeable increase in the monitor reading due to the first traces of the gas reaching the sensor) at the output of the tubes (T_0), the level of gas to reach 90% (T_{90}) and 100% (T_{100}) of the maximum concentration during exposure, and the recovery time taken to reduce to 10% (T_{10}) of the maximum concentration during purging, were compared for each stage of the investigation. The difficulty in defining T_{100} can result in uncertainties in the readings recorded for this value. These uncertainties are much reduced in the T_{90} values which must therefore be the values of prime consideration in these investigations.

The flow rate of gas through the MiniRAE was measured before and after each set of experiments, the average taken, and the clearance time (T_C) (assuming plug flow) calculated. The flow rate was found to be independent of the dimensions of the tubing, however, throughout the duration of this investigation, the flow rate of the various gases through the various lengths and diameters of tubing was found to display some measure of inconsistency due to the inconsistency of the pump itself. This was taken into account in any situation where the differences in flow rates between corresponding dimensions may have caused a change in the clearance time (greater than the accuracy limit of the readings of 1 s). The Equations 2.1 and 2.2 below allow the determination of the change in clearance time due to the change in flow rate, and the increases in flow rate required to change the calculated clearance time by 1 second ($\delta F_{(1s)}$) and 2 seconds ($\delta F_{(2s)}$) for each corresponding length and diameter of tubing are shown in Table 2.4:

The clearance time is calculated using Equation 2.1:

$$T_C = \frac{V}{F} \quad \text{Equ. 2.1}$$

where T_C is in s, V is the internal volume of the tubing in m^3 , and F the is the flow rate in m^3/s .

The increase in the MiniRAE flow rate from 500 ml/min to effect a change of 1 second on the clearance time is calculated using Equation 2.2, and shown as δF in Table 2.4.

$$\delta t = \frac{V}{F_1} - \frac{V}{F_2} \quad \text{Equ. 2.2}$$

where δt is the time in s, V is the internal volume of the tubing in m^3 , F_1 and F_2 are the initial (500 ml/min) and adjusted flow rates in m^3/s .

Table 2.4: Tubing and flow characteristics

ID (mm)	Length (m)	Volume (m ³)	$\delta F_{(1s)}$ (ml/min)*	$\delta F_{(2s)}$ (ml/min)*
3.40	2.5	22.7×10^{-6}	290	1381
3.40	5.0	45.4×10^{-6}	112	290
3.40	10.0	90.8×10^{-6}	50	112
4.75	2.5	44.3×10^{-6}	115	301
4.75	5.0	88.6×10^{-6}	51	115
4.75	10.0	177.2×10^{-6}	24	51
6.35	2.5	79.2×10^{-6}	58	133
6.35	5.0	158.3×10^{-6}	27	58
6.35	10.0	316.7×10^{-6}	13	27

* $\delta F_{(1s)}$ and $\delta F_{(2s)}$ are the increases in flow rate required to change the calculated clearance time by 1 second ($\delta F_{(1s)}$) and 2 seconds ($\delta F_{(2s)}$)

To allow more intuitive analysis of the results the FEP and Tygon flow rates were normalised to the PTFE flow rates at corresponding dimensions in each investigation stage in the analysis of the results.

The times taken for each gas to reach the various concentration levels will always include T_0 (which assuming ideal plug flow should be the same as T_C) which should be the same for each type and dimension of tubing (providing there is a reasonable consistency of pump flow rate), and will always be a constant component to be considered when comparing the effects of the individual types of tubing. Figure 2.2 shows the T_C values calculated using Equation 2.1 for each diameter and length of tubing for the typical flow rate of this MiniRAE pump of 530 ml/min and T_C as a function of tube length ($T_{C(L)}$) is determined from the gradient of the trend line.

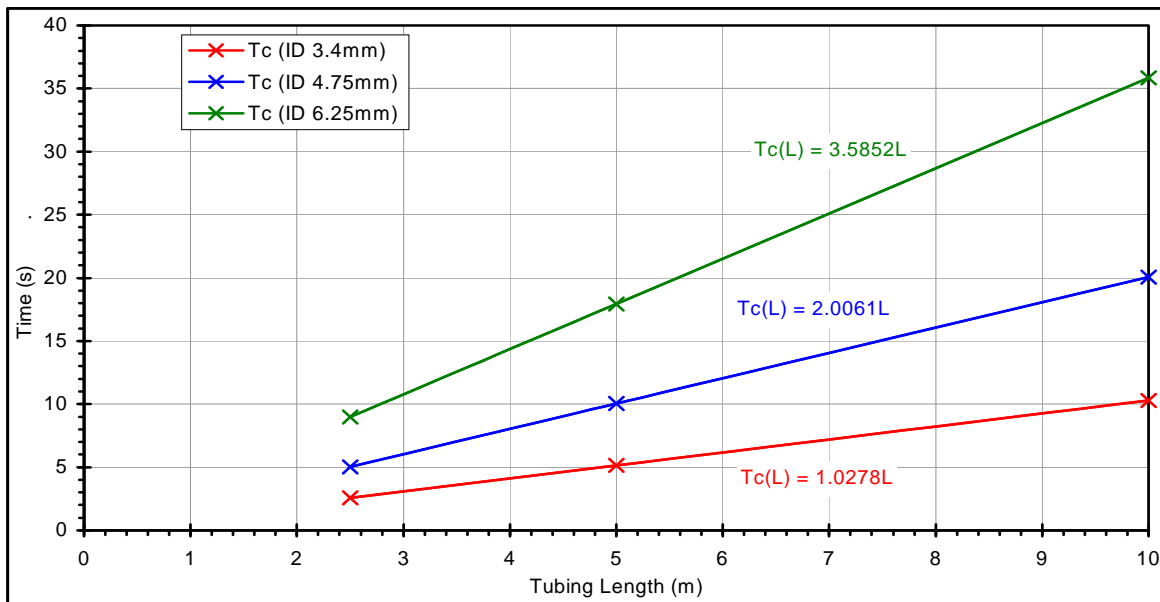


Figure 2.2: T_C values for each diameter and length of tubing as a function of tube length (flow rate of 530 ml/min)

3 RESULTS

3.1 HYDROGEN SULPHIDE (H₂S)

Figures 3.1 to 3.3 show the times taken for initial detection of H₂S (T₀), to reach 90% (T₉₀), 100% (T₁₀₀) and 10% (T₁₀) concentrations when flowing through each type, length and diameter of tubing, and the corresponding clearance times (T_C).

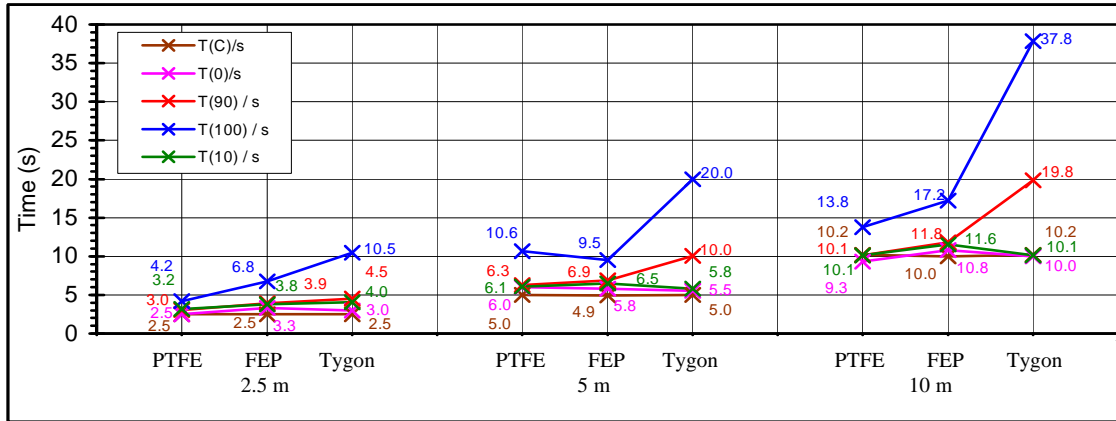


Figure 3.1: Comparison of T_C, T₀, T₉₀, T₁₀₀, and T₁₀ times for each type and length of tubing with 3.4 mm ID with exposure to H₂S

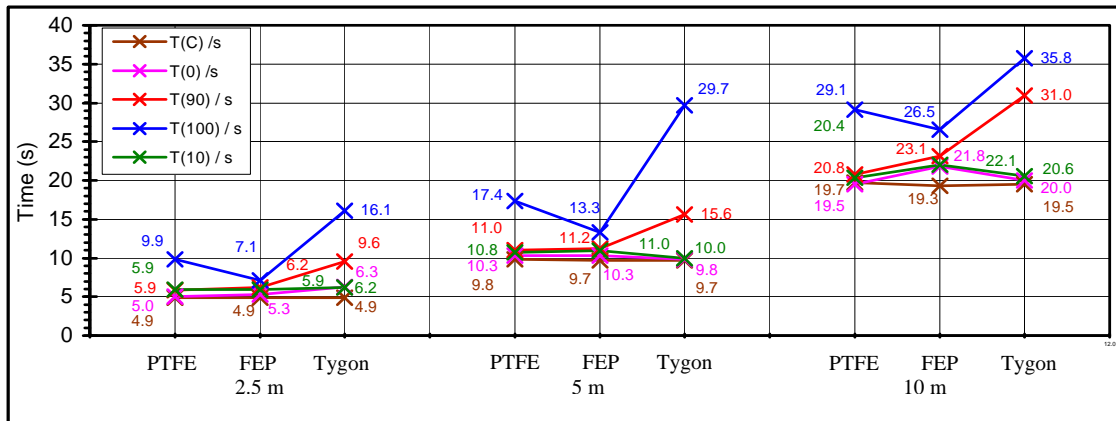


Figure 3.2: Comparison of T_C, T₀, T₉₀, T₁₀₀, and T₁₀ times for each type and length of tubing with 4.75 mm ID with exposure to H₂S

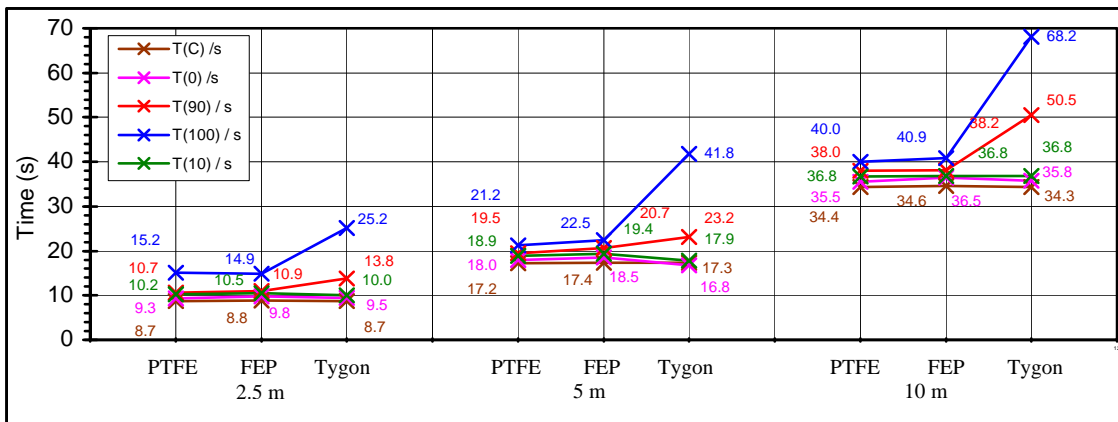


Figure 3.3: Comparison of T_C, T₀, T₉₀, T₁₀₀, and T₁₀ times for each type and length of tubing with 6.35 mm ID with exposure to H₂S

The differences in average flow rates at corresponding dimensions of each type of tubing are not sufficient to affect the clearance times in this stage of the investigation, and all of the concentrations are reached after the calculated clearance time (T_C).

The times taken to reach T_{90} and to reduce to T_{10} are the same within accuracy limits (± 1 s) for PTFE and FEP tubing at a given length and diameter of PTFE and FEP tubing. The times taken to reach T_{100} follow no general tendency to be greater for either type of tubing, the approximate time difference over all lengths and diameters ranging between 0 and 4 seconds. See Section 3.5 for summary of results.

H_2S consistently takes longer to reach T_{90} and T_{100} for each length and diameter of Tygon tubing than through the corresponding lengths of PTFE or FEP tubing, approximately ranging between 0.5 and 12.5 seconds longer to reach T_{90} and 3.5 and 27.5 seconds longer to reach T_{100} but takes a time comparable to both PTFE and FEP to reduce to T_{10} . The differences in the times taken to reach the various concentration levels generally increase with tubing length at each tubing ID. See Section 3.5 for summary of results.

3.2 NITROGEN DIOXIDE (NO₂)

Figures 3.4 to 3.6 show the times taken for initial detection of NO₂ (T₀), to reach 90% (T₉₀), 100% (T₁₀₀) and 10% (T₁₀) concentrations when flowing through each type, length and diameter of tubing, and the corresponding clearance times (T_C).

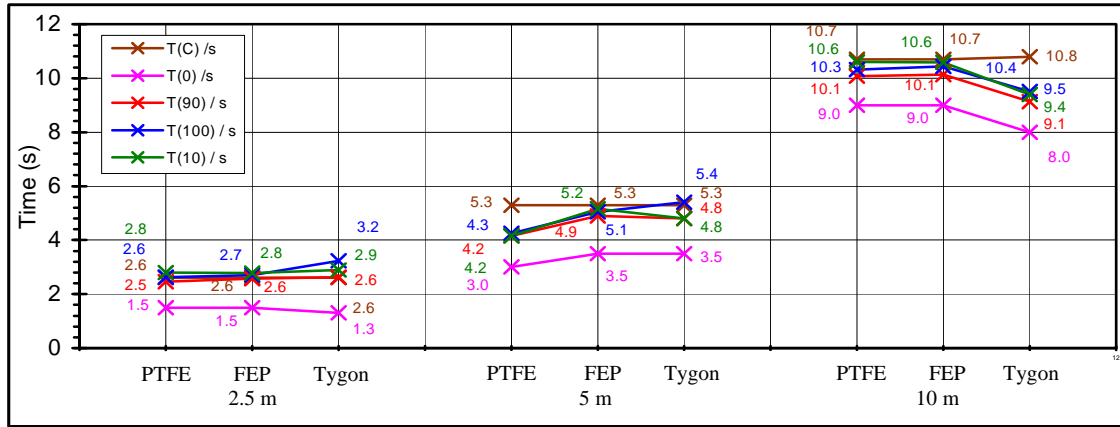


Figure 3.4: Comparison of T_C, T₀, T₉₀, T₁₀₀, and T₁₀ times for each type and length of tubing with 3.4 mm ID with exposure to NO₂

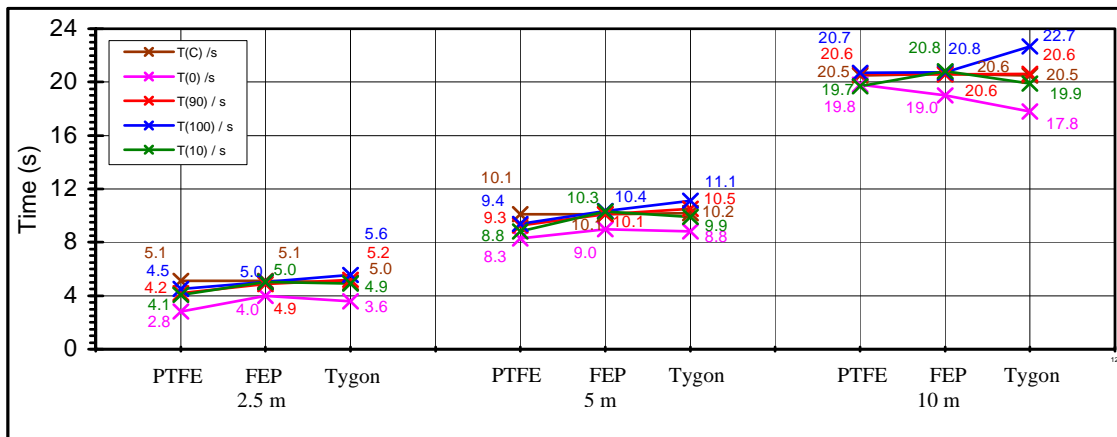


Figure 3.5: Comparison of T_C, T₀, T₉₀, T₁₀₀, and T₁₀ times for each type and length of tubing with 4.75 mm ID with exposure to NO₂

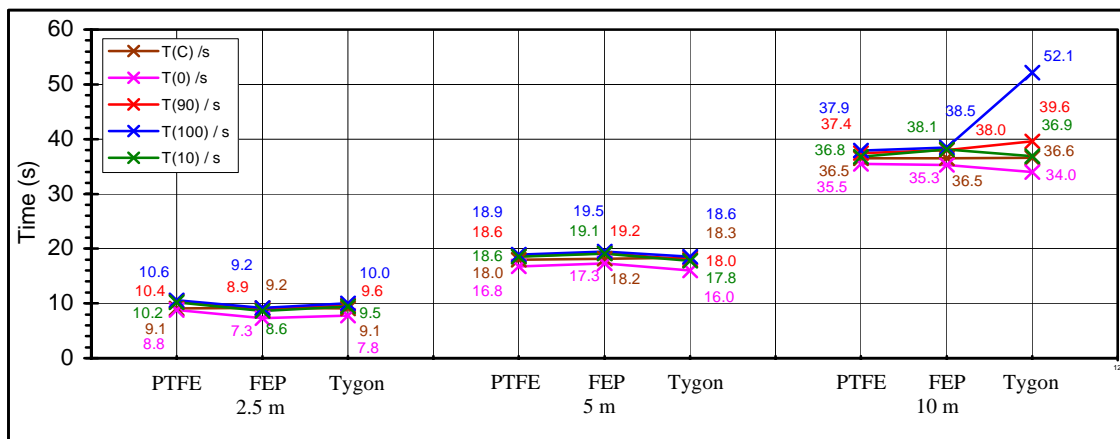


Figure 3.6: Comparison of T_C, T₀, T₉₀, T₁₀₀, and T₁₀ times for each type and length of tubing with 6.35 mm ID with exposure to NO₂

The differences in average flow rates at corresponding dimensions of each type of tubing are not sufficient to affect the clearance times in this stage of the investigation.

In all lengths and diameters of each type of tubing the time taken for the initial detection of gas at the output of the tubing (T_0) is less than the clearance time (T_C) (in 24 of the 27 stages by more than 1 s), in 12 of the 27 stages the time taken for to reach T_{90} is less than T_C , and in 8 of the 27 stages the time taken for to reach T_{100} is less than T_C . See Section 3.5 for summary of results. The ranges of the average flow rates, from which the average was taken, (not shown in this report) in the worst case are ± 5 ml/min. Taking the extremes of these uncertainties into account will result in a difference of 10 ml/min about the mean, altering the clearance time by ± 0.05 s through the minimum volume of tubing (3.5 mm ID \times 2.5 m), and ± 0.7 s through the maximum volume of tubing (6.35 mm ID \times 10 m) and thus cannot account for this. Realistically other factors like inaccurate or inconsistent tube dimensions or drag on the tubing walls reducing the effective ID cannot be the cause either, as these would also affect the results involving the other gases investigated. One possible explanation may be that the sensitivity of the instrument to lower levels of NO_2 may greater than to the other gases used in this investigation.

With the exception of the tests on the 10 m length of 6.35 mm ID Tygon tubing, the times taken for NO_2 to reach T_{90} , T_{100} and T_{10} when flowing through each corresponding length and diameter of each type of tubing are the same within accuracy limits. The time taken for NO_2 to reach T_{100} when flowing through the 10 m length of 6.35 mm ID Tygon tubing is approximately 14 s longer than through the corresponding PTFE and FEP tubing. Inspection of the 4 test results from which the average time is taken (not included in this report) show each to be within ± 3 s of the average, suggesting that this result is a fair representation of the effects observed. See Section 3.5 for summary of results.

3.3 NITRIC OXIDE (NO)

Figures 3.7 to 3.9 show the times taken for initial detection of NO (T_0), to reach 90% (T_{90}), 100% (T_{100}) and 10% (T_{10}) concentrations when flowing through each type, length and diameter of tubing, and the corresponding clearance times (T_C).

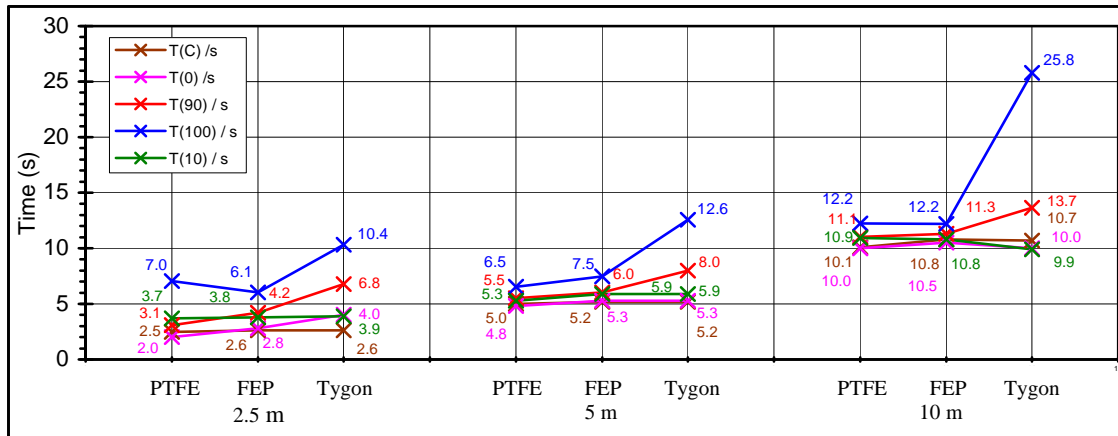


Figure 3.7: Comparison of T_C , T_0 , T_{90} , T_{100} , and T_{10} times for each type and length of tubing with 3.4 mm ID with exposure to NO

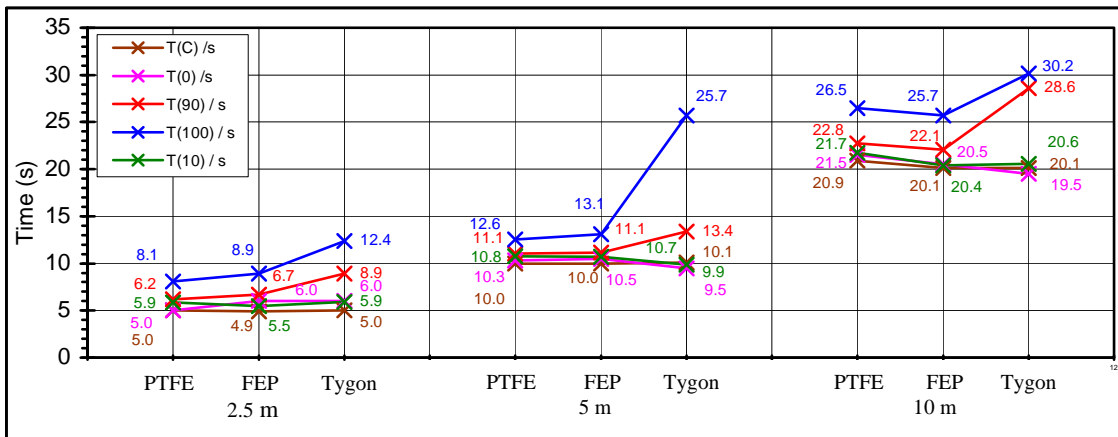


Figure 3.8: Comparison of T_C , T_0 , T_{90} , T_{100} , and T_{10} times for each type and length of tubing with 4.75 mm ID with exposure to NO

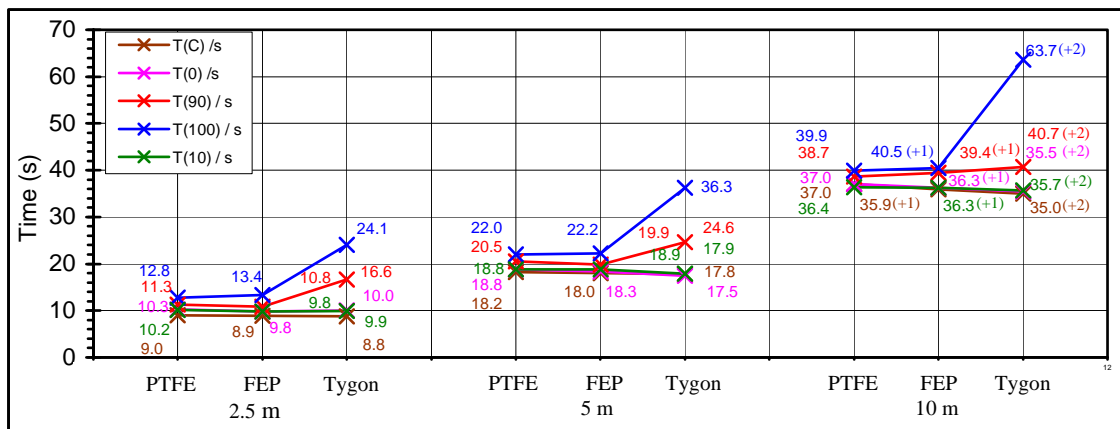


Figure 3.9: Comparison of T_C , T_0 , T_{90} , T_{100} , and T_{10} times for each type and length of tubing with 6.35 mm ID with exposure to NO

The differences in average flow rates at corresponding dimensions of each type of tubing are sufficient to affect some the clearance times in the 6.35 mm ID tubing in this stage of the investigation. Thus, for the 6.35 mm ID tubing the times taken to reach each concentration shown in Figure 3.9 should be increased by 1 second for the 10 m length of FEP and by 2 seconds for the 10 m length of Tygon.

All of the concentrations are reached after the calculated clearance time (T_c) in this part of the investigation, within accuracy limits ($\pm 1s$), as expected.

The times taken to reach T_{90} , T_{100} and to reduce to T_{10} are the same within accuracy limits through each corresponding length and diameter of PTFE and FEP tubing.

NO consistently takes longer to reach T_{90} and T_{100} through each length and diameter of Tygon tubing than through the corresponding lengths of PTFE or FEP tubing, ranging approximately between 2 and 6.5 seconds longer to reach T_{90} and ranging approximately between 3 and 24 seconds longer to reach T_{100} , but takes a time comparable to both PTFE and FEP to reduce to T_{10} . The time differences to reach T_{100} in Tygon tubing generally seem to increase with tubing ID and length, but no such relationship is evident for the time differences to reach T_{90} . See Section 3.5 for summary of results.

3.4 TOLUENE (C₇H₈)

Figures 3.10 to 3.12 show the times taken for initial detection of C₇H₈ (T₀), to reach 90% (T₉₀), 100% (T₁₀₀) and 10% (T₁₀) concentrations when flowing through each type, length and diameter of tubing, and the corresponding clearance times (T_C). All tests using Tygon tubing in this section showed the concentration to be still increasing after more than 1 hour. It was considered therefore that any comparisons with PTFE and FEP concentration times would serve no useful purpose.

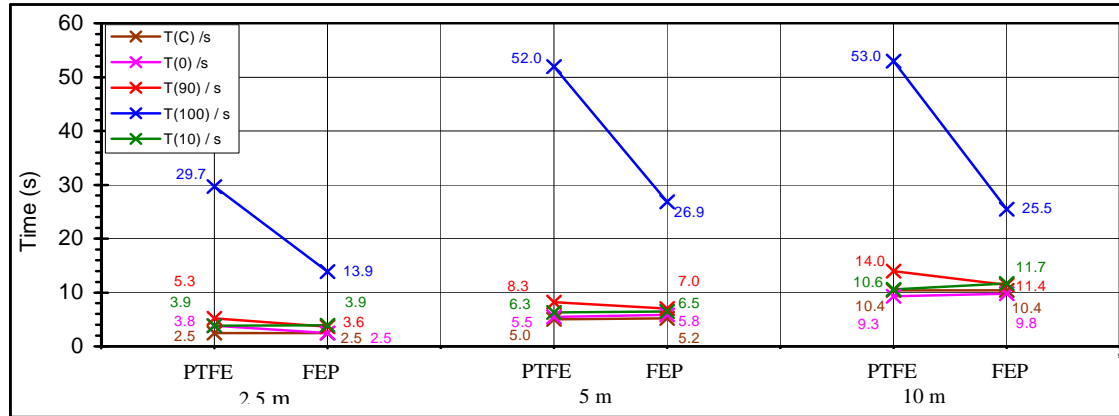


Figure 3.10: Comparison of T_C, T₀, T₉₀, T₁₀₀, and T₁₀ times for each type and length of tubing with 3.4 mm ID with exposure to C₇H₈

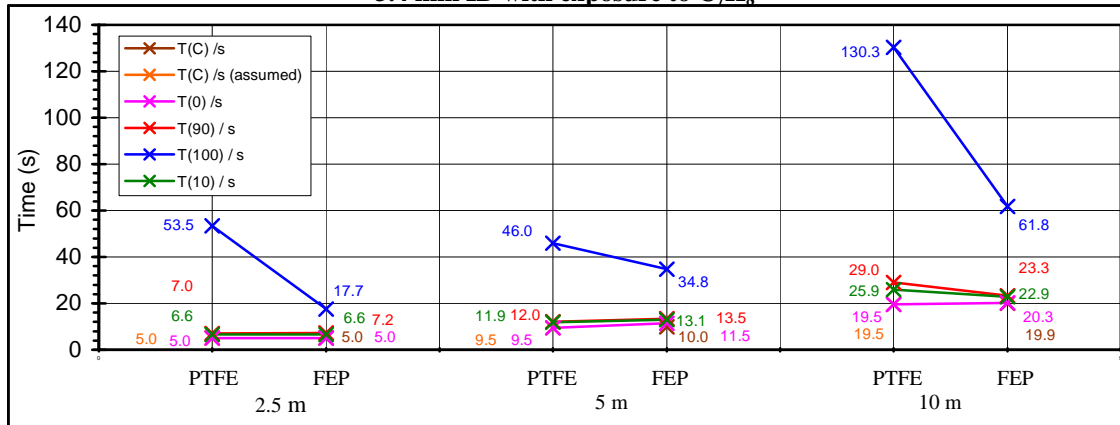


Figure 3.11: Comparison of T_C, T₀, T₉₀, T₁₀₀, and T₁₀ times for each type and length of tubing with 4.75 mm ID with exposure to C₇H₈

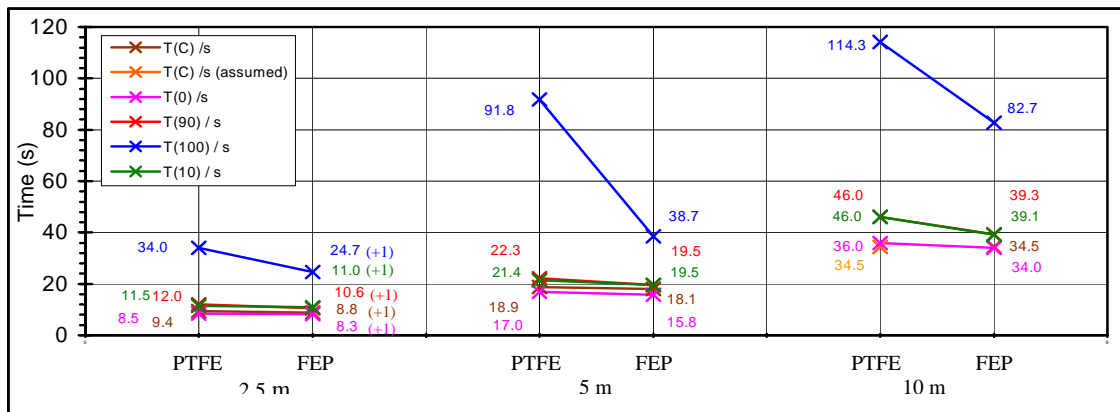


Figure 3.12: Comparison of T_C, T₀, T₉₀, T₁₀₀, and T₁₀ times for each type and length of tubing with 6.35 mm ID with exposure to C₇H₈

Due to technical problems the flow rates were not monitored during the PTFE tests at any lengths of the 4.75 mm ID tubing or the 10 m length of the 6.35 mm ID tubing. This prevented calculations of the differences in flow rates at corresponding dimensions of each type of tubing and the effect on the clearance times in these aspects of this stage of the investigation. However, it can be assumed that the differences would be similar to those in the previous stages and will at worst add 2 or 3 seconds to the respective times taken to reach the various concentration levels. The clearance times in these cases are therefore assumed to be the same as for the corresponding T_0 times. The difference in flow rate at corresponding dimensions of each type of tubing is sufficient to affect the clearance time in the 2.5 m length of the 6.35 mm ID FEP tubing in this stage of the investigation. Thus, the times taken to reach each concentration shown in Figure 3.12 should be increased by 1 second for the 2.5 m length of FEP.

All of the concentrations are reached after the calculated clearance time (T_C) in this part of the investigation, within accuracy limits, as expected, with the exception of the 5m lengths of 6.35 mm ID of PTFE and FEP tubing where T_0 is reached earlier than T_C by more than 1 second. This may be due to unidentified uncertainties or anomalies in these stages of the investigation.

The C_7H_4 consistently takes longer to reach T_{100} through each length and diameter of PTFE tubing than through the corresponding dimensions of FEP tubing, the difference ranging approximately between 9 and 68 seconds, with no obvious correlation between difference and tubing dimensions. There is a general trend towards the C_7H_4 taking longer to reach T_{90} through each length and diameter of PTFE tubing than through the corresponding dimensions of FEP tubing (in 7 out of 9 cases the PTFE T_{90} is greater than the FEP T_{90} , and the same as the FEP T_{90} within accuracy limits in the other 2 cases), the difference ranging approximately between 1 and 7 seconds, again with no obvious correlation between the difference and the tubing dimensions. The times taken to reduce to T_{10} have no general tendency to be greater for either type of tubing. See Section 3.5 for summary of results.

3.5 SUMMARY OF RESULTS

Table 3.1: Change in T_{90} for each gas as a function of tubing length for each type and diameter of tubing

Gas	Tubing ID (mm)	Tubing Type	Ave T_{90}/m (s) *
H ₂ S	3.4	PTFE	1.1
		FEP	1.2
		Tygon	2.0
	4.75	PTFE	2.1
		FEP	2.3
		Tygon	3.1
	6.35	PTFE	3.8
		FEP	3.9
		Tygon	5.0
NO ₂	3.4	PTFE	1.0
		FEP	1.0
		Tygon	0.9
	4.75	PTFE	2.0
		FEP	2.0
		Tygon	2.1
	6.35	PTFE	3.8
		FEP	3.8
		Tygon	3.9
NO	3.4	PTFE	1.1
		FEP	1.2
		Tygon	1.5
	4.75	PTFE	2.3
		FEP	2.2
		Tygon	2.9
	6.35	PTFE	3.9
		FEP	4.0
		Tygon	4.4
C ₇ H ₈	3.4	PTFE	1.4
		FEP	1.2
		Tygon	-
	4.75	PTFE	2.8
		FEP	2.4
		Tygon	-
	6.35	PTFE	4.6
		FEP	3.9
		Tygon	-

* Tubing lengths of 2.5, 5 and 10 m used

It can be seen from Figures 3.1 to 3.12 and Figures 5.1 to 5.12 that:

- With the exception of C_7H_8 passing through Tygon tubing, the change in T_{90} as a function of tubing length is comparable within accuracy limits for all gases at each corresponding tubing type and diameter.
- The times taken for H_2S and NO to reach T_{90} , T_{100} and T_{10} are comparable for all corresponding dimensions of PTFE and FEP tubing, but while the time taken to reach T_{10} is comparable for Tygon tubing, the times taken to reach T_{90} and T_{100} are considerably longer for all corresponding dimensions.
- The times taken for NO_2 to reach T_{90} and T_{10} are comparable for all corresponding dimensions of PTFE, FEP and Tygon tubing and to reach T_{100} for all but the largest dimension of Tygon tubing.
- The times taken for C_7H_8 to reach T_{90} and T_{100} through all dimensions of Tygon tubing were greater than one hour.
- The times taken for C_7H_8 to reach T_{90} and T_{10} are comparable for all corresponding diameters of the 2.5 m and 5 m lengths of PTFE and FEP tubing, but the times taken to reach T_{90} in the 10 m lengths of PTFE and FEP tubing are noticeably longer and to reach T_{100} are considerably longer for PTFE tubing than for FEP tubing .
- The times taken for H_2S , NO and NO_2 to reach each level of concentration are reasonably comparable for all corresponding dimensions of PTFE and FEP tubing, but are noticeably longer for all corresponding dimensions of Tygon tubing.
- The times taken for NO_2 to reach each level of concentration are generally noticeably shorter than the times taken by H_2S , NO and C_7H_8 for all corresponding dimensions of PTFE, FEP and Tygon tubing.
- The times taken for C_7H_8 to reach each level of concentration are considerably longer than the times taken by H_2S , NO and NO_2 for all corresponding dimensions of PTFE and FEP tubing.

4 CONCLUSIONS

PTFE and FEP can be used with minimal effect when sampling H₂S, NO and NO₂.

Tygon may be used when sampling H₂S, NO and NO₂ if PTFE and FEP are not available providing the delay time is not an issue, but the tube dimensions must be as small as practically possible without restricting the flow rate of the sampling instrument.

Tygon is not suitable for use in sampling C₇H₈ but PTFE and FEP may be used providing the delay time is not an issue.

5 APPENDIX 1: EXPERIMENTAL RESPONSE TIME AND FLOW RATE DATA FOR ALL CONDITIONS INVESTIGATED

5.1 HYDROGEN SULPHIDE (H₂S)

The average times taken for the initial detection of the gas at the output of the tubes (T₀), and to reach 90% (T₉₀) and 100% (T₁₀₀) of the maximum concentration during exposure to H₂S, and to reduce to 10% (T₁₀) of the maximum concentration during purging with air, are shown in Table 5.1 and Figures 5.1 to 5.3. The average flow rate of gas throughout each stage, the calculated clearance time (T_C), the flow rate normalised to PTFE flow rate at each stage, and the related effect on the clearance time are also shown in Table 5.1.

Table 5.1: H₂S response and flow data for all tubing types and dimensions

Tubing Type	Tubing ID (mm)	Tubing Length (m)	T _C (s)	Ave T ₀ (s)	Ave T ₉₀ (s)	Ave T ₁₀₀ (s)	Ave T ₁₀ (s)	Ave Flow Rate (ml/min)	Flow Rate Difference wrt PTFE (ml/min)	Effect on T _C (s)
PTFE	3.4	2.5	2.5	2.5	3.0	4.2	3.2	540.5	0.0	0.0
		5.0	5.0	6.0	6.3	10.6	6.1	541.5	0.0	0.0
		10.0	10.2	9.3	10.1	13.8	10.1	533.0	0.0	0.0
	4.75	2.5	4.9	5.0	5.9	9.9	5.9	543.5	0.0	0.0
		5.0	9.8	10.3	11.0	17.4	10.8	538.5	0.0	0.0
		10.0	19.7	19.5	20.8	29.1	20.4	540.5	0.0	0.0
	6.35	2.5	8.7	9.3	10.7	15.2	10.2	546.5	0.0	0.0
		5.0	17.2	18.0	19.5	21.2	18.9	551.5	0.0	0.0
		10.0	34.4	35.5	38.0	40.0	36.8	552.5	0.0	0.0
FEP	3.4	2.5	2.5	3.3	3.9	6.8	3.8	546.0	-5.5	0.0
		5.0	4.9	5.8	6.9	9.5	6.5	551.0	+9.5	0.0
		10.0	10.0	10.8	11.8	17.2	11.6	543.0	+10.0	0.0
	4.75	2.5	4.9	5.3	6.2	7.1	5.9	541.0	-2.5	0.0
		5.0	9.7	10.3	11.2	13.3	11.0	549.5	+11.0	0.0
		10.0	19.3	21.8	23.1	26.5	22.1	549.5	+9.0	0.0
	6.35	2.5	8.8	9.8	10.9	14.9	10.5	537.5	-9.0	0.0
		5.0	17.4	18.5	20.7	22.5	19.4	545.0	-6.5	0.0
		10.0	34.6	36.5	38.2	40.9	36.8	549.0	-3.5	0.0
Tygon	3.4	2.5	2.5	3.0	4.5	10.5	4.0	540.5	0.0	0.0
		5.0	5.0	5.5	10.0	20.0	5.8	543.0	+1.5	0.0
		10.0	10.2	10.0	19.8	37.8	10.1	535.0	+2.0	0.0
	4.75	2.5	4.9	6.3	9.6	16.1	6.2	546.5	+3.0	0.0
		5.0	9.7	9.8	15.6	29.7	10.0	550.0	+12.0	0.0
		10.0	19.5	20.0	31.0	35.8	20.6	554.5	+4.0	0.0
	6.35	2.5	8.7	9.5	13.8	25.2	10.0	546.0	+0.5	0.0
		5.0	17.3	16.8	23.2	41.8	17.9	548.5	-3.0	0.0
		10.0	34.3	35.8	50.5	68.2	36.8	554.5	+2.0	0.0

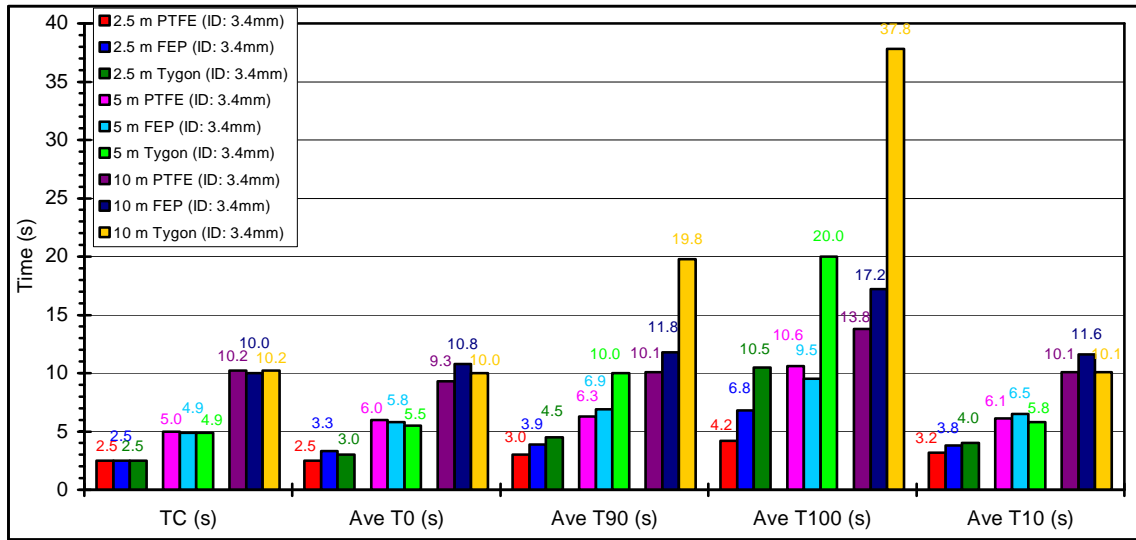


Figure 5.1: Average T_C , T_0 , T_{90} , T_{100} and T_{10} times for each type of tubing with ID of 3.4 mm during exposure to, and recovery from, H_2S .

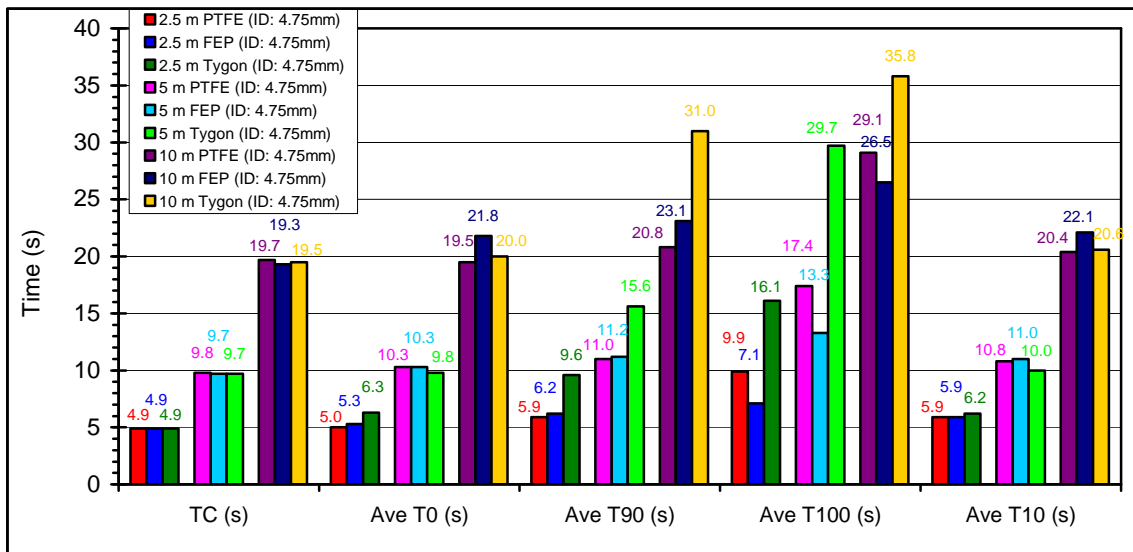


Figure 5.2: Average T_C , T_0 , T_{90} , T_{100} and T_{10} times for each type of tubing with ID of 4.75 mm during exposure to, and recovery from, H_2S .

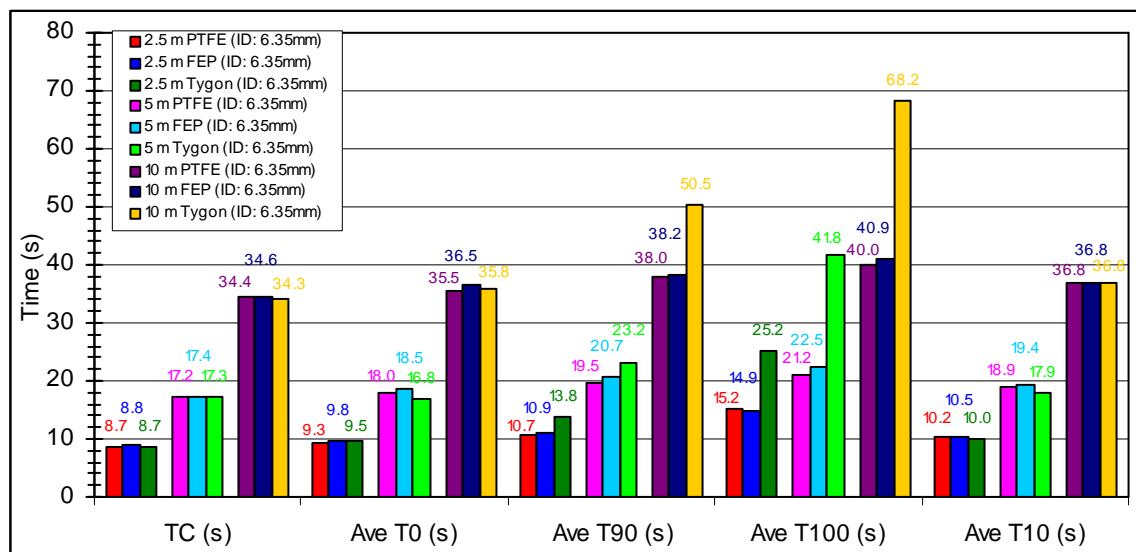


Figure 5.3: Average T_C , T_0 , T_{90} , T_{100} and T_{10} times for each type of tubing with ID of 6.35 mm during exposure to, and recovery from, H_2S .

5.2 NITROGEN DIOXIDE (NO₂)

The average times taken for the initial detection of the gas at the output of the tubes (T₀), and to reach 90% (T₉₀) and 100% (T₁₀₀) of the maximum concentration during exposure to NO₂, and to reduce to 10% (T₁₀) of the maximum concentration during purging with air, are shown in Table 5.2 and Figures 5.4 to 5.6. The average flow rate of gas throughout each stage, the clearance time (T_C), the flow rate normalised to PTFE flow rate at each stage, and the related effect on the clearance time are also shown in Table 5.2.

Table 5.2: NO₂ response and flow data for all tubing types and dimensions

Tubing Type	Tubing ID (mm)	Tubing Length (m)	T _C (s)	Ave T ₀ (s)	Ave T ₉₀ (s)	Ave T ₁₀₀ (s)	Ave T ₁₀ (s)	Ave Flow Rate (ml/min)	Flow Rate Difference wrt PTFE (ml/min)	Effect on T _C (s)
PTFE	3.4	2.5	2.6	1.5	2.5	2.6	2.8	527.0	0.0	0.0
		5.0	5.3	3.0	4.2	4.3	4.2	517.5	0.0	0.0
		10.0	10.7	9.0	10.1	10.3	10.6	507.0	0.0	0.0
	4.75	2.5	5.1	2.8	4.2	4.5	4.1	524.0	0.0	0.0
		5.0	10.1	8.3	9.3	9.4	8.8	524.0	0.0	0.0
		10.0	20.5	19.8	20.6	20.7	19.7	519.0	0.0	0.0
	6.35	2.5	9.1	8.8	10.4	10.6	10.2	524.5	0.0	0.0
		5.0	18.0	16.8	18.6	18.9	18.6	527.0	0.0	0.0
		10.0	36.5	35.5	37.4	37.9	36.8	521.0	0.0	0.0
FEP	3.4	2.5	2.6	1.5	2.6	2.7	2.8	517.5	-9.5	0.0
		5.0	5.3	3.5	4.9	5.1	5.2	515.0	-2.5	0.0
		10.0	10.7	9.0	10.1	10.4	10.6	507.0	0.0	0.0
	4.75	2.5	5.1	4.0	4.9	5.0	5.0	517.5	-6.5	0.0
		5.0	10.1	9.0	10.1	10.4	10.3	524.5	+0.5	0.0
		10.0	20.6	19.0	20.6	20.8	20.8	516.0	-3.0	0.0
	6.35	2.5	9.2	7.3	8.9	9.2	8.6	518.5	-6.0	0.0
		5.0	18.2	17.3	19.2	19.5	19.1	521.0	-6.0	0.0
		10.0	36.5	35.3	38.0	38.5	38.1	521.0	0.0	0.0
Tygon	3.4	2.5	2.6	1.3	2.6	3.2	2.9	516.0	-11	0.0
		5.0	5.3	3.5	4.8	5.4	4.8	512.0	-5.5	0.0
		10.0	10.8	8.0	9.1	9.5	9.4	505.0	-2.0	0.0
	4.75	2.5	5.0	3.6	5.2	5.6	4.9	527.0	+3.0	0.0
		5.0	10.2	8.8	10.5	11.1	9.9	519.0	-5.0	0.0
		10.0	20.5	17.8	20.6	22.7	19.9	519.5	+0.5	0.0
	6.35	2.5	9.1	7.8	9.6	10.0	9.5	521.5	-3.0	0.0
		5.0	18.3	16.0	18.0	18.6	17.8	518.0	-9.0	0.0
		10.0	36.6	34.0	39.6	52.1	36.9	519.5	-1.5	0.0

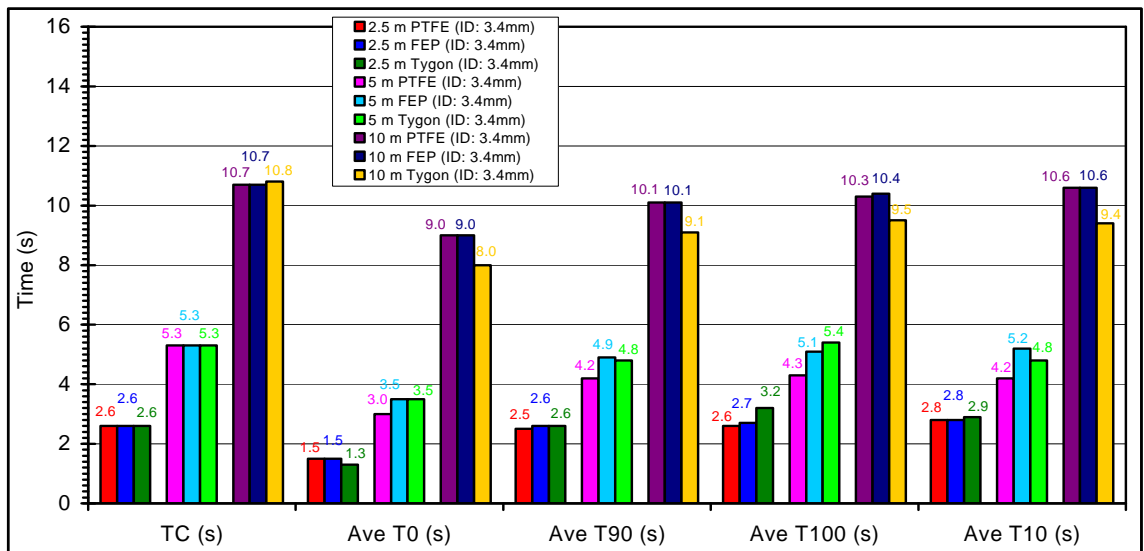


Figure 5.4: Average T_C , T_0 , T_{90} , T_{100} and T_{10} times for each type of tubing with ID of 3.4 mm during exposure to, and recovery from NO_2 .

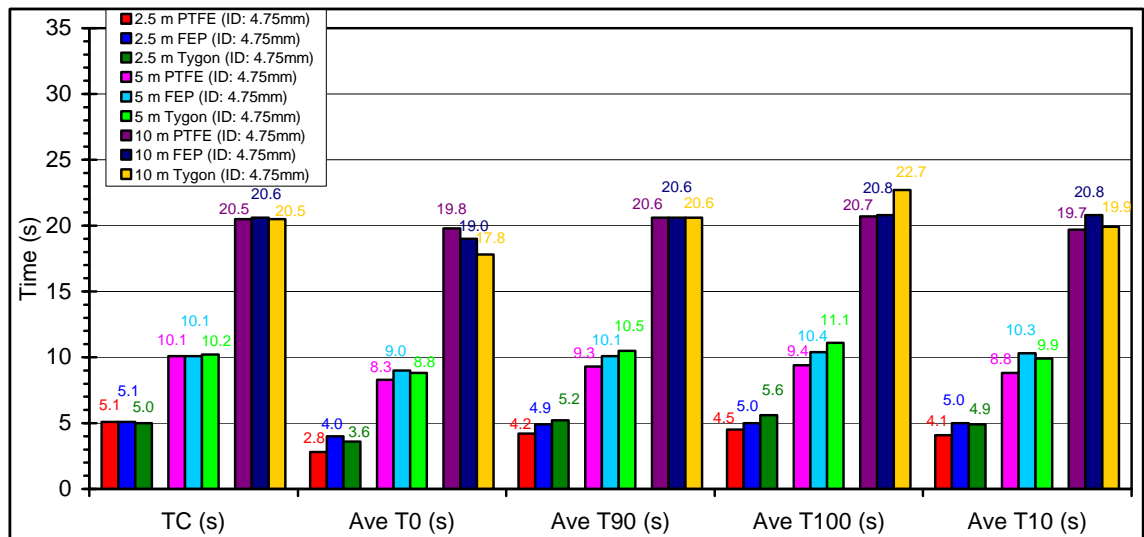


Figure 5.5: Average T_C , T_0 , T_{90} , T_{100} and T_{10} times for each type of tubing with ID of 4.75 mm during exposure to, and recovery from NO_2 .

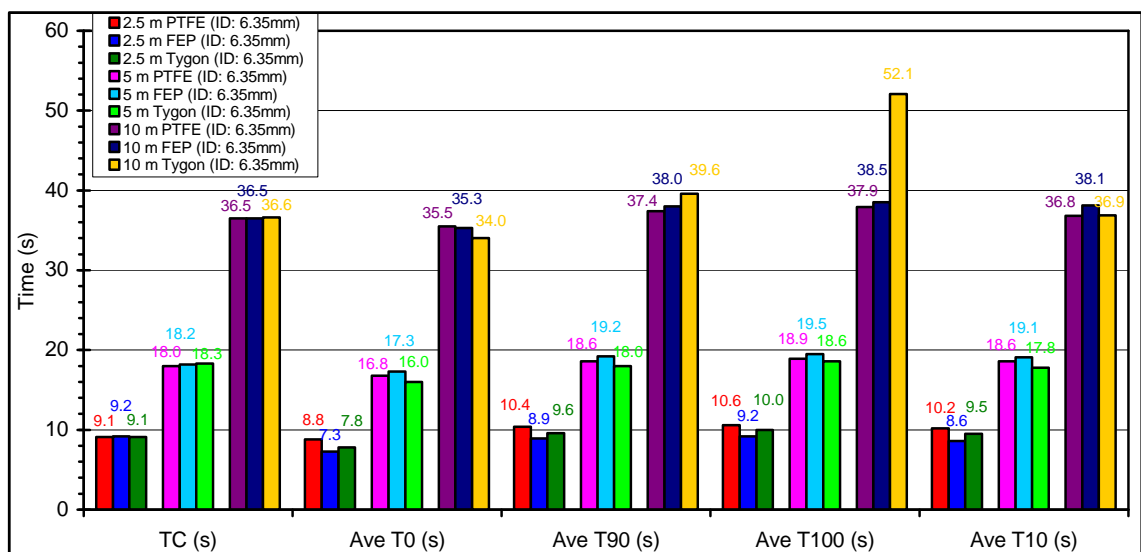


Figure 5.6: Average T_C , T_0 , T_{90} , T_{100} and T_{10} times for each type of tubing with ID of 6.35 mm during exposure to, and recovery from NO_2 .

5.3 NITRIC OXIDE (NO)

The average times taken for the initial detection of the gas at the output of the tubes (T_0), and to reach 90% (T_{90}) and 100% (T_{100}) of the maximum concentration during exposure to NO, and to reduce to 10% (T_{10}) of the maximum concentration during purging with air, are shown in Table 5.3 and Figure 5.7 to 5.9. The average flow rate of gas throughout each stage, the clearance time (T_C), the flow rate normalised to PTFE flow rate at each stage, and the related effect on the clearance time are also shown in Table 5.3.

Table 5.3: NO response and flow data for all tubing types and dimensions

Tubing Type	Tubing ID (mm)	Tubing Length (m)	T_C (s)	Ave T_0 (s)	Ave T_{90} (s)	Ave T_{100} (s)	Ave T_{10} (s)	Ave Flow Rate (ml/min)	Flow Rate Difference wrt PTFE (ml/min)	Effect on T_C (s)
PTFE	3.4	2.5	2.5	2.0	3.1	7.0	3.7	547.5	0.0	0.0
		5.0	5.0	4.8	5.5	6.5	5.3	349.0	0.0	0.0
		10.0	10.1	10.0	11.1	12.2	10.9	541.0	0.0	0.0
	4.75	2.5	5.0	5.0	6.2	8.1	5.9	530.5	0.0	0.0
		5.0	10.0	10.3	11.1	12.6	10.8	529.0	0.0	0.0
		10.0	20.9	21.5	22.8	26.5	21.7	508.0	0.0	0.0
	6.35	2.5	9.0	10.3	11.3	12.8	10.2	527.5	0.0	0.0
		5.0	18.2	18.8	20.5	22.0	18.8	523.0	0.0	0.0
		10.0	37.0	37.0	38.7	39.9	36.4	513.0	0.0	0.0
FEP	3.4	2.5	2.6	2.8	4.2	6.1	3.8	526.0	-21.5	0.0
		5.0	5.2	5.3	6.0	7.5	5.9	519.0	-30.0	0.0
		10.0	10.8	10.5	11.3	12.2	10.8	504.0	-37.0	0.0
	4.75	2.5	4.9	6.0	6.7	8.9	5.5	542.5	+12.0	0.0
		5.0	10.0	10.5	11.1	13.1	10.7	530.5	+1.5	0.0
		10.0	20.1	20.5	22.1	25.7	20.4	528.0	+20	0.0
	6.35	2.5	8.9	9.8	10.8	13.4	9.8	536.0	+8.5	0.0
		5.0	18.0	18.3	19.9	22.2	18.9	528.0	+5.0	0.0
		10.0	35.9	36.3	39.4	40.5	36.3	529.5	+16.5	-1.0
Tygon	3.4	2.5	2.6	4.0	6.8	10.4	3.9	524.0	-23.5	0.0
		5.0	5.2	5.3	8.0	12.6	5.9	520.5	-28.5	0.0
		10.0	10.7	10.0	13.7	25.8	9.9	510.5	-30.5	0.0
	4.75	2.5	5.0	6.0	8.9	12.4	5.9	534.5	+4.0	0.0
		5.0	10.1	9.5	13.4	25.7	9.9	527.5	-1.5	0.0
		10.0	20.1	19.5	28.6	30.2	20.6	530.0	+22.0	0.0
	6.35	2.5	8.8	10.0	16.6	24.1	9.9	542.5	+15.0	0.0
		5.0	17.8	17.5	24.6	36.3	17.9	534.0	+11.0	0.0
		10.0	35.0	35.5	40.7	63.7	35.7	542.5	+29.5	-2.0

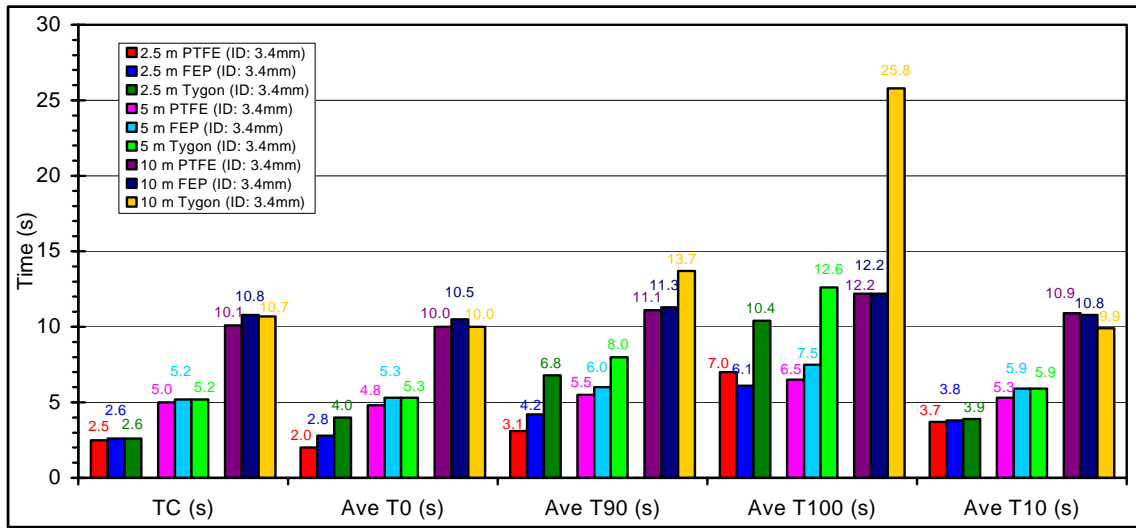


Figure 5.7: Average T_C , T_0 , T_{90} , T_{100} and T_{10} times for each type of tubing with ID of 3.4 mm during exposure to, and recovery from NO.

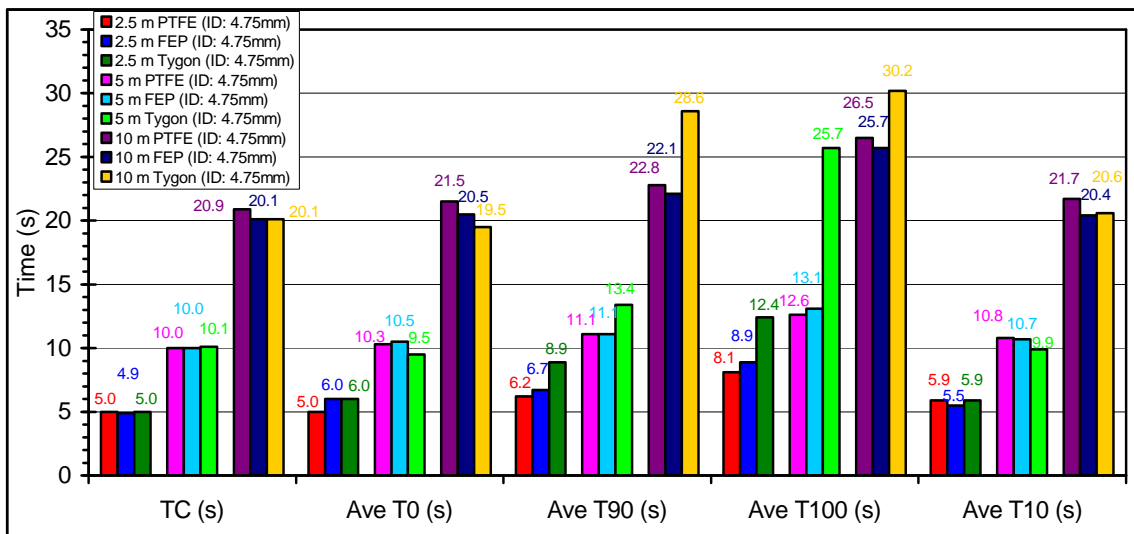


Figure 5.8: Average T_C , T_0 , T_{90} , T_{100} and T_{10} times for each type of tubing with ID of 4.75 mm during exposure to, and recovery from NO.

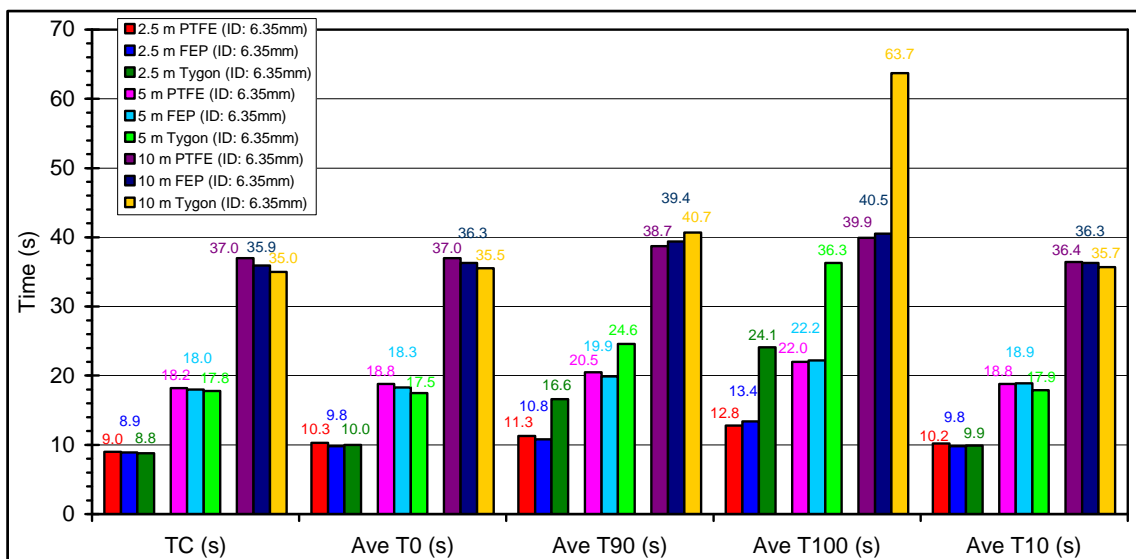


Figure 5.9: Average T_C , T_0 , T_{90} , T_{100} and T_{10} times for each type of tubing with ID of 6.35 mm during exposure to, and recovery from NO.

5.4 TOLUENE (C₇H₈)

The average times taken for the initial detection of the gas at the output of the tubes (T₀), and to reach 90% (T₉₀) and 100% (T₁₀₀) of the maximum concentration during exposure to C₇H₈, and to reduce to 10% (T₁₀) of the maximum concentration during purging with air, are shown in Table 5.4 and Figures 5.10 to 5.12. The average flow rate of gas throughout each stage, the clearance time (T_C), the flow rate normalised to PTFE flow rate at each stage, and the related effect on the clearance time are also shown in Table 5.4.

Table 5.4: C₇H₈ response and flow data for all tubing types and dimensions

Tubing Type	Tubing ID (mm)	Tubing Length (m)	T _C (s)	Ave T ₀ (s)	Ave T ₉₀ (s)	Ave T ₁₀₀ (s)	Ave T ₁₀ (s)	Ave Flow Rate (ml/min)	Flow Rate Difference wrt PTFE (ml/min)	Effect on T _C (s)
PTFE	3.4	2.5	2.5	3.8	5.3	29.7	3.9	549.0	0.0	0.0
		5.0	5.0	5.5	8.3	52.0	6.3	543.0	0.0	0.0
		10.0	10.4	9.3	14.0	53.0	10.6	526.0	0.0	0.0
	4.75	2.5	NA	5.0	7.0	53.5	6.6	NA	NA	NA
		5.0	NA	9.5	12.0	46.0	11.9	NA	NA	NA
		10.0	NA	19.5	29.0	130.3	25.9	NA	NA	NA
	6.35	2.5	9.4	8.5	12.0	34.0	11.5	504.0	0.0	0.0
		5.0	18.9	17.0	22.3	91.8	21.4	503.0	0.0	0.0
		10.0	NA	36.0	46.0	114.3	46.0	NA	NA	NA
FEP	3.4	2.5	2.5	2.5	3.6	13.9	3.9	536.0	-13.0	0.0
		5.0	5.2	5.8	7.0	26.9	6.5	527.0	-16.0	0.0
		10.0	10.4	9.8	11.4	25.5	11.7	525.0	-1.0	0.0
	4.75	2.5	5.0	5.0	7.2	17.7	6.6	535.0	NA	NA
		5.0	10.0	11.5	13.5	34.8	13.1	533.0	NA	NA
		10.0	19.9	20.3	23.3	61.8	22.9	534.0	NA	NA
	6.35	2.5	8.8	8.3	10.6	24.7	11.0	537.0	+33.0	-1.0
		5.0	18.1	15.8	19.5	38.7	19.5	526.0	+13.0	0.0
		10.0	34.5	34.0	39.3	82.7	39.1	551.0	NA	NA
Tygon	3.4	2.5	NA	NA	NA	NA	NA	NA	NA	NA
		5.0	NA	NA	NA	NA	NA	NA	NA	NA
		10.0	NA	NA	NA	NA	NA	NA	NA	NA
	4.75	2.5	NA	NA	NA	NA	NA	NA	NA	NA
		5.0	NA	NA	NA	NA	NA	NA	NA	NA
		10.0	NA	NA	NA	NA	NA	NA	NA	NA
	6.35	2.5	NA	NA	NA	NA	NA	NA	NA	NA
		5.0	NA	NA	NA	NA	NA	NA	NA	NA
		10.0	NA	NA	NA	NA	NA	NA	NA	NA

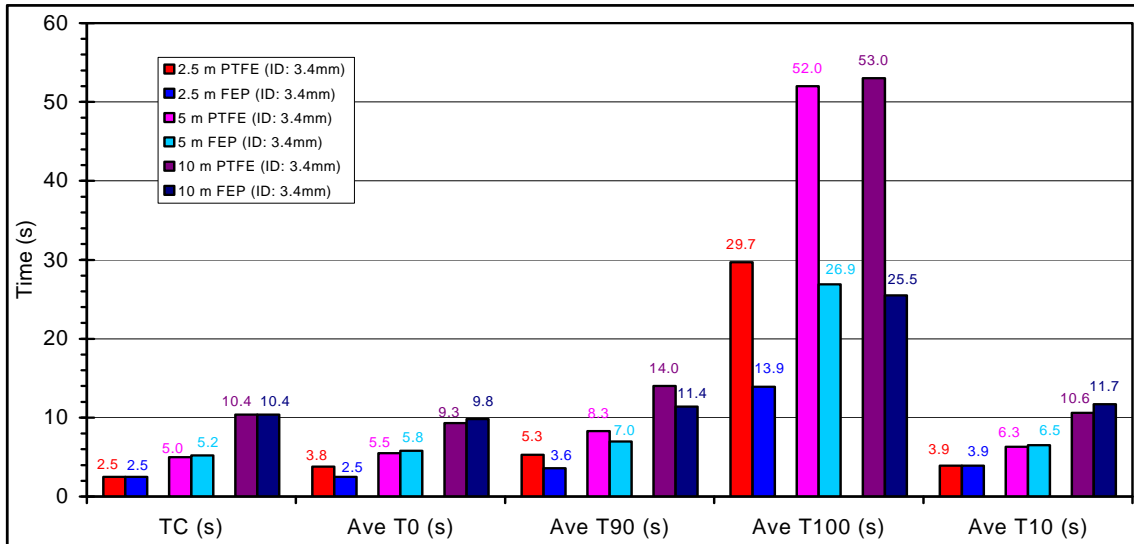


Figure 5.10: Average T_C , T_0 , T_{90} , T_{100} and T_{10} times for each type of tubing with ID of 3.4 mm during exposure to, and recovery from C_7H_8

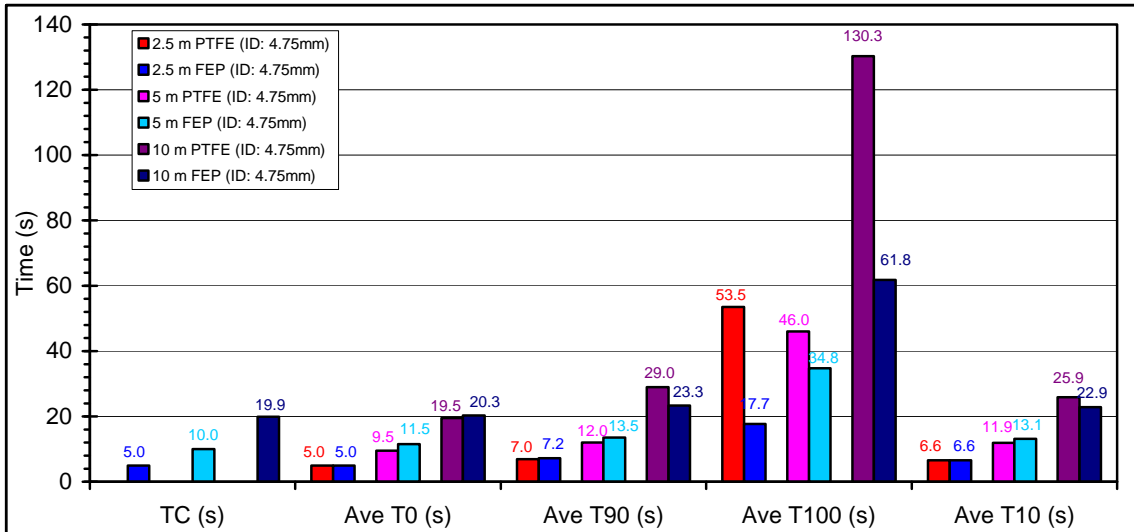


Figure 5.11: Average T_C , T_0 , T_{90} , T_{100} and T_{10} times for each type of tubing with ID of 4.75 mm during exposure to, and recovery from C_7H_8

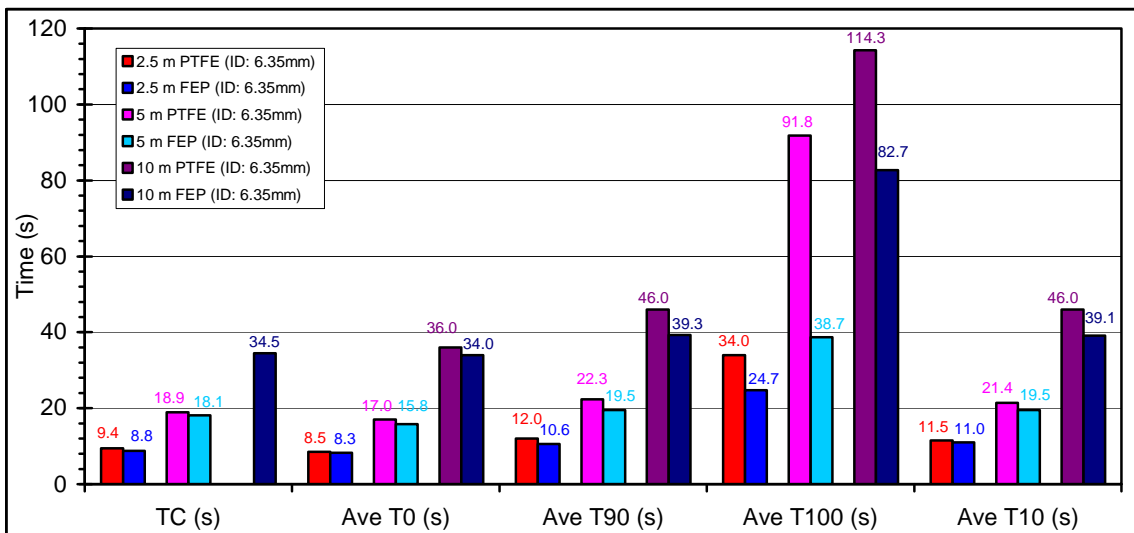


Figure 5.12: Average T_C , T_0 , T_{90} , T_{100} and T_{10} times for each type of tubing with ID of 6.35 mm during exposure to, and recovery from C_7H_8

6 REFERENCES

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2. http://www.boedeker.com/ptfe_p.htm, accessed 2005.
3. http://www.boedeker.com/feppfa_p.htm, accessed 2005.
4. <http://www.acutechplastics.com>, accessed 2005.
5. <http://www.tygon.com>, accessed 2005.
6. www.raesystems.com, accessed 2005.

Effect of tubing type on gas detector sampling systems

Reactive gases are defined as gases which, because of their high chemical activity, are easily sorbed (adsorbed and/or absorbed) by the exposed surfaces of gas detection systems including detector housings, calibration adapters and remote sample draw accessories (tubing). Because of their greater tendency to be depleted from a gas sample by the exposed surfaces of gas detection systems, special care must be taken to ensure accurate monitoring results. The principle danger is that failure to use compatible materials and proper calibration procedures can result in dangerously inaccurate (low) readings and increased response times [1].

Many of the gases monitored by HSL field and laboratory scientists in their normal line of work may be classed as reactive. This investigation was designed to determine the effect of various types of tubing on the response times of the detection systems utilised to monitor a range of reactive gases.

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.