

AIR INGRESS INTO NITROGEN INERTED VENT PIPES

P. Hooker, G.R. Astbury and G. Fauré*

Avecia Limited, P.O.Box 42, Blackley, Manchester M9 8ZS,

*Ecole des Mines d'Albi, Campus Jarlard, 81013 Albi, Cédex 09, France

Providing a continuous flow of nitrogen through a vent pipe can avoid the ingress of air back down the vent. In the event of the nitrogen flow stopping air will enter the vent pipe. This could result in the loss of the inert gas blanket within the vented vessel if the nitrogen flow was not re-established quickly enough. Knowledge of how quickly air enters the vent pipe would be useful in devising a suitable corrective action plan. This paper presents the results of a series of experiments in which pipes of 1", 2", 4" and 6" nominal bore were inerted with nitrogen, the nitrogen flow stopped and the ingress of air into the pipes measured. Comparison of the experimental results with a theoretical model revealed that the predictions of the model were of the same order of magnitude as the experimental results for many of the test conditions. However, it was apparent that transient effects became dominant in situations where the vent pipe volume is small compared to the volume of the vessel.

inert gas diffusion nitrogen oxygen concentration vent pipe

INTRODUCTION

Many chemical process operations involve the use of flammable materials. In many cases it is possible to avoid the occurrence of fires and explosions by implementing precautions to avoid potential ignition sources. However, in other processes there are inherent ignition sources, such as pyrophoric materials, that cannot be avoided. In such circumstances it is common practice to operate the process in an inert atmosphere, where oxygen is displaced by an inert gas to such an extent that the oxygen concentration is too low to support combustion. In many cases it is necessary to provide the vessel in which the inert atmosphere is established with an atmospheric vent, for example, if gases are liberated during the process. In order to prevent air diffusing back down the vent line a continuous flow of inert gas can be applied to the vent.

The flow of inert gas through the vent line will establish an equilibrium oxygen concentration profile along the length of the vent. The oxygen concentration profile has been studied previously by Husa^{1,2} for a number of vent pipe diameters, employing various purge gas types and flow rates. The work of Husa indicated a logarithmic relationship between oxygen concentration and distance from the open end of the vent pipe under steady-state conditions. Recently reported work by the authors³ has given evidence to support the relationship proposed by Husa. However, there is little practical information available on the rate of air ingress into vent pipes when the flow of inert gas stops. Earlier work by the authors had suggested that there was a power law relationship between the time taken for the oxygen concentration to increase to a particular value and the distance from open end of the pipe. Analysis by the authors of data generated by Tite, Greening and Sutton⁴ had also indicated that there may be a power law relationship between these two parameters. The relationship determined by Husa has been used as the starting point in the development of a theoretical model of the relationship between the oxygen concentration, depth down the pipe and time. Experiments were carried out to measure these parameters for a number of pipes with different diameters. Nitrogen was used in the experiments since it is commonly employed as the inerting medium in industrial process plants.

THEORY

Husa's first paper gave the following equation to link the purge gas velocity, pipe diameter, purge gas molecular weight, oxygen concentration and distance down the pipe.

$$V = \frac{0.022}{h} \times \left(\frac{6}{X}\right)^{0.64} \times \left(\frac{28}{M}\right)^n \times \left(e^{0.16 \times D} - 0.96 \times e^{0.16 \times (D-M)}\right) \quad (1)$$

The above equation is in the form given Husa's paper, in which SI units are *not* used.

For a fixed pipe diameter, purge gas and oxygen concentration the equation can be expressed in the simplified form:

$$V = \frac{K}{h} \quad (2)$$

where K is a constant

If it is assumed that the purge velocity, V , represents the velocity at which oxygen will diffuse into the vent line at a given position, h , from the end of the vent pipe then it is possible to calculate the time taken for the oxygen concentration to reach the chosen value.

If the vent pipe is split into a series of small sections, each of height δh , it is reasonable to assume that the velocity within each section will be constant. The time taken to cross each section will then be given by:

$$\delta t = \frac{\delta h}{V(h)} \quad (3)$$

Substituting in for $V(h)$ from equation (2) gives:

$$\delta t = \frac{h}{K} \delta h \quad (4)$$

As δt tends to zero, then

$$dt = \frac{h}{K} dh \quad (5)$$

The total time taken for the chosen oxygen concentration to reach a depth, h , can be obtained by integrating the equation (5) with respect to h .

$$\int dt = \int \frac{h}{K} dh \quad (6)$$

Integrating equation (6) between 0 and h yields:

$$t = \frac{h^2}{2K} \quad (7)$$

Where:

$$K = 0.022 \times \left(\frac{6}{X}\right)^{0.64} \times \left(\frac{28}{M}\right)^n \times \left(e^{0.16 \times D} - 0.96 \times e^{0.16 \times (D-M)}\right) \quad (8)$$

Equation (7) shows that for a particular pipe and purge gas the time taken for the oxygen concentration to reach a chosen value is dependant upon the square of the distance from the open end of the pipe.

The experiments conducted for this paper employed 2", 4" and 6" nominal bore pipes and nitrogen was used as the purge gas (ie $M = 28$). Therefore, equations (7) and (8) can be expressed in simpler forms.

For example, for the 2" pipe:

$$K = 0.022 \times \left(\frac{6}{X}\right)^{0.64} \times \left(\frac{28}{28}\right)^n \times \left(e^{0.16 \times 2} - 0.96 \times e^{0.16 \times (2-28)}\right) \quad (9)$$

which simplifies to:

$$K = 0.0943 X^{-0.64} \quad (10)$$

Therefore,

$$t_{2''} = \frac{h^2 X^{0.64}}{0.1886} \quad (11)$$

Similarly for the 4" and 6" pipes:

$$t_{4''} = \frac{h^2 X^{0.64}}{0.2598} \quad (12)$$

$$t_{6''} = \frac{h^2 X^{0.64}}{0.3578} \quad (13)$$

As will be seen later in this paper, the predictions made using equations (11), (12) and (13) were compared with experimentally obtained results.

EXPERIMENTAL

EXPERIMENTAL TEST RIG

The experiments were carried out in the open air using 4 m long pipes. Pipes of 1", 2", 4" and 6" nominal bore were used. A vessel with a volume of approximately 70 litres was connected to the bottom of the vent pipe under investigation and the system sealed so that the only route for air to enter the system was through the top of the vent pipe. The experimental rig is shown in Figure 1.

The oxygen concentration within the vent pipe was measured using "Schools" Type Oxygen Probes and Model OT4 Oxygen Meters, both supplied by Walden Precision Apparatus Ltd., of Cambridgeshire, UK. The probes could be inserted into the vent pipes at any of nine pre-determined locations along the length of the pipe, the unused positions being sealed with plugs. The outputs from the oxygen meters were logged on a personal computer using the Orchestrator data logging package. The oxygen measuring system was calibrated

across the range from 0 to 20.8% v/v oxygen before each experiment. Also, because the experiments were carried out over several hours, the probes were checked for drift at the end of each experiment. The upper limit was calibrated in fresh air and zero was set using oxygen-free nitrogen. The response time of the probe/meter system across the full calibrated range was less than 2 seconds.

The nitrogen used in the experiments was Oxygen-Free grade supplied by BOC and the flow rate to the pipes was measured using a Model 826-CE-NX-OV1-PV1-V1 mass flow meter supplied by Sierra Instruments Inc. of Monterey, USA. The flow meter was pre-calibrated using nitrogen by the manufacturer. As with the oxygen meters, the flow-meter output was logged using the Orchestrator data logging package. The nitrogen supply was connected to the bottom of the vessel via a pressure regulator and the flow meter.

In some experiments air was forced across the top of the pipe to simulate wind. A 300 mm diameter wind tunnel, incorporating flow straighteners, was placed across the top of the pipe and the air movement was achieved using a fume extractor. The fume extractor had a nominal air flow of $3740 \text{ m}^3 \text{ hr}^{-1}$ which resulted in a nominal average wind speed of 14.7 m s^{-1} (53 km hr^{-1}) through the wind tunnel.

A manometer was connected to the 1" diameter pipe during later experiments in order to investigate the transient effects that had been observed.

EXPERIMENTAL PROCEDURE

Once the oxygen probes had been calibrated, they were inserted into the pipe at the required locations. The vessel was then purged with nitrogen until the oxygen concentration profile within the vent pipe reached equilibrium conditions. The nitrogen flow was then stopped and air allowed to enter the vent. The oxygen concentration was recorded until the oxygen concentration at the probe position furthest from the open end had increased significantly, normally to a concentration of 10% v/v.

Experiments were performed using the 6", 4" and 2" diameter pipes under "wind" and "no-wind" conditions. The wind condition was achieved by providing a continuous flow of air across the top of the pipe, using the wind tunnel described above. For the no wind condition, an open topped box structure was placed around the top of the pipe in order to minimise the effect of the atmospheric air movement.

In order to investigate whether the volume of the vented vessel influenced the oxygen profile some experiments were carried out in which the vessel was removed from the 1" pipe.

The recorded oxygen concentration profiles were analysed in order to determine the time required for the oxygen concentration at various positions down the pipe to reach a chosen value. It was decided to carry out this analysis for three particular values of oxygen concentration. The values of 10%, 5% and 2% v/v were chosen since these would be representative of the typical range of interest in systems employing inert gas blankets.

RESULTS

EXPERIMENTS EMPLOYING THE LARGER DIAMETERS

In all experiments the oxygen concentration within the pipes increased once the nitrogen flow was stopped. For the 6" and 4" pipes the oxygen concentration was observed to increase steadily apart from when the probe was placed very close to the open end of the pipe. A typical example is shown in Figure 2. However, the change of oxygen concentration in the 2" pipe was more variable, and the oxygen concentration was seen to fluctuate considerably during experiments involving the 1" pipe. The transient effects observed for the 1" pipe are reported later.

The relationship between the time required to reach 2%, 5% and 10% v/v oxygen under nominal “no wind” conditions and the distance from the open end of the pipe, is shown graphically in figures 3, 4 and 5, respectively. Each graph shows data for the 6”, 4” and 2” pipes.

Regression analysis of the data revealed that the time taken for the oxygen concentration to reach a particular value can be represented as a power law function of the depth, similar to equation (7) predicted by theory. This relationship can be expressed as:

$$t = \frac{h^b}{K'} \quad (14)$$

where K' is constant for a particular pipe diameter and oxygen concentration. The exponent, b , has a value between 1.7 and 2.4, with no apparent trend with respect to pipe diameter.

THE EFFECT OF WIND ON THE EXPERIMENTS USING THE LARGER PIPES

The application of a constant air flow across the open end of the pipe appeared to modify the rate at which air entered the pipe, when compared to the data obtained for the no-wind conditions. The effect was particularly noticeable for the 6” pipe where the time taken to reach a particular oxygen concentration was significantly reduced, to as little as 25% of the time observed for the no wind condition in some cases. The effect was less evident for the 2” and 4” pipes. Examples of the effect of wind are shown in figures 6, 7 and 8.

TRANSIENT EFFECTS OBSERVED FOR THE 1” PIPE

Soon after experimentation started on the 1” pipe, transient effects became evident. This behaviour, an example of which is shown in figure 9, exhibited the following characteristics. After a period in which the oxygen concentration appeared to rise reasonably smoothly, the oxygen concentration at the top probe position would increase rapidly, often reaching 21% v/v. After a short period, typically a few minutes, the oxygen concentration would decrease again and rejoin the “baseline”. These “oxygen spikes” were seen to occur at the top probe position at intervals of about 10 - 15 minutes. Similar peaks were observed at lower probe positions later on in the experiments. When these transients were seen at more than one probe position, the upper probe position exhibited the increase in concentration first, followed by the middle probe position and finally the lowest position. At the end of the transient, the concentration recorded at the lowest probe position returned to the baseline first, followed by the middle probe and finally the upper probe. The transient effects were seen to be more prevalent under conditions of changing wind speed than when the pipe was guarded against wind or subjected to a continuous air flow.

In order to investigate the phenomenon, temperature and pressure measurements were carried out. The temperature measurements did not reveal any significant differences between the temperature of the ambient air surrounding the facility and the nitrogen within the test equipment. The application of a constant air flow across the open end of the pipe caused a small decrease in pressure within the pipe of less than 1 mbar.

Further experiments were carried out in which the vessel was disconnected from the 1” pipe, the bottom of the pipe was sealed and the pipe alone was purged with nitrogen. When the nitrogen flow was stopped the oxygen concentration increased steadily, as observed with the larger diameter pipes when they were connected to the vessel.

DISCUSSION

The experimental results suggest that there is a reasonable amount of evidence to support the use of a power law relationship between the distance from the end of the pipe and the time required for the oxygen concentration to reach a particular value. The exponent for the experimentally determined power law was reasonably close to the theoretical value of 2, as derived above. A comparison has been made of the time predicted by the theoretical model, using equations (11), (12) and (13), and the shortest times found by experiment, including the values found under wind conditions.

The predicted times are of the same order of magnitude as the experimentally determined times. However, there are many occasions when the predicted time is longer than that found experimentally. A comparison of the predicted and experimental times to reach 2%, 5% and 10% v/v oxygen is given in Table 1.

Table 1. Comparison of predicted and experimental time to reach 2%, 5% and 10% v/v oxygen at a distance, h, down the pipe.

Pipe Size	Distance from open end of pipe (metres)	Predicted Time to Reach 2% v/v (minutes)	Exp'tal Time to Reach 2% v/v (minutes)	Predicted Time to Reach 5% v/v (minutes)	Exp'tal Time to Reach 5% v/v (minutes)	Predicted Time to Reach 10% v/v (minutes)	Exp'tal Time to Reach 10% v/v (minutes)
6"	0.95	0.7	0.2	1.3	0.3	2.0	0.7
6"	1.43	1.6	0.6	2.9	1.3	4.5	> Theory
6"	1.9	2.8	0.9	5.1	1.4	7.9	4.2
6"	2.3	4.1	2.0	7.4	3.6	16.1	11.1
6"	2.85	6.4	2.5	11.4	5.2	17.8	14.8
6"	3.3	8.5	4.0	15.3	7.3	23.9	17.2
6"	3.8	11.3	4.5	20.3	8.3	31.6	20.4
4"	0.95	1.0	0.3	1.8	0.9	2.7	> Theory
4"	1.43	2.2	1.1	4.0	2.7	6.2	> Theory
4"	1.9	3.9	2.8	7.0	6.7	10.9	> Theory
4"	2.3	5.7	4.1	10.3	9.6	16.0	> Theory
4"	2.85	8.7	8.2	15.7	> Theory	24.5	> Theory
4"	3.3	11.7	9.3	21.1	> Theory	32.9	> Theory
4"	3.8	15.6	9.3	28.0	> Theory	43.6	> Theory
2"	0.95	1.3	> Theory	2.4	> Theory	3.8	> Theory
2"	1.43	3.0	2.2	5.4	> Theory	8.3	> Theory
2"	1.9	5.4	> Theory	9.6	> Theory	15.0	> Theory
2"	2.3	7.8	> Theory	14.0	> Theory	21.6	> Theory
2"	2.85	12.0	> Theory	21.6	> Theory	33.7	> Theory
2"	3.8	21.3	20.2	38.1	> Theory	58.9	> Theory

From table 1 it can be seen that the theoretical predictions are worst for the 6" pipe, and best for the 2" pipe. It is possible that this is because turbulent mixing effects would be more prevalent in the 6" pipe, where the distance to diameter ratio is smaller, and less influential in the 2" pipe where the distance to diameter ratio is somewhat greater. Turbulent mixing effects at the open ends of vent pipes have been studied previously by Bryce and Fryer-Taylor⁵.

Although the times predicted by the model can be shorter than those found experimentally, the model could be used to carry out an order of magnitude estimation, particularly if a suitable safety factor is applied.

TRANSIENT EFFECTS

The reason for the transient effects seen for the 1" pipe are not satisfactorily explained. The decrease in pressure in the pipe observed during the application of a continuous "wind" would only explain a movement of a column of gas a few centimetres in length, ie insufficient to explain the almost simultaneous increase in oxygen concentration at points within the pipe separated by about 1 metre.

Another potential reason for the transients could be bubbles of air, introduced by turbulent vortices caused by wind, flowing down the pipe in a plug-flow manner as discussed by Panchenko⁶ However, the oxygen concentration at the top probe position was seen to increase before, and decrease after, that measured at the lower positions (see figure 9). Therefore, it appears that the transients are unlikely to be caused by Panchenko's bubble mechanism in this case.

What is evident is that the effect does not occur when there is no vessel attached to the bottom of the 1" pipe. During the experiments with the larger sized pipes, which were all connected to the same size vessel, no significant transient effects were seen with the 6" and 4" pipes. Although some transients were seen with the 2" pipe, these were significantly less than those observed for the 1" pipe. This suggests that the ratio of the total system volume to the vent pipe volume plays an important role in the occurrence of the transient effects. The ratios for the systems used in these experiments are given in Table 2.

The problem of transients was not reported by Tite, Greening and Sutton, but examination of their full scale system shows the ratio of total system volume to vent volume to be about 3. In our experiments with ratios of 3.2 and less no transients were noted. With larger ratios transients were noticed, the effect being greater for greater ratios.

The short term deviations exhibited during the experiments with the 1" pipe suggest that, in the event of nitrogen flow failure, a flammable atmosphere may form for short periods along the full length of the vent pipe. However, the behaviour of the baseline indicates that the oxygen concentration within the vented vessel is not increasing rapidly.

Table 2. Volumes and volume ratios for systems used in the experiments

System Description	Vent Pipe Volume (litres)	Vessel Volume (litres)	Total System Volume (litres)	Ratio of Total Volume to Vent Pipe Volume
6" Pipe with Vessel	73.0	72.1	145.1	2.0
4" Pipe with Vessel	32.4	72.1	104.5	3.2
2" Pipe with Vessel	8.1	72.1	80.2	9.9
1" Pipe with Vessel	2.0	72.1	74.1	37.1
1" Pipe without Vessel	2.0	Nil	2.0	1.0

CONCLUSIONS

1. A theoretical model has been developed to predict the time required for the oxygen concentration to reach a chosen value at a particular distance from the open end of the pipe.
2. Experimental data indicates that the model can be used to carry out an order of magnitude estimate of the time required for the oxygen concentration to reach a chosen value at a particular distance from the open end of the pipe, although care would be needed and a suitable safety factor applied.
3. When the vent volume and vessel volume were similar the increase in oxygen concentration at a given point down the vent increased in a smooth manner and the model was in reasonable agreement with measured values.
4. Where the vessel volume is large compared to the volume of the vent pipe transient effects were seen to dominate, the oxygen concentration within the pipe increasing and decreasing rapidly. It appears that these transient effects are observed when the ratio of the total system volume to the vent pipe volume approaches a value of about 10.
5. The existence of transient increases in oxygen concentration could introduce the potential for an extensive, though short-lived, flammable region within a vent pipe servicing a vessel containing flammable vapours or gases.
6. Further work is required to investigate the rate of oxygen ingress into the process vessels that are connected to atmosphere via vent pipes.

ACKNOWLEDGEMENTS

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NOMENCLATURE

V	Velocity of inert gas through the vent pipe (feet per second)
h	Distance from open end of vent (feet)
X	Oxygen concentration (% v/v)
M	Molecular weight of inert gas
D	Internal diameter of vent pipe (inches)
n	Exponent given in Husa's 1964 paper
t	Time taken to reach a particular oxygen concentration (s)
K	A constant derived from Husa's 1964 equation for constant pipe diameter and purge gas type.
b	An experimentally determined exponent with values between 1.7 and 2.4
K'	An experimentally determined constant

REFERENCES

- 1 Husa, H.W., 1964, *Hydrocarbon Proc. And Petr. Ref.*, **43**, 179-82
- 2 Husa, H.W., 1977, "Purging Requirements of Large Diameter Stacks" (Presented at Fall 1977 Meeting API Fire/Safety Subcommittee, Sept 13-15 1977, San Francisco)
- 3 Astbury, G.R., and Hooker, P., 2000, *IChemE Symposium Series No.147*, 221-34
- 4 Tite, J.P., Greening, K., and Sutton, P., 1989, *Chem. Eng. Res. Des.*, **67**, 373-80
- 5 Bryce, S.G., and Fryer-Taylor, R.E.J., 1994, *J. Loss Prev. Proc. Ind.*, **7**, 249-55
- 6 Panchenko, V.I., 1993, *Khemicheskoe i Neftyanoe Mashinostroenie*, No 5, 5-7

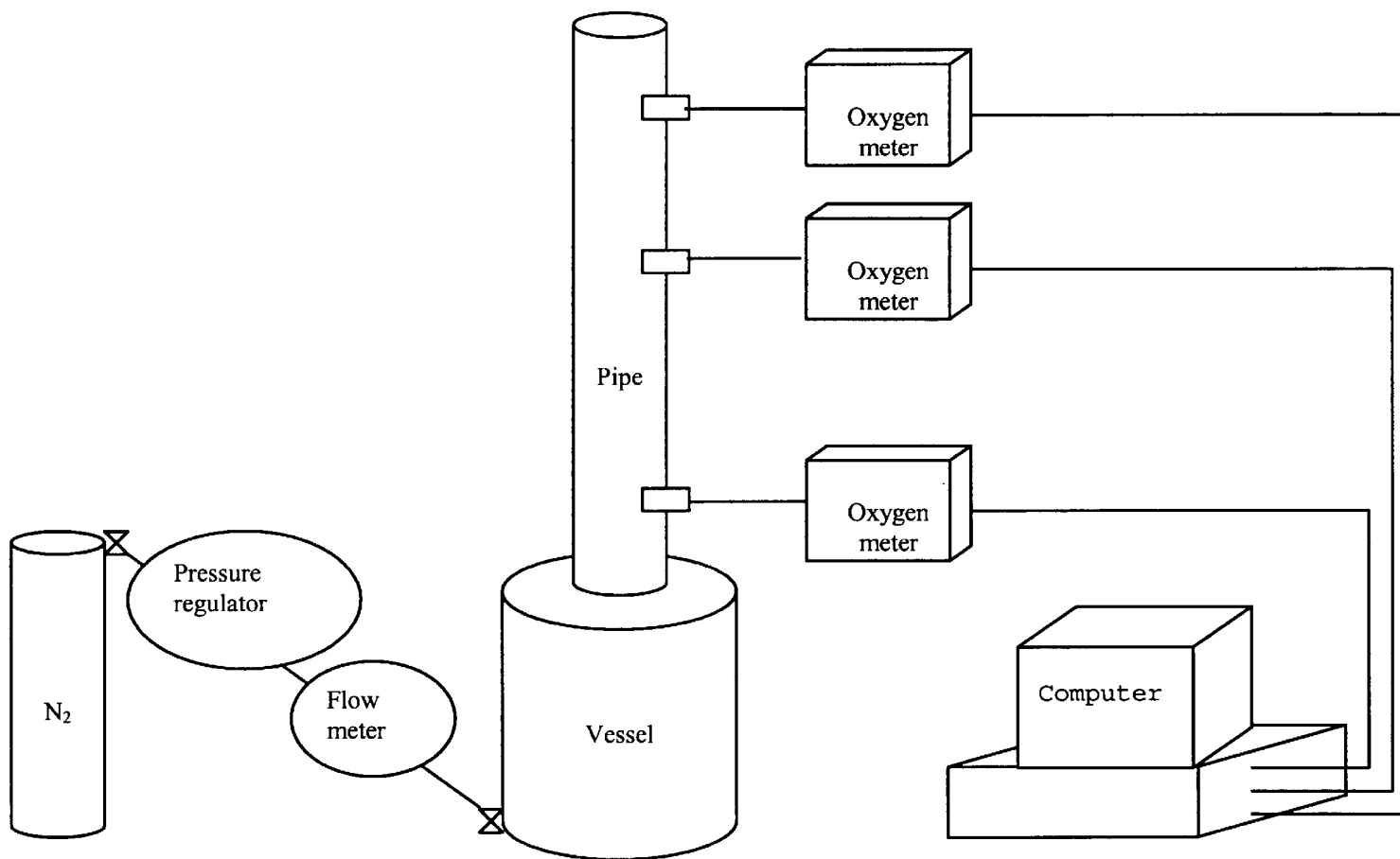


Figure 1. Schematic of Experimental Arrangement

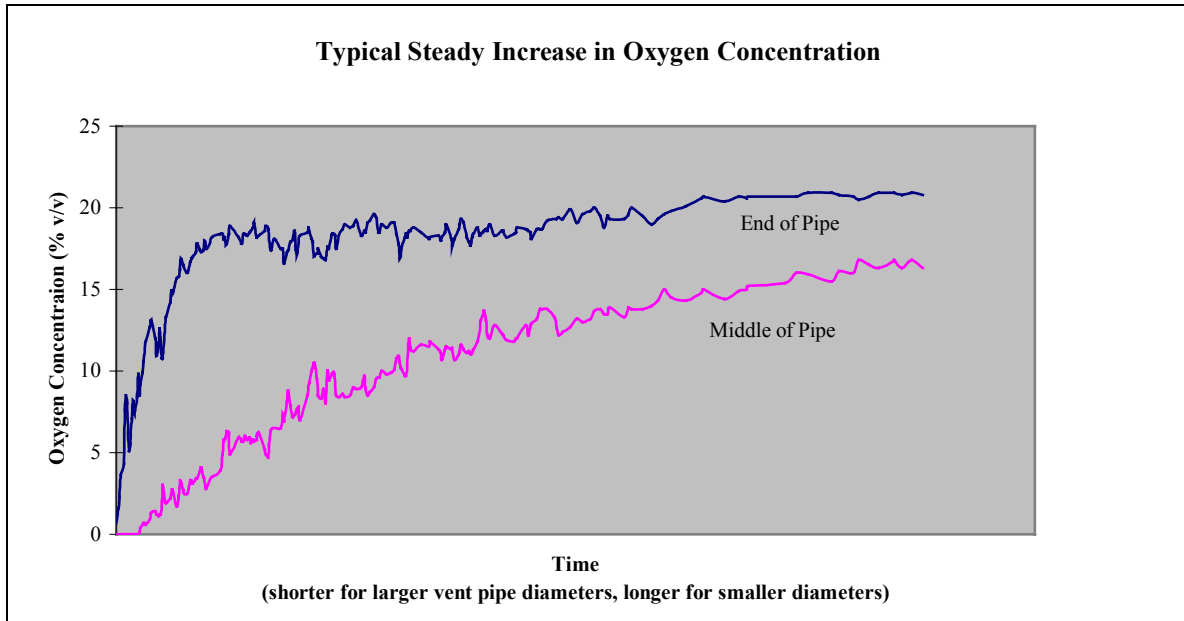


Figure 2. Typical Increase in Oxygen Concentration After Stopping Nitrogen Flow in Large Diameter Vent Pipes

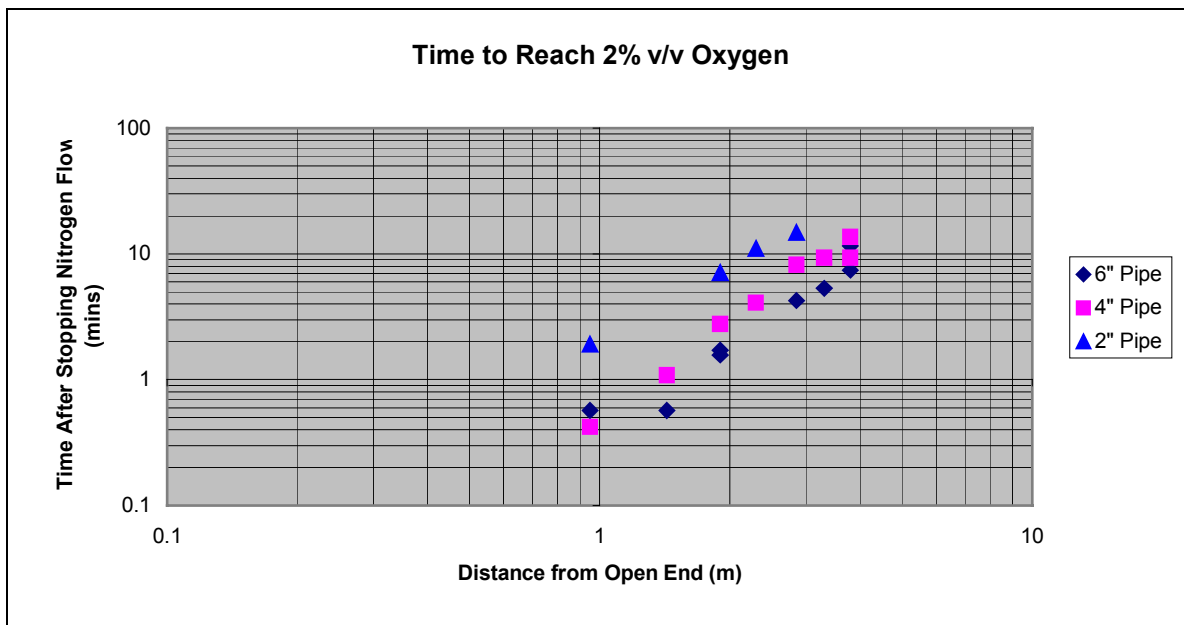


Figure 3 Time Taken to Reach 2% v/v Oxygen in 2", 4" and 6" Nominal Bore Pipes

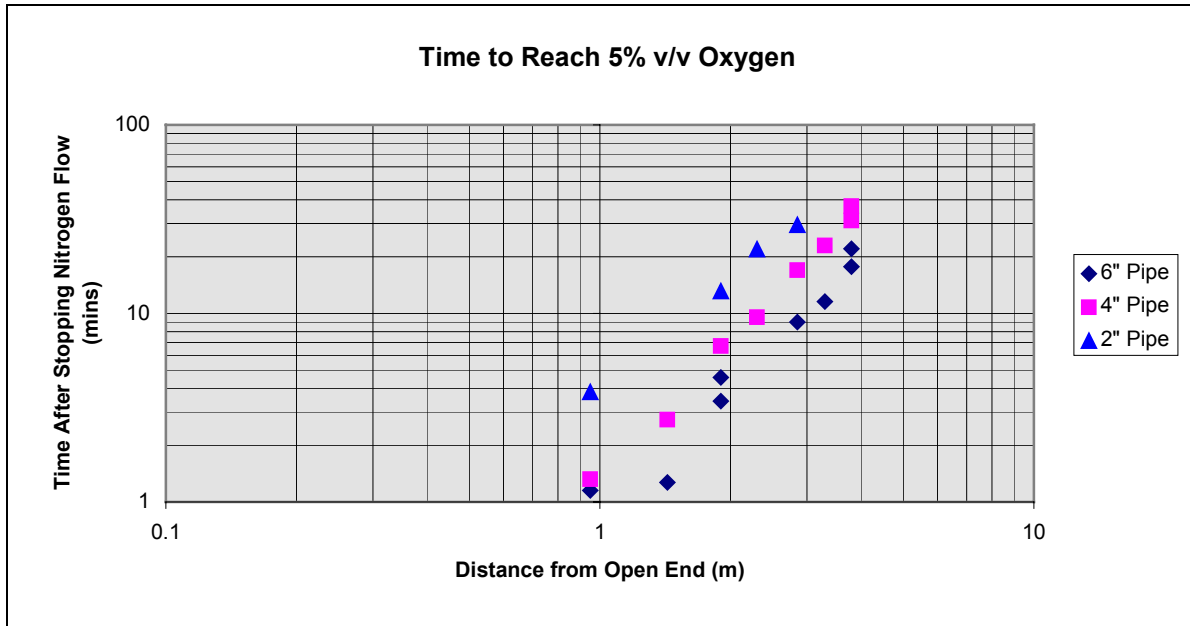


Figure 4 Time Taken to Reach 5% v/v Oxygen in 2", 4" and 6" Nominal Bore Pipes

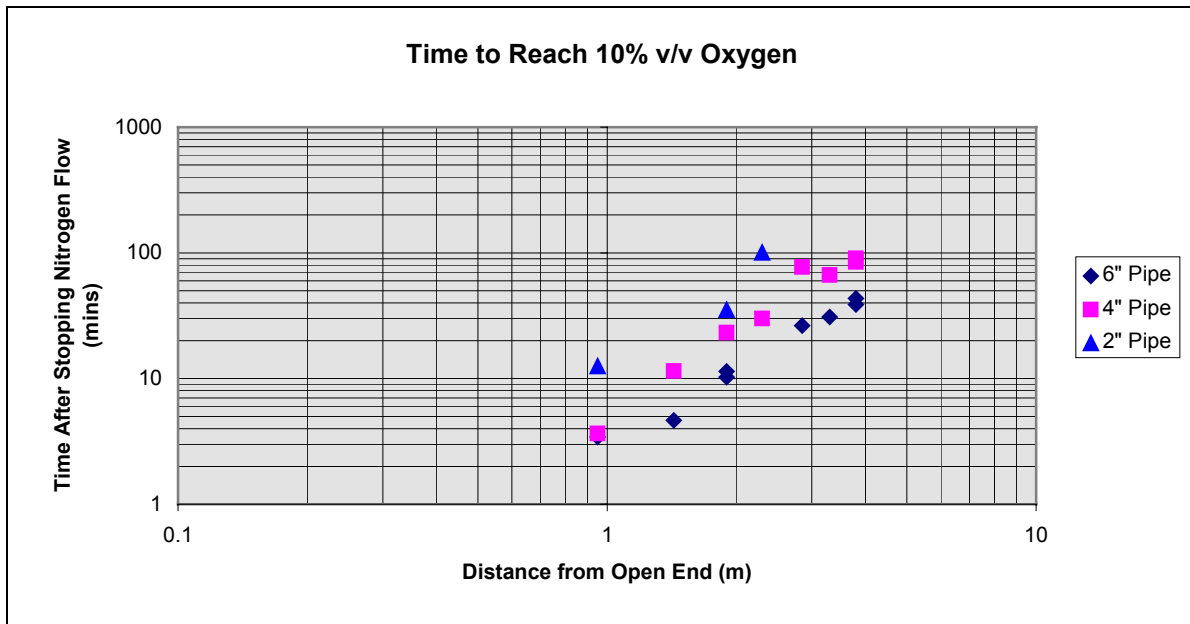


Figure 5 Time Taken to Reach 10% v/v Oxygen in 2", 4" and 6" Nominal Bore Pipes

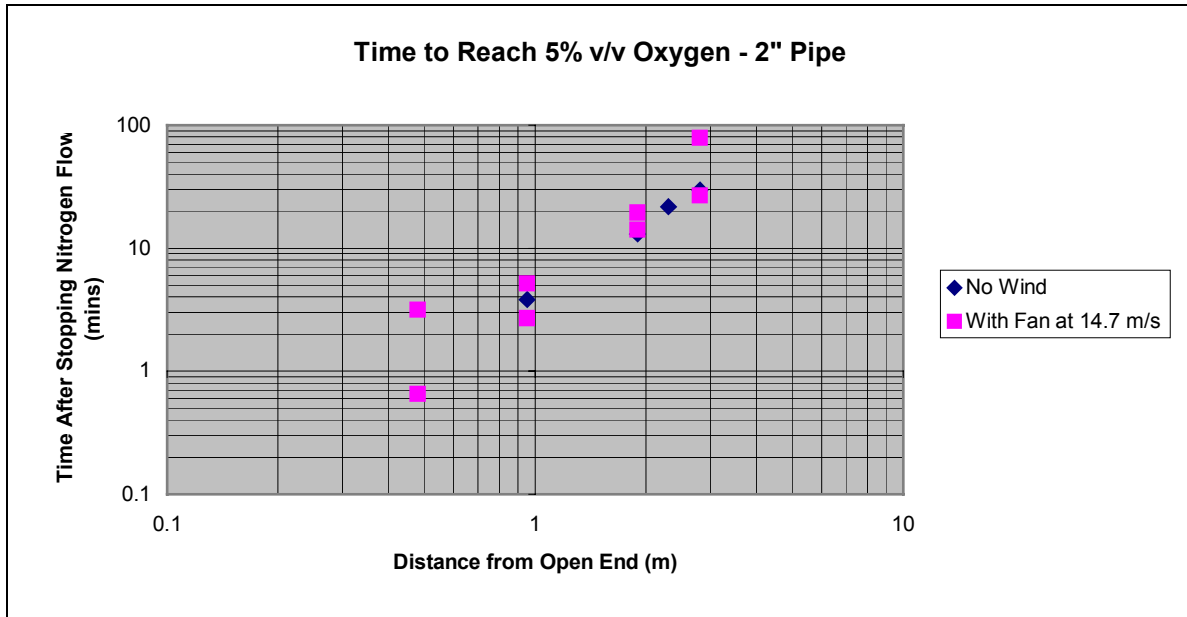


Figure 6. Effect of Wind on 2" Nominal Bore Pipe

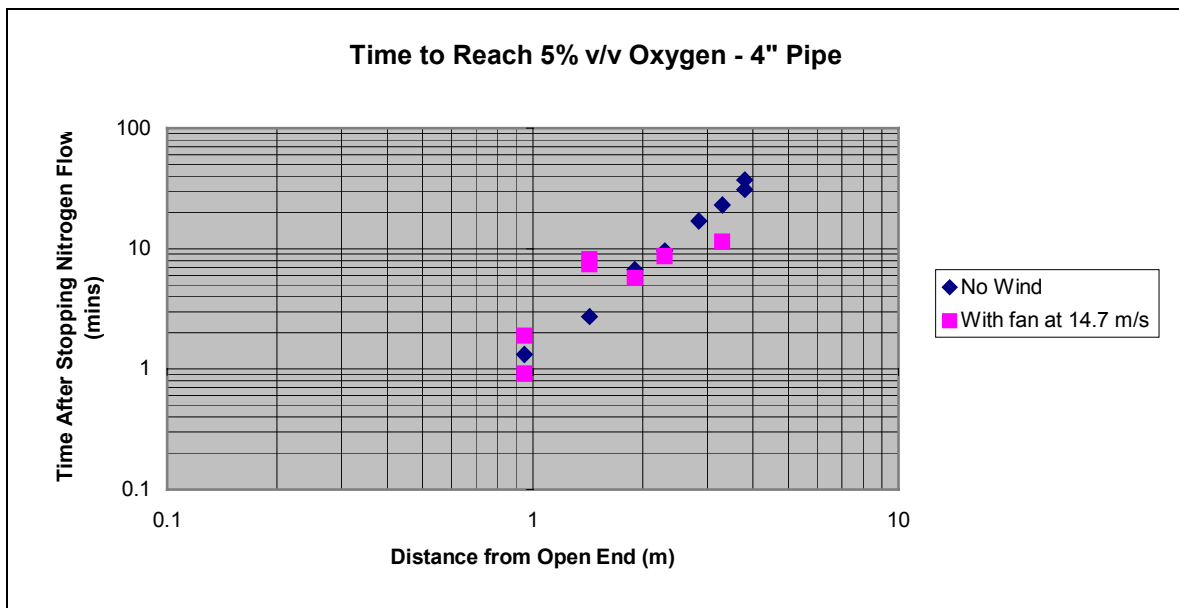


Figure 7. Effect of Wind on 4" Nominal Bore Pipe

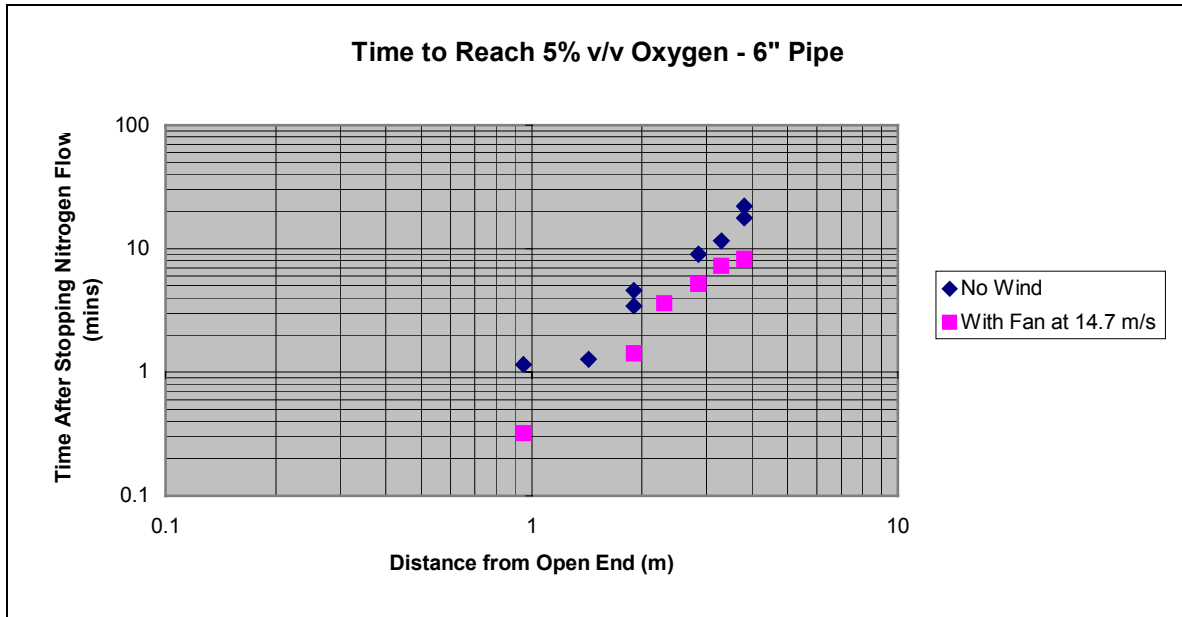


Figure 8. Effect of Wind on 6" Nominal Bore Pipe

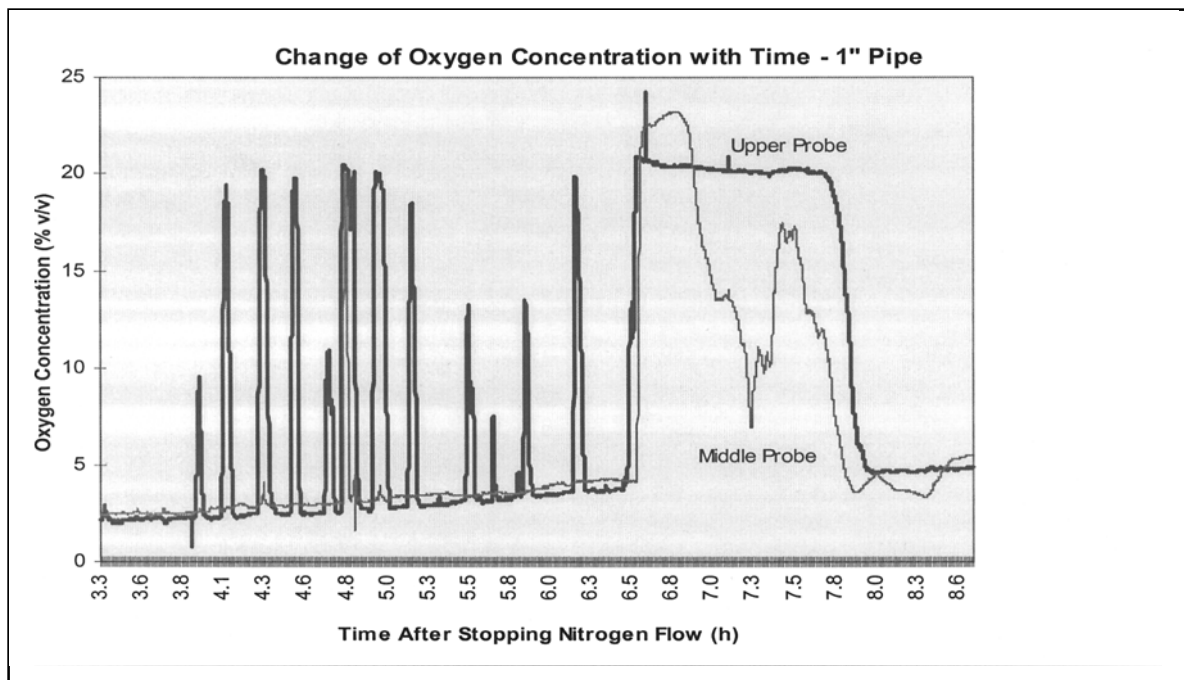


Figure 9. Transient Effects Observed for the 1" Nominal Bore Pipe