

Air Change Rate Measurement: The Log/Linear Decay of Tracer Gas Concentration with Time

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Introduction

A great deal of the literature on general ventilation expresses the adequacy of the volumetric flow rate of air in terms of the number of room air changes per hour. Although the concept of air change rate has very little relevance to the control of contaminants as it relates to the size of the room and not to the scale of the problem, the overall amount of air entering and leaving a workplace is of fundamental importance in assessing the quality of the working environment. The measurement of air change rates is the traditional way of determining air movement and remains a very widely used and quoted concept, possibly because of the relative ease with which it can be measured and visualised. Air change rates can be measured by the use of tracers, usually in a gaseous form. In the UK, the Health and Safety Executive(1) gives a method for the on-site measurement of air change rates in factories and offices based on the decay of the concentration of tracer gas which has been mixed throughout the area. A log/linear analysis of concentration with time is used to deduce the air change rate. Using this analysis it has frequently been observed that a "dog leg" occurs in the log/linear plot of concentration/time which should yield a straight line. Possible causes of this and other non-linearities are investigated.

Method

A quantity of tracer gas is released into the room and mixed with the air, usually by means of a small fan. The release is terminated and the mixing fan may or may not be turned off. Charlesworth(2) for example recommends that in naturally ventilated rooms artificial mixing ceases before monitoring of the tracer concentration decay commences so as not to alter the natural conditions which are to be measured. However most of the work reported here was with forced ventilation and the mixing fan was left on throughout the measurement period. The tracer concentration will diminish with time and this decay is measured at one or more points in the room. Ideally, when the ventilation rate remains constant during the measurement period, the log/linear plot of concentration/time will give a straight line fit. Unfortunately this is not always the case and the reason is often not investigated. On close examination of the data it is frequently found that there is a distinct change in the gradient of the decay. This may be as a result of a sudden change in the ventilation rate. For example, recent measurements of air change rates carried out by the Health and Safety Laboratory (HSL) in naturally ventilated hospital maternity units showed that, on one occasion during a period of hot weather, there was a sudden change in the gradient of the decay curve. The time of this change corresponded with the opening of doors in another part of the building that resulted in a real change in the ventilation rates throughout the building. However in work reported by Kalliokoski(3), the non-exponentiality of the lower part of a decay

graph was attributed to re-entry of tracer from an adjacent room and to the unstable zero level of the gas analyser. In other cases it may not be possible to determine the reason; Figure 1 shows the results of the decay of nitrous oxide tracer gas in a closed greenhouse. A distinct change of gradient occurs at an N_2O concentration of about 17 ppm. The change occurs at a relatively high concentration and should not be due to the instrument calibration or, as will be shown, zero drift. It may have been due to entry of tracer from adjacent rooms but the reason is not known with any certainty.

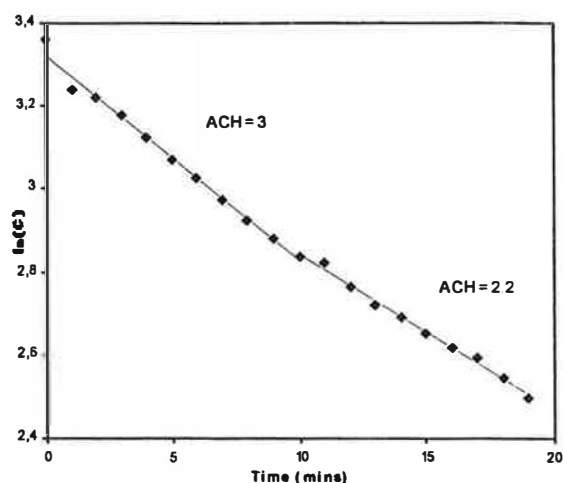


Figure 1 N_2O decay in a closed greenhouse

Gas Analyser Calibration and Zero Drift

The instruments most commonly used at HSL in investigations of this type are infra-red gas analysers. The absorbance measured by the analyser is not linear in relation to concentration and the analysers are calibrated at frequent intervals and usually checked on use. Three factors have been found to effect the shape of the concentration decay curves: i) the order of the fit applied to the calibration data, ii) calibration accuracy and iii) zero drift.

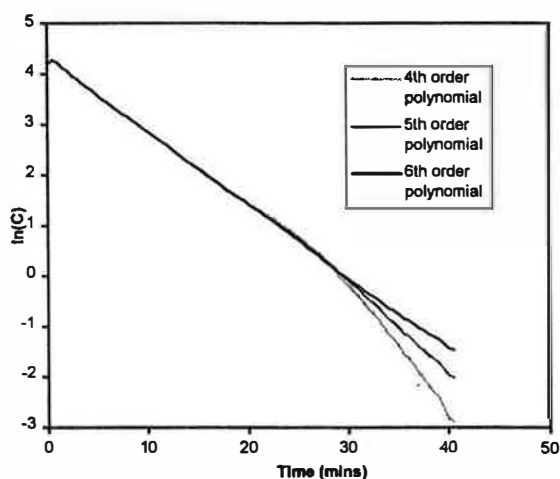


Figure 2 Effect of ploynomial fitted to the calibration data.

decay experiment. Figure 2 shows the effect of the order of the polynomial on the measured decay. Whilst the 6th order polynomial gives a single straight-line fit, the lower orders produce a distinct and sudden change in the gradient of the line at low values of the concentration i.e. a "dog leg".

ii) Calibration accuracy: Two effects were investigated; firstly a reduction in the number of calibration points. Using the same set of calibration points as in i) but with every other value was omitted, a 6th order polynomial was fitted to the remaining

i) Fit to the calibration data: A Miran 1A gas analyser was calibrated for SF_6 using a closed loop system for 13 concentrations up to approximately 80 ppm. Using the least squares method, polynomials of the 4th, 5th and 6th order were fitted to the data. The equation for each fit was then applied to the absorbance recorded during a concentration

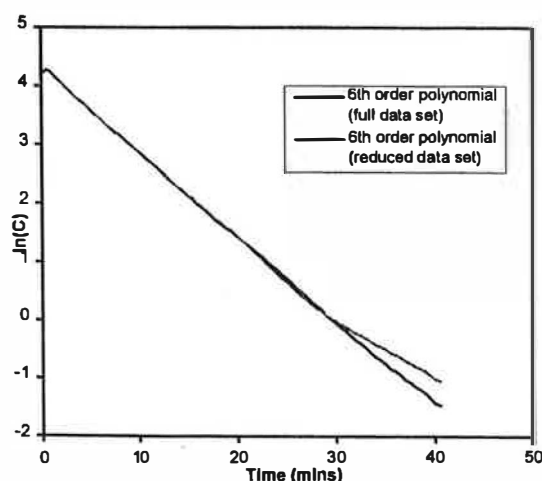


Figure 3 Effect of reducing the number of calibration points

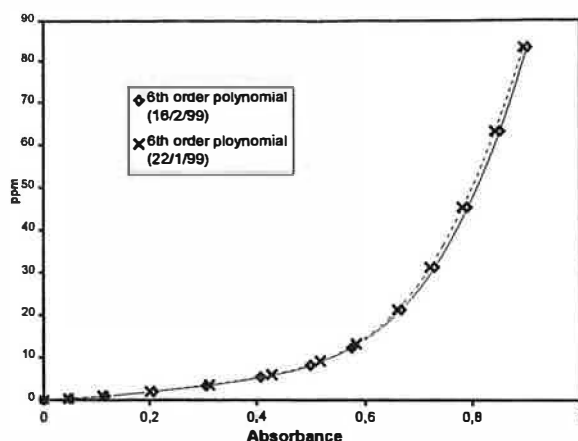


Figure 4 Miran calibrations

with 6th order polynomials. Although the calibration curves look identical at concentrations less than 10 ppm and diverge at higher values, it can be seen from Figure 5 that the decay curve are effectively the same at the high concentrations whilst at low concentrations the decay from the older calibration departs from linear.

iii) Zero drift: A series of experiments were carried out on the simultaneous build-up and subsequent decay of acetone vapour and sulphur hexafluoride (SF₆) inside a ventilated test cabin. The sampled air was passed through two analysers, each of which had been calibrated to measure one component. The log/linear plot of the SF₆ data gave a straight-line decay whilst that of acetone gave a curve [see Figure 6]. The zero of the acetone analyser was found to have drifted upwards during the course of the test. A correction for the drift was applied to the data and the results replotted. Both sets of data now lie on straight lines.

7 values. The resulting formula was used to reprocess the decay data in i). Figure 3 shows the decay with both calibrations and again a distinct, sudden change of gradient is apparent. Secondly, the effect of a slight change in the calibration is shown which could result from disturbing the instrument settings. Figure 4 shows two calibrations which were carried at an interval of 3½ weeks and each fitted

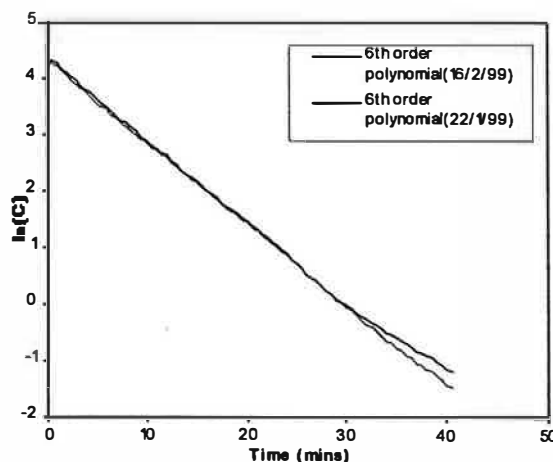


Figure 5 Data processed using calibrations from different dates.

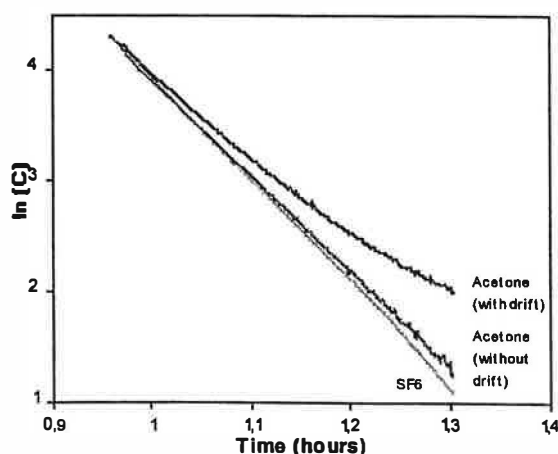


Figure 6 Effect of zero drift

Conclusion

Although the non-exponentiality of the log/linear plot of tracer gas concentration decay may be due to a real variation in the air change rate, this has not been found to be the most likely cause. The accuracy of the instrument calibration, especially at low values of the tracer concentration, is a likely cause of a sudden change in the gradient. It may be advisable to restrict the range over which the decay is measured. Particular care should be taken with instruments that are pre-calibrated or where a library of

calibrations is available. Where zero drift occurs there will be a continuous change in the gradient of the decay curve.

References

1. MDHS 73, Measurement of air change rates in factories and offices, HMSO, London, ISBN 0-11-885693-6, 1992.
2. Charlesworth PS, Air exchange rate and airtightness measurement techniques – an applications guide. Air Infiltration and Ventilation Centre, Coventry, document no. AIC-AG-2-88, ISBN 0 946075 38 7, August 1988.
3. Kalliokoski P, Niemela R, Salmivaara J. The tracer gas technique – a useful tool for industrial hygiene. Scand J Work Environ Health 1980; 6:123–130.