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**Quantification of
Sewage Odours**

C. C. L. KOE and

D. K. BRADY

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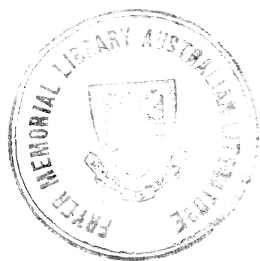
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Department of Civil Engineering,
University of Queensland,
St Lucia, Q 4067, Australia,
[Tel:(07) 377-3342, Telex:UNIVQLD AA40315]

QUANTIFICATION OF SEWAGE ODOURS

by

C.C.L. Koe, BE(hons), MSc (*Sing*), PhD (*Q'ld*), AMASCE, Grad.IES
Lecturer in Civil Engineering, National University of Singapore

and

D.K. Brady, BE (*Auck*), MS, PhD (*Johns H.*), MIEAust, MASCE
Senior Lecturer in Civil Engineering

RESEARCH REPORT NO. CE 40

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Synopsis

It is possible for mixtures of gases to be less odorous than any of their constituents. Because machines cannot replicate this masking phenomenon, odour quantification requires a reliable human nose. An olfactometer measures the amount of dilution with de-odourised air needed to render an odorous sample barely detectable. Because odour sensitivity varies enormously between individuals, each observer must be calibrated with reference to a standard, for which the population's mean sensitivity is now proposed.

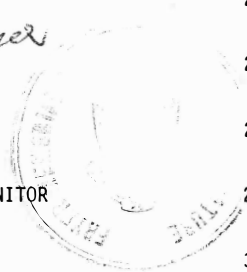
Hydrogen sulphide is a common constituent of sewage air, but until now its correlation with sewage odour has proved somewhat elusive. Research on real sewage odours at two sites has now demonstrated that such correlations are quantifiable. These correlations reveal that the H₂S in sewage air is naturally odour-masked. Such masking of odours from toxic gases is considered dangerous in certain circumstances.

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1. INTRODUCTION

Growing public concern about odours near wastewater facilities has given rise to substantial scientific research in this area, especially in the last decade. Sewerage authorities have adopted various techniques for odour control (e.g. 6, 7, 9, 15), but as yet there are no standard methods by which the effectiveness of these techniques can be quantified.

Many recent researchers have contributed to the identification of odorous compounds commonly present in sewer atmospheres (e.g. 1, 2, 7, 13, 14,15). Without exception, they include hydrogen sulphide (H_2S) among the major odorous constituents, and in some cases (e.g. 2, 14) a dominant role of H_2S has been acknowledged. However, no quantitative relationship between sewage odour and gaseous H_2S concentration has yet been established.

The pioneering paper by Fair and Moore (5) (on development of their osmoscope for quantifying odours derived from samples of sewage) called for "more precise means of measurement and expression" in this area. Most subsequent research into odour assessment technology has been conducted in the food and perfume industries. In the last few years, high quality dynamic olfactometers have become commercially available. These devices, based on the principle of continuous dilution-to-threshold of odorous air with odour-free air (see Appendix D) take advantage of inert materials to avoid certain inadequacies of earlier models. Applications of this new technology to quantify odours from wastewater facilities are just emerging (e.g. 4, 7, 10, 11, 13).

An interesting recent development aimed at identifying major sources of odour within a wastewater plant has involved sampling and mapping the spatial distribution of gaseous H_2S around the plant site (11). Implicit in this approach is the presumption that sewage odours are quantifiable in terms of H_2S concentrations. A primary objective of this report is to justify that presumption. A secondary objective is to answer the call by Fair and Moore (op. cit.) for an improved system for expressing odour concentrations and source strengths.

2. ODOUR CONCENTRATION UNITS

For any observer, the apparent concentration of odour in an air sample is reflected by the number of dilutions (with odour-free air) needed to render the odour barely detectable. In a continuously diluted system, if Q_o (m^3/s) is the flowrate of odorous sample, and Q_f (m^3/s) is the dilutant flowrate, then the apparent odour concentration is:

$$C_a = (Q_o + Q_f)/Q_o \quad (1)$$

Although this appears dimensionless, it is convenient to view C_a as if it were expressed in apparent odour units per unit volume (au/m^3), because this will enable odour sources to be quantified in terms of emission rates expressed in odour units per unit time. For sources involving odours derived from unidentified substances, or from odorous mixtures, no other basis for such quantification currently exists.

A standard odour unit (sou) is now defined as the amount of odorous substance which, when diluted in a unit volume ($1 m^3$) of odour-free air, achieves the normal threshold odour concentration TOC_n (of that substance), i.e. becomes barely detectable by a "normal"

observer. A normal observer is one whose sensitivity to this odorant is equal to the mean value for the whole population. This central measure is chosen as the "standard" for odour sensitivity, partly because of its inherent stability (compared with panels of observers with differently superior sensitivities), and partly because it is desirable that environmental engineers should be able to take into account the odour sensitivities of "ordinary" people who live near wastewater facilities. The standard odour unit retains its usefulness whether the substance(s) causing the odour can be identified or not, because the numerical value of TOC_n is unimportant in the definition.

If PHI_n represents the factor by which a particular observer's odour sensitivity is superior to that of a normal observer, then the standard odour concentration corresponding to Equation (1) is:

$$C_s = C_a / PHI_n \quad (\text{sou/m}^3) \quad (2)$$

Observers with relatively dull senses of smell will have PHI_n values less than unity. By employing odour observers with superior olfactory senses (e.g. $PHI_n = 5$), very weak odours with concentrations down to about 0.2 sou/m^3 are theoretically quantifiable. (Note: C_a cannot be less than unity.)

For certain identifiable odorous gases that are available in pure form at known concentrations in odour-free air, results of TOC tests are available (e.g. 15). These are generally reported in units of parts per billion (ppb) (by volume). Authorities responsible for these TOC determinations tend to select observers with superior senses of smell, but no measure of their superiority above normal (say PHI_n^*) is reported. It is considered likely that PHI_n^* values for such observers would probably exceed 5 (see Section 6), so one might expect

that normal TOC_n values would exceed published TOC values by at least this factor, i.e.

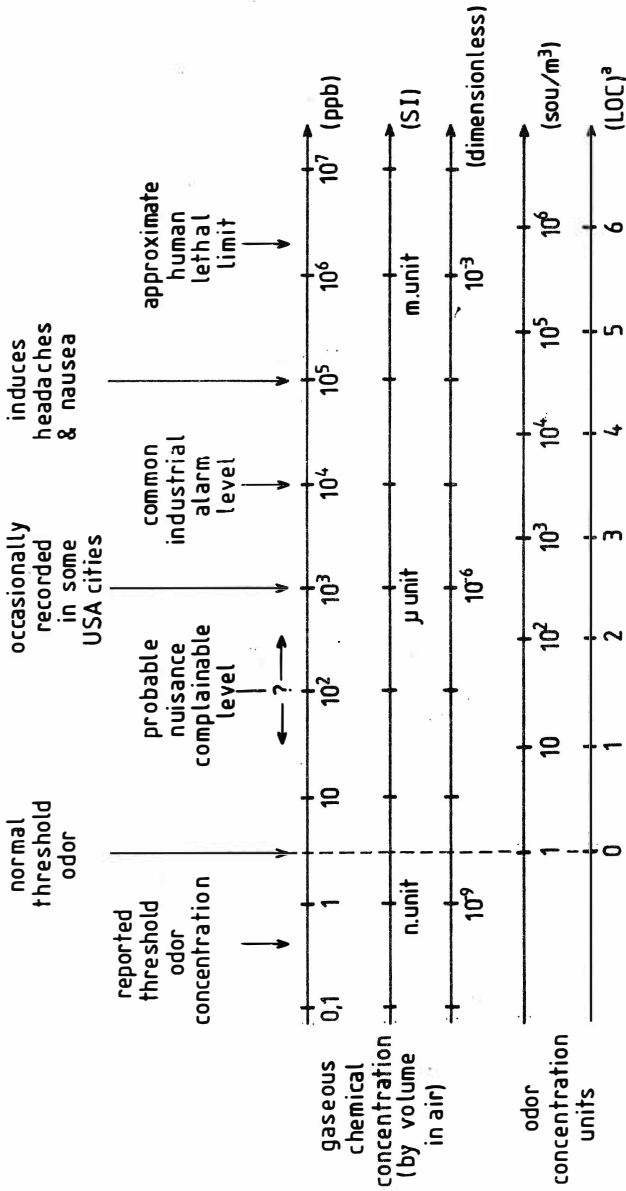
$$\text{TOC}_n = \text{TOC} \cdot \text{PHI}_n^* \quad (\text{ppm}) \quad (3)$$

For example, the commonly reported TOC for H_2S is about 0.5 ppb (15). If this value has been based on measurements using observers with $\text{PHI}_n^* = 5$ (say), then Equation (3) indicates that TOC_n for H_2S is about 2.5 ppb. This is about six orders of magnitude less concentrated than the value of 2000 ppm which is considered to be the lethal limit of H_2S concentration for humans (see Figure 1), which indicates that the range of human odour detectability is very broad.

Fig. 1 shows how the newly defined units for odour concentration (sou/m^3) relate to the chemical concentration of H_2S (acting alone). When the H_2S concentration approaches the human lethal limit, numerical values of odour concentrations tend to become inconveniently large (hundreds of thousands of sou/m^3). Under these circumstances, an alternative scale of logarithmic odour concentration units may be used, in which $\text{LOC} = \log_{10} [\text{sou}/\text{m}^3]$. When $\text{LOC} = 0$, the odour is barely detectable by a normal observer, whereas fatal concentrations would be represented by $\text{LOC} = 6$ or thereabouts. (This alternative scale is analogous to the scale of bels and decibels in the quantification of sound and noise.)

If a particular odorous gas, e.g. H_2S , is diluted with odour-free air to a concentration of X (units ppb or ppm), where $X > \text{TOC}_n$, then the standard odour concentration of this air mixture is:

$$C_s = X/\text{TOC}_n \quad (4)$$



^a LOC = log-odour concentration units, ie log₁₀ (sou/m³)

Figure 1 : Comparative scales for gaseous concentration and odour concentration of pure H₂S

where both X and TOC_n are expressed in the same units (ppb or ppm). Like Equation (1), Equation (4) appears dimensionless, but C_s should be regarded as having units of sou/m^3 . To clarify this point, it is convenient to define the specific odour potential of an odorant, S_o , as the standard odour concentration (sou/m^3) that would be expected to arise from each unit (ppm) of its chemical (gaseous) concentration. Thus:

$$S_o = C_s/X \quad (\text{sou m}^{-3} \text{ ppm}^{-1}) \quad (5)$$

where X must be expressed in ppm units, in this case.

Comparison of Equations (4) and (5) indicates that S_o and TOC_n are simply reciprocal. i.e.

$$S_o = 1/\text{TOC}_n \quad (\text{sou m}^{-3} \text{ ppm}^{-1}) \quad (6)$$

where TOC_n must be expressed in ppm units, for this purpose. Thus, the units of S_o are now clarified so that:

$$C_s = X.S_o \quad (\text{sou}/\text{m}^3) \quad (7)$$

3. EXPECTED DOMINANCE OF SEWAGE ODOUR BY H_2S

If it were assumed (later to be proved invalid, see Section 7) that the expected concentration of odour in a typical sample of sewer air could be predicted by summing the contributions of each of its known major odorous constituents (as if each acted independently, i.e. without interactions), such a prediction would be exemplified in Table 1. This table indicates that, if the assumption were correct, the

TABLE 1. - Anticipated Independent Odour Concentrations of Prominent Odorants in Sewer Air

Prominent sewer air odorant	Typical gaseous concentration ^a X (ppb) (2)	Typical reported threshold ^b TOC (ppb) (3)	Deducted normal threshold ^c TOC _n (ppb) (4)	Specific odour potential ^d S _o (sou m ⁻³ ppm ⁻¹) (5)	Anticipated odour contribution ^e C _s (sou/m ³) (6)
Hydrogen sulphide	1000	0.5	2.5	400.	400.
Ethyl mercaptan	20	0.2	1.0	1000.	20.
Skatole	50	1.	5.	200.	10.
Dimethyl sulphide	20	1.	5.	200.	4.
Methyl mercaptan	20	1.	5.	200.	4.
Aldehydes	30	6.	30.	30.	0.9
Ammonia	100	40.	200.	5.	0.5
Methylamine	20	20.	100.	10.	0.2
Dimethylamine	20	50.	250.	4.	0.1
TOTAL (assuming independent contributions summable)					440.

- a Reference 14
- b Reference 15. Rounded values used. Extra precision unwarranted.
- c Estimated using Equation (3), assuming PHIn* = 5.
- d Using Equation (6), incorporating conversion from ppb to ppm units.
- e Col.(6) = Col.(2) x Col.(5)/1000, from Equation (7).

total odour concentration in sewage air could be anticipated to be about 440 sou/m^3 (i.e. requiring about 440 dilutions to be just detectable by a normal observer).

Of this total, the dominant odour contribution (about 92%) ought to come from H_2S (despite ethyl mercaptan being a stronger odorant) mainly because the typical chemical concentration of H_2S in sewage air is relatively high. This observation suggests that a search for possible correlations between odour concentrations and H_2S concentrations in sewage air ought to be fruitful.

4. SIMULTANEOUS FIELD TESTS OF SEWAGE ODOUR AND H_2S

With the objective of quantifying correlations between odour and H_2S concentrations in sewage atmospheres, an extensive program of field tests was carried out during 1977 in the City of Ipswich, Queensland. This program involved simultaneous tests of both parameters over a wide range of each.

Observations of sewage odour were made with a dynamic olfactometer described in Appendix D, using the procedure outlined in Appendix E. Since two persons were required to operate the olfactometer, it was convenient to interchange their roles periodically, and thereby achieve two pools of results (pertaining to observers denoted A and B, the authors of this report). The time taken to complete each odour observation was generally about 1 minute, with an additional period of 1 minute between observations (for odour-free refreshment of the observer). Variability among successive observations was smoothed by grouping all results in independent sets of three, and reporting only their triplet mean values (each point

representing a time-average over an interval of approximately 5 minutes).

Measurements of H_2S concentration were made with a gaseous H_2S monitor described in Appendix C. The analog output from this device was presented simultaneously (a) on the monitor's built-in dial gauge, where a linear scale spans the working range from zero to 20 ppm, and (b) on a simple chart-recorder, so that readings could be rechecked after each survey session. Because the response of the monitor's optical system is delayed by 3 minutes from the time of exposure (see Appendix C), it was important to account for this delay when establishing synchronous results for odour and H_2S concentration (especially when sampled H_2S levels varied markedly with time). After correcting for this time-offset, the H_2S reading corresponding to the central odour observation (of each triplet) was assumed to be already time-averaged (over a similar period to the odour triplet value) due to the H_2S monitor's in-built scanning system (see Appendix C).

In order to ensure that the maximum range of the H_2S monitor would be fully exploited in this field program, preliminary surveys were conducted to identify suitable sampling locations in existing sewerage systems where natural H_2S concentrations reached as high as 20 ppm fairly often. These preliminary surveys involved leaving the monitor operating with its recorder unattended at each location for several days at a time. For reasons involving both availability of power supply and security from vandalism, sampling locations were generally restricted to two categories:- (i) sewage pumpstations, and (ii) wastewater plant intakes. Eventually, two locations were selected, one in each category.

The first selected sampling location (Site 1) was the air-space within an enclosed intake structure at a wastewater treatment plant receiving approximately 2.3 ML/d of predominantly domestic sewage via several pump rising mains. Site 2 was the air-space within the wet-well of a sewage pumpstation handling an average daily flow of about 4.2 ML/d (of which about 10% was industrial wastewater derived mainly from a poultry abattoir).

5. COMPARISON OF ODOUR SENSITIVITIES OF TWO OBSERVERS

Throughout the field program of simultaneous sewage odour/H₂S tests at Sites 1 and 2, it was noted that observer A exhibited significantly greater sensitivity (to sewage odour) than observer B. Independently of whether odours were strong or weak, the dilution flowrate needed to achieve Observer A's threshold was generally about 3 times greater than that for Observer B. This indicated that the two observers' sensitivities were probably related by a constant ratio, PHI_{ab} , which would need to be quantified before their results could be pooled.

On many occasions during the field program, H₂S concentrations were observed to remain fairly steady before and after exchanges of roles between A and B in operating the olfactometer. These "quasi-steady" occasions offered reasonable opportunities to assume that proximate pairs of A-B odour readings (separated by only a few minutes in every case) could be used to quantify PHI_{ab} . This assumption was necessary because (a) sewage air is not conveniently available in standard pressurised containers for more precise tests, and (b) odour sensitivity is known to be odorant-specific (see Appendix E) which precludes using, say, standard H₂S instead of sewage air for this purpose.

A total of 18 such steady occasions yielded the results depicted in Figure 2, spanning a wide range of H_2S concentrations between 0.1 ppm and 19.1 ppm. Although the observed ratios of odour sensitivity also varied widely (between 1.3 and 9.8), no correlation between sensitivity and H_2S concentration is evident. It was decided to adopt the geometric mean sensitivity ratio ($\text{PHI}_{ab} = 2.82$), because the way in which olfactometer dilutions are contrived encourages a logarithmic approach to odour quantification (i.e. errors being large when values are large, but not when values are small).

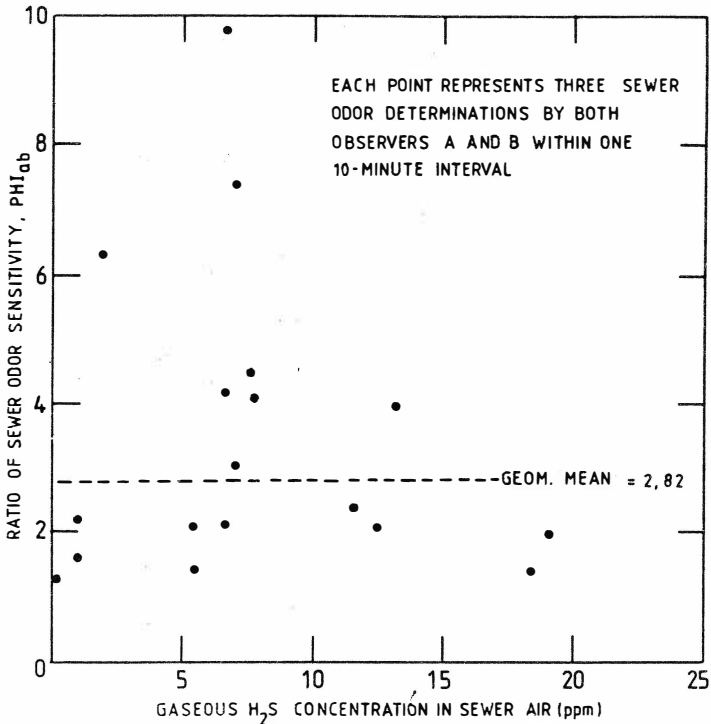


Figure 2 : Apparent superiority of observer A (over B) in odour sensitivity tests on sewer atmospheres

6. CALIBRATION OF ODOUR SENSITIVITY OF ONE OBSERVER

In order to present results of sewage odour determinations in absolute terms, using standard units defined in Section 1, it was first necessary to establish the odour sensitivity of one of these researchers (say A) with reference to the mean odour sensitivity of the general population. Given that sensitivity is odour-specific, this should have required that large numbers of people (sampled randomly) should be subjected to the same kind of comparative tests on sewage odours as those just described for Observers A and B. For various reasons, this has not yet proved practicable, so the procedure described in the following three paragraphs was adopted instead.

In view of the anticipated dominance of H_2S in determining sewage odour concentration, it was assumed (for this section only) that an observer's sensitivity to gaseous H_2S is not markedly different from his/her sensitivity to sewage odour. A sample of 21 people (including Observer A), representing (i) both sexes, and (ii) a wide range of ages (between 18 and 55), was given TOC tests (3 each) using standard 10 ppm commercial H_2S during a 2-hour interval on a typical workday morning. A larger sample would have been preferred, but the possibility of temporal variations in sensitivity (see Appendix E) required the testing period to be sufficiently short to ensure that variability among individuals was not confounded with variability due to time of day (and only one dynamic olfactometer was available for testing).

A frequency analysis of the results is presented in Figure 3.

It is evident that:

- (a) H_2S odour sensitivities are approximately lognormally distributed,
- (b) the geometric mean TOC_n for H_2S is apparently about 6.6 ppb, whereas the reported TOC value (probably established by a panel of "super-noses") is only about 0.5 ppb (see Table 1),
- (c) the standard deviation of logarithms (base 10) of TOC values is about 0.5 (corresponding to a sensitivity ratio of about 3), and
- (d) Observer A is more sensitive to H_2S than a "normal" observer by a factor of about $PHI_{an} = 3.1$.

Item (c) is quite remarkable. It indicates that variability of odour sensitivity among individuals is so high that, in a typical sample of only about two dozen persons, the best sense of smell is likely to be nearly 100 times more sensitive than the worst. Certain odours that are quite offensive to some residents in a community may be quite imperceptible to others in the same neighbourhood.

The procedure for standardizing an odour determination by Observer A was then as follows. Apparent odour concentrations, C_a (aou/m³), were calculated from olfactometer dilution flowrates (Equation (1)). These were converted to standard odour concentrations, C_s (sou/m³), by dividing by Observer A's odour sensitivity factor ($PHI_{an} = 3.1$). (Values of C_a recorded by Observer B were converted into equivalent apparent concentrations for Observer A by multiplying by the value of PHI_{ab} (= 2.8 approx.) deduced in Section 4. These were then treated as if they had been A's observations.)

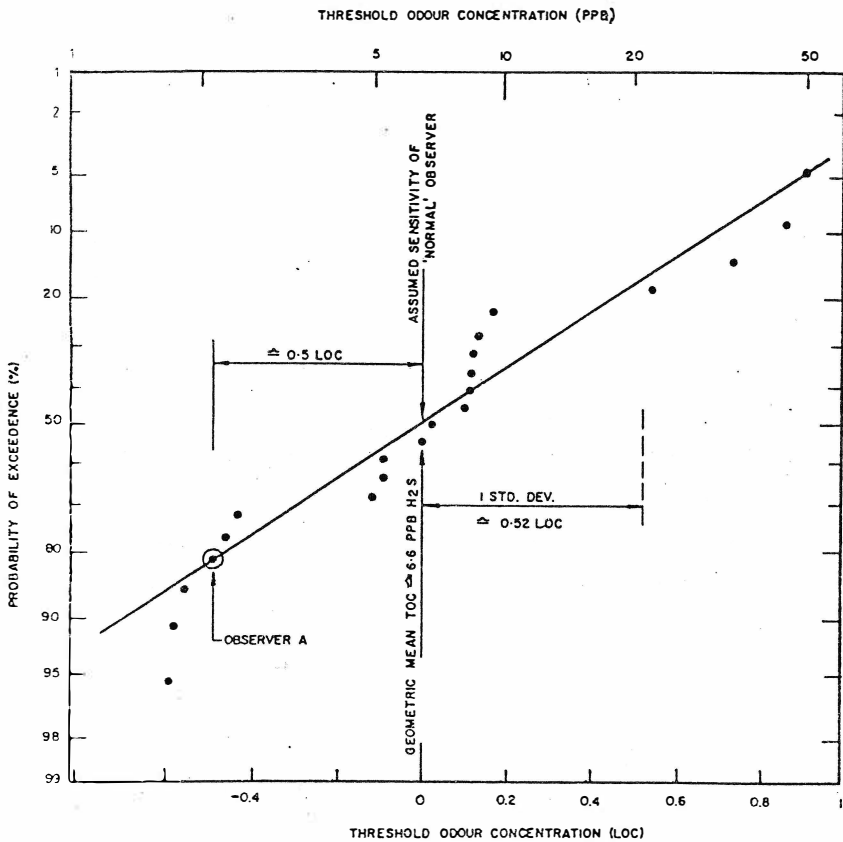


Figure 3 : Demonstration of variability of odour sensitivity among general public

7. RESULTS OF SIMULTANEOUS SEWAGE ODOUR/H₂S TESTS

Using the procedures outlined in Section 4, a total of 136 synchronous data pairs were obtained relating sewage odour to gaseous H₂S concentration. These were distributed between Sites 1 and 2, and between Observers A and B, as follows:

	Observer A	Observer B	Total
Site 1 (wwtp intake)	10	11	21
Site 2 (pumpstation)	81	34	115
	<u>91</u>	<u>45</u>	<u>136</u>

After standardising the odour concentrations as indicated in Section 5, these data were merged and plotted on a single semi-log graph of C_s (log scale) versus H₂S (linear scale) as shown in Figure

4. Despite considerable scatter of the results, it is evident that:

- when H₂S concentrations are relatively high (>10 ppm), sewage odour concentrations are also relatively high,
- when H₂S values are relatively low (<5 ppm), odours tend to be about one order of magnitude less concentrated than for high H₂S values, and
- for any particular H₂S value, odours at Site 2 (the pumpstation wetwell, receiving 10% industrial wastes) are generally slightly higher than those at Site 1 (the wwtp intake, receiving wholly domestic sewage).

Plotting these results in 4 separate categories, in order to identify potential differences between Observers A and B and between Sites 1 and 2, Figure 5 is divided into four quadrants, each of which is based on a log-log format with the scales suitably aligned for comparative purposes. The log-log format was chosen to provide the

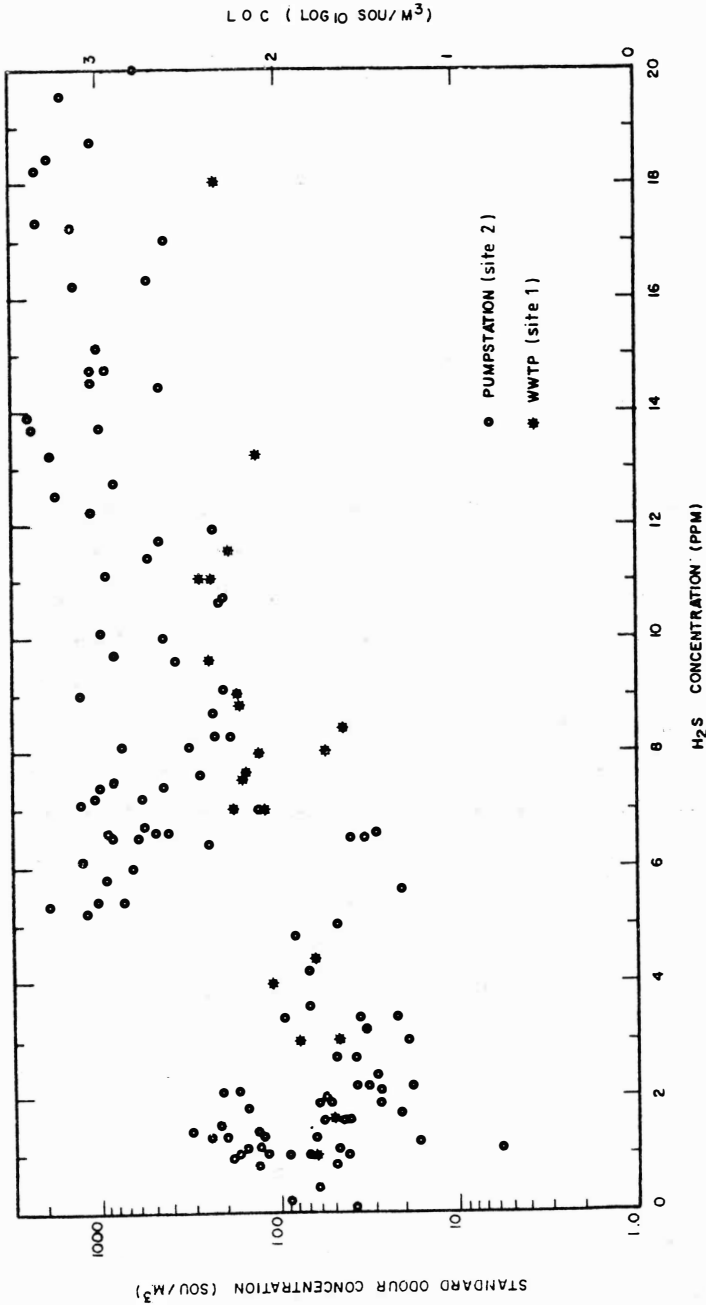


Figure 4 : Superimposed results of sewer odour versus H₂S concentration at two sites

most convincing evidence of correlation between odour and H_2S concentration. Linear regression analyses were performed on the logarithmic data to yield power functions of the form:

$$C_s = m [H_2S]^n \quad (8)$$

Values of m ranged between 51 and 71, and values of n ranged between 0.48 and 1.0. The proportions of variances "explained" by these regression relationships ranged between 60% and 77%. This indicates that, if the gaseous H_2S concentration in sewer air is known, the residual variance of sewage odour concentrations (logarithms) is only about one-third of what it would be if H_2S were unspecified. In view of the variability not only of sewage odours themselves, but also of the effects of weather on their measurement and of observer sensitivities, this set of four significant correlations obtained under field conditions is considered very satisfactory.

It is noteworthy that the form of Equation (8) implicitly assumes that sewage odours must vanish if there is no H_2S present. This property is not clearly evident from the distribution of points in Figure 4. However, linear regression analyses based on the latter figure yield (a) inferior correlation coefficients to those reported above, and (b) relatively small intercept values (i.e. very low odour concentrations at zero H_2S). Confidence intervals for these intercepts did not justify concluding that they were significantly non-zero.

Detailed examination of the distributions presented in Figure 5 indicates that:

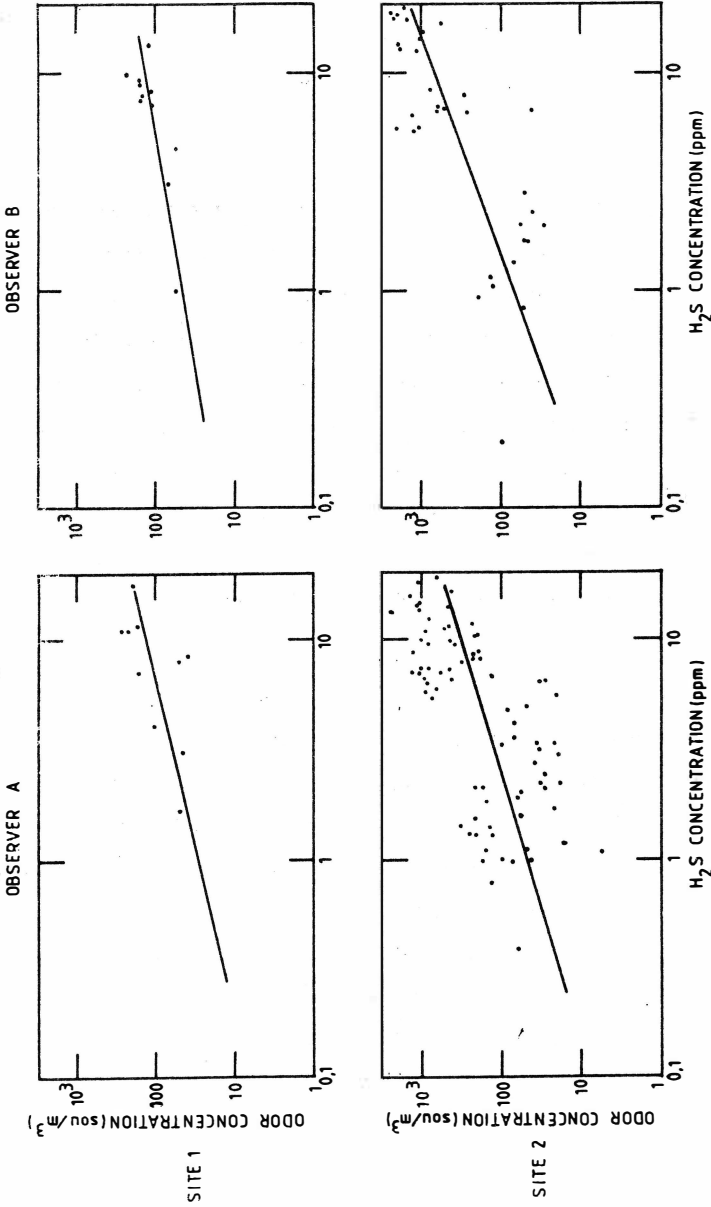


Figure 5 : Correlations between odour concentrations and gaseous H₂S concentrations using two observers at each of two sewer locations

- (i) the two Observers (A and B) yield insignificantly different results (once the odour concentrations have been standardised), and
- (ii) Sites 1 and 2 yield significantly different odour versus H_2S relationships.

It was therefore decided to pool the data into two groups (for Sites 1 for these intercepts did not justify concluding that they were significantly non-zero.

Detailed examination of the distributions presented in Figure 5 indicates that:

- (i) the two Observers (A and B) yield insignificantly different results (once the odour concentrations have been standardised), and
- (ii) Sites 1 and 2 yield significantly different odour versus H_2S relationships.

It was therefore decided to pool the data into two groups (for Sites 1 and 2) for separate analyses.

8. MASKING EFFECT OF OTHER SEWER GASES ON H_2S ODOUR

When the data pertaining to Site 1 for both Observers A and B are merged, the resulting log-log plot is shown in Figure 6. A regression analysis of these data yields the following relationship for Site 1:

$$C_s(\text{sou/m}^3) = 41 \times [H_2S (\text{ppm})]^{0.57} \quad (9)$$

The correlation coefficient for this regression is $r = 0.65$. It is appreciated that, if similar tests were performed at different wastewater plants receiving raw domestic sewage, the values of m and n

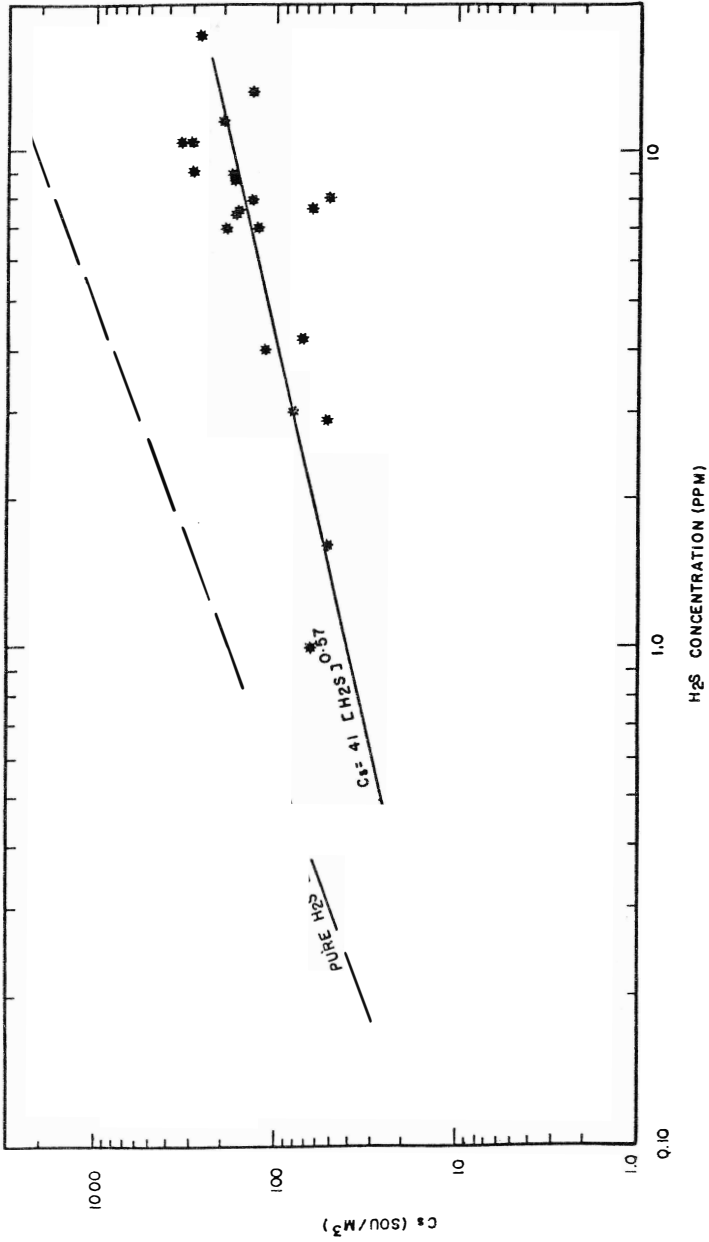


Figure 6 Correlation of H_2S concentration and sewer odour at Site 1, revealing masking phenomenon

would probably differ somewhat from those in Equation (9) on account of various factors, such as population served, sewer flow velocities, length of pump rising mains, extent of sewer ventilation, etc.

It is interesting to consider how Equation (9) would have appeared if no gaseous substances had been present in the sampled sewage air except the observed H_2S . Since the TOC_n for H_2S is apparently about 6.6 ppb (see Figure 3), Equation (6) yields the specific odour potential as $S_o = 150 \text{ sou m}^{-3} \text{ ppm}^{-1}$. Hence, for pure H_2S , Equation (7) yields:

$$C_s (\text{sou/m}^3) = 150 \times [H_2S (\text{ppm})] \quad (10)$$

This relationship is superimposed on Figure (6), and reveals that every odour concentration observed at Site 1 was much less odorous (by a factor of 10, roughly) than if the recorded H_2S had been present by itself. This result indicates that other gaseous substances naturally present in domestic sewage atmospheres must have a strong masking effect on odours attributable to H_2S . Unfortunately, this natural air-freshening effect may have quite dangerous ramifications for persons employed by sewerage authorities who may be required to enter sewers or other wastewater facilities where H_2S levels are high. It is not certain, at this stage, whether this masking phenomenon is caused by odorous or non-odorous substances, but it is natural to anticipate that the effect is probably attributable to interactions with other odorous gases. This matter is certainly worthy of further investigation.

When the procedure outlined above is repeated for the data pertaining to Site 2, the results are similar (see Figure 7). The regression relationship applicable to sewage air at the pumpstation

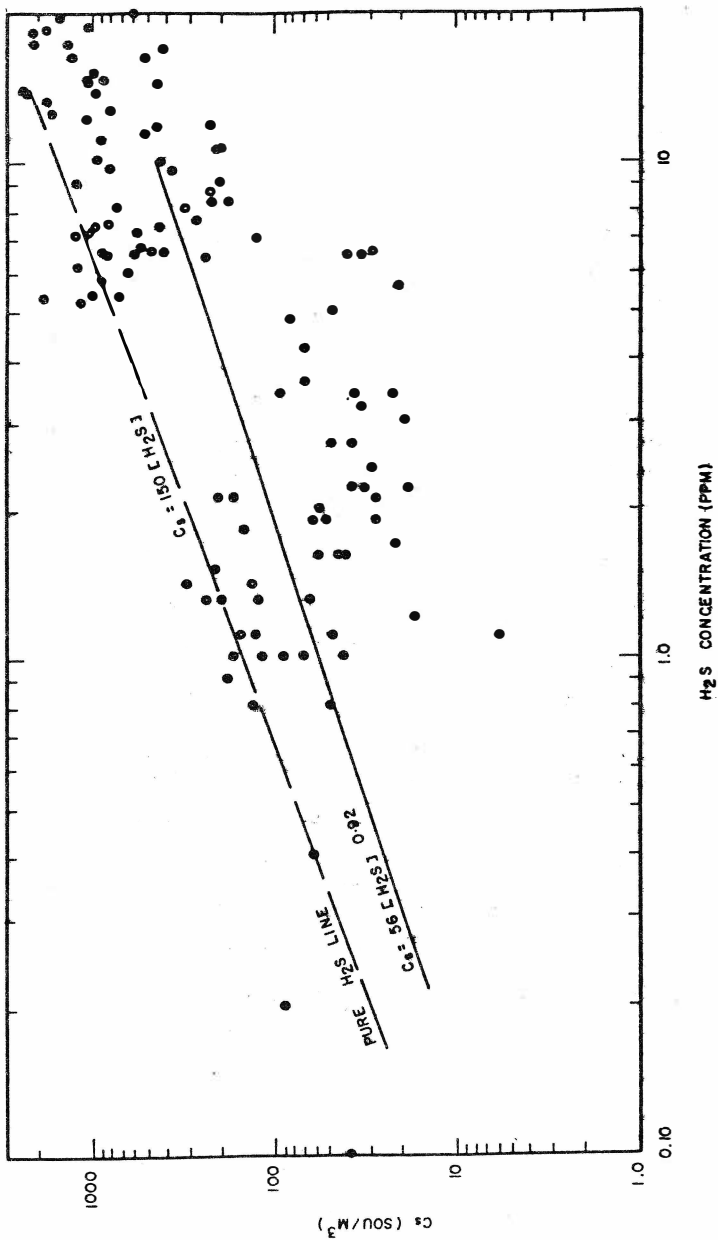


Figure 7 : Correlation of H₂S concentration and sewer odour at Site 2

receiving this mixture of domestic sewage and industrial wastes is:

$$C_s(\text{sou}/\text{m}^3) = 56 \times [\text{H}_2\text{S}(\text{ppm})]^{0.92} \quad (11)$$

In this case, the masking effect is not quite so dramatic (i.e. suppression of pure H_2S odours is evident in only 85% of observations in Figure 7 compared with 100% in Figure 6), nevertheless the effect is still quite convincing. It is conceivable that the presence of unusual volatile substances in the industrial components of the wastewaters at Site 2 may have interfered with, and perhaps weakened, the otherwise strong masking effect of substances in ordinary domestic sewerage air. This possible inhibition of masking should also be investigated further.

9. CONCLUSIONS

From the results presented and discussed above, the following conclusions are drawn:

- (a) Sensitivity to odours is so variable among individuals that, in a random sample as small as 24 persons, the most acute sense of smell is likely to be about 100 times more sensitive than the dullest.
- (b) In order that odour measurements by one observer may be comparable with those of any other, especially when odours are derived from mixed odorants, all odour concentration results should be standardised in relation to some stable, central measure of human odour sensitivity.
- (c) Authorities previously reporting threshold odour concentrations of specific odorants have generally employed panels of observers with unspecified superior odour sensitivities. If

the sensitivities of these observers could be related to those of the population at large, it would enable their work to be extendable to undetectable odour mixtures, and their special capabilities would thus become very useful in a wide range of field situations involving offensive odours in communities.

- (d) It is recommended that odour concentrations should be expressed in terms of standard odour units (sou) per cubic meter, where 1 sou is the amount of odorant which, when diluted in 1 m^3 of odour-free air, is only just detectable by a normal human observer (with average sensitivity to that odorant).
- (e) The range of detectable odour concentrations is so wide that very strong odours may need to be expressed in hundreds of thousands of sou/m^3 . In such cases, logarithmic odour concentration units [$\text{LOC} = \log_{10}(\text{sou}/\text{m}^3)$] may be more convenient.
- (f) For pure gaseous H_2S , the threshold odour concentration pertinent to a normal observer has been investigated by testing a sample of people of various types, and found to be $\text{TOC}_n = 0.0066 \text{ ppm}$. The reciprocal of this TOC_n may be viewed as the specific odour potential of H_2S , i.e. $S_0 = 150 \text{ sou m}^{-3} \text{ ppm}^{-1}$, which represents the standard odour concentration that would be associated with each 1 ppm of gaseous H_2S .
- (g) Although pure air containing about 10 ppm of H_2S would therefore be expected to yield odour concentrations of about $1500 \text{ sou}/\text{m}^3$, tests on sewage air containing about 10 ppm of H_2S derived from domestic sewage have yielded odour concentrations of only about $150 \text{ sou}/\text{m}^3$, indicating a strong masking effect by other gaseous substances in the sewage air. This masking effect is potentially dangerous.

- (h) At a treatment plant intake which received wastewaters that were predominantly domestic sewage, a strong correlation has been observed between standard odour concentrations, C_s (sou/m³) and H₂S concentrations (ppm) of the form $C_s = m[H_2S]^n$, where $m = 41$ and $n = 0.57$.
- (i) At a pumpstation wetwell, where wastewaters were mainly domestic sewage (but included about 10% of mainly poultry wastes), tests reveal a similarly strong correlation, with $m = 56$ and $n = 0.92$.
- (j) Interference effects (including masking effects) among odorous substances in sewage air render it invalid to assume that its overall odour concentration may be calculated by summing the independent contributions of its odorous constituents. The masking phenomenon renders the human sense of smell much more difficult to quantify than the senses of sight and hearing, and it follows that human observers are unlikely to be superseded by machines for quantification of odours.

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APPENDIX A - REFERENCES

1. ANDO, S., "Odor Control of Wastewater Treatment Plants", Journal, Water Pollution Control Federation, Vol. 52, No. 5, 1980, pp 906-913.
2. BAILEY, J.C. and VINEY, N.J., "Gas Chromatographic Investigation of Odours at a Sewage Treatment Works", Water Research Centre, Technical Report TR125, Stevenage, U.K., 1979.
3. DAVIDSON, M.J. and DUFFY, P.M., Neighbourhood Tolerance of Sewage Treatment Plants, B.E. Thesis, Dept of Civil Engineering, Univ. of Queensland, Brisbane, 1976, 77pp.
4. DRAVNIKS, A. and JARBE, F.H., "Odor Threshold Measurement by Dynamic Olfactometry", Proc. 72nd Annual Meeting, Air Poll. Control Assoc., Cincinnati, USA.
5. FAIR, G.M. and MOORE, E.W., "Measurement of Intensity and Concentration of Odors Associated with Sewage Treatment Processes", Sewage Works Journal, Vol. 7, No. 2, 1935, pp 182-199.
6. HENRY, J.G. and GEHR, R., "Odor Control: an Operator's Guide", Journal, Water Pollution Control Federation, Vol. 52, No. 10, 1980, pp 2523-2537.
7. HUANG, J.Y.C., WILSON, G.E. and SCHROEPFER, T.W., "Evaluation of Activated Carbon Adsorption for Sewer Odor Control", Journal, Water Pollution Control Federation, Vol. 51, No. 5, 1979, pp 1054-1062.
8. KEDDIE, A.W.C., "The Quantification of Emissions and Dispersion of Odours from Sewage-Treatment Works", Water Pollution Control, Vol. 81, No. 2, 1982, pp 266-279.
9. MATTHEWS, P.J. and BOON, A.G., "Odour Nuisance in Sewerage and Treatment Systems: Problems and Control", Water Pollution Control, Vol. 77, No. 2, 1978, pp 248-258.

10. MOLTON, P.M. and CASH, D.M.S., "Novel Combination Method Assesses Sewage Odors", Water and Wastes Engineering, Vol. 15, No. 2, 1978, pp 47-52.
11. NORTH, A.A., "Odours at a Sewage Treatment Works", Water Research Centre, Technical Report TR126, Stevenage, U.K., 1979, 15 pp.
12. REINSCH, D.A., PARR-SMITH, G.A. and CORNELL, M.A., "Odour Assessment and Control in Sewage Treatment Works", Proc. 7th Federal Convention, Australian Water and Wastewater Assoc., Canberra, Aust., 1977.
13. Sacramento Area Consultants, Sewage Sludge Management Program: Wastewater Solids Processing and Disposal, Report to Sacramento Regional County Sanitation District, Calif., USA, 1978.
14. THISTLETHWAYTE, D.K.B. and GOLEB, E.E., "The Composition of Sewer Air", Proc. 4th Conf., International Assoc. on Water Pollution Research, 1972, pp 281-288.
15. Water Pollution Control Federation, Odor Control for Wastewater Facilities, Manual No. 22, Washington, D.C., 1979.

APPENDIX B - NOTATION

<u>Symbol</u>	<u>Meaning</u>	<u>Typical Units</u>
aou	apparent odour unit	(dimensionless)
C_a	apparent odour concentration (in air)	(aou/m ³)
C_s	standard odour concentration	(sou/m ³)
H ₂ S	hydrogen sulphide	(-)
[H ₂ S]	concentration of H ₂ S(in air)	(ppm = uL/L)
m	coefficient relating [H ₂ S] to C _s	(sou m ⁻³ ppm ⁻¹)
n	exponent of [H ₂ S] in relation to C _s	(dimensionless)
PHI	odour sensitivity ratio (=)	(dimensionless)
PHI _{ab}	sensitivity of A relative to B	(dimensionless)
PHI _{an}	sensitivity of A relative to normal	(dimensionless)
PHI _n	sensitivity of observer relative to normal	(dimensionless)
PHI _*	sensitivity of experts relative to normal	(dimensionless)
ppb	parts per billion (by volume) = nL/L	(dimensionless)
ppm	parts per million (by volume) = uL/L	(dimensionless)
Q _f	Flowrate of odour-free dilutant air	(m ³ /s)
Q _o	flowrate of odorous sample	(m ³ /s)
r	coefficient of statistical correlation	(dimensionless)
sou	standard odour unit	(dimensionless)
S _o	specific odour potential of odorant	(sou m ⁻³ ppm ⁻¹)
TOC	threshold odour concentration	(ppm = uL/L)
TOC _n	TOC for normal observer	(ppm = uL/L)
uL	microlitre = 10 ⁻⁶ litre	(-)
X	concentration of odorous substance (in air)	(ppm = uL/L)

APPENDIX C - GASEOUS HYDROGEN SULPHIDE MONITOR

For measuring gaseous hydrogen sulphide (H_2S) concentrations in sewer atmospheres, an instrument manufactured by Universal Environmental Instruments (U.K.) was used. Model 7010, costing about 2k\$ in 1979, measures the intensity of light (emitted by a fibre-optic source) that is reflected from the surface of a paper ribbon impregnated with lead acetate.

An electrically-operated vacuum pump within the instrument samples sewer air at 2.5 mL/s and draws it through an H-shaped aperture (see Figure 8). The acetate ribbon, supplied in a presealed cassette, is moved slowly past this aperture via a friction-drive capstan at a steady rate of 10 cm/h. The cross-bar of the H-shaped aperture is set perpendicular to the direction of ribbon motion. Because this cross-bar is 1.5 mm wide, a sudden spike of sampled H_2S would cause darkening over a length of ribbon representing a time duration of about 0.9 minutes. Thus, the ribbon image is time-averaged over a (moving) 1-minute interval.

Scanning of the darkened ribbon by the instrument's optical densitometer takes place about 5 mm (i.e. 3.0 minutes) "downstream" of the exposure aperture. Because a dual scanning system is used, by which the darkened reflection is compared with a simultaneous reflection from unexposed ribbon, errors caused by variations in paper texture are eliminated. The scanning window measures 4 mm x 4 mm, so the degree of darkening becomes further time-averaged over a moving interval of 2.4 minutes.

In summary, when used for continuous monitoring as described here, and when incoming H_2S concentrations are fluctuating, the

instrument's response is:

- (a) attenuated, due to time-averaging, over a total interval of 3.3 minutes, and
- (b) delayed by a total period of 3.0 minutes, due to slow transport of the ribbon between its exposure and scanning positions.

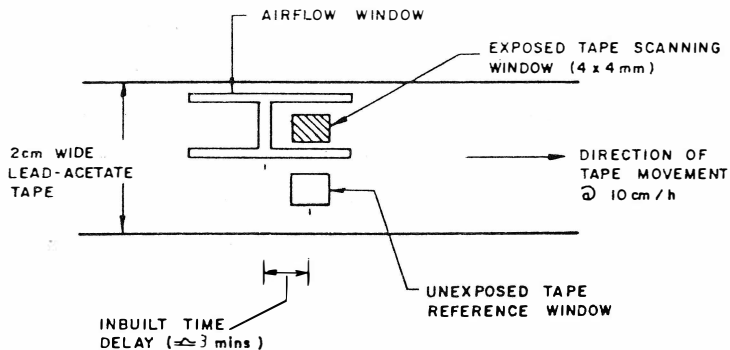


Figure 8 : Geometry of air-sampling aperture and optical scanning windows of H₂S monitor

APPENDIX D - DYNAMIC OLFACTOMETER

To permit regular and frequent observations of odour concentrations in sewage atmospheres, a dynamic olfactometer manufactured by Sierra-Misco of Berkeley (Calif.) was used. A 12-volt battery-powered version of Model 7250, costing about 5k\$ in 1979, pumps a continuously flowing mixture of (a) odorous sample and (b) de-odorised air (at a mixed flowrate of about 12 L/min) to a face-mask worn by an observer. The degree of dilution of the mixture is adjusted until the odour becomes "just detectable". Normally an assistant is required for this adjustment, because repeated tests have indicated that results become biased if the observer knows the control settings as his/her odour threshold is being approached.

When sampled odours are relatively weak (see Figure 9, Mode 1), a single-stage dilution process is employed, whereby a small stream of odorous sample is diluted by a larger flow (up to 1200 times greater) of air that has been de-odorised in a column of activated carbon. By adjusting needle control valves and observing rates of flow through tapered-glass suspended-ball flowmeters, the dilution ratio needed to reach the observer's odour threshold may be calculated. However, the range of human odour sensitivity is so wide that, when sampled odours are relatively strong, this single-stage process is inadequate to reach the observer's threshold. Under these circumstances, the olfactometer is modified to achieve a two-stage dilution, by which the output of the first stage is further diluted with odour-free air to achieve the desired objective (see Figure 9, Mode 2). By this means, dilution ratios up to 300,000 are possible, but extra care must be taken to ensure that the de-odorising columns do not become prematurely exhausted when operating in this mode.

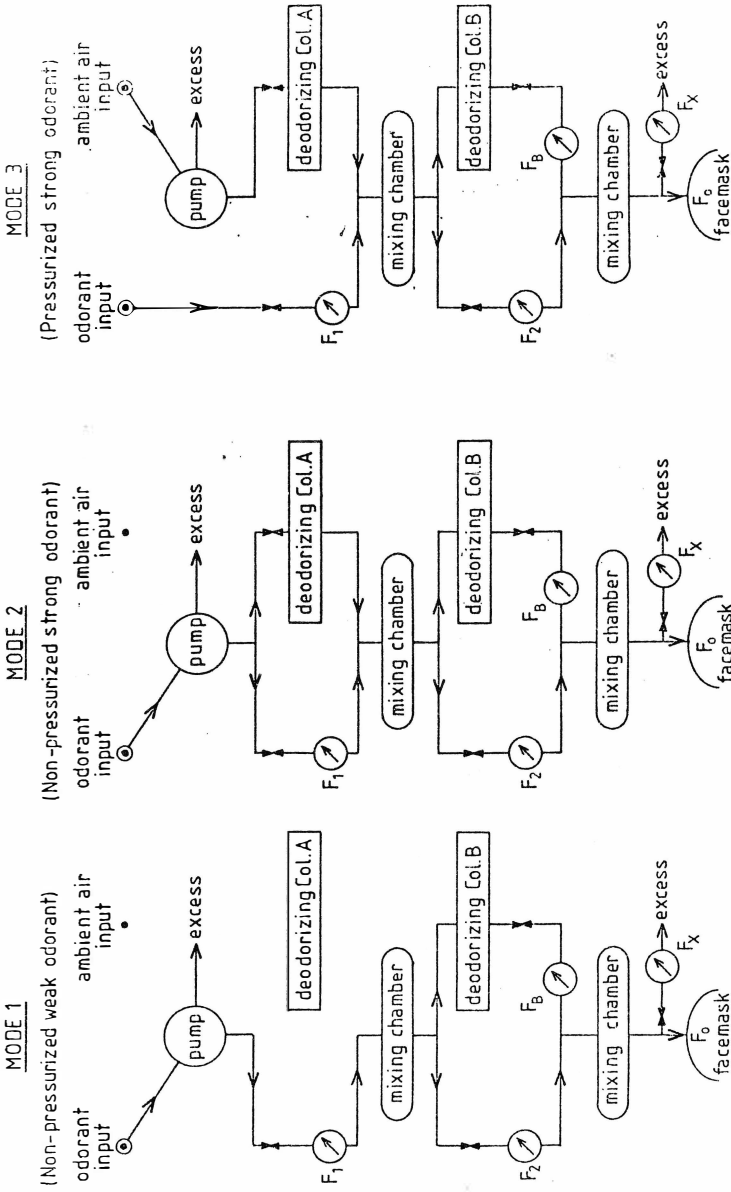


Figure 9 : Flow charts depicting alternative operating modes for dynamic olfactometer

If a specific odorous gas is being studied (e.g. H_2S) that is commercially available at known concentrations in pressurised containers, the dynamic olfactometer may be further modified to enable an observer's threshold odour concentration to be calibrated (for that gas). Because the olfactometer's pump is not needed to pressurise the odorant in this case, the pump is used to supply ambient air to the de-odorising columns (see Figure 9, Mode 3), thereby greatly prolonging their life.

Although the diluted odorous mixture is supplied to the facemask continuously, it is not possible to make threshold observations faster than once every 1 or 2 minutes, on account of the time needed (a) to refresh the observer with pure de-odorised air after each observation, and (b) to gradually increase the odorant concentration until the observer indicates that odour has just become detectable (see Appendix E).

APPENDIX E - CALIBRATION OF HUMAN OLFACTORY SENSITIVITY

Human olfactory sensitivity varies markedly among individuals (see Section 6). For a particular person, odour sensitivity depends on the nature of the odorant; some people even exhibit allergic reactions to specific odours.

For a particular odorant, a person's threshold odour concentration (TOC) may vary with time, being dependent on such factors as age, health, general fatigue, odour acclimation, degree of alertness, and both seasonal and hourly effects of atmospheric pollution. In attempting to calibrate an observer's sensitivity to a particular odour, it is important that variable effects of these factors should be minimised. Observers must be healthy, alert, and currently unencumbered by allergic reactions to airborne pollens. Their testing on any one day (or group of days) must not induce fatigue, and each individual test must guard against acclimation effects.

The logical procedure by which acclimation effects may be avoided is:

- (a) to refresh the observer with odour-free air for a suitable period (e.g. 1 minute), then
- (b) to increase the odorant concentration steadily (i.e. ramp dose) until the observer's threshold concentration for that particular odour is reached. If the "ramp slope" is too steep, the observer's detection signal may become delayed (due either to uncertainty, or to unlucky timing of breaths), and the resulting TOC value will be erroneously over-estimated. However, if the ramp is too flat (i.e. the observer is held for significant periods at sub-threshold odorant concentrations),

not only might undetectable acclimation effects occur, but also the duration of each test will be needlessly prolonged. For the olfactometer described in Appendix D, a satisfactory compromise between these extremes is apparently achieved if the odorant concentration is roughly doubled every 3 breaths of the observer.

In prolonged test sessions involving a single observer and a particular odorant, effects of fatigue were never observed within 2 hours, but were often noted after 3 hours of repetitive testing.

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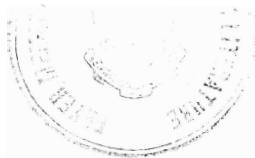
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