# Empirical prediction on sulphide generation in Malaysian sewage

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*Abstract*—The course of sulphide degradation and production via simulated sewer conditions was observed. Sulphide concentrations decrease under aerobic conditions, whereas sulphide concentrations increased significantly under anaerobic conditions. A regressed sulphide prediction equation under anaerobic sewer conditions is proposed with coefficient $a = 0.0265$ and $b = 0.5$ and a forecasting model $\Delta S = 0.0265 \, C^{0.5} \, 1.07^{(T-20)} \, t_h \, (A/V)$.

*Keywords: Sulphide, sewer, forecasting equation, aerobic, anaerobic*

## I. Introduction

One of the major problems in sewer operation and maintenance is sulphide build-up [1,2]. Hydrogen sulphide ($H_2S$) in the sewer gas phase diffuses into the thin liquid present at sewer surfaces. This leads to corrosion from the reaction of the biogenic sulphuric acid with the cementitious material of the concrete and eventually failure of the sewer structure [3]. The main source of sulphur in sewage and domestic wastewater is from sulphate ($SO_4^{2-}$) at concentrations ranging from 40–200 mg/L [4–6].

Prediction of $H_2S$ emission rates into the sewer gas phase is a prerequisite for a better control over sulphide-related problems in sewer collection systems [7]. Previous studies [8–10] have developed an equation consisting of two terms using field data gathered from gravity sewers: the first term predicts the rate of sulphide generation in the sewers and the second represents the rate of sulphide degradation from the aqueous phase. Despite a handful of kinetic studies on sulphide emission, almost none are found on predicting sulphide generation in Malaysian sewage. Therefore, the current paper aims to study the aerobic and anaerobic behaviour of sulphide generation in the sewer-like conditions of Malaysian sewage. In addition, the modified sulphide forecasting equation was also proposed to suit the local sewage generation characteristics.

## II. Material and Methods

*A.    Sampling of sewage*

Fresh sewage samples were collected from the equalization tank of one of sewage treatment plant in Penang, Malaysia. The samples were preserved in accordance with the United State Environmental Protection Agency (USEPA) method [11].

*B.    Experimental set-up*

Degradation of sulphide in sewage was observed under aerobic and anaerobic conditions in laboratory. The degradation took place in six 250 mL flask wrapped with aluminium foil, which were observed for 2, 4, 8, 16, 30, and 50 h retention time. The aluminium foil protected the reactors from exposure to light, thereby preventing photolysis. The samples were poured until the flasks filled to the brim as to avoid trapped air. The content of each  flask was stirred slowly with a magnetic bar and kept in the BOD incubator (HACH Model 205) to maintain the temperature within $29 \pm 0.5$ ºC, to simulate the actual temperature in the sewerage network. The aerobic condition was provided through surface aeration from stirring. The dissolved oxygen measured was within the range 1–2 mg/L, which mimicked actual sewer conditions. For the anaerobic conditions, the mouth of each conical flask was closed tightly with a rubber stopper to avoid surface aeration. The sewage sample in each flask was analysed for sulphide for a predetermined retention time. The experiments were run in triplicate.

Sulphide analysis was done using the methylene blue test, Method 8131, chemical oxygen demand (COD) and soluble chemical oxygen demand (SCOD) parameters were determined by using Reactor Digestion, Method 8000, HACH. [12]. No seeding of biomass was done to maintain high F/M ratios and to simulate the actual sewer condition.

## III. RESULT AND DISCUSSION

Figure 1 depicts the sulphide concentration profile under simulated aerobic and anaerobic sewer conditions. Under aerobic conditions, the average sulphide concentration was reduced as the residence time increased. Initial sulphide concentrations from 0.141 mg/L were reduced to 0.005 mg/L within 50 h residence time. At 20 h retention time, the sulphide concentrations were almost depleted. Reference [7] explained that there was minimal sulphide production under aerobic conditions because sulphate reduction is hindered by the oxygen concentration. The sulphide loss under aerobic conditions might be due to the combined effects of minimal biological oxidation, the stripping process, and the indirect effect of natural ventilation [8–10].

However, sulphide concentration evidently increased with residence time under the anaerobic process. The initial sulphide concentration of 0.114 mg/L was increased to 2.961 mg/L within 50 h, which is more than 96% of the initial value. Reference [8] explained that the sulphate was reduced to sulphide by the sulphate-reducing bacteria *Desulphovibrio*

and *Desulphotamaculum* during anaerobic reaction. The process can be described by the following reaction:

$$SO^{2-} + 8H^+ + 8e^- \rightarrow S^{2-} + 4H_2O \qquad (1)$$
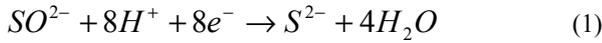
This reaction does not take place if dissolved oxygen (DO) or another more thermodynamically favoured electron acceptors, such as nitrate, are present in the water.

As shown in Figure 1, after 16 h residence time under anaerobic conditions, the $H_2S$ concentration accumulated to more than 0.45 mg/L, which exceeds the lethal threshold [13]. Thus, this information could be used as a guideline so that the 'cleansing' velocity of sewers must be design in such a way that $H_2S$ accumulation must not exceed 0.45 mg/L or the retention time must be less than 16 h to avoid fatal $H_2S$ exposure. At concentrations as low as 0.015 mg/L, $H_2S$ can cause nausea, headache, and conjunctivitis. Above 1.5 mg/L, $H_2S$ can cause serious health problems and loss of the sense of smell, along with the burning of eyes and respiratory tract. Above 0.45 mg/L, death can occur within a few minutes. High $H_2S$ concentrations reversibly inhibit the cytochrome oxidase system, blocking aerobic metabolism, and causing death from respiratory arrest [14].

The equations that relate the amount of sulphide build-up in the sewers, with parameters that influence sulphide generation, have been developed. These parameters include organic matter (electron donor), sulphate, temperature, and residence time [8]. Although pH greatly influences sulphide generation, it is not usually taken into account in forecasting equations because the rate of sulphide formation is highest within the pH range of 6.0 to 8.5 [15], which is the usual pH range of sewage. Most of the equations proposed are as follows [8]:

$$\Delta S = aC^b 1.07^{(T-20)} t_h \left(\frac{A}{V}\right) \qquad (2)$$

where $\Delta S$ is the increase in $S^{2-}$ (mg/L), $C$ soluble or total COD or $BOD_5$, T is the temperature (°C), A is the inside area of the pipe ($m^2$), V is the total pipe volume ($m^3$), $t_h$ is the residence time (hour), and $a$ and $b$ are coefficients. In most equations, $b = 1$ and $a$ depends on the organic matter parameter used (COD and $BOD_5$) and the quality of wastewater studied.
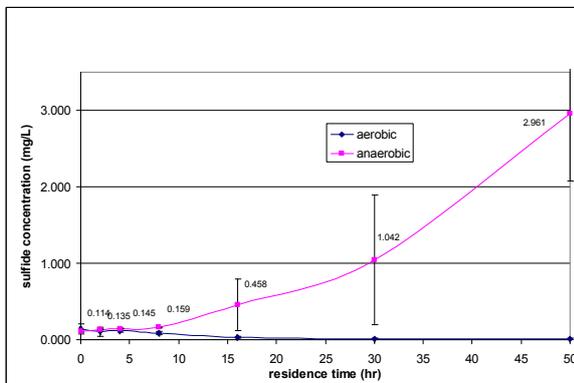
Previous studies [16,17] have proposed equations for predicting sulphide production in sewer pipe that transport raw wastewater high in organic matter content (Total COD = 500–1000 mg/L) as listed in Table 1.

TABLE I.　　SULPHIDE GENERATION FORECASTING EQUATION

| References | Equation |
|---|---|
| [16] | $\Delta S = 0.228 \times 10^{-3} COD 1.07^{(T-20)} t_h \left(\dfrac{A}{V}\right)$ |
| [17]* | $\Delta S = 1.5 \times 10^{-3} (COD_s - 50)^{0.5} 1.07^{(T-20)} t_h \left(\dfrac{A}{V}\right)$ |

*$COD_s$ represents soluble COD, i.e., coefficient for typical domestic wastewater with $COD_s < 500$ mg/L.

Figure 2 depicts the sulphide generated predicted using both equations in previous studies [16,17] and compared with the measured experimental data. The sulphide concentrations in the study were the average values of three runs of experiments. The prediction equations proposed in the recent studies [16,17] did not fit the sulphide generation in the sewage samples investigated. In this case, the sulphide concentrations predicted by both equations in previous studies [16,17] were always lower than that of the measured values. However, both equations were developed for raw sewage in sewer with much higher total COD values than in the current study. Furthermore, the characteristics of the sewage generated were very site-specific. The sewage composition produced might be slightly different from the studied domestic wastewater in as in [16,17]. Hence, the coefficients of the general sulphide generation Equation 2 should be re-evaluated. Figure 3 depicts the regression of the experimental data with Equation 2 and the values of coefficients $a$ and $b$ were determined. A computer software (Curve Expert version 1.3) was used in the determination of the $a$ and $b$ coefficients.



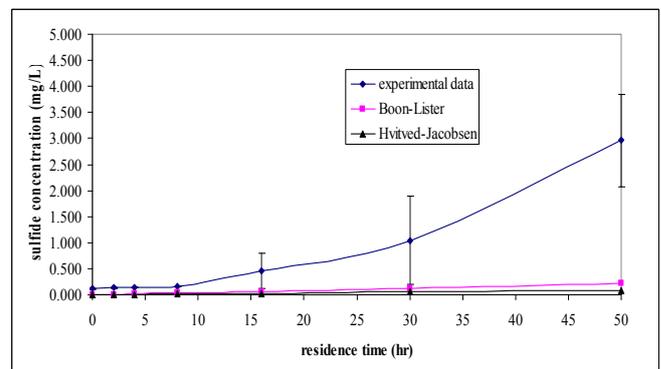Figure 1.　Sulphide generation and reduction during aerobic an anaerobic process



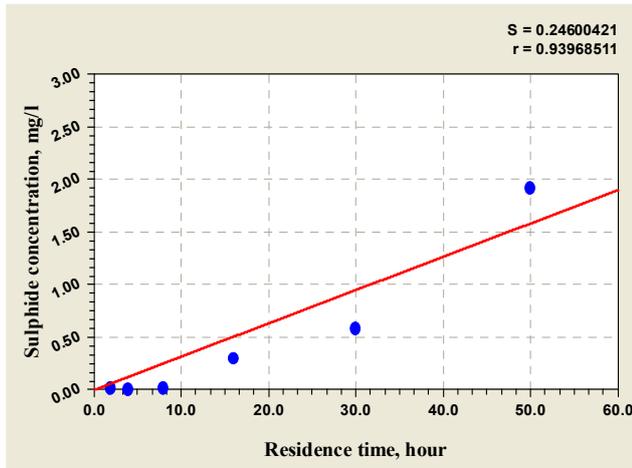Figure 2.　Average predicted and experimental sulphide built-up for the period of study

Figure 3. Regression of experimental data with general sulphide generation Equation 2 to determine the *a* and *b* coefficients.

As shown in Figure 3, coefficients *a* and *b* were 0.0265 and 0.5, respectively and the correlation coefficient *r* was 0.9401. Thus, Equation 3 was proposed to predict the sewage sulphide generation in the Malaysian climate,

$$\Delta S = 0.0265 C^{0.5} 1.07^{(T-20)} t_h \left( \frac{A}{V} \right) \qquad (3)$$

which is valid for COD < 400 mg/L.

The sulphide formation observed under simulated sewer conditions is directly related with the organic matter content, measured as COD. This finding is supported by [8], wherein the sulphide concentration generated increased with increasing COD values.

## IV. CONCLUSIONS

Under aerobic conditions, sulphide concentrations are almost depleted after 20 h aeration under sewer-like conditions. In contrast, under anaerobic conditions, the sulphide concentration reaches beyond the lethal threshold within 16 h in Malaysian sewer-like conditions. An equation for sulphide generation in sewage is proposed as follows:

$$\Delta S = 0.0265 C^{0.5} 1.07^{(T-20)} t_h \left( \frac{A}{V} \right)$$

The study also indicates that sulphide generation is strongly related to site-specific sewage characteristics.

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