# $H_2S$ AND VFA REMOVALS FROM FOUL AIR IN A FIBROUS BED BIOREACTOr

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ABSTRACT

Odour control in Hong Kong has been addressed as an important issue by the authority. Odours pollution is emitted from many sources including wastewater treatment plants. Although a number of technologies are available for odour treatment and control, biological technique is still important due to its low cost and less maintenance. A newly innovated bioreactor consisting of two columns has been designed and set up in our lab. In which an inner column was centred in an outer column, and was fully filled with water in order to absorb the odorous components from foul gas. Many factors affecting the $H_2S$ and butyric acid removals, such as pH value in solution; gas flow rate variation; sulphate content in solution; maximum elimination capacity; ... were studied. The reduction rate of 97.8% for $H_2S$ and 99.9% for butyric acid were achieved. The experiment demonstrated that this bioreactor was a compact odours gas treatment system with application potential for treating foul air with high odour strength and low air flow such as the gases produced from sludge treatment processes in a wastewater treatment plant.

KEYWORDS

Odour; hydrogen sulphide removal; odour pollution; bioreactor; biological treatment

## INTRODUCTION

Odour pollution has been paid more and more attention in the recent years. Since odour is produced in association with different industrial processes, such as petroleum refining, rendering, food processing, wastewater treatment and municipal solid wastes management, one of them is the odour pollution control

from wastewater treatment plants. The odour generated from wastewater treatment plant mainly consists of hydrogen sulphide ($H_2S$), mercaptans ($CH_3SH$) and other volatile organic acids (VFA), which contributes to the terrible smell with the threshold as low as 0.5 ppb as highly odorous air pollutants. As main responsible odorous components in foul air, hydrogen sulphide and mercaptans need to be controlled restrictedly for odour reduction because of their low thresholds.

There are several applications as existing techniques to eliminate odorous pollutants from foul gases as on-site odour control processes, such as chemical scrubbing, activated carbon adsorption and some chemical masking or neutralisation. Although those techniques can effectively remove the odourants from contaminated air under certain conditions, the requirement of daily chemical addition or periodical adsorbent replacement result in a relatively high operating cost to be compared with biological treatment techniques. At present, the main biological treatment processes applied for odour abatement are biological filtration and biological scrubbing. Although the biofiltration technique has been successfully applied for odour pollution control in sewage treatment works, the large footprint required by the biofilters has been known as the vital shortcoming because of its lower biological oxidation reaction rate. In addition to the proper condition required by microorganisms, the adequate food supply for their growth is also another important factor. The more substrates transferred from foul gas, the more microorganisms will grow, which is responsible for the odorous substance removal rate. In Hong Kong, many odour-producing factories are commonly located in multi-storey buildings and some sewage treatment works are just located within a residential area. It is difficult for them to find out sufficient space to house a large biofilter. Thus, it is necessary to develop a cost-effective approach for a practical application. The objectives of this research were to develop a new structure bioreactor, bubble recirculation bioreactor for the removal of hydrogen sulphide, and to be ware of its operation and performance.

## EXPERIMENTAL METHOD

### Synthetic foul gas

The synthetic foul gas used in this experiment was a mixed gas mainly containing $H_2S$ and butyric acid as main odorous pollutants. A technical grade of $H_2S$ gas cylinder with a certified concentration of 5000 ppm was used as $H_2S$ source. The concentrate $H_2S$ gas was first diluted by mixing with clean air after carbon filtration at a high ratio. The analytical grade of butyric acid liquid was used as a VFA source. The butyric acid gas was generated by pumping clean air through the butyric acid solution continuously. Then the diluted H2S and the butyric acid gas were further mixed to generate foul air for experimental use.

### Fibrous bed bio-reactor

A lab-scale fibrous bed bioreactor system was developed and set up in the laboratory. It was a column reactor made of Perspex, which consisted of inner column with diameter of 44 mm and outer one with diameter of 94 mm, and effective height of 800 mm. Fibrous materials were attached on the outer surface of the inner column and the inner surface of the outer column, and the gap between two columns were fully filled by water, which was secondary effluent from a sewage treatment plant as shown in Figure 1. A diffuser was mounted at the bottom of inner column, from which the odorous gas was introduced to the water phase in the reactor and air bubbles would go upwards in the inner column and emit at the top. The water between the inner and the outer column would over flow from the edge of inner column and flow downward in the gap between two columns due to its specially structured shape. The wastewater in the reactor is continuously driven by the upflow air bubbles and recirculated within the bioreactor. Due to foul air bubbling in water phase, the odorous substances in foul gas were absorbed by the water transferred during a short contact time of the bubbles and the water.

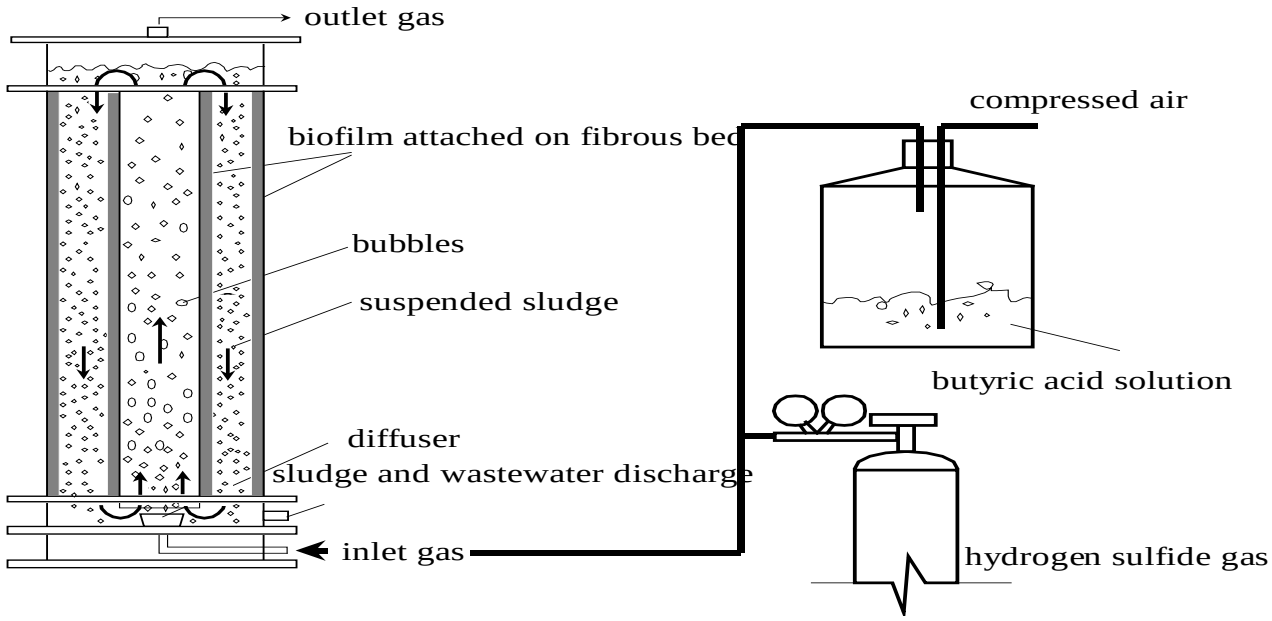


Figure 1. Schematic diagram of bio-reactor

The absorbed odorants were biologically degraded by the microbes attached on the fibrous material and also suspended in water phase. This recirculation leads to two major advantages over any other equipment. Firstly, numbers fine bubbles can continuously move with the recirculated water between the inner and the outer column, since the up-moving velocity of these bubbles is slower than the that of the downwards moving water. It make that a significantly portion of air flow can travel not only once when they pass through the reactor, which increases the air flow retention time in the reactor. Secondly, the turbulent recirculated water can shear the water film on the biomass surface, which is responsible for the mass transfer resistance and also to the improvement of mass transfer rate.

**Sampling and analyses**

Inlet and outlet gases were sampled at different experimental period. H2S in gas was analysed by a by a $H_2S$ Converter Model 340 - Pulsed Fluorescent $SO_2$ Analyser Series 430 manufactured by Thermo Electron Corporation with the minimum limit of 0.01 ppm/v for the determination of hydrogen sulphide. The butyric acid concentration was determined by GC (HP5890) with FID and a column of DB-FFAP. The Total hydrocarbon (THC) in gas was determined by a THC analyser (APHA300E) with minimum limit of 0.01. The sulphate content in water solution was also analysed by an Ion Chromatograph (ISCO Model 2350).

## RESULTS AND DISCUSSION

**Start-up of Bio-reactor System**

This fibrous bed bio-reactor has been operated for a period of 120 days through the experiment. Originally, the biomass (activated sludge) collected from a wastewater treatment plant was seeded into the bio-reactor for inoculation. Carbon source and other necessary nutrients required by the microbes were provided by butyric acid and adding settled water respectively. The synthetic foul gas was continuously fed into the bio-reactor at a constant flow rate of 2 L/min. The $H_2S$ and butyric acid concentrations in inlet gas were maintained at 27 ppm and 21 ppm respectively, while the outlet gas was monitored continuously. It was

found that $H_2S$ concentration in outlet was fluctuated at the initial period and gradually stabilised after 40 days. However, the butyric acid concentration in outlet gas was very low throughout the experiment, which was below the detection limit. The history of bio-reactor stabilisation is shown in figure 2. As shown in that figure, the outlet concentration of $H_2S$ gradually increased with the operation in the first 10 days, because no bacteria could degrade the $H_2S$, the removal of the $H_2S$ was due to the adsorption of the suspended biomass. With the running, adsorption ability of the biomass trended to saturation and the suspended biomass decreased, which were responsible for the increase of the $H_2S$ content in outlet gas. Then the pH value of the solution went down which indicated that the $H_2S$ had been degraded by the microbes.

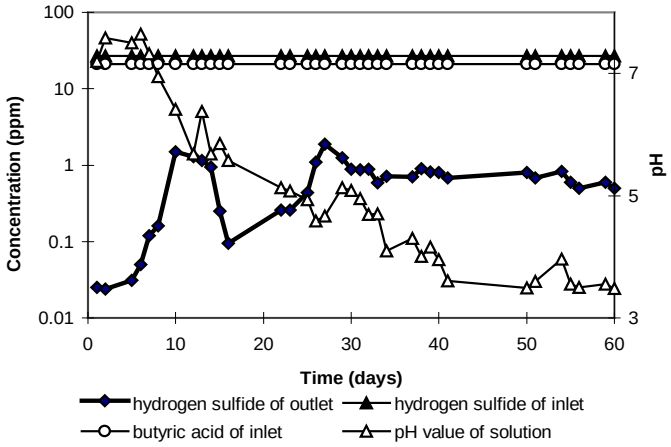


Figure 2. History of bio-reactor stabilisation

During the first three days of experiment, the $H_2S$ content in outlet gas was maintained at a very low level (< 0.05 ppm), due to water absorption and activated sludge adsorption of $H_2S$ from gas phase. Later on, the $H_2S$ concentration in outlet gradually increased up to about 2 ppm in the following week, since the suspended biomass was at a lag phase of their growth on the new substrate of H2S and the bio-degradation rate was very low. It was found that the more and more suspended bio-mass moved to the surfaces of the fibrous material by attachment. After about 10 days, the bio-mass adapted the H2S environment and the bio-degradation commenced so that the H2S concentration in outlet was getting lower down again and pH was also declined due to the conversion of H2S to sulphate products. Once the bio-degradation dominate the process in this period, the $H_2S$ content in outlet gas and pH value of the solution were approximately stabilised at 0.6 ppm and 3.5 respectively.

Figure 3 shows the $H_2S$ content in outlet gas effected by the total suspended solid. No doubt, the increase of the TSS would lead to the decrease of the $H_2S$ content in outlet gas.

**Effect of air flow rate on $H_2S$ Removal**

In this bio-reactor, the odour removal was achieved by absorption of H2S and butyric acid from foul gas phase into water phase. The difference of partial pressure between the two phases is a driving force. In this physical process, the mass transfer rate of odourant from gas to water is a key factor to determine the odour removal efficiency in the reactor, which depends on the both driving force and contact time. The bio-degradation of odorants in water can maintain low $H_2S$ and butyric acid concentrations in water phase to achieve a significant driving force for gas absorption. To maintain the gas bubbles with a longer contact time in water phase, special structure makes the bubbles possible to recirculate in the equipment. The fine bubbles with a great deal of specific surface area would not be able to escape from the water when the water was moving downwards in the space between the inner and the outer, only the bubbles with the up-moving velocity larger than the velocity of the downwards moving water can escape from the water. Therefore, the

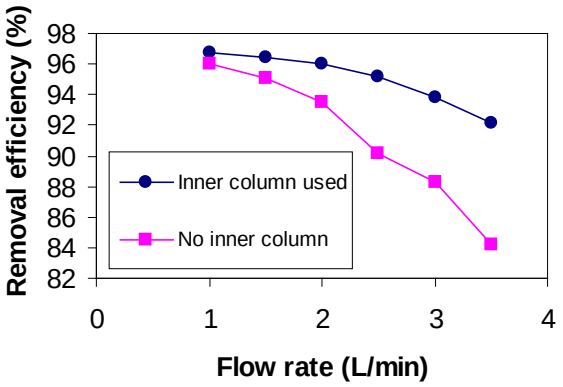


Figure 4. $H_2S$ removal effected by air flow rate

space between the inner and the outer is full of a great amount of fine bubbles which tend to increase the retention time of the bubbles and total mass

transfer area, which could improves the bio-reactor performance. The odorous gas flow rate with constant concentration of 27 ppm was gradually increased, and the outlet $H_2S$ content with inner and without inner column was analysed and the results are shown in figure 4. Series 1 and 2 in figure 4 show the effects of flow rate variation on the removal efficiency with inner and without inner column respectively. Almost no removal efficiency difference when with and without inner column at the flow rate of 1 L/min. The reason for that is that the low flow rate leads to the low velocity of the water in the space between the inner and the outer. A lot of fine bubbles with big enough up-moving velocity could escape from the water. Almost there was no bubbles recirculation occurring, which tends to less retention time and less specific surface area for mass transfer. When increasing the flow rate, the fine bubbles did the recirculation movement, The retention time and the specific surface area would be improved. Having removed the inner, there was no bubble recirculation occurring, therefore, the removal efficiency sharply decreased. Compared with these two situation, when flow rate of odour gas was increased to 3.5 L/min, removal efficiency decrease of 4.8% with the inner was observed, while, without the inner, it was 12.3% decrease. If the flow rate adopted was out of certain range, Channelling would occur, which also could lead to the sharp decrease. The empty space velocity in inner column was controlled in the range of 1.08 ~ 3.97 cm/s in this experiment.

**Effect of water pH on $H_2S$ Removal**

Optimum condition in bio-reactor for microbes can result to higher removal efficiency. The pH of solution was controlled and adjusted by HCl and NaOH to desired value. Following several days operation, the outlet gas samples were analysed when the operation became stable. The removal efficiency results are shown in figure 5. The $H_2S$ removal was intensively influenced by pH value during 3 ~ 5.5 range and almost was independent of pH higher than 5.5. The maximum $H_2S$ removal occurred at pH value of around 4. which is close to the one in a literature published[8]. It shows that the sulphur oxidising bacteria can live in the environment having a wide pH range from 2 ~ 8 in this experiment. The pH value of around 4 will be preferable for higher $H_2S$ removal.

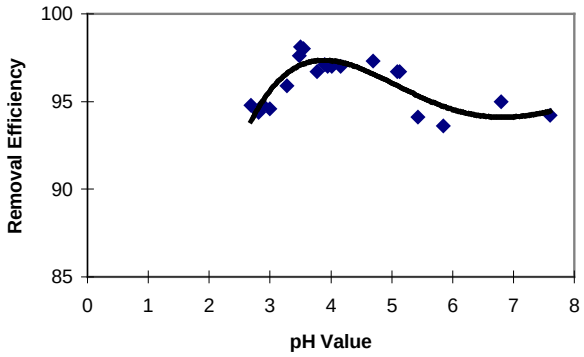


Figure 5. $H_2S$ removal effected by pH in water

**Effect of Sulphate on $H_2S$ Removal**

The effect of sulphate concentration in solution on $H_2S$ removal was studied in this experiment. The sulphate source is the conversion of $H_2S$ by means of microbes' activity. The sulphate concentrations of the 238, 333, 434, 535.6, 648.31 mg/L were maintained by $Na_2SO_4$. The system was operated at the $H_2S$ loading rate of 1.031g/$m^3$ h. The results are shown in figure 6. Almost no effect on $H_2S$ removal when sulphate changed in the range of 238 ~ 648.31 mg-S/L. The absorption of $H_2S$ and the bacteria's activities were not influenced by the concentration of sulphate. The results are in accordance with the conclusion in the literature published by other researchers.

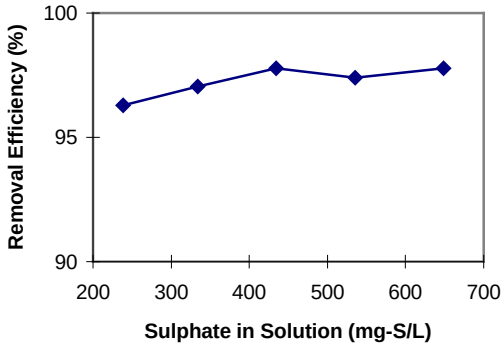


Figure 6. $H_2S$ removal effected of sulphate

### Effect of $H_2S$ Loading Rate on the Elimination Rate

The maximum $H_2S$ elimination capacity for this system was determined during its operation. The $H_2S$ concentration of the inlet foul gas varied from 27 ppm to 4416 ppm and foul gas was continuously supplied at a constant flow rate of 2L/min. During the determination, the $H_2S$ loading rate was gradually increased from 1.031 $g/m^3h$, and the $H_2S$ concentration in outlet gas was monitored, the elimination rates were plotted against $H_2S$ loading rates as shown in figure 7. The maximum elimination capacity was determined when the curve reached the maximum value, which is 63.4 $g/m^3h$.

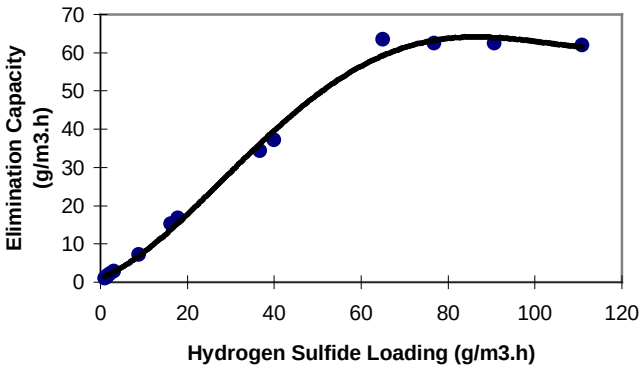


Figure 7. Maximum elimination capacity

### Effect of gas retention time on $H_2S$ Removal

The effect of odour gas retention time on $H_2S$ removal was studied in this research work. It was determined by maintaining a constant inlet $H_2S$ concentration of 27 ppm, changing the gas flow rate through the tower reactor, which was carried out at $H_2S$ loading from 0.5 $g/m^3.h$ ~ 1.804 $g/m^3.h$ during this experiment. As shown in figure 8, there was no significant effect on $H_2S$ removal when the retention time was longer than about 38 second. While the retention time was shorter than about 38 second, $H_2S$ removal was significantly effected. The reason was that when the gas flow rate was increased, fine bubbles would collide each other and then became larger dimension bubbles with high rising velocity, further increasing, even tending to channelling in inner column. The results indicated that enough retention time should be provided for two phase contact, otherwise there would be no enough mass transferred into liquid as substrate for biomass which was responsible for the reduction of $H_2S$.

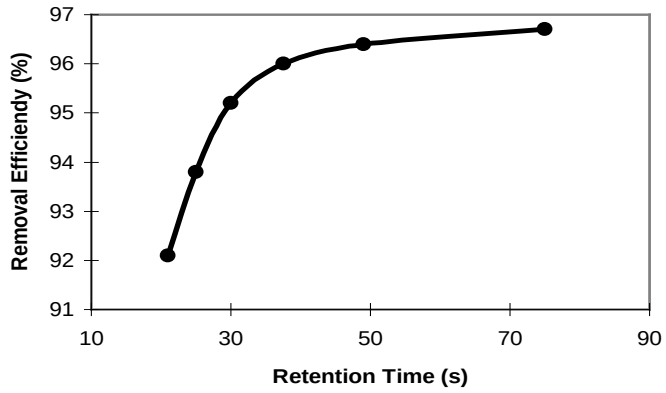


Figure 8. $H_2S$ Removal effected by gas retention time

### The Effect of Fluctuation of $H_2S$ Concentration on $H_2S$ Removal

The effect of fluctuation of $H_2S$ concentration on $H_2S$ removal was studied in this experiment.

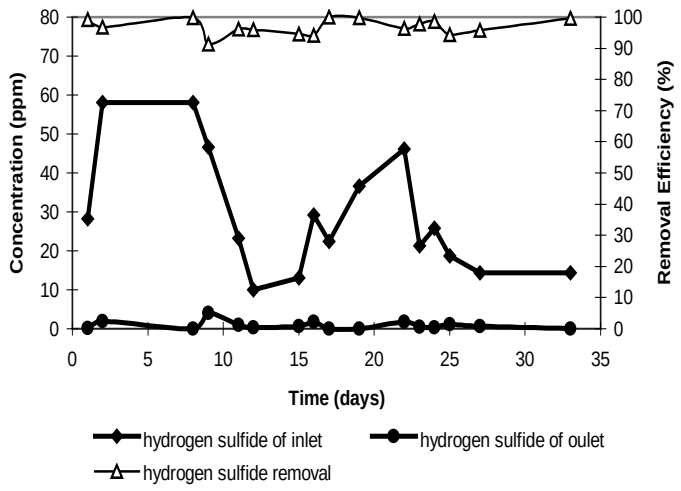


Figure 9. $H_2S$ Removal effected by $H_2S$ conc. of inlet

Various $H_2S$ concentration was obtained by changing $H_2S$ flow rate mixed with the compressed air at a constant foul gas flow rate of 3 L/min provided to the equipment. Outlet $H_2S$ concentrations were kept being monitored, and the results are shown in figure 9. As figure 9 shows that this tower-shaped equipment adequately buttered the fluctuation of $H_2S$ concentration of 10 ppm ~ 58 ppm, while the $H_2S$ removal efficiency was higher than 91% consistently.

## CONCLUSIONS

Synthetic odour gas consisting of butyric acid and hydrogen sulphide was demonstrated to be successfully treated with removal efficiency as high as 97% at the loading rate 1.031 ~ 8.78 $g/m^3.h$. The mass transfer was improved due to the fine bubbles recirculation, which was demonstrated by comparing results when it operated with inner column and without inner column. The maximum capacity for this equipment at the operation condition of 2 L/min and all biomass attached to the fibrous materials was 62.5 $g/m^3.h$. The results indicate that $H_2S$ removal was independent of sulphate concentration in solution, and highly dependent on the TSS, pH value, and dimension of fine bubbles and retention time.

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