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The effect of pressure on removal of carbon monoxide in biofilter

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Abstract−Solubility of carbon monoxide in water is very important for its biological oxidation or removal process of gaseous pollutants. Present research shows the effect of pressure on solubility of carbon monoxide in liquid phase and its removal process by a biofilter. The results are considered as laboratory research on carbon monoxide elimination. In this method a pressurized trickle-bed biofilter was used to increase pressure in the reactor. The biofilter was filled with Leca-stones and inoculated with microorganisms. When the system's pressure is increased, the solubility of carbon monoxide will be increased, respectively, and it causes a better reaction of the microorganisms for removing of gaseous pollutants. The efficiency was improved significantly by increasing the pressure in the reactor.

Key words: Carbon Monoxide, Biofilter, Bioreactor, Pressurized Biofilter

INTRODUCTION

The solubility of gas in liquid plays an important role in industrial processes. Gas solubility has been investigated for decades. Carbon monoxide is one of the most important reactants in the troposphere. It influences the fate of methane and ozone by removing the major atmospheric oxidizing agent, hydroxyl radicals. The background CO mixing ratios range is about 50 to 300 ppb and varies considerably over time and space. Fossil fuels, biomass burning, and oxidation of atmospheric hydrocarbons (methane and other compounds) are accounted as the strongest source of CO (1,200 to 2,850 Tg year-1). The CO consumption rates reached a maximum amount at temperature between 27-32 Celsius. Carbon monoxide is a colorless, odorless and neutral gaseous oxide that is highly poisonous. After it is inhaled, it combines with hemoglobin in blood and prevents the absorption of oxygen and causes asphyxiation. The solubility of carbon monoxide in water is as follows:

At	0 °C,	1 atm	3.54 ml/100 ml
At	25 °C,	1 atm	2.14 ml/100 ml
At	37 °C,	1 atm	1.83 ml/100 ml

Carbon monoxide is an important industrial gas which is widely used as a fuel. It is also an important reducing agent in the chemical industry. For example, the industrial production of iron involves reducing iron (III) oxide in a blast furnace. Most of the iron (III) oxide has been reduced by using carbon monoxide gas. This gas is a reducing agent which takes the oxygen away from iron (III) oxide as in the following equation:

$$Fe_2O_3\ (s)+3\ CO\ (g)\rightarrow 2\ Fe\ (s)+3\ CO_2\ (g)$$

Carbon monoxide has a low solubility in water, so the thermodynamic quantities measurement may be difficult. Thus, the accuracy of gas solubility data or more appropriately Henry's constant values must be emphasized since a differentiation step has been involved in the evaluation of the entropy, enthalpy of solution.

Using natural measures such as microorganisms is a suitable method for removing the gaseous pollutants. This method is related to the economical and environmental aspects. Carbon monoxide and other gas emissions are common constituents of many industrial chemical operation effluents. In this study, a new biological technique is developed to enhance the removal of carbon monoxide in a pressurized bio filter.

Biological processes by atmospheric pressure can also be used for the treatment of carbon monoxide [1-3] or for VOC polluted air streams [3-8]. Results in this research indicate the elimination of CO is improved by the variation of the system's pressure.

Assuming the validity of Henry's law, the binary gas-liquid equilibrium for the lighter component can be described by the following equation:

$$y_i \cdot P \cdot \phi_i^v = H_i \cdot x_i \text{ or } P_i^* \cdot \phi_i^v = H_i \cdot x_i \qquad (5)$$

Here ϕ_i^v represents the vapor phase fugacity coefficient of component i referring to the solution, y_i and x_i are, respectively, the vapor and liquid phase mole fraction of component I, and P is the system's pressure H_i, is Henry's constant.

The solubility of gas in liquid has an important role in the biological removal process, and the literature identifies a number of processes about solubility of gas in liquid [9-13]. Carbon monoxide has low solubility in water. The liquid film is mainly controlled by the mass transfer resistance. Therefore, the pressurized reactor was chosen in order to enhance the diffusion of carbon monoxide into the liquid phase.

MATERIALS AND METHODS

A trickle-bed biofilter was selected as bioreactor which was filled with Leca-stones and inoculated with microorganisms to remove carbon monoxide containing waste gases. The microorganisms adhered to the rough surface of the stones. They catalyzed the oxidation from carbon monoxide and then utilized part of the produced

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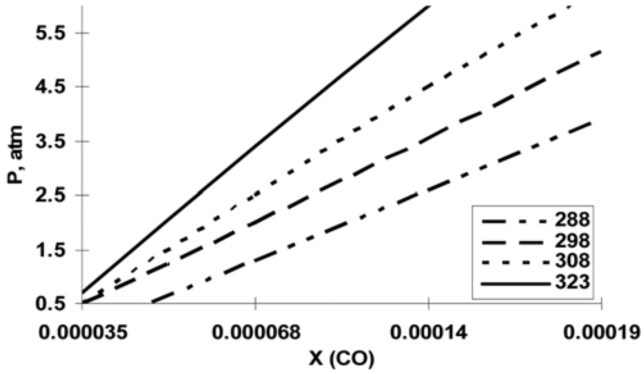

Fig. 1. Shows a p-x equilibrium diagram for CO-water system. Fig. 1 present experimental carbon monoxide solubility data in pure water at various temperature and pressure.

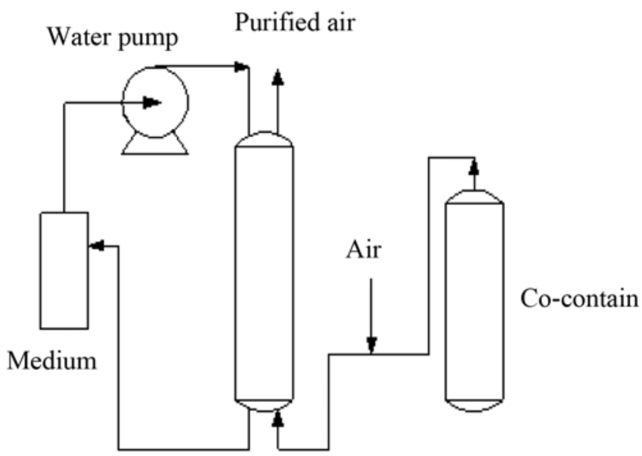

Fig. 2. Shows a bioreactor under atmospheric pressure.

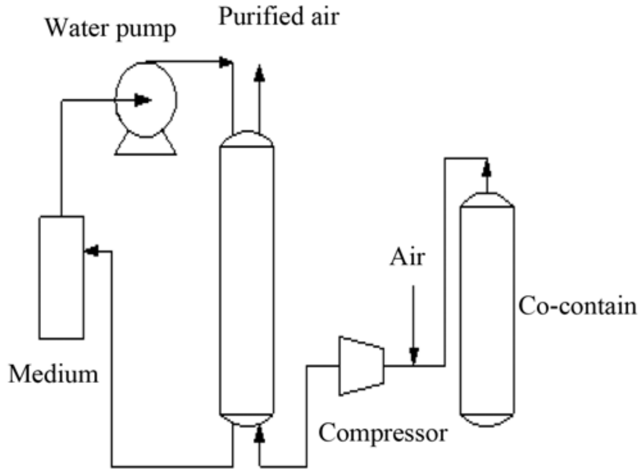

Fig. 3. Shows a pressurized bioreactor.

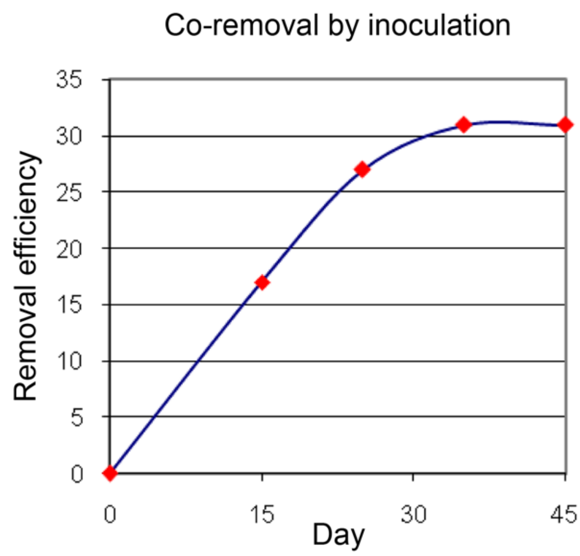

Fig. 4. Shows the removal (inoculation) of co under atmospheric pressure.

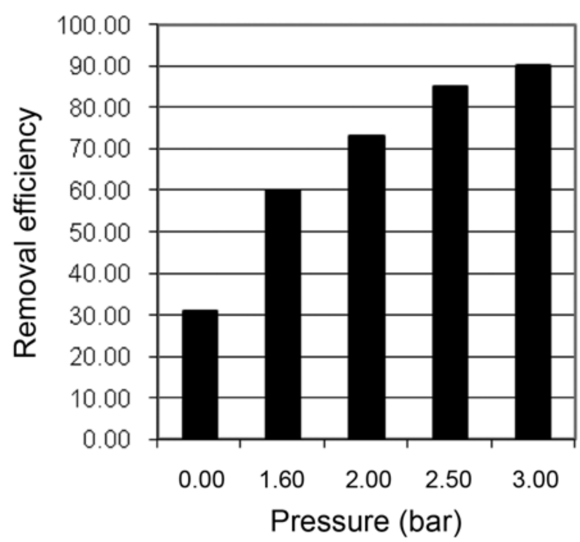

Fig. 5. Shows the removal of co in dependence on the pressure.

carbon dioxide for biomass formation.

The reactor volume was 4 liters and the inlet concentration was 400 mg/m^3 approximately. The flow rate of gases was 250 lit/h. The concentration of waste air was adjusted with compressed air.

The analytic control of carbon monoxide was carried out at the inlet and the outlet of the reactor.

EXPERIMENTAL SET-UP

Carbon monoxide gas and compressed air pass through pipe line mixed together and enter the first biofilter (Fig. 2), and the same mixture enters first in the compressor than in secant biofilter (Fig. 3). To achieve the desired concentration, a valve on the gas tank was installed. The concentration of the input and output of the biofilter can be seen by a monitor of computer. The first reactor at atmospheric pressure for inoculation was considered. Therefore, after 45 days we were able to achieve efficiency as high as 31 percent (Fig. 4). Pressurized biofilter in Fig. 5 shows that increasing the pressure caused increasing of the efficiency of carbon monoxide removal significantly. For example, in 3 bar pressure we are able to achieve 90% efficiency. It was about an hour for each experiment (1.6 bar, 2 bar, 3 bar) considered to achieve maximum efficiency of removal. Here after, the removal efficiency remained almost constant. Mean-

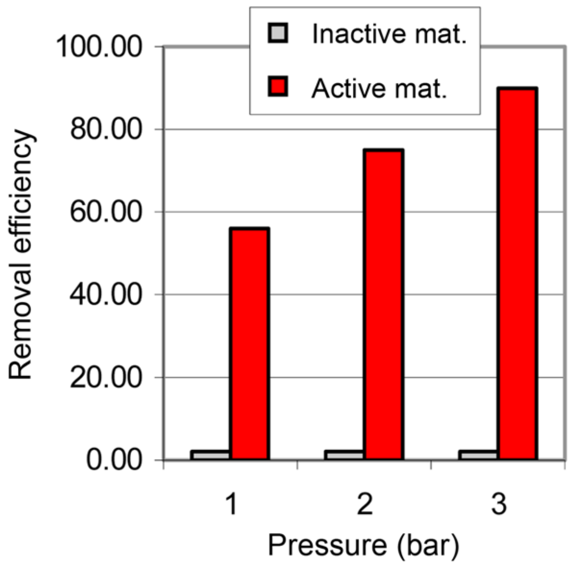

Fig. 6. Shows the biological removal of co in a pressurized-bioreactor with active and inactive material.

while, temperature remained almost constant (room temperature) for all experiments.

The exposure to carbon monoxide was continuously carried out with a cyclic flow of nutrient medium in the reactor, which caused the enrichment of autotrophic culture. The adjustment of waste air concentration was done with compressed air. A compressor was used to increase the system's pressure. The water would spray into the trickle bio reactor (Fig. 2 and 3). Under atmospheric pressure in the bioreactor, the removal efficiency was achieved at 31% (Fig. 4). With increasing the partial pressure, the saturation concentration was increased, too. Hence, microorganism would react better to remove carbon monoxide (Fig. 5).

Fig. 6 shows two reactors which were compared together. The first reactor was raised with active materials till 3 bars and the removal efficiency was good. The second reactor was carried out with the same system pressure as the first reactor, but consisted of inactive material. There was no elimination at all.

1. Gas Analyzer

Infrared gas analyzer (company monitor labs Inc.)

RESULTS AND DISCUSSION

The effect of packing materials in the removal of carbon monoxide has been already investigated [2]. In the related research, the performance of two packing materials was compared. They were lava rock alone and a mixture of peat and lava rock. The results show that the biofilter packed with the mixture of peat and lava rock performed much better than the other one.

However, no attention was paid to the concept of pressurized biofilter, while our study shows that when the system's pressure is increased, the solubility of carbon monoxide will be increased, too. It led to a better reaction of microorganisms for eliminating gaseous pollutants. It is important that the result of the pressurized reactor was always solid and constant. To find out whether the removal of carbon monoxide is actually done by the microorganisms and not by physical absorption, two different laboratory experiments were executed. In the first experiment, the system's pressure was raised with active materials (with microorganisms) until 3 bars; the maximum removal efficiency was achieved by 90% (Fig. 6). A second experiment was carried out with the same system's pressure like the first experiment but with inactive material (without microorganisms). There was no elimination at all (Fig. 6). The results in this work indicate that the elimination of CO was actually done by microorganisms only specially when the solubility of CO in water increased.

A blind test was done with inactive materials.

CONCLUSION

Our study shows that the CO removal efficiency strongly depends on pressure. Under atmospheric pressure in a bioreactor, the removal efficiency was achieved by 31%. The results were improved significantly by increasing the pressure in the reactor. The removal was increased to 90% at pressure of 3 bars (Fig. 5).

With regards to the influence of biological reaction from carbon monoxide through the increase of partial pressure, the most significant results on the removal efficiency are from 31% to 90% at 3 bars.

From the economical point of view, it is stated that a pressurized biofilter could be expensive and it can be used for special cases.

NOMENCLATURE

H_i : Henry constant
P : system pressure
ϕ : fugacity coefficient
y : vapor phase mole fraction
c : liquid phase mole fraction

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