

Simultaneous absorption of hydrophilic and hydrophobic VOCs in a novel Higeer-scrubber

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Abstract—A Higeer-scrubber, in the form of a rotating packed bed, has shown dramatic improvement in its absorption performance as compared with a conventional scrubber. But the absorption is often limited to hydrophilic volatile organic compounds (VOCs) with water-based solvents, simply because hydrophobic VOCs are relatively insoluble in the aqueous system. In this report, we experimentally demonstrated that this novel Higeer-scrubber could handle dual-solvent (e.g. water/silicone oil) properly due to its centrifugal force. Consequently, simultaneous removal of both hydrophobic VOC (e.g. toluene) and hydrophilic VOC (e.g. isopropanol) was efficiently accomplished in a single unit. This Higeer-scrubber showed not only the superior absorption performance but also the capability of handling solvents of significant viscosity difference and immiscibility, thus, drastically expanding its applicability.

Keywords—Higeer-scrubber, rotating packed bed, dual-solvent absorption, hydrophobic and hydrophilic VOCs

I. Introduction

Volatile organic compounds (VOCs) from industrial processes cause serious environmental concerns in air pollution. Among the possible treatments, scrubber (absorption) is a well-accepted and popular unit operation. Usually, water-based absorbents may absorb the hydrophilic VOCs satisfactorily, but it could not remove hydrophobic compounds efficiently. That is, conventional water-based absorbent seems inappropriate for hydrophobic VOCs because of their low solubility. On the other hand, while better solubility may be expected with oil-based absorbents for hydrophobic VOCs, poor mass transfer and hydrodynamic behavior, mainly due to the high viscosity, would hinder the applicability of these potential oil-based absorbents.

A rotating packed bed (RPB), which replaces the gravity force with a centrifugal force up to several hundred folds, can enhance the efficiency of mass transfer significantly. Sometimes, it is also called “Higeer”, standing for high gravity. Higeer equipment has been developing for many years since 1981 by Ramshaw¹. Thereafter, many applications by the Higeer unit were reported, such as stripping, absorption, adsorption, and distillation²⁻⁶. Thus, a Higeer-scrubber, in a form of RPB, is expected to enhance mass transfer efficiency dramatically. Further with our previous experience, it was also considered to be applicable to handle oil-based absorbents that can absorb hydrophobic VOCs efficiently⁷.

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Furthermore, the idea of absorbing hydrophobic and hydrophilic VOCs simultaneously by both water and oil-based absorbents in a Higeer-scrubber was developed. In short, toluene absorption by silicone oil, isopropanol absorption by water in a single Higeer-scrubber as a model system was evaluated in this study.

II. Materials and Methods

A. Experimental Setup

The schematic experimental setup is shown in Figure 1. Solvents flowed through the center of the rotor and sprayed outward due to the centrifugal force with the rotor speed from 500 to 1700 rpm. An air stream was introduced into a bubbler containing aqueous VOCs and then diluted by another air stream to the desired VOCs concentrations. Gas stream contacts solvents within the rotating bed in a cross flow pattern. The inner and outer radii are 1.3 and 5.4 cm while the height is 10.4 cm. The packing used is 0.22-mm diameter stainless steel wire mesh, whose porosity and interfacial area are 0.962 and 598 m²/m³, respectively.

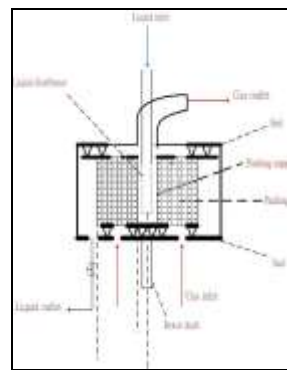
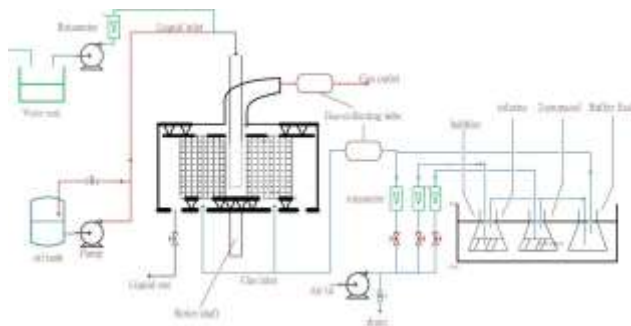


Fig.1 Experimental setup of the system

B. Analytical Method

The concentrations of isopropanol and toluene were measured by a gas chromatography equipped with an FID detector and a dimethyl polysiloxane column (30m in length, 0.53mm ID and 1.5 μ m film thickness).

III. Results and Discussion

The test began from absorption by individual solvent in this scrubber, a cross-flow rotating packed bed. Figure 2 shows the absorption fraction of toluene (2A) or isopropanol (2B) by water at various rotor speeds. Because toluene is a hydrophobic compound, relatively insoluble in water, less than 0.1 fraction of absorption was noticed for the experimental range of water flowrate (up to 0.5 L/min) and rotation speed (up to 1700 rpm) as shown in Fig 2A. On the other hand, the absorption of isopropanol increased with increasing water flow rate as well as rotation speed. The absorption fraction could reach 0.9 when water flowrate was 0.5 L/min and rotation rate was higher than 800 rpm as shown in Fig 2B. This difference between toluene and isopropanol indicates that water is a good absorption medium for hydrophilic compound.

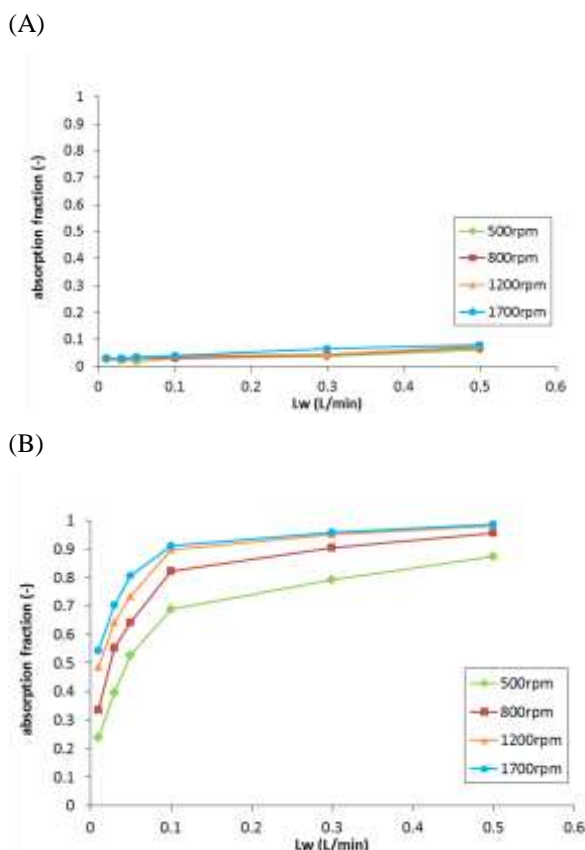


Fig. 2 Absorption by water for various rotation speeds (A) toluene, inlet concentration 1800ppmV, (B) isopropanol, inlet concentration 2600ppmV, gas rate: 22 L/min

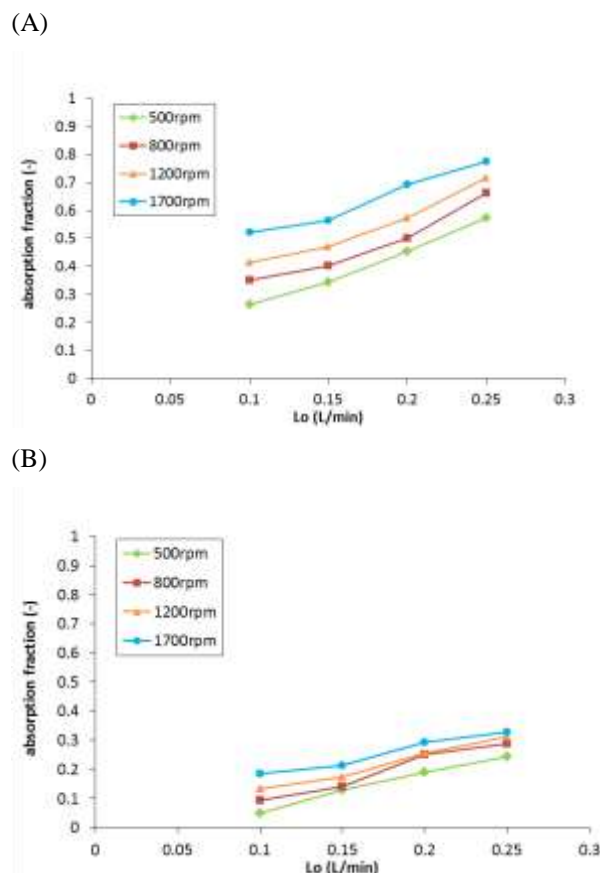


Fig. 3 Absorption by silicone oil for various rotation speeds (A) toluene, inlet concentration 1800ppmV, (B) isopropanol, inlet concentration 2600ppmV, gas rate: 22 L/min

Higee equipment has been recognized as its mass transfer intensification to a significant level. However, because toluene absorption by water is an equilibrium-controlled case, Higee operations could not improve the absorption significantly. For isopropanol absorption, water is a good solvent for its relatively high solubility, thus, increasing rotation speed could obviously enhance absorption fraction.

When silicone oil being the solvent, Fig 3 shows the absorption of either toluene (3A) or isopropanol (3B) by silicone oil for various rotation speeds and oil flowrates. Because toluene has a better solubility in silicone oil, the absorption increased from 0.25 to 0.6 at 500 rpm, and from 0.5 to 0.75 at 1700 rpm while oil flowrate increased from 0.1 to 0.25 L/min. For isopropanol absorption by silicone oil, the absorption fraction remained less than 0.3 and increased with increasing oil rate and rotation speed. Obviously, silicone oil absorbed toluene better than isopropanol for its hydrophobicity. In practical applications, VOCs from industrial effluents could include both hydrophilic and hydrophobic compounds. Conventional scrubber, mainly using water as its absorption medium, would have the limitation to handle both hydrophilic and hydrophobic VOCs at the same time. Thus, we further tested this Higee scrubber to simultaneously absorb toluene and isopropanol with dual solvents (water, silicone oil) and the results are shown in Fig

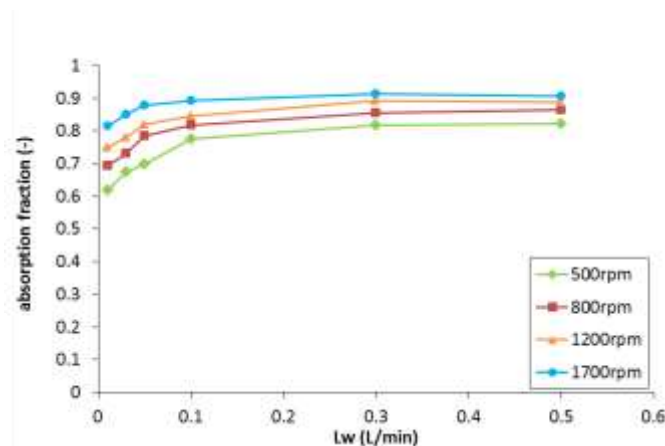
4. This figure shows the absorption of both VOCs at silicone flow rate of 0.25 L/min for various water rates and rotation speeds. It was noted that the absorption fractions for both VOCs increased with increasing water rate and rotation speed, and could both reach 0.9 at water rate 0.5 L/min and 1700 rpm. First, the centrifugal force due to rotation could virtually handle the dual solvents, though the viscosity difference was roughly 300 folds. Second, it is interesting to note that, at 1700 rpm, toluene absorption fraction was about 0.08 by 0.5 L/min water (Fig. 2A) and 0.75 by 0.25 L/min silicone oil (Fig 3A), respectively. The actual absorption (0.9) by dual solvents was slightly higher than the sum of individual absorption medium. Meanwhile, the 0.95 absorption fraction of isopropanol by dual solvents was less than the sum of individual solvents of the same conditions, i.e. 1700 rpm, and 0.5 L/min water (0.9) or 0.25 L/min oil (0.3). Similar trend was observed for other conditions. It seems that there was some gain for toluene absorption and loss for isopropanol absorption.

This might attribute to the interfacial surface area variation within the rotating packed bed when dual solvents were involved. The fluid flow within the bed, due to rotation, could be either in form of film or droplet⁸. The film flow refers to the liquid film moving on that packing surface, wired mesh of stainless steel in this case. And the droplet designates liquid drops flying within the void fraction (96%) of the packing material due to the strong centrifugal force up to 100 times of gravity. The trend of gain in toluene absorption accompanied with losing isopropanol absorption suggested an increase of silicone oil surface area and a decrease of water surface area. This implied oil might cover the water surface, either on the droplet form or film form. This proposition is consistent with the surface tension difference⁹. Water has higher surface tension (72 dynes/cm) than silicone oil (27 dynes/cm). And high surface tension would be likely to confine itself to less surface area, and thus tends to be entrapped by oil if in a droplet form, or covered by oil along the wired mesh. Therefore, a gain in toluene absorption and isopropanol absorption would often be observed in this simultaneous absorption by dual solvents.

Though there was either gain or loss of absorption interfacial area when two solvents were in the Higee scrubber. The intensified mass transfer was expectedly noticed, and centrifugal forces play roles in both distributing viscous solvent and better mixing. The absorption performance did increase with increasing rotation speed and solvent flowrate. This study demonstrated the feasibility of Simultaneous absorption of hydrophilic and hydrophobic VOCs in a novel Higee-scrubber

To summarize, this Higee scrubber could not only enhance absorption because its centrifugal force, but also could handle more than one solvent, either of significant viscosity difference or immiscible, to absorb various VOCs of different properties. These characteristics provide its versatility for many practical applications that would not be possible with a traditional one.

(A)



(B)

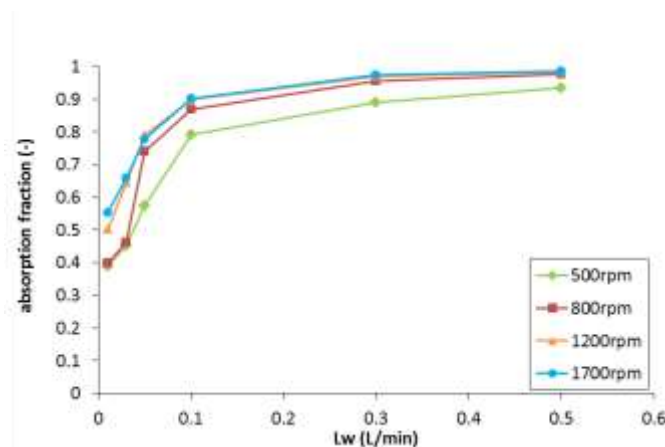


Fig. 4 Simultaneous absorption of (A) toluene (B) isopropanol by water/silicon oil for various rotation speed and water rates, oil rate: 0.25 L/min, gas rate: 22 L/min

Acknowledgment

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