Hydrogenation Process Intensification in a Pilot-Scale HiGee-Aided Fixed Bed Reactor: Size Characteristics of Microbubbles

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Highlights

- A pilot-scale HiGee-aided fixed bed reactor, including a HMG and a catalyst bed, was proposed.
- Size characteristics of microbubbles in diesel was investigated.
- An empirical correlation and an ANN model were established to predict $(d_{32})_o/(d_{32})_i$.
- This study provides significant data for the design of the industrial-scale HFBR.

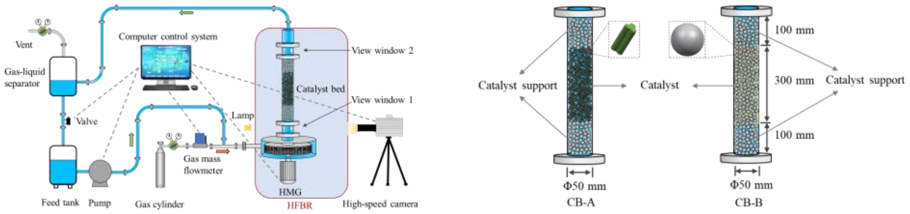
1. Introduction

Microbubble technology is very promising in diesel hydrogenation process. However, the effects of catalyst bed and operation parameters on the size characteristics of microbubbles is not clear, which seriously hinders the industrial application of diesel hydrogenation process intensification with microbubble technology. In this study, a pilot-scale HiGee-aided fixed bed reactor (HFBR), including a HiGee microbubble generator (HMG) and a catalyst bed, was proposed and designed to investigate the size characteristics of microbubbles in diesel by high-speed photograph technology. Based on experimental data, an empirical correlation and an artificial neural network (ANN) model were established respectively to predict $(d_{32})_o/(d_{32})_i$ of the catalyst bed.

2. Methods

2.1 Experimental setup

Figure 1a shows the schematic diagram of the pilot-scale experimental setup. The HFBR includes a HMG to generate microbubbles in diesel and a catalyst bed for diesel hydrogenation. In the experiments, the catalyst bed packed with trilobal catalyst (CB-A). In order to consider the influence of shape and void fraction, the catalyst bed packed with sphere catalyst (CB-B) was selected for the comparison, as shown in Figure 1b. The whole system of the experimental setup was controlled by a computer through the Digital Loop Carrier. The gas from the cylinder was measured by a mass flowmeter and introduced to the inlet of HMG. The liquid from the feed tank was pumped to the inlet of HMG through a metering pump. Millimeter and centimeter bubbles were broken into microbubbles by turbulence inside HMG and flowed to the catalyst bed. After flowing through the catalyst bed, the bubble flow went to the gas-liquid separator, where the gas-liquid separation was carried out.



(a) (b)

Figure 1. Schematic diagram of (a) experimental setup and (b) different catalyst beds.

2.2 Analysis method of image of microbubbles

The microbubbles were detected and the pixel diameters of microbubbles were obtained based on the principle of circular Hough transform since microbubbles were usually round. The BSD under each experimental condition was obtained and the d_{32} was calculated by eq 1. Successive images were processed using programs based on the principle of circular Hough transform. The BSD and d_{32} of the bubbles were determined by measuring more than 1000 bubbles for every experimental condition.

$$d_{32} = \frac{\sum_{i=1}^{n} d_i^3}{\sum_{i=1}^{n} d_i^2} \tag{1}$$

where n is the number of bubbles and d_i is the diameter of ith microbubble.

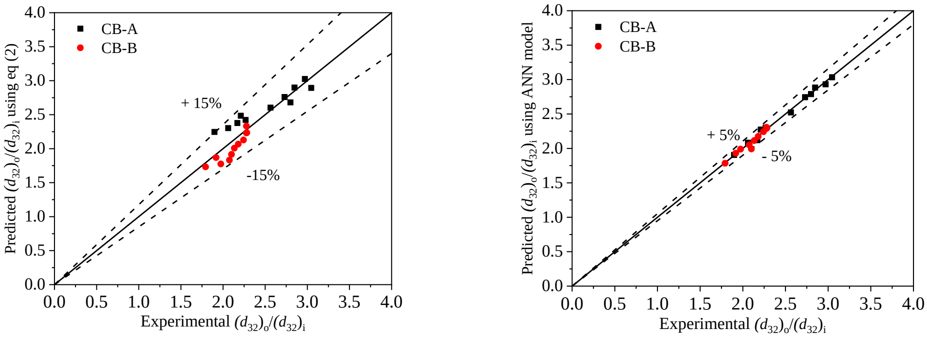
3. Results and discussion

To obtain a correlation of $(d_{32})_o/(d_{32})_i$ of catalyst bed, it was worthwhile to identify the relevant variables was analyzed and an empirical correlation was established by using the multiple linear fitting method based on the experimental data as shown in eq 2.

$$\frac{(d_{32})_o}{(d_{32})_i} = 1.15\beta^{0.16} Re_L^{-0.036} Re_G^{-0.11} \left(\frac{\varepsilon_b}{1-\varepsilon_b}\right)^{-0.21} \quad R^2 = 0.88 \tag{2}$$

where β is the high-gravity level, Re_L is Reynolds number of the liquid phase, Re_G is Reynolds number of the gas phase, and ε_b is the void fraction of catalyst bed.

A comparison between prediction results based on this correlation and the experimental results is shown in Figure 2a. The results showed that the deviation between the predicted value and experimental data was within ± 15%. Furthermore, an ANN model is established and the comparison between predicted values and experimental values of $(d_{32})_o/(d_{32})_i$ is shown in Figure 2b. The predicted results agreed well with the experimental data, having a deviation within ± 5%, which suggested that the ANN model can realize the goal to predict $(d_{32})_o/(d_{32})_i$. Whereas the empirical correlation was explicit, easy to calculate, intuitive, and convenient to be used in practical industrial applications.



(a) (b)

Figure 2. Comparisons of experimental and predicted values of $(d_{32})_o/(d_{32})_i$ using (a) empirical correlation and (b) ANN model.

4. Conclusions

A pilot-scale HFBR was proposed and designed to investigate the size characteristics of microbubbles in diesel by high-speed photograph technology. The dimensionless correlation and ANN model considering the experimental conditions were proposed to predict the $(d_{32})_o/(d_{32})_i$, and the deviations were ± 15% and ± 5%, respectively. It was of great significance to guide rational design of the HFBR.

References

[1] L.H. Wang, L. Jiang, H.L. Liao, S.H. Cai, Y. Luo*, J.F. Chen, Ind. Eng. Chem. Res. 62 (2023), 18867–18878

Keywords
Microbubble; High gravity; Catalytic hydrogenation; Diesel