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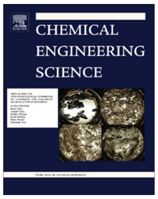

A hydrophobic wire mesh for better liquid dispersion in air

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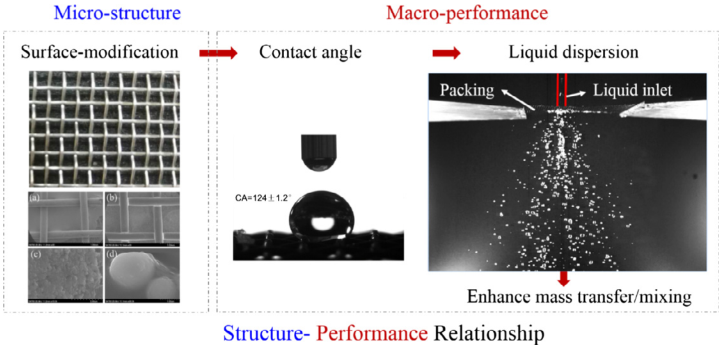
HIGHLIGHTS

- A hydrophobic surface-modified stainless steel wire mesh was prepared.
- Liquid splashing was studied by using a high-speed camera.
- The cone angle generated by the SSM was larger than that of the NSM.
- A correlation was established to predict the mean droplet diameter.
- Rosin–Rammler distribution appropriately represents the droplet size distribution.

GRAPHICAL ABSTRACT

The structure-performance relationship of the hydrophobic surface-modified RPB packing enhances the macro-dispersion of liquid.



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ABSTRACT

Liquid dispersion significantly affects the mass transfer performance in chemical systems, such as in a rotating packed bed (RPB). Previous studies focused on the structure and type of packing to improve the liquid dispersion for better mass transfer performance. However, using a packing with a hydrophobic surface for liquid dispersion enhancement has scarcely been assessed. Our research prepared a hydrophobic surface-modified stainless steel wire mesh (SSM), already widely used as packing. SEM and XPS analyses demonstrate that the hydrophobicity of the SSM is due to the co-effect of the low-energy coating material used and its rough surface with microstructures. The SSM has shown high stability and adhesivity. Liquid dispersion was studied by using a high-speed camera when liquid passes through the SSM layer. Investigation covered the effects of surface hydrophobicity, liquid velocity, liquid surface tension and viscosity on the cone angle, mean droplet diameter, and droplet size distribution, by analyzing the photographs recorded by the camera. The cone angle generated by the SSM was larger than that of a non-surface-modified stainless steel wire mesh (NSM) under the same experimental conditions. The mean droplet diameter obtained by the SSM was smaller than that of the NSM. A correlation was established to predict the mean droplet diameter, and the predicted values were found to be in agreement with the experimental values with deviations generally within ±10%. The Rosin–Rammler distribution (RRD) can appropriately represent the droplet size distribution.

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Nomenclature

a	fiber diameter of the stainless steel wire mesh (mm)
c	square opening of the stainless steel wire mesh (mm)
CA	contact angle (°)
D	inner diameter of the liquid inlet pipe (mm)
D_o	outer diameter of the liquid inlet pipe (mm)
d	mean droplet diameter (mm)
d_1	minor axis lengths of the oval droplet (mm)
d_2	major axis lengths of the oval droplet (mm)
$\overline{d}_R$	mean diameter in the RRD (mm)
$f_{RRD}(d)$	droplet size distribution in the RRD (%)
m	value of the width of distribution in the RRD
NSM	non-surface-modified stainless steel wire mesh
SSM	surface-modified stainless steel wire mesh
s	calibrated spatial resolution of the droplet image
RRD	Rosin-Rammler distribution
u	liquid velocity at the outlet tube (m/s)
u_0	liquid initial velocity (=0.1 m/s)
σ	surface tension (mN/m)
σ_w	water surface tension (74.92 mN/m)
μ	liquid viscosity (mPa·s)
μ_w	water viscosity (1.31 mPa·s)
θ_S	contact angle degree of the SSM (°)
θ_N	contact angle degree of the NSM (°)
θ_s	contact angle degree of steel plate (=75°)

1. Introduction

Liquid dispersion significantly affects the mass transfer performance in chemical systems (Gerbec et al., 1995). A better liquid dispersion will result in smaller liquid droplets and a higher liquid surface area, which benefits the transfer process in multiphase reactors or contactors for gas-liquid, liquid-liquid, or gas-liquid-solid systems. Taking a rotating packed bed (RPB) as an example, the porous packing with a high rotor speed in the RPB is used to split the liquid into tiny liquid elements of droplets, films, etc. By this advantage of excellent liquid dispersion, the mass transfer performance in the RPB can be intensified by 1–3 orders of magnitude when compared with the traditional packed bed (Wu et al., 2016). Due to the remarkable mass transfer intensification, RPBs have been successfully applied to gas-liquid systems (Agarwal et al., 2010; Chu et al., 2014a, 2014b), liquid-liquid systems (Chen et al., 2010; Chu et al., 2015), and gas-liquid-solid systems (Dhiman et al., 2005; Chen et al., 1996).

The end effect, which occurs in the inner edge of the rotor at a depth of 10–15 mm, is an important phenomenon in a RPB (Luo et al., 2012). Experimental results suggest that the mass transfer accomplished in this end zone can be about 4 times the value achieved in the rest of the rotor, called the bulk zone. The main reason for the lower mass transfer coefficient in the bulk zone is that the liquid motion becomes synchronized with the packing in the rotor and collisions between liquid and porous packing are rapidly weakened, which leads to a poor liquid dispersion in the bulk zone compared to the end zone. Major efforts of rotor structure innovation (Luo et al., 2012) and packing development (Chu et al., 2014a, 2014b) have been devoted to improve the liquid dispersion in the bulk zone for the new built RPBs, aiming to enhance the mass transfer performance in this zone and improve the mass transfer efficiency within the whole rotor. To enhance the liquid dispersion of the bulk zone in the old conventional RPBs is still a challenge.

Studies show that the packing's surface wettability has a significant influence on the liquid droplet motion and flow pattern transition. Richard et al. (2002) investigated the contact time of a bouncing drop on a super-hydrophobic solid and found that the super-hydrophobic solid considerably affects the contact time and modification of droplet form. Li et al. (2013) revealed that wetting properties have important effects on the dynamic behavior of water droplet when colliding onto a textured hydrophobic/superhydrophobic surface. Dong et al. (2015) developed an extremely smart and effective strategy to control the overflow by the micro-nanostructured superhydrophilic surface.

Even though wire mesh may appear to be planar in many practical applications, its characteristics with respect to droplet impaction are quite complicated. Previous experiments of the droplets impacting on single wires (Hung and Yao,1999) revealed that both the finer disintegrated droplets and larger dripping drops could be generated. In addition, the wetting of the surface would affect the interfacial contact phenomenon. In their continuous work, Hung and Yao (2002) studied the dripping phenomena of water droplets impacting on a horizontal wire mesh. Cao et al. (2015) designed a superhydrophobic "pump" to achieve spontaneous anti-gravity water delivery by using a superhydrophobic wire mesh without any external forces. Utilizing the superhydrophobic "pump", water droplets can be spontaneously uplifted to the centimeter scale, forming a continuous water flow.

Since a stainless steel wire mesh is the most popular material for packing used in the experimental and industrial RPBs over the past years, our research intended to prepare a hydrophobic surface-modified stainless steel wire mesh (SSM) and evaluate its liquid dispersion performance as the first step. The second step is to replace the non-modified stainless steel wire mesh (NSM) packing in the bulk zone of the RPB by a SSM packing with the purpose of enhancing the liquid dispersion in the existing "first generation" RPB for further mass transfer intensification. In this work, the focus is on the first step and evaluates the liquid dispersion performance of the SSM by high speed imaging. The characterization of the surface micro-structure and elements, wettability, stability, and adhesivity of the SSM were investigated. The high speed imaging provided a clear insight into the liquid dispersion for both SSM and NSM layers. The effects of surface hydrophobicity, liquid velocity, liquid viscosity, and liquid surface tension on the liquid cone angle and mean droplet diameter were investigated. Furthermore, the droplet size distribution and its width were discussed by analyzing the abundant liquid dispersion images.

2. Experimental

2.1. SSM preparation and characterization

Fig. 1(a) shows a photograph of the NSM with its unitary details displayed in Fig. 1(b). The fiber diameter (a) and the width of the square opening (c) of the stainless steel wire mesh were about 0.6 mm and 2 mm, respectively.

A facile and inexpensive multi-spray-dry method was adopted to prepare the SSM. Firstly, the substrate was scrubbed with acid to remove rust, and then it was washed and dried. A homogenous fluoro-resin solution (Daikin Industries, Ltd.) was sprayed uniformly on the stainless steel wire mesh surface by dry compressed air (0.6 MPa). Subsequently, polytetrafluoroethylene (PTFE)