International Journal of Multiphase Flow 98 (2018) 128–138

Contents lists available at ScienceDirect

International Journal of Multiphase Flow

journal homepage: www.elsevier.com/locate/ijmulflow

Role of particles spatial distribution in drag reduction performance of superhydrophobic granular coatings

H. Aziz, H. Vahedi Tafreshi*

Department of Mechanical and Nuclear Engineering, Virginia Commonwealth University, Richmond, VA, 23284-3015 United States

ARTICLE INFO

Article history:
Received 29 April 2017
Revised 1 September 2017
Accepted 15 September 2017
Available online 19 September 2017

Keywords:
Granular coating
Superhydrophobic surface
Drag reduction
Air-water interface modeling
Water repellent surface

ABSTRACT

This work presents a detailed computational study on the role of microstructural properties of a superhydrophobic granular coating on its drag reducing performance. More specifically, the effects of the Young–Laplace contact angle, particle diameter, and solid volume fraction on drag reduction are studied for submerged superhydrophobic granular coatings under negative (suction) and positive hydrostatic pressures. In addition, four different particle arrangements (square, staggered, reticulated, and random) are considered to investigate the effects of particle spatial distribution on coatings' drag reduction performance. This was accomplished by accurately predicting the 3-D shape and surface area of a coating's wetted area fraction, and then by using this information to solve the flow field over the coating in a Couette configuration to obtain its drag reduction efficiency. As expected, it was found that drag reduction performance of submerged superhydrophobic coatings decreases with increasing hydrostatic pressure. However, in contrast to coatings comprised of sharp-edged pores, it was found that drag reduction efficiency of granular coatings monotonically increases with decreasing the pressure when the pressure is negative. It was also found that spatial distribution of the particles has no significant effect on drag reduction. The only exception to this conclusion is the case of coatings with reticulated particle packing. Results of our simulations are compared with available data in the literature and discussed in detail.

1. Introduction

Superhydrophobic (SHP) coatings, coatings that bring about roughness and hydrophobicity, have been reported to reduce the friction drag between a body of water and a surface (Extrand, 2004; Shirtcliffe et al., 2004; Choi and Kim, 2006; Lee et al., 2008; Rothstein, 2010; McHale et al., 2009, 2010; Sbragaglia and Prosperetti, 2007a). This effect is attributed to the ability of a rough hydrophobic surface to entrap air bubbles in its pores and thereby reduce the contact between the solid surface and the water. The contact area and the friction between the water body and the SHP surface can be manipulated by controlling the volume and the pressure of the air bubbles entrapped in the pores of the SHP surface in the submerged condition (Verho et al., 2012) as well as for the case of a droplet deposited on a SHP surface (Vourdas et al., 2015, 2016). SHP surfaces can potentially be applied to the hull of a boat or the inner walls of a pipe to reduce friction (Dong et al., 2013; Jiang et al., 2010; Pan and Wang, 2009).

SHP surfaces are often produced by microfabricating small features on a smooth surface and then applying a hydrophobic coating to the roughened surface (e.g., Shirtcliffe et al., 2004; Choi and Kim, 2006). A more cost-effective alternative is to coat the smooth surface with a porous hydrophobic material, e.g., Polystyrene fibers or aerogel particles among many others (Ma et al., 2008; Emami et al., 2011; Emami et al., 2012; Samaha et al., 2012; Wang et al., 2017). Depending on coating geometry and flow parameters, the Wenzel state (fully-wetted), the Cassie state (fully-dry), or a series of transition states in between the two extreme states may prevail over a submerged SHP surface (Bucher et al., 2015; Bormashenko, 2015; Marmur, 2003; Bormashenko et al., 2007; Verho et al., 2012). Unfortunately, even a slight departure from the Cassie state may result in a rapid increase in the surface wetted area (solid area in contact with water), and a consequential diminishment of the drag reduction effect, as will be discussed later in this paper (Hemeda and Tafreshi, 2015).

Predicting the shape and position of the air–water interface over a SHP surface comprised of round objects (e.g., spherical objects) is not a trivial task. This is because the air–water interface does not become pinned to the round entrance of the pores, and

* Corresponding author. .
E-mail address: htafreshi@vcu.edu (H.V. Tafreshi).

http://dx.doi.org/10.1016/j.ijmultiphaseflow.2017.09.006
0301-9322/