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DNS study by a bilayer model on the mechanism of heat transfer reduction in drag-reduced flow induced by surfactant ☆

Bo Yu [a,*], Xuan Wu [a], Jinjia Wei [b], Fengchen Li [c], Yasuo Kawaguchi [d]

[a] Beijing Key Laboratory of Urban Oil and Gas Distribution Technology, China University of Petroleum (Beijing), Beijing, 102249, PR China
[b] State Key Laboratory of Multiphase Flow in Power Engineering, Xi'an Jiaotong University, Xi'an 710049, PR China
[c] School of Energy Science and Engineering, Harbin Institute of Technology, Harbin 150001, PR China
[d] Department of Mechanical Engineering, Faculty of Science and Technology, Tokyo University of Science, Noda, Chiba 2788-510, Japan

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ABSTRACT

A bilayer model proposed in [1] is used to investigate the mechanism of heat transfer reduction of surfactant-induced drag-reducing channel flow with a constant heat flux imposed on both walls by direct numerical simulation. In the bilayer model, Newtonian fluid and viscoelastic fluid are assumed to coexist with shear stress balance satisfied between the two fluid layers. A Giesekus model is used to model the viscoelastic fluid induced by the addition of surfactant additives. High-order compact difference schemes are applied to discretize the convective and diffusion terms whereas MINMOD scheme is used to discretize the convective terms in the Giesekus constitutive equations to enhance numerical stability. The effectiveness of the surfactant additives at different flow region on heat transfer reduction is investigated.

1. Introduction

It is well known that the addition of a small amount of surfactant additives into turbulent pipe flow may remarkably reduce friction drag, increase flow rate and/or decrease pressure drop. The drag reduction produced by surfactant additives when applied in industry can bring tremendous economical and social benefits. However, accompanied by drag reduction, heat transfer of the fluid is also reduced because of dramatic suppression of turbulence by surfactant additives [2–5]. The significant reduction of heat transfer rate can affect the efficiency of heat exchanger and decrease the performance of the heat transfer system and therefore deteriorate the capacity of the entire system. Efforts should be made to control the heat transfer reduction appropriately to minimize the negative effect of surfactant additives. In order to precisely control turbulent transfer, at the first stage how heat reduction is affected by additives at different flow region should be understood. It is interesting not only in terms of scientific research but also from the standpoint of engineering application.

In 2005 a DNS study on turbulent heat transfer of a drag-reducing fluid was first carried out by Yu et al. [6], in which a viscoelastic Giesekus model was employed and most of the experimental phenomena were successfully reproduced. The mechanism of heat transfer reduction in drag-reducing flow was discussed. Later, Kagawa et al. (2008) [7] performed a DNS of viscoelastic drag-reducing fluid flow accompanied by heat transfer at isoflux wall condition. Three cases of high heat transfer reduction rate were simulated and the effect of surfactant additives at different rheological parameters was identified. The total thermal resistance, inverse of Nusselt number, was determined by two components calculated quantitatively, which clarified the mechanism of heat transfer reduction. This kind of analyses were performed by Fukagata et al. (2005) [8] to analyze the contribution of turbulent heat flux to the Nusselt number in turbulent Newtonian channel flow. Through the analyses, they proposed a strategy examined by DNS for the simultaneous control of turbulence.

Till now, all the DNS studies on turbulent heat transfer reduction of drag-reducing flow by surfactant additives assumed that network structures were formed by surfactant additives existing in a whole flow region at a same concentration. In fact, the network structures are not distributed uniformly in an entire flow field, and they are likely affected by many factors such as shear stress or temperature during their formation and may have different distributions at different conditions. In order to investigate the effect of surfactant additives on heat transfer at different flow regions, we need to establish a model which can consider the non-uniform distribution difference of surfactant additives. In [1] a simplified and ideal bilayer model with coexisting Newtonian and viscoelastic fluid was proposed to study the drag-reduction features by surfactant additives. In the present study, we employ the bilayer model to simulate the turbulent heat transfer of surfactant drag-reducing fluid flow and examine the effectiveness of surfactant additives to turbulent heat transfer at different flow regions.

2. Physical model

A bilayer model for flow with Newtonian and viscoelastic fluid coexistence was proposed in [1]. The flow to be studied was a fully-

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* Corresponding author.
E-mail address: yubobox@yahoo.com.cn (B. Yu).

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