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Laminar flow heat transfer of dilute viscoelastic solutions in flattened tube heat exchangers

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ABSTRACT

Heat transfer studies of non-Newtonian liquids in non-circular exchangers are not many, and much less on viscoelastic liquids in flattened tubes. Heat transfer studies of dilute viscoelastic liquids in flattened tubes with 0.635 cm and 1.27 cm original diameters and 50 cm–76 cm lengths and aspect ratios ranging from 1.4 to 5.7 were carried out. Five flattened tube heat exchangers with four thermocouples soldered at regular intervals on the outside wall were placed in turn in the experimental circuit to determine the heat transfer coefficients. Hot water was used as the heating medium; and dilute solutions of polyacrylamide in water and in water/glycerol mixtures were used as the viscoelastic solutions. Heat transfer increase as a result of flattening the tubes could be 101% higher while the effect due to secondary flow had a maximum additional increase compared to that for water of 40% for the 250 ppm solution at an aspect ratio of 1.6. Corresponding values for the 500 ppm solutions in water and in water/glycerol mixture were about 53% and 55% respectively at an aspect ratio of 1.8. Increased polymer concentration had only a marginal effect on heat transfer performance.

1. Introduction

Heat transfer performance could be improved by replacing the medium from the wall boundary layer. These had been successfully demonstrated by Bott [1,2], Bott and Romero [3], Chong [4] and Tahti [5] by physical scraping of the exchanger surface. The heat exchanger could also be vibrated as conducted by Song [6], or electrostatic forces applied to it as demonstrated by Nassauer and Kessler [7]. Rotation of the exchanger tubes had also been conducted by Pattenden and Richards [8] to improve heat transfer performance. Replacement of the medium by secondary flows as a result of centripetal forces created in curved tubes is well-established as shown by Liu and Masliyah [9] and Yang and Chung [10]. In the case of viscoelastic solutions, secondary flow could also be induced through the use of suitable and appropriate cross-section by the creation of differences in normal forces as shown by Green and Rivlin [11]. The flows in isosceles triangular ducts had been studied by Carlson and Irvine Jr. [12], Deissler and Taylor [13], Mitsuishi et al. [14], Middleman [15] and Sparrow [16]. The more acute the triangle the more pronounced was the secondary flow created. Flow in rectangular ducts could also generate secondary flows as demonstrated by Beyer and Towsley [17], Hartnett and Kostik [18], Rao [19] and Wheeler and Wissler [20]. Mitsuishi and Aoyagi [21] conducted studies of non-Newtonian flow in both triangular as well as rectangular cross-section ducts using dilute solutions of 1–7% carboxymethyl cellulose (CMC) and similar results were obtained.

The Nusselt numbers for polyacrylamide solutions were about 25% higher than those for water at comparable values of Prandtl number and Rayleigh number. Ray and Date [22] numerically predicted characteristics of laminar flow and heat transfer through square duct with twisted tape insert and found that the correlation for friction factor was excellent. The study showed significant improvements could be achieved with the square duct, particularly at higher Prandtl numbers. Laminar heat transfer in flattened tubes had been studied by Oliver and Karim [23]. Secondary flow had the effect of enhancing heat transfer. Effective increase in wall shear rate also increased heat transfer coefficient. The normal stresses in viscoelastic liquids generate secondary flow in transverse direction of the main flow. Flow behavior and heat transfer characteristics of viscoelastic liquids could be found in the processing of polymers, agricultural and food products. The flow properties could be described for various conditions and geometries as illustrated by Metzner et al. [24] and Metzner and White [25]. Heat transfer in non-circular tubes has a main application in compact heat exchangers. However, only a limited shape is foreseeable. The

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