Experimental Thermal and Fluid Science 35 (2011) 939–947

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

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

Energy losses of ice slurry in pipe sudden contractions

L. Mika *

Institute of Thermal and Process Engineering, Krakow University of Technology, Jana Pawła II 37 St., 31-864 Kraków, Poland

ARTICLE INFO

Article history:
Received 19 October 2010
Received in revised form 24 January 2011
Accepted 25 January 2011
Available online 1 February 2011

Keywords:
Ice slurry
Flow resistance
Loss coefficient
Non-Newtonian
Experimental data

ABSTRACT

The paper presents the results of the experimental research on the ice slurry loss coefficient during its flow through sudden contractions. Experimental studies were conducted using a few of the most common contractions of copper pipes. Six contraction ratios were covered: 0.500, 0.615, 0.650, 0.769, 0.800 and 0.813. In the experimental research, the mass fraction of solid particles in the slurry ranged from 20 to 30 (20%, 25%, 30%). Research results allow for determining the theoretical correlation for the ice slurry, in order to calculate the loss coefficient in contractions during laminar flow. The results of experimental investigations also confirmed that the loss coefficients in contractions in turbulent (transitional) flow of the ice slurry are the same as in the case of Newtonian liquids. The paper also presents original theoretical correlation for calculating the kinetic energy correction factor in the laminar range flow of liquid in the Bingham model. This correlation is used in this work for calculation of the ice slurry flow through contractions.

1. Introduction

Environmentally friendly refrigerants such as ammonia, carbon dioxide, hydrocarbons, or water (and solutions) are more and more frequently used nowadays. Ice slurry belongs to new ecological coolants applied in indirect cooling systems. It is a mixture of a basic liquid (which can even be water) and solid particles with the size of up to 0.5 mm. The coolant has a range of advantages, such as the fact that it causes no adverse environmental effects, has good thermal qualities (high thermal capacity – the heat transfer coefficient of the ice slurry is less dependent on the mass fraction of solid particles in the turbulent flow area, than in laminar range [1]). Ice slurry is mostly used as a secondary coolant (although not very frequently) in cooling systems.

Ice slurry is a non-Newtonian liquid, most frequently described in reference works as the rheologically stable liquid (with the exception of [2]). Such rheological models as the Bingham model [3–6], Oswald-de Waele power model [7,8], and Casson model [9] are the ones most often associated with this liquid [1]. In the literature, the first two models are associated with ice slurry produced on the basis of ethanol, with both constant (11%) and changeable (5%, 10%, 20%) initial concentration of ethanol.

This paper also deals with ice slurry produced on the basis of the ethanol with an initial concentration of 10.6%. The Bingham model was used to describe this phenomenon.

As presented in paper [6], when determining the resistance flow, one can expect lower flow resistance of the ice slurry with a high ice mass fraction (25–30%), than of the liquid without the ice fraction, at the same flow velocity (for Re around 3000). This phenomenon is connected with the difference in the rheological qualities of the ice slurry and the liquid without ice (different moment of transition from laminar to turbulent flow). Some researchers dealing with ice slurry flow suggest that the slurry can demonstrate some features of the Newtonian liquid for given ice contents in the mixture. As it is presented by the researchers in such works as [1,10], the critical Reynolds number Re_{crit}, determining the moment of the transition from laminar to turbulent flow, is not constant and depends among other things, on the content of solid ice particles in the slurry and on pipe diameter. In literature, Reynolds numbers are defined by authors in various way, and as a consequence, Reynolds numbers have various critical values. As started in other studies, in depending of the Hedström number (He) and the quotient of the diameter of the ice solid particles and the internal pipe diameter, the critical value of the Re_{crit} can amount to 1900–2500 [1,11], and more for He above 3500 [1,12].

2. Mathematical flow modelling

In relevant works, one can find information on frictional losses of ice slurry in the straight sections of circular pipes, frictional losses in the slit pipes, or the local losses in the bends and elbows [6,13]. There is still lack of studies on other parts of the fittings, such as ball and poppet valves, control valves, contractions, expansions, three-way pipes, distributors and others.

* Tel.: +48 12 628 3589; fax: +48 12 628 3500.
E-mail address: mikaluk@mech.pk.edu.pl

0894-1777/$ - see front matter © 2011 Elsevier Inc. All rights reserved.
doi:10.1016/j.expthermflusci.2011.01.013