Size Effect Model on Flow and Heat Transfer Characteristics of Ammonium Alum Hydrate Slurries Treated with Surfactants

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Abstract

Latent heat transportation systems have attracted many researchers working on saving energy for air-conditioning systems, because they have high heat density. In the previous study, authors (2013) reported that an inorganic system with aluminum ammonium sulfate (ammonium alum) dodecahydrate is suitable for high temperature transportation. It has 251 kJ/kg of latent heat and its phase change temperature is 51 ^{o}C at the concentration of 35wt%. However, the slurry with ammonium alum hydrate particles has high viscosity compared with that of water. This causes low fluidity in heat transport pipe systems. In order to improve the fluidity of the slurry, authors (2012) suggested that a technology using drag-reducing surfactants and reported that some surfactant system is effective for reducing the drag of the ammonium alum hydrate slurries. However, such drag-reducing surfactants add visco-elasticity to the fluid. Thus, the flow and heat transfer characteristics of ammonium alum hydrate slurries with drag-reducing surfactants are severely affected by the size of pipes. Usui *et al*. (1998) reported the pipe size effects on the flow characteristics of water system with drag-reducing surfactants and suggested a technique to estimate the pipe size effects on the flow characteristics.

In this paper, an estimation method for flow and heat transfer characteristics of ammonium alum hydrate slurries with drag-reducing surfactants has been developed. Flow characteristics will be calculated following the method suggested by Usui *et al*. On the other hand, the heat transfer characteristics will be estimated by a newly suggested method based on the modified Prandtl number and the similarity between heat and momentum transfers. For the validation of the present model, the experimental study on the pipe size effects on flow and heat transfer characteristics has been also performed.

In order to estimate the heat transfer characteristics of the solidification heat

transfer of ammonium alum hydrate slurries treated with surfactants in a pipe, the Gnielinski's model based on the similarity between heat and momentum transfers was adopted as follows.

$$Nu = \frac{(f/2)(Re_{\mathrm{w}} - 1000)Pr_{\mathrm{w}}}{1 + 12.7\sqrt{f/2}\left(Pr_{\mathrm{w}}^{2/3} - 1\right)}$$

Here, Nu (-), f (-), Re_{w}(-) and Pr_{w}(-) are Nusselt number, friction coefficient, Reynolds number defined with the viscosity on the pipe wall and Prandtl number defined with the viscosity on the pipe wall.

The friction coefficient used in the Gnielinski's model was obtained by the Usui's model with a visco-elastic dumping function. A modified Prandtl number newly suggested in the following was applied instead of the normal Prandtl number, Pr^*(-), used in the Gnielinski's model in the cases when the solidification occurs

$$Pr^* = \left(1 + \frac{H_f}{Ste}\right) Pr_{\mathrm{w}}$$

Here, Ste (-) and H_{f}(-) are Stefan number, the maximum hydrate fraction in the slurries. The Stefan number includes the effects of the pipe diameter and the pipe length of the pipe.

Flow and heat transfer experiments have been performed with a test pipe whose diameter was changed from 8 to 25 mm in three steps. As drag-reducing surfactants, behenyltrimethylammonium chloride was used at 2,000 ppm. It was used with a counter-ion supplier of sodium salicylate, whose molar ratio to the surfactants was set at 1.5. The experimental data on the flow and solidification heat transfer characteristics were compared with the model estimation in order to confirm the model accuracy.

From the results, it was found that the flow and heat transfer characteristics of ammonium alum hydrate slurries with and without surfactants were well expressed with the present analytical estimation. Thus, the similarity between the heat and momentum was confirmed for the ammonium alum hydrate slurries even in cases treated with the drag-reducing surfactants and the modified Prandtl number worked for the estimation of

the heat transfer characteristics of the ammonium alum hydrate slurries.

References

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