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Local composition shift of mixed working fluid in gas–liquid flow with phase transition

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ABSTRACT

Local composition shift is an important characteristic of gas-liquid mixture flow with phase transition. It affects the heat transfer process, stream sonic velocity and the mixture distribution in the thermodynamic cycle. Presently, it is mainly calculated through the empirical models of the void fraction from pure fluid experiments. In this paper, we made efforts to obtain it and its rules basing on conservation equations derivation. The result calculated with propane/i-butane binary mixture was verified by the experiment in the evaporator of a refrigerator. As an extending, it was applied to a ternary mixture with components of methane, propane and butane and more information was presented and analyzed. The calculation approach presented in this paper can be applied any multicomponent mixture, and the rules will be helpful to improve the composition shift theory.

1. Introduction

The simultaneous transportation of gas and liquid in mixture flow is popular in various industries, such as natural-gas liquefaction, air separation, ethylene industry, etc. In recent years, in order to reduce the ozone depletion potential (ODP) and global warming potential (GWP), many people devote their efforts to find the eco-friendly work fluid for refrigeration and more and more mixed refrigerants are proposed. As a result, the mixture composition shift in this field is becoming an important issue.

Mixture composition shift can be divided into two sorts. One is the mixture composition shift of a closed cycle system. In a non-azeotropic mixture cycle, because of inhomogeneous distribution of the work fluid in different components of the system, the circulating mixture will deviate from the charged composition. 1996, Judge and Radermacher reported the difference between circulating refrigerant composition and charged composition measured in their heat pump using R407C as refrigerant [1]. After that, as an alternative refrigerant to R22, the circulating composition shift of non-azeotropic mixture R407C is studied by many scholars [2–4]. Of course, other mixed refrigerant systems were also investigated. 2007, Kim et al. measured the circulating composition shift in refrigeration system with CO2/propane mixtures and discussed the causes [5]. 2010, A method for estimating the composition of the mixture to be charged to get the desired composition in circulation in a single-stage JT refrigerator was presented by Lakshmi Narasimhan [6].

Besides circulating mixture composition shift in the closed cycle system, there is another mixture composition shift existing in gas–liquid flow with heat transfer. It is one of the causes of the mixture composition shift in the cycling system mentioned above. What's more, it affects the heat transfer process and sonic velocity. Therefore, it is of interest from a commercial as well as an academic point of view.

In gas–liquid flow, there are two sorts of working fluid composition, local composition and flow composition, described by Euler and Lagrange method, respectively. They are equal in single phase flow, but different in gas–liquid flow, which is called as two-phase-flow composition shift.

The phenomenon of two-phase-flow composition shift has been observed in experiment [7–9]. However, the certain value of local composition cannot be easily measured. In order to calculate local composition, presently, people applied void fraction models to calculate the local composition in gas–liquid mixture flow. For example, Chen applied the void fraction model [10–12] of Hughmark [13], and Beggs-Brill model [14] was applied by Gong et al. [15,16]. Of course, this approach is easier but maybe less accurate, because the void fraction models generally obtained from pure fluid such as water. What's more, the approach skips the derivation of void fraction will lose much important information. As a result,

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