Experimental Thermal and Fluid Science 35 (2011) 1484–1489

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

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

Characteristics of R-123 two-phase flow through micro-scale short tube orifice for design of a small cooling system

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ARTICLE INFO

Article history:
Received 27 January 2011
Received in revised form 14 June 2011
Accepted 19 June 2011
Available online 29 June 2011

Keywords:
Short tube orifice
Discharge coefficient
Two-phase flow
Vapor quality
Small active cooler

ABSTRACT

We present a new discharge coefficient correction method for the orifice equation for R-123 two-phase flows. In this method, an evaporator is mounted after the orifice as a vapor refrigeration cycle, and the evaporator is used to measure the quality of downstream flow through the orifice. Quality is estimated from the measured temperature and pressure of the evaporator inlet and outlet, respectively, instead of by direct measurement of quality. The condition of upstream flow of the orifice is the liquid state at 3 bar and 60 °C. The liquid flow is changed to two-phase flow after passing through the orifice. Orifice diameters of 300, 350, 400, and 450 μm are used for the experiment, and the results are analyzed. Experiments are conducted for various conditions of flow rate between 20 and 70 ml/min and for cooling loads of 60, 80, and 100 W. The results show that the quality of flow downstream from the orifice can be calculated using the enthalpy difference between the inlet and outlet of the evaporator. An equation to determine the discharge coefficient is formulated as a function of quality. We expect that these results can be used to help design a small cooling system.

1. Introduction

Recently, heat dissipation in portable electronic devices has become a crucial issue [1–3]. As integrated electronics become faster, more heat is generated. Passive cooling systems such as fan-fins and heat pipes are commonly used; however, they have limitations due to the available heat transfer efficiency. Therefore, small coolers based on a vapor compression refrigeration cycle have been suggested as a possible solution. We proposed a stack-type active cooler with a size of $50 \times 50\,\text{mm}^2$ [4]. Recently, a prototype of the cooler was designed and tested as shown in Fig. 1.

In the vapor-compression refrigeration cycle, an expansion device is necessary for the isenthalpic process between the condenser and the evaporator. The expansion device receives liquid refrigerant from the condenser and converts the liquid into two-phase flow composed of gas and liquid. Since wet steam causes poor compressor performance, it is important that the flow downstream of the orifice has sufficient quality to maintain constant superheat at the outlet of the evaporator. An orifice is commonly used as a simple expansion device in a small cooling system. As a passive expansion device, the design of the shape and dimensions of the orifice is very important because these parameters significantly affect performance. Liu et al. [5] experimentally investigated and analyzed effects of orifice design parameters of R744 two-phase flow. Nilpueng and Wongwises [6] investigated two-phase flow characteristics of HFC-134a through short tube orifices.

The discharge coefficient (C_d) in the orifice equation is a specific characteristic of the orifice and is typically derived from experimental data. Generally, C_d for two-phase flow is not defined as a constant, so C_d needs a correction method based on experimental data. Kim and O'Neal [7,8] applied a nonlinear regression technique to correct C_d according to the experimental data. Diener and Schmidt [9] applied a homogeneous nonequilibrium method to estimate C_d. Tu et al. [10] revised C_d based on empirically determined constants in single-phase flow and two-phase flow. Han et al. [11] analyzed two-phase flow characteristics through a short tube orifice by numerical modeling approach. The common variable in these methods is the quality of the orifice downstream flow. However, quality is difficult to measure directly.

We suggest a simple C_d correction method using an evaporator. A micro-evaporator [12] was mounted on the orifice outlet, and the temperature and pressure of the evaporator were measured instead of measuring quality directly. Temperature and pressure can easily and accurately be measured using commercial sensors. The enthalpy difference can be obtained from the superheat at the evaporator outlet, and the quality of the flow at the evaporator inlet can be calculated by the enthalpy difference, which is the same as the quality of the orifice outlet. A correlation equation between the quality and the C_d of the orifice can be derived from experimental data. The corrected C_d, which is a function of quality,

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doi:10.1016/j.expthermflusci.2011.06.008