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Modeling refrigerant maldistribution in microchannel heat exchangers with vertical headers based on experimentally developed distribution results

Yang Zou [a], Hanfei Tuo [a], Pega S. Hrnjak [a,b,*]

[a] Air Conditioning and Refrigeration Center, Department of Mechanical Science and Engineering, University of Illinois at Urbana Champaign, 1206 West Green Street, Urbana, IL 61801, United States
[b] Creative Thermal Solutions, Inc., 2209 North Willow Road, Urbana, IL 61802, United States

HIGHLIGHTS

- R134a and R410A distribution in microchannel HXs with vertical header was explored.
- A model was built with experiment data or empirical distribution function as input.
- Maldistribution is related to HX capacity reduction compared to uniform case.
- For R410A, the capacity of two-pass HX is reduced up to 30%.
- For R134a, the capacity of two-pass HX is reduced up to 5%.

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ABSTRACT

R410A and R134a upward flow in the transparent vertical header and distribution into the horizontal parallel microchannel tubes were investigated. Refrigerant entered into the header by the five tubes in the bottom pass and exited through the five tubes in the top pass, representing the flow in the outdoor coil under the heat pump mode of reversible systems. Inputting the experimental quality results into a microchannel heat exchanger model, the capacity degradation compared to the uniform distribution case was calculated. The capacity degradation is related to the coefficient of variation of refrigerant maldistribution, which is affected by header geometry and inlet conditions. The capacity degradation of the whole two-pass microchannel heat exchanger was calculated by inputting the derived empirical distribution function in to the model. It was found that the capacity was reduced by up to 30% for R410A and 5% for R134a, respectively, for the conditions examined.

1. Introduction

The compactness and good air side heat transfer of the microchannel heat exchanger (MCHX) enables its broad use in both residential and automotive air-conditioning system. However, the refrigerant maldistribution in MCHX is also a very important issue. It creates unwanted superheated region, where the heat transfer is lower than the liquid and two-phase region due to the lower heat transfer coefficient of refrigerant vapor and less temperature difference between refrigerant and air. Thus, the heat exchanger capacity and/or system COP are usually lower than the case with uniform distribution.

Numerous studies were conducted on the two-phase flow in the header and refrigerant distribution in parallel microchannel tubes. Studies in Refs. [1–5] examined the two-phase flow in the horizontal headers and refrigerant distribution into the vertical parallel tubes. It usually appeared in the indoor microchannel evaporators. On the other hand, maldistribution also occurred in the outdoor MCHX. It became very important when the outdoor coil was used as the evaporator in the heat pump mode. And studies of Refs. [6–11] investigated the refrigerant distribution in the inlet and/or intermediate vertical header, which were commonly used in the outdoor heat exchangers. All of the above studies showed that maldistribution was a very complex problem that was affected by numerous parameters, such as header geometry and inlet flow conditions, etc. The flow regime in the header, which was affected by the above parameters,

* Corresponding author. Air Conditioning and Refrigeration Center, Department of Mechanical Science and Engineering, University of Illinois at Urbana Champaign, 1206 West Green Street, Urbana, IL 61801, United States. Tel.: +1 217 244 6377; fax: +1 217 244 6534.
E-mail addresses: yangzou1@illinois.edu (Y. Zou), pega@illinois.edu (P.S. Hrnjak).

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had a strong influence on liquid distribution into the branch tubes in two-phase flow.

There are some other studies focused on how badly that refrigerant maldistribution affected the heat exchanger and system performance. Kulkarni et al. [12] simulated the effect of R410A maldistribution induced by the pressure drop in the horizontal header. The microchannel evaporator's capacity was reduced by 20%. Brix et al. [13,14] modeled R134a and R744 maldistribution in two microchannel tubes. The cooling capacity was calculated as up to 23% and 18% lower than the uniform case, respectively. Byun and Kim [9] presented R410A maldistribution in a two-pass MCHX. The capacity was reduced by up to 13.4% compared to the uniform case. Tuo and Hrnjak [15] showed that quality maldistribution could result in up to 18% capacity and 7% COP reduction for the R134a mobile air-condition system. Zou et al. [16] simulated that the cooling capacity was reduced by about 5% due to R410A maldistribution in the two-pass MCHX.

It is noticed that these two types of studies (quantification of maldistribution and effects of maldistribution on heat exchanger performance) are usually dissociative. Quantification of maldistribution is usually generalized with the statistical parameter such as standard deviation or coefficient of variation, which does not indicate MCHX performance directly. On the other hand, the effects of maldistribution on MCHX performance is studied by measuring MCHX capacity in the wind tunnel but not knowing the exact values of distribution directly, or modeling MCHX performance using assumed distribution function, e.g. linear quality distribution. Therefore, the objective of this paper is to associate the MCHX performance with refrigerant maldistribution by establishing a relationship between the coefficient of variation and capacity degradation. It is achieved by building a model with the capability to simulate the performance of single pass and multipass MCHX with vertical headers using experimentally derived distribution function.

2. Experimental method to quantify distribution and eventually derive distribution function

The test loop was constructed to study R410A or R134a distribution in MCHX with vertical header, as shown Fig. 1. The subcooled liquid refrigerant was pumped into the inlet header. It was assumed that the single phase subcooled liquid was distributed evenly into the microchannel tubes in the bottom pass, where the refrigerant was heated to the desired quality. The two-phase fluid entered into the test header and turned 90° to flow upward in the bottom part. In the upper part of the header, due to maldistribution, different amounts of liquid exited through the microchannel tubes in the top pass. In each exit tube, the refrigerant was heated again to provide equal superheat at the exit. The single phase superheated vapor was then brought to the condenser. Through the receiver and the subcooler, the subcooled liquid was returned to the pump. The liquid mass flow rate in each exit tube was obtained based on the total mass flow rate, heaters power, temperature and pressure at the outlet superheated point. The details of the test rig are available in Zou and Hrnjak [10,11].

The liquid mass flow rates were generalized with coefficient of variation (Equation (1)) and liquid fraction (Equation (2)). Uniform distribution was described as $\sigma = 0$ and $LF_i = 0.2$. The worst distribution, for this case (five tubes), was when $\sigma = 2$.

$$\sigma = \frac{1}{\overline{m}_l}\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(m_{l,out,i} - \overline{m}_l\right)^2} \quad (1)$$

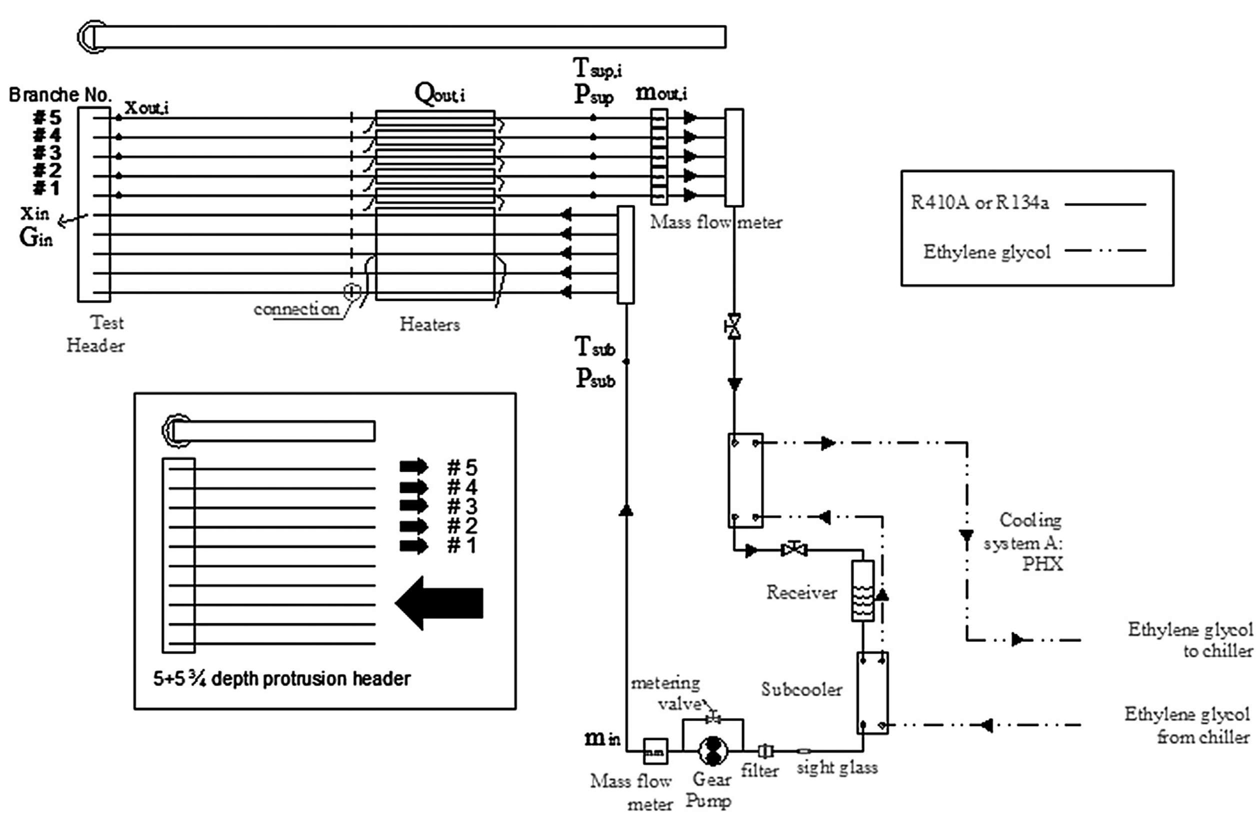

Fig. 1. System schematics.