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Design and analysis of multiple parallel-pass condensers

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ABSTRACT

This paper describes and analyzes a novel design of multiple parallel-pass (MPP) micro-channel tube condenser and its applications to automotive A/C systems. A flow distributor concept is introduced in MPP condenser in order to enable parallel flow arrangement in adjacent flow paths. Throughout analysis of two-phase flow and heat transfer processes in MPP condenser, a two-phase zone enlargement technique is developed to enhance condensation heat transfer and reduce pressure drop. Visual observation indicates a more uniform refrigerant quality entering the next cooling pass can be achieved in MPP condenser because superheated vapor through a pass-through hole on flow distributor directly injects into the separated liquid–vapor zone in a header tube. Performance test results show MPP condenser is able to improve heat transfer rate as high as 9.5% while its refrigerant mass flow increases 13.34% when comparing to a benchmark PF condenser.

Conception et analyse des condenseurs à passages multiples parallèles

Mots clés : Cndenseur à air ; Conditionnement d'air ; Automobile ; Microcanal ; Conception ; Amélioration ; Transfert de chaleur

1. Introduction

Heat exchanger technology has wide applications in automotive HVAC and powertrain cooling industry as summarized by Jabardo et al. (2002), Yang and Webb (2005), and Webb and Wu (2002). Global challenges on conservation of non-renewable energy and the ever-increasing awareness on environmental protection demand thermal scientists and engineers to accelerate technology innovation in pursuit of lighter, greener, more compact and effective heat exchangers.

During the past two decades, considerable attentions have been paid to the fundamental and application researches in two-phase flow and heat transfer of microchannel tube

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Nomenclature

A	area (m^2)
D	diameter (m)
D_h	hydraulic diameter (m)
f	friction factor
H	height
h	specific enthalpy (kW kg^{-1})
K	loss coefficient
L	length
MPP	multiple parallel-pass
m	mass flow rate (kg/h)
p	pressure (kPa)
PF	parallel flow
Q	heat transfer (kW)
S	compressor rotational speed (rpm)
T	temperature (°C)
W	width
x	split ratio of refrigerant between mainstream and bypass flow
ΔT_r	subcool of refrigerant at condenser outlet (°C)

Subscripts

a	air
h	hydraulic
r	refrigerant
i	inlet
n	number of flow passes
o	outlet

condenser technology as presented by Chang et al. (1997), Chung et al. (2002), and Wilson et al. (2003). The pioneering researchers have laid a solid foundation for automotive industry to completely embrace microchannel condenser technology because of its merits in thermal performance, structural robustness, compactness and weight reduction, as well as corrosion resistance in comparison to traditional tube and fin heat exchanger technology. The successful application of microchannel heat exchanger in automotive industry also opens up a new frontier and creates a positive momentum for other industries, such as residential and commercial HVAC industries, to quickly move into the position of adapting and improving the microchannel heat exchanger technology as presented by Jacobi et al. (2005), and Kim and Bullard (2002).

Multiple parallel-pass (MPP) condenser, a variant of microchannel heat exchangers designed by Zeng and Ye (2007), is basically constructed in such a way that one or several baffles in the header tubes of a condenser are turned into flow distributors. The flow distributors alter in-series refrigerant flow arrangement into parallel flow between two adjacent passes. Throughout analysis of two-phase flow and heat transfer processes in MPP condenser, the authors developed a two-phase zone enlargement technique that can be employed to enhance condensation heat transfer and reduce pressure drop, which provides a design method for enabling a lighter and more compact condenser.

Experiments in both visualization and performance tests are carried out to evaluate the two-phase flow and heat transfer mechanism of MPP condenser by referencing a same-sized parallel flow (PF) condenser. Visual observation by using a high-speed camera indicates that a more uniform two-phase refrigerant mixture entering the downstream cooling pass can be achieved in MPP condenser because superheated vapor through a pass-through hole on flow distributor directly injects into the separated liquid–vapor zone and creates vigorous turbulence in header tube. In addition, analytical and test results show MPP condenser, being designed to enlarge two-phase condensing zone, is able to improve heat transfer rate as high as 9.6% while its refrigerant mass flow increases 13.34% when comparing to a benchmark PF condenser.

2. Microchannel tube condenser

Microchannel condenser (Fig. 1) mainly consists of microchannel tubes (Fig. 2), louvered fins (Fig. 3), header tubes, baffles, receiver/dryer bottle, and inlet/outlet fittings. Parallel flow (PF) condenser, widely used in automotive A/C system, is a typical microchannel heat exchanger. In a PF condenser, refrigerant flows through microchannel tubes in parallel within the same pass while in series from pass to pass. In other words, the mass flow of refrigerant in any pass is

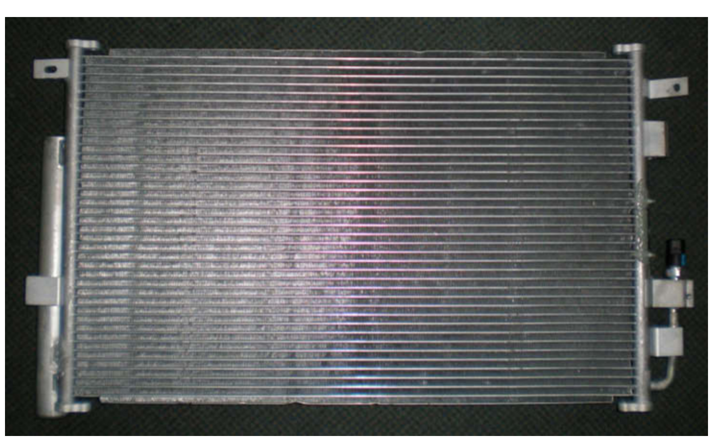

Fig. 1 – Schematic of microchannel tube condenser.