TWO-PHASE FLOW DISTRIBUTION IN WITH DOWN-SCALING

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Abstract— To reduced channel hydraulic diameter we use heat exchangers and flow channel length.To keep the pressure loss at acceptable levels, an implication of the diameter down-scaling is an increase in the number of parallel flow channels through the heat exchanger. The growing number of parallel flow channels increases the challenge of distributing two-phase flow equally among the channels. Making heat exchangers more compact involves reduction of channel hydraulic diameters and length of the flow channels. Heat exchangers with MPE-tubes are now utilized in a growing number of applications, e.g. mobile and residential air conditioning.

Keywords—Heat Exchanger Manifold; Two-Phase Flow Distributio.

I. INTRODUCTION

The use of compact heat exchangers has increased over the last years due to the need for higher efficiency equipment in smaller package volumes. Lower operating costs because of rising energy prices has justified the larger initial cost of such heat exchangers. Making heat exchangers more compact involves reduction of channel hydraulic diameters and length of the flow channels. Heat exchangers with MPE-tubes are now utilized in a growing number of applications, e.g. mobile and residential air conditioning. The good air and refrigerant-side performance of such heat exchangers has been documented extensively in the literature (Jacobi, 2001). Another advantage of microchannel heat exchangers (MCHE) is the possible charge reduction, often important in systems with flammable or poisonous refrigerants.

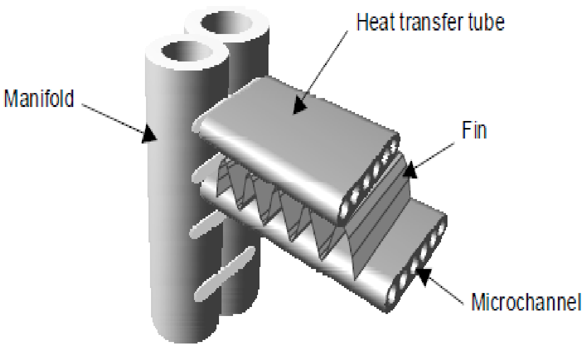


Figure 1.1: Principles of heat exchanger geometry for high operating pressures using MPE-tubes, folded fins, and a compact ”double barrel” manifold (Pettersen, 2002). The heat exchanger is assembled by brazing in a furnace.

Generally, an implication of down-scaling the tube diameter is an increase in the number of parallel flow channels through the heat exchanger to keep the pressure loss at acceptable levels. The heat exchanger pressure losses affects the COP (Coefficient Of Performance) of the system. Because of the increasing number of parallel flow channels, the issue of fluid distribution has received growing attention. One of the common assumptions in basic heat exchanger design theory has been that the fluids are distributed uniformly. In practice, a flow maldistribution often occurs, which can significantly reduce the performance of heat exchangers with parallel flow circuits

1.1 Heat exchangers - significance of maldistribution

To determine the limit of the effect of two-phase flow maldistribution, Beaver et al. (2000) set up a system with two alternative methods for feeding the evaporator in an air-conditioning system operating with CO_2 in transcritical mode. First, the evaporator was connected in conventional mode with an expansion valve at the inlet and a low pressure receiver at the outlet of the evaporator. Second, the evaporator was fed with pure liquid from a separator located upstream the evaporator. The flash gas from the separator was bypassed the evaporator to the suction line of the compressor. The air outlet temperatures showed a much more uniform distribution in the second setup, indicating an improved two-phase distribution. The system COP (Coefficient Of Performance) was claimed to be increased by 20%. Choi et al. (2003) conducted experiments with R-22 in a three-circuit finned tube evaporator to determine the capacity degradation due to non-uniform refrigerant and air flow distributions. The refrigerant distribution between the three circuits was controlled individually and the superheat at the exit was measured. The study showed that refrigerant maldistribution between the three circuits could cause an evaporator capacity deg

radation of 30%. Two of the circuits were run with an elevated superheat of 11.1±C, while the third was flooded to keep the overall superheat at the exit unchanged compared to the base-case. Tests with forced air maldistribution were found to cause
a capacity degradation up to 8.7%. A 4% capacity recovery was obtained by controlling refrigerant mass flow rate in each circuit to maintain equal exit superheat. More details from this study were presented by Payne and Domanski (2002), where also a simulation model, taking into account the distribution issues, was outlined. The simulation model was verified against the experimental measurements.

II. MANIFOLD FLOW DISTRIBUTION - EXPERIMENTAL INVESTIGATIONS

Only a limited number of publications in the open literature are dealing with the problem of two-phase distribution in manifolds. In light of the large number of variables that come into play, e.g. manifold and branch tube geometry, number of branch tubes, orientation of the manifold and the branch tubes, as well as operating conditions and physical properties of the test fluid, it is difficult to make definite conclusions regarding the two-phase distribution in heat exchanger manifolds. Also, only some authors have used heat load on the branch tubes, while measuring the two-phase flow distribution in the manifold. In the following sections, an overview of the published literature containing experimental results on two-phase distribution in round tube heat exchangers, plate heat exchangers and MPE-tube heat exchangers is given.

2.1 Round tube heat exchanger manifolds

Asoh et al. (1991) studied two-phase R113 distribution in a simulated automobile air conditioning system using downward flow into three vertical branch tubes (ID 7.9 mm, center distance 50 mm) from a horizontal manifold (ID 13.9 mm). The manifold was made out of glass, and the authors could observe the two-phase flow in the manifold. The flow pattern at the inlet of the manifold during the experiments was slug or froth flow. Copper branch tubes were heated by electrical cables and the evolution of static pressure in the manifold and in the branch tubes was measured. The authors found that refrigerant maldistribution appeared due to two-phase fluid dynamics and non-uniform thermal load. Also, the flow rates of both phases entering the branch tubes were controlled more by the liquid flow rate in the manifold than that of the vapour.

2.2 Plate heat exchanger manifolds

Some experimental work has been done on two-phase distribution in plate heat exchanger manifolds. Rong et al. (1995) studied distribution of air and water in a heat exchanger simulating a plate evaporator with seven 75 mm wide flow passages, both in vertical upward and downward orientation. Measured values of air and water flow rates in each passage were reported for varying inlet flow rates and adiabatic conditions. The authors found that the manifold geometry was a critical factor, because it determined the two-phase flow characteristics, which had
a strong influence on the distribution. At low air and high water flow rates (low vapour fraction), the inlet flow pattern was slug flow and air and water in the manifold tended to separate due to gravity, resulting in severe maldistribution among the channels. At higher air flow rates, annular flow was observed in the distribution manifold. In these experiments, the first branches received most water while the last branches of the manifold received most air, both in upward and downward configuration. Flow blockages at the inlet of the heat exchanger channels were tested to manipulate the two-
phase distribution. One of the blockage designs showed significant improvement and was recommended for actual application. Rong et al. (1996) identified the phase distribution at the manifold inlet and especially the liquid momentum as an important factor determining the two-phase distribution in the manifold. At low liquid momentum in downward configuration, the water flow was almost homogeneously distributed, while at higher momentum the liquid could skip the first channel entrances and reach channels further downstream.

2.3 Two-phase flow patterns in horizontal pipe flow

As pointed out in the previous Section, several authors mentioned that the flow pattern at the inlet of the manifold and along the manifold length was of great importance for the two-phase distribution. Therefore, it is useful to consider the flow patterns which occur in two-phase flow in pipes as a basis for understanding the flow patterns of the developing flow in the manifold. One complication in the analysis of horizontal pipe flow compared to vertical flow is that the flow is not symmetrical around the axial centre axis. The flow patterns that can be observed in horizontal two-phase flow are shown in Figure 2.2.

Bubbly flow: At low gas flow rates, the gas is distributed in discrete bubbles in a continuous liquid phase. The bubbles tend to flow in the upper part of the tube due to buoyancy.

Plug flow (elongated bubble flow): An increase in gas flow rate cause the bubbles to coalescence into large elongated plug-type bubbles, which flow in a continuous liquid phase in the upper part of the tube.

Slug flow: The liquid flow is contained in liquid slugs, separating successive gas bubbles. The length of the gas bubbles can vary considerably and contain liquid droplets. Gas bubbles may be dispersed in the liquid slug.

Stratified flow: The liquid is flowing in the lower part of the tube with a relatively smooth interface to the gas in the upper part.

Wavy flow: At increasing gas velocity, the interface between the gas and the liquid becomes wavy.

Annular Flow: At even higher velocities, a liquid film will form a continuous annulus along the tube wall with the gas flowing in the core. Due to gravity, the film will be thicker at the bottom of the tube (”crescent” liquid interface).

Dispersed mist flow: The liquid is transported as droplets in the continuous gas phase.

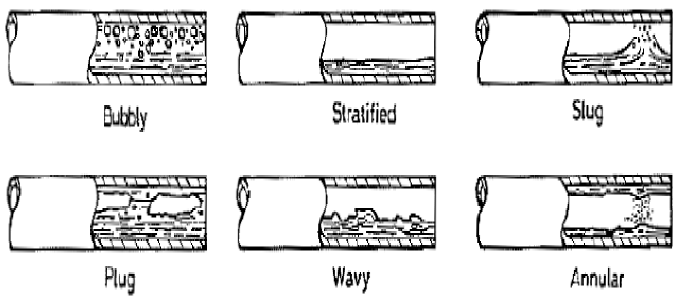


Figure 2.1: Flow patterns in horizontal flow. Reproduced from Collier and Thome (1994).

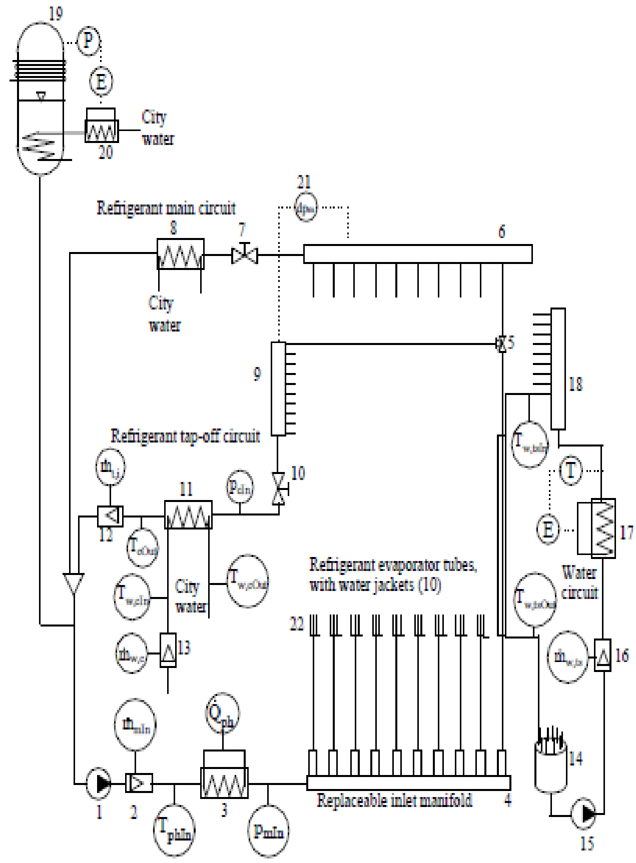
III. CONCEPTS FOR MEASURING TWO-PHASE DISTRIBUTION

3.1 Available measurement concepts

Different approaches for evaluation of two-phase distribution in heat exchanger manifolds can be used. In practice, the methods can be divided in two main groups:

Direct measurements: The two-phase flow parameters are measured by direct measurement on the refrigerant flow circuit. This implies an intrusion into the real heat exchanger geometry, to be able to measure the mass flow rate and vapour fraction in each branch tube.

Indirect measurements: The two-phase refrigerant distribution can be indirectly evaluated by measurements on the secondary side of the heat exchanger. Measurement of wall temperatures or the secondary fluid temperature distribution at the outlet of the heat exchanger will give qualitative information of the refrigerant distribution at the primary side of the heat exchanger.



1 Refrigerant pump
2 Mass flow meter
3 Electrical preheater
4 Inlet manifold
5 Three-way valves (10)
6 Main outlet manifold
7 Valve
8 Main condenser
9 Tap-off outlet manifold
10 Valve
11 Tap-off condenser
12 Tap-off mass flow meter
13 Water mass flow meter
14 Water tank
15 Water pump
16 Water mass flow meter
17 Electrical water heater
18 Water inlet manifold
19 Refrigerant tank
20 Electrical water heater
21 Differential pressure cell
22 Water jackets (10)

Figure 3.1: Schematic diagram of the experimental apparatus with main instrumentation locations.

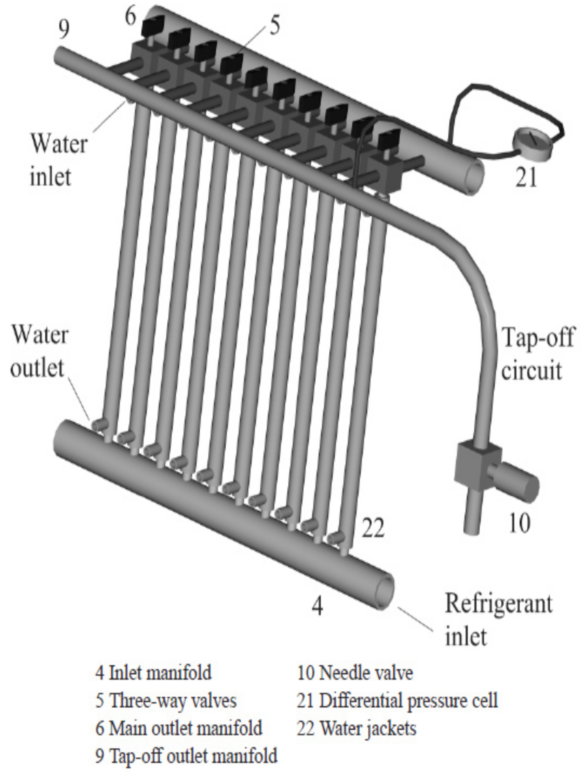


Figure 3.2: Simplified drawing of the test section with the principles of two-phase flow distribution measurements.

IV. EXPERIMENTAL RESULTS

A drawing of the base-case MPE-tube manifold (M5) is shown in Figure 4.1 and geometrical details are given in Figure 4.2. The manifold was constructed in aluminum, such that the extruded aluminum MPE-tubes could be brazed to the manifold. The manifold had an upper part and a lower part, as shown in Figure 4.1, such that modifications to the geometry could easily be done.

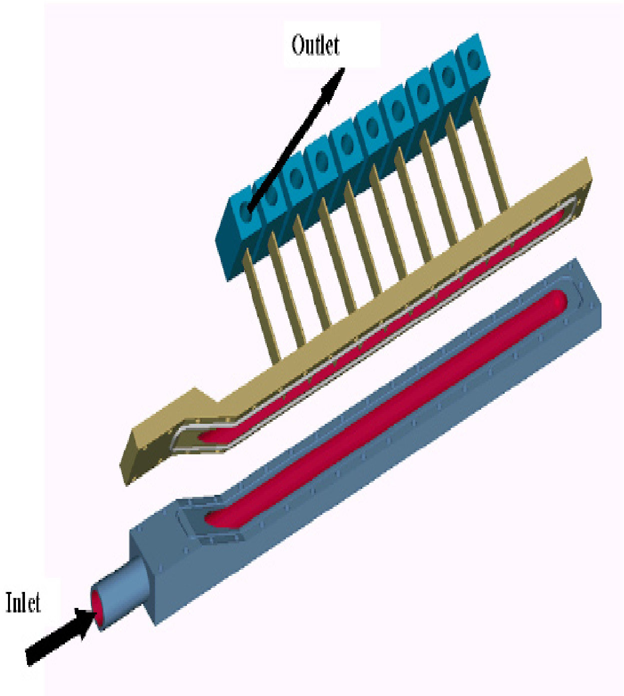


Figure 4.1: Manifold M5 (Base-case MPE-tube manifold). Round tube refrigerant inlet, MPE-tubes and screw couplings to the round heat exchanger branch tubes are shown

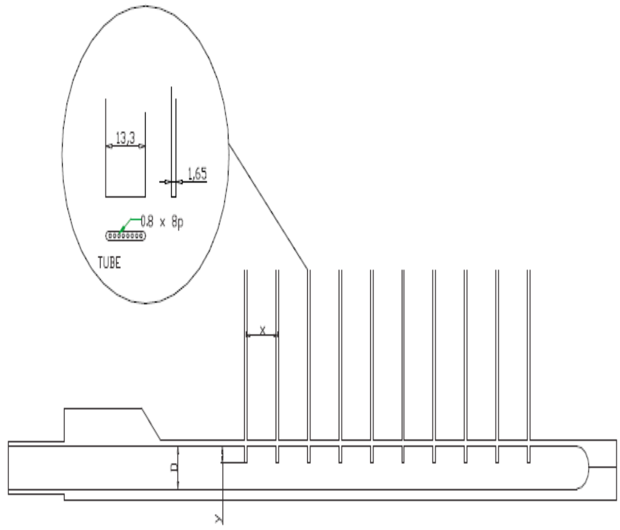


Figure 4.2: Manifold M5 (Base-case MPE-tube manifold). The MPE-tubes were inserted into the manifold with a length of y = 0:4D (tube insert ratio r = 0:4) and the tube pitch was x = 21 mm. The MPE tubes had eight ports of 0.8 mm internal diameter.

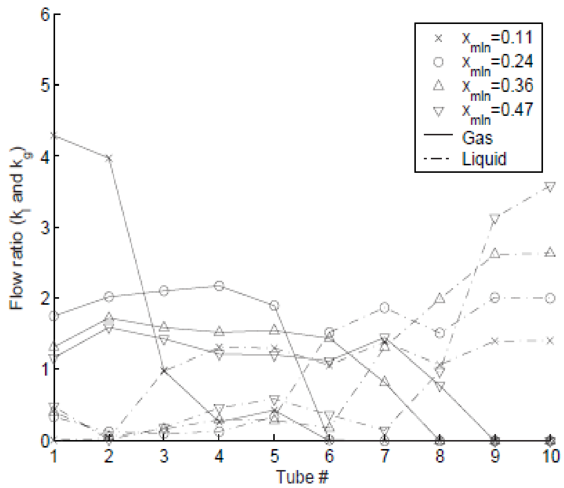


Figure 4.3: Measured two-phase distribution at varying xmIn, MPE-tube manifold (M5), upward flow configuration, refrigerant: HFC-134a, m˙ mIn = 0:033 kg/s, Tw;tsIn = 50±C and TmIn = 29:5±C.

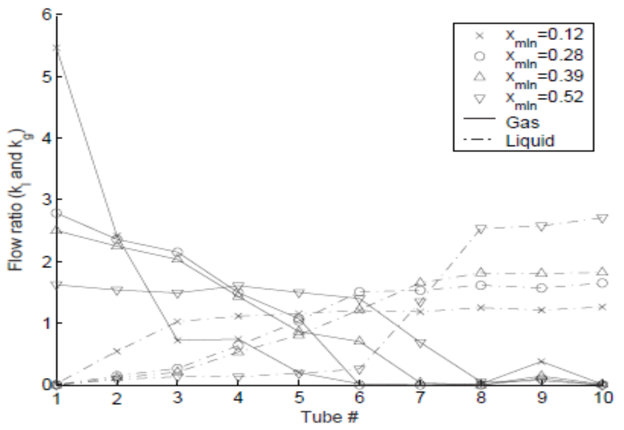


Figure 4.4: Measured two-phase distribution at varying xmIn, MPE-tube manifold (M5), upward flow configuration, refrigerant: CO2, m˙ mIn = 0:033 kg/s, Tw;tsIn = 40±C and TmIn = 18:7±C.

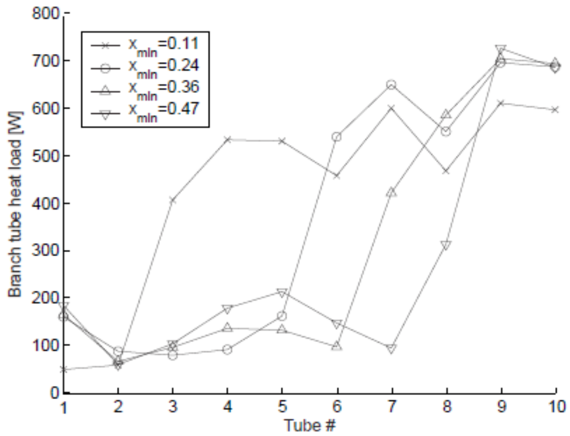


Figure 4.5: Measured branch tube heat load at varying xmIn, MPE-tube manifold (M5), upward flow configuration, refrigerant: HFC-134a, m˙ mIn = 0:033 kg/s, Tw;tsIn = 50±C and TmIn = 29:5±C.

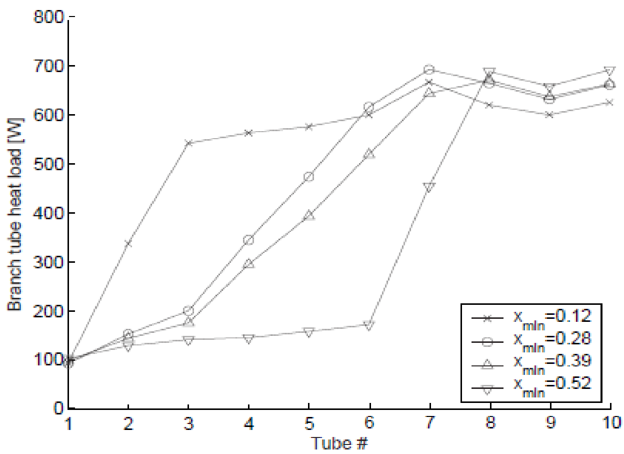


Figure 4.6: Measured branch tube heat load at varying xmIn, MPE-tube manifold (M5), upward flow configuration, refrigerant: CO2, m˙ mIn = 0:033 kg/s, Tw;tsIn = 40±C and TmIn = 18:7±C.

CONCLUSION

A new measurement concept has been developed, such that two-phase refrigerant distribution can be measured in the inlet manifold of compact heat exchangers under realistic operating conditions and using relevant manifold geometries. The understanding of mechanisms affecting two-phase manifold distribution has been improved by analysis of measurements of mass flow rate and phase distribution in twelve different manifold geometries. The two phase flow was in general not evenly distributed. Gravity and difference in momentum flux between gas and liquid was important factors, affecting the distribution. Only minor differences between HFC-134a and CO2 were found, with HFC-134a performing best in downward branch tube configuration, while CO2 performed best in upward branch configuration. The tested geometry modifications to the MPE-tube manifold did not show significant improvements in two-phase flow distribution.
However, a static mixer insert at the inlet of the manifold showed some improvement. The length of the inlet tube to the manifold was important for distribution in the ID 8 mm manifold. A short inlet tube of 50 mm (compared to the original 250 mm) improved the distribution quite significantly, showing that the two-phase flow regime at the manifold inlet was important for two-phase distribution. Measurements in the star manifold showed maldistribution of the two-phase flow, comparable to the MPE-tube manifolds in downward branch tube configuration.

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