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Experimental Comparison of Different Two-Phase Refrigerant Distribution Devices

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Abstract

For larger air-source heat pumps, especially when trying to minimize the inner volume and the refrigerant content in the evaporator, refrigerant distribution to a high amount of parallel passes through the evaporator is a challenge. As the refrigerant leaves the expansion valve partly evaporated, this 2-phase refrigerant has to be distributed to the passes of the evaporator in a way that ideally all passes get the same amount of liquid.

In the frame of the EU-founded project "GreenHeatPump" a novel distributor concept was developed and included in a prototype Heat Pump. This novel distributor and several conventional distributors have been subject to extensive tests on a dedicated test rig.

In this paper the test rig is explained in detail and the results for the different distributors are presented.

Keywords: evaporator; two-phase refrigerant; distribution; experimental results; R290

1. Introduction

In the frame of the EU-founded project "GreenHeatPump" [1], a novel bionic refrigerant distributor [2] was designed, build, and tested. In order to compare it to conventional fluid distributors, a nozzle distributor a Venturi distributor and a cascade of Venturi distributors have also been tested. In most published experimental results on two-phase refrigerant distribution testing, the setup comprised a fluid distributor or manifold together with an evaporator [3,4]. In this work, the fluid distributor is examined isolated from the evaporator in order to specifically analyze the effect of the fluid distributor.

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2. Test Rig

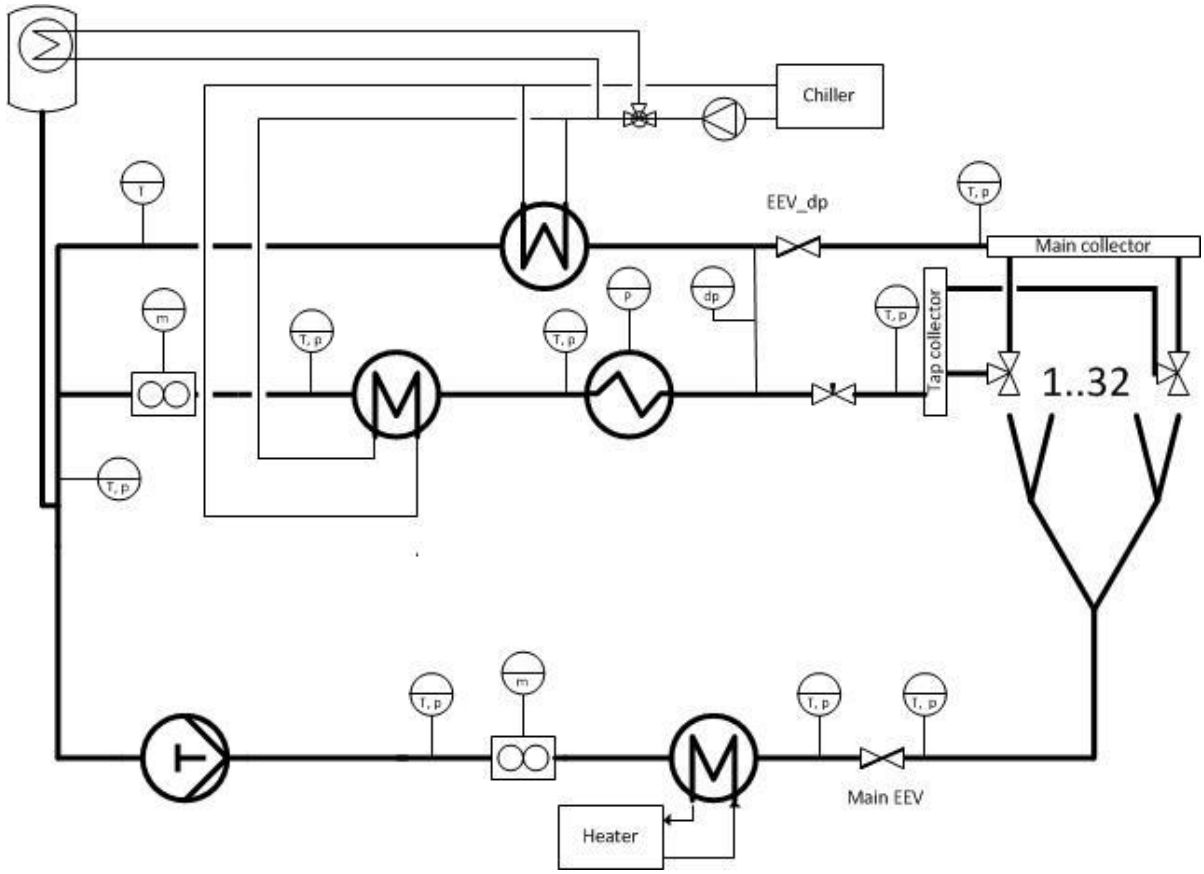


Figure 1: Schematic of the Test Rig with the position of the pressure (P), temperature (T) and mass flow (m) measurements.

In order to measure two-phase refrigerant distribution, a test rig (see Figure 1) was designed and built. Cold liquid refrigerant is pumped to a high pressure with a diaphragm piston pump. Then its mass flow is measured with a Coriolis flow meter and it is heated to a temperature just below boiling point. Next, in the main expansion valve it is expanded to the low pressure. Low pressure can be controlled with the aid of a cooled vessel connected to the low pressure part of the system. By controlling the pump's speed, the high pressure, the low

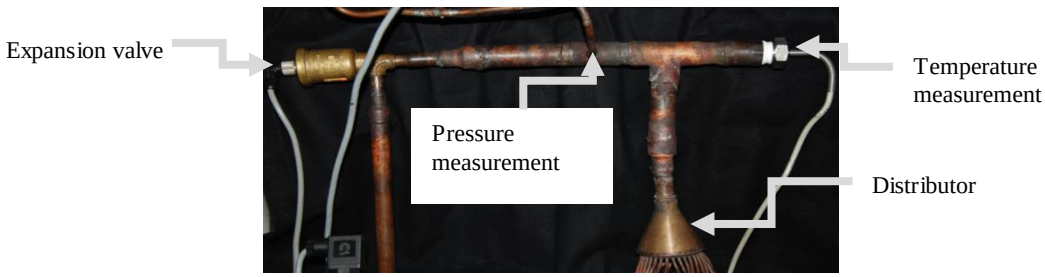


Figure 2: Positioning of the expansion valve and the distributor

pressure and the temperature before the EEV, a defined state in terms of mass flow, pressure and vapor quality can be chosen.

This refrigerant flow is then distributed under examination. Each exit of the distributor is connected to a tap-off valve. The differential pressure after the main collector and the tap collector is controlled to be zero. The tap-off flow is evaporated and superheated in an electrical heater in order to determine its initial vapor quality, then it is

condensed again and its mass flow is measured. Finally, together with the condensed main flow, it is lead back to the pump. So, one after one, for all exits the mass flow and the vapor quality can be measured.

The refrigerant used was R290. Due to its flammability a gas detector connected to an automated air extraction system was used as security device.

Ideally, the refrigerant distributor should be connected directly to the expansion valve, because there the liquid is dispersed in the gas. As in the test rig the pressure and the temperature had to be measured between the expansion valve and the distributor, the connection is not direct.

3. Tested Distributors

On this test rig, 5 different distributors have been tested. Four of them have 32 exits and one only 16. In the next section, the tested distributors are described in detail.

3.1. Nozzle distributor

This distributor is a commercial nozzle distributor from Sporlan with 32 exits. The nozzle is size 4, the tubes are 5x0.5mm copper tubes of 1.5m length.

3.2. Venturi distributor

This distributor is a commercial Venturi distributor with 32 exits. It is connected to 3x1mm tubes of 0.8m length.

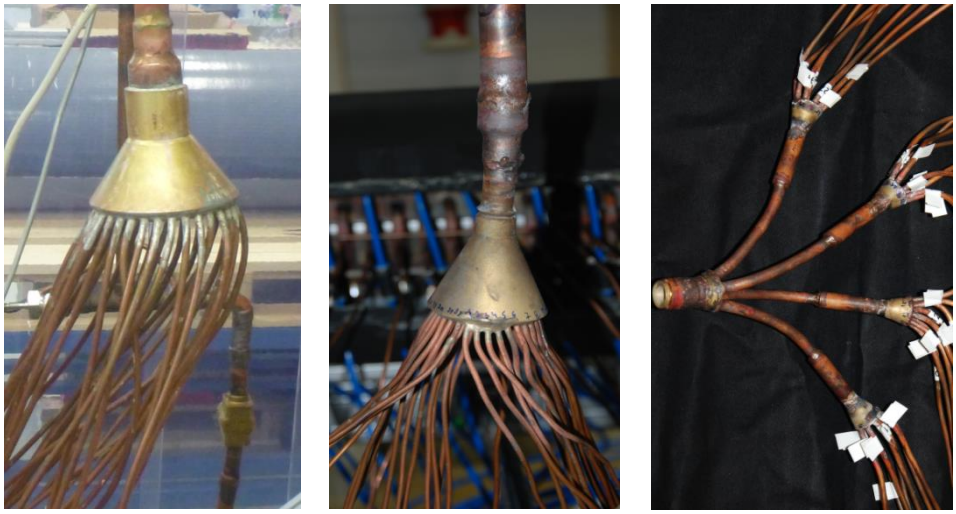


Figure 3: Nozzle distributor (left) and Venturi distributor (center) and cascade of Venturi distributors

3.3. Cascade of Venturi distributors

In order to get a cheap solution for a distribution to 32 exits, this distributor consists of one Venturi distributor with 4 exits connected to 4 Venturi distributors with 8 exits. The cost for the distributors is about one fourth compared to a 1-to-32 Venturi distributor, but there is a bit more brazing to do. All distributors are from Roland Schenderlein. The tubes between the distributors are 8x1mm and 100 mm long, then a 40 mm piece of 12x1mm tube for the connection to the 1-to-8 distributors. The distributor tubes are 4x0.5mm copper tubes of 0.5 m length.

3.4. Bionic PMMA

As an alternative to the conventional distributors, a tree-shaped channel structure was designed. This first prototype is produced in Plexiglas in order to get optical access. It has channels with circular cross section of between 11.3 and 2 mm of diameter. The semi-circular channels have been milled in Plexiglas plates, these have then been glued.

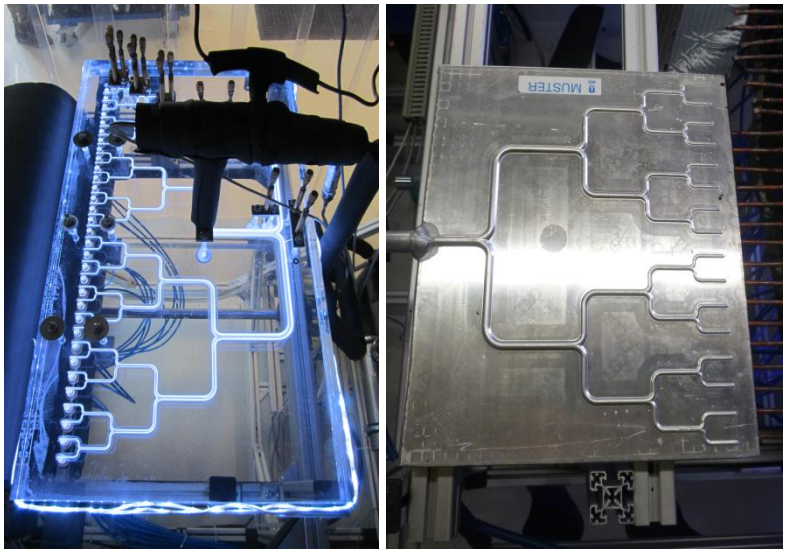


Figure 4: Bionic distributors made of PMMA (left) and Aluminum (right)

3.5. Bionic Aluminum

This is a prototype of the tree-shaped distributor produced in aluminum. It has only 16 exits because it turned out that the production of the 32 exits is much more difficult. The flow sections are semi-circular with a diameter of between 8 and 2 mm. It has been produced by stamping the channels into an aluminum sheet and then brazing it onto a flat aluminum sheet in a vacuum furnace.

4. Tested load points

For all distributors, four different load points have been tested. For the different load points the refrigerant mass flow, the vapor quality and the evaporation temperature at the exit of the distributor (which would be the entrance of the evaporator in a real heat pump) have been varied. The load points are shown in the following Table 1:

Table 1: Load points for the 1 to 32 distributors

	Max. Load	**High Load**	**Design Load**	**Low Load**
x at exit [-]	0.39	0.32	0.31	0.22
T_{Sat} at exit [°C]	3	0	-1	6
Total mass flow [kg/h]	160	121	100	50

Maximum load point is equivalent to an evaporation capacity of 10kW. Ideally, the evaporation temperature for the maximum, high and design load points should be lower (equivalent to lower outside temperatures), but the test rig did not allow further lowering of the low pressure due to cavitation problems in the refrigerant pump.

Design load is the load point, at which the highest amount of heating energy has to be delivered in one year by the heat pump designed in the GreenHeatPump project (climate of Düsseldorf, Germany) [1].

The 1-to-16 bionic aluminum distributor has some deviation in its load points. The total mass flow is half in order to have the same mass flow in each exit. The evaporation temperature could be lowered compared to the other measurements.

Table 2: Load points for the bionic aluminum distributor

	Max. Load	**High Load**	**Design Load**	**Low Load**
x at exit [-]	0.43	0.37	0.35	0.22
T_{Sat} at exit [°C]	-6	-7	-7	5
Total mass flow [kg/h]	79	61	51	25

5. Results

As a result, the liquid and the gas flows at each exit of the distributor can be plotted. In the following, the

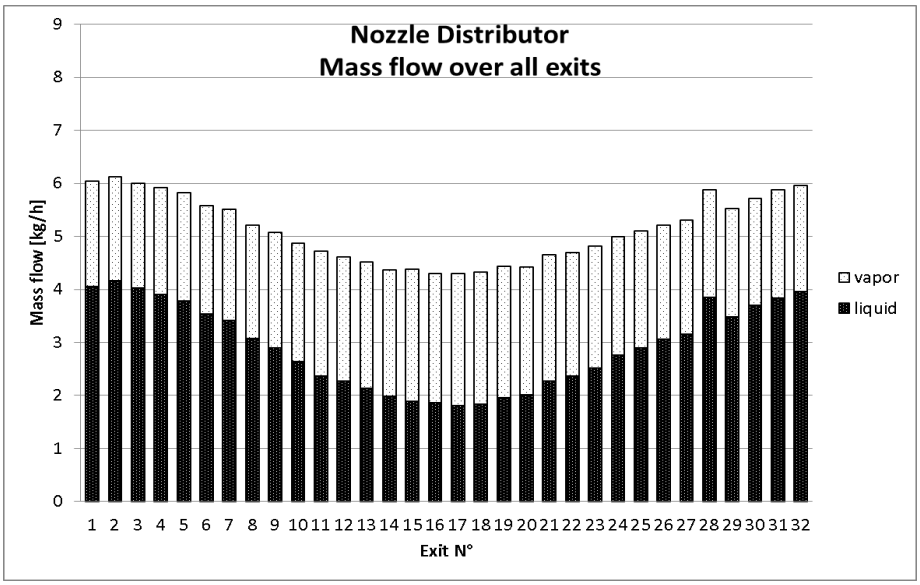


Figure 5: Liquid and vapor mass flow distribution over all exits of a nozzle distributor at maximum load point

maximum load points for all distributors are shown and discussed. In the cases, where in part load other interesting effects occur these are plotted as well, for the other cases, the part load points show a similar behavior as the maximum load point.

5.1. Nozzle distributor

For the nozzle distributor the mass flow is shown in Figure 5. Its distribution seems to depend on the exit´s position on the circumference of the distributor. As the distributor was mounted vertically downward the effect can not be explained by the influence of gravity. The other influence more likely to cause this kind of distribution is that before the distributor the flow's direction was changed in a bend (see Figure 2). Interestingly, the highest flow is registered in the tubes on the inside of the bend (exit 1 and 32 are on the left side of the distributor in Figure 2, while N° 16 is on the right side). Only one exit (N°28) seems to be influenced by another effect.

5.2. Venturi distributor

The Venturi distributor shows a similar overall distribution pattern to the nozzle distributor (Figure 6), but it seems that there is another aleatory influence on top of the dependence from the circumferential position of the exit. A possible explanation is, that the Venturi distributor has smaller connection tubes (2 mm inner diameter instead of 3 mm for the nozzle distributor) and therefore differences in the bending of these tubes or the soldering of the connections have a much higher influence.

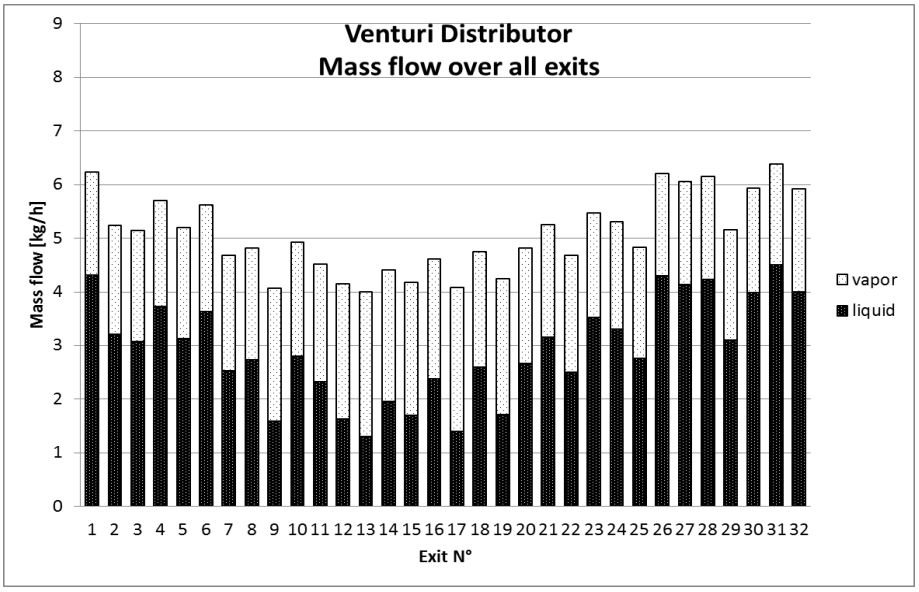


Figure 6: Liquid and vapor mass flow distribution over all exits of a Venturi distributor at maximum load point

5.3. Cascade of Venturi distributors

In the distribution of the cascade of venture distributors it is more difficult to recognize any pattern (Figure 7). For each of the 1-to-8 distributors there seems to be a similar dependence on the circumferential position as for the large nozzle and Venturi distributors. Even tough there is no bend directly before the 1-to-8 distributors, the incoming flow pattern seems to be asymmetric and the Venturi nozzle does not equalize this completely.

In low load the behavior is quite different from the other load points (correlation between maximum load and low load is 0.15).

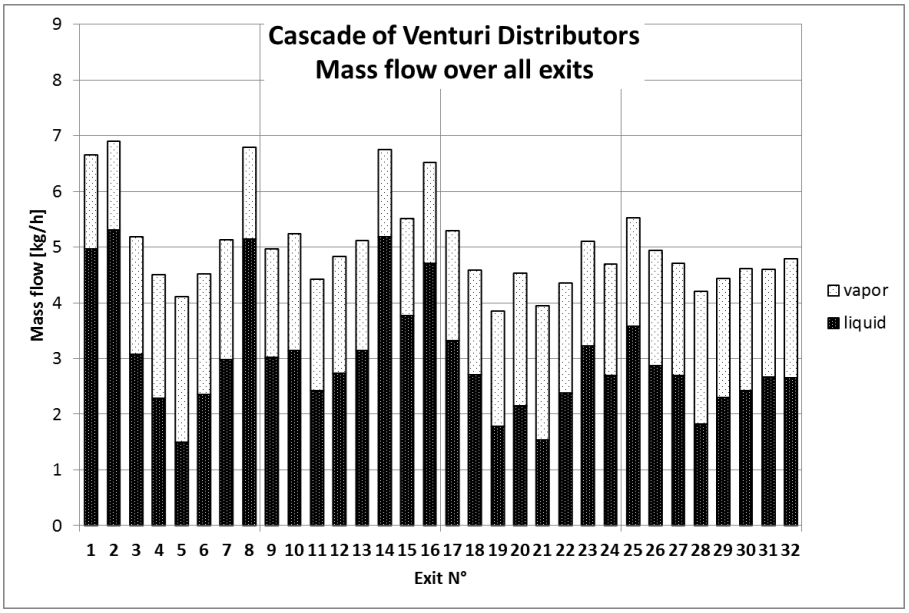


Figure 7: Liquid and vapor mass flow distribution over all exits of the cascade of venturi distributors at maximum load point

5.4. Bionic distributor PMMA

The bionic distributor shows a completely different pattern (Figure 8). On first sight the distribution seems quite aleatory. But connecting it with the geometry of the distributor, some patterns become visible. Assuming that in the bifurcations the flow is not completely symmetric, but still being influenced by the bend before, the pattern becomes easy to explain.

A simple model consists in assuming that in each bifurcation one side is favored over the other. So each exit has five bifurcations upstream, four of which have unequal distribution due to the bend before (the first bifurcation is assumed to be equal distributed because there is no bend upstream). Therefore each exit may be favored between 0 and 4 times. Fitting the model so that each exit gets a basic flow of 4 kg/h and an extra flow of 0.5 kg/h for each favored bifurcation, the distribution in maximum load is described quite well, as shown in Figure 9. The correlation coefficient between the measured and the modelled data is 0.8.

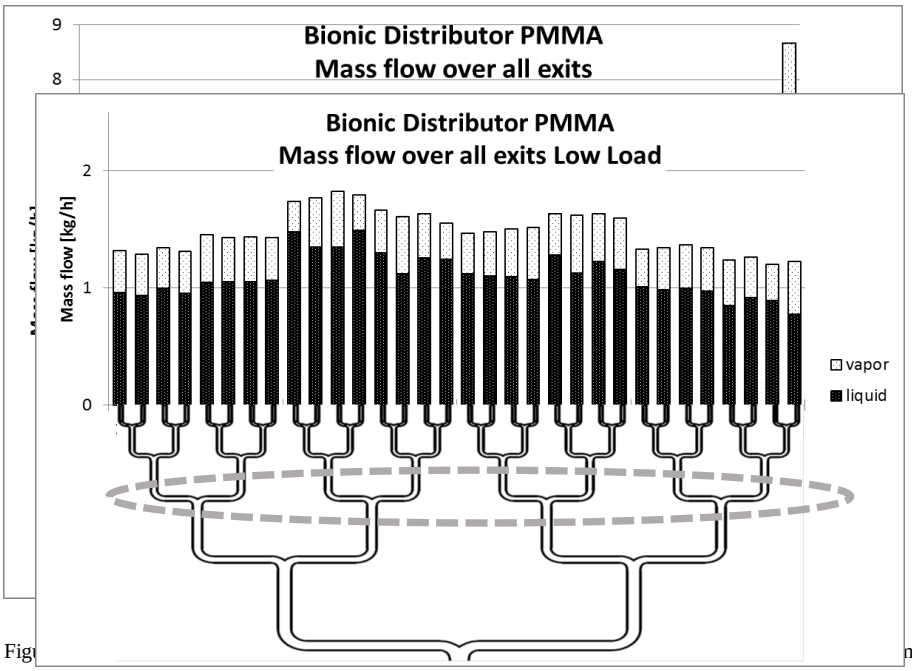


Fig num load point

Figure 10: Liquid and vapor mass flow distribution for the bionic distributor at low load point

But this model completely fails for describing the low load point. Interestingly, even between the measured mass flows at maximum load and low load there is a negative correlation of -0.54. The only explanation for this

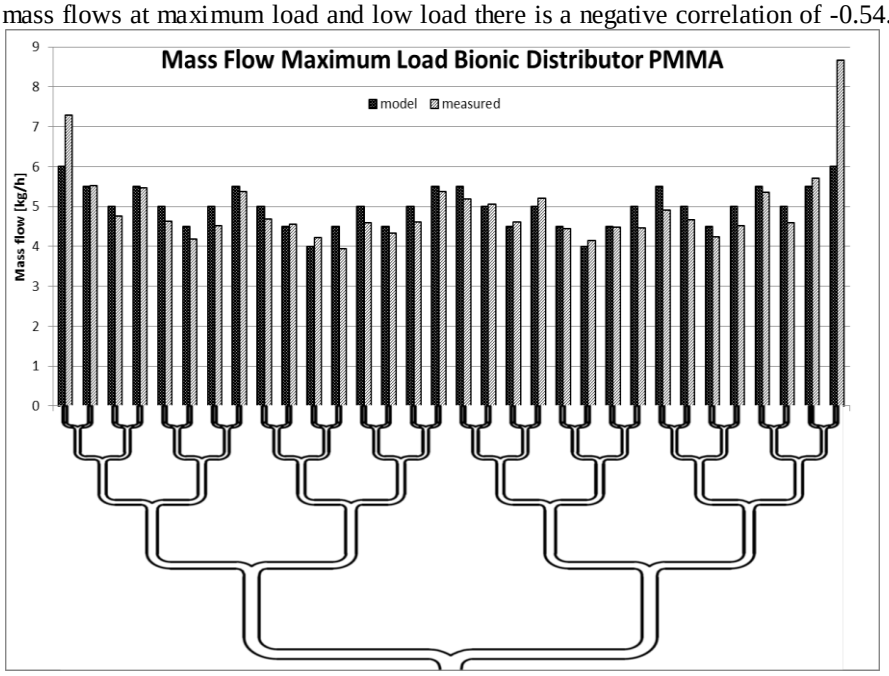


Figure 9: Comparison between measured flow and modelled flow in each exit of the bionic distributor at maximum load point

is that at low load point at least for some of the bifurcations, the preferred sides are inverted. So apparently the liquid refrigerant which is pushed to the outside in the curve swings back and has an impulse to the inside at the bifurcation's position. In Figure 10 this effect can be seen for the marked bifurcation level.

5.5. Bionic distributor Aluminum

For the bionic distributor made of aluminum, the influence of the bends and bifurcations is much weaker than in the PMMA distributor (see Figure 11). This can be explained by the difference between the flow channels.

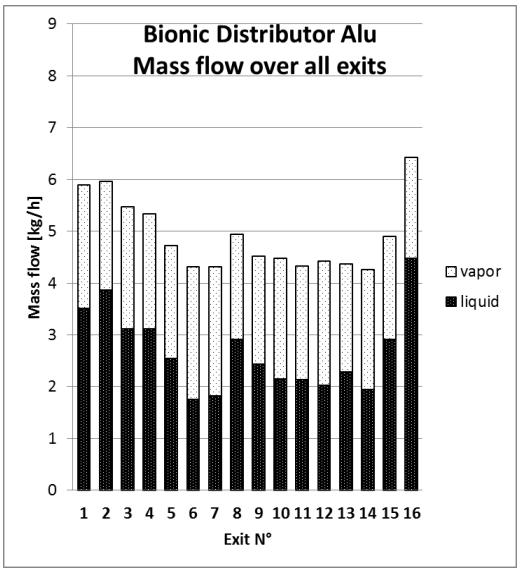


Figure 11: Liquid and vapor mass flow distribution over all exits of the bionic aluminium distributor at maximum load point

The aluminum prototype has flow channels with a semi-circular section (while the PMMA prototype´s are circular) and secondly the walls are quite rough due to the brazing of the aluminum sheets. These two effects seem to maintain a flow regime closer to ideal annular flow in the channels.

5.6. Overall results

As an overall result, the distribution qualities for the different distributors were compared. The measure for the distribution quality was defined as the difference between the highest flow and the lowest flow divided by the average flow.

$$quality = \frac{\max(\dot{m}) - \min(\dot{m})}{average(\dot{m})}$$

With this measure, zero would be perfectly equal distribution. Any deviation of a single channel will result in low quality; other measures of quality, e.g. mean deviation from average, would give less penalty in this case. But this measure was chosen because in a real evaporator even a single channel with too high mass flow gives penalty to the whole system. In a future analysis, a measure taking into account the effects in a refrigeration system could be developed.
The distribution quality has been calculated for the total flow and for the liquid flow. For the evaporation capacity, the liquid flow is more relevant. Figure 12 shows the results for the different distributors.

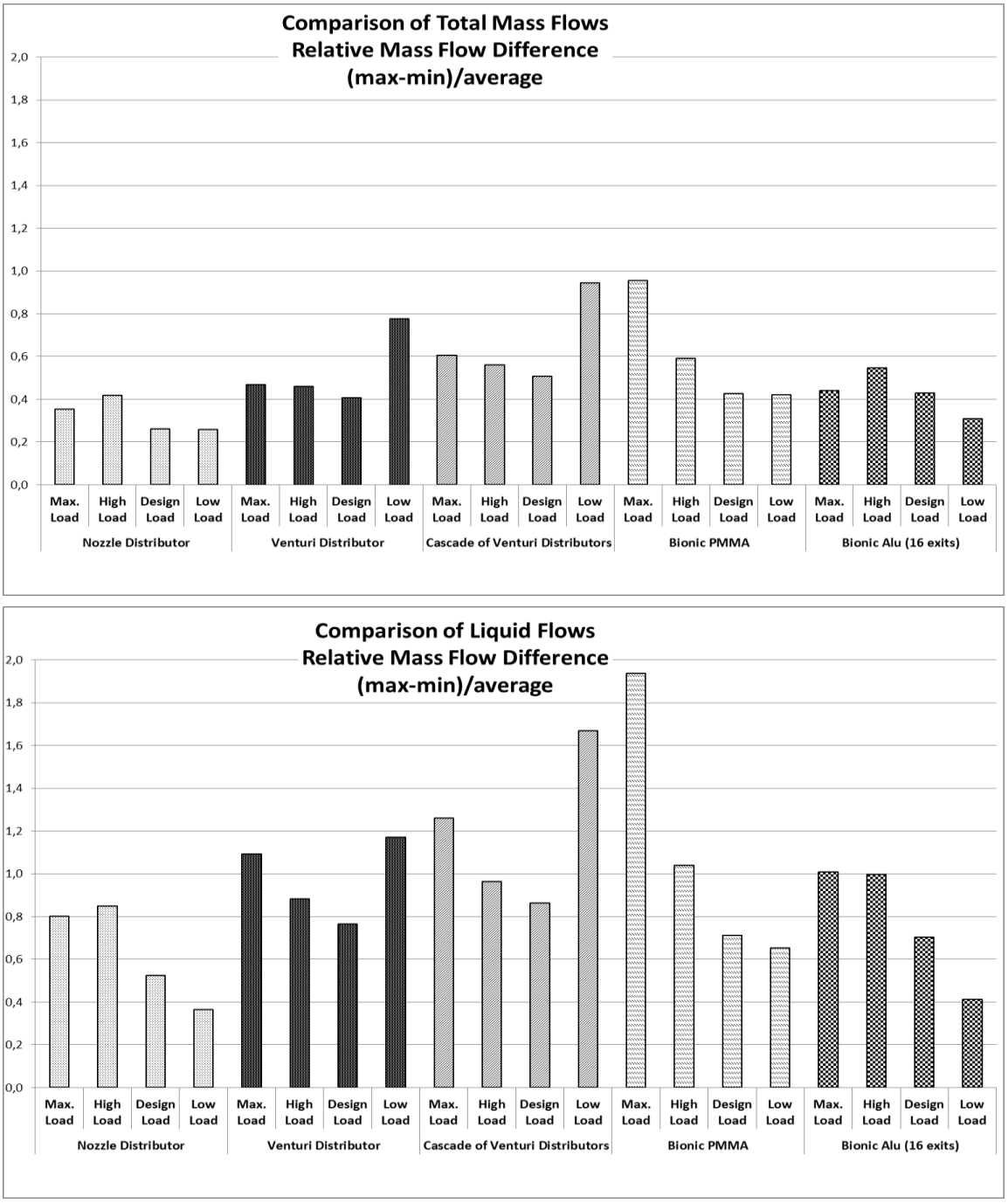


Figure 12: Comparison of the distribution qualities of the different distributors considering total mass flow (above) and only liquid mass flow (below)

6. Conclusion

The two-phase refrigerant distribution was measured for several different distributor types. Different behavior of the different distributors could be distinguished and analyzed.

It could be shown, that the nozzle and the Venturi distributors show a strong dependence of the mass flow of each channel on the circumferential position. This can only be explained by an asymmetric flow in the inlet which in this case probably was caused by the bend upstream. Manufacturers of distributors recommend

positioning them directly at the outlet of the expansion valve in order to avoid asymmetries in the inflow. Our results underline this recommendation.

For the bionic distributors, this dependence on the inflow is negligible. The Plexiglas prototype showed a strong maldistribution due to the effect of centrifugal forces. This effect is more pronounced in an ideal system with smooth walls and perfect circular channels, as the Plexiglas was. In the aluminum prototype, this effect was much weaker, leading to a better distribution quality. As the aluminum prototype is much closer to a real application, the bionic distributor can be considered as a more robust alternative to conventional distributors in terms of inflow conditions.

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