

DEMONSTRATION OF A MICROCHANNEL HEAT EXCHANGER FOR OPERATION IN A REVERSIBLE HEAT PUMP SYSTEM

*Hantz, D., Gulyas, G., Bensafi, A.
Centre Technique des Industries Aéronautiques et Thermiques (CETIAT)
BP 2042 – 69603 Villeurbanne - Cedex France*

*Mercer, K. B.
Modine Manufacturing Company
1500 DeKoven Ave, Racine, WI 53403 U.S.A.*

ABSTRACT

This paper presents results from the integration of a microchannel heat exchanger (MCHEX) into a conventional R410A reversible air-to-water heat pump system. This implementation is made assuming equal face areas for the heat exchangers analyzed. The overall goal of the investigation is to achieve an easy integration of the MCHEX into the baseline unit and an efficiency increase in both heating and cooling modes. The impact of utilizing a MCHEX on refrigerant charge and refrigerant distribution, along with frosting concerns are also evaluated. The baseline unit was tested to establish operating conditions for properly designing the MCHEX into the heat pump system. The new system, equipped with the MCHEX, shows very encouraging results in terms of refrigerant charge reduction (nearly 50% versus baseline unit) and efficiency gain (about 15%) for cooling mode. Tests performed in heating mode demonstrate similar frosting characteristics to the baseline unit and successful draining of the condensed humidity. Distribution patterns of the liquid refrigerant in two phase-flow indicate inadequate circuiting, which leads to approximately equal performance with the baseline unit instead of an anticipated increase. Analysis of the MCHEX circuiting with a thermal imaging (IR) camera has identified areas for further design improvements that will be tested.

Key Words: *Micro channel heat exchanger, heat pumps, distribution, frosting, water drainage.*

1 INTRODUCTION

Microchannel heat exchangers are being considered as an alternative technology to the classical round, copper tube-aluminum plate-finned coils. The major advantages of these types of heat exchangers include increased air-side heat transfer coefficient, decreased air-side pressure drop, and superior corrosion resistance because of an all aluminum construction. From a geometric point of view, the MCHEX has significantly reduced internal volume, leading to less refrigerant charge along with reduced overall weight.

According to past studies, microchannel heat exchangers have demonstrated substantial gains in heat transfer performance compared to traditional round tube plate-fin coils using grooved tubes and efficient fins with the same external face area (TIAX, 2002).

This paper presents the integration of a microchannel heat exchanger into a conventional R410A reversible air-to-water heat pump system. The assumptions and goals for this implementation are as follows:

- fit the microchannel heat exchanger into the cabinet of the heat pump
- match face area of round tube plate-fin coil and microchannel heat exchanger
- reduce overall system refrigerant charge
- increase efficiency both in cooling and heating modes
- investigate refrigerant distribution and frosting issues during heating mode
- indirectly decrease fan noise by reducing air-side pressure drop

2 DESCRIPTION OF THE BASELINE HEAT PUMP

For this experimental study, the reversible R410A heat pump system has a standard heating capacity of 8 kW (with air at 7°C Dry Bulb (DB) temperature, 6°C Wet Bulb (WB) temperature, and a water regime of 30/35°C). The cabinet foot print of this unit is 0.4 m². This heat pump is also equipped with a two-way thermostatic expansion valve. The baseline unit cabinet enclosure is shown in Fig. 1.



Fig. 1. Baseline unit cabinet.

The geometric characteristics of the conventional round tube plate-fin heat exchanger are described in Table 1. This heat exchanger uses new advanced technology of slit fins and 7 mm grooved tubes. The coil is bent 75 degrees, to fit into the cabinet of the heat pump.

Table 1. Description of the round tube plate fin coil in the baseline heat pump.

Characteristics	Units	Values
External Diameter of copper tubes	mm	7
Row spacing	mm	21
Tube spacing	mm	13.5
Fin type	/	Slit fins
Fin spacing	mm	1.7
Fin thickness	mm	0.11
Tubes rows	/	2
Number of tubes per row	/	32
Finned length	mm	1060
Finned height	mm	690
Face area	m ²	0.73
External heat exchange area	m ²	21.5
Weight (with headers)	kg	8.6
Circuiting	/	8 circuits of 8 tubes
Internal volume	l	2.2

3 TESTS PERFORMED ON THE BASELINE HEAT PUMP

The baseline heat pump system was tested according to four standard testing points used in the certification scheme in France:

- Two test points for heating mode with ambient air at 7°C DB and 6 °C WB, along with two water regimes: 30/35°C (for floor heating applications) and 40/45°C (for fan coil unit applications)
- Two test points for cooling mode with ambient air at 35°C, along with two water regimes: 23/18°C (for floor cooling applications) and 12/7°C (for fan coil unit applications)

In addition, one qualitative test was conducted for observation of frosting behavior of the round tube plate-fin coil.

During testing of the baseline heat pump at the nominal points, the heat exchanger was ducted to measure the airflow rate. At the end of the qualitative frosting test, the attached duct was removed to observe frosting characteristics and measure the air-side pressure drop through the coil. Temperature, pressure and mass flow rate on the refrigerant-side are recorded also to ensure an adequate energy balance. Table 2 describes the results obtained from the test performed on the baseline heat pump.

In addition to these results, the behavior of condensate drainage and frosting characteristics were noted as follows:

- The observed drainage patterns of condensate are very typical for such round tube plate-fin coils. Water drains off the vertically oriented slit fins and around the horizontal tubes for easy collection.
- System operation in heating mode at the air conditions of 2°C DB (1°C WB) show frosting of the coil. The circuiting shows that the distribution of the fluid is satisfactory, even if some circuits in the middle of the plate-fin coil are not fed as well as the other circuits. During frosting/defrosting cycles, the following values were obtained:

- The time of one frosting/defrosting cycle is about 35 minutes
- The defrosting time remains constant for each cycle and is less than 4 minutes
- The heating capacity of the coil recovers after a defrosting cycle and then becomes the same

- as before frosting
- This heating capacity remains constant about 15 to 20 minutes during one frosting/defrosting cycle.

Table 2. Test results on the baseline heat pump.

	<i>Air Temp.</i>	<i>Water Temp.</i>	<i>COP</i>	<i>Evaporating Pressure</i>	<i>Evaporator Superheat</i>	<i>Condensing Pressure</i>	<i>Condenser Subcooling</i>	ΔP Refrigerant	ΔP Air across Coil
	°C	°C	W/W	rel. bar	K	rel. bar	K	bars	(Pa)
Heating Mode	7 DB (6 WB)	30/35	4.1	6.7	2.4	22.6	7.6	0.4	25
		40/45	3	6.8	2.4	29.9	11	0.43	24
Cooling Mode	35	23/18	3.2	9.9	9.9	29.7	2.7	0.1	20
		12/7	2.5	7.7	7.7	28.1	2.6	0.1	20

4 MICROCHANNEL HEAT EXCHANGER DESIGN

The design of the MCHEX is based on:

- The performance obtained from test results on the baseline heat pump
- Assuming the same face area of the actual round tube plate-fin coil in the baseline heat pump
- Consideration of refrigerant distribution issues known with microchannel extrusions
- Characteristics of frosting and water drainage to be complimentary to the round tube plate-fin coil

Taking into account manufacturing constraints, the only viable design for this experimental study is to use a MCHEX with horizontal extrusions and vertical headers. This type of design ensures that the MCHEX will fit correctly into the baseline unit at a non-prohibitive cost and is manufacturable. Refrigerant distribution concerns are addressed by using 8 individual inlets. In each inlet section, five extrusions are present and then separated by baffles. Figure 2 is a diagram of the circuiting scheme.

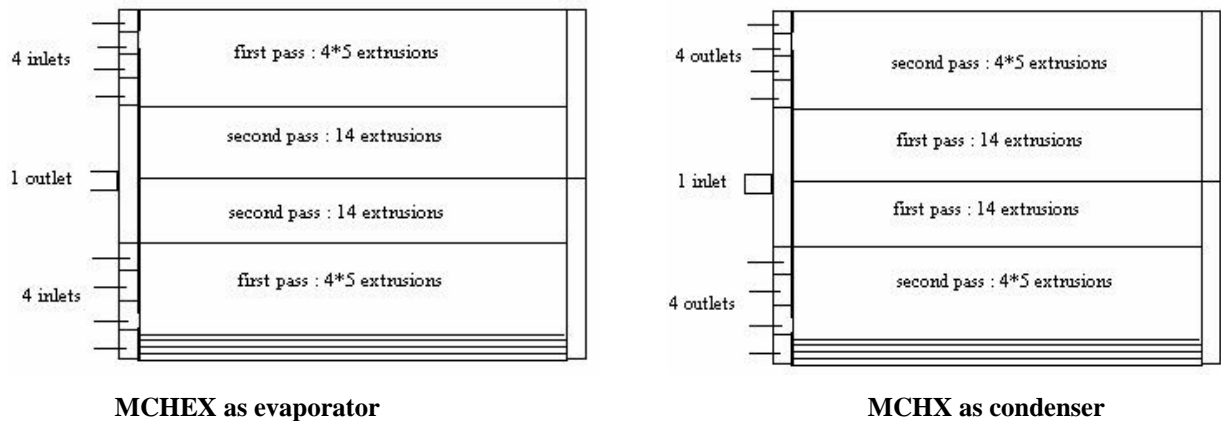


Fig. 2. MCHEX design for condensing and evaporating mode.

The frosting and condensate drainage concerns are addressed with a specific plate-fin design that allows water to fall down at the back side of the MCHEX. Figs. 3 and 4 depict the direction of airflow and illustrate how water drainage is achieved with such orientation of the MCHEX.

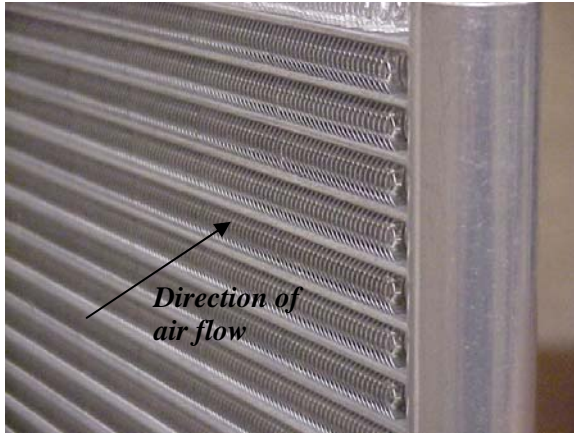


Fig. 3. Front side of MCHEX.

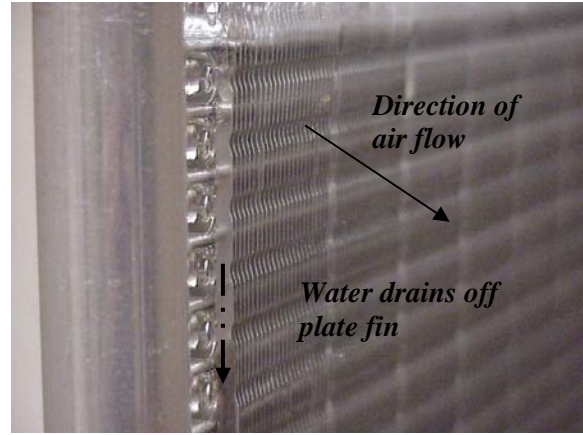


Fig. 4. Back side of MCHEX.

The geometric characteristics of the MCHEX are described in Table 3.

Table 3. Physical description of the MCHEX selected.

Characteristics	Units	Values
Extrusion length	mm	1060
Extrusion width	mm	19
Extrusion height	mm	1.9
Total Number of extrusions	/	68
Number of rows	/	1
Fin width	mm	21.5
Fin height	mm	8
Fin thickness	mm	0.11
Fin geometry	/	"half moon"
Fin spacing	mm	1.6
Finned length	mm	1060
Finned height	mm	690
Face area	m ²	0.73
External heat exchange area	m ²	19.9
Mass with header	kg	8.8
Circuiting	/	2 circuits of 2 passes
Internal volume	l	1.3

5 EXPERIMENTAL EVALUATION OF THE MCHEX ON A REVERSIBLE HEAT PUMP SYSTEM

5.1 Geometric Comparison Between Plate-Fin Coil and MCHEX

Table 4 compares the primary dimensions of the round tube plate-fin coil and the all aluminum microchannel coil. From this table, it can be noted that:

- Coil weight was not reduced by utilizing a MCHEX in this case. The main reason is the size of the aluminum headers on the MCHEX which are much heavier, compared to the copper headers used on the classical plate-fin coil.
- The MCHEX presents a total size reduction of 20% because of only 1 row in depth, compared to 2 rows deep of the round tube plate-fin coil.
- The internal volume of the MCHEX is 40% less than that of the round tube plate-fin coil.

5.2 Integration of the Microchannel Coil into the Heat Pump System

As shown on Fig. 5, the bent MCHEX provided for this study fits perfectly in the cabinet for the baseline heat pump.

Table 4. Geometric comparison of the plate-fin coil and the MCHEX.

Dimensions	Units	Round tube plate-fin coil	MCHEX
Finned length	mm	1060	1060
Coil height	mm	690	690
Coil depth	mm	27	21.5
Face area	m ²	0.73	0.73
External heat exchanger area	m ²	21.5	19.9
Total weight	kg	8.6	8.8
Internal volume	ltr	2.2	1.3

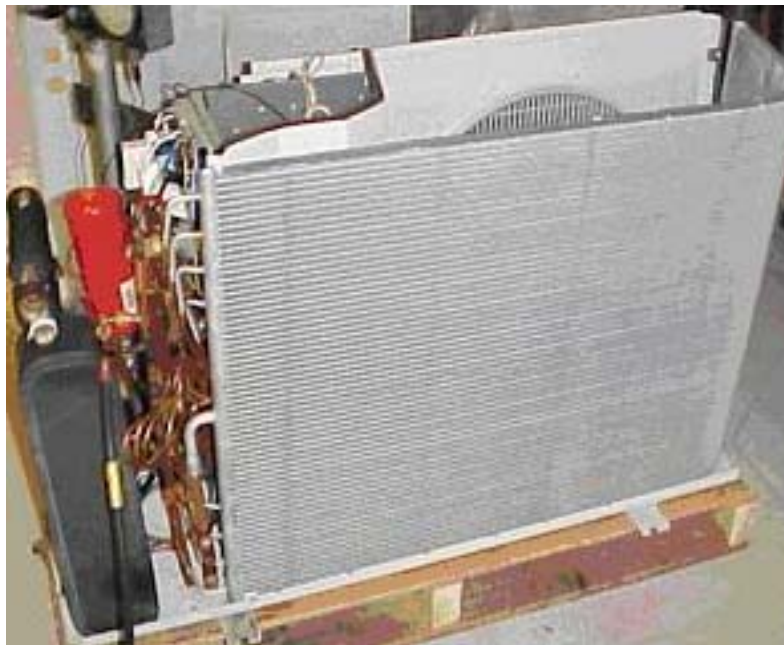


Fig. 5. Arrangement of MCHEX in the baseline heat pump.

5.3 Test Results in Cooling Mode

In this mode of operation, the MCHEx operates as a condenser. The refrigerant charge determination is conducted with 35°C air temperature and a 12/7°C water regime on the brazed plate heat exchanger. When comparing with the baseline results, this determination ends up with a 40% charge reduction, an increase of 9 % on the cooling capacity and an efficiency improvement of the heat pump system by 15%. The increased efficiency is gained with the MCHEx because the condensing pressure is decreased from 48°C to 45°C.

5.4 Test Results in Heating Mode

In this mode of operation, the MCHEx operates as an evaporator. The experimental evaluation is performed with 7°C DB/6 °C WB air temperature and a 40/45°C water regime on the brazed plate heat exchanger. The refrigerant charge determined during cooling mode is used during this test. The results obtained, in comparison with the baseline heat pump, are as follows:

- Almost identical heating capacity and efficiency
- To get this performance with MCHEx, superheating has been reduced to the minimum.

The objective was to also increase performance on the evaporator side, however, because of mal-distribution, this goal was not met.

5.4.1 Distribution concern

As mentioned by other researchers, the distribution of refrigerant liquid in two phase flow at the inlet and through any return header of a MCHEx is a critical issue. Due to the fact that the MCHEx used in this experimental study includes horizontal extrusions, this issue becomes even more critical. Fig. 6 shows the temperature repartition of the face of the coil, thus indicating the refrigerant distribution in the MCHEx acting as an evaporator. This image, taken with an IR camera, demonstrates that the second pass of the upper part of the MCHEx is not correctly fed with refrigerant, due mainly to the effect of gravity in the return (at the right on the figure) header.

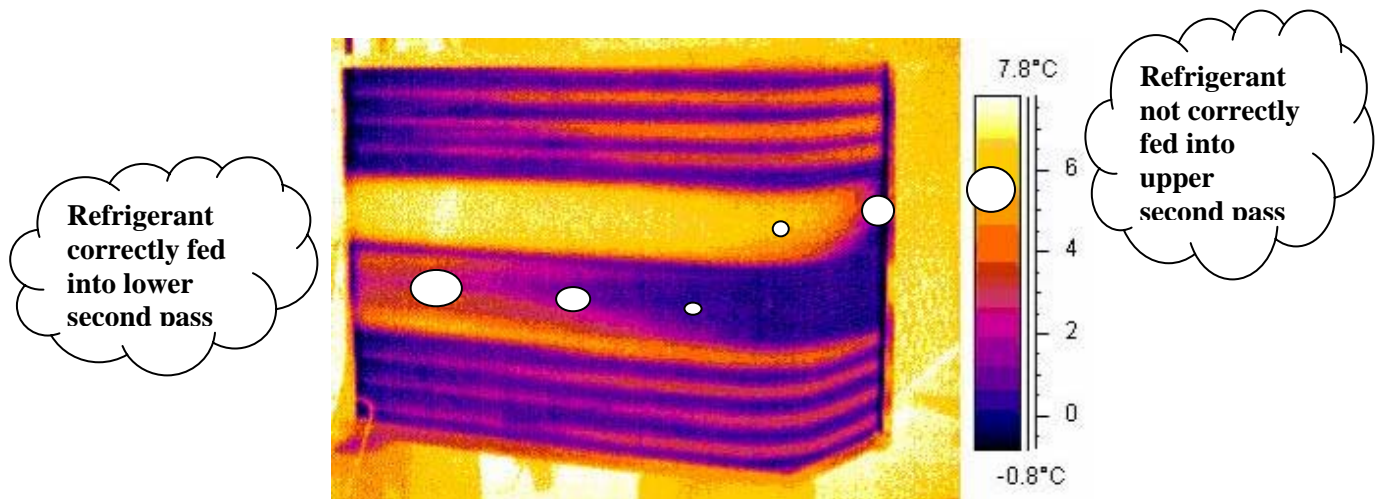


Fig. 6. IR image showing distribution of temperature in MCHEx.

5.4.2 Drainage of condensate concern

Tests performed by some American laboratories (ACRC, Purdue University), and confirmed by CETIAT in 2002 have concluded that conventional microchannel heat exchangers must have a horizontal header orientation (and therefore vertical tubes) to allow for drainage of water condensate. Traditionally so far, such microchannel coils are made with a serpentine fin design, therefore not allowing a route of drainage if utilized with vertical headers. As previously shown, the MCHEX used in this study is manufactured with a plate fin at the back-side of the coil to provide a path for water drainage. To validate this technical feature, during thermal performance tests, the evolutions of air pressure drop and of the air flow rate through the MCHEX are recorded. Fig. 7 demonstrates experimentally that no variation effects for both air flow rate and air pressure drop exist. This trend allows one to conclude that water drainage performs correctly.

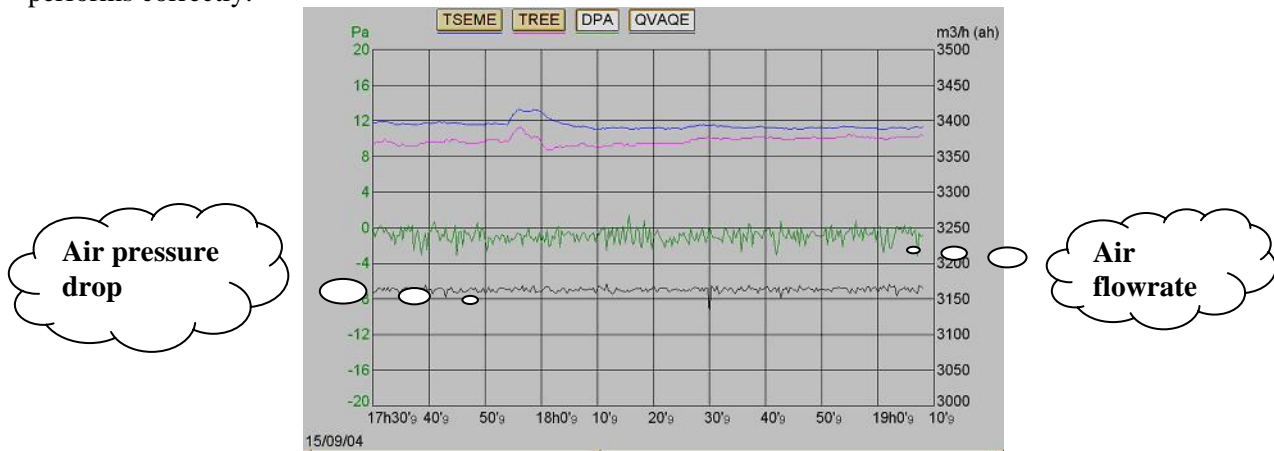


Fig. 7. Dynamic behavior of MCHEX during testing in heating mode.

5.4.3 Frosting concern

The frosting of the MCHEX is analyzed at the air conditions of 2°C DB / 1°C WB. Fig. 8 shows the aspect of the MCHEX after 30 minutes of frosting. Mal-distribution in the second pass of the upper section can be clearly seen as too much superheat is returned. Gravity forces much of the liquid to the bottom tubes in the upper section.



Fig. 8. MCHEX aspect after 30 minutes of frosting.

The behavior of the MCHEx during defrosting is illustrated in Fig. 9. The defrosting process corresponds directly to the way the MCHEx has been fed.



Fig. 9. MCHEx defrosting behavior (after one minute at the left, and three minutes at the right).

During frosting/defrosting cycles, the following values are obtained:

- The time of one cycle frosting/defrosting is about 35 minutes (identical to the cycle time observed on the baseline heat pump)
- The defrosting time remains constant for each cycle and is about 7 minutes (clearly longer than the 4 minutes measured on the baseline heat pump)
- The heating capacity recovers after a defrosting cycle, the same value as before frosting (as on the baseline heat pump)
- This heating capacity remains constant about 15 to 20 minutes during one cycle frosting/defrosting (as on the baseline heat pump)

6 FIRST CONCLUSIONS AND WORK IN PROGRESS

This experimental study of the implementation of a MCHEx in place of a round tube plate-fin coil is still in progress. However, the results presented in this paper allow the following conclusions to be made:

- The designed MCHEx has proven to fit correctly into the chassis of the baseline heat pump unit ;
- The MCHEx allows a 40% reduction of the refrigerant charge compared to the base line heat pump system ;
- During cooling mode, an efficiency increase of 15% was shown for the MCHEx system ;
- **During heating mode, no efficiency increase was shown for the MCHEx system, however, there was no degradation in performance ;**
- **The manufacturer of the MCHEx has achieved a fin design to allow for vertical headers and enable water drainage for this coil orientation**

Table 5 summarizes the quantitative and qualitative results obtained during this experimental study.

Table 5. Summary of experimental results obtained.

	Baseline HP		HP with MCHEX	
	Cooling mode	Heating mode	Cooling mode	Heating mode
Refrigerant Charge	100	100	-41%	-41%
Refrigerant feeding	/	/	GOOD	MEDIUM
Refrigerant ΔP	0.08	0.43	0.14	0.48
Thermal duty	100	100	8%	-1%
Power Input	100	100	-5%	1%
EER/COP	100	100	14%	-3%
Drainage of water	/	OK	/	GOOD
Defrosting time	< 4 minutes		about 7 minutes	

6.1 In Cooling Mode (MCHEX as a condenser):

Results obtained show in a real application an increase of the cooling capacity by approximately 10% and an efficiency improvement of the heat pump by 15%. In consequence, it can be concluded that the use of a MCHEX as a condenser is very beneficial for generating substantial gains in efficiency and/or in compactness compared to actual units that utilize traditional round tube plate-fin coils. Further, and assuming operation at constant EER, substantial gains in capacity can be obtained, which enable manufacturers to increase the nominal capacity of a given unit, whilst using the same chassis and a larger size compressor.

6.2 In Heating Mode (MCHEX as an evaporator):

Results obtained satisfy 2 of the 3 objectives related to the critical concerns linked to the use of microchannel heat exchangers as evaporators:

- Good drainage of water is achieved by use of a plate-fin design for a vertical header (horizontal extrusions) oriented coil ;
- Frosting/defrosting cycles are repeatable and comparable to those obtained with a classical round tube plate-fin coil ;

The remaining critical concern is the feeding of the MCHEX with liquid during the two-phase flow regime. As shown in Fig. 6, when using vertical headers, gravity effects in the return header play a huge role. Density of liquid is much higher than vapor, and as a result the liquid droplets quickly fall to the bottom. However, when fed against the gravitational force, much better distribution is achieved. This is shown in the bottom pass of the MCHEX. The IR camera photographs show clearly that there is room for improvement in the feeding of the MCHEX.

Work in progress is in consequence concentrated on such a design improvement of MCHEX circuiting to achieve better refrigerant distribution in heating mode.

This work will allow a statement to be made as to the potential and merits of microchannel used in heat pump system applications.

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