Potential Of Brazed Finned Tube Heat Exchangers In Comparison To Mechanical Produced Finned Tube Heat Exchangers

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POTENTIAL OF BRAZED FINNED TUBE HEAT EXCHANGERS IN COMPARISON TO MECHANICAL PRODUCED FINNED TUBE HEAT EXCHANGERS

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ABSTRACT

Mechanically assembled finned tube heat exchangers are currently used for most refrigeration and domestic A/C systems. The tubes and fins of such heat exchangers mostly consist of different metals, e.g. copper and aluminum. The system weight, especially in mobile systems, can be reduced when only aluminum is used for the constructions. For the last 15 years micro channel heat exchangers were developed for automotive air conditioning systems. For this design the aluminum fins are brazed between aluminum profiles in order to increase the heat transfer, the efficiency and the design flexibility. In addition to the reduction in heat exchanger size and weight, these systems can be operated with lower refrigerant charge. All aluminum heat exchangers show advantages concerning recycling.

Literature researches have shown an increase of heat transfer for brazed designs in comparison to mechanical designs. The contact resistance between the tube and the fin is reduced and the heat transfer performance is improved. Capacity measurements were carried out to confirm the theoretical considerations and to show the potential of brazed heat exchangers. Mechanically produced and brazed heat exchangers of identical dimensions and designs were simultaneously investigated in a wind tunnel. All internal and external values were kept constant during the measurements. The heat exchangers were water heated and air cooled during the experiments.

INTRODUCTION

Perspectives of aluminum as a construction material for stationary air-conditioning systems were presented at the last Purdue Refrigeration and Compressor Engineering Conference in 2000. A test facility for the investigation of different heat exchanger designs was introduced as a perspective for further studies [1].

Mechanically expanded finned tube heat exchangers are mostly applied in stationary air-conditioning systems. Copper tubes are inserted into aluminum fin plates with collars and stabilized by mechanical expansion of the tubes. Such mechanically produced joints have shown, however, imperfect interfaces on a microscopic scale, causing so called contact resistances [2]. These contact resistances can be eliminated by brazing or welding.

In the present study two identical aluminum finned tube heat exchangers, usually used in refrigeration systems, were tested. One of these heat exchangers was additionally brazed in order to evaluate the contact resistance influence on the heat exchanger capacity.

The heat exchangers were simultaneously tested in a test facility, water heated and air cooled during the experiments. All important data were continuously measured and recorded. The capacities were calculated and the results of each heat exchanger were compared.

This study does not intent to promote a new heat exchanger design. The results rather implicate that the most preferred design in consideration of the aluminum brazing production technology is the micro channel heat exchanger design.

STATE OF THE ART

Basics

Energy in form of heat will generally transmit between two fluids in heat exchangers. The fluids are separated from each other through tube or profile walls. Heat will transmit from the fluid with higher temperature to the fluid with lower temperature via the wall. A general equation for the heat exchanger capacity $\dot{Q}$ is:

$$\dot{Q} = k \cdot A \cdot \Delta\vartheta_m \qquad (\Delta\vartheta_m : \text{logarithmic temperature difference}) \tag{1}$$

with

$$\frac{1}{k \cdot A} = \frac{1}{\alpha_{Air} \cdot A_{Air}} + \frac{\delta_{Tube}}{\lambda_{Tube} \cdot A_{Tube}} + \frac{1}{\alpha_{Liquid} \cdot A_{Liquid}} \tag{2}$$

As shown in equation 1 and 2, the heat transfer only depends on the product $k \cdot A$. A low heat transfer coefficient k can be compensated by an increased heat transfer area A. When considering air cooled finned tube heat exchanger, k will be mainly influenced by the heat transfer coefficients of the liquid fluid α_{Liquid} in the tube and the air outside of the tube α_{Air}, from the wall thickness δ_{Tube} as well as from the heat transfer characteristic of the tube material λ_{Tube}.

The heat transfer coefficient of a liquid is much higher than the heat transfer coefficient of a gas [3]. Air cooled finned tube heat exchangers will be equipped with large heat transfer surfaces on the air side in order to obtain higher heat transfer capacities. Until now most developments are focused on improving the heat transfer by increasing of heat transfer surfaces.

The heat transfer performance on the air side can be increased with fins while alternated designs of fin surfaces have been applied to optimize their efficiency. In addition, enhanced designs of internal tube surfaces are used to optimize the heat transfer characteristics on the fluid side. Little effort has been spent to reduce heat transfer resistances on connecting surfaces of metal parts. Good results were obtained for example at the aluminum brazing of the contact area fin/tube from micro channel heat exchangers in automotive air conditioning systems [4].

Contact resistance and heat transfer

The joints between fin and tube were thoroughly investigated in previous studies [5]. In this study, fin/tube joints formed by mechanical expansion and aluminum brazing were produced in order to compare the different contact areas in more detail. The joints were cut and polished to prepare samples for the microscopic surface analysis. Enlarged pictures of the microscopic surface analysis are shown in figure 1.

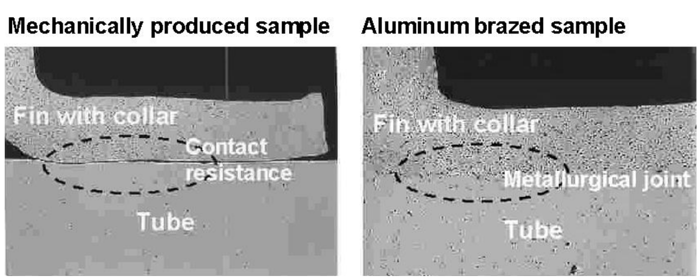

Figure 1: Microscopic surfaces of a mechanical produced and aluminum brazed joint sample [5]

A small gap between the tube and fin can be seen in the mechanical produced joint sample in figure 1. Mechanical joints do not completely contact on a microscopic scale which causes so called contact resistance. The contact resistance can be eliminated by a metallurgical bond as depicted on the aluminum brazed sample.

Contact resistances can decrease the heat transfer [1, 2]. The heat transfer of a conventional air cooled heat exchanger can be calculated with semi empirical equations from the literature [6].

Literature references about the comparison of brazed and mechanically produced joints show improved heat transfer of up to 15% [7,8]. These improvements are predominately related to the contact areas between tubes and fins. A test facility was designed and built in order to verify the theoretical values and to demonstrate the benefits of brazed finned tube heat exchangers.

TEST FACILITY

Figure 2 represents the test facility for the heat exchanger investigations.

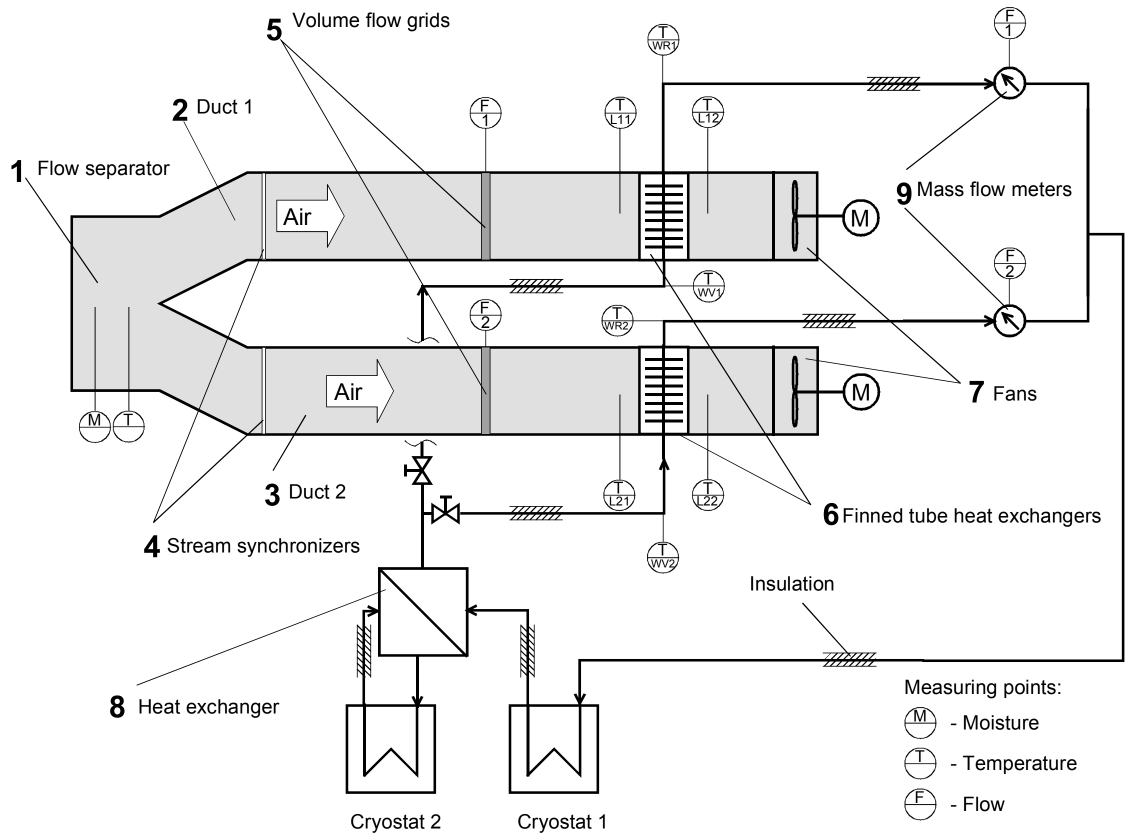

Figure 2: Test facility

Fans draw ambient air into a flow separator (1) as depicted in figure 2. The ambient air will be distributed in duct 1 (2) and duct 2 (3) behind the flow separator. Stream synchronizers (4) were installed in both ducts to produce homogenous streams. The air volume flow is measured by volume flow grids (5). The heat exchangers are located in special fixtures (6) which are inserted into the ducts during the simultaneous trials. The fans (7) are mounted at the outlet of the ducts. The fan speed for both ducts can be adjusted independently. The cryostats 1 and 2 are connected via a heat exchanger (8) in order to supply the finned tube heat exchangers with hot water. All hot water tubes are insulated. Magnetic mass flow meters (9) are installed at the outlet of both heat exchangers. All experimental data for the investigations of the heat exchangers are continuously measured and recorded by a data acquisition system.

Characteristics of the test facility

The standards ASHRAE 33-78 [9], DIN EN 305 [10] and DIN EN 306 [11] were followed for the capacity measurements of heat exchangers in this study. Both heat exchangers were simultaneously tested under identical conditions. Table 1 represents the requirements of the standards and the characteristics of the test facility.

Table 1: Requirements of the standards and the characteristics of the test facility

Values	Test facility	DIN EN 305/306	ASHRAE 33-78
Water volume flow Flow rate: Accuracy:	 ≤ 70 l/h 0,25 %	 ≤ 50 l/h 1 %	 No information 1%
Air volume flow Velocity: Accuracy:	 ≤ 7 m/s 2 %	 ≤ 100 m/s 5 %	 No information 5 %
Water temperature Accuracy:	 ± 0,25 K	 No information	 ± 0,50 K or 2 %
Air temperature Accuracy:	 ± 0,25 K	 No information	 ± 0,5 K

All values measured with the test facility are within the accuracy of the considered standards. In addition, the average capacity was calculated and the heat balance between water and air side was recorded and controlled for all measurements. The calculated balances should be within the range of ±5% [9].

Heat exchanger samples

Aluminum brazing involves joining of heat exchanger components with a brazing alloy, usually an aluminum alloy (Al-Si) whose melting point is appreciably lower than that of the components. This brazing alloy is usually made available from cladded aluminum sheet (in this particular case from fin cladded plates, see table 2) and the assembly is then heated to brazing temperature (600°C) where the brazing alloy melts but not the components. Upon cooling, the brazing alloy forms a metallurgical bond between the joining surfaces of the components.

Table 2: Heat exchanger sample characteristics

Characteristics	Mechanical produced heat exchanger	Aluminum brazed heat exchanger
Total height	3120 mm	3120 mm
Total Weight	2126 g	2187 g
Number of fins	89	91
Height of fin package	250 mm	249 mm
Length of inlet and outlet tube	105 mm	105 mm
Joint - tube/fins	Fins: cladded aluminum sheets (8816 Finspon/Saba), tubes were mechanically expanded, clad AA 4343	Fins: cladded aluminum sheets (8816 Finspon/Saba), tubes were mechanically expanded, fluxed and brazed , clad AA 4343

The differences in table 2 are based on the different production procedures. A higher total weight of the brazed heat exchanger is mainly caused by the used flux.

CAPACITY MEASUREMENTS

The test facility was started and the heat exchanger water inlet temperatures were adjusted. Stationary conditions were achieved after approx. 3 hours. Measurements were taken in long term tests for different ambient temperatures at constant air mass flows and water volume flows, as well as in short term tests for constant air mass flows and different water volume flows at a constant temperature. All data were continuously recorded by a data acquisition system. Same turbulent stream patterns were estimated for the air and water side for the evaluation of each heat exchanger.

Each heat exchanger was investigated in each duct in order to eliminate systematic duct errors. Different temperature deviations for the air and water side could be observed.
Air side: The air inlet temperatures were different and showed deviations of 0,23 to 0,5K between the ducts after the flow separator. A systematic error however was not evident.

Water side: The deviations of the water inlet temperatures were below 0,25K and within the total accuracy of the temperature sensors. Consequently only, the water inlet and outlet temperatures were used for the calculation of the capacity. These results were confirmed by [12].

The capacity transfer on the water side is determined with the isobaric heat capacity of water $c_{p,W}$, the water mass flow $\dot{m}_W$ and the difference of the inlet and outlet heat exchanger water temperatures ΔT_W with equation 3:

$$\dot{Q}_W = \dot{m}_W \cdot c_{p,W} \cdot \Delta T_W \tag{3}$$

RESULTS AND DISCUSSION

In a first test the mechanically produced heat exchanger was installed in duct 1 and the brazed heat exchanger in duct 2. Long and short term experiments were conducted under the above mentioned conditions. The results are depicted in figure 3 and 4.

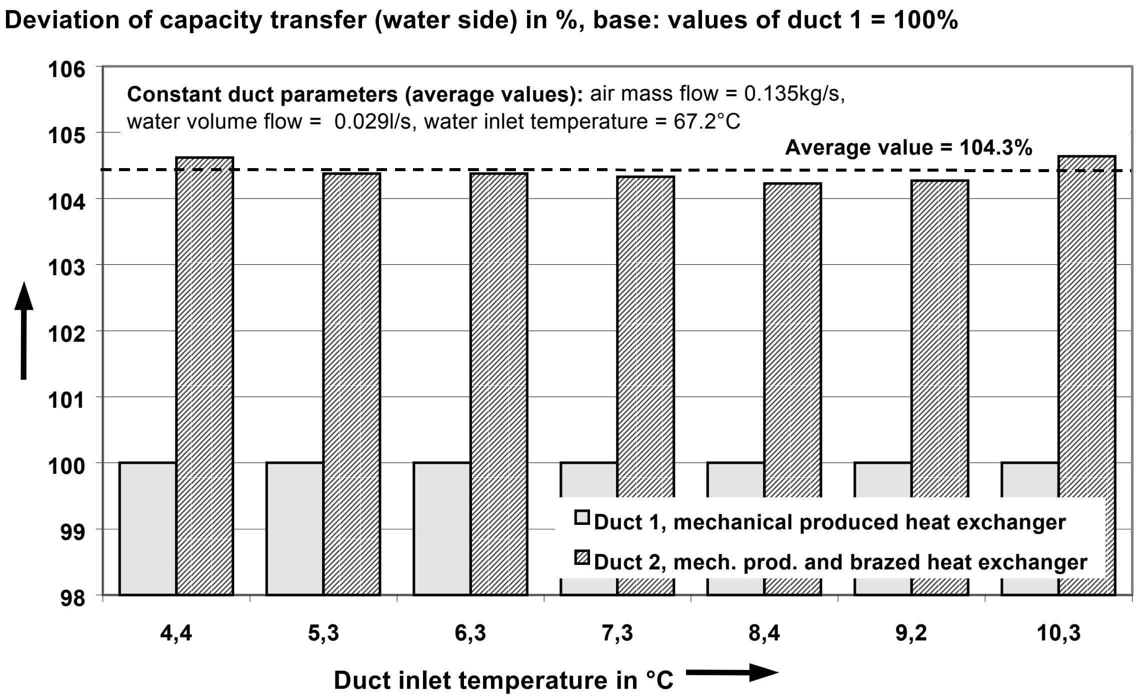

Figure 3: Long term test, capacity transfer (water side) for different duct inlet temperatures and heat exchangers

As shown in figure 3 the average capacity transfer is about 4.3% higher for the brazed than for the mechanically produced heat exchanger. Capacity deviations at different duct inlet temperatures can be neglected.

As pictured in figure 4 the capacity transfer on the water side increases with higher water volume flows. The brazed heat exchanger in duct 2 shows average capacity improvements of 5.3% compared with the mechanically produced heat exchanger.

In a second trial the mechanically produced heat exchanger was assembled in duct 2 and the brazed heat exchanger in duct 1. A systematic error of the capacity characteristics of the two ducts was detected in previous investigations [12] and confirmed in this study.
The 4.3% capacity benefit for the brazed assembly turned into a 1.5% penalty after the heat exchangers where switched between the ducts.
Results were consistent in long term tests with varying air inlet temperatures as well as in short term tests with varying water volume flows.

A comparison of both long term test results is illustrated in figure 5.

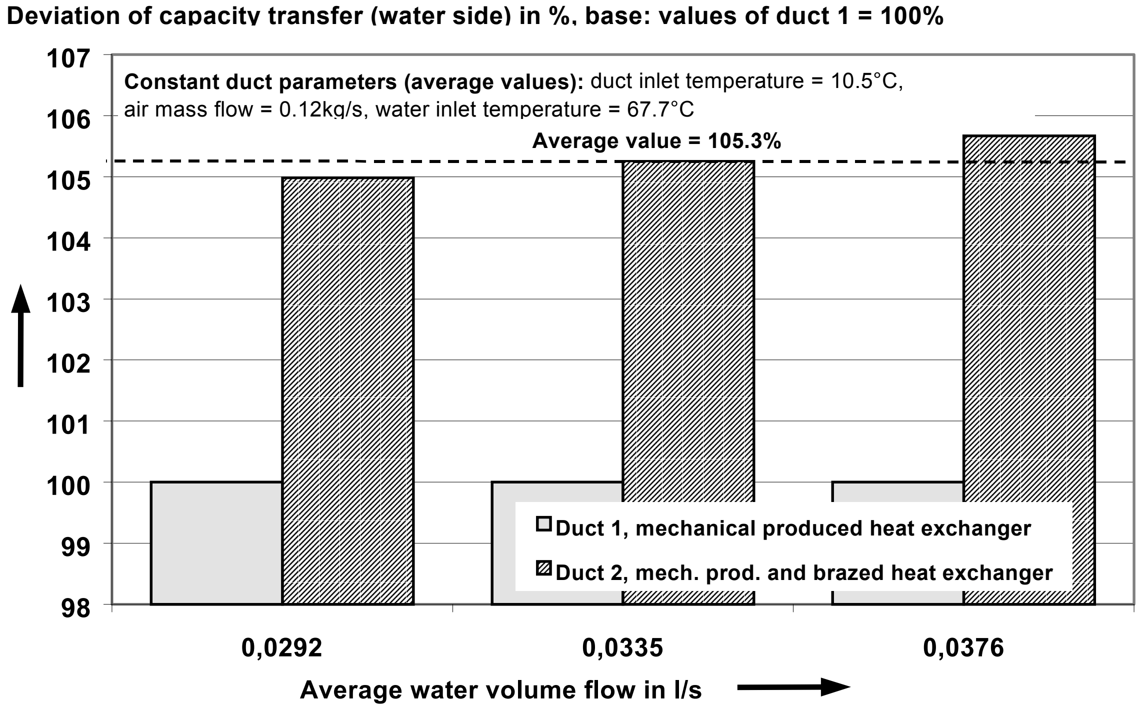

Figure 4: Short term test, capacity transfer on the water side for different average water volume flows and heat exchangers

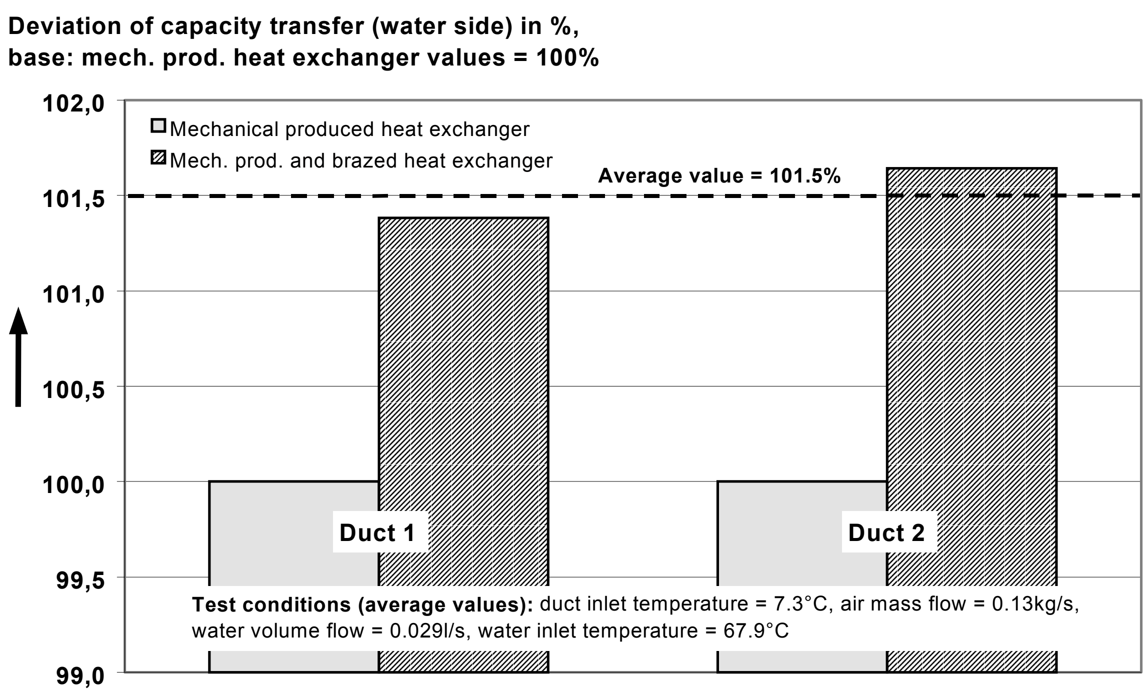

Figure 5: Comparison of the average capacity transfer of different heat exchangers in duct 1 and 2 from both long term tests

As can been seen in figure 5, the brazed heat exchanger shows better values than the mechanically produced heat exchanger when positioned in duct 1 and duct 2. Average capacity improvements of 1.5% are demonstrated. These improvements, however, are not as high as expected from the results of theoretical studies.

After the capacity trials, the brazed heat exchanger was cut into segments and the brazing joints of the tube to fin areas were metallographically examined in order to investigate the reasons for the differences in theory and practice.

The microscopic analysis of the brazed heat exchanger showed that less than 50% of the collar surfaces were joined to the tubes. Poor joint formation therefore resulted in only minor capacity benefits of the brazed unit.

As the investigated brazed heat exchanger was the optimum result of intensive trials, where several options to apply filler metal and flux where tested, it must be contested that this conventional heat exchanger design (fin plates and round tubes) is not appropriate for furnace brazing.

Nevertheless a benefit in performance, resulting from partial metallurgic bonds between fin collar and tube surfaces were demonstrated.

SUMMARY

Simultaneous capacity measurements of a mechanically expanded and mechanically expanded aluminum brazed finned tube heat exchanger were carried out in an existing test facility. The heat exchangers were water heated and air cooled during the experiments. ASHRAE 33-78 and DIN EN 306 were followed during all measurements. Measurements were taken in long term tests for different ambient temperatures at constant air mass flows and water volume flows, as well as in short term tests for constant air mass flows and different water volume flows at a constant temperature. Each heat exchanger was investigated in each duct in order to eliminate systematic duct errors. The heat balance between air and water side was continuously compared during the experiments.

In average, capacity improvements of 1.5% were measured for the aluminum brazed heat exchanger.

A metallographic analysis of the brazed collar-tube to fin contacts revealed incomplete joint formation. Lower then expected capacity benefits can be attributed to this fact.

ACKNOWLEDGEMENTS

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