STUDIES AND RESEARCHES REGARDING THE OFFSET FIN INFLUENCE ON THE ALUMINUM BRAZED PLATES HEAT EXCHANGERS PERFORMANCES

PhD thesis - Summary

to obtain the scientific title of doctor at

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in the doctorate field of Mechanical Engineering

autor Eng. Septimiu Radu ALBEŢEL

Scientific leader Prof.univ. emerit dr. ing. Mihai NAGI

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The thesis is structured in 6 chapters and 3 annexes. The first 3 chapters are introductory and supporting chapters in which the motivation of the thesis is explained, the current state of research in this field is presented and the concepts necessary for the rest of the thesis are introduced. The next chapters describe the conducted research on the offset fin type. The last chapter shows the conclusions and the personal contributions. The 3 annexes detail the work procedures like the error handling (Annex A), the source code for the software used for the data interpretation (Annex C) and part of the raw experimental data (Annex B).

Chapterl Introduction

In nature there are three different ways in which the heat transfer process can occur: radiation (this takes place between two bodies with different temperatures - higher than 0 K), conduction (the heat transfer occurs between solid bodies and a stationary liquids) and convection (the heat transfer takes place between a stationary medium and moving liquid).

The devices used to ensure the heat transfer are called heat exchangers. These devices can be built in different types of constructive solutions depending on the type of heat transfer they make. So, in agricultural, automotive, industrial industries the heat transfer is mainly convective. For electronics applications, the heat transfer is usually conductive while in aerospace industry the heat transfer is done exclusively radiant.

The heat exchangers have a big variety of constructive solutions and can be manufactured out of a lot of different types of metals (copper, aluminum, steel). The big majority of heat exchangers use atmospheric air as a cooling medium, still there are heat exchangers that are used for indirect cooling which use other mediums (for example oil cooled with water).

Lately, all heat exchangers use solutions to enhance their cooling power. These solutions are generally known as extended surfaces, the most common of all being the fins. Fins have also a big variety of different constructive solutions which are usually particular to every different heat exchanger manufacturer. Nevertheless, the fins can be classified as wavy, louvered, and offset.

Due to this huge diversity of the potential constructive solutions and du to the fact that the performances of these fins depend on a lot of external factors, it is imperative to consult the existing literature prior to running the heat exchangers dimensional calculations ([Kays și London [4], Wang et al [6] Dong et al [7]-[9], Nagi. [10]-[12], Theil [13], Ilieș [14]-[16]). The main challenge is that when using the existing correlations, the differences between them is quite high, reaching ±30 %.

This leads to the necessity that each cooling system manufacturer develops its own specific correlations customized for their production characteristics. The continuous development of the company RAAL S.A. Bistrița towards new markets generated the need to accelerate the research regarding the brazed plates heat exchangers.

S.C. RAAL S.A. is a complete cooling system company, which means that all the activities required for the design, manufacturing and validation of a cooling system can be done in house.

The testing laboratory includes all the hardware required for the complete validation of the cooling systems including two wind tunnels, burst pressure installation, pressure cycle installation, thermal cycle installation, corrosion test chamber and a vibration test bench.

The traditional market for RAAL has changed drastically in the last years. If back in 1991 most of the clients came from traditional industries> agriculture, industrial or construction fields, nowadays the automotive and electronics and batteries cooling systems gained a lot of ground.

RAAL company continuous development led to the forming of a solid research team, which in collaboration with the Polytechnic University of Timisoara. The scope of this research team is to develop and optimize the different heat exchangers. The outcome of this work can be quantified by the participation at different conferences [1]–[9], technical documentation „Proiectarea și încercarea schimbătoarelor de căldură” [10], and other scientific papers and articles [17], [18], [11]–[16].

This research focuses on finding a set of criterial equations for newer constructive solutions to improve the existing heat exchanger dimensioning software.

Chapter 2. Current stage in the development of heat exchangers

Chapter 2 describes the most important extended surfaces used for improving the heat exchange. The current stage in the development of the heat exchangers is also detailed here with special focus on the brazed plate heat exchangers with offset fins.

The need of improving the convective heat exchange and the reduction of the heat exchangers’ dimensions leads to the use of extended surfaces. Since gases have a low heat transfer coefficient, the heat exchange takes place mainly by the mixing of the fluid rather than by transmitting the heat directly to the walls or other fluids. So, the main purpose of the extended surfaces is to brake the boundary layer or to reduce its development [19].Another important role of these extended surfaces is to compensate the low heat transfer coefficient by increasing the heat transfer area in the same envelope. The downside is that by increasement of area generates additional pressure.

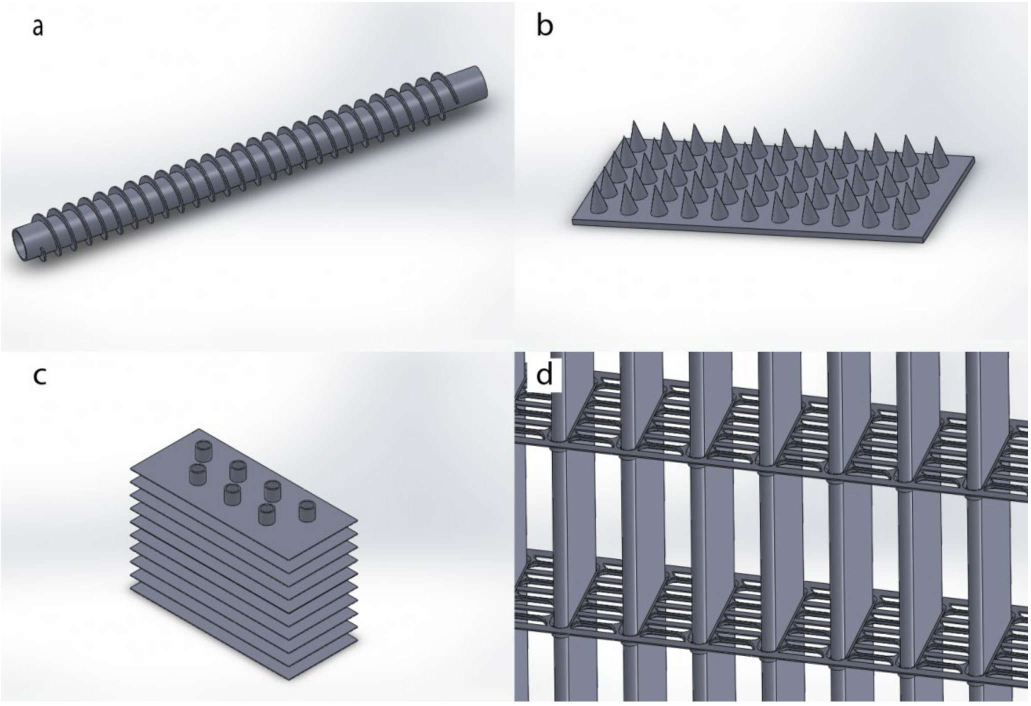

Figura 1 Extended surfaces: a) finned tubes, b) needle fins, c) straight fins, d) louvered fins

Since the extended surfaces have a very important role in the heat transfer, at RAAL there is a very high interest in finding and optimizing geometries that can help in improving the heat exchange rate. This interest generates a huge number of different shapes and geometries. Some of these solutions can be seen in figura 1.

All the solutions shown in figura 1 are suitable for a specific type of heat exchanger. The finned tubes are mainly used for very big industrial heat exchangers, this being one of the first extended surfaces solutions used. For electronic equipment, the needle fins solution is use figura 1b [20]. In figura 1c. and 1d the straight fins and louvered fins can be seen. These are usually used in mechanically assembled heat exchangers.

All the above showed solution have the main advantage that they generate low pressure drop values. Their disadvantage is that the generated heat rejection is also reduced. This downside can be compensating just by building very big heat exchangers.

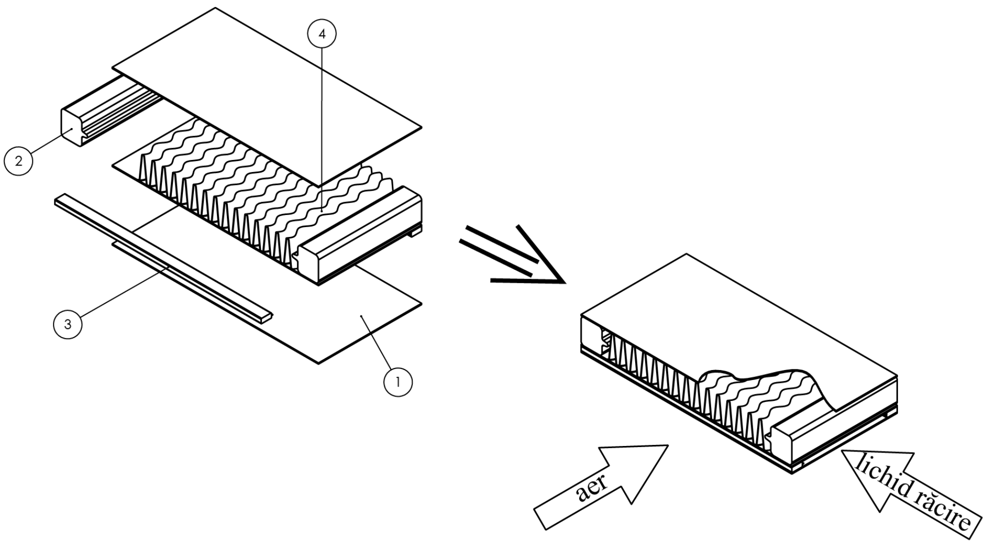

Figura 2 The assembly of a compact heat exchanger: 1 side wall; 2 air spacer; 3 coolant spacer; 4 air fin

Nowadays the most common type of extended surface used are the generic named fins. In figura 2 there is the schematic detail of such a solution. The necessity of this type of construction appeared as a solution at the same time with the compact heat exchanger. Their most important role is to improve the heat transfer on the cooling air side.

Compact heat exchangers are structures which are manufactured using a welding process name brazing. This method eliminates the potential additional resistances generated by mechanical imperfect connections and ensures a better heat exchange.

Chapter 2 also presents the main extended surfaces with emphasis on the offset fins.

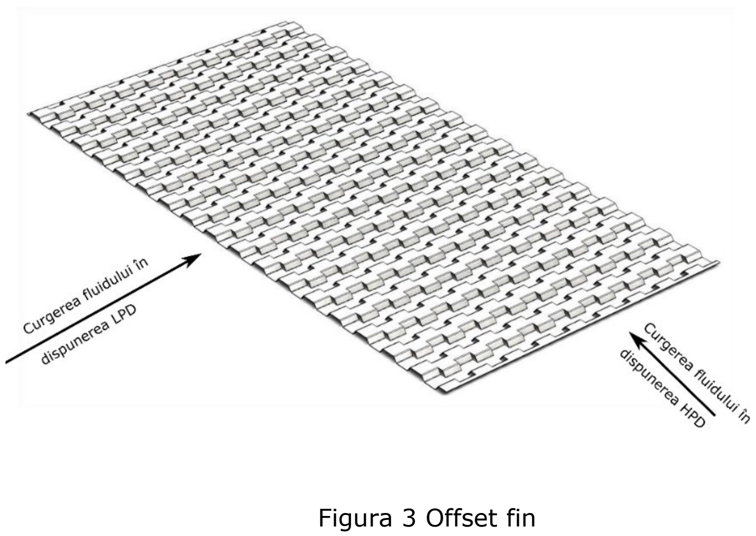

Figura 3 Offset fin

Chapter 3 **The calculation of heat exchangers**

Most industrial installations have heat exchangers in their construction. This can be individual or combined heat exchangers. The fluids that are used for these heater exchangers are called thermal agents. All heat exchangers need to fulfill a set of requirements which can be seen below:

- To respect all design required parameters during their life cycle.
- Heat exchangers need to require low investments and maintenance costs.
- The constructive solutions need to be simple, compact and to required small envelopes
- Easy to be cleaned.
- to have a long-life expectancy
- To be environment friendly

In this chapter the classification criteria of the different heat exchangers is also described and also the main heat exchanger types used in RAAL. The main two methods of dimensioning the heat exchangers are also shown in this chapter. The first method is known as the logarithmic temperature difference, mainly used for counter flow heat exchangers. The second method is the ϵ - NTU and is used for cross flow heat exchangers. This second method is used also further in this research for the interpretation of the experimental data.

Chapter 4. **Experimental research regarding the influence of the offset fins on the performances of brazed plate heat exchangers**

The scope of these research is to find a set of criterial equations which define the heat exchange during the passage of fluid through offset fins.

To be able to run the research a set of 3 different brazed plate heat exchangers were built in RAAL company Bistrita. The brazed plate heat exchangers, shown in figura 4 are composed of a base plate, lower plate, main plate, upper plate, turbulators (offset fins) and the fluid connections.

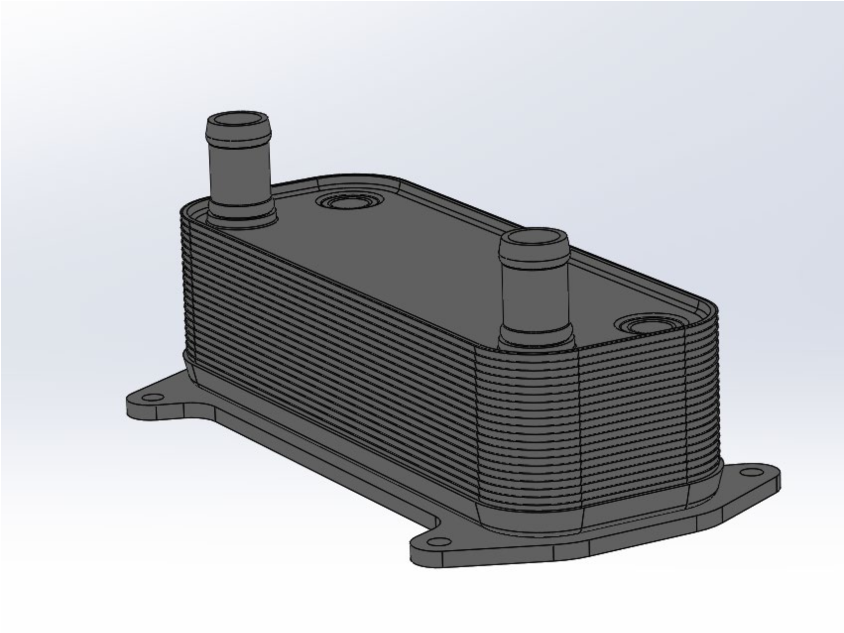

Figura 4 Brazed plate heat exchangers

For the designed prototypes, the geometric characteristics were determined: heat exchange area, flow area, hydraulic dimeters.

Taking into consideration that RAAL current production uses turbulator offset fin pitches of 8 mm, 6.8 mm and 5 mm, the built prototypes use these solutions. The experimental test was performed on a test bench used especially built or testing of coolant-to-coolant heat exchangers. All tested prototypes have identical structures on the cold fluid and hot fluid sides.

The test bench cand be seen in figura 5. The test system includes two closed coolant circuits, one for the cold side and one for the hot side, an acquisition system (not shown in the sketch) and a heat exchanger. The coolant circuits are built to ensure a counter flow fluids circulation for the tested prototype.

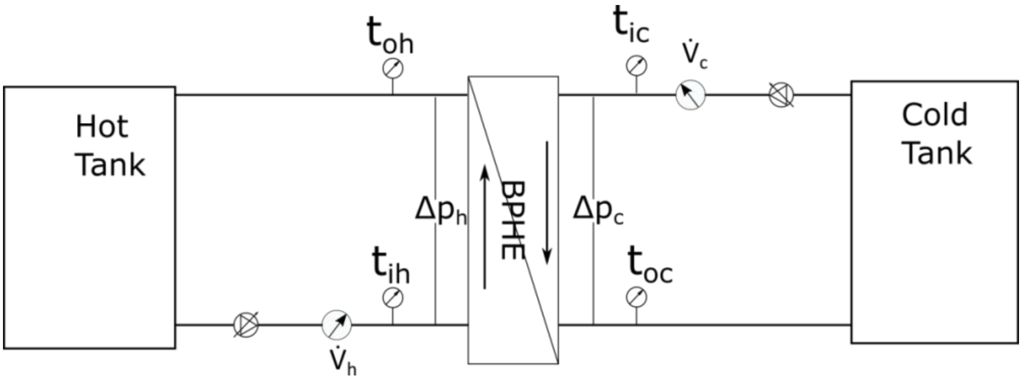

Figura 5. Test bench working sketch.

Each coolant circuit is designed with its own 1000 l tank, its own pump with variable speed. The pump allows to set the coolant flow to the desired value. The coolant flow is measured with a electromagnetic flow meter with a precision of ±0.2%. The temperature is measured with thermo resistances with a precision of ±0.1 °C. the pressure drop is measured with a pressure difference sensor with a precision of ±0.4 %.

To be able to analyze the measured data by taking into consideration the errors generated by the transient regime of the test bench, each measured point was repeated 10 -50 times in a 2-minute interval. Each measured point was registered in an approximately equal time interval. Tables with the raw measured data can be seen in annex B.

Chapter 5. **Determination of criteria equations for offset fins**

The experimental data was analyzed using the error theory and the equations, which were implemented in a Python script shown in annex C.

All the following graphs show the measured point with the errors generated by the testing process. The vertical lines represent the errors of the calculated values (Nu, f) while the horizontal lines represent the Re number errors.

The first step generated a set of equations for (Nu, f) for each different measured structure.

The scope of this research being the finding of general criterial equations for the offset fins an additional set of data that could be used for all geometric structures was determined.

To be able to achieve this scope a new non dimensional parameter was added in order to describe the geometric structure.

By doing so the general equations for (Nu, f) were obtained:

$$Nu = (3.77 \pm 0.68) \cdot 10^{-5} \cdot F_p^{1.65 \pm 0.062} \cdot Re^{-0.51 \pm 0.022} \cdot Pr^{\frac{1}{3}} \quad (5,8)$$

$$f = (1.04 \pm 2.1) \cdot 10^{-3} \cdot F_p^{6.37 \pm 1.93} \cdot Re^{-0.14 \pm 0.12} \quad (5,9)$$

The above equations were obtained by regressing more than 6000 different test points. This process was automatized by using Python software. The listing can be seen in annex C.

Chapter 6. **Conclusions and personal contributions**

This paper shows research that were made on the hydraulic and thermal performances of brazed plate heat exchangers with the final scope of obtaining criterial equations that can be used for the dimensioning of heat exchangers built at SC RAAL SA Bistrita.

The present stage in the construction of this types of heat exchangers was also shown with focus on the offset fin type. This analysis showed that even if there is a generally accepted analytical expression for determining the Nusselt number and the friction coefficient, the coefficient of this equations need to be experimentally determined as the differences between the different existing equations can be very high.

The study of heat exchange surfaces is very dynamic and for this reason the actual research has a very big importance in the cooling system manufacturing industry.

For RAAL company the variation of the Nusselt number and the friction coefficient with the geometric parameters of the offset fin is of great interest. To be able to achieve this scope, 3 prototypes were built and tested in more than 6000 points.

The data interpretation was achieved by using the Python code written by the author. The listing of the most important functions can be seen in annex C. this code enabled the possibility of automating the experimental data. The code realizes the regression of the non-dimensional parameters and find the criterial equations coefficients.

The general equations (5.8) and (5.9) can be used for the performance calculations of the brazed plate heat exchangers with offset fins.

- The measurements were performed on a single type of fluid (coolant), this does not create any issues as the found criterial equations are independent of the fluid type used. So, they can be used for coolant-to-coolant heat exchangers and for coolant to oil coolers or oil to oil coolers.
- The uncertainty of the points used for the regression is 3σ which means that there is only a 5 % probability that the measured points are outside the interval $\bar{X}-\epsilon, \bar{X}+\epsilon$ where the value is generated by $\bar{X}\pm\epsilon$
- The uncertainty of the regression coefficients is 1σ; for better confidence, these intervals can be converted to a 3σ precision by multiply the errors by 3.

To further improve the results the author wants to:

- Make some changes to the acquisition software in order to register automatically the values at a constant time interval with no intervention from the operator once the acquisition process is started.
- Building coolers with a higher number of channels. The study considered the influence of the heat transfer of the end channels with the ambient to be insignificant.
- Testing different fluid combinations coolant – oil and oil – oil

Personal contributions:

The thesis „**Studii și cercetări privind influența geometriei nervurilor discontinue dispuse alternant (OFFSET) asupra performanțelor schimbătoarelor de căldură din aluminiu în plăci brazate”** is based on the theoretical knowledge generated by 16 years of experience from the author and also on the collaboration with the Polytechnic University from Timisoara.

Below can be seen the personal contributions in the study of brazed plate heat exchangers:

- 3 prototypes with different geometric parameters were designed, manufactured and tested.

- a customized test bench was built in order to be able to test these prototypes.
- the experimental measurements were performed only a very wide range of input parameters so to be able to draw the correct conclusions (more than 6000 measured points)
- the experimental data interpretation was done automatically using a software able to process a big volume of data (Python)s
- the analysis and finding of the general criterial equations (5.8) and (5.9) which allow the calculation and dimensioning of brazed plates heat exchangers.
- the found equations are already used in RAAL for the dimensioning of brazed plate heat exchangers which use offset fins.
- the improvement of the calculation software used in RAAL with these new equations.

The published papers from Experimental Heat Transfer [17] indexed ISI, Applied Mechanics and Materials [98]–[100], Applied Mechanics and Materials [98]–[100] indexed BDI, the paper from London UK Heat Transfer Conference [15] and also the contribution to the „**Proiectarea și încercarea radiatoarelor**" [10] which is a guide for the dimensioning of the heat exchangers.

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