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NEW FINNED HEAT EXCHANGER DEVELOPMENT WITH LOW REFRIGERANT CHARGE

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ABSTRACT

Many types of air cooled heat exchangers are used in the HVACR sector. The paper presents the results of development in new compact finned tube geometry 20x17.32mm. The technology employs 5.0mm diameter copper tubes and advanced louvered fins for condenser applications.

First, the fin geometry development process and the definition of the new grooved tube generation is illustrated; the basis of development is CFD analysis of heat exchanger performance which is able to find the optimum compromise from several geometric parameters in order to maximize the heat transfer coefficient and minimize air pressure drop.

Theoretical outcomes are then compared by an extensive testing campaign of sample coils in the wind tunnel and in the calorimetric room in condenser mode. The test results have been used as the basis of sophisticated software for performance calculations. Software prediction deviations from the accurate test results are also finally mentioned. The main advantages of the new technology are lower refrigerant charge due to the current finned tube technologies combined with high performance as a whole. These characteristics allow product with low life cycle costs to be designed, and help to reduce plant refrigerant charge required by the current strict European standardization.

The article later compares the new geometry with traditional finned tube technology heat exchanger with geometry 25x21.65 m and 9.52mm diameter copper tubes and Micro Channel tube heat exchanger with extruded aluminium tubes and corrugated fins.

Thermal performance characteristics, fin efficiency, pressure loss characteristics, refrigerant charge, reliability (product installation, resistance in the field, dirt accumulation) and manufacturing flexibility are the technical arguments for the selection of the suitable technology. Hence the article collates characteristics of condensers with heat output of 20kW. Calculation frontier properties are 25°C air temperature and condensing temperature 40°C. The chosen heat output is selected for comparability with real applications such as local air conditioning systems or small refrigeration units.

1. INTRODUCTION

In recent years in the refrigeration and air conditioning sectors, there has been a great deal of discussion about environmental sustainability. At first the attention was concentrated on ozone depleting refrigerants, then the focus turned to greenhouse effect reduction, following the TEWI approach (i.e. combining direct and indirect emissions). Furthermore in some countries taxes or limitations to HFC refrigerant charges have been introduced.
Therefore an answer to those driving forces had to be given and both authors over the last few years carried out a wide-ranging research activity in different directions, analyzing all the possible alternatives and finally developing a completely new coil geometry, based on copper aluminium technology with tube diameter of only 5mm. There are several advantages to such a solution; this paper explains R&D activity regarding the new geometry, its main features, a comparison with the current state of the art and with Micro Channel technology.

1.2 New coil geometry

In order to satisfy the request for high heat exchange efficiency and low refrigerant charge, the new coil geometry TURBOFIN 5 has been developed as shown in Figure 1. It is very compact and reaches very high density of capacity/fin surface.

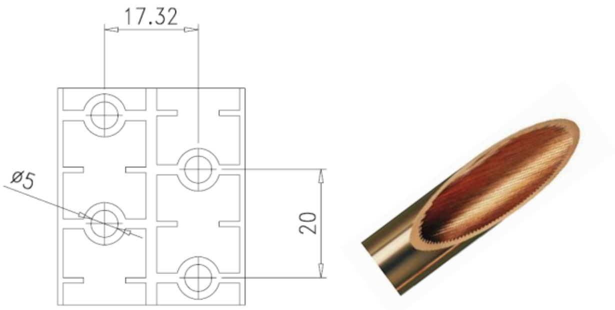

Figure 1 : new coil geometry TURBOFIN 5

The fins have special corrugations that combine with internal grooved tubes increasing the internal surface > 1.8 to give very high performance.
The coil headers can be chosen according to the refrigerant flow, without any particular mechanical limitation and consequently their volume can be reduced.

2. CFD APPROCH

The traditional approach followed by heat exchanger designers was traditionally focused on the selection of the global coil characteristics: tube diameter and length, tube and fin spacing, thickness and row number, in the attempt to obtain the best compromise between heat transfer performance, industrial costs and fan characteristics. In the past, the main choices and the solutions adopted were primarily based on experience and empirical correlations, derived from experimental tests [1,2]. Less attention was given to the true core of the heat exchanger and to the behaviour of the complex flow field crossing the coil. This empirical approach is appropriate when used for coils of simple geometry, such as those with plain tubes and fins, but it is not warranted when applied to the design of modern, state-of-the-art coils, using rippled tubes and fins with sophisticated shapes.

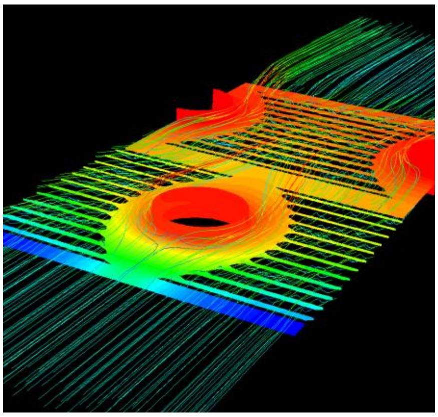
Figure 2 - CFD simulations

CFD has always been of great help in the heat transfer field of application [3]. Nowadays, the great advances of computational techniques and the availability of more and more accurate and flexible numerical models, together with the growth of competences and know-how of researchers and engineers in the field of CFD, make the implementation of new strategies for advanced heat exchanger design feasible and convenient [4], [5], [6]. The approach described in this paper is based upon the massive use of numerical simulations with the goal of discovering the profound details of the fluid flow in order to gain a major understanding (i.e. based on the principles of fluid dynamics) of their heat performance and pressure losses. CFD is combined with an extensive experimental approach. In this frame, each of the two approaches gives a fundamental

contribution: the former is able to support engineers by providing a fast in-depth analysis of the flow field for selecting the best fin shape; the latter is of key relevancy for measuring the predicted coil overall performance, as well as for validating numerical calculations.
More than 30 different fin configurations were investigated. A set of 2D calculations, coupled with wind-tunnel experiments, was carried out at various air velocities and fin pitches in order to compare the numerical and the experimental trends for each configuration.
This intensive activity gave valuable suggestions about the calibration of the computational tools and the influence of the fin shape on heat transfer performance. The results of the research activity demonstrate the new frontier opened by the optimization process for the fin shape and prove how this feature is relevant in enhancing overall coil performance, thus confirming that CFD is able to effectively support advanced heat exchangers design.

3. EXPERIMENTATION AND SOFTWARE CALIBRATION

The thermal capacity tests required considerable experimental activity; tests have been carried out inside a calorimetric room, according to the international standard ENV 327. The testing equipment is composed by an internal room where the product (in this case the condenser) to be tested is placed and kept at constant temperature, thanks to a cooling system that gives the same capacity of measuring condenser. The external room ensures to have minimum thermal losses in the internal one. The thermal capacity is measured 2 times: the first time by measuring directly the condenser capacity a second time by measuring the capacity on the internal cooling system. The 2 capacity at constant room temperature can have a max difference of ±4%. Inside the refrigerant used is R507A. The room temperature during test was 25±0,5°C and the condensing temperature varied from 35°C to 50°C, in all test conditions. Precision of temperature sensors is ±0,2°C, ±0,02 bar for pressure sensors and ±2,0% for flowmeters.

Figure 3 – Picture of testing calorimetric room

Plenty of tests were carried out to define performance under the most varied operating conditions (e.g. at different frontal air speed, mass velocity of the inside fluid, condensing temperature and air temperature at the inlet of the heat exchanger). All these tests helped to calibrate the calculation code in order to be able to estimate the performance of every unit with new geometry in the most varied operating conditions.

3.1 Heat exchangers with tubes found on the market

A first solution for unit coolers utilized a type of grooved tube found on the market, certainly not optimized for our particular use. This had characteristics typical of unit coolers, i.e. helix angle of the micro-fin near to 18°. The fig. 4a) graph shows the comparison of experimental data of thermal capacity with data determined using the calculation code; as can be seen, the deviation is very small, less than 4%. This confirms the reliability of the calculations in different operating conditions.

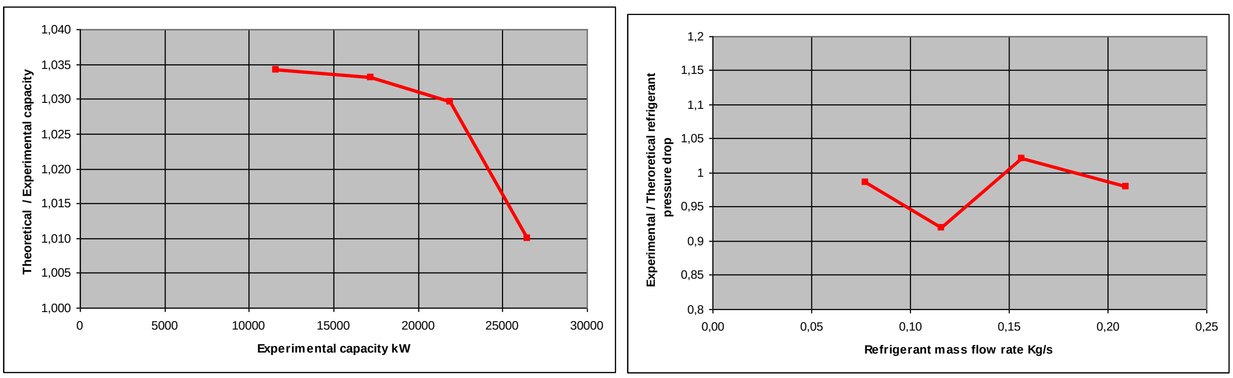

Figure 4a – deviation between calculated and measured capacity (standard tube)

Figure 4b – deviation between calculated and measured refrigerant pressure drop(standard tube)

The fig. 4b) graph also indicates the comparison of experimental data with calculation data concerning refrigerant side pressure loss (inside tube) as a function of the mass flow rate.
Normally accepted tolerances are of the order of ±20%; in these experimental cases the error is comfortably within this interval (±8%).

3.2 Heat exchangers with optimized tubes

The ever-closer collaboration with producers of micro-fin tubes has brought about the definition of a high-performing type of tube for unit coolers. Performance tests on the tube alone were carried out directly by the supplier who provided us with all the heat exchange and pressure drop information at different values of Reynolds and Prandtl number.
These characteristics were implemented in the calculation code which - together with all the information concerning the outside heat exchange, airflow, size of the heat exchanger and the operating temperatures – enabled us to define the thermal capacity exchanged in the test conditions.
Errors between the experimental data and the calculation data are shown in the graph on fig. 5. As it shows, the difference is indeed very small, less than 5%.

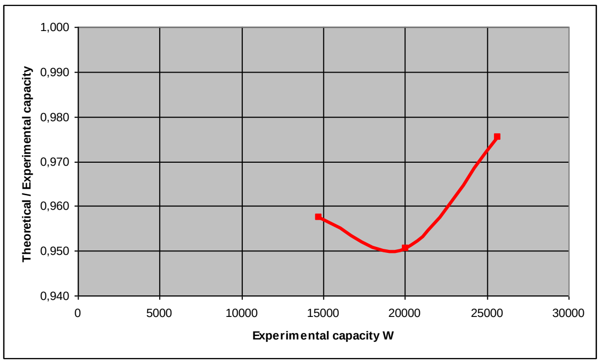

Figure 5 – deviation between calculated and measured capacity (optimized tube)

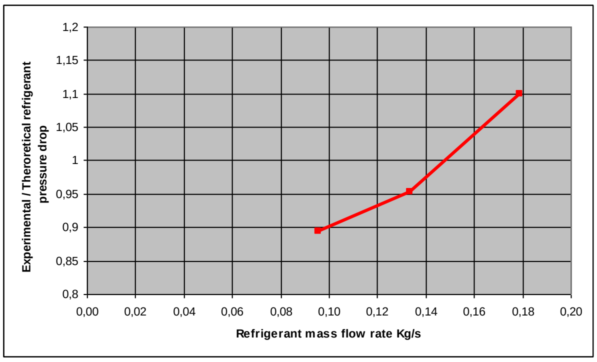

Figure 6 – deviation between calculated and measured refrigerant pressure drop(optimized tube)

The same comparison was made for the internal side pressure drop (test refrigerant fluid R507A), where the fig.6 graph defines the errors between the experimental data and the calculation data.
The value of the pressure drop includes the inlet and outlet headers, so that these components – fundamental for the definition of the machine itself - can also be calibrated.
Also in this case, the deviations are greatly inferior to ±20%.
The great mass of experimental data has enabled the best calibration of the calculation code: this valuable instrument – used in the design and commercial areas – represents the strategic heart of the company in that it gathers together all the thermodynamic experience.
Estimating the performance of our machines within the values of ±3% (thermal capacity), allows us to offer our customers extremely precise performance optimized for their purposes as well as helping the design department to conceive and constantly improve our products.

4. HEAT EXCHANGER COMPARISON

To check the correctness of the TURBOFIN 5 exchange matrix, an accurate comparison was made in two directions: firstly with the copper-aluminium heat exchanger, geometry 25x21.65mm grooved tube 3/8" diameter of the latest generation, with louvered fins (which is to say, standard company production) and secondly with a Micro Channel solution.

4.1 Micro Channel with parallel flow configuration

Figure 7 shows a typical configuration of Micro Channel in parallel flow arrangement.

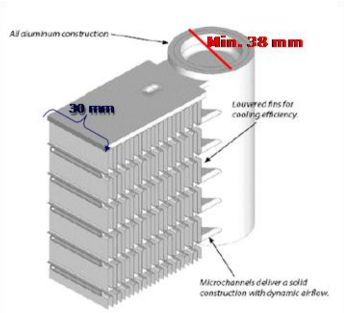

Figure 7 : drawing of Micro channel parallel flow

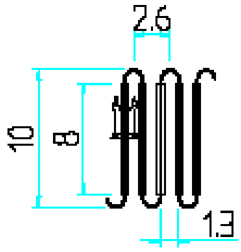

Figure 8: detail of fin spacing

Because of the mechanical construction, Micro Channel in parallel flow arrangement needs to have rather big headers, at least big enough to let the aluminium profile enter into the header. From our research activity it appears that an aluminium profile of 30mm in depth is a good compromise in order to get proper performance from a condenser; therefore a minimum header diameter of 38mm is required. This is one of the main reasons why Micro Channel technology has still a bigger internal volume than necessary and the main refrigerant charge is located in the headers. Figure 8 shows the fin configuration of Micro Channel; here the definition on fin spacing is rather different from the one normally used for finned coil. In fact the geometric definition leads to considering the fin spacing as the distance between two repetitive elements, in our example the 2 waves (i.e. fin spacing = 2.6mm), in reality the real distance between 2 fins is half that (1.3mm illustrated), a much lower value compared to what at the present the market is used to for ventilated condensers (i.e. between 2.0 and 2.5mm).

4.2 Heat exchanger matrices

The graph in fig. 9 shows an interesting performance comparison (coefficient of thermal exchange and air-side pressure drop) of three different geometries: a) 25x21.65 mm with tube of 9.52mm; b) 20x17.3mm with tube of 5.00mm; c) solution with micro-channels (tube 30mm).
Comparing the performance of these geometries, in relation to an air velocity value of 2.0m/s, it can be stated that: the geometry with 5.0mm tube possesses a coefficient of heat exchange which is slightly inferior to the other two (especially at high speed), but on the other hand it has a significantly lower pressure drop; these results render the geometry with 5mm tube very interesting. This comparison was made with the same fin spacing: 1.3mm, same frontal area, 1 row coil for geometry a) and b).

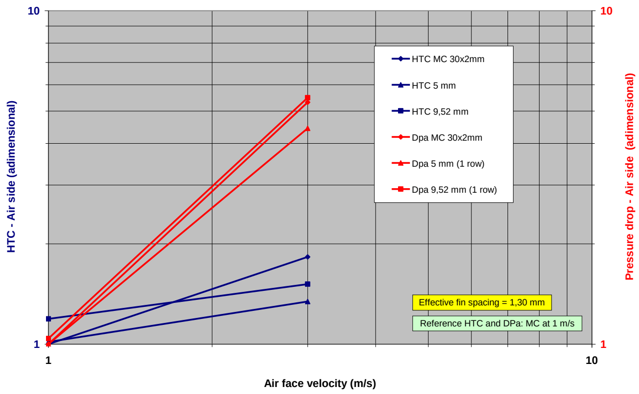

Figure 9 performance comparison among different coil arrangement

4.3 Internal volume comparison

Table 1 shows a comparison between 3 possible air cooled condensers having similar capacity, same frontal areas, same fans (2 x Ø 350mm 4 poles).

Model	SHVN 19/0	Special 5mm tubes	Special multichannel
Capacity [kW]	19,6	20,2	19,5
Tube diameter [mm]	9,52	5,0	multichannel 30 x 2
Tubes volume [dm3]	5,15	2,04	1,90
Header volume [dm3]	0,36	0,36	0,91
Total coil internal volume [dm3]	5,51	2,41	2,81
Header diameter [mm]	22	22	38
Internal volume difference	100%	43,6%	50,9%
Internal volume difference		100%	116,7%

Table 1: air cooled condenser with different coil comparison

The first column shows the data of condenser type SHVN 19/0 of the current company production range, having coil geometry 25x21.65mm and 9.52mm tube diameter. In the second column is a solution with new TURBOFIN 5 geometry 20x17.32mm and 5mm tube, in the third column a solution with Micro channel configuration.
In order to illustrate more clearly the behaviour of internal volume for the 3 different configurations, the internal volume for tubes (or extruded profiles for micro channel) and for headers is indicated separately. The result of the comparison shows clearly that by using more modern technology it is possible to greatly reduce the refrigerant charge; furthermore the advantage of new TURBOFIN 5 geometry appears in comparison to micro channel (16.7% further reduction), thanks to the smaller header diameter.

4.4 Comparison in terms of technology and applications

Whilst the passage to the TURBOFIN 5 geometry does not cause any significant change for the user or installer compared to the product they normally use today, using a Micro-channel solution modifies the scene dramatically. This is why a comparison was made including multiple parameters, highlighting the advantages and disadvantages of each solution. The table below contains the results of this comparison.

	new geometry TURBOFIN 5	Micro channel	Comment
Installation	+	-	Installer has to solder copper pipes as usual in both cases but MC has a joint Cu-AL rather fragile that can be damaged and repairing is difficult
Cost			Very much influenced by production lot, however till 50 pieces batch 5mm is surely competitive
Lifetime	+	??	No real experience on MC is available, tests on car can be used???
Flexibility	+	-	MC has very rigid production, difficult to provide special circuiting or enlarged coil. 5mm is very flexible as actual Cu/Al tecnology shows
Weight	~	~	Very similar values
Recicling	-	+	MC has advantage of mono-material construction
Dirt accumulation	+	-	MC has in reality 1,3mm fin spacing, dirt accumulation is much quicker
Cleaning	-	+	MC is stronger, cleaning is quicker and easier without damage risk

Table 2 : comparison between the new coil geometry TURBOFIN 5 and Micro channel

4.5 Analyses in terms of fouling

The fouling of a condenser is a very important factor in the efficiency of a refrigeration cycle which is why a precise analysis of this subject was carried out.
Recent international studies demonstrate how relatively independent the deposit of dirt is as a function of the fin space (dimensions from 0.01 to 100µm) while greater weight is given to the air speed (Bulk Air Velocity). In particular, returning to fig. 10 which highlights how - varying with the size of the dust particles released into the airflow hitting the heat exchanger at a speed of 2m/s - they do not make much difference to the deposit, varying with the fin space (fin space analyzed: approx. 1.6, 2.1, 3.2mm). The three curves more or less coincide. (within the values of ±5%) [10].

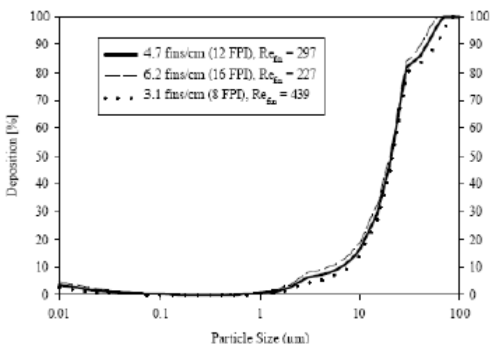

Figure 10 :Modelled deposition as a function of Fin Spacing for a Bulk air velocity of 2m/s

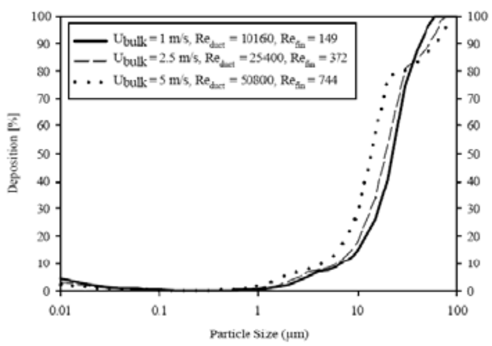

Figure 11 :Modelled deposition as a function of Bulk air velocity on 4,7 fin/cm heat exchanger

The graph in fig. 11 on the other hand shows an appreciable variation in the dust deposition varying with the air speed (or the volumetric airflow which flows through the heat exchanger); in particular, the greater the velocity, the greater the deposition of particles (especially those with dimensions of between 1 and 50µm).
This analysis was carried out on a heat exchanger with a fin space of approx. 2.1mm.

The graph in fig. 10 has demonstrated that the deposit of dust particles is roughly independent of the fin space [10], but the influence of such deposit on the thermal performance is not clearly the same. In fact for narrower fin spaces the layer of dust deposited (less high, as more distributed over a larger fin surface area) implies a greater pressure drop on the air side and consequently a greater decrease in the airflow (and therefore in capacity).
Other studies using sophisticated experimental and analytical methods [11] using standard ASHRAE dust show that the fouling of a 1.3 mm fin space micro-channel heat exchanger with 135 g of dust presents the same decrease in performance in terms of heat exchange coefficient and pressure drop as a traditional 2.0 mm fin space exchanger with 400g of dust.
Therefore the micro-channel solution entails a decrease in performance which is much more serious and as a consequence an increase in the number of maintenance interventions by a factor of approx. 3 (400/135).

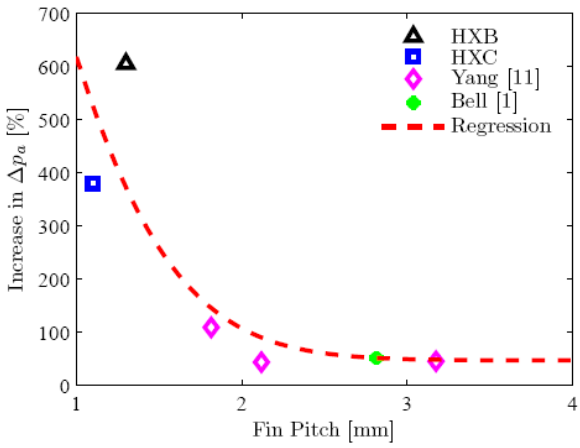

Figure 12 : Increase in air-side pressure loss as a function of the fin space with the injection of 1612.5 g/m^2 of standard ASHRAE dust [11].

The graph in fig. 12 [11] summarizes some of the studies of fouling carried out on coils with embossed fins; the x-axis shows the fin space while the y-axis shows the increase in air-side pressure drop following the injection of 1612.5 g/m^2 of standard ASHRAE dust.
Presupposing that a doubling of the air-side pressure drop would require the cleaning of the fin pack, fig 10 shows that going from a fin space of 1.8mm to 1.3mm requires a triplication of the interventions.

5. CONCLUSIONS

A recent development of new coil geometry based on copper aluminium technology has been presented and compared with the current state of the art copper aluminium condenser and with aluminium micro channel solution. There are several advantages to the new proposal; in particular it appears the best way to lower the internal volume and consequently the refrigerant charge - an issue that is more and more requested in order to ensure environmental sustainability of all the products. Furthermore, the new TURBOFIN 5 keeps all the advantages of copper technology and in particular the high manufacturing flexibility, in other words the possibility to design the air cooled condensers for the specific demand of the different refrigeration plants. The last comment concerns effective plant operating conditions. Recent study on air side fouling shows that very low fin spacing (typical of Micro Channel solution) may bring about the rapid accumulation of dirt. Instead, TURBOFIN 5 has significantly higher fin spacing, ensuring that the interval between coil cleaning is the same as found in the field today.

6. REFERENCES

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