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Review Article

Investigation of number and methods of circuits in finned tube heat exchangers

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ABSTRACT

In recently, the importance of energy saving and, accordingly, optimization studies are increasing day by day. In addition, energy saving, and optimization studies are seriously discussed in heating and cooling applications. Fan coil devices, known as cooling devices, have also been seriously included in the studies in this context. With the developed regulation conditions, this development in both the combi boiler (heating) used, the air conditioner and larger cooling devices are mostly shifting towards water systems. Global warming has brought heating and cooling applications to the fore in aqueous systems due to gases formed because of combustion and other atmospheric polluting factors. In this study, the effect of the number of circuits on the heating process and the circuit methods in fan coil devices designed as 2 pipes in water systems were examined. By including different fin types and pipe diameters, the effect of both fin type and pipe diameter has been directly revealed in the experimental studies. In addition, with this study, the effect of the change in the number of circuits on the total heating capacity, the effect on the outlet air temperature and the change in water side pressure loss are conveyed. All experimental studies were carried out under the same conditions and air and water side conditions specified by Eurovent. Considering three different air flow rates, the relationship between air flow and heating capacity is also revealed. The pump power was compared according to the capacity obtained and the air flow rate, and its effect was correlated in energy saving and optimization studies. All these factors were brought together and the number of circuits, circuit method, fin type, pipe diameter, air velocity and pump power were evaluated together in the heat exchanger design in the heating process.

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INTRODUCTION

These structures, which enable two or more fluids of the same type or fluids of different types to transfer heat between each other, are generally called heat exchangers. Heat exchangers, which are used today and on which many improvements are made in order to be developed day by day, are at a very important point in the field of engineering, especially in the heating, cooling and ventilation sector. In addition, since energy efficiency is a very valuable point today, studies on heat exchangers are even more important. Heat exchangers are used in many branches of industry such as the air conditioning industry, chemical process and power generation facilities, the automotive industry, elect-

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ronic devices, the use of alternative energy sources, and the aviation industry [1].

Many parameters should be considered at the same time during the design phase of heat exchangers. In general, only the material type and structure of the pipe used, the fin type and structure, the number of circuits designed, the circuit type and flow type (reverse flow, cross flow, parallel flow) except for the fin geometry affect the capacity and efficiency of the heat exchanger very seriously.

Today, cross flow is preferred as the flow type in heat exchanger designs, mostly in cooling products. However, the number of circuits designed during the regulation of this flow and the circuit method also affect the design significantly.

In general, using the same type of pipe, many different circuit methods are applied in order to increase the energy efficiency and energy gain on the heat exchangers by changing the effect of the fin type, the number of circuits and the circuit type. By changing the circuit type, it will be possible to optimize the logarithmic temperature difference, the water side pressure drop as well as the air side pressure drop. Considering all these factors together, considering energy efficiency, it is stated that it is possible to design a more efficient heat exchanger by changing the circuit methods.

LITERATURE REVIEW

When the literature is examined in general, there are many studies to improve the capacity irregularities of finned-tube heat exchangers in systems using refrigerant and aqueous systems. These development stages are evaluated in two steps, and they appear under two main headings as external convection air side and internal forced convection. In some of these studies, it is seen that only the circuitry methods are improved, the logarithmic temperature difference is improved in order to reduce the pressure loss in the internal flow and increase the heat transfer in the external flow, and at the same time the heat transfer coefficient of the air side is increased. In addition, in most of these development studies, systems with refrigerant were preferred in order to examine the effect of the circuit method on the capacity. In addition, studies on single-phase fluids that do not undergo phase change are very few. One of the main reasons for choosing a refrigerant is that its temperature was constant during the process, and the temperature remained constant on the pipe and fin surface. In this study, the number of circuits and methods will be examined by using water instead of refrigerant gas, and both the water flow and the pressure loss in the interior will be examined according to the number of circuits, the circuit type, keeping the water inlet and outlet temperature constant. In addition to these, for a circuit, different blade types will be compared and data on cost analysis, pressure loss on the capacity-water side and new circuit methods that can be predicted by numerical study will be compared. At this stage, we will examine the different fin types, circuit types and optimizations of heat exchangers that have been studied in the literature before. In addition, the studies carried out also increase the CO_2 Brayton cycle and today energy efficiency reaches the highest levels. Likewise, reducing the amount of emissions also has a serious effect on energy efficiency. By supporting these systems with solar energy, efficiency has been moved to higher levels. Sheng-hui Liu et al. conducted an experimental study on the fluid flow in a flat-channel circuit heat exchanger (PCHE Plate Coil Heat Exchanger) on this subject, and they used CO_2 as the fluid and also conducted experiments on a certain Reynolds number. When the results were examined, a deviation of 4.6% was found and supported by a new correlation study. Likewise, another study in the literature similar to this study is the study with NG (natural gas). In this study, blade diversity was also studied and improvements were made on both thermal and hydraulic performances [2-3]. Omer Sarfraz and his colleagues examined the capacity differences according to the circuit methods and the number of circuits in the study as shown Figure 1 for circuits, they carried out in 2019. The main purpose of the study is to obtain the solution by shortening the simulation time by converting a multi-circuit heat exchanger into identical structures. While doing this, it is to

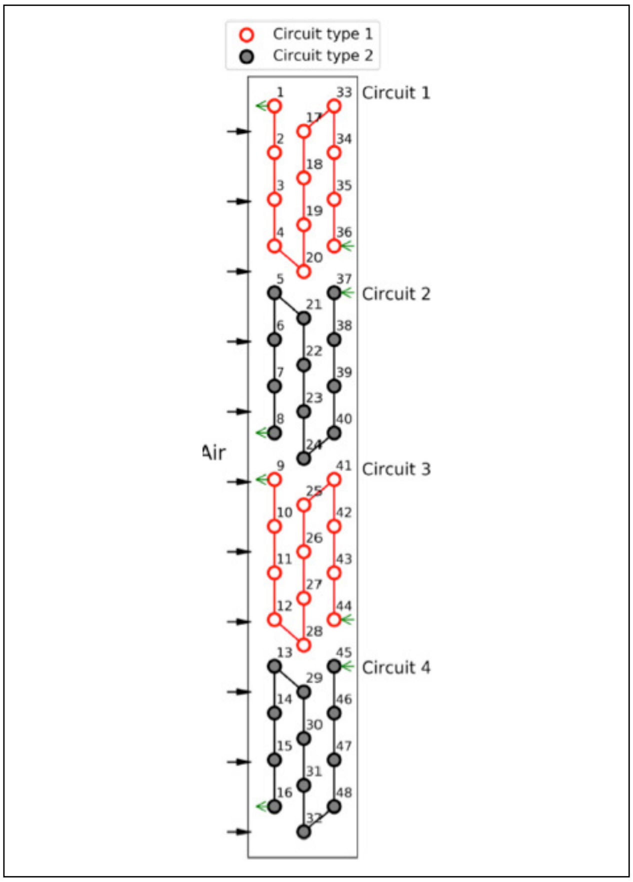

Figure 1. A coil with 2 sets of identical circuits (same coil as in Figure 1 (left) with tube numbers add [4].

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determine the best circuit using the identical structure. By reducing a 25-circuit structure to 7 self-circuits, more than 70%-time savings and a 2% deviation on the capacity side are obtained. The main purpose here is to save time by providing simulation and to determine the ideal circuit. They have made this possible with this study [4].

Can Chen, Youyi Wang et al. compared 4 different circuit as shown Figure 2 for circuits numbers in their study. These circuit numbers are 1,2,4, and 8 circuits. Considering the different water flow and pressure loss in these designed four different heat exchangers, the effect on the capacity has been examined. From the results, 4 different heat exchangers with flat 2 rows were examined under different water flow rates. In the results, it was concluded that although the 1-circuit design is more efficient in terms of heat transfer, the more optimum design is 2-circuit [5].

Another exemplary study on this subject was done by Won-Jong Lee, Hyun Jung Kim, Ji Hwan Jeong on refrigerants. The main work is to determine the optimum number of circuits on the refrigerants. It is aimed to use the heat exchanger in the most efficient area. With this study, it was aimed to obtain the maximum heat transfer coefficient from both the air side and the fluid side, that is, the inner convection side. In this study, both different circuit numbers were tried and tests were carried out with different circuit methods by keeping the number of circuits the same as shown Figure 3. In general, it is desired to determine the optimum number of circuits and circuitry by keeping the number of rows, the number of pipes and the fin type the same. When the result is examined, it has been valid as numerical modeling. The number of circuits in which the air side, that is, the outer convection, and the inner refrigerant side convection coefficients of the most ideal circuit can be equal to each other, has been accepted as optimum [6].

Abhay Vardhan et al. (1997) carried out the theoretical analysis and experimental verification of the heat exchangers. The model has been validated with the available data. The deviation in cooling capacity is between 0.2% and 16% using the Gray 3 correlation predicted and graded by the

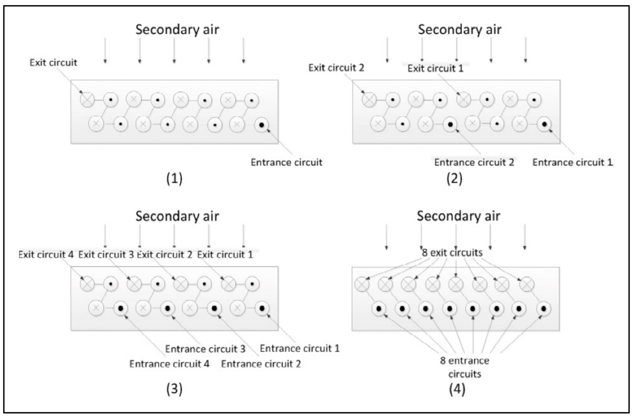


Figure 2. Conventional 1-circuit (1) and multiple-circuits (2–4) arrangements [5].

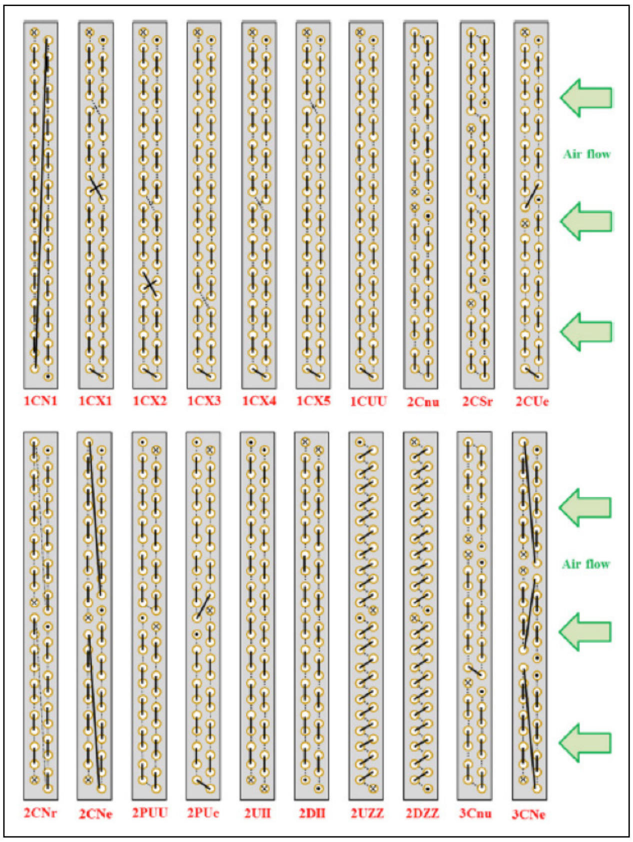


Figure 3. Refrigerant circuitries of fin-tube heat exchangers [6].

model and 0.6-11% heat transfer coefficient for the Air side using the McQuiston 6 correlation. Reasonable cooling estimate 1.4-14.0% different from what is rated by the software. Considering the fact that most correlations exist, these results can be said to validate the model if the heat transfer coefficient and pressure drop estimates have at least ± 10% uncertainty levels [7]. Ahmadali Gholami et al. studied new corrugate fin types and performed simulations on new patterns in order to increase efficiency in heat exchangers. With this study, the optimization of heat transfer and pressure loss has been improved with new different patterns. Zhao-gang and his group studied the factors affecting heat transfer using 15 different samples. Five basic variables were considered in this study. These factors are blade spacing, blade thickness, blade angle, number of louvers and flow depth. In corrugate fin type, these five basic factors were changed and their effects on total heat transfer were investigated. Experiments were carried out using the Taguchi method, and pressure drop and capacity graphs were created by comparing the obtained findings. According to the findings, it was observed that the flow depth affects 31.27%, fin spacing and fin thickness 21.53%, and the number of louvers 20.34% affect heat transfer. These findings play an important role in the optimization of the heat exchanger [8-9]. In a study for louver finned heat exchangers, Kijung Ryu et al. performed numerical modeling for optimization study trials. In this study, improvement and optimization were carried out for louver patterned blades by changing the parameters. According to the results obtained, an improvement of 14% to 32% was achieved as a result of the JF factor. In another study, both experimental and numerical modeling studies were carried out for louver finned heat exchangers by considering the Fp/Lp> 1 fin pitch and the distance ratio between the pipes by Kijung Ryu and Kwan-Soo Lee. The louvered blade properties were investigated by numerical modeling of the friction factor f and Colburn factor j, and these results were also supported using experimental results. F and j correlations are derived as the ratio of blade pitch to louver pitch. The newly developed f and j correlations were not only Fp/Lp <1 but also Fp/Lp> for 100 <Re <3000 1. The F and j correlations pressure drop and heat transfer properties were small (±5%). In addition, the current flow efficiency difference is supported by a correlation. ±15% within an error for 100 <Re <3000 [10-11]. Another study in this field is vortex formation, which is an interesting study in the literature recently. It has been proven both numerically and experimentally that these eddies increase the heat transfer. Ahmadali Gholami has done CFD work in this area and compared the numerical models as single-flute and 3-slot. When the results are examined, a pressure drop of up to 20% is shown. In this way, heat transfer and hydraulic pressure loss improvement were achieved [12]. Another study, Miloš Mihailović et al., is an experimental heat transfer study of the air side heat transfer coefficient on plate finned tube heat exchangers. In general, heat transfer on in-line flat plates with 3,4 and 8 pipes was investigated. The factors affecting heat transfer are emphasized. The overall aim of the research is to reliably relate heat transfer in cross-flow and cross-flow finned finned heat exchangers. It is focused on calculating the heat transfer coefficient of the air side. A new correlation has been developed that can be studied in the Reynolds number from 57 to 11100. Correlation validity was demonstrated between 0.24 m/s and 14.57 m/s on the air velocity heat exchanger[13]. Worachest Pirompugd et al. studied the heat transfer in 2010 by working on the cooling process using flat fin and staggered array. A total of 15 straight finned tube heat exchangers were tested. The tests were carried out by changing the fin thickness, fin spacing and number of rows. In addition to these, the wing geometry has also been changed. According to the data obtained, a new wet surface correlation was created and it was reported that this correlation was valid with a ratio of 83.81% of the total wet surfaces within 10% tolerance. The other results are that whether the number of fins is increased, that is, the fin spacing is decreased or the number of rows is increased, both of them have a positive effect on the heat transfer and it has been seen that the temperature distribution is further reduced [14]. Another study in the literature is the calculation of the cabin cooling system and the study to increase efficiency. Saranmanduh Borjigin et al. conducted a study on this subject in 2019. They derived different ε-NTU methods by considering the cabinet-style cooling system and also compared the traditional ε-NTU method with the coupling ε-NTU method. This study also changed many parameters. The models of the plate heat exchanger with its effective length, height and different gaps between the plates were also verified by numerical methods. This work has also had an impact on the cooling devices we know as Fan-Coils today. Examples can be taken from this study on design. Results show that coupling ε-NTU method results are smaller than traditional ε-NTU method [15]. A study was conducted on maximum heat transfer by determining the heat capacity ratio and the best heat exchanger type performed by Özden Ağra, Şevket Özgür Atayılmaz and their colleagues. This study was on geothermal. It has been prepared on the calculation method in order to use the heat accumulated underground in the heating processes in the best way. Tried different streams. The results were compared. And the best result ε*Cr was determined as the highest point. This result was added functionally as a variable parameter of the NTU method and studied on [16]. Much work has been done on mathematical modeling of multi-tube finned heat exchangers as well. In particular, colburn factor and fanning factor have been studied in order to both reduce pressure drops and provide optimization, that is, high heat transfer. This study was compared by Miftah Altwieb et al., both by creating a test method and by mathematical modeling. When the results were examined, new and more improved correlation coefficients were obtained with 10% error rate. In addition to this, turbulator studies were also carried out in order to increase the heat transfer rate. With this work, the heat transfer rate is approximately doubled compared to a normal flat structure. At certain Reynolds numbers, Reynolds in the range 2588-7045, new parameters are proposed. As a result, it was shown as a 13% correlation ratio in the Reynolds number in the range of 2588-7045 at a rate of 93.75%. At the same time, a numerical study was made to examine the pressure drop and heat transfer and a cross-flow heat exchanger was used. In the study, the rate of heat transfer transfer on different pipe shapes was investigated. Three different pipe types were used. They are elliptical, circular and wind shaped. For each geometry, the study was completed and general correlations were obtained. As a result, the elliptical shape has come across as the most efficient [17-19]. In a study on circuitry, Hussam Jouhara et al., both experimentally and theoretically, examined the effect on performance by having different circuit numbers and number of passes to increase heat transfer. The performance of a multi-pass heat pipe-based heat exchanger (HPHE) is investigated. Heat pipes consist of copper pipes. The heat transfer transition was investigated by passing hot air on one side and passing water on the other. Here, the effect of the Reynolds number was also considered and studied.

More than 25% heat transfer increase has been achieved. It has been shown that increasing the number of transitions increases the Reynolds number. The overall performance of the HPHE as well as the outlet temperatures of the liquids are shown. Calculated using two theoretical models based on the Log Average Temperature Difference (LMTD) method and the Efficiency-Transfer Unit Number (ε-NTU) method. These calculated values were then compared with the test results. The ε-NTU model shows the result with a maximum error of 19%, while the outlet temperatures of both air and water streams are ±0.7 C [20]. Ismail Teke et al. have worked on the determination of the best heat exchanger type for heat recovery. In this study, the problems in the selection of the heat exchanger in the heat recovery devices, which are a serious problem, are discussed. In addition, a modeling was developed according to the most suitable settlement and type. The studies were supported by an example case. Graphs were obtained as a function of NTU and heat ratio in the results. Based on these graphs, the best and most suitable heat exchanger model has been developed. At the same time, another study was on the design of the heat exchanger with the lowest savings-investment ratio corresponding to the marked area for sizing, comparison and selection of heat exchangers. In this study, a new method was developed to determine the area of waste heat recovery heat exchangers. This method is proposed as "Bucket Number" and presented as a derivative according to the NTU method. Here, values are calculated with a unitless parameter, symbolized as E, and compared with ε or NTU values for different types of heat exchangers. In addition to these, studies have also been made on insulation thickness and selection. In the study, it is aimed to calculate the optimum thickness in processes such as heating-cooling, taking into account the effects of the main target heat transfer. The result was obtained with the modeling method. In this study, a general solution of the optimum distribution and its distribution over the amount of heat insulation material transfer and total energy cost are shown, taking into account the total heat amount [21-23]. Another study was carried out on underground heat exchangers in order to examine and increase the heat transfer on both experimental and numerical models and to be evaluated in terms of energy efficiency. This study proposes a new method for soil resource. At the same time, it is aimed to establish an environmentally friendly system. The study was also supported by a numerical model. In the results obtained, the maximum difference between the measured values for the part under the ground and the calculated average fluid inlet and outlet temperatures were found to be 8.36% and 5.58%. In the concrete part, the maximum difference between the measured and calculated daily fluid inlet and outlet temperatures was 7.14% and 6.38%, respectively [24]. In a study and literature, Ali ihsan Koca, Ş. It is for the experimental investigation of condensation (dehumidification process) and heat transfer with the new model made by Özgür Atayılmaz and Özden Ağra. In the study, the effect of surface temperatures on the dehumidification process and sensible cooling and the heat transfer rate were investigated in the experimental setup. According to the results, three different models and equations were derived, namely convection, latent and radiation (with radiation) [25].

METHODOLOGY

In this section, the conditions of the tests, information about the number of tests according to different heat exchangers and how the tests are carried out will be explained in detail.

The prepared sample heat exchangers were tested on condition that each condition was the same. The tests were carried out in the enthalpy laboratory in Figure 4, as stated in the previous section, in the test room capable of measuring 7.5 HP power and with the use of enthalpy devices. At the same time, the tests in the laboratory were compared with the independent Eurovent test application laboratories, which had been done before, and the uncertainty deviation ratio was determined as ± 0.1%. The laboratory en-

Figure 4. Measurement points in the test installation **(a)** Fan coil unit connection, **(b)** Temperature measurement of the air entering the fan coil unit, **(c)** Mains section, power measurement, **(d)** Voltage information control panel, **(e)** Temperature measurement of the inner room, **(f)** Enthalpy cell nozzle and the part where the air velocity is measured, **(g)** Connection of the water pipes, **(h)** Connection of the boiler system providing hot water, **(j)** Measurement of the outlet air temperature, **(k)** The path followed by the air flow, **(m)** Adjustment of the static pressure of the outdoor fan.

vironment, that is, the inner room, has been conditioned in accordance with the predetermined Eurovent requirement.

After the room in which the device is located was set to 20 °C dry bulb temperature and 15 °C wet bulb temperature, the laboratory was started and waited until the ambient condition stabilized. After the ambient condition became stable, the test device was started from the lowest fan speed. The regulator was used to start the test and the power supply frequency converter regulator was set by operating 230 V/ 50 Hz single phase. During all tests, the power and current values drawn from the system were checked. At the same time, attention was paid to have a power factor (FK) ratio of 0.98 and above.

3 different NC layout was prepared in Figure 5 for heating capacity experimental working. Before starting the capacity tests, before any flow is provided in the heat exchanger, air flow measurements were made for each fan speed and these measurements were completely determined as 20 °C dry bulb temperature and 15 °C wet bulb temperature in the laboratory environment. 20 °C and the outlet temperature was maximum + 0.4 °C. During the air flow tests, the air speeds on the nozzle were kept close to each other and it was necessary to change the nozzle to adjust this speed. In the tests carried out, a single nozzle was used and the air speed on the nozzle was considered as 20 m/s ~ 23 m/s on average. The nozzle diameters used were chosen according to the air velocity as Ø80 mm, Ø100 mm and Ø110. Considering the air velocity throughout the test boat, the air velocity and air temperature on the nozzle were monitored at each fan speed. In the air flow tests, the density of the air on the dry heat exchanger was also monitored in the laboratory environment and set as 1.198 kg/m3.

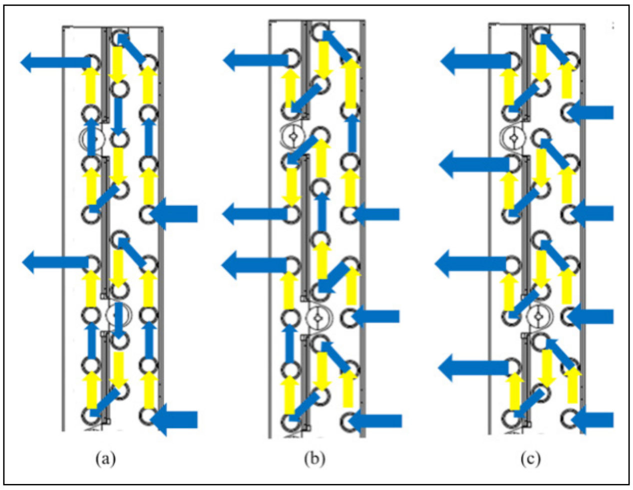


Figure 5. **(a)** 2-circuit symmetrical circuit diagram, **(b)** 3-circuit asymmetrical circuit diagram, **(c)** 4-circuit symmetrical circuit diagram.

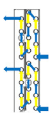
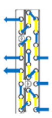
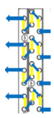
Straight Fin Experiment Results

A total of 9 capacity tests were carried out on the flat fin and the results are shared in Table 1 below. First, the air flow results were shared before the capacity experimental results were shared. Here, it is to show that the air flow rate is measured higher in the measurements with the density change of the heated air.

Experimental Results of Louver Fin Heat Exchanger

In the first stage of our louver finned heat exchanger tests, as mentioned before, 3 rows of 10 pipes and 3 circuits were studied. 2-circuit operation has been tried before, and since the water side pressure loss is very high at the lowest fan speed, approximately 210 Kpa, 2-circuit operation test results are not included in this study. Since it is far outside the accepted

Table 1. Total heat transfer amount, air flow rate, water side pressure drop and AC motor power consumption values in 2, 3 and 4 NC flat finned heat exchangers

NC	NC Diagram	Air Flow (m3/h)	Capacity Watt	Water Flow (m3/h)	Water Pressure Drop kPa	Motor Power Watt
2		556.92	3708.8	0.647	35.5	61
2		701.37	4458.7	0.778	49.3	71
2		944.00	5618.4	0.964	72.1	93.6
NC	**NC Diagram**	**Air Flow (m3/h)**	**Capacity Watt**	**Water Flow (m3/h)**	**Water Pressure Drop kPa**	**Motor Power Watt**
3		552.63	3672.0	0.637	13.2	59.9
3		700.87	4432.7	0.763	18.3	70
3		942.24	5566.2	0.965	28.3	93
NC	**NC Diagram**	**Air Flow (m3/h)**	**Capacity Watt**	**Water Flow (m3/h)**	**Water Pressure Drop kPa**	**Motor Power Watt**
4		551.76	3655.3	0.639	8.0	59.4
4		701.94	4427.6	0.774	11.1	69.8
4		941.00	5562.6	0.952	16.0	92.5

value, the results of the 2-circuit tests were not obtained.

Afterwards, it was continued as 3 NC in order to compare and see the tests. In order to ensure symmetry of the circuit method and to carry out the comparison more accurately, a test was carried out with 3 NCs. Purely the purpose here is to preserve the symmetry structure of the circuit and compare it with the flat, wavy fin type, this circuit is adopted in Table 2.

Experimental Results of Wavy Fin

A total of 9 capacity tests were carried out on the way fin and the results are shared in Table 3.

CONCLUSION

The heating process is generally emphasized. The results obtained have resulted in shortening the duration of research-development studies, optimizing the choices in design and gaining energy consumption.

These results are as follows;

- It has been observed that the number of circuits has no effect on the heat transfer rate in a heat exchanger in the heating process, provided that the inlet and outlet temperatures remain the same.
- While the change in the number of circuits almost does not affect the heat transfer rate in the heating process, it significantly reduces the pressure loss on the water side.
- The heat transfer rate has been obtained in a way that is close to the linear equation depending on the air flow rate.
- In the heating process, the air flow and heat transfer rate increase linearly both in the same number of circuits and in different number of circuits.
- It has been observed that the symmetry or non-symmetrical nature of the circuit methods does not have a

Table 2. Total heat transfer amount, air flow rate, water side pressure drop and AC motor power consumption values in 2, 3 and 4 NC flat finned heat exchangers

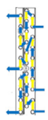
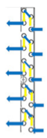
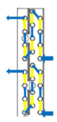
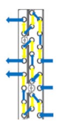
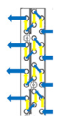
NC	Row	NC Diagram	Air Flow (m3/h)	Capacity Watt	Water Flow (m3/h)	Water Pressure Drop kPa	Motor Power Watt
3	3		522.36	3811.4	0.672	70.4	59.5
3	3		668.88	4699.0	0.826	102.3	69.7
3	3		900.41	5981.5	1.031	153	92.2
NC	**Row**	**NC Diagram**	**Air Flow (m3/h)**	**Capacity Watt**	**Water Flow (m3/h)**	**Water Pressure Drop kPa**	**Motor Power Watt**
5	2		973.79	5081.9	0.881	27.4	94.3

Table 3. Total heat transfer amount, air flow rate, water side pressure drop and AC motor power consumption values in 2, 3 and 4 NC flat finned heat exchangers

NC	NC Diagram	Air Flow (m3/h)	Capacity Watt	Water Flow (m3/h)	Water Pressure Drop kPa	Motor Power Watt
2		505.39	3663.2	0.636	34.0	59
2		644.65	4506.0	0.793	50.5	68
2		856.89	5684.6	0.976	73.7	90.1
NC	**NC Diagram**	**Air Flow (m3/h)**	**Capacity Watt**	**Water Flow (m3/h)**	**Water Pressure Drop kPa**	**Motor Power Watt**
3		510.92	3655.5	0.635	13.4	60
3		643.70	4447.7	0.778	19.3	69.7
3		853.95	5602.2	0.978	29.9	91
NC	**NC Diagram**	**Air Flow (m3/h)**	**Capacity Watt**	**Water Flow (m3/h)**	**Water Pressure Drop kPa**	**Motor Power Watt**
4		510.95	3613.4	0.625	7.2	60
4		642.44	4386.9	0.763	10.4	69.7
4		853.4	5515.2	0.961	15.8	91

serious effect on the heating process.

- Depending on the air flow, the water flow also increases linearly.
- As the number of circuits increases, the water side pressure loss decreases significantly.
- The difference of fin types seriously affects the heat transfer rate.
- The louver wing type is the most efficient wing type result compared to the other two wing types.
- Air side pressure loss is considerably high in louver blade type.
- In the conditioned air heating process, an increase in air flow was observed due to the decrease in the density of the air and the increase in rpm.
- The pipe diameter affects the water side pressure loss very seriously despite the same number of circuits and methods.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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