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Examination of Different Heat Exchangers and the Thermal Activities of Different Designs

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In this study, instead of gasketed or brazed plate heat exchangers, which are used in various fields of application, a direct metal sintering method is used to design a heat exchanger with its original geometry and with different geometries. Studies of heat exchangers found in published literature were reviewed, and the thermal behaviors of the proposed unique designs were examined. Usually heat exchangers using this design do not use channel spacing angles of 30–45–60–75° for the plate ducts. The thermal behaviors of the fluid-circulating systems were analyzed using ANSYS FLUENT software, and they used the boundary conditions found in the literature for this design. Heat transfer between the heat exchanger channels and channel walls was calculated. The analyses results show that an increase in the amount of heat transfer surface area and also an increase in surface roughness increased the amount of positive heat transfer.

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PACS/topics: heat exchangers, compact heat exchanger, micro channel heat exchanger

1. Introduction

One of the most important and most common process engineering applications is the exchange of heat between two or more fluids at different temperatures. Mild steel, alloy steels and especially other alloys such as copper — and for special purposes materials such as graphite or ceramics — are used in the construction of heat exchangers. A wide range of factors need to be considered in their manufacture. These include physical characteristics, such as durability in acidic or alkaline working conditions, corrosion resistance, ease of fabrication of the metal materials, heat transfer and heat diffusion coefficients, size and density along with the heat and pressure involved, and the price. Increasing the surface area of the heat exchanger — because this directly affects the amount of heat to be transferred — to produce a larger surface area in a smaller volume is increasingly required. The main methods of increasing the surface area in heat exchangers include the use of porous substrates and the formation of extra surfaces. Both projecting and porous surfaces can both be successfully applied to their manufacture [1].

In a review of studies in literature, direct metal laser sintering (DMLS) technology is an important method for manufacturing precision and quality products that are difficult or impossible to produce with existing methods. This technology is used in medicine — for implant construction and the manufacture of medical equipment — in the aerospace industry, for satellite systems and aircraft parts, in mini jet turbines and for the production of various components — such as the compressor and engine parts — in the production of gas turbines with parts and equipment using complex geometries.

The DMLS system uses aluminium, stainless steel, titanium and its alloys, nickel and cobalt; metal powder such as chromium may also be used. Although a certain degree of extra cost is involved, the DMLS method of compact heat exchanger production is an effective and easy method of production for more complex geometries required when making low-volume, high-performance heat exchangers [2–7]. Using different fluids in heat exchangers allows an evaluation of the performance of the heat exchanger. This involves looking at the cooling process and the temperature difference, and deriving correlations between the concentration and flow, and the boiling temperature [8–13]. Examination of the thermal and dynamic analysis of plate-type heat exchangers has been performed using computational fluid dynamics (CFD) programs, and analytical studies using numerical calculations that have been used to investigate the thermal conductivity of heat exchangers have been reviewed in published literature. A range of different channel angles have been investigated to show the effect of surface area on heat transfer. The heat transfer and heat transfer coefficient has been examined with important parameters, such as the Reynolds number and the Nusselt number, and taken into account in the design of heat exchangers [9–14].

2. Numerical modelling

The numerical modelling is carried out on a design for a compact heat exchanger that can be manufactured using the DMLS process. Table I shows the measurements produced by a classical method for a heat exchanger designed as a solder-plate heat exchanger using the original 3D CAD (SolidWorks) design (Fig. 1). This heat exchanger's geometry follows a standard commercially available heat exchanger. This design, made using the boundary conditions used in literature for the thermal fluid circulating in the system, is analysed using ANSYS-FLUENT software. Benefiting from this analysis work, a different and unique geometry has been designed, and this de-

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*corresponding author; e-mail: mehmetkan@sdu.edu.tr sign's thermal behaviour has also been investigated with the help of ANSYS-FLUENT software.

TABLE I

The geometric properties of the heat exchanger.

the length of the heat exchanger	192 mm
the width of the compact heat exchanger	74 mm
hot water inlet-outlet pipe diameter	18 mm
cold water inlet-outlet pipe diameter	13 mm
number of heat exchanger plates	10

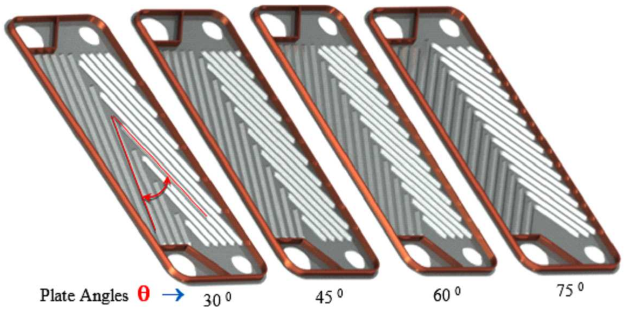

Fig. 1. Design of brazed–plate heat exchangers with different angles of geometry and flow volumes.

3. Materials and method

In this study, firstly the 3D CAD design of the heat exchanger is manufactured using the DMLS method. 3D designs are used for higher-performance and smaller size. The fluid circulating in a compact heat exchanger can be placed in a smaller volume. Input, output and channel flow CFD analysis systems using ANSYS-FLUENT software are used to determine the thermal and dynamic behaviour. The DMLS method is used to produce a 3D CAD heat exchanger design with 4 plate channel angles of 0°, 45°, 60° and 75°, working at a flow rate of 0.3 kg/h, and analyses were performed with ANSYS-FLUENT CFD software [20]. In the analysis, cold fluid (water) at a temperature of 15 °C enters the heat exchanger, the hot fluid (water) inlet temperature is 60 °C and the ambient temperature is taken to be 25 °C (Table II). The heat exchanger activity coefficient and the amount of heat transfer are the basic parameters that determine the performance of the heat exchanger.

Parameters used in the analysis. TABLE II

hot water inlet temperature	60 °C
cold water inlet temperature	15 °C
ambient temperature	27 °C
channel angle	30–45–60–75° original design
fluid (water) flow	0.3 kg/s

3.1. Heat exchanger thermodynamic analysis

Heat transfer in a heat exchanger, which is only between fluids and where it is accepted that there is no heat loss to the environment, can be calculated with Eq. (1) [1]:

$$\dot{Q} = kA\Delta T_m. \tag{1}$$

According to this, $\dot{Q}$ = heat that passed from heat exchanger [W] = heat from the cooling hot fluid cools = heat that warms the cold fluid.

The most suitable parameter for comparisons of heat exchangers with each other is heat exchanger effectiveness. This can be written as follows in Eq. (2) [1]:

$$\varepsilon = \frac{T_{hg} - T_{hc}}{T_{hg} - T_{cc}} = \frac{C_c(t_{cc} - t_{cg})}{C_h(t_{hg} - t_{cc})}, \tag{2}$$

3.2. Basic equation and methods of analysis used in ANSYS-FLUENT software

Based on the ANSYS-FLUENT finite volume method (other modeling programs can be used). The mesh file is limited by the program boundary conditions and parameters are selected by applying a solution for the system. Working in the background, the ANSYS-FLUENT program delivers a system solution using the equations that follow. The numerical analysis works in three-dimensions, uses conservation of mass and is assumed to be time independent to solve the momentum and energy equations [20].

Continuity equation, as shown in Eq. (3) below

$$\frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0. \tag{3}$$

Conservation of momentum equation, as shown in Eqs. (4)–(6): below:

$$u\frac{\partial(\rho u)}{\partial x} + v\frac{\partial(\rho v)}{\partial y} + w\frac{\partial(\rho w)}{\partial z} = -\frac{\partial P}{\partial x} + \mu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2}\right), \tag{4}$$

$$u\frac{\partial(\rho u)}{\partial x} + v\frac{\partial(\rho v)}{\partial y} + w\frac{\partial(\rho w)}{\partial z} = -\frac{\partial P}{\partial y} + \mu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} + \frac{\partial^2 v}{\partial z^2}\right), \tag{5}$$

$$u\frac{\partial(\rho u)}{\partial x} + v\frac{\partial(\rho v)}{\partial y} + w\frac{\partial(\rho w)}{\partial z} = -\frac{\partial P}{\partial z} + \mu\left(\frac{\partial^2 w}{\partial x^2} + \frac{\partial^2 w}{\partial y^2} + \frac{\partial^2 w}{\partial z^2}\right). \tag{6}$$

Conservation of energy equation, as shown in Eq. (7) below

$$u\frac{\partial(\rho T)}{\partial x} + v\frac{\partial(\rho T)}{\partial y} + w\frac{\partial(\rho T)}{\partial z} = -\frac{\partial P}{\partial x} + \frac{\mu}{T}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right). \tag{7}$$

Table III shows the parameters used in ANSYS FLUENT software [20].

TABLE III

Parameters used in ANSYS FLUENT software.

simulation condition	steady-state
solver type	pressure based
mesh structure/number	tetrahedral/10 million
turbulence model	standard k-ε turbulence model
wall-turbulence interaction	standard wall-function
speed-pressure interaction	SIMPLE algorithm
decomposition method	second order upwind

4. Results

The heat exchanger produced by ANSYS FLUENT software with channel spacing of 30–45–60–75° and using the temperature distribution, the pressure distribution, and the hot and cold fluid velocity vectors from the original heat exchanger design is shown in Figs. 2–5.

Analysis obtained from the data used in the calculations is shown in Table IV.

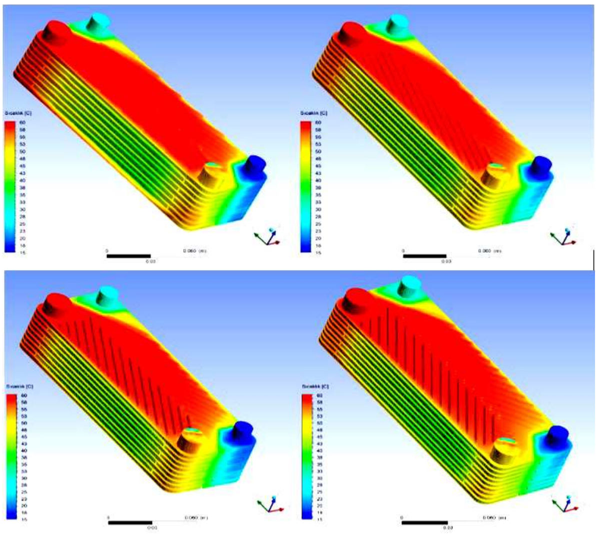

Fig. 2. Snapshots of temperature distribution for 30–45–60–75° channels in the heat exchanger.

TABLE IV

The data obtained from the analysis and calculations.

No.	Channel angle	Hot water input input velocity [m/s]	Hot water output velocity [m/s]	Cold water input velocity [m/s]	Cold water output velocity [m/s]	Hot water output temperature [°C]	Cold water output temperature [°C]	Hot water input pressure [Pa]	Cold water input pressure [Pa]	Heat transfer reduction [W]	Effectiveness ε
1	30°	0.787	1.008	0.831	0.961	52.36	27.61	706.93	617.32	9585	23.59
2	45°	0.787	1	0.831	0.954	52.27	28.05	710.54	627.53	9698	24.19
3	60°	0.787	1	0.831	0.953	52.12	28.24	749.78	652.08	9886	24.81
4	75°	0.787	0.993	0.831	0.945	52.07	28.80	818.30	682.33	9949	25.41
5	original design heat exchanger	2.593	2.967	1.426	1.789	48.36	35.96	11654.98	9655.55	14604	48.4

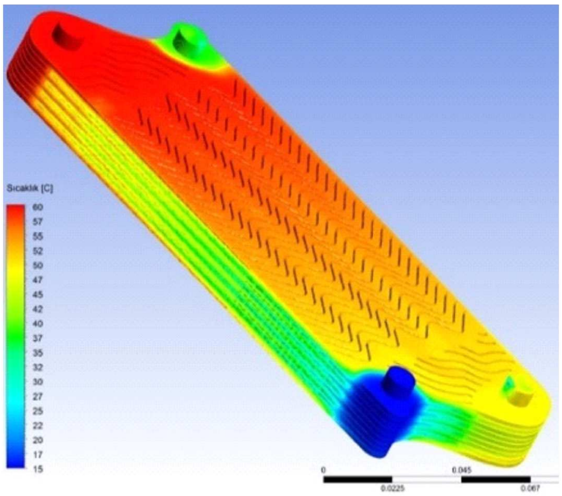

Fig. 3. Temperature distribution for the original design of the heat exchanger.

These analyses result in the highest amount of heat transfer, as shown in Fig. 6, achieved by the original design.

The heat exchanger analyses show the best efficiency results as seen in Fig. 7 achieved by the original design.

5. Conclusions

According to the temperature, pressure and effectiveness analysis good results are obtained with the original compact heat exchanger design. Micro-sized heat exchangers designed using the DMLS method can be manufactured in one piece. A heat exchanger manufactured by the DMLS method can be simulated in experimental tests. As a result, the importance of numerical analysis has emerged in the manufacture, design and optimization stage for compact heat exchangers. The pressure value in the experimental version of the original heat exchanger

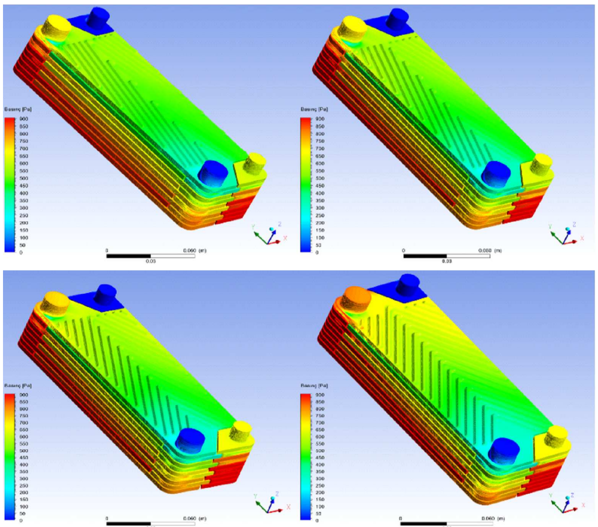

Fig. 4. Snapshot of pressure distribution for 30–45–60–75° channels in the heat exchanger.

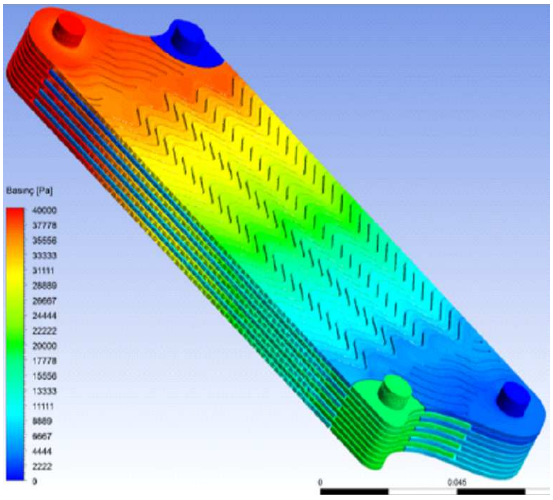

Fig. 5. Pressure distribution in the original design in the heat exchanger.

design is higher than the classical heat exchanger. The 75° channel angle brazed heat exchanger effectiveness is better than other channel angles. The amount of heat transferred by the original heat exchanger design — with a 75° channel angle — at 46.7%, is higher than a standard brazed heat exchanger. The 75° channel angle brazed heat exchanger values were higher than the other channel angles. The 30° channel angle brazed heat exchanger's pressure decreased to a lower value compared to the other channel angles and the original heat exchanger design.

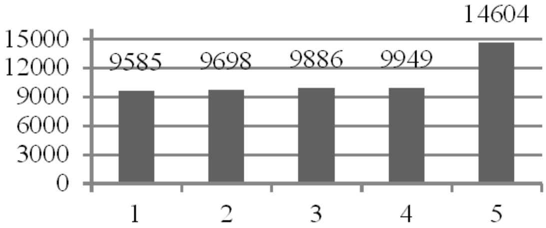

Fig. 6. Chart showing amount of heat transfer.

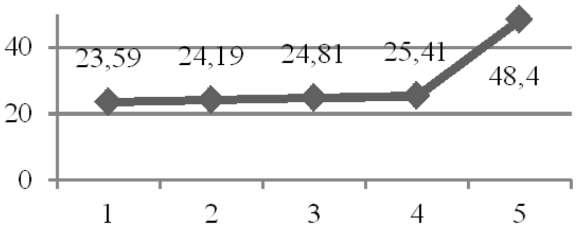

Fig. 7. Chart of effectiveness.

In future studies, the compact heat exchanger design can be improved, and the pressure decreased by designing a new channel geometry profile. Therefore, designing new heat exchangers can reduce the volume required for the heat exchanger, increase the amount of heat transfer and increase their effectiveness.

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