EFFECTS OF THE FLUID FLOW DYNAMIC PARAMETERS ON THE HEAT EXCHANGE CAPACITY OF THE PLATE HEAT EXCHANGER FOR M503Б ENGINE

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Abstract: *The fluid flow dynamic parameters have a decisive influence on the heat exchange capacity as they pass through the channels of the heat exchanger. This paper presents the results of a study evaluating the influence of the fluid flow dynamics parameters on the heat exchange capacity of plate heat exchanger for M503Б engine by using the CFD method in ANSYS Fluent Software.*

Keyword: *fluid flow dynamics, plate heat exchanger, M503Б engine, CFD, ANSYS Fluent.*

Classification number: *2.1*

1. Introduction

Nowadays, plate heat exchangers have been widely used in many different fields such as heater, in the food industry, chemical industry, marine... because they have the advantages superior to conventional tube-type heat exchangers. First of all, in the plate heat exchanger liquid fluids are exposed to a much larger surface area because of the liquid spreading on the plates, which improves the heat exchange capacity, in when the device is smaller in size. Moreover, since they are quite simple structure, easy to disassemble so it is very convenient in maintenance, cleaning plates, especially in tight space conditions such as on the waterway.

The heat exchange capacity of a plate heat exchanger depends on many factors such as the structure of the equipment, the working conditions, the fluid flow dynamic parameters... In particular, the dynamic parameters of the fluid streams have a decisive influence on the heat exchange capacity as they pass through the channels of the heat exchanger. The dynamic parameters of the fluid flow can be referred to as velocity, pressure, temperature, viscosity, tangency. In order to improve the heat exchange capacity of plate heat exchanger, many studies in the world have focused on the effect of the geometry of the plates, the layout of the flow channels.

The purpose of this paper is to present the theoretical and computational and simulation bases of ANSYS Fluent Software in order to provide an overview of the effects of the fluid flow dynamic parameters on the heat exchange capacity of the plate heat exchanger.

2. Theory, modelling and simulation

2.1. Theory of heat transfers through flat plate

The heat transfers between the fluid flow and the flat plate surface is a forced convection heat exchanger. The heat transfer coefficient α between the fluid flow and the plate surface is determined by the Nucene standard [2, 6].

$$\alpha = \frac{Nu.\lambda}{d_{td}} \quad [W/(m^2.^oC)] \tag{1}$$

$$Nu = 0{,}135\,\mathrm{Re}^{0,73}\,\mathrm{Pr}^{0,43}\left(\frac{\mathrm{Pr}}{\mathrm{Pr}_{cm}}\right)^{0,25} \tag{2}$$

where, $\mathrm{Re} = \frac{w.d_{td}}{\nu}$ - Reynold number; $\mathrm{Pr} = \frac{c_p.\nu.\rho}{\lambda}$ - Prandtl number; Pr_{cm} - Prandtl number corresponding to the average temperature of the plate surface; w - Liquid flow rate, [m/s]; $d_{td} = 1{,}3\frac{(b.h)^{0,625}}{(b+h)^{0,25}}$ - Equivalent diameter of the liquid layer between the plates, [m]; b - Liquid layer width, [mm]; h - Liquid layer height, [mm]; ν - Kinematic viscosity of the liquid, [m^2/s]; c_p - Specific heat of the liquid, [J/(kg.^{o}C)]; ρ - Density of the liquid, [kg/m^3]; λ - Thermal conductivity of liquid, [W/(m.^{o}C)].

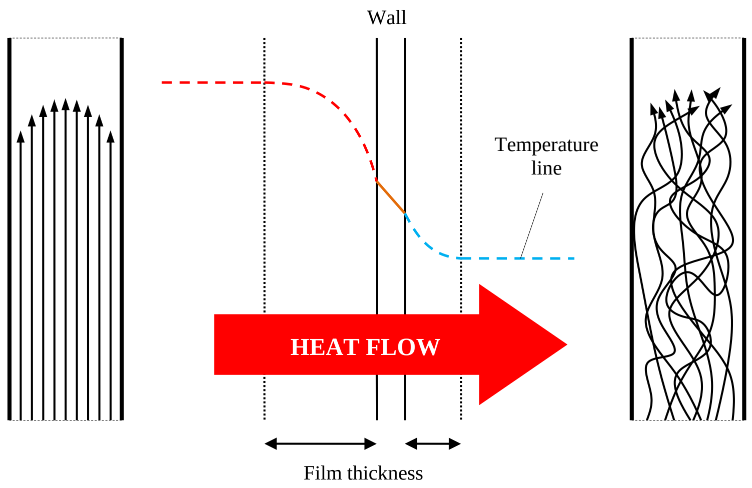


Figure 1. *The change of the thermal field corresponds to the laminar flow and the turbulent flow through the flat plate*

The heat transfers between the two liquid streams through the plate is a heat exchanger that combines heat and convection. The boundary between the dotted lines and the planar walls in Figure 1 is called the thickness of the film. The heat transfer through film thickness is considerably lower than in the liquid layer (temperature gradients are significantly reduced in this region). This is because the area close to the surface of the flat plate always creates the laminar flow. The energy of laminar flow is smaller than turbulent flow. The total heat transfer coefficient shows the effect of heat transfer by heat transfer and convection as determined by the formula [3]:

$$\frac{1}{k} = \frac{1}{\alpha_{hot}} + \frac{\delta}{\lambda} + \frac{1}{\alpha_{cold}} \quad (3)$$

Where, k - Total heat transfer coefficient, [W/m^2.^{o}C]; α_{hot}, α_{cold} - Convective heat exchange coefficient of hot and cold fluid flow with flat plate, [W/m^2.^{o}C]; δ - Thickness of the plate, [m]; λ - Thermal conductivity of the sheet material, [W/m.^{o}C].

The energy transferred from the hot fluid to the cold fluid through the heat exchanger plate:

$$\dot{Q} = k.S.\Delta T \ \text{[W]} \quad (4)$$

Where, S - Area of heat transfer, [m^2]; ΔT - Average temperature difference between the two liquid flows, [^{o}C].

From equation (4) shows the effect of factors to total heat transfer coefficient. With a flat plate the thickness and thermal conductivity of the material is fixed. Increasing the convection heat exchange coefficient of the fluid flow with the flat plate α will increase the total heat exchange coefficient. The coefficient α depends on the temperature, flow velocity, area, shape, direction and roughness of the surface of the heat exchanger. For turbulent flow, the convective heat exchange coefficient α is always higher than the laminar flow.

Liquid flow rate inside the liquid layers is much higher than that in the tube heat exchangers. This is because plates of the heat exchangers are constructed in the form of herringbone as shown in figure 3 while in the tube heat exchangers are constructed in the form of straight pipe. The turbulences of the fluid flow in the plate heat exchanger can be achieved with a Re ≥ 2300 value at a lower flow rate [4].

The energy in the single-phase liquid current is described by the equation [3, 5]:

$$\dot{Q} = \dot{m}.C_p.\Delta T_1 \ \text{[W]} \quad (5)$$

where, $\dot{m}$ - Mass flow of fluid flow [kg/s]; C_p - the specific heat of liquid flow

[J/kg.ºC]; *ΔT₁* - Temperature difference between inlet and outlet of liquid flow [ºC].

Assume that the heat transfer between the fluid streams and the environment is ignored. According to the law of conservation of energy:

$$\dot{Q} = \dot{m}_1.C_{p1}.\Delta T_1 = \dot{m}_2.C_{p2}.\Delta T_2 \text{ [W]} \quad (6)$$

2.2. Modelling the geometry of fluid flow

Model of fluid flow simulation between two ribbed heat exchangers plate. The heat exchanger plate has a row of ribbed, the size of the ribbed shown in figure 2. The geometry of the liquid layer is shown in table 1.

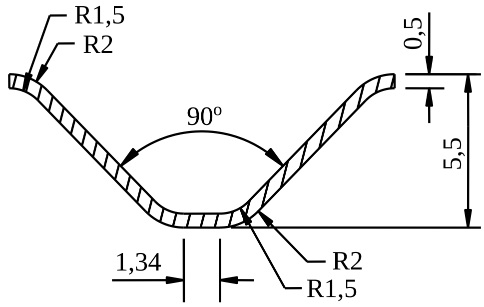
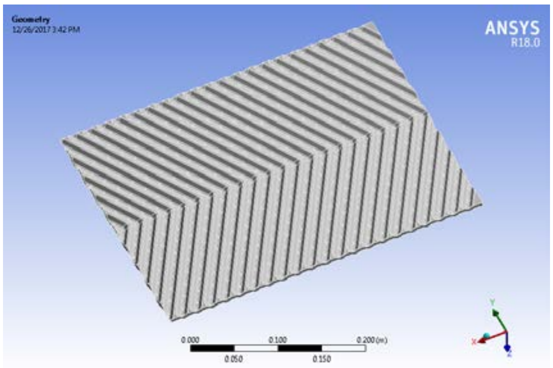


Figure 2. *Dimension of trapezoid ribbed of heat exchanger plate.*

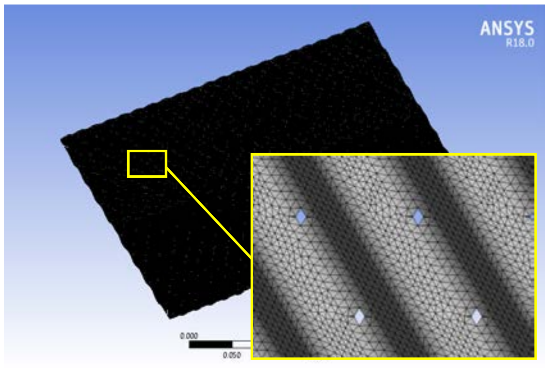
Table 1. *The geometry of the liquid layer.*

o	Parameter	U nit	Value
	Liquid layer width	m	0,3
	Liquid layer length	m	0,4
	Liquid layer height	m	0,005
	Ribbed	-	Trape zoid
	Number of ribbed	-	1
	Angle created by the ribbeds	đ ộ	120

The geometry of the fluid layer constructed using Autodesk Inventor software then put in ANSYS Fluent software is shown in figure 3.



a)



b)

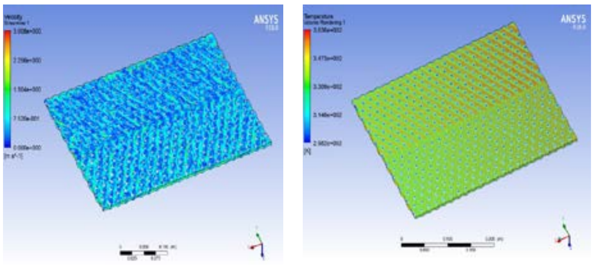
Figure 3. *Geometric model (a) and finite element model (b) of the layer.*

2.3. Determine the survey mode

The fluid flow dynamic parameters are evaluated, surveyed including: fluid flow and dynamic viscosity. The fluid flow through the fluid layer is determined by the flow of the fresh water pump on the M503Б on the Navy's 266E ship. The flow range is taken linearly according to the crankshaft speed of engine (*n* = 1780; 1600; 1400; 1200; 1000 và 800 rpm). The dynamic viscosity range of the fluid stream is determined by the fluid viscosity of the water. Dynamic viscosity values were selected for the survey: μ = 0,0002; 0,0003; 0,0005; 0,0007 và 0,0009 kg/m.s (Corresponding to the water temperature varies in the interval 25÷110 ºC). In the simulation process, the temperature of input liquid is 90 ºC. It is assumed that the heat transfer between the cold liquid flow and the heat exchanger plate is unchanged.

3. Results and discussion

The results of the simulation of the temperature and velocity of the liquid layer are shown in figure 4:



a) b)

Figure 4. *Velocity distribution (a) and temperature (b) of the liquid layer*

- The flow of the liquid flows along the channels of the liquid layer. This is because the channels are arranged in the shape of herringbone, they create turbulence of the fluid flow.

- The temperature distribution at positions in the whole liquid layer is the equally. There was no substantial difference in temperature at sites along ribbeds.

3.1. The effect of flow on the heat transfer capacity of the fluid flow

The results of investigating the effect of flow on the heat transfer capacity of liquid flow are shown in table 2:

Table 2. *Effect of flow on the heat transfer capacity of liquid flow*

No	Parameter	Value					
1	Crankshaft speed (rpm)	1780	1600	1400	1200	1000	800
2	Flow of the fresh water pump (m^3/h)	160	144	126	108	90	72
3	Mass flow of liquid flow (kg/s)	0,8873	0,7986	0,6987	0,5989	0,4991	0,3993
4	Velocity of input liquid (m/s)	0,5745	0,517	0,4604	0,4029	0,3454	0,2878
5	Temperature of output liquid (°C)	71,1	68,1	69,5	72,9	70,7	68,0

- At different flow values, the average temperature at the outlet of the substrate does not change much. The difference in temperature versus the input of the liquid flow in the interval 17,1 ÷ 22,0 °C.

- Supposed $w_1 = a.w_2$. According to equation (2), the convective heat exchange coefficient between the fluid flow and the flat plate corresponds to the flow:

$$\frac{\alpha_1^{tp}}{\alpha_2^{tp}} = a^{0,73} \qquad (7)$$

where, α_1^{tp} and α_2^{tp} is the convection heat exchange coefficient between the liquid flow and the flat plate when the inlet velocity is w_1 and w_2 (m/s).

Convection heat exchange coefficient between fluid flow and heat exchanger corresponds to flow:

$$\frac{1}{\alpha_2} = \frac{a}{\alpha_1} + (a-1)\left(\frac{\delta}{\lambda} + \frac{1}{\alpha_{cold}}\right) \qquad (8)$$

Where, α_1 and α_2 is the convection heat exchange coefficient between the liquid flow and the ribbed heat exchangers plate when the inlet velocity is w_1 and w_2 (m/s).

Easy to see:

+ With $a > 1$: $\alpha_2 < \alpha_2^{tp}$

+ With $a < 1$: $\alpha_2 > \alpha_2^{tp}$

Thus, the effect of the flow rate on the convective heat transfer coefficient between the fluid flow and the plate in the case of using the ribbed heat exchangers plate is greater when using a flat plate. This means that when using a ribbed heat exchanger plate it increases the convective heat transfer coefficient between the fluid flow and the plate compared to the flat plate. Higher flow velocities increase the collision between liquid particles. Therefore, the convective heat exchange coefficient when the turbulent flow is greater than the laminar flow.

3.2. The effect of dynamic viscosity on the heat transfer capacity of the fluid flow

The results of investigating the effect of dynamic viscosity on the heat transfer capacity of liquid flow are shown in table 3:

Table 3. *Effect of dynamic viscosity on the heat transfer capacity of liquid flow.*

No	Parameter	Value				
1	Dynamic viscosity of liquid flow (kg/m.s)	0,0002	0,0003	0,0005	0,0007	0,0009

2	Flow of the fresh water pump (m^3/h)	160	160	160	160	160
3	Mass flow of liquid flow (kg/s)	0,8873	0,8873	0,8873	0,8873	0,8873
4	Velocity of input liquid (m/s)	0,5745	0,5745	0,5745	0,5745	0,5745
5	Temperature of output liquid (°C)	70,7	72,3	72,5	70,7	71,3

- At different dynamic viscosity values, the average temperature at the outlet of the substrate does not change much. The difference in temperature versus the input of the liquid flow in the interval 17,5 ÷ 19,3 °C. This happens because of the turbulent of the fluid flow is huge. The inertia of the flow is much larger than the viscosity force, therefore viscosity does not have a significant effect on the heat transfer between liquid and ribbed plates.

4. Conclusion

When using a ribbed heat exchanger plate, the convective heat exchange coefficient between the fluid flow and the plate is larger than when using a flat plate. The total heat transfer coefficient between the two liquid flows through the heat exchanger plate is proportional to the mass flow of the fluid flow.

The ribbed heat exchanger plate produces a very high degree of turbulence of fluid flow. Therefore, the effect of dynamic viscosity on the heat exchange capacity between fluid flow and ribbed heat exchanger plate is negligible.

Increasing the Reynold's coefficient increases the turbulence of the flow and the heat exchange with the heat exchanger plate. However, this increase will increase the pressure loss of the fluid flow ❑

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