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The effect of fin structure on forced heat convection in a pentagonal channel

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The main purpose of this study is to examine the effect on forced heat convection properties of fin structures in a pentagonal duct. For this purpose, rectangular shaped fins are placed in the selected duct. The study was carried out under the constant heat flux ($q''=500$ W/m^2) and fully developed turbulent flow ($10000 \leq Re \leq 40000$) conditions. As a result of the study, an improvement in velocity distribution and convective heat transfer rate was observed with increasing Reynolds number and the use of rectangular fins. In addition, with the use of fins, the movement area of the flow was narrowed and an increase in the Darcy friction factor was observed.

Keywords – Heat Transfer, Turbulent Flow, Internal Flow, Pentagonal Channel, CFD, Ansys Fluent

I. INTRODUCTION

With the development of technology, it is important to cool industrial equipment and therefore to increase efficiency in energy use. There are new developments in this field every day, new methods are tested by conducting research [1]. In order to increase heat transfer, finned surfaces are used in heat exchangers in the part with low heat transfer coefficient. These surfaces provide additional surface area and increase heat transfer [2]. By using pin fins on the surface of the heat source to be cooled, both the surface area that the cooling fluid comes into contact with and the heat convection coefficient are increased. Fin shape, fin size, and fin arrangement also play an important role in this method [3]. Fin structures are used in many areas such as industrial furnaces, radiators and space vehicles, cooling, heating and air conditioning processes, chemical industry, and cooling of electronic circuits [4].

When the studies in the literature are examined, important studies on circular and rectangular ducts, dimpled ducts, and twisted ducts have been published [5]. However, research is needed to understand the heat transfer and flow properties on pentagonal finned channels. In order to fill the gap in the literature, smooth pentagonal duct and pentagonal duct with rectangular fins are numerically investigated using air as the working fluid under turbulent flow condition ($10000 \leq Re \leq 40000$) and constant heat flux ($q''=500$ W/m^2) on the walls. Atmospheric pressure was chosen as the outlet boundary condition while the inlet temperature of the air was kept at 20°C. The problem was solved using ANSYS Fluent [6], one of the computational fluid dynamics programs.

II. MATERIALS AND METHOD

The image of the smooth duct to be examined within the scope of the study is shown in Figure 1. a, and the image of the rectangular finned duct is shown in Figure 1.b. The mesh structures of the analyzed ducts are shown in Figures 1.c and 1.d. In order to better examine the flow characteristic, a dense mesh structure was used in the regions close to the walls and fins of the duct. In order to obtain the optimum mesh number at Re=40000 for both channels, solutions with different mesh structures were made. In the mesh study for the smooth duct, it is seen that the Nusselt number converges after

20 edge sizing and is shown in Figure 2. The mesh work for the rectangular finned duct was made according to the element size and it was observed that the Nusselt number converged after the 4 mm size elements and as shown in Figure 3. The length of one edge of the channel is 20 mm and the hydraulic diameter is

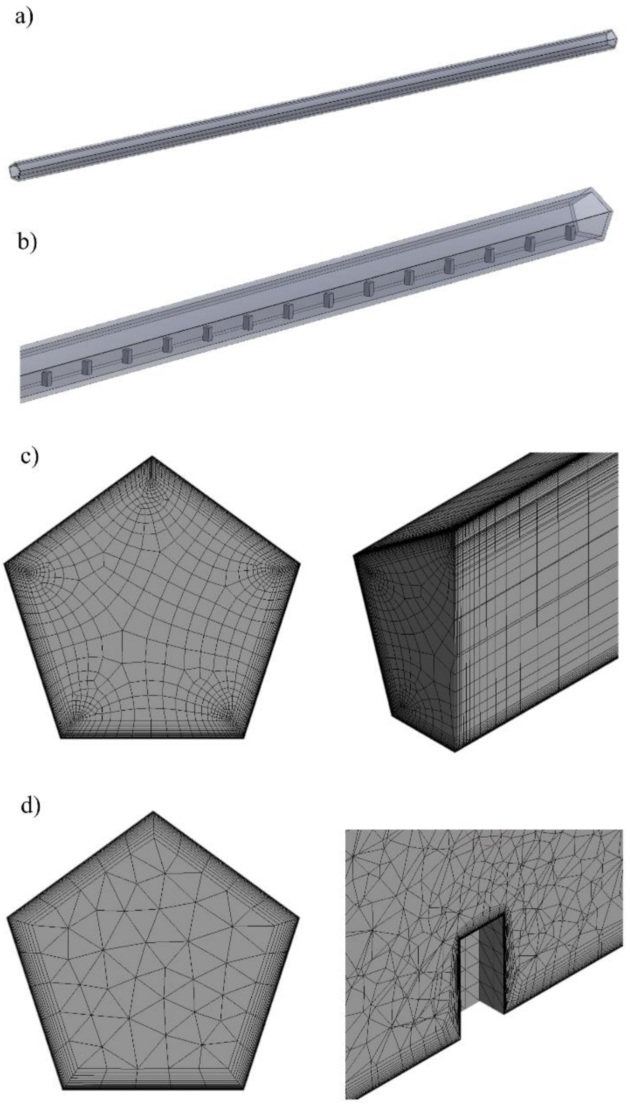


Fig. 1 a) Smooth duct b) Rectangular finned duct c) Mesh structure of smooth duct d) Mesh structure of finned duct

0.0275276 mm. The total length of the duct is 2500 mm, with a length of 1000 mm in front for the flow to become fully developed. The rectangular fins in the duct are 5 mm x 10 mm in size and placed perpendicular to the flow, 50 mm apart. A constant heat flux of q=500 W/m^2 was applied around the test duct. Air was used as the working fluid and the air was considered as Newtonian fluid. The dynamic viscosity of the air entering the duct at 20°C is μ=1.825.10^{-5} kg/m.s, and the thermal conductivity coefficient is k=0.02514 W/m.K.

Heat transfer by forced convection is investigated in this numerical model. Flow dynamics and heat transfer are analyzed under continuous flow, steady-state conditions and the radiation effect is neglected. All solutions are obtained using energy, momentum, and continuity balances [7]. Realizable k-ϵ turbulence model, second order upwind discretization, SIMPLE pressure-velocity coupling algorithms were used to solve the analysis.

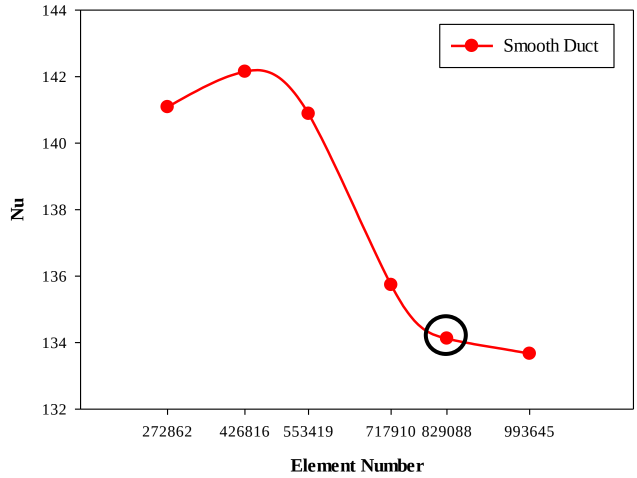


Fig. 2 Mesh independence test for smooth duct

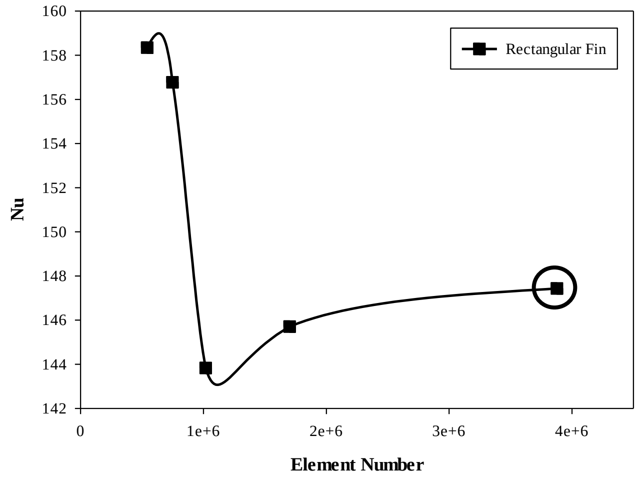


Fig. 3 Mesh independence test for rectangular finned duct

III. Results

First of all, the results of the study were Mesh independence test for finned ductconfirmed with the literature. As seen in Figure 4, the study was confirmed by Petukhov correlation and Gnielinski correlation [8]. The variation of the Nusselt number with the Reynolds number is shown in Figure 5 and the variation of the friction coefficient with the Reynolds number in Figure 6.

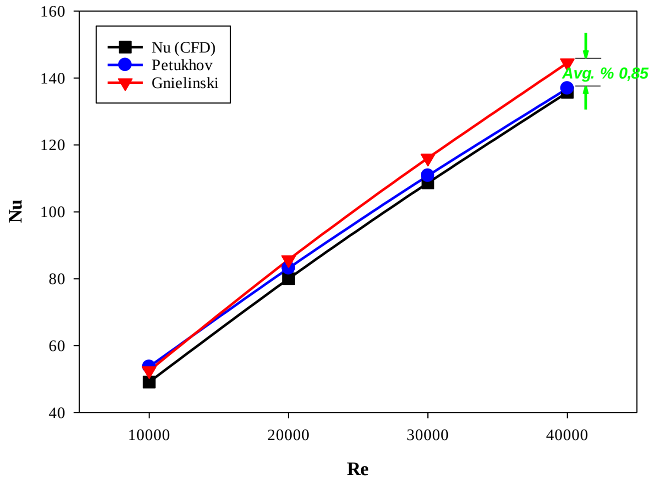


Fig. 4 Comparison of the Nu number with the literature

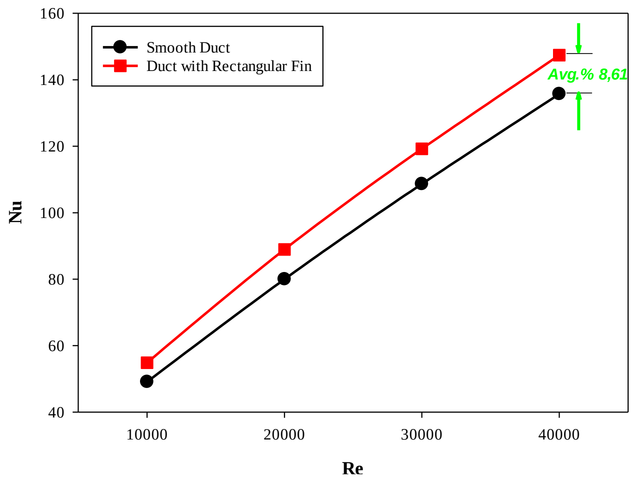


Fig. 5 Varying of the Nu number with Re number

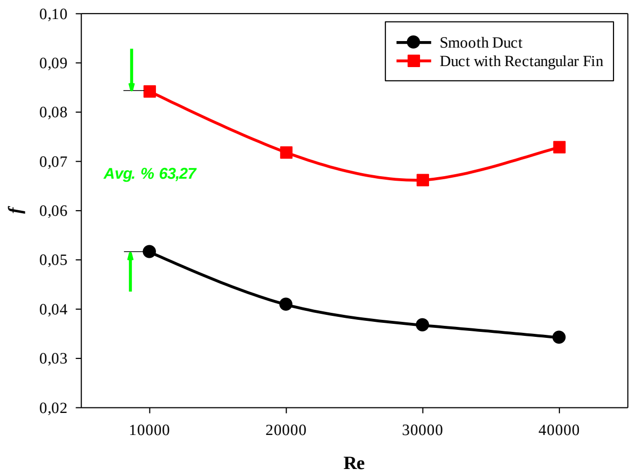
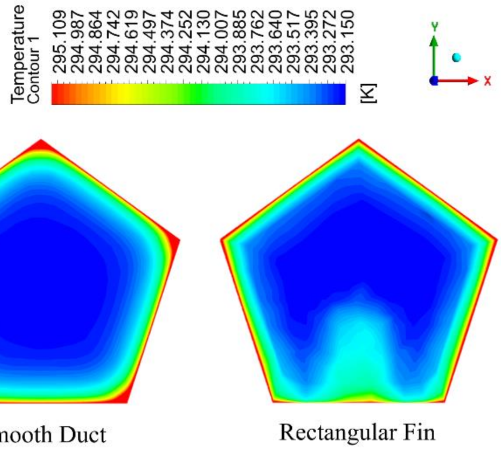


Fig. 6 Varying of the f with Re number

IV. DISCUSSION

It was observed that the Nusselt number increased as the Reynolds number increased for the duct with rectangular finned. The temperature and velocity distributions of the channels examined in Figure 7 and Figure 8 are compared, respectively. For this comparison, the middle sections of the channels at Re=40000 are considered. When the velocity contours are examined, it is seen that the



flow is concentrated on the finned structure.

Fig. 7 Temperature distribution for channels

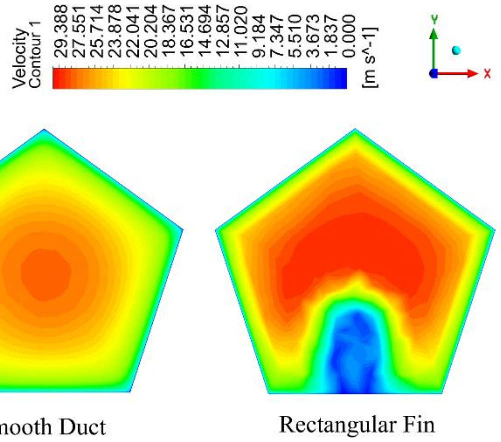


Fig. 7 Velocity distribution for channels

V. CONCLUSION

As a result of this numerical study, the effects of the rectangular fin on the heat transfer under forced convection were obtained. To summarize the conclusions of the study:

• Nu number increased with increasing Reynolds number. In addition, the use of fins in the duct increased the Nu number and improved heat transfer.

• Since the movement area of the flow is narrowed by the use of fins, there has been an increase in the velocity and pressure of the flow.• With the use of rectangular fins, the Nu number increased by 8.61% compared to the smooth duct at Re=40000.

• An increasing in the Darcy friction factor was observed with the use of rectangular fins, and this increasing was calculated as 113.49% at Re=40000.

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