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RESEARCH ARTICLE

CFD Analysis of Using Umbrella Shaped Turbulators to Improve Heat Transfer in a Horizontal Pipe

Ahmet Numan ÖZAKIN[1,*]

[1] *Department of Mechanical Engineering, Faculty of Engineering, Ataturk University, Erzurum, Turkiye*

* *Corresponding author E-mail: ahmet.ozakin@atauni.edu.tr*

HIGHLIGHTS

> The effects of umbrella-shaped flow elements with equal projection areas perpendicular to the flow and different angles on the heat transfer characteristics were examined.

> The most effective flow element was determined by taking into account the convection coefficients obtained at constant Reynolds number and under constant heat flux.

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ABSTRACT

Heat transfer in pipes has an important place in the industry. For this purpose, many studies have been carried out to investigate the effects of elements with different geometries placed in the pipe on the heat transfer characteristics. In this study, the effects of umbrella-shaped turbulators with different angles (45o, 60o and 75o) on the heat transfer characteristics, placed in a horizontal pipe with a constant 20000 W/m2 heat flux from its surface, were investigated numerically. When the results of the study were examined, it was determined that the heat transfer was higher in cases where the umbrella opening was higher than in other cases. The maximum Nusselt number obtained in the study was determined to be 171.25 in the case of the 45 degree turbulator and 15000 Reynolds number. In addition, it was concluded that turbulent kinetic energy is an important parameter in increasing the heat transfer.

Contents

1. Introduction

Nowadays, when energy crises and fluctuations in energy prices are manifested severely, the importance of using the existing energy more effectively is increasing. Many applications of energy in industry include thermal applications. The more effective transfer of heat is directly related to the efficiency of the energy used. In heat transfer applications, it is very important to transfer the heat of the fluid passing through a pipe or channel more effectively. In addition, turbulators placed in the flow in order to increase the heat that must be transferred from the pipe or duct stand out as an important application.

There are many studies on higher efficiency in heat transfer applications. Since the heat transfer takes place between the surfaces and the fluids covering these surfaces, the researchers focused on these points [1, 2]. In addition, a circular tube for constant surface area provides the highest heat transfer with the least pressure drop. For this reason,

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circular cross-section pipes are used in devices where heat transfer is required [3]. The effects of balls diameter, pitches and Reynolds numbers on heat transfer, friction factors as well as entropy formation were analyzed in four different Reynolds numbers between 5000 and 20000 in a numerical study aimed at increasing the heat transfer in a square-section channel by using ball-type turbulators. It has been shown that the turbulators determined according to the results of the study create high turbulence even at low Reynolds numbers and have a positive effect on heat transfer [4].

Sungur and Topaloğlu [5] carried out a numerical study by placing conical turbulators inside the smoke pipes in order to increase the efficiency of smoke tube boilers. They determined that as the number of turbulators used increased, the heat transfer increased, but the heat transfer increase was not proportional to the increase in the number of turbulators. As a result, they determined that the best heat transfer was achieved by using thirteen turbulators and the pressure drops increased with the increase in the number of turbulators.

Kahraman et al. [6] in their study, in two different fin openings (b= 0.1 and 0. A numerical analysis was carried out with ANSYS Fluent to examine the effect of turbulators with 2 m) and three different fin angles (θ=30°, 45° and 60°) on the heat transfer performance. They found that the Nusselt number increases when a turbulator is used in the pipe, and the fin distance (b) and fin angle (θ) of the turbulator affect heat transfer.

Şahin et al. [7] carried out heat transfer analysis using a spring type turbulator by reducing the dimensions of a concentric tube-in-tube heat exchanger. Numerical analysis in the range of 3000-18000 Reynolds numbers was performed with the ANSYS Fluent RNG k-ε model. Among the three different turbulence models they used, the best result was the RNG-Standard wall function. They found that it was realized with the model.

Şahin et al. [8] investigated the effects of spring type turbulators with different properties on heat transfer and friction experimentally and numerically. As a result of the analyzes they made at different Reynolds numbers in the range of 3000-17000, they determined that the heat transfer performance using turbulators was 2.28, 2.07 and 1.95 times better than the straight pipe for p = 15, 30 and 45 mm pitch distances, respectively.

Xiong et al. [9] investigated the heat transfer and flow characteristics of conical and fusiform turbulator geometries in the range of 4000-13000 Reynolds numbers in their numerical study. They stated that the best heat transfer coefficient is obtained in the case of using a heat exchanger with a circular inner tube. They obtained more efficient heat transfer by converting the shape of conical turbulators to fusiform.

Shabanian et al. [10] conducted an experimental and numerical study on the heat transfer, friction factor and thermal performance of an air-cooled heat exchanger in which three types of turbulators are integrated, butterfly, conventional and serrated twisted strip. The best heat transfer performance was obtained with the butterfly turbulator with a 90° inclination angle. They also determined that the difference between the heat transfer rates obtained by using conventional and serrated fins decreases by decreasing the twist rate. They carried out an experimental and numerical study on friction factor and thermal performance. The best heat transfer performance was obtained with the butterfly turbulator with a 90° inclination angle. They also determined that the difference between the heat transfer rates obtained by using conventional and serrated fins decreases by decreasing the twist rate [10]. They carried out an experimental and numerical study on friction factor and thermal performance. The best heat transfer performance was obtained with the butterfly turbulator with a 90° inclination angle. They also determined that the difference between the heat transfer rates obtained by using conventional and serrated fins decreases by decreasing the twist rate [10].

Porous media, which is one of the important methods of increasing heat transfer, provides about 50% better heat transfer and causes significant pressure drops. In order to prevent this pressure drop, flow gaps are left at certain points. [11, 12].

In a numerical study by Jang and Chen [13], flow analysis of porous media placed in the canal was performed using the Darcy-Brinkman-Forchheimer model. Al-Nimr and Alkam [14] obtained a transient solution for heat transfer analysis in a porous medium. They stated that when the pipe is partially filled by leaving gaps in the form of annular, the Nu number increases up to 12 times. Improvement of heat transfer in porous media also has uses in renewable energy systems [15–19].

There are many methods used to increase heat transfer. It can be seen from the literature review given that the use of turbulators is very important in order to transfer heat from pipes. The main purpose of the use of turbulators is to increase the turbulence in the parts close to the pipe surface by increasing the local Reynolds numbers in the parts where the flow velocity is low, independent of the average Reynolds number in the flow, and thus to increase the heat transfer. In this study, the effects of umbrella shaped turbulators with different angles (45º, 60º and 75º) on the heat transfer characteristics in the pipe with different Reynolds numbers were numerically investigated.

2. Material and Method

In the CFD analyzes carried out to determine the effects of umbrella shaped turbulators on the heat transfer characteristics of a horizontal pipe , models were made at different turbulator angles (45º , 60º and 75º) with a constant heat flux of 20000 W/ m^2 . In the study, analyzes were made at 5000, 10000 and 15000 Reynolds numbers. The geometries used in CFD analysis are shown in Figure 1 and the umbrella shape turbulator geometry is shown in Figure 2.

(a)
45º

(b)
60º

(c)
75º

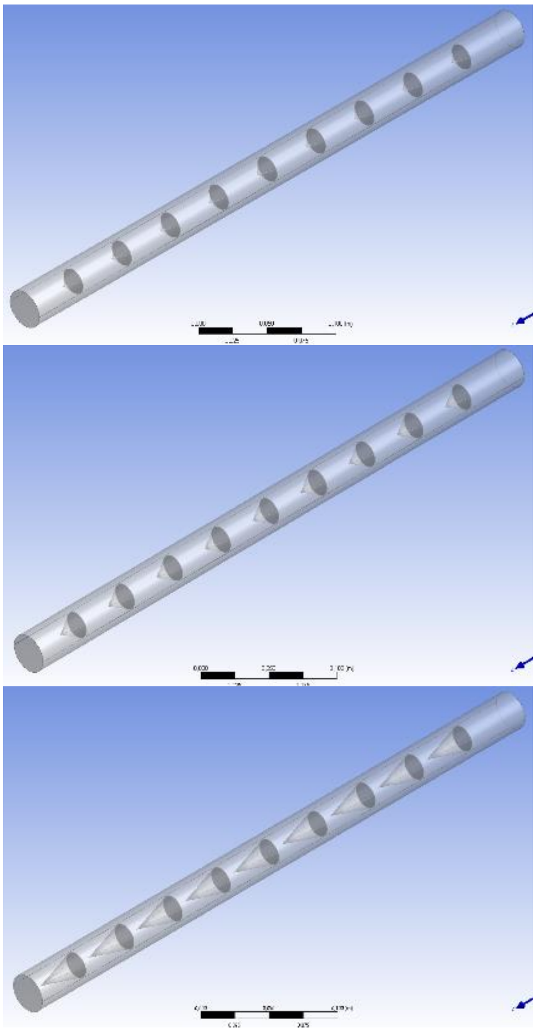

Figure 1 Geometries used in CFD analysis. (a), (b) 60º, (c) 75º

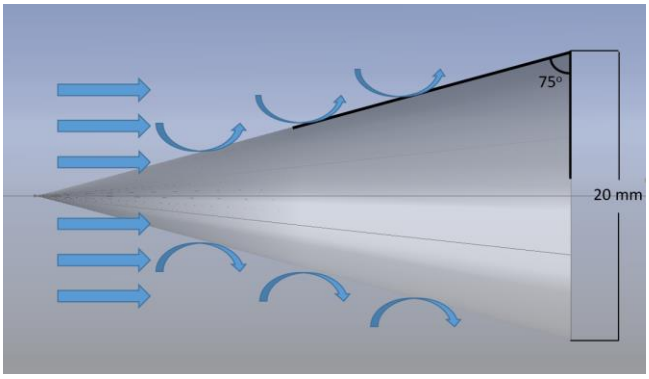

Figure 2 75 umbrella shaped turbulator used in CFD analysis.

The turbulators shown in Figure 1 are placed in a 500 mm long and 30 mm diameter pipe. As seen in Figure 2, although the horizontal lengths for turbulators vary with angle, the circular base part is fixed with a diameter of 20 mm. CFD analyzes were performed for the models obtained under steady-state conditions. ANSYS-Fluent 16 software was used for CFD analysis. In analysis; Water, which does not include steam or solid phases, is used as the fluid, the thermodynamic properties of water change only with temperature and pressure, the water flow is constant and the effects of gravity are neglected.

Considering the above-mentioned assumptions, the conservation of mass equation;

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho u}{\partial x}+\frac{\partial \rho v}{\partial y}+\frac{\partial \rho w}{\partial z}=0 \qquad (1)$$

momentum equation;

$$\frac{\partial \rho}{\partial t}+\vec{\nabla}.(\rho\vec{V})=\frac{\partial \rho}{\partial t}+\vec{V}.\vec{\nabla}\rho+\rho\vec{\nabla}.\vec{V}=0 \qquad (2)$$

the equation of conservation of energy;

$$\rho c_v\frac{dT}{dt}=k\nabla^2T+\Phi \qquad (3)$$

analyzes were made with After the model geometry was determined, mesh cells were created to be used in the study. In the study, analyzes were made by starting from relatively low mesh numbers and increasing gradually, eventually creating a minimum of 1,433,982 mesh elements for different geometries. In Figure 3, the mesh geometry in which the analyzes were made, and in Figure 4, the number-independence analysis of the meshes used in the studies is seen.

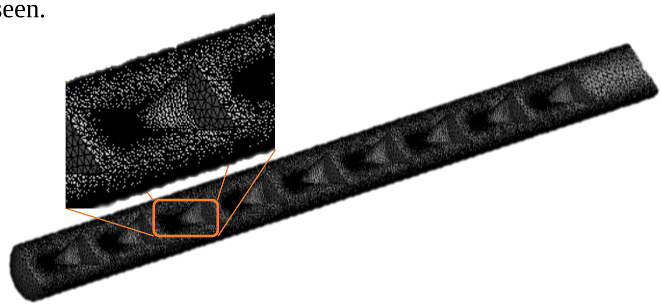

Figure 3 Mesh image where C FD analysis was performed.

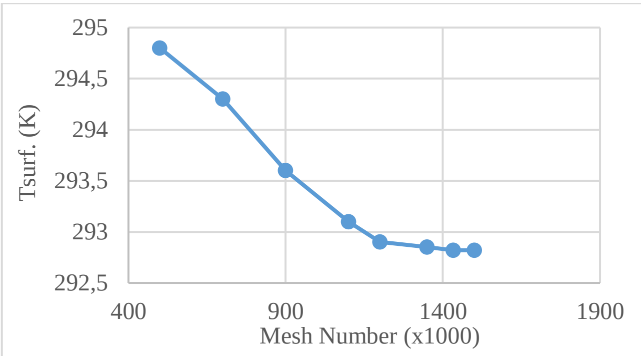

Figure 4 Mesh independence analysis

The mesh independence analysis shown in Figure 4 was performed separately for each geometry. In addition, the "k -Ɛ RNG" model and "Enhanced Wall Functions" conditions were used in the study by applying a constant heat flux of 20000 W/m ^{2} to the outer surface of the pipe.

3. Results and Discussion

In this study, Nusselt numbers were calculated at different Reynolds numbers and different turbulator angles in numerical analyzes to determine the effects of umbrella shaped turbulators placed in the flow volume in the pipe on the heat transfer characteristics. Figure 5 shows Nusselt numbers for different turbulator geometries.

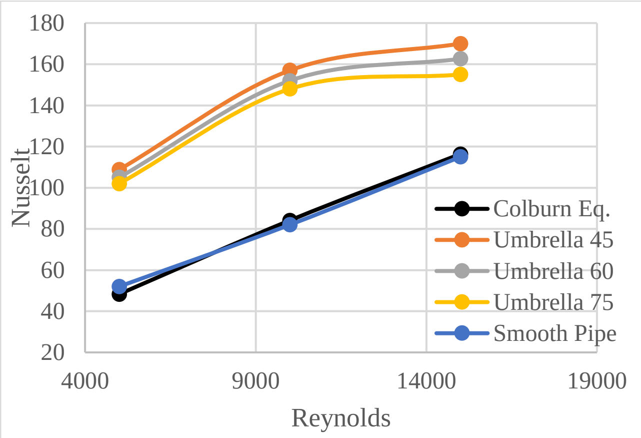

Figure 5 Nusselt numbers for different turbulators.

When the Nuselt numbers for different geometries given in Figure 5 are examined, it is seen that the heat transfer increases approximately 2 times as a result of using turbulators in general. Among the turbulator geometries, it is the one with an angle of 45o that provides the highest heat transfer coefficient. The reason why this turbulator provides higher heat transfer is that it provides higher turbulence in the flow. In addition, it is seen that the analyzes made with the smooth pipe give very close heat transfer results with the Colborn equation. Eq. Colburn correlation with 4 is given.

$$Nu = 0.023 Re^{0.8} Pr^{1/3} \quad (4)$$

In the Nuselt curves given in Figure 5, it is seen that the turbulator geometry named with umbrella 45 provides the best heat transfer. As it is known, high turbulence in the flow is very important in terms of heat transfer. Figure 6 shows the turbulent kinetic energies generated in the flow for the turbulators used in the pipe.

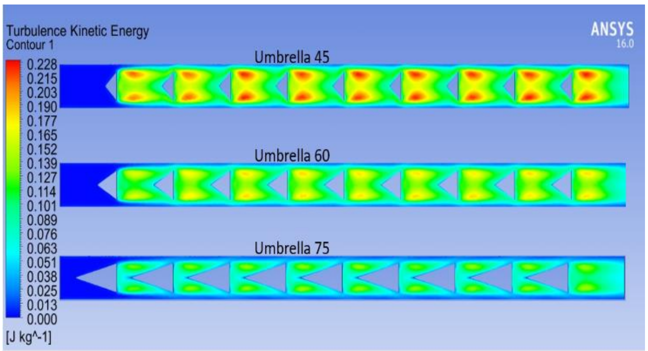

Figure 6 Turbulent kinetic energy gradients created by turbulators with different geometries Re=15000

When the turbulence kinetic energy gradients given in Figure 6 are examined, it is clearly seen that the turbulator with an angle of 45° creates higher turbulence compared to the others. The presence of a sharper element in the flow increases turbulence and therefore heat transfer. After the turbulator, which has an angle of 45°, comes turbulators with an angle of 60° and 75°, respectively, in terms of both heat transfer and turbulent kinetic energy . Figure 7 shows the temperature gradients on the pipe surfaces when different turbulator geometries are used.

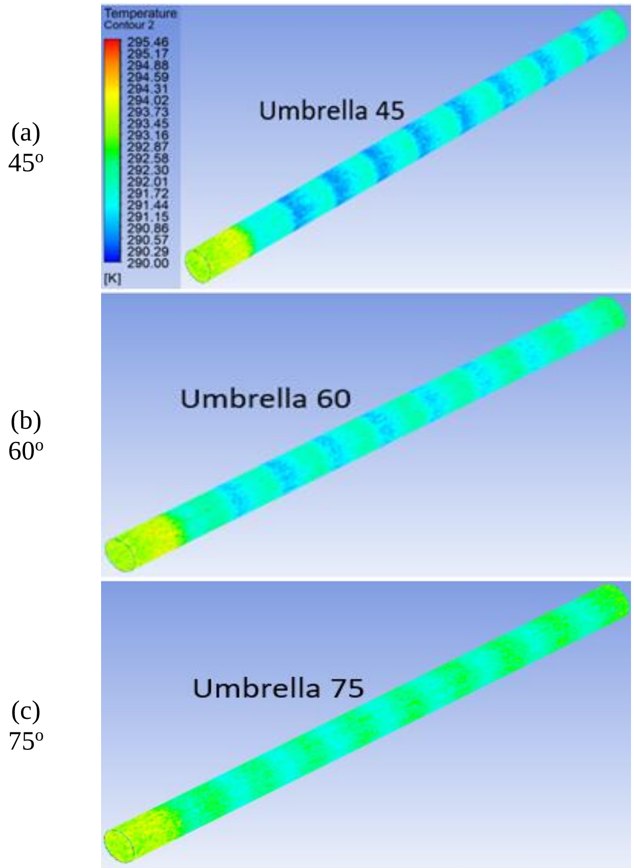

Figure 7 Temperature gradients created by different turbulators Re=15000.

When the temperature gradients seen in Figure 7 are examined, the temperature distribution on the surface of the turbulator geometry with an angle of 45o is lower compared to other geometries. This is in agreement with the Nusselt values seen in Figure 5.

4. Conclusions

This study numerically reveals the heat transfer characteristics in a horizontal pipe with turbulators with angles of 45°, 60° and 75° whose model has been established. In the study, analyzes were made for flows in different geometries using ANSYS-Fluent 16 software. According to the results of the study, it was determined that the turbulator geometry with an angle of 45° provides the best heat transfer. In case this method is used, the heat transfer improvement rate is determined as minimum 34.7%. In addition, it has been determined that the abrupt change of the flow direction of the geometries placed in the pipe is a way to increase the heat transfer and turbulent kinetic energy.

Declaration of Conflict of Interest

Authors declare that they have no conflict of interest with any person, institution, or company.

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