TURBULENT FLOWS AROUND RECTANGULAR AND TRIANGULAR TURBULATORS IN BAFFLED CHANNELS
A Computational Analysis

by

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Original scientific paper
https://doi.org/10.2298/TSCI22S1191S

The present paper highlights a computational analysis of air-flows around rectangular and triangular turbulators inside baffled heat exchanger channels in order to improve heat transfer between the fluid and their heated areas. The dynamic and thermal fields as well as fluid temperature curves at the outlet of the exchanger are studied. The computational study is conducted by utilizing SIMPLE algorithm with FLUENT system based on the finite volumes. The analysis clearly demonstrated the presence of highly turbulent flows and the appearance of many vortices in various regions of the exchanger. By comparing the different heat exchangers, it was found that the baffled channel fitted with rectangular turbulators produced high fluid temperature values at the channel outlet, indicating the significance of using this rectangular form of turbulators in order to enhance the interaction between the hot spaces and the used fluid.

Key words: *analysis, turbulence, turbulators, baffles, fins*

Introduction

Due to the significance of its application in various heat exchanger devices such heat exchanger ducts and solar receiver tubes, the study of fluid-flow are one of the fundamental axis of many contemporary studies. For instance, see Saravanakumar *et al.* [1], Li *et al.* [2], Rashidi *et al.* [3], Hu *et al.* [4], Daliran and Ajabshirchi [5], Du *et al.* [6], Kumar and Layek [7], Kumar *et al.* [8], Abdullah *et al.* [9], and Chamoli *et al.* [10], as seen in tab. 1. They used

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Table 1. Applications of heat transfer fluid-flows in various baffled heat exchanger devices

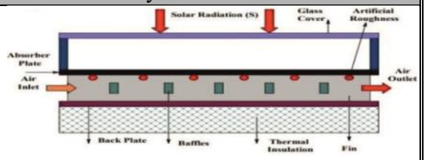
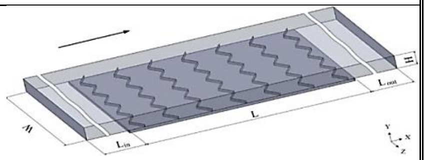
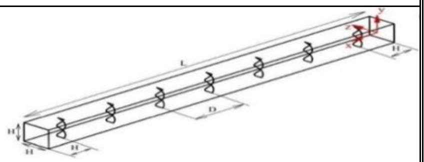
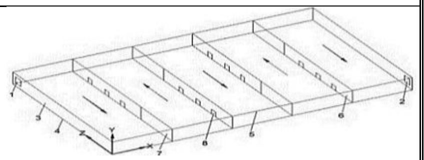
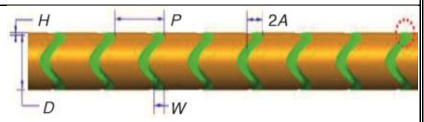
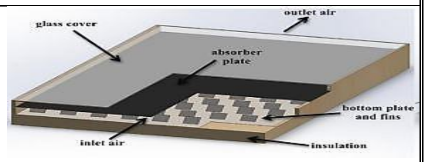
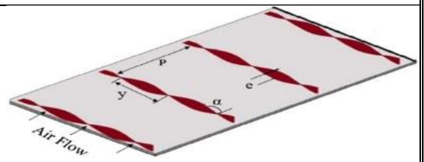
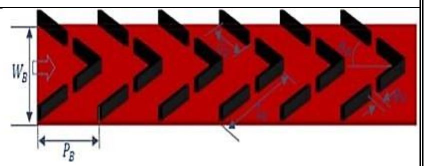
Author (s)	Highlights	Physical model
Saravanakumar *et al.* [1]	Investigation of roughened solar air heater (SAH) with fins and baffles	
Li *et al.* [2]	Optimization of the thermal performance of turbulent flow in a channel with multiple V-shaped baffles using numerical simulation	
Rashidi *et al.* [3]	Nanofluid-flow inside a square duct with transverse twisted baffles is studied in three dimensions using numerical thermo-hydrodynamics and second-order analysis	
Hu *et al.* [4]	Analyzing the characteristics of flow and heat transfer while optimizing the parameters of solar air collectors with holes on the baffle	
Du *et al.* [5]	The thermal-hydraulic performance of new sinusoidal rib tubes with different geometric characteristics was investigated	
Daliran and Ajabshirchi [6]	Effect of fin attachment on solar air collector operating parameters and thermal efficiency: theoretical and experimental investigation	
Kumar and Layek [7]	The purpose of the experiment is to test the effectiveness of using a brand-new artificial roughness on the absorber plate of a rectangular duct	
Kumar *et al.* [8]	Comparison of the effects of different obstruction configurations on the thermal hydraulic performance in a roughened air route	 V-baffle with gaps (for example)

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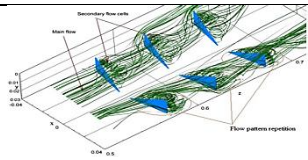
Table 1. Continuation

Author (s)	Highlights	Physical model
Abdullah *et al.* [9]	Evaluation of a new counterflow, double-pass solar air heater with turbulators	
Chamoli *et al.* [10]	An enhancement in the thermal performance of a solar air heater equipped with winglet vortex generators.	

numerical and experimental methods to assess the thermal performance under various flow conditions in their investigations.

In the current work, a baffled heat exchanger's performance is enhanced by inserting variously shaped turbulators inside of its rectangular channel. To demonstrate the ideal model in the presence of turbulent air flow, a comparison is done between two different turbulator models, namely the rectangle and the triangle. The canal is studied dynamically and thermally, showing the different areas of recycling and their effect on enhancing the heat transfer, and the different areas with high thermal gradients are identified with the evaluation of the fluid temperature at the outlet of the channel to extract the best model for the turbulators.

Mathematical modelling

A horizontal, rectangular channel heat exchanger supported by upper and lower obstacles is the subject of the present study. It is based on the design proposed by Demartini *et al.* [11].

The purpose of this research is to improve the heat exchanger channel's performance by inserting a turbulator between the right and left sides of the upper and lower obstacles, fig. 1.

Turbulators of two different models are utilized. A rectangular turbulator is present in the first model, fig. 1(a), while a triangular turbulator is present in the second, fig. 1(b).

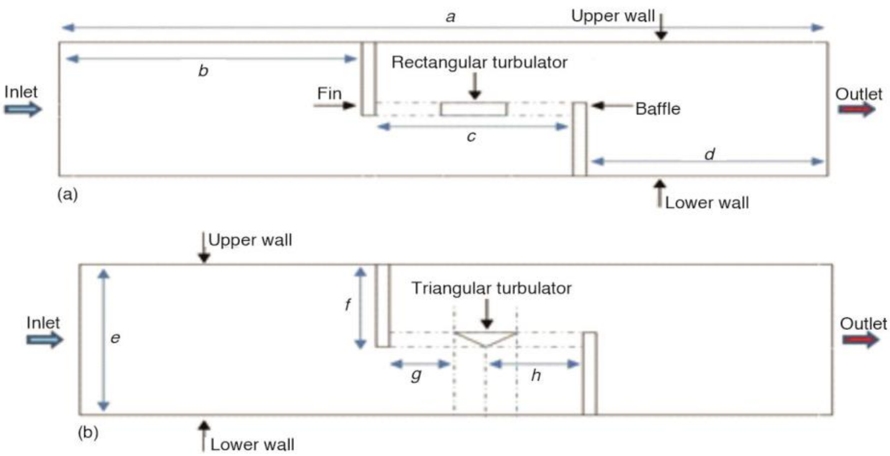


Figure 1. Schematic diagram of the baffled heat exchanger channel, in both turbulator cases; (a) rectangular and (b) triangular

Table 2 provides a detailed assessment of the heat exchanger channel's dimensions. In contrast to the dimensions and placements of the rectangular and triangular turbulators, which are suggested in the current study, the baffled channel dimensions *a*, *b*, *c*, *d*, *e* and *f* are based on the numerical and experimental analysis of Demartini *et al.* [11].

Table 2. Dimensions used

Dimension	Symbol	Value [m]
Heat exchanger channel length	a	0.554
Distance between the channel entrance and the front side of the fin	b	0.218
Space between the sides, the back of the fin and the front of the baffle	c	0.142
Distance between the back side of the fin and the outlet of the channel	d	0.174
Heat exchanger channel height	e	0.146
Baffle height (= fin height)	f	0.08
Distance between the right side of the baffle and the left side of the turbulator	$g = c/3$	0.047
Distance between the tip of the triangular turbulator and the right side of the fin	h	0.299

The boundary conditions for each channel frontier must be specified in order to investigate the model numerically, fig. 2. The channel's left side represents the flow inlet where the fluid-flows with an axial velocity according to the OX horizontal axis [11]. While the right side of the channel represents the outlet of the flow where the pressure is equal to atmospheric pressure [11]. In both cases of the heat exchanger, the top of its channel is subjected to a constant temperature as found in Nasiruddin and Siddiqui's numerical study [12]. While the lower side of the same channel is thermally insulated as used in the experimental study of Dutta and Hossain [13].

Finally, the fluid-flows with a temperature of 300 K [12], while the temperature of the hot wall is 375 K, *i.e.* there is a variation in the temperature that will result in forced-convection heat transfer.

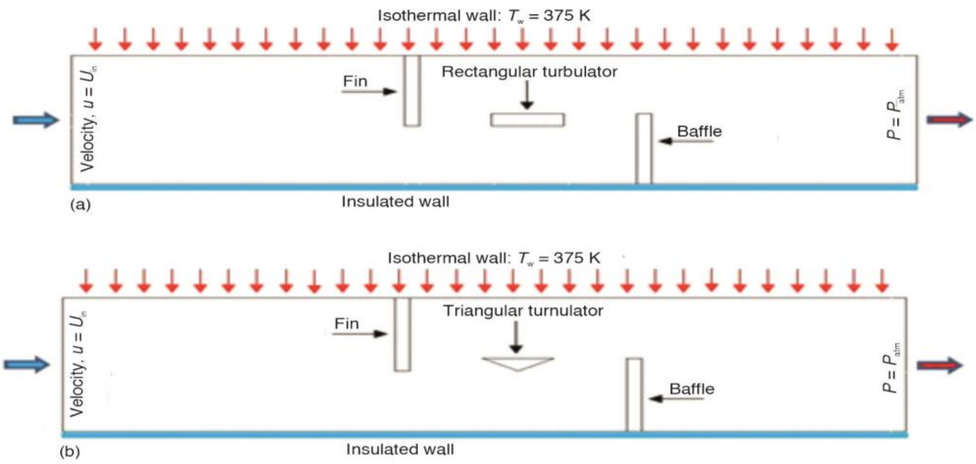


Figure 2. Boundary conditions, for the baffled heat exchanger channel, in both turbulator cases; (a) rectangular and (b) triangular

The flow is modeled using the standard k-ε model [14] and has the following properties:
- It is stationary.
- It is flowing in two dimensions.

– It is turbulent.
– It is incompressible.
– It is Newtonian in nature.
– The fluid and solid's thermophysical characteristics are considered as constants.

The continuity, momentum, and energy equations are the governing equations to be taken into account. The governing equations can therefore be expressed as follows in their standard form [15]:

$$\frac{\partial}{\partial x}(\rho u\varphi)+\frac{\partial}{\partial y}(\rho v\varphi)=\frac{\partial}{\partial x}\left[\Gamma_{\varphi}\frac{\partial\varphi}{\partial x}\right]+\frac{\partial}{\partial y}\left[\Gamma_{\varphi}\frac{\partial\varphi}{\partial y}\right]+S_{\varphi} \tag{1}$$

where u, v, k, ε, and T are the dependent variables represented by ϕ, u and v – the velocity components, k and ε – the turbulent kinetic energy and its dissipation ratio, respectively, and Γ_{φ} and S_{φ} denote the turbulent diffusion coefficient and source term, respectively. All the details are found in Yang and Hwang 's numerical study [15].

In areas with significant gradients, such as those adjacent to the solid boundaries, a non-uniform mesh with a significant concentration of nodes was used. By using the finite volume approach [16], and Second-order upwind and QUICK schemes [16, 17] to solve the governing equations, the turbulent field is described. The SIMPLE algorithm is used to solve the velocity and pressure terms of momentum equations [16]. The validity of the numerical model for the baffled channel heat exchanger (with no turbulator) has been demonstrated in many of our previous studies such as Menni *et al.* [18].

Results and analysis

In both instances, low dynamic-pressure air-flow is directed to the left side of the baffle from the channel inlet, as shown in fig. 3. In both models, dynamic-pressure values are also low on the top of the turbulator and on the baffle's right side. Additionally, the front and back circumferences of the fin have low values for the same parameter.

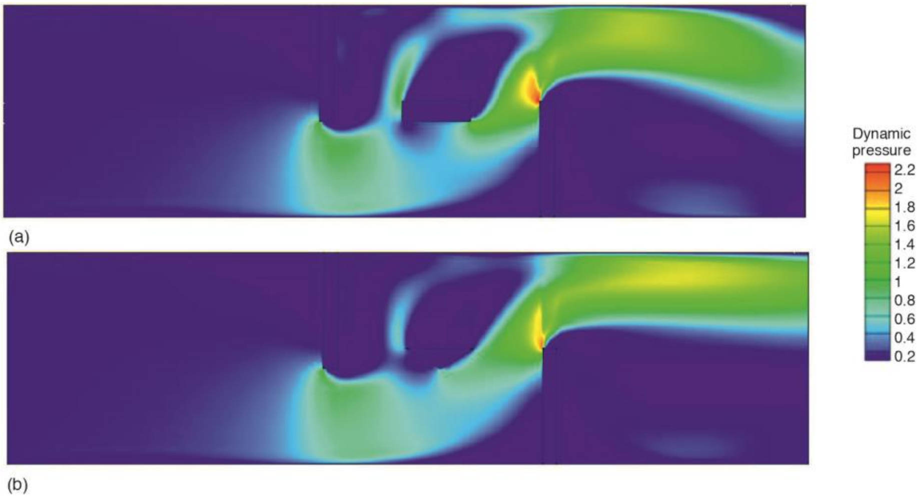


Figure 3. Dynamic pressure fields in both studied cases, Re = 5000; (a) baffled channel with a rectangular turbulator and (b) baffled channel with a triangular turbulator

On the other hand, dynamic-pressure levels in the bottom portion of the channel steadily increase, beginning at the left head of the baffle. This development keeps expanding until it reaches the front side of the fin. The dynamic-pressure clearly also increases on the upper side of the channel, where the primary flow is located, while it lowers on the lower side of the same exchanger on the back side of the same fin. It is clear from comparing the two exchangers that the leading edges of the fins exhibit maximum values, where the first channel model exhibits the greatest improvement.

The air-flow traverses the channel in irregular lines, parallel at the entrance and at the level of the gaps, just below the baffle and above the fin, as indicated in fig. 4. On the other hand, these lines turbulent sharply on the rest of the flow areas in the form of strong recirculation rings and centered to the left of both the baffle and the fin, while on the top of the turbulator, whether rectangular or square, as a result of the pressure drop in these areas. In addition, small vortices are formed on the upper front sides of the left and right obstacle, next to the upper and lower exchanger solid surfaces, due to the presence of a decrease in pressure values also in these areas. The presence of the turbulator, rectangular or triangular, in the center of the flow space, between the edges of the obstacles (baffle and fin) and the channel walls allows for enhanced fluid mixing.

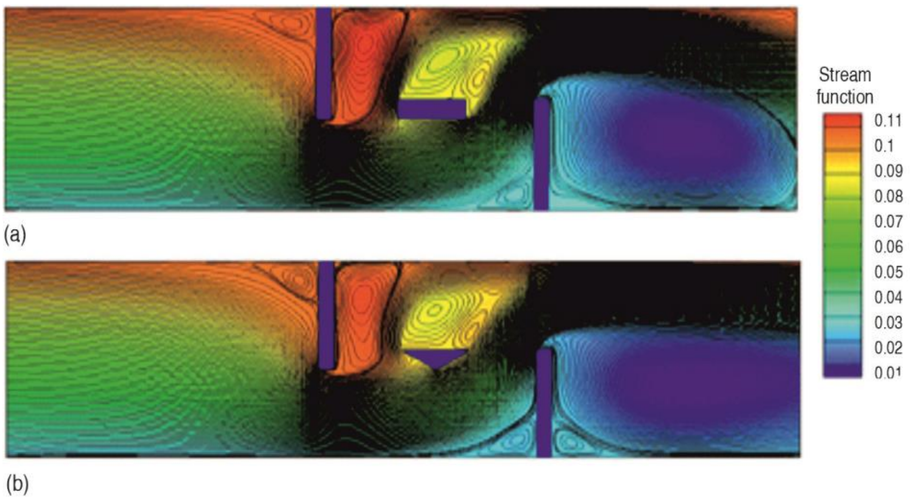


Figure 4. Streamlines in both studied cases, Re = 5000; (a) baffled channel with a rectangular turbulator and (b) baffled channel with a triangular turbulator

The study assesses the flow's velocity as well. Examining the evolution of velocity at the level of positive main flows as well as in the presence of secondary opposite flows with a constant value of the Reynolds number estimated at 5000 are just a few examples of how these barriers' effects on flow velocity are examined in various significant aspects of the channel, fig. 5.

There are large values of flow at the level of the four gaps, which are between the upper edges of the barriers and walls as well as those the left and right of the turbulator in both situations, as can be seen from the mean velocity fields indicated on fig. 5. Main air currents with varied speeds are flowing through these gaps from the exchange channel's left to right. The figure also makes it very evident that there is a significant region subject to extremely fast flow, which runs straight from the upper front edge of the fin to the outlet close to the upper surface. Conversely, the velocity values decrease wherever there is a pressure drop, exactly on the field of the vortices. When comparing the two scenarios under study, both models show an increase in upper leading edge velocity, but the square turbulator's presence results in higher values since it secretes larger vortices.

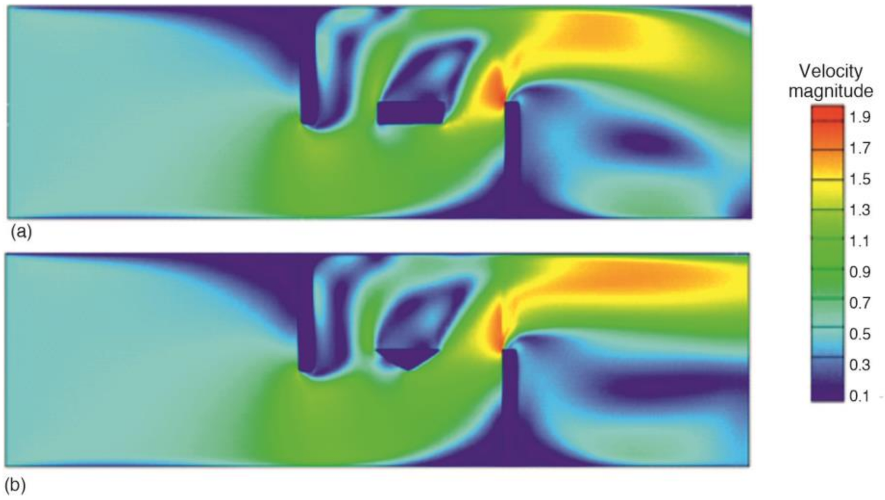


Figure 5. Mean velocity fields in both studied cases, Re = 5000; (a) baffled channel with a rectangular turbulator and (b) baffled channel with a triangular turbulator

In this study, explanation of how obstacles affect the heat exchanger structure is also highlighted in order to choose the best model. As seen in fig. 6, the exchanger's upper portion is heated to a constant temperature of 375K, while the lower portion is thermally insulated. Air flows at a temperature of 300K which allows it to gain heat energy from heated spaces by forced heat transfer. The air-flow temperature is high next to the fin on both its left and right sides. The presence of the turbulator on the back of the baffle allows enhanced flow turbulence and good fluid mixing.

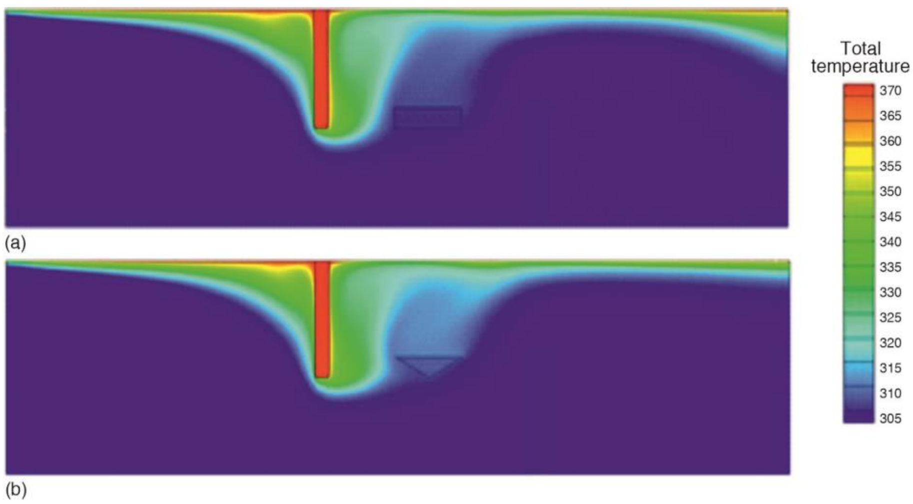


Figure 6. Temperature fields in both studied cases, Re = 5000; (a) baffled channel with a rectangular turbulator and (b) baffled channel with a triangular turbulator

Figure 7 highlights the fluid temperature changes at the outlet of the channel for both cases studied.

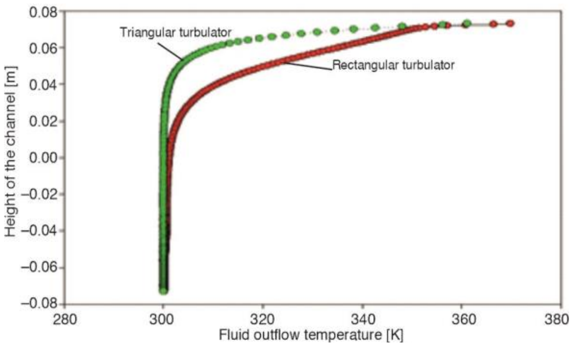


Figure 7. The fluid temperature in both cases evaluated at the outflow, Re = 5000

The temperature curve is indicated along the channel height for thermal evaluation of both the top and bottom sides of the exchanger. The pressure and velocity fields showed strong areas for recycling as the rectangular turbulator case gave greater reinforcements at all levels, allowing for good fluid mixing and significant energy gain from the hot spaces and thus raising the temperature at the exchanger outlet. Therefore, equipping the heat exchanger with rectangular turbulators shows a remarkable thermal improvement due to the strong turbulent structure produced by these barriers in such baffled heat exchangers.

Conclusion

The investigation was conducted in a 2-DS field of a heat exchanger with an air-flow passing through a baffled channel with a variable-shaped turbulator. The finite volumes method was used to carry out the analysis computationally. On both the dynamic and thermal levels, many fields were examined. Primary and secondary streams were established and examined. The findings demonstrated the presence of very strong vortices in both models studied. Additionally, by including a turbulator inside the channel duct, the exchanger's hydraulic structure becomes more turbulent, promoting efficient fluid mixing and maximizing heat energy. Moreover, the rectangular turbulator model can enhance the exchanger's thermal structure more effectively than the other type due to its dynamic reinforcements at all levels.

Acknowledgment

The authors R. Jarrar, H. Shanak and J. Asad would like to thank Palestine Technical University- Kadoorie for supporting this work financially.

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Paper submitted: September 5, 2022
Paper revised: October 15, 2022
Paper accepted: October 24, 2022