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New method for designing an effective finned heat exchanger

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HIGHLIGHTS

► We develop a method for designing an effective finned heat exchanger.
► This new design characterize by smaller dimensions of the heat exchanger.
► The tubes bend in a zigzag shape. Consequently, the fin block forms a zigzag shape.
► The new design leads to significant increase in the heat transfer.

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ABSTRACT

This paper presents a computational analysis of the heat transfer and pressure drop in a finned tube heat exchanger. The main objectives are to develop a method for designing an effective finned heat exchanger through changing the arrangement of the fins and tubes so that the tubes can be bent in a zigzag shape. Thus, they present an angle of less than 90° to the vertical fins. Consequently, the fin block forms a zigzag shape. The construction and the dimensions of the developed alternative heat exchanger are comprehensively presented. This new design is characterized by smaller dimensions of the heat exchanger and allows an increase of the heat transfer on the surface of the fins. Furthermore, a slight increase in the fan and pump power can result, which is very small compared with the recovered heat transfer. However, an effective model is analyzed by means of the computational fluid dynamics (CFD), FLUENT code, which is used to solve the equation for the heat transfer and pressure drop. The major results of the work show an increase in the heat transfer value of 59.13% in comparison to the existing old model. This increase is also accompanied by an increase in the ratio between the total power consumption and the amount of heat transfer obtained of 3.84% compared to 0.8% in the old model.

1. Introduction and problem description

Finned tube heat exchangers are widely used in thermal engineering applications. Due to their fins, a large total heat transfer area can be provided. In this case, many studies have been carried out in order to enhance the convective heat transfer of finned tube heat exchangers. Therefore, many investigations into heat transfer performance characteristics of the finned tube exchangers have been experimentally and numerically executed. Most of these focus on the change of the geometrical parameters of tubes and fins and, accordingly, their shape. For example, the diameter of the tubes, their arrangement and forms have been investigated under various conditions by Kaminski and Groß [1], István [2] and Lu et al. [3]. The effect of the number of tube rows on the efficiency of finned tube heat exchangers has numerically been investigated by Kaminski [4]. He showed that increasing the number of tube rows causes a decrease in the heat transfer coefficient and an increase in the pressure drop. Remero-Mendez et al. [5] and Liu et al. [6] have analyzed the effects of the fin pitch on the heat transfer and the pressure drop. Kim et al. [7] have conducted experimental investigations into the effects of fin type and fin and tube alignment on the heat transfer performance. They have shown that the heat transfer performance can be improved by 20% by applying both the staggered fin and tube alignments in comparison to the continuous flat plate finned tube. Different tube arrangements with plain and corrugated fins have been investigated by Abu Madi et al. [8] both experimentally and numerically. They showed that corrugated fins entail a better heat transfer and a higher friction factor due to their

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Nomenclature

$\dot{Q}$	heat transfer rate, W
T	temperature, K
K	thermal conductivity, W/m K
u	velocity, m/s
C_p	specific heat capacity, J/kg K
ρ	density for an incompressible fluid, kg/m^3
μ	dynamic viscosity, kg/s m
φ	conserved quantity per unit mass
S_φ	volumetric source term, with units of conserved quantity per unit volume per unit time
Γ_φ	kinematic diffusivity for the scalar
$\dot{V}$	volumetric flow rate, m^3/s
$\dot{m}$	mass flow rate, kg/s
Δp, p	pressure drop and pressure, N/m^2
P	loss power associated with pressure drop, W
η	the effectiveness of the fan or pump
θ°, β°	inclined fin and tube angle
α°	angle of elbow of the tubes
A	heat transfer surface area, m^2
ΔT	inlet and outlet temperature difference of the air, K

higher turbulence. Tsai and Jang [9] have investigated numerically the fin and tube heat exchanger with louver fin. They have used the louver angle of the fin as optimizer to achieve the maximum performance of the heat exchanger. In addition, a literature survey of publications which addressed different types of arrangements of fins was presented in Ref. [10]. Furthermore, Ghiani [11] has developed a flat tube heat exchanger for the use in motor vehicles. The heat transfer increases due to the enlarged surfaces of the tubes by bending the flat tubes in a zigzag shape. Pasha [12] has investigated the heat transfer and the pressure drop for a bank of inclined flat tubes. The angle of inclination varied from 0° to 90°. The heat transfer and pressure drop values were considerably increased within the range from 20° to about 80° while both values were slightly increased at the angles smaller than 20° and greater than 80°. Sahin et al. [13] have investigated a commercial heat exchanger with plain fins by performing a three-dimensional, steady-state, laminar flow system numerically. Both the heat transfer and pressure drop values have been analyzed with inclined fins at different angles (0°, 5°, 10°, 15°, 20°, 25° and 30°). It has been shown that the inclination of the fins at different angles has a substantial effect on the increase in heat transfer. Hence, an increase in the inclination angles of the fins causes a decrease in the distance between adjacent fins, which increases the flow velocity on the cross-section areas between the fins. Furthermore, the contact area between the fins and tubes is increased. In return, this leads to an enhancement of the heat transfer values. Since the increase in the fin angle causes a reduction of the dimensions of the heat exchanger, an inclination angle of 30° was determined to be optimal. Karmo and Ajib [14] have studied the influence exerted by a change of the shape and inclination of the fins on heat transfer. It has been shown that increasing both the area and the inclination of the fins at the same time leads to the largest gain in the heat transfer values. The more the fin angle is increased, the more the heat transfer and also the pressure drop increase.

Because the fin inclination leads to a considerable improvement in heat transfer without any additional investment costs, we will concentrate on the two previous studies. Also, the disadvantages must be investigated and eliminated as far as possible. To keep the dimensions of the heat exchanger constant, the fin number must be reduced by increasing the inclination of the fins. To better illustrate this disadvantage, a graphical comparison between two arrays of fins and tubes is illustrated in Fig. 1. It is assumed that the heat exchanger consists of only one tube row as in Ref. [13]. Fig. 1b shows that a part of the tube with mean length ($j/2$) at the two sides of the tube cannot be covered with fins any more. This means that the length of the uncovered tube part is ($2.j/2$). This value equals the fin height H multiplied by sin $\theta°$.

$$j = H \cdot \sin \theta^\circ \tag{1}$$

The more the fin angle increases, the longer the non-covered tube part is, and, therefore, heat transfer is lower in the heat exchanger. Assuming that the heat exchanger consists of more than one tube row, this could mean that the inclination of fins is no longer plausible because of the long non-covered tube part, which depends on the length and on the inclination of the fins. In order to enable an economical inclination of the fins in heat exchangers with more tube rows, it is necessary to develop an approach for providing a new arrangement of the fins and the tubes in heat

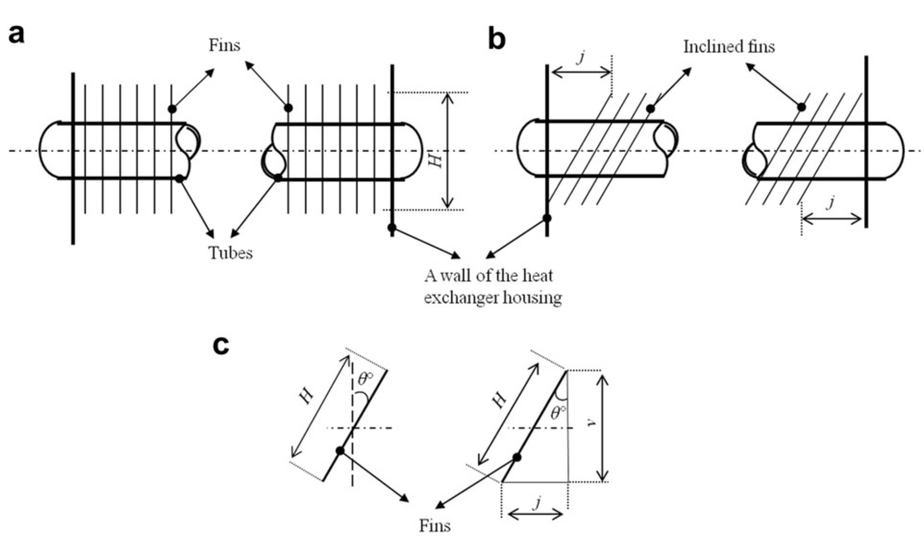

Fig. 1. Representation of the influence of the inclination angle of fins on their number; (a) fins and tube perpendicular to each other, (b) heat exchanger with inclined fins, (c) representation of the tube part, which cannot be covered with fins.