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Piotr WAIS[1]

FIN-TUBE HEAT EXCHANGER PERFORMANCE FOR DIFFERENT LOUVER ANGLES

To choose the proper design for a heat exchanger in engineering industry and to evaluate the finned surface performance it is important to calculate fin efficiency. The heat transfer conditions, in tube-fin heat exchangers, can be modified for instance by changing the fin shapes. The angle of louver inclination affects the fluid flow direction and it has the effect on the heat transfer and temperature changes. In the paper, the heat transfer is estimated numerically for fins with and without louvers to choose the optimal louver angle in the car radiator. Numerical analyses are carried out to examine finned tube heat exchanger and to determine the performance of the radiator for eight different louver angles. Solutions are obtained by means of ANSYS program. The tube material is kept fixed as well as the heat exchanger fin and tube pitches (spacing) and the inlet air velocity.

Keywords: car radiator, louver inclination, efficiency, heat transfer

1. Introduction

The heat exchangers used in cars are based on tube/fin designs. To improve air side heat transfer and to reduce the air side thermal resistance, the fins are used. There are various fin patterns such as rectangular fins, louvered fins, offset strip fins, perforated fins and wavy fins. It can be seen that it is very important for engineers and researchers to find out the optimum shapes of the louvered fin to reach the working objectives such as thermal performance, radiator dimensions (envelope), weight, durability, heat transfer rate or pressure drop. The optimizations of the louver angle are performed experimentally or numerically, many times in combination with other fin parameters. Most studies assumed a single louver angle for all the louvers in the heat exchanger and analysed the louvered fins without tube-fin interaction.

Considering that an automotive radiator is an important part of the car cooling system, the louvered fin heat exchanger is often the subject of research.

Wang and Chi presented the airside performance of fin-and-tube heat exchangers with plain fin configurations. Depending on the number of tube rows,

[1] Piotr Wais, Cracow University of Technology, al. Jana Pawla II 37, 31-864 Krakow, e-mail:wais@mech.pk.edu.pl

it was found that the heat transfer characteristics were strongly related to the fin pitch [10]. Saboya and Saboya determined average transfer coefficients for plate fin and elliptic tube exchangers. Mass transfer experiments were performed using the naphthalene sublimation technique. They showed that the performance advantage of the elliptical tube arrangements resulted from the higher fin efficiency [6]. Lyman et al. conducted experiments in a number of large-scale louver models with varied fin pitch and louver angle over a range of Reynolds numbers [3]. Nuntaphan et al. analysed the effect of inclination angle on the louver finned tube heat exchanger in natural convection condition. At an inclination angle such as 30–45^o, a considerable increase of heat transfer performance was seen [5]. Vorayos and Kiatsiriroat focused on the effects of the louvered fin heat exchanger's design parameters, which include the louver pitch and louver angle, on the convective heat transfer. The louver angles were set to different values and they showed that the heat transfer characteristic dropped as the angle went beyond 30^o [8]. Wais analysed the heat transferred from the tube/fins to the moving air in a single raw heat exchanger. It was shown that the fin shapes modified the heat transfer conditions by changing the distribution of fluid mass in the channel [9]. Vaisi et al. investigated experimentally air-side heat transfer and pressure drop characteristics of flow over louvered fins in compact heat exchangers (using flat plates) [7]. Butha et al. focused on the applications of Computational Fluid Dynamics (CFD) in the field of heat exchangers. It was found that CFD has been employed for the following areas of study in various types of heat ex-changers [1]. Lee et al. presented the numerical method to efficiently predict heat transfer phenomena of a louver fin radiator [2].

Analysing the papers, it is seen that the performance of a heat exchanger in automotive applications depends on the fin/tube dimensions. The radiator characteristics are determined by different variables such as tube shape, tube thickness, fin material, fin thickness, number of louvers, louver pitch, louver height and louver angle. Any change in geometrical parameters impacts the flow characteristics and as a consequence effects the heat transfer. The heat amount transferred to the air depends strongly on the air flow patterns in the heat exchanger.

It can be also noticed that the articles generally regard the louvered fins attached to the flat tubes. Because the circular tubs are the simplest and cheapest there are still in use for different car models despite the wake region behind the tube that reduces the heat transfer on downstream fin regions. Also, automotive companies often realize their own Cost Improvement Process to reduce the manufacturing cost keeping suitable heat transfer requirements. The optimum heat transfer rate can be obtained by changing the geometrical parameters of the fin. Numerical investigations are carried out to analyse the heat transfer characteristics of a louvered fin. Studies found in literature focus on flat tube heat exchangers. Hence, the objective of this work is to examine the effect of louver angles on the heat transfer in a circular tube heat exchanger applied in the automotive industry.

The paper focuses on the conventional automotive radiator, tubular fin heat exchanger, for which the manufacturing cost is cheaper, comparing to other tube designs (elliptical or flat tubes). The paper presents the heat transfer calculations and the influence of louver angles on the heat transfer performance. The power of the car radiator segment is also estimated. The contact resistance at the interface between the tube and the fin is assumed to be negligible. A computational fluid dynamics program is used for the analysis. These calculations are compared to the result received for the fin without louvers.

2. Optimization function

The goal function is defined as the amount of heat transferred to the passing air:

$$\dot{Q} = \dot{m}_{AIR}\, c_{AIR}\, (T_{OUT} - T_{IN}) \tag{1}$$

The optimization problem can be resolved by finding the maximum value of the function:

$$\dot{Q} = \dot{m}_{AIR}\, c_{AIR}\, (T_{OUT} - T_{IN}) \rightarrow \max \tag{2}$$

The temperature at the outlet section, T_{OUT}, is found numerically for different louvered angles. The air temperature value is evaluated in the outlet section according to the formula:

$$T_{OUT} = \frac{\sum (\dot{m}_{AIR\,n}\, T_{AIR\,n})}{\dot{m}_{AIR}} \tag{3}$$

3. Fin heat exchanger description

The car radiator, on which the investigation is carried out, is a cross flow type compact heat exchanger, with water flowing inside tubes, and air flowing over the tubes and fins. The car radiator consists of two tube rows. The three dimensional view of the small part of analyzed heat exchanger and its configuration is shown in Figure 1. The radiator characteristic dimensions are written in Table 1. The geometry of the heat exchanger is presented in Figure 2 and Figure 3.

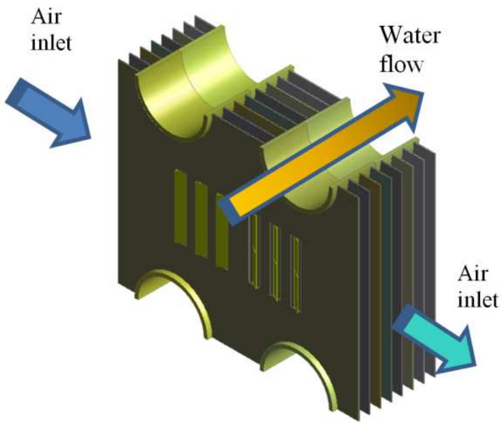

Fig. 1. Analyzed heat exchanger with circular tubes

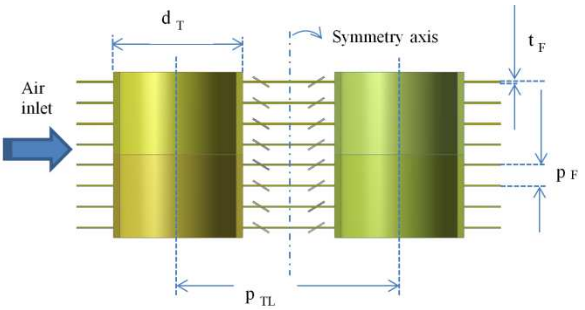

Fig. 2. Cross section perpendicular to the fin surface

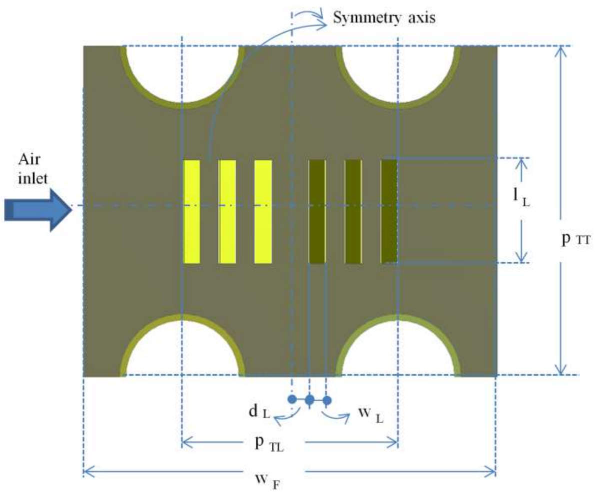

Fig. 3. Cross section parallel to the fin surface

The flow and heat transfer phenomena in a round tube heat exchanger with and without louvered fins are analysed numerically. The three-dimensional computational domain with louvers is shown in Figure 4. The fin thickness is 0.081 mm. The louver pitch is assumed to be the same as the louver length since the louver is formed from cutting the fin material. The similar model is built for the fins without louvers keeping the same fin pitch. The computational domain is extended both upstream and downstream to minimize the influence of the potential back flow. The heat transfer along a louver depends on the flow field surrounding a particular louver and the thermal field. Due to the symmetry, only few segments are modelled.

Table 1. Radiator dimensions

Tube	Symbol	Value
Transversal tube pitch	p_{TT}	18.60 mm
Longitudinal tube pitch	p_{TL}	12.00 mm
External tube diameter	d_T	7.00 mm
Tube thickness	t_{TT}	0.35 mm
Fin	**Symbol**	**Value**
Fin pitch	p_F	1.05 mm
Fin thickness	t_F	0.081 mm
Fin width	w_F	23.00 mm
Louver	**Symbol**	**Value**
Louver angle	α	0^o, 20^o, 25^o, 30^o, 35^o, 40^o, 45^o, 50^o
Louver thickness	t_L	0.081 mm
Louver length	l_L	6.00 mm
Louver width	w_L	1.00 mm
Louved distance	d_L	1.00 mm

Considering the computer resources, the mesh structure is defined in a way that the solution process can give stable results. The mesh structure contains tetrahedral mesh elements in the air volume and hexahedral elements in the tubes. The computational domain consists of over 5.1 million elements. Surface mesh element sizes are controlled to obtain fine mesh elements close to the louvers. The mesh grows in size outward from the fin and louver to the tubes and extended domains. The simultaneous heat transfer occurs through the air and the finned surface. The property values of air and the fin/tube solid material (aluminium) are given in Table 2.

Boundary conditions for all the boundaries are specified for the computational domain. The flow is assumed to be three dimensional and steady. At the entrance of the domain, the inlet air temperature is taken as 25°C and the uniform inlet velocity of the air is 15 m/s that gives car velocity of 54 km/h. The turbulent inlet intensity is set to 5%. The internal tube temperature is constant and equals 90°C. The relative average static pressure is assumed to be 0 Pa at the outlet. The heat transfer direction is considered from tube/fins to the passing air. The SST model is used for calculations thanks to its reliability and precision. RMS residual level is defined as 10^{-4}. The CFD computations are obtained for eight models (louver angles 0°, 20°, 25°, 30°, 35°, 40°, 45°, 50°).

Table 2. Physical properties of air and tube/fin material

Air	Symbol	Value
Density	ρ_{AIR}	1.185 kg/m^3
Molar mass	M_{AIR}	28.96 kg/kmol
Specific heat capacity	c_{AIR}	1004.4 J/(kg K)
Thermal conductivity	k_{AIR}	0.0261 W/(m K)
Dynamic viscosity	μ_{AIR}	1.831 10^{-5} kg/(m s)
Aluminium	**Symbol**	**Value**
Density	ρ_{MAT}	1.185 kg/m^3
Molar mass	M_{MAT}	28.96 kg/kmol
Specific heat capacity	c_{MAT}	1004.4 J/(kg K)
Thermal conductivity	k_{MAT}	0.0261 W/(m K)

4. Results and conclusion

The plane parallel to the fin surface, located between upper and lower fins are introduced to illustrate the air temperature and velocity field in the space between the fins (Fig. 4).

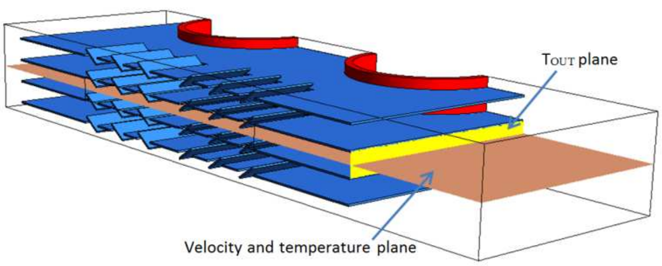

Fig. 4. Velocity and temperature plane, T_{out} plane

Analyzing the velocity fields, the wake zone can be noticed between tubes. The air temperature in the wake zone (between tubes) is high, but there is not any advantage for the amount of heat transferred to the air because the velocity of the air is almost zero. It can be seen that the temperature and velocity profiles have the same trend for other louver angles. To find the radiator goal function, the mean air temperature at the outlet section is calculated at the cross section, T_{OUT} plan, presented in Figure 4. Detailed results are written in Table 3.

Table 3. Radiator heat transfer characteristics

Model name	**Louver angle, α**	$\dot{m}_{AIR}$, **g/s**	T_{OUT}, **°C**	$\dot{Q}$, **W**	$\dot{Q}$, **%**
Model 0	No louver	0.174	46.98	3.84	100.0
Model 20	20°	0.174	49.67	4.31	112.2
Model 25	25°	0.174	50.16	4.40	114.5
Model 30	30°	0.174	50.27	4.42	115.0
Model 35	35°	0.174	50.49	4.45	116.0
Model 40	40°	0.174	51.05	4.55	118.5
Model 45	45°	0.174	51.48	4.63	120.5
Model 50	50°	0.174	51.24	4.59	119.4

It can be seen that, the heat output from the radiator depends on the louver angles and for circular tubes he maximum value can be reached at 45^o. In the study, the air flow and temperature fields as well as the heat transfer are examined for a louvered car radiator. The three dimensional models are built to optimize the heat transfer process. The tube material is kept fixed as well as the heat exchanger fin and tube pitches (spacing). Applied numerical studies enable to optimize the fin geometry and can be used as an alternative activity for more costly experimental studies. The paper subject is to present the flow and thermal effects of the louver angle on the heat transfer for the circular tube heat exchanger.

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SPRAWNOŚĆ OŻEBROWANEGO WYMIENNIKA CIEPŁA DLA RÓŻNYCH KĄTÓW USTAWIENIA ŻALUZJI

S t r e s z c z e n i e

W celu właściwego doboru wymiennika ciepła i prawidłowego określenia kryteriów pracy niezbędne jest oszacowanie sprawności zastosowanego ożebrowania. Warunki wymiany ciepła mogą ulec zmianie między innymi poprzez zmodyfikowanie kształtu żeber. Modyfikując kąt pochylenia żaluzji ożebrowania można spowodować zmianę kierunku prędkości przepływającego powietrza i wpłynąć na wymianę ciepła. W pracy przeanalizowano ilość wymienianego ciepła w chłodnicy samochodowej dla ośmiu różnych kątów nachylenia żaluzji w celu określenia położenia optymalnego, dla którego ilość oddawanego ciepła będzie największa. Przeprowadzano analizy numeryczne w celu zbadania użebrowanej rury wymiennika ciepła oraz aby określić wydajność grzejnika dla ośmiu różnych kątów żaluzji. Obliczenia wykonano za pomocą programu ANSYS. Badania wykonano dla tego samego materiału rury, żeber wymiennika ciepła oraz dla stałej podziałki żeber oraz prędkości powietrza wlotowego.

Słowa kluczowe: chłodnica samochodowa, kąt żaluzji, sprawność, wymiana ciepła

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