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Parametric Study of Finned Surfaces Using a Graphical User Interface Developed in Matlab

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The use of heat exchangers on extended surfaces has obtained high importance in the last years due to their high implementation in industrial processes, computer systems, refrigerators, electronic equipment, etc. It implies the use of computer technology to have a better comprehension of the phenomena that involve heat transfer in finned surfaces to design new prototypes with high efficiency. There are lots of parameters to consider when designing fins such as their geometry and the type of material making the design highly complex. Also, a selection of adequate fins requires knowledge of temperature distributions through them, which will depend on the properties of the fin material. In this article, it is presented the study of the energy transfer and effectiveness in Extended Surfaces using an educational graphical user interface developed in Matlab as a pedagogical strategy to promote the significant learning in engineering. The program uses the most important experimental correlations reported in the literature for solving real problems. The systems studied were Straight Rectangular Fins, Straight Triangular Fins, Cylindrical Pin Fins, and Straight Parabolic Fins, all the cases with air as refrigerant and Aluminum, Copper, Iron, and Stainless Steel as the fin working materials. Three case studies were made, the total heat transfer of the fins as a function of air velocity for different geometric configurations and materials of the fins to see the effect of the natural and forced convection, the effect of convection in the efficiency of the fins, and the effectiveness as a function of thermal conductivity of the fins for the geometrical configurations mentioned above. It was found that the configuration with the highest removal of heat was the straight rectangular fin. The cylindrical fin presented the highest efficiency, and the best working material was the copper.

1. Introduction

The chemical and process industries in general, generate large amounts of heat that must be dissipated so that they can be operated efficiently. There are many different types of heat exchangers that help to remove this heat. However, the most efficient heat exchangers are those with extended surfaces, usually called fins. The high efficiency is due to their large amount of area in contact with the surroundings. They are highly used in a large number of applications (Stehlík at al., 2014) such as, Industrial processes, vehicles, computers, refrigerators, among other things that need a special control of temperature.

There are different parameters to consider in detail at the moment of designing a fin heat exchanger such as the shape, thickness, length, material, space, and number of fins. The natural shape of fin heat exchanger causes high external fluid friction that must be considered. The temperature distribution has to be known before building an extended surface heat exchanger which depends on the parameters previously mentioned. A great number of investigations have been done about fin heat exchangers such as the study of a high-temperature heat exchanger with hybrid internally and externally finned tubes (Zhang et al., 2017), the air side heat exchanger performance under the effect of louver angle (Hrnjak et al., 2017), the optimization of variable louver angle and initial louver angle solved numerically using commercial CFD (Jang and Chen, 2015), the heat transfer performance of a fin heat exchanger and the frost behavior at the middle of louver fin surfaces (Park et al., 2017), experimental investigation of the effect of different inlet constructions on the distribution of two-phase flow in a plate-fin heat exchanger (Zhang et al., 2017), the effect of the fin length and spacing on the thermal

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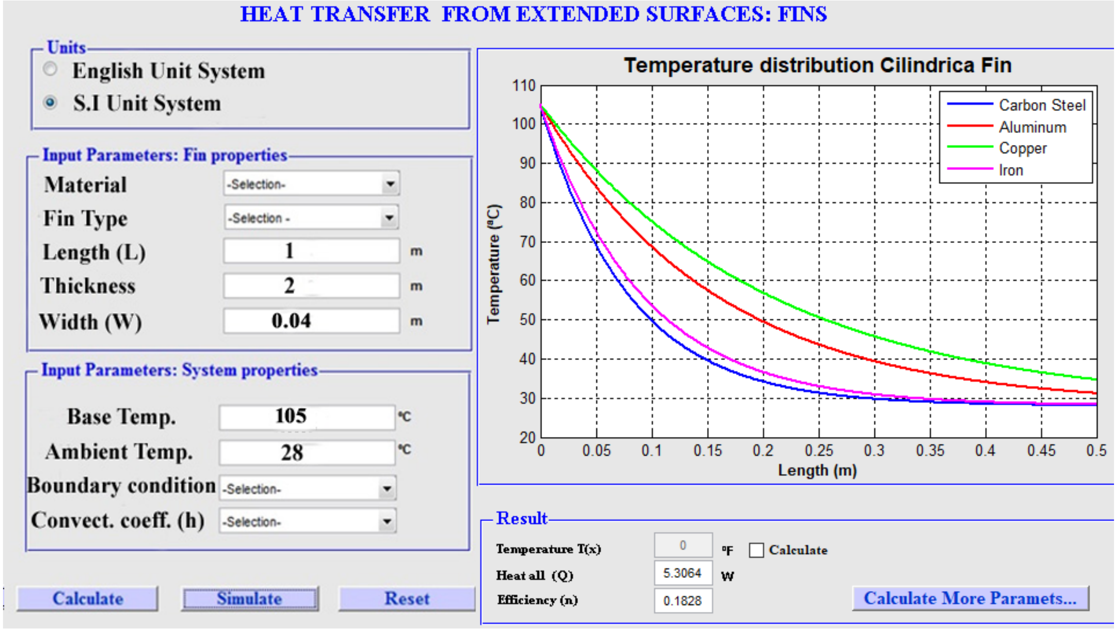
performance of finned-tube thermoacoustic heat exchangers (Kamsanam et al., 2016), the study of the effect of end plates on heat transfer of plate heat exchanger due to the contact between the corrugated surfaces of adjacent plates (Jin and Hrnjak, 2017), and the study of different geometries of fin heat exchangers such as the numerical modeling for predicting the performance of a thermoelectric generator system analyzing the fin geometry on the hot side heat exchanger (Borcuch et al., 2017), the prediction of the dynamic performance of spiral wound heat exchangers under sloshing conditions (Sun et al., 2017), and the numerical study of the fouling characteristics and heat transfer performance after fouling on 10-row H-type finned tube heat exchangers (Wang et al., 2017). However, to have high efficacy in the research of this area, it is necessary the implementation of computers to simulate behavior profile of heat and temperature profile in fin heat exchangers. The knowledge in the design of newly extended surface heat exchangers enhanced in the two last decades, so it surges the need to take advantage of modern computational tools with graphical interfaces to have a better understanding in designing and optimizing this kind of equipment.

The contribution of this article is to show the importance of the use of an easily interactive computational tool to design fin heat exchangers that help to choose among the right fin among a great variety of fin shapes. Two case studies are shown the total heat transfer as a function of air velocity for different types of materials of the fins, and the effectiveness of the fins as a function of the heat transfer area. Both cases were made for the geometric configurations Straight Rectangular Fins, Straight Triangular Fins, Cylindrical Pin Fins, and Straight Parabolic Fins.

2. Material and method

2.1 Presentation of the algorithm

Figure 1 is a screen capture of the main view of the graphical user interface used. It shows the inputs given by the user and is designed to solve real problems of extended surfaces for chemical engineering students and engineers. It is important in the industry for effective decision making about the size of the fin heat exchanger being designed. The computational tool allows students to have a better comprehension of heat transfer in extended surfaces.



HEAT TRANSFER FROM EXTENDED SURFACES: FINS

Units

○ English Unit System

● S.I Unit System

Input Parameters: Fin properties

Material: -Selection-

Fin Type: -Selection -

Length (L): 1 m

Thickness: 2 m

Width (W): 0.04 m

Input Parameters: System properties

Base Temp.: 105 °C

Ambient Temp.: 28 °C

Boundary condition: -Selection-

Convect. coeff. (h): -Selection-

Result

Temperature T(x): 0 °F ☐ Calculate

Heat all (Q): 5.3064 W

Efficiency (n): 0.1828

Figure 1: Main View of the program.

2.2 Flowchart of the GUI

Figure 2 shows a flowchart of the program. As can be seen, it let to work with a great variety of parameters and with the conditions of the external fluid used.

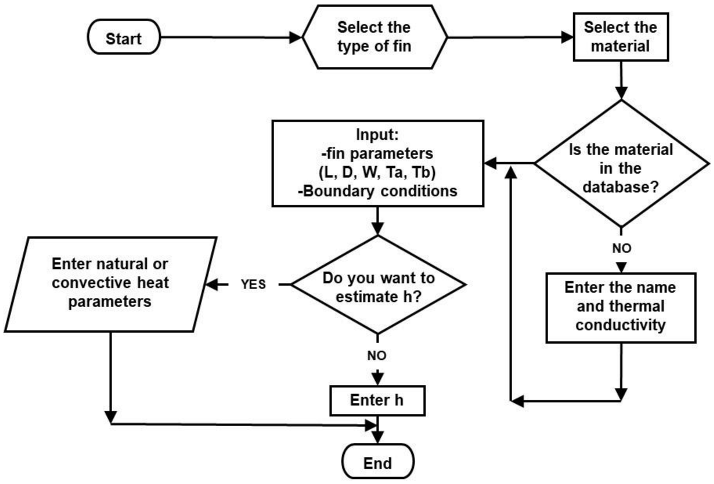


Figure 2: Flowchart of the GUI

2.3 Main relations used in the algorithm

The differential equation that describes the temperature distribution along a fin is given by equation (1)

$$\frac{d}{dx}\left[A(x)\frac{dT}{dx}\right]-\frac{h}{k}\left[T_a-T_b\right]\frac{dp(x)}{dx}=0 \tag{1}$$

Where *A* is the transversal area of the fin, *P* is the perimeter corresponding to the transversal area, *K* is the thermal conductivity of the material of the fin, *Ta* is ambient temperature, and *Tb* is the temperature at the base of the fin. The convective heat transfer coefficient "*h*" was determined using equations 2 and 3 as follows:

$$h=Nu\cdot K/Lc \tag{2}$$

$$Nu=a\,\mathrm{Re}^b\,\mathrm{Pr}^c \tag{3}$$

where Lc is the characteristic length of the fins. The constants a, b and c depend on the geometry of the fins. For Triangular and rectangular fins, a=0.453, b=0.5 and c=1/3. For Parabolic and cylindrical fins a=0.193, b=0.618 and c=1/3. The values of *h* obtained for natural convection were determined by extrapolation of the results obtained with forced convection, and with the Grashof number. The comparison had an error of approximately 1 W/m^{2}K.

3. Result and Discussion

The study was done in fins with different geometrical configurations, straight triangular fin, straight rectangular fin, cylindrical pin fin, and straight parabolic fin. All the fins had the same volume (125 cm^3) assembled to a base with the same area resulting in different lengths because of the shape of each.

3.1 Heat transfer rate behavior of the fins

It was given the following parameters to study the heat transfer behavior: ambient temperature (28 ^{o}C), Temperature of the base of the fins (105^{o}C), the velocity of the air in contact with the fins in m/s [0.5; 1.0; 1.5; 2.0; 2.5; 3.0]. The values of the convective heat transfer coefficient range from 3 to 21 W/m^{2}K for the given vector of velocity. The materials used for the fins are shown in Table 1.

Table 1: Properties of fin materials

Material	K, W/(m^{o}C)	ρ, Kg/m^3	Cp, J/(Kg^{o}C)
Pure copper	395	8933	385
Pure Aluminum	236	2707	903
Pure Iron	76	7870	447
Stainless steels	55	7855	434

Figure 3 shows the heat transfer behavior in the fins. As can be seen, the higher the air velocity, the higher the heat rate transferred. The best profile is obtained with the straight rectangular fin and the worst for the straight parabolic fin. The best working material for all the fins is the copper transferring the highest amount of heat per unit of time. When comparing the materials used when working in with rectangular and cylindrical fins, small differences are found in heat transfer rate. The same pattern is found when comparing straight triangular with straight parabolic fins. When air velocity is near zero (natural convection), the rate of heat transfer is the same for triangular and parabolic fins, no matter which material to use. However, the difference increases when the fluid velocity increases implying that the best working material, in that case, is copper. As can be seen in all the plots, the degree of inclination of all the curves is high indicating that working at high velocity of the fluid does increase the rate of heat transfer considerably. There is no difference in the removed heat when working with materials with high thermal conductivity.

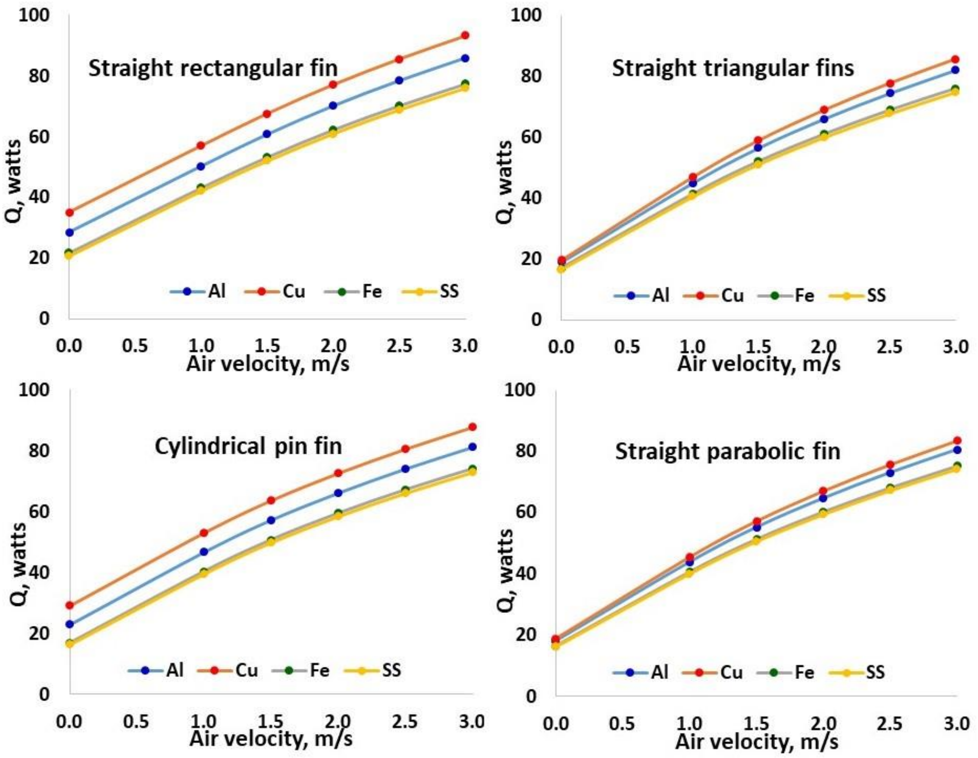


Figure 3: Heat transfer rate at different air velocities

3.2 Effect of the convection in the efficiency of the fins

For all the plots in Figure 4, the efficiency decreases when the velocity of the fluid in contact with the fin increases, which is directly related to the convective coefficient. It means that it is necessary to put the fin in contact with a fluid of low convective heat transfer coefficient to work at high efficiency. It indicates that the use of fins is better when working with gases instead of liquids, and when the heat transfer is by natural convection instead of by forced convection. The best working material is copper with the highest efficiency obtained in cylindrical pin fin at the lowest velocity. Straight parabolic again shows the worst behavior obtaining the lowest efficiency.

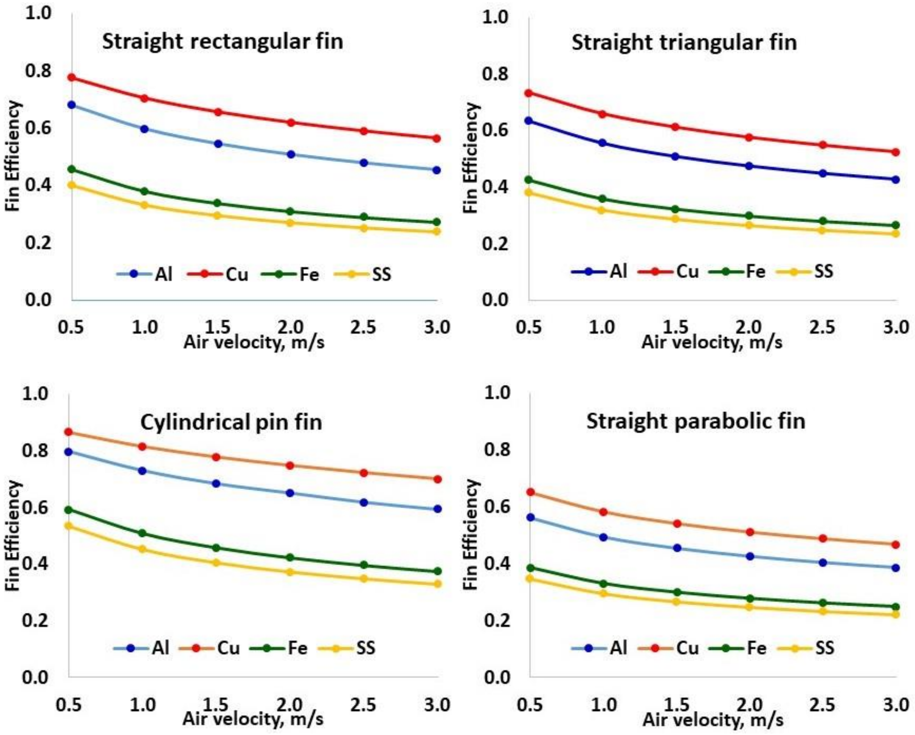


Figure 4: Efficiency of the fins at different air velocities for different materials

3.3 Effectiveness profile of the fins

Figure 5 shows that the effectiveness defined as the relation of the heat transfer rate from the total area of the fin, to the heat transfer rate from the base of the fin. This relation indicates the performance of the fin. As can be seen, for all the cases the fin effectiveness increases when using materials with high thermal conductivities. However, the effect is even higher when working with straight rectangular fins.

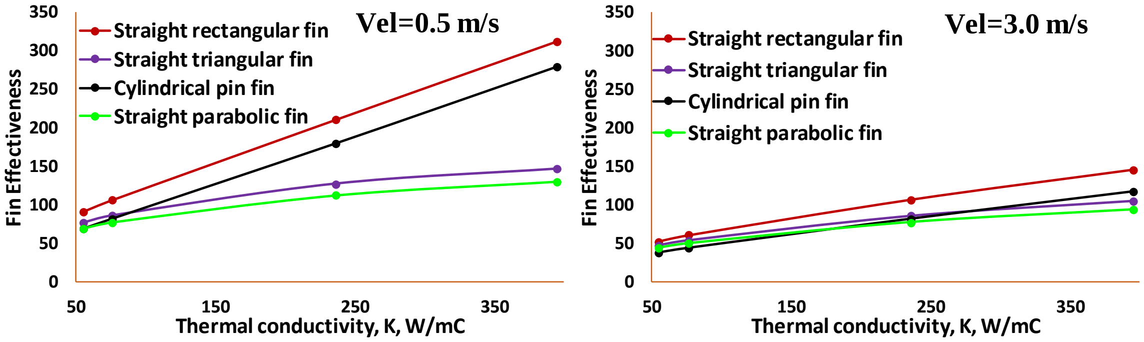


Figure 5: Effectiveness of the fins at different thermal conductivities

One important consideration when trying to have high effectiveness is the velocity of the fluid. It is better when the velocity of the fluid is low. At high velocities Figure, 5 shows that the effect of the type of fin is insignificant. It is indifferent to use triangular, parabolic, or cylindrical fins when working at 3 m/s. The straight rectangular present a better efficiency but the increment is low. The effect of the conductivity decreases as well when increases the fluid velocity. When working at low velocities, there is a large difference in effectiveness among the different types of fins when using the material with the highest thermal conductivity. In this case, straight triangular fin presented the highest effectiveness. When working with material with low thermal conductivities the effect of the type of fin is negligible.

4. Conclusions

It was designed a valuable computational tool that helps increase in engineers and senior students their capacity to analyze the design of fins.

The systems studied were Straight Rectangular Fins, Straight Triangular Fins, Cylindrical Pin Fins, and Straight Parabolic Fins. The study was made of three cases, heat transfer rate behavior of the fins, the effect of the convection in the efficiency of the fins, and the effectiveness profile of the fins.

The best working material is copper with the highest thermal conductivity (395 W/mºC). The highest heat transfer rate was obtained when using straight rectangular fin, at high air velocity using copper as material.

The effect of the air velocity in the heat transfer rate is higher in straight triangular and straight parabolic fins.

Low convection heat transfer coefficient favors the efficiency of the fins, indicating that fins have a better performance in an environment of natural convection that in forced convection. Cylindrical pin fin presented the highest efficiency.

An increase in the thermal conductivities produces an increase in the effectiveness of the fin. When working with material with low thermal conductivities the effect of the type of fin is negligible. There is no difference in the removed heat when working with materials with high thermal conductivity.

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