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Enhancement of Fin Efficiency: a New Proposal

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Abstract – *The heat dissipation by fins is very important in many technological systems. The thermal efficiency of fins can be improved depending on many characteristics; one of them is the surface area. This work presents a new fin shapes model used to increase the surface area, keeping the same volume. However, three different fin geometries are used (cylinder, a new fin geometry consisting of cutting cone with hemisphere and an egg (oval) shape fin). A numerical investigation is used to analyze the thermal efficiency of these three types of fins under free convection consideration. The Finite Element Method (FEM) is used as a numerical analysis in order to compute unsteady temperature distribution and heat flux on the surface, based on Ansys Ver.16.1. The new fin shape presented in this study can increase the efficiency by 4%, compared with classical types. The thermal results show that the egg fins have the best thermal efficiency. Moreover, the result is validated and approved by other researchers.*

Keywords*: Fin, Efficiency, Oval, Enhancement, Finite Element Method*

Nomenclature

Cp	Specific heat capacity [J/kg K]
D	Diameter of the circular fin [m]
H	Fin Height [m]
h	Heat transfer coefficient [W/(m^2 k)]
k	Thermal conductivity [W/(m k)]
L	Length of fin [m]
R	Radius [m]
x	Longitudinal distance from fin base [m]
$T(x,y,z,\tau)$	Fin surface temperature function [K]
T	Temperature [K]
T_w	Surface fin wall temperature [K]
T_o	Base area fin temperature [K]
T_∞	Surrounding temperature [K]
q	Heat transfer rate [W]
q_o	Heat from fin base area [W]
Ac	Cross section area [m^2]
η_f	Fin efficiency
FEM	Finite Element Method
f	Fin
c	Egg fin center

I. Introduction

The main object of the extended surfaces is to enhance the rate of the heat transfer. A fin gives rapid and economical solutions in numerous applications corresponding free convection heat transfer. The choice of a certain fin profile in a wide thermal application is based on surrounding, mass, manufacturing method and economic considerations, furthermore the available thermal properties. Octaviani and Semin [1] have investigated the effect of inlet valve fins on the turbulent flow of dual fuel engines. Three intake valve fins have been compared, namely the original one, an intake valve with three fins, and one with five fins using Ansys Fluent Computational Fluid Dynamics (CFD) software. The result has showed that the best turbulence intensity has been produced by the intake valve with five fins. Sowayan and Hasani [2] have solved numerically the non-linear steady state heat equation for different fin surface profiles using the combined convection and radiation modelling approach. Their results have suggested that the transfer of energy by radiation has been relatively limited relative to the transfer by conduction and convection. Alizadeh et al. [3] have investigated the effect of V-shaped fin on the solidification acceleration. FEM has been used to simulate the solidification process. The findings have showed that using V-shaped fin in the system causes higher acceleration to the procedure, in comparison with nanoparticles dispersion. Hajmohammadi et al. [4] have suggested the incorporation of highly conductive materials in a straight fin. The numerical results have indicated that the highly conductive materials reduce the thermal resistance of the fin and enhance the heat transfer. Yang et al. [5] have proved experimentally the local thermal equilibrium state with and without fin inserted. The parameters of the fin-foam structure, including fin sizes, fin pitch and number have been investigated experimentally. The results have showed that the solidification process can be further enhanced through increasing fin width and number rather than fin pitch. Tian et al. [6] have conducted a comprehensive study in order to analyse the effect of fin material on PCM melting in a rectangular enclosure. Results have showed that, compared with the no-fin scheme, the PCM

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melts faster and the melting time has been reduced by 41.6%, 41.0%, 40.1% and 37.2% with inserting copper, aluminium, carbon steel and steel302 fins. Alizadeh et al. [7] have employed Y-shaped fins in order to enhance the thermal penetration depth. The effect of the geometric parameters of the Y-shaped fins including the bifurcation angle and fin length on the solidification process has been investigated. Results have illustrated that, by enhancing the fin length and the fin bifurcation angle, the average temperature and the total energy of the system experience lower values, while the solid fraction increases. Prajapati [8] has studied numerically the heat transfer and the fluid flow behavior in rectangular parallel microchannel heat sinks with varying fin height.

The net convective surface area and the typical flow behavior caused by available open space have been identified as the major reasons that influence the overall thermal performance of the proposed heat sinks. A novel convection heat transfer enhancement of a circular cylinder by a flexible fin has been studied by Sun et al. [9]. Forced convection heat transfer characteristics from a circular cylinder with a flexible fin with fin length and elastic modulus have been analysed in detail. The findings have showed that a maximum of 11.07% enhancement in heat transfer has been obtained by the flexible fin. Cetin [10] has presented the enhancement of the heat transfer rate within a rectangular enclosure due to the influence of T-shaped constructed fin. The resultant work shows that the fins with slighter thickness and slighter length are suitable for high temperature gradient system. A permeable fins temperature distribution bounded by free convection condition has been investigated and Darcy's model has been used by Saedodin and Olank [11]. The directories explain that the solid properties increase the heat transfer rate enhanced but only in some cases. Kundu and Das [12] have addressed an analytical method to optimize the profiles of longitudinal, spine and annular fins, under variable coefficient of heat transfer. It has been noticed that the fin efficiency has been influenced strongly with variable coefficient of heat transfer. The Differential Transform Method has been used by Fidanoglu et al. [13] in order to estimate the efficiency effectiveness and the entropy generation for various profiles of spine fins. It has been found out that the cylindrical fin profile has the biggest value of heat transfer. A research has been carried out by Fakir and Khatun [14] in order to study the efficiency of the heat distribution through fins using finite element and differential quadrature methods. The two-dimensional heat conduction problem has been solved in both equal and non-equal nodal points distribution cases. The findings have showed that the finite element method has recorded the best results. In another aspect, Fakir and Khatun [15] have conducted a comparative study of temperature distribution in a long, insulated rectangular fin. Surface temperature distribution and error comparison have revealed that the results of the finite element method are better and more accurate than the ones of the differential quadrature method. The optimal designs of fin arrays are addressed from [16]-[22]. Harish et al. [16] have changed the material and the configuration of the cylinder fins to study and optimize the thermal properties in order to cool the cylinder of internal combustion engines. By checking the incoming results of the thermal analysis, the aluminium alloy thermal flux is better than the other two used materials. A horizontal finned tube subjected to a free convection heat transfer has been investigated experimentally by Elsayed et al. [17] and Lee et al. [18]. The calculations have been done with several parametric studies, in order to perform optimal cooling performance and maximum heat transfer rate. The fins spacing optimization matter should be analyzed in order to augment the heat transfer rate. Yardi et al. [19] and Rossi et al. [20] have chosen this objective criterion. The optimization is estimated for vertical and rectangular fins connected with base plate in order to increase the heat transport rate. Subsequently, the investigations are implemented experimentally and numerically, respectively. Fins configurations varying is a method used to optimize the heat transfer rate and it has been implemented by Jain et al. [21], using ANSYS 14.5.

By observing the results, it can be said that the heat transition rate with aluminium triangular fin has been much more compared with the others. Octaviani and Semin [22] have investigated the effect of inlet valve fins on the turbulent flow of dual fuel engines. Three intake valve fins have been compared, namely the original one, an intake valve with three fins, and one with five fins using Ansys Fluent Computational Fluid Dynamics (CFD) software. The result has showed that the best turbulence intensity has been produced by the intake valve with five fins. Chikurde et al. [23] have performed a numerical and experimental review study to analyse various types of fin configurations under natural convection conditions in order to increase the heat transfer with different fin surface roughness. Fins with perforations of rectangular, circular, triangular shape and fins with extensions or protrusions of various shapes have been studied. It has been found out that roughness height plays an important role and it is a decisive factor in increasing or decreasing heat transfer from such surfaces. Ibrahim and Hassan [24] have conducted an experimental investigation to determine the condensation heat transfer characteristics of hydrofluoroolefin R1234yf and R134a on horizontal smooth and finned tubes. The experiments have been managed at a saturation temperature of 39 °C with variable water-cooling temperatures and velocities. The results have showed that the tube with the largest fin pitch, the largest fin thickness, and the smallest fin height provides the highest condensation heat flux. Belhardj et al. [25] have described a new tool developed in laboratory, which has been named FINSTOOL. Their mathematical model has been based on the finite volumes' numerical method for three types of boundary conditions. Khan et al. [26] have investigated the free convection of Casson fluid inside a square cavity with intruded Y-shaped fin at the bottom surface. The findings have showed that in presence of the

Y-shaped fin, all the pertinent parameters and the dimensionless numbers help in enhancing the heat transfer rate along the bottom surface. A vertical pin fins array heat sinks thermal performance has been predicted by Tomar and Sahu [27]. A theoretical and experimental study has been carried out in order to predict the effect of different construction and thermal resistance on the performance of heat transmission. On the other hand, the new geometry with high surface area can be used to improve the heat transfer rate by this fact, which has been presented in many previous works especially with electronic packages and IC engines [28]-[32]. Navid et al [32] have studied the transient heat transfer in longitudinal fins with several profiles types including rectangular, parabolic, convex, exponential, sinusoidal, and cosine profile. All the profiles types have been modeled in COMSOL. The results have found out that the nonrectangular profile provides a higher rate of heat transfer. Fakir et al. [33] have investigated heat transfer through fins for one and two dimensional heat conduction problems. The results have found out that non-equal spacing mesh distribution produces more accurate results than equal spacing mesh. Heat storage unit with Y shaped fins for solidification of NEPCM has been examined by Nguyen-Thoi et al. [34]. A powerful numerical approach has been involved in simulating time-dependent phenomena in a complex geometry.

Homod et al. [35] have investigated the effect of the direction of longitudinal fins on a three-dimensional convection heat transfer in a rectangular channel and they have also studied the effect of the lateral and longitudinal inclination of the rectangular channel. New empirical correlations have been developed based on the experimental results. Iman and Farivar [36] have investigated numerically the perforated fins in turbulent flow. In addition, Mazhar et al. [37] have analyzed the radial installed rectangular fins on the pipes using numerical methods. Finally, Pei Cai et al. [38] have enhanced the ice storage performance by increasing the fin structure parameters, including height, thickness and number. The outputs show that the pressure drop happens with tall fin length and the heat transfer rate is enhanced with short fin length. Many new fins' designs have been presented in last years with important applications [39], [40] and [41]. Unger et al. [39] have studied the thermal and the flow performances of new fin shape design used with tube heat exchangers. Hameed et al. [40] have presented several aluminium fins shapes and have discussed numerically and experimentally the natural convection conditions for each. Moreover, Nemati et al. [41] have dealt with optimization of the local shape for multi-row annular finned-tube heat exchangers. On the other hand, Gaur et al. [42] have carried out the way for improving thermal performance of pin fins. The purpose of this work is to optimize the performance and the efficiency of two unique types of fins profiles designs with natural convection heat transfer conditions. This can be done by the multifarious examination of fin shapes in order to obtain the best surrogate shape that gives the maximum effective surface, keeping their volumes.

In this work, the cylinder fin shape is restricted to the standard one and then modified in order to reach to the new fin geometry for increasing the surface area with same volume. Most of the cases in this work are discussed in order to reach this innovate results depending on the idea that the volume of the cylinder comes from the summation of the volumes of cone and sphere while their collection surface area is greater than the one of the cylinder surface area for same main radius (R). However, three cases are presented and will be discussed and elaborated in subsequent articles.

II. Fin Geometries

In this work, three cases with symmetrical shapes are presented (Fig. 1). Case 1 refers to the classical fin that has a cylinder shape with radius 1.5 cm and lengths of 4.5, 3 and 1.5 cm respectively. Case 2 has the same volume of case 1 for each part (a, b and c) but with a new shape consisting of two parts, cutting cone joining with hemisphere. Its surface area involves the surface area of the truncated cone add with surface area of hemisphere.

The unique shape constructed by two opposite eggs observed in case 3 makes the volume constant as depicted in the first case. The relations between the surfaces area and the volumes for all the cases are illustrated in Fig. 3.

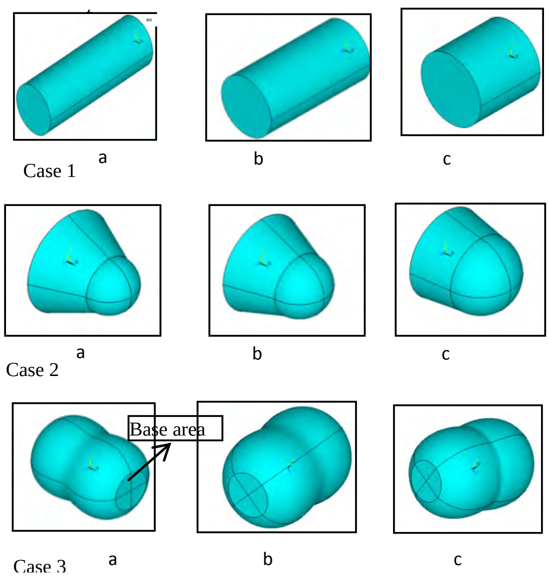

Fig. 1. Physical models, case 1 cylinder shape, case 2 truncated right cone with hemisphere and case 3 the opposite double egg fin shape

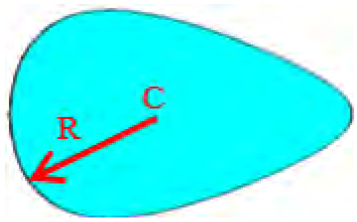

Fig. 2. Egg curve

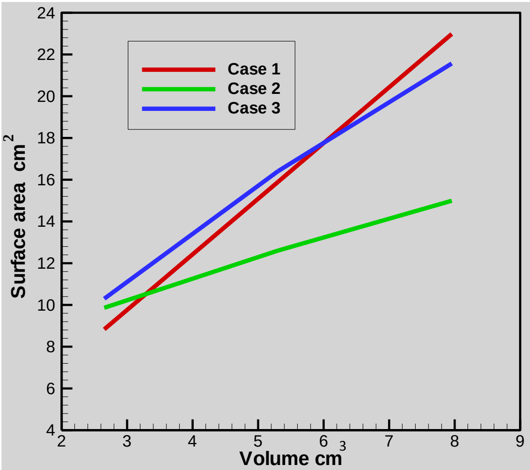

Fig. 3. The relations between volume cm³ and surface area cm² for all the cases

The thermal boundary conditions are fixed for all the cases and are quantified in following values. The surface area and the volume of case 1 and case 2 are discussed in many mathematical books. On the other hand, many researchers have driven suitable equations of egg surface area and volume depending on the egg shape like [43]. In addition, Don Jacobs, M.D., from Daly City, USA [44], has presented a proper equation for the egg profile (1).

Then it has been modified in this work in order to make it more convenient for fin equation as shown in Equation (2). The Scheck of the egg that represents its profile can be seen in Fig. 2:

$$x^2 + \left[1.4^x \times 1.6y\right]^2 = 1 \tag{1}$$

$$x^2 + \left[1.4^x \times 1.6y\right]^2 = R^2 \tag{2}$$

where R is radius of the egg and C is its center. Using numerical methods depends on the last equation to get the surface area and volume for double egg fin of case 3 as shown in Equations (3) and (4) [35]. In addition, the radius of the double egg fin base area is illustrated in Fig. 2. Case 3 is computed by iterative method in order to keep volume constant [35]:

$$\text{Surface area} = \int 2\pi y\sqrt{1+(y')^2}\,dx \tag{3}$$

$$\text{Volume} = \int \pi y^2 dx \tag{4}$$

y can be computed from Equation (2).

III. Formulation of General Fin Heat Equation Efficiency

The main variables in this research are the surface area and the time. In addition, the heat transfer coefficient and the thermal conductivity are assumed constant. All the cases under investigations involve fins made from aluminium with base temperature 80 °C and surrounding conditions (temperature 30 °C and heat transfer coefficient equal 50 W/m^2 K by assuming natural convection). Moreover, the interpretations of the effect of geometry on enhancement of heat transfer rate are reported. The general governing equation will be used for the special innovative shapes presented in this work.

The equation that represents the general conduction in three dimensions without heat generation can be given by [44]:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} = \frac{1}{\alpha}\frac{\partial T}{\partial \tau} \tag{5}$$

T is a function of x because the modes of the fins under consideration are complex. Therefore, the assumption $T \approx T(x,y,z,\tau)$ is very useful to obtain the fin efficiency. Consequently, Equation (5) refers to the temperature distribution though out the shapes of fins with orthogonal directions presented in this paper. In order to calculate the heats lost by the fins that have symmetrical shape with all the directions can be given by [44]:

$$q = \int 2\pi yh\sqrt{1+(y')^2}\left(T(x,y,z,\tau) - T_\infty\right)dx \tag{6}$$

The boundary conditions for all the fin types under consideration are as follows. If x=0 or y=0 or z=0 at any time τ then $T(x,y,z,\tau)=T_o$. At $x=L$ for any value of y and z at any time then $\frac{\partial T(L,y,z,\tau)}{\partial x} = 0$ In order to indicate the improvement by new fin shape on the rate of heat transfer the efficiency should be calculated where [45]:

$$\eta_f = \frac{\text{actual heat transferred}}{\text{heat that would be transferred if entire fin area were at base temperature}} \tag{7}$$

Heat that would be dissipated out can be calculated by the numerical summation of the amount of heat energy dissipated from fin surface area using Equation (8):

$$q_o = \sum 2\pi h\, y\sqrt{1+(y')^2}\,(T_o - T_\infty)\Delta x \tag{8}$$

Many numerical methods are used to calculate the above equations after computed temperature distribution that depends on Finite Element Method (FEM).

IV. Mesh Generation

The problems of the discretized into a collection element of the unique shapes are solved by using tetrahedral type as shown in Fig. 4. The element type is restricted to fin shape. Consequently, the tetrahedral element type is used and achieved by using Ansys program software 16.1. The mesh generation of three cases can be seen in Fig. 4. The error is very small (10^{-6}) for the element number shown in Table I for all the cases. Therefore, this point represents the solution.

V. Validation

The validation of the numerical investigation is done by comparison with [38]. The properties of the boundary conditions of the longitudinal fin shown in Fig. 5 can be seen in Table II. The results give a good agreement of this work at these conditions with ANSYS (16.1) program, which depends on the finite element method.

TABLE I
TESTING GRID FOR BEST VALUES OF EFFICIENCY FOR ALL FIN CASES

Cases	Case 1	Case 2	Case 3
No. of element	192224	385139	719778

TABLE II
BOUNDARY CONDITIONS USED BY HEMANTH J. [46]

L, Length of the fin	0.15 m
w, width of the fin	0.1 m
t, thickness of the fin	0.015 m
h, heat transfer coefficient	5.489 W/m^2 K (for Al)
p, perimeter	0.23 m
A_c, cross section Area	0.0015 m^2
k, thermal conductivity	236 W/m K (for Al)
m	1.888
T_o	200 °C
T_∞	20 °C

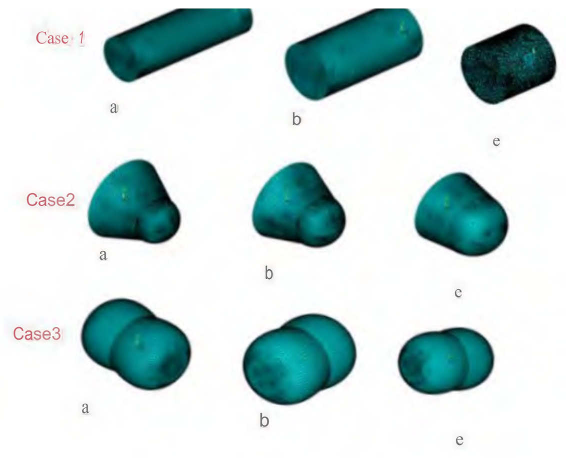

Fig. 4. Mesh generation for case 1, case 2 and Case 3

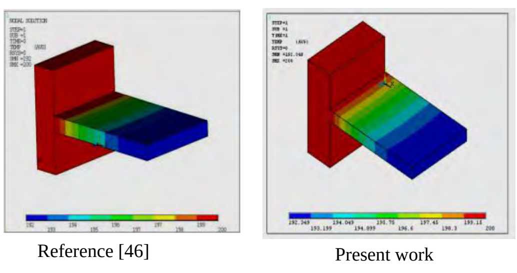

Fig. 5. Validation of the present work with Hemanth J. work [46]

VI. Results and Discussions

According to the fact that increasing the surface area can increase heat dissipation, new fin shapes are presented.

An egg shape fin and its impact on the performance of fin applications in the industrial or electronic system are introduced and numerically investigated. Employing the fact that the cone reduces the surface area and volume, whereas the sphere increases the surface area and volume, each fin consists of two eggs, having cone and sphere that achieve the egg fin shape required to impart the fin a higher performance.

They are placed in an opposite position in order to achieve the advantage of each shape, forming the new one. Consequently, three types of fins have been studied and analyzed. The first type is the classical one that is used for the comparison and the analysis with the other types.

The second type consists of truncating cone with hemisphere in order to exam the effect of their surface area on the performance of this fin type. In this type, the hemisphere is kept constant while the truncated cone is changed in order to obtain the volume required for each part, corresponding to the first type. On the other hand, the third type tries to benefit from the surface area of sphere, producing a new fin shape, depending on the natural one (egg shape). However, the egg shape consists of cone part in cusped end and sphere part at convex end.

Moreover, the convex part has maximum surface area, since the third type contains two opposite eggs shape to reject the cone part.

All the types of fins presented in this work can be seen in Fig. 1. In addition, the variation of the surface area with constant volume is shown in Fig. 3.

Fig. 6 indicates the temperature distribution after 100 s around the surfaces of three cases under consideration.

As shown in the last figure, the temperature distribution for all the cases is the same. Therefore, temperature will slow down the length of all the cases.

The minimum temperature of the surface area will be in case 3. In addition, the surface area that has the minimum temperature can be seen in case 3, which is greater than both case 1 and 2. By keeping the volume constant for all the cases, the fin efficiency of the three cases can be observed in Fig. 7. This figure shows that the fin efficiency is increased for egg fin type case 3 with low volume while high volume efficiency of cylinder is dominated.

Therefore, the low volume egg shape fin is more convenient than other fin types. However, improving heat transfer rate induced by increasing the surface area in small volume is clear in case 3. The high surface area compensates the high length of other types in case 1. For high volume, this type of fin is nerveless. In case 2, the cone part reduces the heat transfer rate less than fin case 2. The thermal transients of the three cases of fins have been carried out. Fig. 8 is a comparison among thermal transient of each case. In addition, the thermal transient within all the parts that have the same volume for each case is investigated and observed separately. As shown in this figure, the time required for small volume to reach the steady state is small in comparison to the large volume. The amount of heat that is removed by convection with high volume is greater than the low ones, because it has more surface area. By comparison, the same minimum value of fin volumes is observed; the low volume is shown in case 3, which rejects out heat more than other cases. On the other hand, case 1 is sufficient and thermal is used effectively for high volumes.

These results come from the increase of cylinder surface area. Case 2 needs low time to reach the steady state because the amount of heat that is dissipated is small.

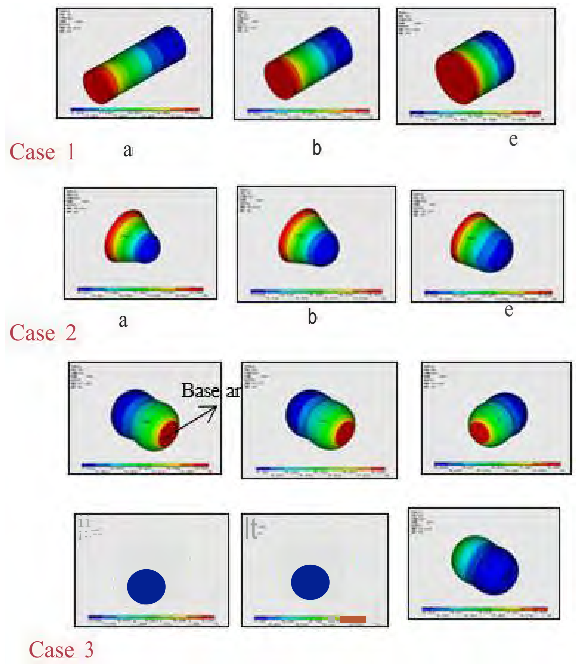

Fig. 6. Temperature distribution for Case 1, Case 2 and Case 3

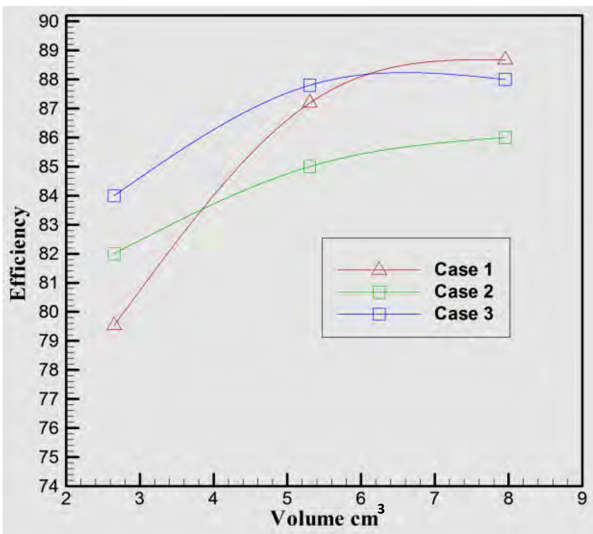

Fig. 7. Percentage efficiency of all cases of fin that have the same volume

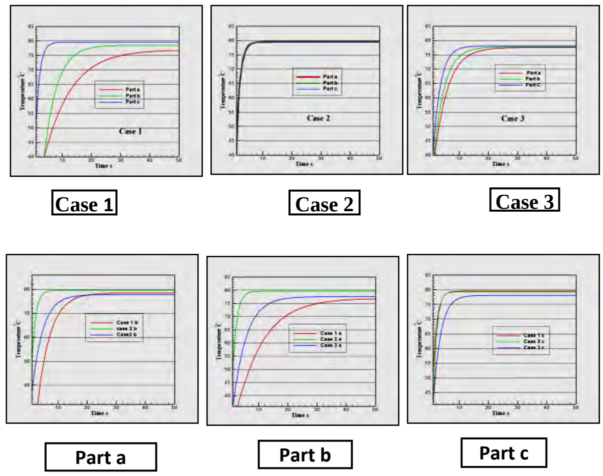

Fig. 8. The variation between temperate (k) at the end point of fin central axis with time (s)

VII. Conclusion

Three cases of fins with the same volumes are numerically investigated. However, case 1 refers to the classical cylinder types; case 2 is a new fine shape consisting of truncated cone with hemisphere and finally the innovative egg fin shaped is presented. In addition, the thermal transients of these three cases are numerically computed. The results can be summarized as follows:

1. The egg shape fin gives large surface area, compared to other types of fins;
2. For small volume, the egg shape fin is more efficient, compared to other fin types;
3. The time required for new shape egg fin part (*c*), which has the smallest volume to reach a steady state, is more than other fins cases that have the same volume;
4. The cylinder type is nerveless for low volume to use; it is used to be compared with egg shape fin at high volume, since it is more efficient;
5. The cone reduces the fin efficiency while the sphere increases it.

The amount of heat removed from fin case 3 is the highest one. The final temperature of fin overall of this case will not be near the base temperature (80 °C) at steady state compare with the others fin types.

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