Alexandria Engineering Journal (2015) 54, 1037–1042

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ORIGINAL ARTICLE

Performance optimization of annular elliptical fin based on thermo-geometric parameters

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Received 26 May 2015; revised 15 September 2015; accepted 29 September 2015
Available online 26 October 2015

KEYWORDS

Annular fins;
Elliptical fin;
Fin efficiency

Abstract Efficiency of annular elliptical fin has been studied numerically. It has been shown that constant temperature lines do not preserve their circular shape in fins with high aspect ratio and therefore, the common methods such as equivalent fin area or sector method may not be applicable. For this reason, a new simple correlation has been proposed to approximate annular elliptical fin efficiency and then the fin geometry optimized, to maximize the rate of heat dissipation for a specified fin volume, when there is a space restriction on the fin minor axis. Results have been presented graphically and a correlation has been deduced also.
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1. Introduction

Annular fins are used vastly in industry to increase the heat transfer area. Although circular type of annular fin has been studied widely [1–5], the elliptical one has not been studied yet. Lesser pressure drop across elliptical fin in comparison with circular fin is its obvious advantage. Moreover, since it can be extended only from one side, it is very useful in the presence of space restriction.

It is clear that increasing fin length decreases the rate of heat transfer. So, maximizing the amount of heat transfer for a specified fin volume is mandatory. Results of this optimization are widely reported for annular circular fins [6–8]. However, shape optimization of annular elliptical fins may be rarely found. In annular elliptical fin, the radius ratio is another variable added to optimization problem. Nagarani and Mayilsamy [9] performed some limited experiments to study the natural convection on specified elliptical fin geometry. Kundu and Das [10] proposed a semi-analytical method similar to sector method to approximate elliptical fin efficiency. However, this method ends to a series of Bessel function families. Later, Nemati and Samivand [11] proposed a simple correlation to determine circular annular fin efficiency. They extend their work to predict elliptical annular fin efficiency, also.

In this study, the shape of annular elliptical fins has been optimized. To do this, at the first step, elliptical fin efficiency has been calculated numerically in a vast range of thermo-geometric parameters. Then, equivalent parameters have been proposed to approximate elliptical fin efficiency, based on circular fin efficiency formula. Knowing the fin efficiency, the

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Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2015.09.016
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Nomenclature

Bi	Biot number, $Bi = hr_b/k$
h	convection heat transfer coefficient (W/m^2 K)
k	fin thermal conductivity (W/m K)
L	fin length, $r_f - r_b$ (m)
$\bar{L}$	arithmetic mean of major and minor fin lengths, $\frac{L_1+L_2}{2}$ (m)
L_1	major fin lengths, $(r_1 - r_b)$ (m)
L_2	major and minor fin lengths, $(r_2 - r_b)$ (m)
m	thermo-geometry parameters, $\sqrt{\frac{h}{kt}}$
N	normal vector
Q	dimensionless heat transfer rate
r	radial distance from tube center (m)
r_1	fin major radius (m)
r_2	fin minor radius (m)
r_b	tube radius (m)
r_f	circular fin radius (m)
R_f	normalized fin radius, r_f/r_b
R_{f1}	major normalized radiuses, r_1/r_b (m)
R_{f2}	minor normalized radiuses, r_2/r_b (m)
$\bar{R}_f$	geometric mean of major and minor normalized radiuses, $\sqrt{R_{f1}R_{f2}}$
t	fin semi-thickness (m)
T_∞	ambient temperature (K)
T_b	fin base temperature (K)
U	dimensionless fin volume,
Greek symbols	
ξ	dimensionless fin thickness, t/r_b
η	fin efficiency
ϕ	angular position from horizontal symmetric line (rad)
ψ	fin efficiency parameter, Eq. (4)
θ	$(T - T_\infty)$ (K)

amount of heat transfer for a specified fin volume has been maximized.

2. Formulation of the problem

An annular elliptical fin around a circular tube is shown in Fig. 1. Fin thickness is $2t$ and tube radius is r_b. r_1 and r_2 are the major and minor radiuses of ellipse, respectively. Convection with constant ambient temperature, T_∞, is the only heat exchange method and the convection coefficient h is constant. Based on the above assumptions, the steady state energy equation for constant fin thermal conductivity, k, in polar coordinate system may be written as

$$\frac{\partial}{\partial r}\left(r\frac{\partial\theta}{\partial r}\right) + \frac{1}{r}\frac{\partial^2\theta}{\partial\phi^2} = m^2\theta \tag{1}$$

Also, the boundary conditions may be presented mathematically as (Fig. 2)

$$\theta = \theta_b \text{ at } r = r_b(0 \leqslant \theta \leqslant \pi/2) \tag{2a}$$

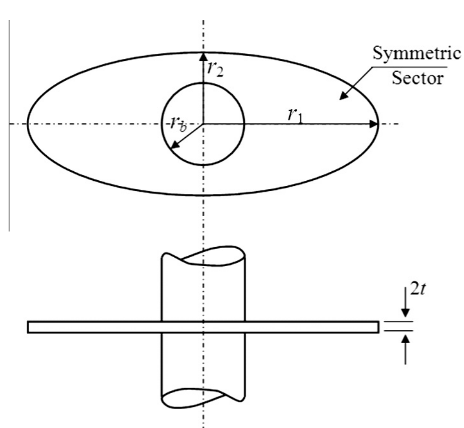

Figure 1 Annular elliptical fin around a circular tube.

$$\partial\theta/\partial\phi = 0 \text{ at } \phi = 0(r_b \leqslant r \leqslant r_1) \tag{2b}$$

$$\partial\theta/\partial\phi = 0 \text{ at } \phi = \pi/2(r_b \leqslant r \leqslant r_2) \tag{2c}$$

$$\partial\theta/\partial N = 0 \text{ at } 0 \leqslant \phi \leqslant \pi/2\left(r = r_1 r_2/\sqrt{(r_1\sin(\phi))^2 + (r_1\cos(\phi))^2}\right) \tag{2d}$$

In the preceding equations, θ is $(T - T_\infty)$, $m^2 = \frac{h}{kt}$ and N is normal vector.

Eq. (1) is separable and can be solved by separation of variables method [12]. However, for elliptical fin, the fourth boundary condition, Eq. (2d), is not separable and no analytical solution may be found for Eq. (1). So a new formula based on circular fin efficiency approximation has been proposed.

3. Fin efficiency approximation

Since the exact solution of Eq. (1) in circular case in which $\partial^2\theta/\partial\phi^2 = 0$ and $r_1 = r_2 = r_f$ is a combination of Bessel function families, it is not a good base to approximate the elliptical fin efficiency. Several equations may be found to approximate circular fin efficiency [13–16]. In this regard the following equation is used for circular annular fin efficiency [11]:

$$\eta = \left[\frac{\tanh(m\psi L)}{m\psi L}\right]^{\psi} \tag{3}$$

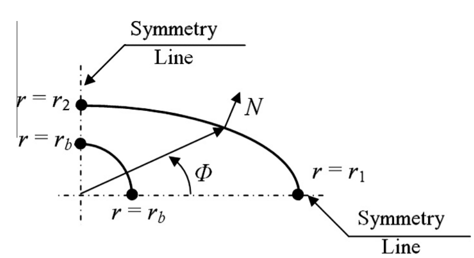

Figure 2 Fin geometry in polar coordinate.

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