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# Investigation of refrigeration efficiency for fully wet circular porous fins with variable sections by combined heat and mass transfer analysis

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ABSTRACT

Temperature distribution equation and refrigeration efficiency for fully wet circular porous fins with variable sections are introduced in this study by a new modified wet fin parameter presented by Sharqawy and Zubair. This parameter can be calculated without knowing the fin tip condition by considering the temperature and humidity ratio differences for the driving forces of heat and mass transfer, respectively. It's assumed that heat and mass convective coefficients vary with fin temperature and heat transfer through porous media is simulated using passage velocity from the Darcy's model. After presenting the governing equation, Least Square Method (LSM) and fourth order Runge-Kutta method (NUM) are applied for predicting the temperature distribution in the sample aluminum porous fins. After that, effects of porosity, Darcy number, Rayleigh number, Lewis number and etc. on fin efficiency are examined. As a main outcome, for reaching to high values of fin efficiency, rectangular fin should be used instead of convex and triangular sections.



# Enquête sur l'efficacité frigorifique d'ailettes poreuses circulaires de section variable avec analyse combinée du transfert de chaleur et de masse

*Mots clés :* Ailettes poreuses circulaires ; Méthode des Moindres Carrés ; Nombre de Darcy ; Nombres de Rayleigh ; Nombre de Lewis ; Humidité

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**Nomenclature**

| | |
|---|---|
| $a_2$ | Variable parameter Eq. (13) |
| $b_2$ | Variable parameter Eq. (14) |
| A | Section area of fin |
| $C_P$ | Specific heat |
| $c_i$ | Constants |
| Da | Darcy number |
| $h_D$ | Mass transfer convective coefficient |
| $h$ | Heat transfer convective coefficient |
| $i_{fg}$ | Latent heat of evaporation for water |
| $k$ | Thermal conductivity |
| $K_r$ | Thermal conductivity ratio [$k_{eff}/k_f$] |
| K | Permeability |
| Le | Lewis number |
| $m_0$ | Dry fin constant |
| $m_1$ | Wet fin constants |
| $n$ | Power index for geometry |
| NUM | Numerical Method |
| $q$ | Conducted Heat |
| R | Non dimensional radius |
| Re(x) | Residual function |
| Ra | Rayleigh number |
| RH | Relative humidity |
| $r$ | radial direction |
| T | Temperature |
| $T_b$ | Temperature at fin base |
| $T_a$ | air temperature for convection |
| $p$ | Power index of temperature-dependent $h$ |
| $\tilde{u}$ | Trial function |
| $\nu$ | Velocity of fluid passing through the fin |
| $W_i$ | Weight function |
| x | Horizontal direction |
| X | Non-dimensional x direction [$x/R$] |
| LSM | Least Square Method |

*Greek symbols*

| | |
|---|---|
| $\beta$ | Coefficient of volumetric thermal expansion |
| $\eta$ | Fin efficiency |
| $\omega$ | Humidity ratio |
| $\theta$ | Dimensionless temperature |
| $\gamma$ | Kinematic viscosity |
| $\rho$ | Density |
| $\varphi$ | Porosity variable |

*Subscripts*

| | |
|---|---|
| b | Base condition |
| dp | Dew point |
| $f$ | Fluid properties |
| eff | Porous properties |
| s | Solid properties |

## 1. Introduction

When the coil surface temperature is below the dew-point temperature of the air, heat and mass transfer will occurs concurrently in cooling and humidity removing processes. The fin is in fully dry condition when its temperature is higher than the environment dew point which only sensible heat transfers from air to the fin. If the fin temperature value is lower than dew point and both sensible and latent heat occurs, it's called that the fin is in fully wet condition. According to these definitions, fin is partially wet when the fin base temperature is below the air dew point and the fin tip temperature is higher than the air dew point (Sabbaghi et al., 2011).

Many researches are applied on straight solid fins such as Sharqawy and Zubair's study (Sharqawy and Zubair, 2008) and limited cases have been carried out on circular and semi-spherical solid fins such as sabbaghi et al.'s research (Sabbaghi et al., 2011) under the fully wet condition, but efficiency's study of circular porous fin under fully wet condition or other conditions has not been considered, so it's the first time that a study on refrigeration efficiency of circular porous fins is investigated in this paper.

Porous media has a widespread use of applications and flow through porous media is mandatory in many thermal engineering applications such as inert packed bed reactors, drying and wetting, filtering, insulation, reactor cooling, heat exchangers, fluid flow beds, solar collectors (Alkam and Al-Nimr, 1999). The concept of using porous fins in heat transfer applications with introducing the Darcy model (Kiwan, 2007a; Kiwan and Zeitoun, 2008) is firstly introduced by Kiwan and Al-Nimr (2001). Following some studies about extended surfaces analysis and porous fins are presented.

Numerous numerical and analytical studies are provided to show a deeper understanding of the heat transfer inside the porous fins. Saedodin and Sadeghi (2013) studied heat transfer of a cylindrical porous fin through fourth order Runge-Kutta method and they found that the heat transfer rate from porous fin could exceed that of a solid fin. An exact solution for thermal diffusion of a straight fin with varying exponential shape when the thermal conductivity and heat transfer coefficients are power laws temperature dependent is introduced by Turkyilmazoglu (2012). He revealed that the efficiency and heat transfer rate of the exponential profiles are higher than those of rectangular fin. Aziz and Beers-Green (2009) obtained an optimum design of a longitudinal rectangular fin attached to a convectively heated wall of finite thickness by Maple package numerical method for reaching a better performance and they compared their results by those obtained by Adomian's decomposition and the differential quadrature method (DQM). Khani and Aziz (2010) applied Homotopy Analysis Method (HAM) for predicting the thermal performance of a trapezoidal straight fin when the both thermal conductivity and heat transfer coefficient are temperature dependent. Finite difference method (FDM) and DQM are applied on a pin fin with different boundary condition by Malekzadeh and Rahideh (2009).

Recently Hatami and Ganji (2013) investigated the effect of Darcy and Rayleigh numbers on a rectangular porous fin by three efficient analytical methods called Galerikn, Collocation and Least Square Method (LSM) and they showed that LSM has