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# Analytical investigation of porous pin fins with variable section in fully-wet conditions

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ABSTRACT

The present work investigates the temperature distribution, heat transfer rate, efficiency and optimization of porous pin fins in fully wet conditions. The thickness varies along the length of the fin and the lateral surface equation is defined as functions that include diversification fins (rectangular, triangular, convex parabolic and concave parabolic sections). Fins are made of aluminium and the tips of fins are insulated. Furthermore, it is assumed that the heat transfer coefficient depends on temperature and in the fin it changes according to temperature changes. In order to derivethe heat transfer equation, energy balance and Darcy model are used. After presenting the governing equation to obtain the temperature distribution, least squares method (LSM) is applied. Comparison of the results between analytical solution and numerical outcome (fourth order Runge–Kutta method) shows that LSM is a convenient and powerful method in engineering problems. Then the effects of various geometric and thermophysical parameters (power index for geometry (n), porosity, Biot number and relative humidity) on the dimensionless temperature fin, efficiency and heat transfer rate are examined. Optimum design analysis was also carried out.



## 1. Introduction

Use of porous surfaces and heat transfer in porous surfaces is prevalent in engineering science and industrial problems. Because of their effects on the heat transfer rate, many studies have been conducted on porous fins nowadays. Kiwan and Al-Nimr introduced the concept of using fins made up of porous materials by introducing the Darcy model for first time [1,2]. Hamdan and Al-Nimr [3] studied the increase in heat transfer between two parallel porous channels by using porous fins. Kundu and his colleagues presented an analytical study to determine the performance of convective porous fins with various geometries [4]. Numerical study on the heat transfer of cylindrical porous fins was carried out by Saedodin and Sadeghi [5] and they also achieved results similar to the previous studies.

In many industrial applications the heat transfer of fin is combined with cooling and dehumidification of ambient air. Assuming that fin surface temperatures is below the dew point temperature of the surrounding air, heat and mass transfer occurs simultaneously in fin surface because of condensation of air humidity. Naphon studied the annular fin under dry-surface, partially wet-surface, and fully wet-surface conditions [6]. In many , a linear function is used to determine the

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relationship between the dry-bulb temperature and specific humidity [7–10] to analyse the performance of the wet fins. Assuming the temperature of the tip is dew point temperature [11], Sharqawy and Zubair determined the fin efficiency of straight wet fins by considering a new linear relationship between specific humidity and sensible temperature. Sabbaghi and his colleagues [12] investigated the efficiency of a semi-spherical fin. The results demonstrate that the overall efficiency of the fin depends on the fin surface conditions and the relative humidity does not have a large effect on efficiency.

The best extended surfaces (fins) are the fins that provide the maximum heat transfer, or the maximum temperature difference. Then the best situation should be found in which all the necessary conditions can be satisfied simultaneously. Several studies have already been done in this area. Yu and Chen studied on optimization of circular fins with variable thermal parameters [13]. For electronics cooling applications, Shuja presented an optimized geometry of fins, based on analytical methods [14]. He also investigated the effects of Reynolds number on output data. Analytical analysis of performance and optimization of circular and SRC profiles fin is conducted by Kundu [7,9]. He concluded that the heat transfer rate increases with the increase of ambient temperature. Kundu and Bhanja examined the influence of some independent parameter on efficiency and optimization of porous fin [15]. The results indicate that the optimum condition of porous fins is a function of ambient and base temperatures. Analytical solution for heat transfer equations of fins with variable geometries under wet conditions is determined by Kundu and Lee[16]. Bouaziz and Aziz introduced the least squares method (LSM) to solve the equations of fin [17,18]. They also illustrate that LSM is a simple and accurate method in comparison with other analytical methods. Hatami, Hasanpour and Ganji [19] have used three analytical methods for analysing the performance of longitudinal fin with temperature-dependent heat generation and indicate that the least squares method is more accurate in comparison with other methods. Analysis of straight fins with temperature-dependent thermal conductivity was performed by Joneidi, Ganji, and Babaelahi [20] using differential transformation method. Recently, Hatami and Ganji studied the thermal behaviour of porous fins with different profiles and different materials in terms of convection and radiation. The results illustrate that LSM is a powerful, efficient method and it also reduces the size of calculations [21,22]. They also studied the heat transfer in porous wet circular fins and they used least squares method to predict the temperature distribution.

Even though use of pin fins in some kinds of heat exchangers (Air Conditioning, Aeronautics Industry) are not prevalent, but this kind of extended surfaces are widely used in the electronics industry. So the effects of pin fins with variable profiles in refrigeration and providing an optimal design is investigated for the first time in the present study.

## 2. Mathematical formulation

The pin porous fins with variable geometries are presented in Fig. 1, under fully wet conditions. The assumptions are as follows: 1) fins are in steady state; 2) moist air flows with constant and uniform velocity around the fins; 3) fin surface is porous, homogeneous and isotropic; 4) there is no any heat generation and contact resistance at the base of the fin; 5) temperature of the fin surface is between the dew point and the fin base temperature. According to the two-dimensional schematic of fin profile, which is shown in Fig. 1e and the aforementioned assumptions, the governing equation can be

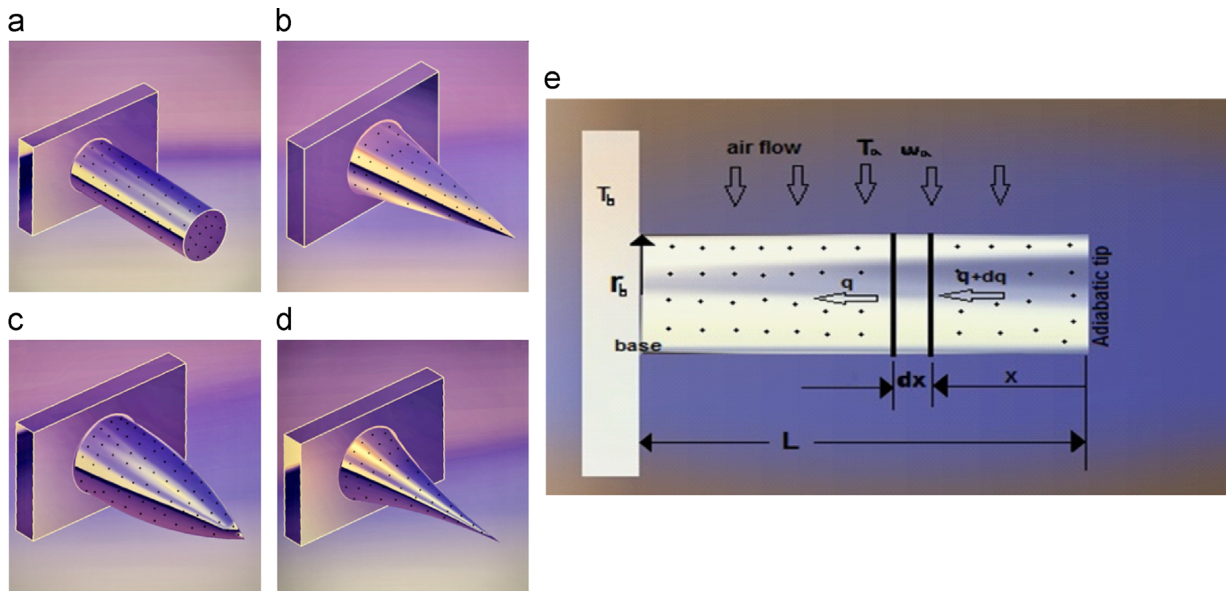


**Fig. 1.** Schematics of fully wet porous pin fins with variable section (a) Rectangular, (b) Triangular, (c) Convex parabolic and (d) Concave parabolic section, (e) Two-dimensional schematic of rectangular profile.