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Natural convection heat transfer from a horizontal hollow cylinder with internal longitudinal fins

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ABSTRACT

Three dimensional numerical simulations have been carried out by solving the continuity, momentum and the energy equations to predict the flow and the temperature field around an internally finned horizontal cylinder in natural convection. The fin height, fin spacing or the fin number and the length of the cylinder were varied at different Ra to predict the heat loss from the finned cylinder and interesting findings were obtained. The heat loss from a short cylinder ($L/D < 1$) can be maximum for certain height of the fin and certain fin number after which the heat loss can reduce if the fin height increases or the fin spacing decreases in the laminar range of Ra to within 10^7. When the length of the cylinder increases ($L/D > 1$) the maximum point of heat loss vanishes for all heights of the fins and fin spacing. A table has been generated to show the optimum configuration of fin height, fin number where maximum heat loss can take place. The average Nu of the finned cylinder was seen to be decreasing with H/D, L/D and increasing with Ra. From the enormous numerical simulations that has been done in the present study a general correlation for the Nu as a function of L/D, H/D, fin number, N and Ra has been developed to within an accuracy of $\pm$ 6% which can be beneficial to the industry and practical designers.

1. Introduction

Natural convection heat transfer plays a significant role in cooling of electronic components [1], hot solid or hollow cylinders lying in industrial bay for cooling, compact heat exchanger design [2,3], cooling of nuclear reactor [4,5] in case of sudden power failure or accidents. Natural convection is preferred over forced convection as it requires no external agent for fluid motion around the hot body for cooling and hence helps improving the reliability of the components in a system in an efficient and cost effective manner with additional advantages of having less noise and vibration. Since the heat transfer coefficient in natural convection is quite low, the enhancement of heat transfer in natural convection has been a challenging topic for most of the researchers in the present days. The most promising solution for enhancing the heat transfer is by employing fins (extended part) on the heated surface which provides the additional surface area for a better heat transfer. While many studies have been performed on natural convection heat transfer from cylinder with external fins [6–9] however, a few literatures are available on natural convection heat transfer from cylinders with internal fins and almost no literature is available on a horizontal hollow cylinder with internal longitudinal fins. Internal fins find its application in many practical field such as electrical heating of cylinders, nuclear heating, heat exchanger devices [10], cooling of annular nuclear reactor in sudden power failure or at the time of closing the power plant, ventilators and radiators [11], annular combustion chamber, hollow electrical conductor of cylindrical shape carrying huge current, where the inner surface of the cylinder is to lose most of the heat. When a heat source is present on the outer surface of the cylinder, it is difficult to attach fins on the outer surface, so the employment of internal fins becomes essential. Since the inner surface of a heated horizontal hollow cylinder losses more heat than that of the outer surface, (when L/D is less than 1 as has been explained by the present authors in their previous work [12,13]), so it would be prudent to use internal fins instead of external fins for a cylinder with aspect ratio less than 1. Many researches have been conducted on forced convection from an internally finned cylinder [14–17] but a few are only available regarding natural convection heat transfer from an internally finned cylinder. One of the earliest in this genre was the work done by Prakash and Liu [18] who investigated the buoyancy induced flow in a vertically internally finned circular duct and reported that there is significant improvements of thermal performance of a finned tube over an un-finned tube. Joo and Kim [19] experimentally and numerically investigated the natural convection heat transfer from internally finned vertical tube and optimized the fin configuration for maximum heat transfer rate. They optimized fin height, fin number and fin thickness under a given diameter and length of the tube and proposed a

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Nomenclature

A_t	total area of convective surface, m^2
A_c	cylinder surface area, m^2
A_f	fin surface area, m^2
D	diameter of horizontal cylinder, m
g	acceleration due to gravity, m/s^2
H	fin height, m
h	average convective heat transfer coefficient, W/m^2 -K
h_c	average convective heat transfer coefficient of the cylinder wall, W/m^2 -K
h_f	local convective heat transfer coefficient of the fin surface, W/m^2 -K
$h_{f\ avg}$	average convective heat transfer coefficient of the fin surface, W/m^2 -K
k_f	thermal conductivity of fluid, W/m-K
k_s	thermal conductivity of solid (fin), W/m-K
L	length of the cylinder, m
Nu	average surface Nusselt number of the finned cylinder based on diameter
N	number of fins
Pr	Prandtl number
p	pressure, N/m^2
Q	total heat transfer rate, W
Q_{max}	maximum heat transfer, W
T	fluid temperature, K
T_f	local fin surface temperature, K
T_w	cylinder surface temperature, K
T_∞	ambient temperature, K
t	time, sec
U	flow velocity, m/sec
x	Cartesian coordinate
Ra	Rayleigh number based on diameter
H/D	fin height to diameter ratio
L/D	length to diameter ratio
s/D	fin spacing to diameter ratio

Greek symbols

α	thermal diffusivity, m/s2
β	thermal expansion coefficient, 1/K
ε	effectiveness of the finned cylinder
η	efficiency of the finned cylinder
μ	dynamic viscosity, kg/m-s
ν	kinematic viscosity, m/s2
ρ	density of fluid, kg/m3

correlation for optimum efficiency as a function of D/L and Rayleigh number based on length of the cylinder. Myhren and Holmberg [11] analyzed the thermal performance of the ventilators radiator with internal convection fins and reported a significant improvement in effectiveness of the ventilation radiator which would save the electrical energy in a notable amount. Soliman et al. [20] analyzed laminar heat transfer in internally finned tube with uniform outside wall temperature. They presented the distribution of temperature in fins and fluid and concluded these were strongly dependent on fin configurations. They highlighted some important applications for the justification of their boundary condition applied to their problem and interestingly this boundary condition suites the present study too.

After a thorough literature survey, it has been found that almost no studies have been conducted on natural convection heat transfer from a horizontal internally finned cylinder where heat transfer occurs from both the inner and outer surfaces. Variation of the heat transfer characteristics such as Nu, effectiveness and efficiency of the internally finned horizontal cylinder as a function of various fin configurations, aspect ratio and Rayleigh number have been studied thoroughly with the help of vector plots and temperature contours in the present work which has not been reported in any literature available till now, which reflects the novelty of the present study. The present study deals with a detailed analysis of the natural convection heat transfer from an isothermal hollow horizontal internally finned cylinder. Numerical simulations of full Navier - Stokes equations along with the energy equation have been performed in a laminar range of Ra spanning from 10^4 to 10^8 to analyze the effect of fin height, fin number and cylinder length on the heat transfer from the cylinder. 3-D heat conduction equation is solved in the fin material taking conjugate heat transfer into account while solving the temperature field in the fluid medium, air. Thickness of the cylinder is set to be zero since it is too less compared to the height of the fin and the length of the cylinder. Two independent parameters of fin configuration such as fin number and fin height are considered in a wide range to obtain an exploded effect on the heat transfer while the fin thickness to cylinder diameter was kept constant at 0.01262 for all the cases. Highly conductive aluminum fins were employed to obtain maximum fin efficiency. There are two competitive opposing mechanisms which affect the thermal performance of the cylinder, namely the increase in heat transfer due to the provision of additional surface area with a simultaneous decrease in heat transfer due to the obstruction of

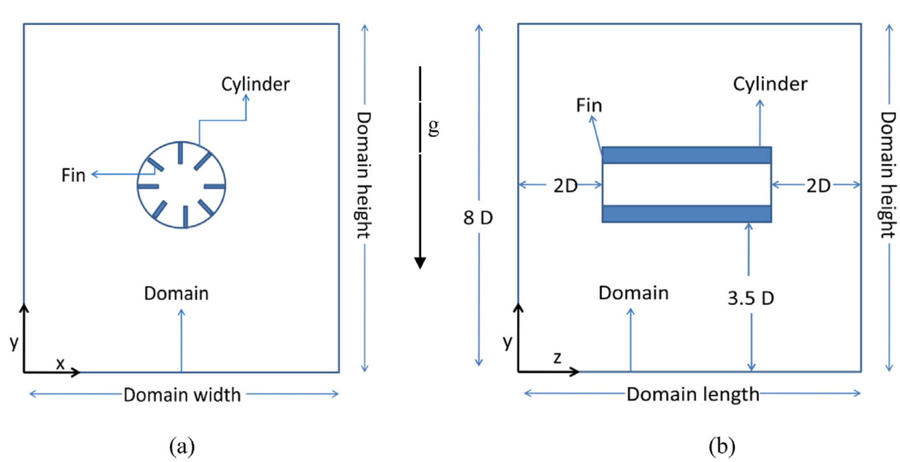

Fig. 1. Schematic representation of a thin hollow horizontal cylinder with internal fins and the computational domain, **(a)** lateral cross section, (b) longitudinal cross section.