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Numerical study of pressure drop and heat transfer from circular and cam-shaped tube bank in cross-flow of nanofluid

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ABSTRACT

Flow and heat transfer of nanofluid inside circular and cam-shaped tube bank is studied numerically. Reynolds number for cam-shaped tube bank is defined based on equivalent diameter of circular tube and varies in range of $100 \leqslant Re_D \leqslant 400$. Nanofluid is made by adding Al_2O_3 nanoparticle with volume fraction of 1–7% to pure water. Results show using nanofluid results in higher heat transfer rate for both circular tube bank and cam-shaped tube bank. Also, staggered arrangement has higher heat transfer for both circular and cam-shaped tube bank. Pressure drop from cam-shaped tube bank is substantially lower than circular tube bank for all range of Reynolds number and volume fraction.

1. Introduction

Flow and heat transfer around tubes have many engineering applications of which it can mention: heat exchanger, cooling tower, HVAC and so on. Using nanofluid in energy system is quite popular for increasing thermal performance and there are many studies related to this subject [1–4]. Xuan and Li [5] studied effects of using nano particles on heat transfer and found that nanofluid has great potential for increasing heat transfer. Hussein et al. [6] investigated effect of tube cross section on friction factor and heat transfer of TiO_2 nanoparticles with water as base fluid. Their results show that flat tube has the highest heat transfer. Hamad [7] studied natural convection of nanofluid from a vertical plate under influence of magnetic field. Hasan [8] numerically investigated flow and heat transfer of nanofluid from a microfin heat sink. His results show that by using nanofluid both pressure drop and heat transfer increase. Wang and Xu [9] adopted combined optimization to find optimal geometric structure for silicon based microchannel heat sink. Ting et al. [10] worked on effect of stream wise conduction on thermal performance of nanofluid in microchannel heat sink.

Heidary and Kermani [11] investigated heat transfer inside a channel with block mounted on bottom wall. They found that mounting these blocks and using nanofluid increase heat transfer. Mansor et al. [12] numerically investigated mixed convection heat transfer from a square lid-driven cavity filled with nanofluid and showed that increasing volume fraction enhances heat transfer. Ahmad and Pop [13] studied mixed convection of nanofluid from a vertical flat plate. Khan and Aziz [14] investigated natural convection of nanofluid over a vertical plate. Their results show that for a fix value of Lewis number, increasing Prandtl number increases friction factor and Nusselt number. Shafahi et al. [15] analytically investigated effect of nanofluid on thermal performance of heat pipes. Ghasemi and Aminssadati [16] found that using nanfluid increases heat transfer inside triangular enclosure. Behzadmehr et al. [17] studied forced convection heat transfer of CuO-water nanolfuid inside circular tube. They found that adding CuO nanoparticle to pure water damped the velocity and energy oscillation.

Hasan and Siren [18] compared thermal performance of circular and oval tubes. Haitham et al. [19] numerically studied flow and heat transfer over bank of flat tubes. They found that from pressure-drop point of view flat tube perform better than circular tube bank with equivalent diameter. Khan et al. [20] analytically investigated convective heat transfer from circular tube bank in cross-flow. Their result showed that compact banks have higher heat transfer rates compare to widely spaced ones. Ibrahim and

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Nomenclature

C	circumferential length (mm)
C_p	Heat capacity (J/kg K)
d	small diameter (mm)
D	large diameter (mm)
D_{eq}	equivalent diameter $D_{eq} = C/\pi$ (mm)
f	friction factor
h	heat transfer coefficient (W m^{-2} K^{-1})
j	Colburn factor $Nu/(Re\,Pr^{1/3})$
k	thermal conductivity (W m^{-1} K^{-1})
L	tube length (cm)
l	distance between centers (mm)
$\dot{m}$	mass flow rate (kg s^{-1})
N_L	number of transverse rows
P	pressure (Pa)
$\dot{Q}$	heat transfer rate (W)
S_L/D_{eq}	longitudinal pitch ratio
S_T/D_{eq}	transverse pitch ratio
Re	Reynolds number ($U_\infty D_{eq}/\upsilon$)
Nu	Nusselt Number (hD_{eq}/k)
T	temperature (K)
u, v	Velocity component in x and y direction (m s^{-1})

Greek

ρ	density (kg m^{-3})
υ	fluid kinematic viscosity (m^2 s^{-1})
μ	Fluid dynamic viscosity (N s/m^2)
ϕ	Volume fraction
θ	Non-dimensional temperature $(T - T_{in})/(T_s - T_{in})$

Subscripts

ave.	average
cam	cam-shaped tube
eq	equivalent
f	fluid
in	inlet
nf	nanofluid
ex	exit
p	nano particles
s	surface
w	water
∞	free stream

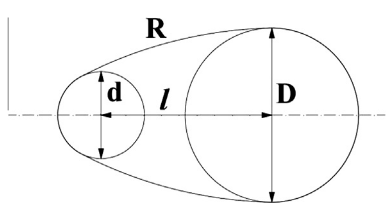

Fig. 1. Schematic of a cam shaped tube.

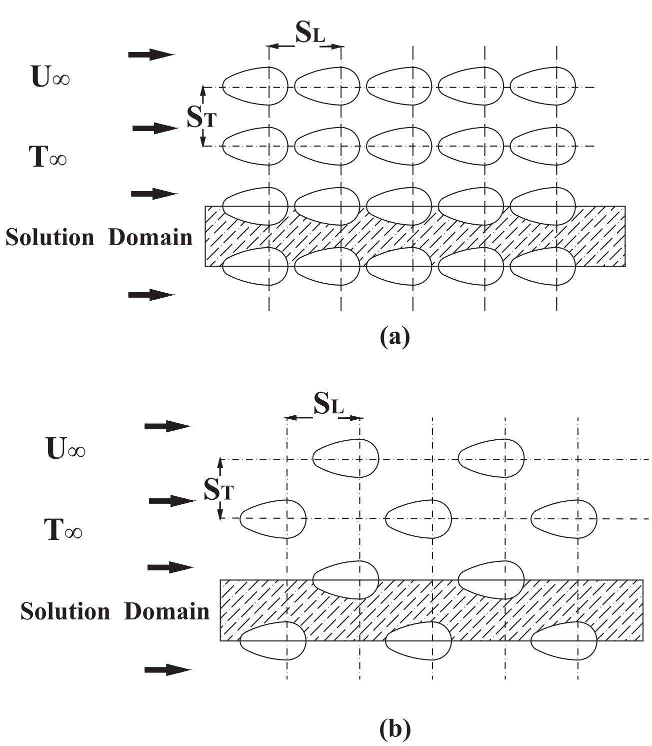

Fig. 2. Cam-shaped tube bank: (a) In-line and (b) staggered.

Gomaa [21] experimentally and numerically measured thermal-performance of elliptic tube bank. Effect of punching curve rectangular vortex generator on heat transfer characteristics of circular tube bank is studied by Gong et al. [22]. Hassan [23] investigated effect of tubes arrangement with condensate inundation on steam flow in small tube bundle. His results show that widening pitch ratio will give steam more penetration in tube nests.

Mirmasoumi and Behzadmehr [24] studied effect of nanoparticle diameter on heat transfer from a horizontal tube and showed that using nanoparticle with smaller diameter will increase heat transfer more than nanoparticle with larger diameter. Kumar et al. [25] reviewed works related to nanofluid in plate heat exchanger. Verma and Tiawari [26] summarized application of nanofluid in solar thermal engineering. Nouri-Borujerdi and Lavasani [27–30] and later Lavasani et al. [31–33] studied flow and heat transfer from cam-shaped tubes in cross-flow of air. They found that cam-shaped tube has higher thermal-hydraulic performance compare to circular tubes.

There were many studies related to flow and heat transfer of laminar flow in channel but few studied flow around tubes. Therefore, in this study focuses on flow and heat transfer from a non-circular tube bank and then compared flow characteristics to circular tube bank in cross-flow of nanofluid.

Table 1
Properties of water and Al_2O_3.

	ρ (kg/m^3)	C_p (J/kg K)	*k* (W/m K)
Pure water	997.1	4179	0.613
Alumina (Al_2O_3)	3970	765	40

Table 2
Comparison of friction factor and average Nusselt number for different grid.

No.	Interval size of node on tube (mm)	Cell No.	f	*Nu*
1	0.1	6460	0.1871	11.5542
2	0.07	9300	0.1844	12.1888
3	0.04	34,800	0.1833	12.2701
4	0.02	66,970	0.1833	12.3417