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# Effect of different nanoparticle shapes on shell and tube heat exchanger using different baffle angles and operated with nanofluid

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ABSTRACT

Nanofluid is a new engineering fluid which could improve the performance of heat exchanger. The aim of this paper is to study the effect of different particle shapes (cylindrical, bricks, blades, and platelets) on the overall heat transfer coefficient, heat transfer rate and entropy generation of shell and tube heat exchanger with different baffle angles and segmental baffle. Established correlations were used to determine the abovementioned parameters of the heat exchanger by using nanofluids. Cylindrical shape nanoparticles showed best performance in respect to overall heat transfer coefficient and heat transfer rate among the other shapes for different baffle angles along with segmental baffle. An enhancement of overall heat transfer coefficient for cylindrical shape particles with 20° baffle angle is found 12%, 19.9%, 28.23% and 17.85% higher than 30°, 40°, 50° baffle angles and segmental baffle, respectively in corresponding to 1 vol.% concentration of Boehmite alumina ($\gamma$-AlOOH). Heat transfer rate is also found higher for cylindrical shape at 20° baffle angle than other baffle angles as well as segmental baffle. However, entropy generation decreases with the increase of volume concentration for all baffle angles and segmental baffle.



## 1. Introduction

Global warming, changes of climate, greenhouse effect, fuel security, high prices of energy and energy losses are now very challenging issues all over the world. These problems are now motivating people to think about energy savings. Energy savings could be done by confirming the efficient use of energy. Eenergy conversion, conservation and recovery are some ways to save energy. To do these, different types of heat exchangers are generally used in all sectors. Different technologies are used to enhance the efficiency of the heat exchanger systems. Increasing of the heat transfer area by using fins and micro channels are ordinarily applied. But, these methods are the reason for bigger and bulky heat exchanger system. Conventional methods i.e.: usage of fins and micro channels have already prolonged to their boundaries [1]. For the higher thermal conductivity of solid particles, the uses of solid particles in conventional fluids are also applied to enhance the heat transfer performance of these fluids. But the problems are fouling, sedimentation and increased pressure drop. The novel invention of nanofluid has provided the possibilities to overcome these problems [2]. Suspension of nanometer size particles (usually below 100 nm) in conventional fluid is called nanofluid. After the discovery of nanofluid, research is going on tremendously on thermal conductivity, different modes of heat transfer and different fundamental properties of nanofluids [3].

Among the available literatures about nanofluids, thermal conductivity is being considered most important thermophysical property of any fluid for heat transfer application. Thermal conductivity is directly related to heat transfer performance of any system. Thermal conductivity of the nanofluid has been studied numerically and experimentally by many researchers. Researchers showed in their experiments that thermal conductivity increases with the increase of volume concentration and temperature [4–6]. The effect of different size and shape of nanoparticles on thermal conductivity of nanofluids is also available in the literature. Although, there are still debate on the effect of particle size of nanofluids thermal conductivity; however, most of the researchers are agreed upon that thermal conductivity decreases with the increase of particle sizes. However, overall performance of the heat exchanger depends on thermal conductivity, viscosity, density and specific heat of the working fluids [7,8].

Most of the research available in the literature about viscosity and density of nanofluids reported that, viscosity and density of nanofluids increases with the increase of volume fractions [9]. Based on existing experimental and theoretical results in the literatures, specific heat of nanofluids decreases with the increase of volume concentration of nanoparticle though there are also some

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**Nomenclature**

| | |
|---|---|
| $A_{cf}$ | cross flow area, m$^2$ |
| $B$ | baffle spacing, m |
| $C_{min}$ | minimum capacity rate |
| $C^*$ | capacity rate ratio |
| $D$ | diameter, m (shell side) |
| $h$ | convective heat transfer coefficient, W/m$^2$ K |
| $n$ | shape factor |
| $N_{TC}$ | total number of tube |
| $k$ | thermal conductivity, W/m K |
| $k_w$ | thermal conductivity of copper wall, W/m K |
| $Pr$ | Prandtl number |
| $q$ | heat transfer rate, kW |
| $T$ | temperature, K |
| $U_o$ | overall heat transfer coefficient, W/m$^2$ K |
| $A_{o,t}$ | tube side flow area per pass, m$^2$ |
| $C_k$ | thermal conductivity ratio |
| $C_{max}$ | maximum capacity rate |
| $C_p$ | specific heat, J/kg K |
| $d$ | diameter, m (tube side) |
| $m$ | mass flow rate, kg/s |
| $NTU$ | number of heat transfer units |
| $Nu$ | Nusselt number |
| $L$ | length, m |
| $P_t$ | square tube pitch, mm |
| $Re$ | Reynolds number |
| $\dot{\delta}_{gen}$ | entropy generation, W/K |
| $u$ | velocity, m/s |

*Greek symbols*

| | |
|---|---|
| $\varepsilon$ | heat exchanger effectiveness |
| $\rho$ | density, kg/m$^3$ |
| Ø | volume fraction |
| $\mu$ | dynamic viscosity, Ns/m$^2$ |
| $\varphi$ | sphericity |
| $\beta$ | baffle angle |

*Subscripts*

| | |
|---|---|
| $b$ | base fluid |
| $fg$ | flue gas |
| $m$ | mean |
| $p$ | particle |
| $t$ | tube |
| $c$ | cold |
| $eff$ | effective |
| $f$ | fluid |
| $e$ | equivalent |
| $nf$ | nanofluid |
| $s$ | shell |
| $o$ | outlet |
| $h$ | hot |

inconsistent results [10]. Zhou and Ni [11], Pak and Cho [12], Pantzali et al. [13] and others showed that specific heat of nanofluids decreases with the increase of volume fraction of nanoparticles.

Nanofluid is deemed potential heat transfer fluid because of its enhanced thermophysical properties which could be applied to heat exchanger [14]. Narrein and Mohammed [15] numerically investigated the heat transfer and fluid flow characteristics of a helical coiled tube heat exchanger operated with nanofluids where various types of nanoparticles ($Al_2O_3$, $SiO_2$, CuO, ZnO) were considered for analysis. Xuan and Li [16] and Li and Xuan [17] examined the heat convection of nanofluids as deionized water with Cu particles in a tube. They found that the convective heat transfer coefficient of the nanofluid was improved by more than 39% compared with the water. Also, this outcome varied with velocity and volume fractions of nanoparticles. Furthermore, Nusselt number was found 60% higher by using nanofluid with 2 vol.% of nanoparticles. Yang et al. [18] experimentally found 22% higher convective heat transfer coefficient by using 2.5 wt.% of graphite nanoparticles in base fluid through a horizontal tube heat exchanger. Zeinali et al. [19] experimentally examined the convective heat transfer of $Al_2O_3$–water nanofluid in a circular tube and found increment in heat transfer coefficients with the increase of the vol.% of nanoparticle. Mohammed and Narrein [20] numerically scrutinized the CuO–water nanofluid through helical coiled tube heat exchanger for parallel and counter flow and acquired "a 34% increment in effectiveness and 29% increment in performance index" for counter flow heat configuration. A comprehensive review was also done by Mohammed et al. [21] on nanoparticle types, properties, heat transfer characteristics and limitation for the application of nanofluid where the effect of nanofluid for micro channel heat exchanger was also analyzed.

Heat exchangers are generally used to transfer thermal energy between two or more media and extensively applied to power engineering, chemical industries, petroleum refineries, food industries and so on [22]. However, shell and tube heat exchangers can be applied in the systems where large and small volume of heat transfer are needed and also can be used in high pressure systems. Therefore, it is widely used in industrial processes and power plants [23]. Farajollahi et al. [24] investigated the effect of dispersing $Al_2O_3$ and $TiO_2$ nanoparticles in water and passed through a shell and tube heat exchanger. The authors found that below 0.3 vol.% of $TiO_2$–water nanofluid shows better heat transfer performance and above 0.3 vol.% of $Al_2O_3$–water nanofluid performs better heat transfer performance at a significant Peclet number.

Studies about the effect of nanoparticle shapes are still scarce. Timofeeva et al. [25] conducted an experimental study on the effect of particle shape on thermal conductivity and viscosity of alumina nanoparticles in water and ethylene glycol nanofluids. Different particle shapes (i.e. blades, platelets, cylindrical, bricks, and spherical) were used during the experiment. Xie et al. [26] reported the first experimental study on thermal conductivity enhancement due to shape of the added nanoparticles into suspension. Murshed et al. [27] conducted an experimental study using cylinder-like (rod) shape particles. Singh et al. [28] studied the effect of silicon carbide (SiC) nanoparticles having a shape like disk or platelet and uniformly dispersed in water on mechanical properties and thermal conductivity enhancement. Zhou and Gao [29] conducted a theoretical study to estimate the thermal conductivity of non-spherical particles in nanofluids using a differential effective medium theory. Several shapes of nanoparticles which have been studied are cylindrical [30], rods [27], and shuttle-like shape [31].

There are also some studies available on the effect of volume fraction [23,32,33] and particle size [34] of nanofluid in heat exchanger systems. Elias et al. [35] investigated the heat transfer and thermodynamic performance of a shell and tube heat exchanger operated with Boehmite alumina ($\gamma$-AlOOH) nanoparticles