SHORT COMMUNICATION

Nanoparticle shape effects on squeezed MHD flow of water based Cu, Al₂O₃ and SWCNTs over a porous sensor surface

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KEYWORDS
Nanoparticle shape factor; Squeezed flow; Sensor surface; SWCNTs; Thermal radiation energy; Magnetic field

Abstract  Impact of nanoparticle shape on the squeezed MHD flow of water based metallic nanoparticles over a porous sensor surface in the presence of heat source has been investigated. In distinctly most paramount studies, three distinctive forms of nanoparticle shapes are employed into account, i.e. sphere (m = 3.0), cylinder (m = 6.3698) and laminar (m = 16.1576). The controlling partial differential equations (PDEs) are regenerated into ordinary differential equations (ODEs) by manipulating consistent conformity conversion and it is determined numerically by handling Runge Kutta Fehlberg method with shooting technique. It is noticed that the solid volume fraction and nanoparticle shape have powerful outputs in squeezing flow phenomena, the sphere shape nanoparticle in Cu – water and cylindrical shape in SWCNTs-water in the presence of magnetic field along with thermal radiation energy has better improvement on heat transfer as compared with the other nanoparticle shapes in different flow regimes.

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1. Introduction

The today problem of squeezing flow bounded by two parallel plates of viscous Newtonian fluid is one of the ideal issues in physics. As long as the technological development and improvement of industries are concerned, the energy and environmental involvements catch the essential aspect. Heat interchange systems must be more skillful and upgrade the heat transfer. Universally, there are many techniques utilized to cultivate the achievement of heat transfer of this mechanism, such as developing the boundary conditions and flow geometry likewise boosting the thermal conductivity of traditional fluid. At the moment, many researchers promote the benefit of nanofluids in a collection of industries and engineering equipment to enhance the energy efficiency and to improve the system’s thermal performance, [1–3]. The most critical physical assets of nanofluids are thermal conductivity that stimulates a necessary act in the reinforcement of energy dynamic heat transfer materials for microelectronics, transportation, energy input/output supply, fabrication, etc. Nanofluid thermal conductivity predicates various parameters such
as nanoparticle concentration, material type, size, shapes and agglomeration.

Recently, the effects of magnetic strength on oscillatory squeezed discharges have been analyzed inside thin films by many authors [4–7] where they show that magnetic strength can decrease flow change abilities inside thin films correlated with immense squeezing issues. Anyhow, the literature absences surveys about the things of the magnetic range on flow and resultantly on thermal and diffusion transfer past a sensor wall sited within fluidic cells accountable to squeezed flow conditions. Nanoparticle research is currently an area of energetic scientific importance due to an extensive cast of possible operations in medical, optical and electrical fields. Squeezing flow within parallel walls has invited fresh researchers and mechanics, [8–11]. There are a lot of informed works about squeezing flow bounded by two parallel plates or disks with the distance developing in time like \( h \sim t^{1/2} \) and among them: [12–16], in which the flow of non-Newtonian fluids in a two- or three-dimensional case is investigated. The significance of such works is essentially associated with alimental, rheological or magnetorheological investigations. Normally, in those works the Navier–Stokes equations in their full scheme with total stress tensor are determined numerically, along with the heat conduction equations.

The unique and excellent views of nanofluids attempt appealing heat transfer properties correlated with traditional heat transfer nanofluids. There are substantial investigations on the remarkable heat transfer resources of nanofluids notably on shape of the nanoparticles, thermal conductivity and convective heat transfer. The increases in effective thermal conductivity of the shape of nanoparticles are important in improving the heat transfer behavior of nanofluids and the number of other variables also plays key roles. Therefore, it is necessary to measure the heat transfer achievement of nanofluids exactly under the shape of the nanoparticles in the nanofluids. The presented literature survey shows that particle shape effects on entropy generation in mixed convection unsteady flow of nanofluids over stretching rotating disk have not yet been addressed. In this study, spherical-, cylindrical-, and disk-shaped particles are taken into account, [17–20]. Furthermore, magnetic nanofluids have much more indication in the numerous scientific and engineering fields. These nanofluids effort to stimulate magnetic fields and thermal energy transfer and hydrodynamic assets. Usually copper, magnetite and aluminum oxide nanoparticles are exhausted in the development of such fluids [21–24]. Recently, Raza et al. [25] investigated the problem of MHD flow and heat transfer of Cu – water in a semi porous channel with stretching walls. It applies a conversion of thermal energy into electromagnetic energy, Kirchhoff’s law, [26]. The most powerful physical characteristic of nanofluids in many employment counting heat exchanger are thermal conductivity [27]. The thermal conductivity improvement of nanofluids can be correlated with different attitudes such as volume fraction, material type, size and shape, [28,29]. Timo-feeva et al. [30] studied an experimental evaluation on the outcome of nanoparticle shape of alumina nanofluids. Distinct particle shapes (i.e. platelets, blades, bricks, cylindrical and spherical) were employed throughout the experiment. Xie et al. [31] predicted the first practical work on thermal conductivity enhancement due to the shape of the admitted nanoparticles into suspension.

Highlighted thermo-physical properties are the prime agreeable characteristics of nanofluids placed on the fact that most solids have much stronger thermal conductivities than natural fluids. Leong et al. [37] analyzed a structure for the effective thermal conductivity of nanofluids regarding the impact of the interfacial layer between particles and fluid. Some investigations [38–48] highly recommend that nanoparticle accretion plays a unique role in the thermal transport in nanofluids. Xuan et al. [38] explained a theoretical design for the effective thermal conductivity of nanofluids by seeing the physical properties of both the base liquid and the nanoparticles, as well as the design of the nanoparticles’ accretion. Hong et al. [39] and Prasher et al. [40] analyzed the impact of the cumulating of nanoparticles on the thermal conductivity of nanofluids. Prasher et al. [41] investigated a three-level homogenization theory to study the impressive thermal conductivity of colloids involving fractal clusters. Keblinski et al. [42] analyzed the impact of clusters in nanofluids at the molecular level, but they did not commit a relevant mathematical explanation. From the raised abrupt review, it is observed that to date a commonly approved expression for the enrichment of thermal conductivity is still not accessible. Zhang and Li [49] analyzed the impact of different shapes of carbon nanotube on heat transfer. Hamzah et al. [50] investigated the impact of thermal radiation energy on squeezed MHD flow of Cu, Al2O3 and CNTs – nanofluid over a sensor surface. It is observed that the water based SWCNTs play a dominant role on heat transfer as correlated with the MWCNTs – water in the flow regime.

Commonly in nanofluid convective heat transfer designing, the nanofluid reflection can be treated in two categories: the single-phase designing which the junctions of nanoparticle and base fluid are assumed as a single-phase mixture with steady properties (joined properties between the nanoparticle and base fluid properties) and the two-phase designing which the nanoparticle assets and attitudes are studied separately from the base fluid properties and attitudes. Göktepe et al. [51] investigated the comparison of single and two-phase models for nanofluid convection at the entrance of a uniformly heated tube. The divergences between the temperature field in the single phase and two-phase designs are stronger than those in the hydrodynamic field. The heat transfer coefficient investigated by the single phase design is raised by accelerating the volume fraction of nanoparticles for all Reynolds numbers while for the two-phase designs, when the Reynolds number is small, enhancing the volume fraction of nanoparticles will increase the heat transfer coefficient in the ahead and the center of the wavy channel, but constantly reduces along the wavy channel.

In this work, we focused on the impact of nanoparticles (Cu, Al2O3 and SWCNTs) shape in the presence of water based unsteady external squeezing MHD nanofluid flow over a flat permeable sensor wall in the existence of thermal radiation energy. The analysis is concerned with certain group of squeezed flows such that the occurring flows may be solved using similarity transformation and afterward the problem is analyzed by applying the fourth or fifth order Runge Kutta Fehlberg technique with shooting method and OHAM. Experimental works have investigated that the nanoparticle shape has a symbolic role on the heat and mass transfer of nanofluids [30,31]. Nanoparticle shapes i.e. sphere, cylinder and laminar, are approved into address in this work. The
parameter confirmation for the problem was executed and is authorized. It is involved that the results will award toward better understanding of nanofluid conflict in channel. Several aspects of the problem are investigated and presented graphically on the account of the physical parameters involved within it and the instant achievements are correlated with the applicable literature.

2. Mathematical analysis

The unsteady two-dimensional MHD squeezing nanofluid flow between two infinite parallel plates is constructed in this work. Natural flow configuration of the aggravation is rooted in such a way that the plate is contained inside a squeezed channel such that the height \( h(t) \) is more advanced than the boundary layer thickness and the squeezing in the free stream is investigated to exit from the edge of the wall as granted in Fig. 1. It is assumed that the height \( h(t) \) is greater than the boundary layer thickness. Micro-cantilever sensor (of length \( L \)) is situated within the walls and the upward wall is depressed while the bottom plate is attached. The lower plate of the channel is fixed at \( y = 0 \) while the upper plate is at \( y = h(t) = h_0/(s + bt)^{1/2} \) (which is squeezing toward the lower plate).

The flow is driven by the external free stream velocity \( U(x, t) \) and the working nanofluid is assigned to be Newtonian and electrically governed with \( \sigma \) as its electrical conductance and the magnetic field with a time-dependent strength \( B_0 \) is excited upright to the flow in the \( y \)-direction while the convinced magnetic Reynolds number is imperceptible. The system of regulating equations is designated [8,9] as

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}
\]

\[
\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -\frac{1}{\rho_{nf}} \left( \frac{\partial p}{\partial x} \right) + \frac{\sigma_{nf} B_0^2}{\rho_{nf} \mu_{nf}} u \tag{2}
\]

\[
\frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \frac{\sigma_{nf}^2}{\rho_{nf} c_{nf}} \frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho_{nf} c_{nf}} \frac{\partial q_f}{\partial y} + \frac{Q_s(T - T_{\infty})}{(pc_{nf})_{nf}} \tag{4}
\]

along with the boundary conditions \( u(x, 0, t) = 0, v(x, 0, t) = v_0(t), -k_{nf} \frac{\partial T(x, 0, t)}{\partial t} = q(x), u(x, \infty, t) = U(x, t), T(x, \infty, t) = T_{\infty} \) (5)

where \( q(x) = q_0 x \) and \( v_0(t) = v_\sqrt{a} \).

\( u, v \) – the velocity constituent in the \( x \) and \( y \) assignments, \( T \) – the temperature of the nanofluid, \( t \) – time, \( p \) – the fluid pressure, \( \sigma_f, \sigma_r \) – the electrical conductivity of the base fluid and the nanofluid, \( v_0(t) \) – (a constant) represents the velocity at the sensor surface when permeable surfaces were considered. Physically, \( v_0 < 0 \) processes injection and \( v_0 > 0 \) signifies suction of the fluid, \( \alpha \) is a constant, and \( Q_0 \) – heat source or sink coefficient. The magnetic Reynolds number is constructed small such that the magnetic boundary-layer thickness is pervasive and the persuaded magnetic field is regularly interacted with the activated magnetic field. For particle-fluid admixtures, several theoretical examinations have been composed evidence back to the classical work of Maxwell. The Maxwell model for thermal energy conductivity for solid-liquid combination of nearly large particles (micro-/mini-size) is good for secondary solid associations. Viscosity describes a fluid constitutional resistance to flow and, in the case of nanofluids, formulates the investigation and size of particles. The authorized nanofluid thermophysical properties are defined as

\[
\sigma_{nf} = \frac{k_{nf}}{(pc_{nf})_{nf}}, \rho_{nf} = (1 - \zeta) \rho_f + \zeta \rho_s, \mu_{nf} = \frac{\mu_f}{(1 - \zeta)\zeta}, (pc_{nf})_{nf} = (1 - \zeta)(pc_{f}) + \zeta(pc_{s})_s, \sigma_{nf} = (1 - \zeta) \sigma_f + \zeta \sigma_s, \frac{k_{nf}}{\rho_{nf}} \tag{6}
\]

where \( \zeta \) – the nanoparticle volume fraction, \( m \) – the nanoparticle shape factor, \( \mu_f \) – the dynamic viscosity of the base fluid, \( \beta_f \) and \( \beta_s \) – the volumetric extension coefficients of the water and nanoparticle, respectively, \( \rho_f \) and \( \rho_s \) – the density of the base fluid and nanoparticle, \( \sigma_f \) and \( \sigma_s \) – the electric conductivity of the base fluid and nanoparticle, \( k_f \) – the thermal conductivity of the fluid, and \( k_s \) – the thermal energy dynamism of the solid fraction. Employing Rosseland’s approximation \( q'_{rad} = q_r = -\frac{d\varepsilon_s}{dt} \frac{\partial \varepsilon_s}{\partial T} \), \( \sigma_s \) – Stefan Boltzmann constant, \( k' \) – penetration coefficient. By Taylor’s series expansion of \( T' \) being \( T' \approx 4T^4_{\infty} - 3 T_4' \), \( \frac{d\varepsilon_s}{dt} = -\frac{16\varepsilon_s T^3_{\infty}}{k_s} \frac{\partial q_r}{\partial T} \). Based on the free-stream conditions, Eqs. (2) and (3) become

![Fig. 1 Flow configuration and coordinate system.](image-url)
\[ \frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = \frac{\partial U}{\partial t} + \frac{\partial U}{\partial x} + \frac{\partial U}{\partial y} - \left( \frac{\mu_{ef}}{\rho_{ef} K_0} + \sigma_{uf} B_0^2 \right) (u - U) \]  
\tag{7}

where \( U \frac{\partial U}{\partial x} = - \frac{1}{\rho_{ef} \partial x} \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) U, K \) - non-uniform permeability of the medium, \( B_0 \) - the externally imposed magnetic strength in the y-direction. The stream function rewarding Eq. (1) with

\[ \nu = \frac{\partial \psi}{\partial y} \quad \text{and} \quad \nu = - \frac{\partial \psi}{\partial x} \]  
\tag{8}

Based on the Eq. (8) with the similarity variables

\[ \eta = \sqrt{\frac{y}{v_s}}, \phi = \sqrt{\alpha y_s^2} f(\eta), a = \frac{1}{s + b} \]
\[ \theta(\eta) = \frac{T - T_0}{\frac{u_s}{\rho_s v_s}} \]  
\tag{9}

\( b, s - \) a random constants, \( a \) - strength of squeezing flow, \( q_0 \) – heat flux, \( v_0 \) – the velocity at the sensor surface when permeable walls are designed. Situated on the conditions explained in Eq. (9), motion of channel’s height is according to the following conditions: \( h(t) = h_0/(s + bt)^{\frac{1}{2}} \) for \( b > 0 \) and \( h(t) = h_0 e^{-at} \) for \( b = 0 \). The surface permeable velocity is confirmed to raise as the time decelerates (\( b > 0 \)) because compressing velocities accelerate as time decelerates.

Eqs. (4) and (7) become

\[ f'' + A1 \left( f^2 + \frac{bn}{\alpha} \right) f' - f^2 + b(f^2 - 1) + \left( \frac{MA^2}{A1} \right) \left( 1 - f^2 \right) = 0 \]  
\tag{10}

\[ \frac{1}{Pr} \left( \frac{k_{ef}}{k_f A3} + \frac{Pr R}{k_f A3} \right) \phi' + \left( \frac{\delta}{A3} \right) \phi + \left( f + \frac{bn}{\alpha} \right) \phi - \left( f + \frac{b}{\alpha} \right) \phi = 0 \]  
\tag{11}

with boundary conditions

\[ f(0) = S, f'(0) = 0, \theta'(0) = - \frac{k_f}{k_{ef}}, f(\infty) \rightarrow 1, \theta(\infty) \rightarrow 0 \]  
\tag{12}

\[ A1 = \left( 1 - \zeta \right)^{2.5} \left( \frac{1 - \zeta + \frac{\rho_s}{\rho_f}}{\sigma_f} \right) \]
\[ A2 = \left( 1 - \zeta \right)^{2.5} \left( \frac{1 - \zeta + \frac{\rho_f}{\rho_s}}{\sigma_s} \right) A3 = \left( 1 - \zeta + \frac{\rho_f}{\rho_s} \right) \left( \frac{\rho_f}{\rho_s} \right) \]  
\tag{13}

\[ Pr = \frac{\rho_s c_p}{\eta} - \text{Prandtl number}, \delta = \frac{\rho_s c_p}{\eta} \] - heat source/sink parameter, \( \zeta = \frac{\eta}{\rho_s c_p} \) - porous parameter, \( M = \frac{k_{ef}}{\eta c_p} \) - magnetic parameter, \( R = 10^6 \frac{\rho_f}{\eta c_p} \) - thermal energy radiation parameter.

Physical quantities are \( C_f = \frac{1}{Re_s^{1/2}} \) - skin friction coefficient, \( Nu_s = \frac{q_s}{k(T_c - T_e)} \) - local Nusselt number where \( T_e \) and \( q_s \) are defined as

\[ C_f(Re_s)^{1/2} = \frac{f'(0)}{(1 - \zeta)^{2.5}}, \quad \frac{Nu_s}{Re_s^{1/2}} = \frac{k_{ef}}{k_f} \]
\[ \text{Re}_s = \frac{S}{\nu} \] - The local Reynolds number.

3. Results and discussion

Estimation are completed by the OHAM-Optimal Homotopy Analysis Method (analytical mechanism) and the fourth or fifth order Runge Kutta Fehlberg technique with shooting approach (numerical mechanism) for different values of parameters. Eqs. (10) and (11) manipulated to the boundary settings (12) have been resolved numerically and experimentally utilizing computer software Maple 18 and Mathemtica 5.2. In mathematics, the Runge–Kutta–Fehlberg method (or Fehlberg method) is an algorithm in numerical analysis for the numerical solution of ordinary differential equations. It was developed by the German mathematician Erwin Fehlberg and is based on the large class of Runge–Kutta methods. The constructed algorithm controls both the error and the time step size simultaneously and possesses a good performance in the computational cost compared to the original method. Eqs. (10) and (11) elaborated to the boundary settings (12) have been determined numerically and experimentally applying computer software Maple 18. The values of \( x \) and \( \beta \) are determined upon solving the boundary conditions \( \nu(0) = x \), and \( \rho(0) = \beta \). Once \( x \) and \( \beta \) are determined, the system will be closed and can be solved numerically again by DSolve subroutine to get the final results. Consequently, only one integration path is enough to solve the problem instead of consuming the time with iteration techniques such as the shooting method. Finally this computation we have pretended \( Pr = 6.2 \) corresponds to nanofluids unless otherwise stated. In order to confirmed our methods, it is observed from Fig. 2 that the compromised with the theoretical result of the temperature profiles and \( f'(0) \) for various character of the \( \zeta \) are interacted with Fig. 4b and Table 2 (water based Cu and Al2O3 when \( \zeta = 0.0 \)) of Rizwan et al. [9]. A very admirable agreement can be noticed between them. Thermophysical characteristics of fluid and the nanoparticles are given in Table 1.

**Nanoparticle shapes**

(i) The sphere and lamina shape \( m = 3.0, 16.1576 \) Cu-water in the presence of heat source (\( \delta = 1.0 \)) plays a dominant role on temperature distribution with increase of nanoparticle volume fraction.

(ii) The sphere and lamina shape Al2O3-water with (\( \delta = 1.0 \)) acts an effective lead on temperature distribution with increase in nanoparticle volume fraction.

(iii) The sphere and cylinder shape SWCNTs Cu-water (\( \delta = 1.0 \)) shows a powerful aspect on temperature distribution with increase in nanoparticle volume fraction.
Fig. 2  Comparison of nanoparticle volume fraction on temperature profiles, Fig. 4a and b of Haq et al. [9] with $f_0 = S = -0.5, b = 0.5$.

Table 1  Thermophysical properties of the fluid and nanoparticles, [32–35].

<table>
<thead>
<tr>
<th>Fluid/Solid</th>
<th>Density ($\rho$) ($\text{kg/m}^3$)</th>
<th>Specific heat ($cp$) ($\text{J/kg K}$)</th>
<th>Thermal conductivity ($k$) ($\text{W/m K}$)</th>
<th>Electrical conductivity ($\sigma$) ($\text{S/m}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure water</td>
<td>997.1</td>
<td>4179</td>
<td>0.613</td>
<td>5.5</td>
</tr>
<tr>
<td>Copper (Cu)</td>
<td>8933</td>
<td>385</td>
<td>401</td>
<td>59.6</td>
</tr>
<tr>
<td>Alumina Al$_2$O$_3$</td>
<td>3970</td>
<td>765</td>
<td>40</td>
<td>16.7</td>
</tr>
<tr>
<td>SWCNTs</td>
<td>2600</td>
<td>42.5</td>
<td>6600</td>
<td>1.26</td>
</tr>
</tbody>
</table>

Table 2  Comparison of nanoparticle volume fraction on skin friction coefficient $Re^{+}C_f$.

<table>
<thead>
<tr>
<th>Nanofluids</th>
<th>Parameter</th>
<th>Numerical method</th>
<th>OHAM [9]</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\zeta$</td>
<td>$Re^{+}C_f$</td>
<td>$Re^{+}C_f$</td>
<td>Num. and OHAM</td>
</tr>
<tr>
<td>Cu-water</td>
<td>0.0</td>
<td>0.866523</td>
<td>0.86652956</td>
<td>0.0000000044</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>1.094550764</td>
<td>1.094550764</td>
<td>0.000000236</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>1.406041874</td>
<td>1.406041874</td>
<td>0.000000126</td>
</tr>
<tr>
<td>Al$_2$O$_3$-water</td>
<td>0.0</td>
<td>0.866523</td>
<td>0.866522956</td>
<td>0.000000044</td>
</tr>
<tr>
<td></td>
<td>0.1</td>
<td>1.058063845</td>
<td>1.058063845</td>
<td>0.000000155</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>1.321152956</td>
<td>1.321152956</td>
<td>0.000000044</td>
</tr>
</tbody>
</table>
(iv) In the existence of heat source, it is realized that the sphere shape nanoparticles in the water based Cu, Al2O3 and SWCNTs perform a powerful role on the temperature profiles as compared with the other shapes (cylinder \((m = 6.3698)\) and laminar \((m = 16.1576)\)) in the squeezed flow regime with increase in nanoparticle volume fraction. Fig. 3. The temperature distribution of \(\zeta = 0.1\) and \(\zeta = 0.2\) for SWCNTs – water is more energetic than that of Cu-water and Al2O3 - water.

Fig. 3 Volume fraction and shapes of the nanoparticle effects on the temperature profiles with \(\delta = 0.0\) and \(\delta = 1.0\) with \(\zeta = 0.01, M = 1.0, Pr = 6.2, R = 0.5, b = 0.5\).
3.2. Analysis of thermal radiation energy and shape of the nanoparticles, Fig. 4

(i) The sphere shape \((m = 3.0)\) Cu-water in the presence of thermal radiation energy \((R = 2.0)\) shows an effective role on temperature distribution with increase in nanoparticle volume fraction.

(ii) The sphere and cylinder shape \((m = 3.0, 6.3698)\) Al2O3-water with \((R = 2.0)\) acts a principal lead on temperature distribution with increase in nanoparticle volume fraction.

(iii) The cylinder shape SWCNTs-water with \((R = 2.0)\) shows a prevalent effects on temperature distribution with increase in nanoparticle volume fraction.

(iv) The analysis of the results obtained shows that the sphere shape nanoparticles in the SWCNTs-water nanofluid squeezed flow field are impressed remarkably by the combined effect of the thermal conductivity and heat capacitance of the SWCNTs-water nanofluid as correlated with the other mixtures in the squeezed flow regime.

3.3. Analysis of squeezed parameter, and shape of the nanoparticles, Fig. 5

(i) The cylinder shape \((m = 6.3698)\) Cu-water with squeezed parameter \((b = 1.0)\) plays a leading role on temperature distribution with increase in nanoparticle volume fraction.

(ii) The sphere \((m = 3.0)\) and lamina shape \((m = 16.1576)\) Al2O3-water with \((b = 1.0)\) enacts a dominant role on temperature distribution with increase in nanoparticle volume fraction.

(iii) The lamina shape \((m = 16.1576)\) SWCNTs-water with \((b = 1.0)\) emotes a predominant role on temperature distribution with increase in nanoparticle volume fraction.

(iv) In the potentiality of thermal radiation energy and squeezed parameter, it is stimulating to notice the sphere shape nanoparticles in the presence of Cu-water and Al2O3-water whereas the cylinder shape nanoparticles in the residence of SWCNTs-water act an effective role on temperature distribution with increase in nanoparticle volume fraction.

3.4. Analysis of magnetic effects and shape of the nanoparticle volume fraction, Fig. 6

(i) The sphere shape Cu-water in the presence of magnetic field \((M = 1.0)\) dramatizes an important impact on temperature distribution with increase in nanoparticle volume fraction.

(ii) The sphere shape Al2O3-water with \((M = 1.0)\) displays an efficient effect on temperature distribution with increase in nanoparticle volume fraction.

(iii) The sphere shape SWCNTs-water with \((M = 1.0)\) plays an essential aspect on temperature distribution with increase in nanoparticle volume fraction.

(iv) In the attendance of magnetic field, it is noted that the sphere shape nanoparticles in the subsistence of water based Cu, Al2O3 and SWCNTs show an exceptional lead on temperature distribution with increase in nanoparticle volume fraction.

It is interesting to notice that the squeezed water based Cu, Al2O3 and SWCNTs in the presence of porous sensor surface play an important role on oscillating temperature profiles, Göpel and Schierbaum [36].

3.5. Analysis of rate of heat transfer, Table 3

(i) In the case of sphere shape nanoparticles, the rate of heat transfer firstly enhances and then reduces in the presence of water based Cu and SWCNTs while the rate of heat transfer decelerates in Al2O3-water nanofluid with increase in nanoparticle volume fraction.

(ii) Cylindrical shape nanoparticles, the rate of heat transfer of the water based Cu, Al2O3 and SWCNTs increase with increase in nanoparticle volume fraction.

(iii) Laminar shape nanoparticles, the rate of heat transfer firstly decreases and then increases in the presence of Cu-water whereas it firstly raises and then degrades in the presence of Al2O3-water nanofluid with increase in nanoparticle volume fraction.

(iv) It is concluded that the cylindrical shape nanoparticles in the presence of SWCNTs-water hit a principal portrayal on heat transfer rate as correlated with the other mixtures in the flow system with increase in nanoparticle volume fraction.

(v) It is interesting to note that the rate of heat transfer of all the three nanoparticle shapes in the presence of the water based Cu, Al2O3 and SWCNTs increases with increase in magnetic strength as shown in Table 3.

4. Conclusion

Performance of nanoparticle shapes (sphere, cylinder and laminar) in the presence of water based on Cu, Al2O3 and SWCNTs is examined between squeezing surfaces in such a form that the top plate is compressed. Association of temperature with the rate of heat transfer among the nanofluids with different nanoparticle shapes is presented in terms of Figures and Tables. Completion notes of the concurrent outcomes are as follows:

- The sphere shape SWCNTs-water with heat source, \(\delta = 1.0\) plays a powerful aspect on temperature distribution whereas the cylinder shape SWCNTs-water attains its maximum and minimum value in the squeezed flow regime over a sensor surface with increase in nanoparticle volume fraction. The sphere \((m = 3.0)\) shape in the presence of squeezed Al2O3-water enacts a dominant role on temperature distribution with increase in nanoparticle volume fraction.
- In the capability of thermal radiation energy, the sphere shape nanoparticles in the presence of Cu-water and Al2O3-water whereas the cylindrical shape nanoparticles in the settlement of SWCNTs-water perform an energetic
Fig. 4 Volume fraction and shapes of the nanoparticle effects on the temperature profiles with $R = 0.0$ and $R = 2.0$ with $\zeta = 0.01, M = 1.0, Pr = 6.2, \delta = 0.5, b = 0.5$. 
Fig. 5 Volume fraction and shapes of the nanoparticle effects on the temperature profiles with $b = 0.0$ with $\zeta = 0.01$, $M = 1.0$, $Pr = 6.2$, $R = 0.5$, $b = 0.5$. 
Fig. 6 Volume fraction and shapes of the nanoparticle effects on the temperature profiles with $M = 0.0$ and $M = 1.0$ with $\zeta = 0.01$, $\delta = 1.0$, $Pr = 6.2$, $K = 0.5$, $b = 0.5$. 
impact on temperature distribution with increase in nanoparticle volume fraction. It is interesting to note that the cylinder shape SWCNTs-water with \( R = 2.0 \) shows a prevalent effect on temperature distribution with increase in nanoparticle volume fraction because of high thermal conductivity of SWCNTs, Table 1.

- The sphere shape nanoparticles in the existence of water based Cu, Al\(_2\)O\(_3\) and SWCNTs with the magnetic strength \( M = 1.0 \) display a remarkable advantage on temperature distribution whereas the thermal boundary layer thickness of sphere shape nanoparticles in the SWCNTs-water is more significant compared with the other mixtures in the flow regime with increase in nanoparticle volume fraction. Particularly, the sphere shape SWCNTs-water with \( M = 1.0 \) plays an essential aspect on temperature distribution with increase in nanoparticle volume fraction.

- The temperature distribution of sphere shape nanoparticles in Cu-water with heat source, \( \delta = 1.0 \), Cu-water with heat source, \( \delta = 1.0 \), and magnetic strength, \( M = 1.0 \) while cylindrical shape nanoparticles in Al\(_2\)O\(_3\)-water with squeezed parameter, \( b = 1.0 \) at the nanoparticle volume fraction, \( \xi = 0.01 \), attain its maximum and minimum value in the squeezed flow regime over a sensor surface.

- The sphere shape nanoparticles in the subsistence of Cu-water with magnetic strength \( M = 1.0 \) have a significant change in the rate of heat transfer as compared to the other shape of the nanoparticles in the attendance of Cu-water with increase in nanoparticle volume fraction. The squeezed water based Cu, Al\(_2\)O\(_3\) and SWCNTs in the presence of porous sensor surface play an important role on oscillating temperature profiles, Göpel and Schierbaum [36].

The thermal conductivity of the SWCNTs-water in the presence of cylindrical shape plays a powerful act on the temperature field as compared with the other shapes in the water based Cu and Al\(_2\)O\(_3\). As a result, the sphere/cylindrical shape nanoparticles in the presence of Cu/SWCNTs-water nanofluid are more promising in terms of increasing the heat transfer performance of the squeezed flow regime over a sensor surface. It is demonstrated that the sphere shape nanoparticles in the water based Cu and cylindrical shape nanoparticles in SWCNTs-water are investigated in this paper can be beneficial in energy systems, rheology, material processing, lubrication and biomedical applications.

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**References**


