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**ARTICLE**

**Natural convection of a the power-law nanofluid in a square cavity with a vertical fin**

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**ABSTRACT**

The behavior of non-Newtonian power-law nanofluids under free convection heat transfer conditions in a cooled square enclosure equipped with a heated fin is investigated numerically. In particular, the impact of nanofluids, composed of water and , , and nanoparticles, on heat transfer enhancement is examined. The aim of this research is also to analyze the influence of different parameters, including the Rayleigh number (), nanoparticle volume fraction (), non-Newtonian power-law indexes (), and fin dimensions (,0.5, and 0.7). Streamlines and isotherms are used to depict flow and related heat transfer characteristics. Results indicate that thermal performance improves with increasing Rayleigh number, regardless of the nanoparticle type or nanofluid rheological behavior. This suggests that the buoyancy force has a significant impact on heat transfer, particularly near the heat source. The Nusselt number is more sensitive to variations in Cu nanoparticle volume fractions compared to and . Moreover, the average Nusselt numbers for power-law nanofluids with () are greater (smaller) than for Newtonian fluids due to the decrease (increase) in viscosity with increasing (decreasing) shear rate, at the same values of Rayleigh number Ra owing to the amplification (attenuation) of the convective transfer. Notably, the most substantial enhancement is observed with Cu-water shear-thinning nanofluid, where the Nusselt number increases by 136% when changing from Newtonian to shear thinning behavior and by 154.9% when adding 16% nanoparticle volume fraction. Moreover, an even larger increase of 57% in the average Nusselt number is obtained on increasing the fin length from 0.3 to 0.7.

**KEYWORDS**

Heat DDA transfer; nanofluid; non-Newtonian fluid; natural DMA convection

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**Nomenclature**

Aspect ratio

Fin’s dimension,

Specific heat at constant pressure, ·)

Gravitational acceleration,

Thermal conductivity,

Cavity length,

M The consistency coefficient

Power law index

Nu Nusselt number

Mean Nusselt number

P Dimensionless pressure

p Pressure,

Ra Rayleigh number

Pr Prandtl number

T Temperature,

u,v Velocity components,

U,V Dimensionless velocity components

x,y Cartesian coordinates,

X,Y Dimensionless Cartesian coordinates

**Greek letters**

*φ* Nanoparticle volume fraction

*β* Coefficient of volume expansion,

*τ* Shear stress, Pa

*ρ* Density,

*α*  Thermal diffusivity,

*µ* Dynamic viscosity,

*Ѳ* Dimensionless temperature

Velocity and thermal boundary-layer thickness, m

*ψ* Dimensionless stream function

**Greek letters**

cold

hot

effective

fluid

Particle

nanofluid

**1 Introduction**

Free 10 s, 15 s, 20 s, and 25 s convection appendix heat formula (1) transfer in 10 min , 15 min, 20 min square 10 s enclosures is largely used in numerous 10 s, 15 s engineering applications such as heat exchangers, buildings, built-in-storage solar collectors and thermal management of electronics [1].ref Researchers have expressed significant concern regarding the enhancement of heat transfer in free convection due to its inherently low heat transfer coefficient refs. Consequently, they actively explored diverse techniques and concepts to improve the ref heat transfer in this process. One of those techniques that researchers frequently focus on is adding nanoparticles to the conventional working fluid. The addition of nanoparticles enhances the thermophysical properties of the base fluid, particularly thermal conductivity, a pivotal parameter that improves the heat transfer mechanisms [2,3,4,5,6]. Therefore, the single-phase model was largely employed due to its simplicity and computational efficiency, making it suitable for diluting nanofluids with low nanoparticle concentrations. However, its simplicity may lead to inaccuracies, as it oversimplifies complex nanofluid behavior and neglects nanoparticle interactions [7]. The two-phase model, initiated in 2006 by Buongiorno, offered a deeper insight into the movement of nanoparticles into the base fluid. Alsabery et al. [8] have concluded in their review that the high computational cost of the two-phase models has limited the adoption of the model of single-phase among researchers. As a result, only 19% of nanofluid studies have opted for the two-phase approach.

**2 Modelling and mathematical formulation**

The square cavity Fig. 1 is enclosed by two vertical walls cooled to a temperature of and two horizontal walls that are adiabatic. A heated fin with dimensionless variable length () is vertically positioned at the cavity’s midpoint, kept at an elevated temperature . The enclosure contains water-based nanofluid incorporating nanoparticles of , , or , assumed as a laminar and incompressible Boussinesq power law model, with a Prandtl number () set at 6.2. Assuming thermal stability between the water-based fluid and nanoparticles, with no slip occurring due to their thermophysical properties as listed in Table 1. Under these conditions and according to the nanofluid model suggested by Tiwari and Das [29,30], continuity, momentum, and energy equations, in laminar incompressible nanofluid may be expressed in their nondimensional form for the numerical solution as follows [24, 27,28,31,32].

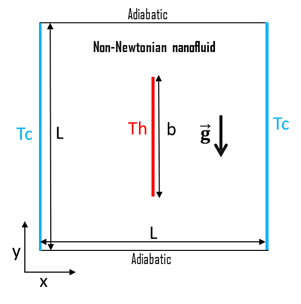


Figure 1: Some functions DDA of

Some relationships are conducted to clarify how Rayleigh number, Prandtl number, and power-law index influence the Nusselt number for the model of power-law fluids [18].

where the hydrodynamic and thermal boundary-layer thicknesses, and , are related by this expression: in which denotes a function of Rayleigh number, Prandtl number, and power-law index. A positive correlation with increasing Prandtl number is expected.

**3 Numerical methodology and validation**

Numerical solutions for the Eqs. (1 – 4), considering the initial and boundary conditions (17), were computed employing COMSOL, a partial differential equations (PDEs) solver that utilizes the Galerkin weighted residual finite element approach is adapted. The flow is laminar and the fluid is assumed to be incompressible. The computational domain was subdivided to triangular elements, and various orders of triangular Lagrange finite elements were employed to represent the various flow variables throughout the computational domain. To handle the non-linear terms present in momentum equations, Newton iterative method was employed for simplifications.

Furthermore, another comparison of the is made among the current work and the one of Turan et al. [18] for various n and , at and is represented in Table 3. The results agree well with those of Turan et al. [18], for the highest error of no more than 0.61% recorded for and

**4 Results and discussion**

Fig. 3 illustrates the changes of the mean Nusselt number () with the volume fraction () of , , and nanoparticles, considering various values of Rayleigh number () and power-law index (). The examination of this figures shows that for all nanoparticles types, the mean Nusselt number has an upward trend as the nanoparticle volume fraction increases, this trend can be caused by the fact that raising this parameter enhances the thermal fluid conductivity, thereby resulting in an improvement in the energy transported by the nanofluid. Additionally, it also improves with the rise in () and a decrease in the (). This reduction results in an amplification of the heat flux magnitude at the vertical walls.

It is apparent from Fig. 8 that as the n value increases (decreases), the intensity decreases (increases) because of a decrease (increase) in convective transport strength relative to the resistance from the viscous flow. It is important to highlight that in the case of pseudoplastic or shear-thinning behavior, their reduced viscosity at higher shear rates allow for better flow and mixing within the fluid. This enhanced flow can facilitate the dissipation of heat from hot regions to cooler regions, resulting in a more uniform temperature distribution. This aspect underscores the favorable effect of shear-thinning heat transfer behavior, providing insights into the fluid dynamics that contribute to the observed heat transfer enhancements in the system.

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Fig. 10 shows that, at a constant and , the reduces with a higher index of power law () and smaller fin dimension (). The impact of the fin's dimension is more pronounced for shear-thinning nanofluids compared to Newtonian and even more so compared to shear-thickening nanofluids. The highest is seen for shear-thinning nanofluid and , this combination yields the most efficient convective heat transfer under the specified conditions. These findings emphasize the significance of both rheological properties and fin geometry in influencing heat transfer efficiency within the cavity.

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Description générée automatiquement

**Figure 10:** the chennai DDA bala number. the *DDA* in *bala* at *various* , , at , for nanofluid.

**5 Conclusions**

In the current study, heat transfer by free convection for , and power-law nanofluid in a square enclosure with the presence of a vertical fin was carried out. This study covered the relevant parameters within the following ranges: the index of power-law (), , the volume fractions ("φ"=0-20% ) and the dimensions of the fin ().

In summary, the improvement of heat transport in the square enclosureis represented by the increment of the . It enhances with the decrease for index of power law, which speeds up the flow because of the reduction of the viscosity of the fluid, the increase of which causes the change of the heat transport mechanism from conductive to convective, the rise of nanoparticles volume fractions and the enlargement of the vertical fin.

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**Conflicts of Interest:** The authors declare that they have no conflicts of interest to report regarding the present study.

**Availability of Data and Materials:** Should a request be made for data used in the study, the authors will endeavor to make the information available.

**Author Contributions:** The authors confirm contribution to the paper as follows: study conception and design: A. M’hadbi, H. Ben Hamed; numerical validation: A. M’hadbi, K. Chtaibi; data collection: A. M’hadbi; analysis and interpretation of results: A. M’hadbi, M. El Ganaoui, A. Guizani; draft manuscript preparation: A. M’hadbi. All authors reviewed the results and approved the final version of the manuscript.

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