MIXED CONVECTION IN A LID-DRIVEN ENCLOSURE FILLED WITH HYBRID NANOFLUID BY FINITE VOLUME METHOD

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DEDICATION

To my inspiration and my support (God). To the pulse of my soul and my heart, my (mother). To the master of my life and my beloved (Ali). To a flower of the heart and my eternal love for my (son).

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ABSTRACT

The heat transfer process in complex geometries is essential due to its wide range of industrial and engineering applications. Understanding fluid flow patterns and convection heat transfer will give scientists or engineers the idea to manipulate the process to achieve the desired results. For the past decade, researchers reported that nanofluid enhances heat transfer and fluid flow. With rapid development in engineering, scientists and engineers have begun to study the fluid flow and heat transfer pattern of hybrid nanofluids. However, there are still many gaps to be filled in. This study will simulate the steady mixed convection flow in a single or double lid-driven cavity filled with hybrid nanofluid (Al_2O_3-Cu-water). The fluid is assumed to be Newtonian and laminar. The flow is two-dimensional and incompressible. Nanoparticles are assumed in a spherical shape. Firstly, the fluid flow pattern and heat transfer behavior on mixed convection in a lid-driven square cavity filled with hybrid nanofluid with cold sidewalls was studied. The bottom wall was uniformly heated, while the top wall was adiabatic. Mixed convection in a double lid-driven horizontal rectangular cavity filled with hybrid nanofluid was determined in the second problem. Non-uniform heating distribution on both horizontal walls was studied in the third problem. Finally, the inclined magnetic field's influences and cavity on mixed convection in a lid-driven rectangular cavity-filled hybrid nanofluid were analyzed. The dimensionless governing equations were formulated by using appropriate reference variables. These equations were solved using the finite volume method. The convection-diffusion terms were discretized using the power-law scheme, while the pressure and velocity components were coupled using the SIMPLE algorithms. The resultant matrices were then solved iteratively using the Tri-Diagonal Matrix Algorithm coded in FORTRAN90. The present solutions obtained were then compared with previous studies, and a good agreement was found. The numerical results were presented in the forms of isotherm and streamline. The results show that the flow circulation strength is enhanced by the hybrid nanofluid addition due to the hybrid nanoparticles' higher thermal conductivity compared with the nanofluids.

ABSTRAK

Proses pemindahan haba dalam geometri komples adalah sangat penting kerana penggunaannya oleh aplikasi dalam bidang kejuruteraan dan industri yang meluas. Memahami corak aliran bendalir dan pemindahan haba perolakan akan memberi idea kepada sainstis atau jurutera untuk memanipulasi proses tersebut bagi mencapai hasil yang diinginkan. Selama berdekad yang lalu, para penyelidik melaporkan bahawa bendalir nano meningkatkan pemindahan haba dan aliran cecair. Dengan perkembangan pesat dalam bidang kejuruteraan, saintis dan jurutera telah mula mempelajari aliran bendalir dan corak pemindahan haba bendalir nano kacukan. Walau bagaimanapun, masih ada banyak jurang yang harus diisi. Kajian ini akan mensimulasikan aliran perolakan campuran mantap dalam rongga dengan satu atau dua penutup yang bergerak yang dipenuhi dengan bendalir nano kacukan (Al_2O_3-Cu-air). Bendalir tersebut dianggap sebagai Newtonian dan lamina. Alirannya adalah dua dimensi dan tak termampatkan. Partikel nano diandaikan berbentuk sfera. Pertamanya, corak aliran bendalir dan tingkah laku pemindahan haba pada perolakan campuran dalam rongga bersegi empat yang dipenuhi bendalir nano kacukan dengan dinding sisi yang sejuk telah dikaji. Dinding bawah dipanaskan secara seragam sementara dinding atas tertebat. Perolakan campuran dalam rongga segi empat tepat mendatar dengan penutup bergerak berganda dipenuhi dengan bendalir nano kacukan telah dikaji pada masalah kedua. Pemanasan secara tidak seragam pada kedua-dua dinding melintang telah dikaji pada masalah ketiga. Akhir sekali, kesan medan magnet dan rongga yang condong pada aliran perolakan campuran dalam rongga segi empat tepat dengan satu dinding bergerak dipenuhi bendalir nano kacukan dianalisis. Persamaan menakluk tak bermatra telah dirumuskan dengan menggunakan pemboleh ubah rujukan yang sesuai. Persamaan tersebut diselesaikan menggunakan kaedah isipadu terhingga. Sebutan perolakan-resapan didiskritkan menggunakan skema hukum kuasa sementara komponen tekanan dan halaju digabungkan menggunakan algoritma SIMPLE. Matriks yang dihasilkan telah diselesaikan secara tertelar dengan menggunakan Algoritma Matrik Tiga Penjuru dan dikodkan dalam FORTRAN90. Penyelesaian yang diperoleh telah dibandingkan dengan kajian yang terdahulu dan mendapat keputusan yang baik.

Keputusan berangka dibentangkan dalam bentuk isoterma dan garis arus. Hasil kajian menunjukkan bahawa kekuatan peredaran aliran ditingkatkan dengan penambahan bendalir nano kacukan kerana kekonduksian terma bendalir nano kacukan yang lebih tinggi berbanding dengan bendalir nano.

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LIST OF SYMBOLS

a	-	power law expressions
A	-	dimensionless coefficient of Peclet number
b	-	simplified variable
CV	-	control volume
D	-	diffusion conductance
E	-	electric field
f	-	element of body force
F	-	body force
F	-	general force
g	-	gravitational acceleration, m/s^2
Gr	-	Grashof number
h	-	heat transfer coefficient
J	-	total fluxes
J_E	-	current density
L	-	length of the rectangular cavity, m
m	-	number of grid point in x- direction
M	-	mass flow
n	-	number of grid point in y- direction
$\overline{Nu}$	-	average Nusselt number
Nu_x	-	local Nusselt number
p	-	pressure, Pa
$\mathcal{P}$	-	dimensionless pressure

$\wp$ - Peclet number

Pr - Prandtl number

Re - Reynolds number

Ri - Richardson number

T - temperature, ^{0}C

u , v - velocities in the $x -$ and $y -$ direction respectively

U , V - dimensionless velocity in $X -$ and Y – direction respectively

$U_{\circ}$ - lid velocity, m/s

V - velocity vector

x , y - Cartesian coordinates

X , Y - dimensionless Cartesian coordinates

d_f - molecular diameter of water

l_f - path of fluid particles

k_b - Boltzmann constant $k_b = 1.380648 \times 10^{-23}(J/K)$

Re_B - Brownian motion Reynolds number

T_0 - reference temperature $(310K)$

u_B - Brownian velocity of the nanoparticle

Greek Letter

α - thermal diffusivity

β - thermal expansion coefficient

γ - magnetic field inclination angle

ε - amplitude ratio

θ - dimensionless temperature

μ - dynamic viscosity

ν - kinematic viscosity

ρ	-	density
υ_f	-	kinematic viscosity of the fluid (m^2/s)
Ω	-	phase deviation
ϕ	-	general variable
Φ	-	dissipation
φ	-	solid volume fraction
ω	-	cavity inclination

Subscripts

b	-	bottom
c	-	cold
f	-	fluid
h	-	hot
l	-	left
r	-	right
nf	-	nanofluid
hnf	-	hybrid nanofluid
t	-	top
∞	-	reference state

Superscripts

$\circ$	-	old value
$*$	-	guess value
$'$	-	correction value

LIST OF PUBLICATIONS

1. I.R. Ali, Ammar I. Alsabery, N.A. Bakar and Rozaini Roslan "Mixed Convection in a Double Lid-Driven Cavity Filled with Hybrid Nanofluid by Using Finite Volume Method" Symmetry 12, no. 12 (2020). https://doi.org/10.3390/sym12121977. (ISI) (Impact factor 2.645)

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CHAPTER 1

INTRODUCTION

1.1 General introduction

Considering the expansive scope of uses, such as greasing system polymer processing, chemical processing apparatus, hydrodynamic machinery, building ventilation, electronic hardware, the investigation of natural convection, forced and combined convection heat transfer and fluid momentum has been regarded as one of the most important research topics. Moreover, during recent years, many studies have focused on heat transfer mixed convection in cavities due to its widish applications in industry, such as electronic refrigeration devices, food storage, and lubrication technologies Morzynski and Popiel (1988). Despite its wide applications, its convection heat transfer performance has been characterized by its poor adequacy due to the low thermal conductivity of the convection fluid. To improve the heat transfer properties of the liquid, numerous numerical and experimental investigations have been performed utilizing different methods such as the use of extended surfaces including fins, microfins, vortex flow devices, jet impingement, electromagnetic field, ultra-high thermal conductivity composite materials, and phase-change devices. Moreover, there are different methods to improve the effectiveness of heat transfer.

In general, there are two groups of technologies for intensifying heat transfer. The first set of technologies is required for external energy input by mechanical vibration, rotation, mixing, and addition of external magnetic or electrostatic field, which has been utilized effectively to improve heat and mass transfer. However, external power inputs are expensive and difficult under compacted situations. In the second group of techniques, the heat transfer magnification can be attained by modifying fluids property by adding nanoparticles, surface shape changes, surface area enhancement, and disorder. Geometric shapes play an adequate role in controlling the velocity of flow and heat distribution in the region. From a convection standpoint, flows over rotating or stationary surfaces are important for the thermal design of different types of industrial equipment, such as nuclear waste disposal cans, rotating heat exchangers, nuclear reactor cooling systems, rotating stable rockets, and geothermal tanks. In the ongoing past decades, many researchers have been interested in obtaining solutions to the problems of the thermal transfer phenomenon that occur in fluid dynamics, plasma physics, aerodynamics, and meteorology utilizing various procedures. One of these is the numerical techniques used to predict flow behaviors and heat transfer performance. In this study, the mixed convection with hybrid nanofluids (Al_2O_3-Cu-water) in a lid-driven cavity was studied. The bottom wall was maintained at temperatures T_h and vertical walls were maintained at temperatures T_c and adiabatic. The effects of the magnetic field, inclination angle, and sinusoidal heating method on the flow field were investigated.

In the next sections, the topic of heat transfer with hybrid nanofluids is introduced, focusing on mixed convection. In the current study, the dimensionless non-linear partial differential equations subjected to the given boundary conditions were solved numerically.

1.2 Fluid mechanics

The liquid state in physics and chemistry is one of the three states related to thermodynamics, along with the gaseous state and the solid-state. A liquid is a fluid that has a constant volume at temperature and pressure, which takes the shape of the container it contains. The liquid also applies pressure to the surface of the container in the same way that the liquid applies pressure to anything inside. Liquids tend to have better thermal conductivity than gases, and the ability to flow makes a liquid suitable for removing excess heat from mechanical components Vargaftik (1993). Also, the fluid is known as a substance that continuously deforms (flows) under the action of shear stress. Liquids can be divided into two stages, liquids, and gases. The gas is constantly expanding and occupying the full volume of any container Cohen (2010). The density of a gas is much less than that of a liquid. As a result, force and pressure are found in fluid mechanics where the weight of any type of fluid plays an important role compared to the weight of a gas Massey (2006).

Fluid mechanics is the branch of physics that deals with the mechanics of fluids (liquids, gases, and plasmas) and the forces they exert on them. It has applications in a wide range of disciplines, including mechanical, civil, chemical, and biomedical. Engineering, geophysics, oceanography, meteorology, astrophysics, biology, including those containing computing forces and moments on aircraft, limiting the volume flow measurement of petroleum through pipelines, forecasting weather models, comprehending nebulae in interstellar space, and modeling fission weapon detonation. Some of its laws are even employed in traffic engineering, where traffic is considered as a continuous fluid.

It can be divided into fluid statics, the study of fluids at rest, and fluid dynamics, the study of the effect of forces on the movement of fluids. Streeter and Wylie (1979) It is a branch of continuum mechanics, a subject that models matter without using the information that it is made of atoms; that is, it models matter from a macroscopic rather than a microscopic point of view. Fluid mechanics, especially fluid dynamics, is an active field of research, typically mathematically complex. Many problems are totally or partially unsolved and are best approached by numerical methods, usually using computers. A modern discipline, called computational fluid dynamics (CFD), is dedicated to this approach nature of the fluid flow. As shown in Figure 1.1.

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