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The Influence of Thermophysical Properties on The Heat and Flow Characteristics of a Nano-Lubricant Based on Aluminum Oxide

Olojede, M.A., Itabiyi, O. E., Sangotayo, E.O,
Department of Mechanical Engineering, Ladoke Akintola University of Technology, Ogbomoso, Nigeria,

Muraina, A. B.,
Department of Work and Maintenance, Bells University of Technology, Ota, Ogun State, Nigeria,

Akinrinade, N.A.,
Department of Mechanical Engineering, Bells University of Technology, Ota, Ogun State, Nigeria,

Sulaiman A. O.
Department of Aeronautics and Astronautics Engineering, Kwara State University, Malete, Kwara, Nigeria.,

Abstract—
The potential of nano-lubricants to improve heat transfer and flow characteristics in a variety of engineering applications has motivated a significant amount of interest in the study of their thermophysical properties in recent years. This paper examined the influence of thermophysical properties, including thermal conductivity, viscosity, density, and specific heat capacity, on the heat and flow behavior of aluminum oxide (Al_2O_3)-based nano-lubricants that are flowing through a cylindrical channel.
The governing equations for momentum and energy were converted to non-dimensional form and solved using a finite difference scheme that was implemented in C++. The analysis examined the impact of thermal conductivity ($0.3<\kappa<1.5$), viscosity ($0.001<\mu<0.3$), density ($998< \rho <3592$), heat capacity ($1100 < Cp < 4200$), and the Eckert number ($1.0<Ec<40.0$) on the heat and flow characteristics of the Alumina Nanolubricant while maintaining Reynolds number of 100.
The findings revealed that the modified nanofluid exhibits improved thermal conductivity as a result of the integration of Al_2O_3 nanoparticles into a base lubricant. This results in improved heat dissipation and temperature distribution along the channel walls. The flow dynamics are also influenced by the altered viscosity of the Nanolubricant, which affects the coefficient of drag friction, stream function, and circulation.
The results demonstrated that the heat transfer effectiveness is significantly improved by the inclusion of Al_2O_3 nanoparticles, while the flow characteristics are simultaneously altered. Consequently, the Al_2O_3-based Nanolubricant is an attractive option for use in thermal management systems, heat exchangers, and automotive systems,

Keywords— **Nanolubricants, Aluminum Oxide (Al_2O_3), Thermophysical properties, Heat transfer, Flow dynamics, Cylindrical channel.**

I. INTRODUCTION

Nanofluid is an attractive heat transfer medium for increased heat transfer applications, owing to its superior thermal conductivity and rheological properties [1]. The incorporation of millimeter or micrometer-sized particles into the base fluid modifies its thermophysical properties, thereby enhancing heat transfer [2]. The utilization of nanofluids in several fields has been enabled by their unique characteristics, such as improved heat transfer efficiency and heightened stability and the use of nanoparticles enhances the efficacy of the base fluid compared to standard fluids [3]. Nanofluids enhanced the thermal performance of heat sinks for cooling electronic processors by augmenting the heat transfer rate and efficiency [4]. Nanofluid applications are primarily categorized into two groups: heat transfer and non-heat transfer applications. Nanofluids are utilized as coolants in industries like aerospace, automotive, and electronics for high-temperature applications [5]. The higher thermal conductivity of nanofluids has resulted in improved HT performance and reduced energy usage [6]. The utilization of nanofluids is a rapidly growing domain with potential applications across various sectors. Nanofluids are advantageous substitutes for traditional fluids owing to their unique characteristics. Currently, research focuses on improving their performance for various applications in heat exchangers and nanofluids influence particle sedimentation and their stability within the domain of heat exchangers [4] .
Nanofluids, NFs are fluids engineered to contain suspended nanoparticles and this suspension enhances the nanofluid's characteristics, including augmented thermal conductivity and heat transfer efficiency. NFs can improve medicine delivery to targeted areas in the body, enhance solar cell efficiency, and optimize heating and ventilation system performance [7]. Non-fungible tokens (NFTs) represent an innovative technology with the capacity to revolutionize various industries in the future and a variety of nanofluids are produced through the amalgamation of base fluids (BFs) and nanoparticles, such as Copper Oxide (CuO), Alumina, Silver (Ag), Zinc Oxide (ZnO), Titanium Dioxide (TiO_2), Iron Oxide (FeO), Magnesium Oxide (MgO), Cerium Oxide (CeO_2), and Gold Nanoparticles (Au). Common base fluids may encompass bio-fluids, ethylene glycol, and other coolants and lubricants [8].
The understanding of the thermophysical characteristics of nanofluids is crucial for forecasting their heat transfer behaviour and the inclusion of nanoparticles, which have distinct thermophysical properties, unequivocally modifies the

thermophysical characteristics of conventional working fluids. Thermal conductivity, viscosity, specific heat capacity, and density constitute the thermophysical properties of nanofluids. The thermal conductivity of nanofluids is affected by various factors, including particle size, shape, and composition, along with base fluid, additives, and temperature. The thermal conductivity of nanofibers is the most thoroughly investigated characteristic in the existing literature and NFs are differentiated from traditional BFs by their superior thermal conductivity and other novel thermophysical properties [9].

In addition to numerical studies, numerous experimental studies have been conducted by various researchers to examine the thermal conductivity of NFs using various varieties of BFs. The impact of dispersant concentration and other parameters, including temperature, mass fraction, and standing duration, on the thermal conductivity of CNT-nanofluid. They discussed and observed the temperature range of 20–60 °C and the humidity range of 0–7%, respectively. The thermal conductivity of the NF increased as the temperature increased, as demonstrated by Shahsavar et al. [10]. Numerous theoretical studies have been conducted by a variety of researchers to investigate the variations in the thermal conductivity of NFs [11, 12]. In recent decades, there has been a significant amount of research conducted on the viscosity (μ) of nanofluids due to their potential applications in a variety of industrial and medical sectors. Several factors, including the type, concentration, size, and surface characteristics of NPs, as well as the type of BFs, influence the viscosity of NFs. Moreover, the viscosity of NFs is also influenced by the temperature, with a decrease in viscosity as the temperature increases [13].

Saeedinia and Razi [14] conducted an investigation into CuO-oil-based NF and tested particle weight concentrations ranging from 0.2 to 2% at temperatures between 293 and 343 K. The results revealed that viscosity increases with nanoparticle concentration, notably at lower nanofluid temperatures. Li & Zou [15] deliberated on the performance benefits of utilizing two conventional HT fluids by combining 60% water and 40% EG in an energy system. The temperature decreases and the fluid behaves similarly to a Newtonian fluid. Ibrahim et al. [16] employed HNFs, which are synthesized by suspending a variety of nanoparticles in a combined form. To enhance heat transmission and pressure drop, the hybrid nanofluid balances the advantages and disadvantages of each suspension. Klazly and Bogn [17] suggested a correlation that was standardized to the dynamic viscosity of the BFs. The specific heat capacity (Cp) of the NFs significantly influences the rate of heat transfer.

Sekhar and Sharma [18] developed an equation using water-based nanofluid data (CuO, Si, and Ti). Nanofluid Cp decreased as particle concentration increased as a result of thermal diffusivity. In comparison to the use of pure water as the working fluid, the thermal efficacy of a flat plate solar collector was enhanced by 1.0 vol%, and entropy generation was reduced by the nanodiamond NFs, as investigated by Alklaibi et al. [19]. The efficacy of nanofluid heat transfer is influenced by density, a thermophysical property. The flow parameter and friction factor are influenced by density; therefore, it is necessary to assess and implement it in HT. The nanoparticles' increased mass is the primary cause of the NFs' increased density. The overall density of the nanofluid can be considerably increased by the addition of NPs, which have a significantly higher density than the majority of BFs [20].

The influence of thermophysical characteristics and viscous dissipation on the heat transfer and flow of nanofluids in a moving cylindrical isothermal pipe was analyzed using a numerical approach by Sangotayo [21]. The research indicated that enhanced heat capacity, density, thermal conductivity, and viscous effects elevate fluid temperature, whilst reduced viscosity and thermal conductivity optimize flow patterns. The initiative seeks to improve researchers' comprehension of boundary layer thermal dynamics by utilizing nanofluid as a heat transfer medium in isothermal engineering processes such as boiling and condensation. Itabiyi et al. [22] studied the impact of nanoparticle concentration on the thermophysical properties and heat transmission of aluminum oxide (Al_2O_3) nano-lubricants in a cylindrical channel. The findings revealed that increasing the quantity of Al_2O_3 nanoparticles enhances the thermal conductivity and heat transfer capability of the lubricant. Sangotayo and Hunge [23] presented the impact of nanoparticle concentration on thermophysical characteristics and convective heat transfer in a square cavity filled with CuO nano-fluid. The study examined the property patterns and energy distribution of nanofluid at different nanoparticle concentrations ($0 \leq \varphi \leq 0.9$). Nanoparticle volume concentration has a significant impact on heat distribution, and nanofluid density, viscosity, thermal conductivity, and thermal diffusivity increase with nanoparticle volume concentration, while specific heat capacity decreases with volume fraction concentration.

The objective of this study is to numerically analyze how thermophysical properties, including thermal conductivity, viscosity, density, and specific heat capacity coupled with viscous dissipation affect the heat and flow behavior of aluminum oxide (Al_2O_3)-based nano-lubricants that are flowing through a cylindrical channel. The simulation findings will provide useful information about the appropriate thermophysical attributes for improved heat transmission Specifically, this study examined the influence of thermal conductivity, viscosity, and specific heat capacity on Nusselt number and drag coefficient which enhance the advancement of effective heat transfer systems foundation on Al_2O_3 nano-lubricants for diverse industrial uses.

II. MATERIALS AND METHODS

A. Numerical Model

Figure 1 shows the two-dimensional laminar boundary layer flow of an incompressible Newtonian fluid with viscous fluid on the cylinder's surface. The surface temperature is greater than the free stream temperature and water contains Aluminum oxide nanoparticles. Laminar natural convection heat transport was simulated in a saturated H_2O-Al_2O_3 nanofluid vertical cylinder. Free circulation and fluid motion relative to the solid surface come from density change-induced buoyancy and the momentum field accounts for buoyancy forces as body forces. These conditions link continuity, momentum, and energy equations. The thermophysical properties stated in Table 1 are considered to be constant [24].

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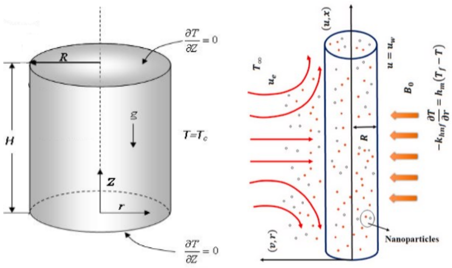

Figure 1: Geometrical configuration, boundary conditions, and coordinate system

B. Governing Equations

The governing mathematical equations were resolved under the following conditions: fluid incompressibility, laminar flow, no internal heat inputs, two-dimensional flow, the Boussinesq approximation, and thermal equilibrium between water and nanoparticles. The current model proposes a laminar, incompressible, viscous-free flow that is constant and two-dimensional. Gravity acts vertically downward, but radiation is disregarded. Mass and momentum conservation formulae are flow-regulating formulae over the continuum [25, 26].

The continuity formula is expressed in Eq. (1)

$$\frac{\partial \rho}{\partial t}+\frac{1}{r}\frac{\partial(\rho r v_r)}{\partial r}+\frac{1}{r}\frac{\partial(\rho v_\theta)}{\partial \theta}+\frac{\partial(\rho v_z)}{\partial z}=0 . \quad (1)$$

R and Z Navier-Stokes equations are Eq. (2) and Eq. (3).

$$\rho\left(\frac{\partial v_r}{\partial t}+v_r\frac{\partial v_r}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_r}{\partial \theta}+v_z\frac{\partial v_r}{\partial z}-\frac{v_\theta^2}{r}\right) =-\frac{\partial p}{\partial r}+\mu\left[\frac{\partial}{\partial r}\left(\frac{1}{r}\frac{\partial}{\partial r}(r v_r)\right)+\frac{1}{r^2}\frac{\partial^2 v_r}{\partial \theta^2}+\frac{\partial^2 v_r}{\partial z^2}-\frac{2}{r}\frac{\partial v_\theta}{\partial \theta}\right]+\rho g_r \quad (2)$$

$$\rho\left(\frac{\partial v_z}{\partial t}+v_r\frac{\partial v_z}{\partial r}+\frac{v_\theta}{r}\frac{\partial v_z}{\partial \theta}+v_z\frac{\partial v_z}{\partial z}\right) =-\frac{\partial p}{\partial z}+\mu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v_z}{\partial r}\right)+\frac{1}{r^2}\frac{\partial^2 v_z}{\partial \theta^2}+\frac{\partial^2 v_z}{\partial z^2}\right]+\rho g_z \quad (3)$$

Equation (4) provides the formula for thermal energy exchange

$$\rho_{nf}(c_p)_{nf}\left(u\frac{\partial T}{\partial r}+v\frac{\partial T}{\partial z}\right)=k_{nf}\left(\frac{\partial^2 T}{\partial r^2}+v\frac{\partial^2 T}{\partial z^2}\right). \quad (4)$$

The nanofluid heat capacity $(c_p)_{nf}$, density, ρ_{nf}, thermal expansion coefficient, β_{nf}, and thermal diffusivity, α_{nf} are expressed in Eq. (5-11), [27, 28, 29].

Equation (5) provides an approximation of the nanofluid's effective thermal conductivity

$$\frac{k_{nf}}{k_f}=\frac{k_{cu}+2k_f-2\varphi(k_f-k_{cu})}{k_{cu}+2k_f+\varphi(k_f-k_{cu})} \quad (5)$$

Table 1: Water-Al_2O_3 Nanofluid's Thermophysical Characteristics

	DENSITY (KGM^{-3})	HEAT CAPACITY (J/KG^{-1}K^{-1})	THERMAL CONDUCTIVITY (WM^{-1}K^{-1})	THERMAL EXPANSION (K^{-1})	VISCOSITY
H_2O	997.1	4179	0.613	21X10^{-5}	9.09X10^{-5}
AL_2O_3	3880	773	36	2.43X10^{-5}	2.0

This equation only applies to spherical nanoparticles and does not address other nanoparticle shapes. This model is appropriate for studying nanofluid-enhanced heat transfer [6–10]. Eq.(6) provides the viscosity of the nanofluid [29].

$$\mu_{nf}=\mu_f(1-\varphi)^{-2.5} \quad (6)$$

Equation (7) is the formula for the nanofluid's density [10]

$$\rho_{nf}=(1-\varphi)\rho_f+\varphi\rho_{cu} \quad (7)$$

Equation (8) expresses the nanofluid's heat capacitance [28, 29]

$$(\rho c_p)_{nf}=(1-\varphi)(\rho c_p)_f+\varphi(\rho c_p)_{cu} \quad (8)$$

The nanofluid's thermal expansion coefficient is written in Eq (9) [29]

$$(\rho\beta)_{nf}=(1-\varphi)(\rho\beta)_f+\varphi(\rho\beta)_{cu} \quad (9)$$

Eq. (10) provides the nanofluid's thermal diffusivity [29]

$$\alpha_{nf}=\frac{k_{nf}}{(\rho c_p)_{nf}} \quad (10)$$

C. Analytical Techniques and Solution Schemes

Hyperbolic, elliptic, or parabolic partial derivative formulae are Navier-Stokes equations. The pressure gradient between equations (2) and (3) was eliminated using the vorticity-stream technique. Equation (11) illustrates the vortex scattering transport expression by employing the continuity concept from equation (1).

$$\omega=\frac{\partial v}{\partial r}-\frac{\partial u}{\partial z} \quad \mathbf{(11)}$$

The dimensional vorticity transmission equation is given in equation (12)

$$u\frac{\partial \omega}{\partial r}+v\frac{\partial \omega}{\partial z}=-\beta g\frac{\partial T}{\partial r}+\upsilon\left(\frac{\partial^2 \omega}{\partial r^2}+\frac{\partial^2 \omega}{\partial z^2}\right) \quad (12)$$

Equation (13) utilizes stream function derivatives to define velocity in two-dimensional cylindrical dimensions.

$$u=\frac{\partial \psi}{\partial z}, \quad v=-\frac{\partial \psi}{\partial r} \quad (13)$$

Equation (14) offers the Poisson formula when substituted in Eq.(11)

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$$\omega = -\left(\frac{\partial^2\psi}{\partial r^2} + \frac{\partial^2\psi}{\partial z^2}\right) \quad (14)$$

The transport equation, energy equation, and operational conditions were converted to a non-dimensional notation for a variety of physical parameters, using L, U_W, (T_w - T_∞), $\psi_W L$, and ω_W / L respectively for length, velocity, temperature, stream function, and vorticity as shown in Eq.(15) [23]

$$Z = \frac{z}{L},\quad R = \frac{r}{L},\ V = \frac{v}{U_w},\quad U = \frac{u}{U_w},$$
$$\theta = \frac{(T - T_\infty)}{(T_w - T_\infty)},\ \Omega = \frac{\omega}{U_w/L},\quad \Psi = \frac{\psi}{U_w L}, \quad (15)$$

Eq. (16–19) provides the normalized equations for the R- and Z-velocity components, vortex shedding, stream constituent, and energy transport:

$$U = \frac{\partial\varphi}{\partial Z},\quad V = -\frac{\partial\varphi}{\partial R} \quad (16)$$

$$\omega = -\frac{\partial^2\varphi}{\partial Z^2} - \frac{\partial^2\varphi}{\partial R^2} \quad (17)$$

$$U\frac{\partial\omega}{\partial Z} - V\frac{\partial\omega}{\partial R} = Ra\Pr\frac{\beta_{nf}}{\beta_f}\frac{\partial\theta}{\partial Z} + \frac{\mu_{nf}}{\rho_{nf}\alpha_{nf}}\left(\frac{\partial^2\omega}{\partial Z^2} + \frac{\partial^2\omega}{\partial Z^2}\right) \quad (18)$$

$$U\frac{\partial\theta}{\partial Z} - V\frac{\partial\theta}{\partial R} = \frac{\alpha_{nf}}{\alpha_f}\left(\frac{\partial^2\theta}{\partial Z^2} + \frac{\partial^2\theta}{\partial Z^2}\right) \quad (19)$$

Where μ is dynamic viscosity, k is thermal conductivity, Ra is Rayleigh number, Gr is Grashof number, Re is Reynolds number, Pr is Prandtl number and Cp is specific heat capacity,

Non-dimensional border conditions are:

$$\Omega \neq 0;\ V = 0;\ \Psi \neq 0;\ \theta = U = 1 \text{ at } Z = 1;\ 0 \le R \le 1;$$

$$U = \Psi = \theta = V = 0;\ \Omega \neq 0;\ at\ Z = 0;\ 0 \le R \le 1;$$

$$V = \theta = U = \Psi = 0;\ \Omega \neq 0\ at\ R = 0;\ 0 \le Z \le 1;$$

$$\Psi = \frac{\partial U}{\partial R} = \frac{\partial\theta}{\partial R} = \frac{\partial V}{\partial R} = 0;\ \Omega \neq 0 \text{ at } R = 1;\ 0 \le Z \le 1.$$

One of the most effective problem-solving techniques for nonlinear energy transport and vorticity formulae (18) and (19) is the finite difference approach. The concurrent system of equations was assessed by utilizing heat transmission and relaxation between a fluid and a surface, which resulted in a temperature gradient that was proportional to the neighboring Nusselt quantity, as illustrated in Eq. (20) [30].

$$Nu_x = \frac{h r_x}{k} = -\left(\frac{\partial\theta}{\partial Z}\right)_{Z=1} \quad (20)$$

Eq. (20) is the enclosed Nusselt number across the heated contact space yields the usual Nusselt quantity as shown in Eq. (21) [30].

$$N\bar{u} = \frac{\dot{Q}_{conv}}{\dot{Q}_{cond}} = -\int_0^1 \left.\frac{\partial\theta}{\partial Z}\right|_{Z=0\ or\ 1} dR \quad (21)$$

The Rayleigh number (Ra_{nf}) of the nanofluid was determined using Equation (22) and the Grashof number (Gr_{nf}) was determined using Equation (23). The Buoyancy factor (BF_{nf}) was determined using Equation (24). [29, 30]

$$Ra_{nf} = \frac{g\beta_{nf}H^3}{\alpha_{nf}\mu_{nf}} \quad (22)$$

$$Gr_{nf} = \frac{Ra_{nf}}{\Pr_{nf}} \quad (23)$$

$$BF_{nf} = \frac{Gr_{nf}}{\sqrt[3]{\text{Re}}} \quad (24)$$

The temperature and vortex fields were established following the conditions for stable flow, as illustrated in Eq. (25) [23]:

$$\frac{\sum_{i=2}^{N}\sum_{j=2}^{M}\left|\phi_{ij}^{n+1} - \phi_{ij}^{n}\right|}{\sum_{i=2}^{N}\sum_{j=2}^{M}\left|\phi_{ij}^{n+1}\right|} < \delta \quad (25)$$

The variable ϕ denotes Ω, Ψ or θ, and n refers to the number of iterations required for convergence of the outcomes. The value utilized varies between 10^{-3} and 10^{-8} in distinct forms of literature (Sangotayo and Hunge, 2020)

III RESULTS AND DISCUSSIONS

Figure 2 shows the results of estimating the local Nusselt number at different convergence factor values (ranging from 10^{-1} to 10^{-8}), to evaluate the effect of the convergence standard on numerical results. According to Sangotayo and Hunge [23], grid independence studies reveal that a 41 by 41 grid layout is sufficient for excellent numerical solutions, field precision, and high accuracy. The results imply a convergence factor of 10^{-4}.

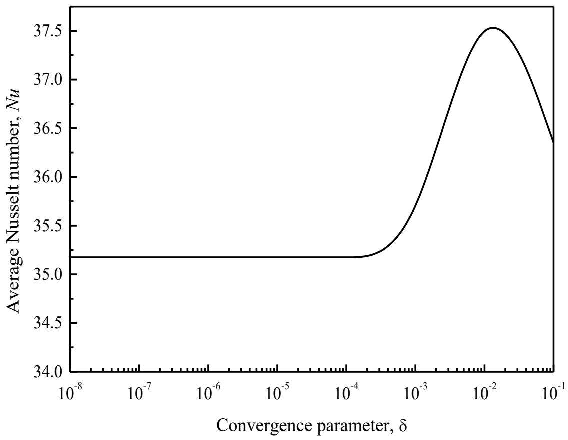

Fig. 2. A graph of the mean Nusselt number, Nu, versus convergence variable. δ

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Fig. 3 shows how changing the nanoparticle sizes and the Eckert number, Ec between 1 and 40 affects the Nusselt number. The Nusselt values increase with the increase in Eckert values. As Ec increases, the Nusselt number (Nu) increases, which suggests that the convective heat transfer process is more efficient. Additionally, the convective heat transfer coefficient and the temperature gradient near the wall increase. The Nusselt number (Nu) increases as the size of the nanoparticles decreases from 0.5 to 0.0, which suggests that convective heat transfer is improved. Additionally, the convective heat transfer coefficient increases and the thickness of the thermal boundary layer diminishes. Comprehending the impact of nanoparticle size and Ec on Nu is essential for the design of effective heat transfer systems.

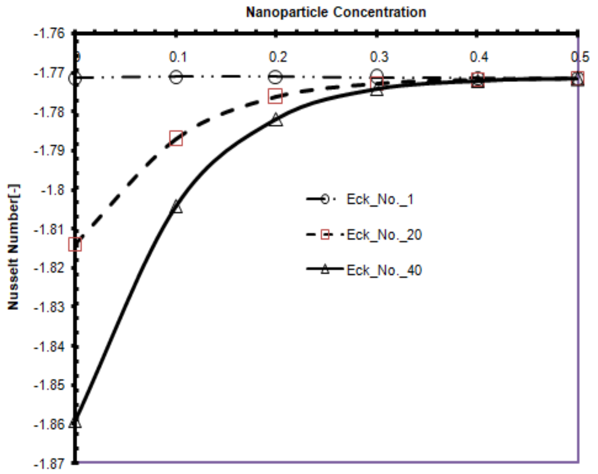

Fig. 3 The influence of altering the nanoparticle sizes and Eckert number on the Nusselt number

Figure 4 illustrates the impact of varying density and Eckert number on the Nusselt number. As density escalates from 1000 to 2100, the Nusselt number diminishes, signifying enhanced conductive heat transmission. Fluids with lower density exhibit less viscosity, hence enabling fluid motion and improving convective heat transfer. The trends of the Nusselt Number (Nu) demonstrate that Nu rises with increasing Ec, signifying enhanced heat transfer efficiency and that Nu also increases as density diminishes, indicating superior convective heat transfer. The convective heat transfer coefficient rises with increasing Ec, whereas decreasing density and viscous dissipation (Ec) affect heat transmission mechanisms.

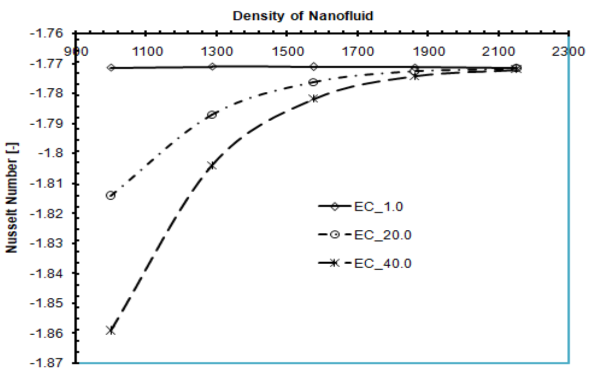

Fig. 4 Plot of Nusselt Number versus density

Figure 5 illustrates the effect of varying the viscosity of nanofluid on the local drag coefficient. The local drag coefficient diminishes as the nanoparticle percentage increases. The local drag coefficient decreases as the viscosity increases, owing to the higher viscosity imparted by the nanoparticles to the base fluid. The reduction of the local drag coefficient (CD) with increased viscosity of nanofluid appears contradictory, yet it is observed that as viscosities increase, the flow shifts from turbulent to laminar, hence diminishing drag forces. The elevated viscosity improves particle dispersion, reducing aggregation and drag. Certain nanofluids display non-Newtonian characteristics, wherein increased viscosity diminishes drag. Hence reducing velocity gradients and drag. It is corroborated by Hwang et al. [31]and Pouranfard et al. [32]

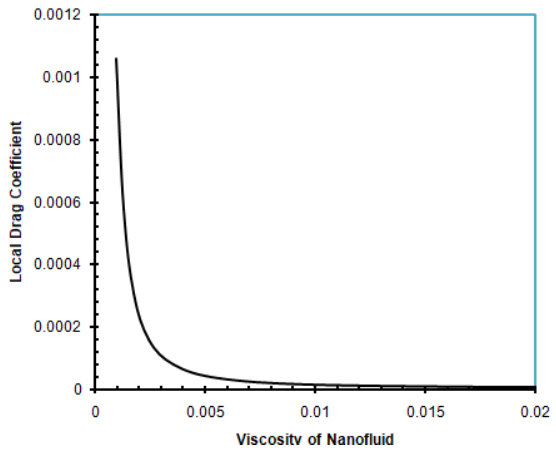

Fig. 5 Plot of Local Drag Coefficient versus Viscosity of Nanofluid

Figure 6 demonstrates the effect of changing the nanofluid's viscosity, which ranges from 0.0009 to 0.0035, and the Eckert number on the Nusselt number. Increasing nanofluid viscosity (μ) and lowering Eckert number (Ec) result in a decrease in Nusselt number (Nu). As fluid flow decreases, the viscosity (μ) increases. Higher viscosity limits fluid velocity, hence reducing convective heat transfer. Eckert number (EC) lower Ec means that viscous dissipation is minimized, resulting in less kinetic energy being converted into thermal energy. Lower Ec minimizes fluid friction, hence reducing heat transmission. Lower Ec can increase fluid velocity, but the reduced viscosity effects take precedence.

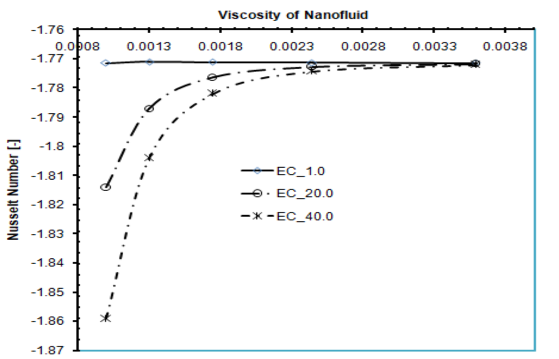

Fig. 6 Plot of Nusselt Number versus Viscosity

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Figure 7 depicts the effect of varying the nanofluid density from 1000 to 2400kg/m^3 on the local drag coefficient (CD). A reduction in the local drag coefficient (CD) occurs with an increase in the density of nanofluid under particular conditions: Elevated density amplifies the momentum of the fluid, diminishing velocity fluctuations and drag. Higher-density nanofluids provide enhanced kinetic energy, facilitating smoother flow and reducing turbulence. Density-induced alterations in boundary layer thickness diminish drag forces. Particle-particle interactions intensify increasing density, and reducing clustering and drag. As nanoparticle size increases, the density of the nanofluid elevates due to a higher mass percentage of nanoparticles and increased nanoparticle aggregation, leading to a larger effective particle size.

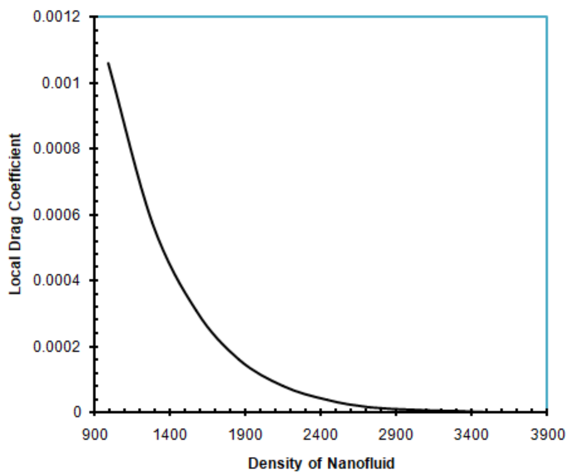

Fig. 7 Plot of Local Drag Coefficient versus Density of Nanofluid

Figure 8 illustrates the impact of altering the nanofluid density from 1000 to 2400kg/m^3 and the Eckert number on the Nusselt number (Nu). The decrease in the Nusselt number (Nu) with rising density (ρ) of nanofluid and decreasing Eckert number (Ec). Increased density results in decreased fluid velocity, hence diminishing convective heat transfer and increased density amplifies fluid inertia, diminishing flow fluctuations and heat transmission and it was a collaboration by Said et al.[20]. Reduction of Eckert Number (Ec) means reduced viscous dissipation: A lower Ec signifies less viscous dissipation, resulting in less kinetic energy being transformed into thermal energy. A decreased Ec results in reduced fluid friction, hence minimizing heat transfer, and a lower Ec diminishes turbulence, hence minimizing heat transfer.

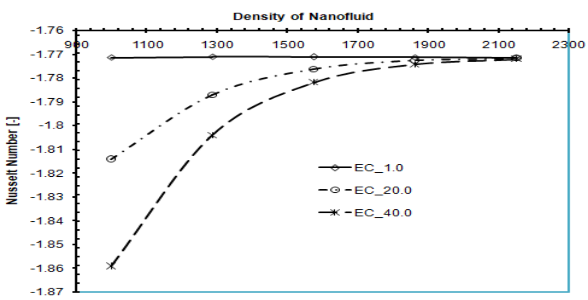

Fig. 8 Plot of Nusselt Number versus density and Eckert number

Figure 9 depicts the impact of varying the thermal conductivity of the nanofluid from 0 to 0.5 and the Eckert Number (Ec) on the Nusselt number. The decrease in the Nusselt number (Nu) with rising thermal conductivity (k) and diminishing Eckert number (Ec). It implies that elevated thermal conductivity (k) lessens temperature disparities, hence reducing convective heat transfer and enhanced thermal conductivity increases thermal diffusion, diminishing the necessity for convective heat transfer. A higher thermal conductivity (k) results in an augmented thermal boundary layer thickness, hence diminishing the heat transfer coefficient. Reduction of Eckert Number (Ec) means reduced viscous dissipation: A lower Ec signifies less viscous dissipation, resulting in less conversion of kinetic energy into thermal energy. A lower Ec reduces fluid friction, hence decreasing heat transfer and a diminished Ec can enhance fluid velocity, decreasing residence time and heat transmission.

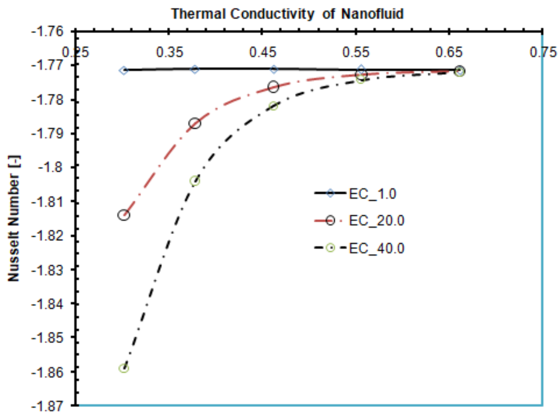

Fig. 9 Plot of Nusselt Number versus Thermal Conductivity

Figure 10 illustrates the effect of altering the thermal conductivity of the nanofluid from 0.2 to 0.65 on the local drag coefficient (CD). The diminution of the local drag coefficient (CD) with the enhancement of nanofluid thermal conductivity implies that nanofluids with elevated thermal conductivity improve heat transmission, hence diminishing boundary layer thickness and drag forces and elevated thermal conductivity diminishes fluid viscosity, promoting smoother flow and reducing drag. The enhanced thermal conductivity facilitates uniform particle distribution, reducing clumping and drag and improved thermal conductivity mitigates temperature gradients, resulting in reduced fluid density changes and drag.

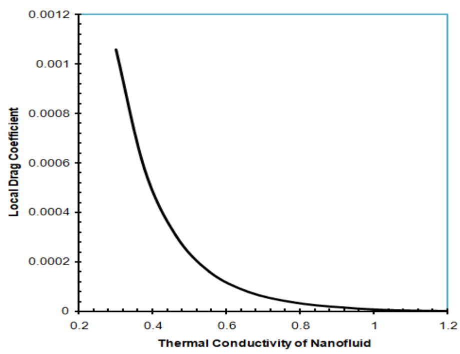

Fig. 10 Plot of Local Drag Coefficient versus Thermal Conductivity of Nanofluid

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Figure 11 depicts the effect of altering the specific heat capacity of nanofluid between 2800 and 4200 J/kg, as well as the Eckert number between 1.0 and 40 on the Nusselt number (Nu). The augmentation of the Nusselt number (Nu) concerning both heat capacity (Cp) and Eckert number (Ec) implies that elevated heat capacity (Cp) enables the fluid to retain greater thermal energy, hence augmenting convective heat transmission and a higher Eckert number (Ec) signifies augmented viscous dissipation, transforming kinetic energy into thermal energy, improving heat transfer. Elevated Cp and Ec diminish the thermal boundary layer thickness, hence enhancing the heat transfer coefficient. It is supported by Klazly and Bogn [17]. Alterations in fluid characteristics (e.g., density, viscosity) with temperature improve heat transmission.

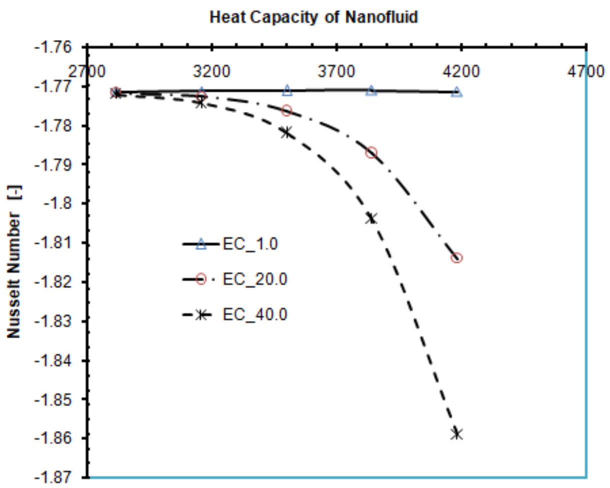

Fig. 11 Plot of Nusselt Number versus Heat Capacity

Figure 12 depicts the effect of altering the specific heat capacity of nanofluid between 2800 and 4200 J/kg, on the local drag coefficient (CD). The local drag coefficient signifies the resistance to fluid flow at a specific region, influenced by factors such as fluid properties (viscosity, density), flow regime (laminar, turbulent), surface texture, and particle interactions. Thermal capacity of nanofluid. Heat capacity is the amount of thermal energy required to increase the temperature of a unit mass of fluid by 1 degree. Nanofluids have enhanced heat capacity due to the increased surface area-to-volume ratio of nanoparticles. Improved thermal conductivity and Interactions between particles and fluids

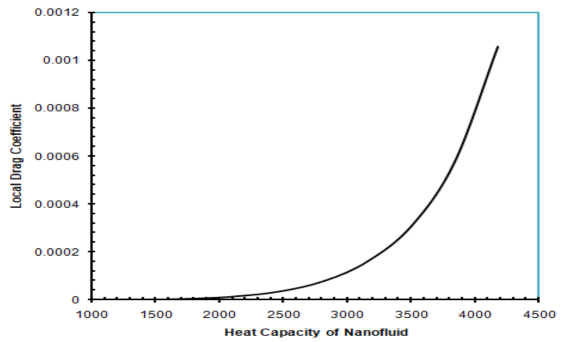

Fig. 12 Plot of Local Drag Coefficient versus Heat Capacity of Nanofluid

IV.CONCLUSIONS

This work conducted a numerical analysis of the influence of thermophysical characteristics coupled with viscous dissipation on the heat and flow characteristics of aluminum oxide (Al_2O_3) based nano-lubricants within a cylindrical channel. The results demonstrated that the thermal conductivity and heat transfer properties of the nano-lubricant significantly enhanced the heat distribution of Al_2O_3 nanoparticles. The viscosity, and density of the Al_2O_3 nanofluid augmented with an increase in nanoparticle size reduces the local drag coefficient and the specific heat capacity of the nanofluid diminishes. Thermal properties, including thermal conductivity and heat transfer coefficient, escalate with nanoparticle size and decline with the Eckert number. The findings offer significant insights into the design and utilization of nanoparticle-enhanced lubricants for thermal management, highlighting the capability of Al_2O_3 nano-lubricants to improve heat transfer efficiency across various engineering applications, Future research could examine the effects of different nanoparticle materials, base fluids, and flow conditions to improve the effectiveness of nano-lubricants.

NOMENCLATURE

Symbols	Definitions	Unit
m	Mass flow rate	[kg/hr]
Qu	Useful energy	[W]
C_p	Heat capacity	[J/kg.K]
Cp_{nf}	Nanofluid heat capacity	[J/kg.K]
Cp_f	Fluid heat capacity	[J/kg.K]
Cp_p	Nanoparticle heat capacity	[J/kg.K]
K_f	Fluid thermal conductivity	[W/m.K]
K_p	Nanoparticle thermal conductivity	[W/m.K]
K_{nf}	Nanofluid thermal conductivity	[W/m.K]

Greek Symbols

Symbols	Definitions	Unit
ρ_{nf}	Nanofluid density	[kg/m^3]
φ	Nanoparticle size	[-]
ρ_f	Fluid density	[kg/m^3]
μ_{nf}	Nanofluid viscosity	[m^2/s]
ρ_p	Nanoparticle density	[kg/m^3]
μ_f	Fluid viscosity	[m^2/s]

Subscripts

nf	Nanofluid
p	Particle
f	Fluid
Bf	Base Fluid

Greek symbols

μ	viscosity
φ	Volume fraction
ϱ	Density

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REFERENCES

[1] Mikkola, V., Puupponen, S., Granbohm, H., Saari, K., Seppälä, A., 2018. Influence of particle properties on convective heat transfer of nanofluids. Int. J. Therm. Sci. 124 (October 2017), 187–195.

[2] Sundar, L.S., Sharma, K.V., Singh, M.K., Sousa, A.C.M., 2017. Hybrid nanofluids preparation, thermal properties, heat transfer and friction factor – A review. Renew. Sustain. Energy Rev. 68 (March 2016), 185–198. https://doi.org/10.1016/j.rser.2016.09.108.

[3] Salman, S., Talib, A.R.A., Saadon, S., Sultan, M.T.H., 2020. Hybrid nanofluid flow and heat transfer over backward and forward steps: a review. Powder Technol. 363, 448–472. https://doi.org/10.1016/j.powtec.2019.12.038.

[4] Afshari, F., Manay, E., Rahimpour, S., Sahin, B., Muratçobanogˇlu, B., Teimuri-Mofrad, R., 2022. a Review Study on Factors Affecting the Stability of Nanofluids. In: Heat Transfer Research, vol. 53, Issue 18, pp. 77–91. https://doi.org/10.1615/HEATTRANSRES.2022041979.

[5] Saidina, D.S., Abdullah, M.Z., Hussin, M., 2020. Metal oxide nanofluids in electronic cooling: a review. J. Mater. Sci. Mater. Electron. 31 (6), 4381–4398. https://doi.org/10.1007/s10854-020-03020-7.

[6] Kumar, S., Kumar, A., Maithani, R., Sharma, S., Singh, D., 2022b. Exergy analysis of various solar thermal collectors. Mater. Today: Proc. 69 (xxxx), 323–327. https://doi.org/10.1016/j.matpr.2022.08.543.

[7] Nobrega, G., de Souza, R.R., Gonçalves, I.M., Moita, A.S., Ribeiro, J.E., Lima, R.A., 2022. Recent developments on the thermal properties, stability, and applications of nanofluids in machining, solar energy, and biomedicine. Appl. Sci. (Switzerland) 12 (3). https://doi.org/10.3390/app12031115.

[8] Sajid, M.U., Ali, H.M., 2019. Recent advances in the application of nanofluids in heat transfer devices: a critical review. Renew. Sustain. Energy Rev. 103, 556–592. https://doi.org/10.1016/j.rser.2018.12.057.

[9] Okonkwo, E.C., Wole, I., Ismail, O., Yasser, W.A., Tareq, M.A., Ansari, A., Deionised, D. I., 2021. An updated review of nanofluids in various heat transfer devices. J. Thermal Anal. Calorimetry 145 (6). https://doi.org/10.1007/s10973-020-09760-2.

[10] Shahsavar, A., Shaham, A., Amin, M., 2022. Assessment of thermal conductivity of polyethylene glycol-carbon dot nanofluid through a combined experimental data mining investigation. J. Mater. Res. Technol. 19, 2695–2704. https://doi.org/10.1016/j.jmrt.2022.06.033.

[11] Yang, L., Xu, X., Jiang, W., Du, K., 2017. A new thermal conductivity model for nanorod-based nanofluids. Appl. Therm. Eng. 114, 287–299. https://doi.org/10.1016/j.applthermaleng.2016.11.183.

[12] Pare, A., Ghosh, S.K., 2021. A unique thermal conductivity model (ANN) for nanofluid based on experimental study. Powder Technol. 377, 429–438. https://doi.org/10.1016/j.powtec.2020.09.011.

[13] Suresh, S., Venkitaraj, K.P., Selvakumar, P., Chandrasekar, M., 2011. Synthesis of Al2O3-Cu/water hybrid nanofluids using a two-step method and its thermo physical properties. Colloids Surf. A Physicochem. Eng. Asp 388 (1–3), 41–48. https://doi.org/10.1016/j.colsurfa.2011.08.005.

[14] Saeedinia, M., Razi, P., 2012. Thermal and rheological characteristics of CuO – Base oil nanofluid flow inside a circular tube. Int. Commun. Heat Mass Transfer 39, 152–159. https://doi.org/10.1016/j.icheatmasstransfer.2011.08.001.

[15] Li, X., Zou, C., (2016). Thermophysical properties of water and ethylene glycol mixture based SiC nanofluids: An experimental investigation. International Journal of Heat and Mass Transfer. 101, 412–417. https://doi.org/10.1016/j.ijheatmasstransfer.2016.05.089.

[16] Ibrahim, Nguyen, H. M., Bakhtiyari, A.N., Asadi, A., 2019. Feasibility of ANFIS-PSO and ANFIS-GA models in predicting thermophysical properties of.

[17] Klazly, M., Bogn, G., 2022. A novel empirical equation for the effective viscosity of nanofluids based on theoretical and empirical results. 135 (April). https://doi.org/10.1016/j.icheatmasstransfer.2022.106054

[18] Sekhar, Y.R., Sharma, K.V., 2015. Study of viscosity and specific heat capacity characteristics of water-based Al2O3 nanofluids at low particle concentrations. J. Exp. Nanosci. 10 (2), 86–102. https://doi.org/10.1080/17458080.2013.796595.

[19] Alklaibi A.M., L.S. Sundar, A.C.M. Sousa (2021), Experimental analysis of exergy efficiency and entropy generation of diamond/water nanofluids flow in a thermosyphon flat plate solar collector Int. Commun. Heat Mass Transfer, 120 Article 105057, 10.1016/j.icheatmasstransfer.2020.105057

[20] Said, Z., Sundar, L.S., Kumar, A., 2021. Recent advances in the fundamental physical phenomena behind stability, dynamic motion, thermophysical properties, heat transport, applications, and challenges of nanofluids. Phys. Rep. https://doi.org/10.1016/j.physrep.2021.07.002.

[21] Sangotayo E. O.(2021) Influence of Thermophysical Properties on Heat Characteristics and Fluid Flow in a Moving Isothermal Cylindrical Pipe, Proceeding book of International Congress on Scientific Advances, ICONSAD'21 pp. 647-659, ISBN: 978-605-74234-9-8, Turkey

[22] Itabiyi, O. E., Sangotayo, E.O., Akinrinade, N.A and Muraina, A. B. (2024). Effect of Nanoparticle Concentration on Thermophysical Properties and Heat Transfer Performance of Aluminum Oxide (Al_2O_3) Nano-lubricants in a Cylindrical Channel: A Numerical Investigation. International Journal of Advances in Engineering and Management (IJAEM) Volume 6, Issue 09 Sep. 2024, pp: 499-508 www.ijaem.net

[23]Sangotayo, E. O.. and Hunge O. N. (2020). Numerical Analysis of Nanoparticle Concentration Effect on Thermo-physical Properties of Nanofluid in a Square Cavity, International Journal of Mechanical and Production Engineering (IJMPE), 8(2), pp.18-23,

[24] Öztop, H. F., Estellé, P., Yan, W.-M., Al- Salem, K., Orfi, J., and Mahian, O. (2015). A Brief Review of Natural Convection in Enclosures under Localized Heating with and without Nanofluids. Int. Commun. Heat Mass Transfer 60, 37–44. doi:10.1016/j.icheatmasstransfer.2014.11.001

[25] Shahi, M. Mahmoudi, A.H. and Talebi, F. (2011) "A numerical investigation of conjugated-natural convection heat transfer enhancement of a nanofluid in an annular tube driven by inner heat generating solid cylinder", International Communication of Heat and Mass Transfer, vol. 38, no. 4, pp. 533-542

[26] Lin, K.C. and Violi, A. (2010) "Natural convection heat transfer of nanofluids in a vertical cavity: Effects of nonuniform particle diameter and temperature on thermal conductivity", International Journal of Heat and Fluid Flow, vol. 31, pp. 236-245

[27] Saleh, H. Roslan, R. and Hashim, I. (2011) "Natural convection heat transfer in a nanofluid filled trapezoidal enclosure", International Journal of Heat and Mass Transfer, vol. 54, pp. 194-201

[28] Nazar, R. Tham, L. Pop, I. and Ingham, D.B. (2011) "Mixed convection boundary layer flow from a horizontal circular cylinder embedded in a porous medium filled with a nanofluid", Transport in Porous Media. 86(2), pp. 517-536

[29] Esmaeilpour, M. and Abdollahzadeh, M. (2012) "Free convection and entropy generation of nanofluid inside an enclosure with different patterns of vertical wavy walls", International Journal of Thermal Science, vol. 52, pp. 127-136

[30] Waheed, M. A. (2009) "Mixed convective heat transfer in rectangular enclosures driven by a continuously moving horizontal plate", International Journal of Heat and Mass Transfer, vol. 52, pp. 5055–5063

[31] Hwang et al. (2016). Experimental investigation of drag reduction in nanofluids. Journal of Mechanical Science and Technology, 30(5), 2261-2268.

[32] Pouranfard, A., Mowla, D. and Esmaeilzadeh, Feridun. (2014). An experimental study of drag reduction by nanofluids through horizontal pipe turbulent flow of a Newtonian liquid. Journal of Industrial and Engineering Chemistry. 20. 633–637.