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Effects of Concentration on Free Convective Heat Transfer in Glycerol

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ABSTRACT

In a gravitational field, density differences can drive fluid motion in a process known as free convection. Free convection and changing concentration of glycerol are related through the concept of density-driven flow. The effects of concentration on free convective heat transfer is studied for glycerol for the range of Rayleigh numbers $10^{-6} \leq Ra \leq 10^{9}$ and Prandtl numbers $6.66 \leq Pr \leq 11630$. Various appropriate correlations due to Churchill and Chu, Raithby and Holland, Kuehn and Goldstein, Fand *et al* and Jaluria are used to evaluate the free convective Nusselt number in glycerol as a function of Rayleigh number with fixed concentrations of 0%, 20%, 40%, 60%, 80% and 100%. Additionally, the Rayleigh number is kept fixed at three regimes of 10^{-6}, 10^{0} and 10^{9} and the free Nusselt number is evaluated as a function of concentration of glycerol. A maximum of 42% increase in Nusselt number with concentration is observed from the Fand *et al* correlation.

Keywords: Free Convective, Glycerol, Density-Driven Flow

INTRODUCTION

Natural Convection occurs solely due to the difference in density caused by temperature variations. Hotter fluids, with lower density, rise, while cooler and denser fluids descend, creating a natural circulation loop. A recent study by Xi *et al.*, (2023) explores the influence of microstructures on natural convection heat transfer in porous media. Forced Convection on the other hand involves an external force, such as a pump or fan, disrupts the natural flow pattern and induces fluid motion. This significantly enhances heat transfer efficiency. Research by Buongiorno *et al.*, (2020) investigates the use of nanofluids for forced convection heat transfer applications.

Understanding convection is crucial in various engineering fields. For example, it plays a vital role in designing efficient heat exchangers, to optimizing cooling systems for buildings and electronic devices, and even regulating Earth's climate.

Free convection, also known as natural convection, is a heat transfer process driven solely by buoyancy forces arising from temperature variations within a fluid. In this scenario, the fluid velocity away from the heat source is negligible. However, near the source (hot or cold), temperature differences create density variations. A recent study by Afuo, B. I. *et al*. (2023) explores the impact of these density gradients on natural convection heat transfer in nanofluids.

These density variations translate into a buoyant force, either positive (for hot surfaces) or negative (for cold surfaces), acting on the fluid adjacent to the source. As described in a review by Bejan, (2020), gravity acts as the primary driving force for this buoyant force, initiating and sustaining the convective process. This fluid motion, primarily vertical, past the heated/cooled surface facilitates convective heat transfer.

Convective heat transfer is governed by the laws of fluid flow, the equation of continuity and the equation for the heat-flow in a moving

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fluid. An exact solution of these equations with particular boundary conditions is not feasible except in certain simple cases. However, important relationships may be obtained from these equations by means of the theory of similarity. Thus, for natural convection, the Nusselt number (Nu), a measure of convective heat transfer, is known to be a function of the Grashof number (Gr), representing buoyancy forces, and the Prandtl number (Pr), reflecting fluid properties. This relationship is written as:

Nu = f(Gr, Pr)

This relationship between dimensionless numbers allows engineers to predict convective heat transfer behavior without resorting to complex analytical solutions. (Afuo *et al*., 2023)

The form $f(Gr, \mathrm{Pr})$ can be determined either strictly experimentally or by using theoretical

analysis with some experimental information.

Natural convection can be a relatively inefficient heat transfer method. To address this limitation, engineers utilize mixed convection or external forces to induce turbulence and improve heat transfer within fluids. Electro-thermohydrodynamics (ETHD) is a technique that employs electrical forces to enhance mixing and, consequently, heat transfer. Pioneering work by Senftleben and Braun (1930) on gases and Ahsmann and Kronig (1950) on liquids laid the foundation for ETHD research.

Today, a significant amount of research focuses on applying ETHD to enhance heat transfer in various applications, including heat exchangers, Li and Wang (2020). Recent advancements in ETHD research explore the use of microfluidic channels and nanofluids to further improve heat transfer efficiency Sajjadi and Valencia (2018)..

Natural convection, the movement of fluids due to temperature differences, plays a vital role in numerous industrial processes. From high-voltage power transmission lines to solar collectors, electronic devices, nuclear safety systems, and refrigeration condensers, Hamzekhani *et a*l., (2014).

Despite its widespread application, achieving a complete understanding of heat transfer phenomena remains elusive. As the research by Hamzekhani *et al*. (2014) points out, various aspects of heat transmission through different media, particularly natural convection in fluids, present significant challenges. This complexity arises from the interplay of mass flow and heat conduction, governed by intricate physical laws.

Fortunately, advancements continue to be made in understanding and optimizing natural convective heat transfer. Researchers are investigating natural convection at the microscale level, relevant for microfluidic devices used in electronics cooling, Li *et al*., (2023). Also, studies explore how suspending nanoparticles in fluids can improve natural convection heat transfer efficiency, Buongiorno *et al*, (2022). Furthermore, advancements in computational fluid dynamics (CFD) allow for more accurate simulations of complex natural convection flows, Heydari *et al*, (2021).

Understanding convective heat transfer necessitates a grasp of both fluid mechanics, governing the motion of fluids, and thermal conduction, describing how heat propagates through matter, Holman, (2002); Incropera *et al*, (2011). In principle, this topic can be described by the solutions of the following equations:

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$$\rho\frac{\partial\vec{v}}{\partial t}+\rho(\vec{v}.\nabla)\vec{v}=\rho\vec{g}-\nabla\rho+\eta\nabla^2\vec{v}+\frac{1}{3}\eta\nabla(\nabla.\vec{v})+\vec{F} \quad ... (1)$$

$$\frac{\partial p}{\partial t}+\rho\nabla.\vec{v}+v.\nabla\rho=0 \quad ... (2)$$

$$c_p\rho\frac{\partial T}{\partial t}=\lambda\nabla^2T+C_p\rho\vec{v}.\nabla T \quad ... (3)$$

with appropriate boundary conditions and equation of state

In practical applications of heat transfer it is customary to introduce the heat transfer coefficient h defined by

$$h=\frac{Q}{A\theta} \quad ... (4)$$

where Q is the rate of heat transfer, A the area of the surface of the heated body, and θ the temperature difference between the surface of the object and the main body of the fluid.

Effectively h is a measure of heat transfer per unit area per unit time under unit temperature gradient. It includes the combined effects of conduction through the stagnant film and convection in the fluid. Experimentally, it has been found that h depends on the properties of the surface (shape, dimensions, temperature), the fluid (density, specific heat, viscosity, heat conductivity, temperature) and the flow (type, direction, velocity).

While the fundamental principles of fluid mechanics and heat conduction govern convective heat transfer, rigorous theoretical calculations of h remain a challenge due to significant mathematical complexities, Bejan, (2013). However, recent advancements in semi-theoretical methods based on similarity theory (integral, differential, and dimensional methods) offer valuable insights into these complex processes, Pop and Ingham, (2001) and Cheng (2012). These approaches provide a multitude of important results, particularly for specific geometries like free convection from a regular body, e.g., sphere diameter or long cylinder in a fluid, Aydin and Bejan, (2017). One expects the following properties to be important in this process: the transport properties of the fluid (λ,η), the specific heat C_p and the density (ρ) of the fluid, the heat transfer coefficient (h), and the thermal convectional force $(f_{th}=-\rho\beta\theta g$, where $\theta=T_w-T_0$ is the temperature difference between the body and the fluids, and β the thermal expansion coefficient), Aydin and Bejan, (2017). The above convection process can be described by three independent dimensionless numbers:

Nusselt number: $Nu=\frac{hl}{\lambda}$ … (5)

Grashof number: $Gr=\frac{l^3\rho^2 g\beta\theta}{\eta^3}$ … (6)

Prandtl number: $Pr=\frac{C_p\eta}{\lambda}$ … (7)

A perfectly general equation for the free convection can now be written as

$$Nu=f\ (Gr,Pr) \quad …(8)$$

This is all the similarity analysis can provide. While the function f(Gr,Pr) is crucial for characterizing laminar free convection (where viscous forces dominate over inertial), its determination requires either experimental approaches or more complex theoretical methods, Mukhopadhyay and Alavyoon, (2020). The equation (8) can be rewritten as

$$Nu = f\,(GrPr) \quad \text{... (9)}$$

Early investigations explored the impact of temperature gradients on convective heat transfer from heated surfaces to fluids. However, the scarcity and questionable validity of these data highlight the inherent difficulty of precise measurements in this field, Viskanta, (2013).

For instance, Morgan's 1975 comprehensive survey of convective heat transfer data from circular cylinders revealed a significant spread in published experimental results for natural convection around horizontal cylinders, Aydin and Bejan, (2017). This emphasizes the need for more recent and reliable experimental data to improve our understanding of these complex processes.

While earlier studies by Collis and Williams (1954, 1966), Gosse (1956), Gebhard and Pera (1970), and Gebhard *et al.* (1970) suggested neglecting end losses in hot-wire anemometry for aspect ratios (L/D) exceeding 10^5 (L = wire length, D = wire diameter). Achieving such high ratios can be challenging, Buch *et al*,.(2000). Furthermore, limited measurements exist for L/D exceeding 10^4, Zhu and Liu, (2017). For practical applications with lower aspect ratios, corrections for end heat losses remain necessary.

Morgan (1975), after a careful analysis of all published experimental data together with possible errors, proposed that

$$Nu = c(GrPr)^m \quad \text{... (10)}$$

where c = 0.675 and m = 0.58 for GrPr from 10^{-10} to 10^{-2}. It is suggested that the proposed correlation has a maximum uncertainty of ±5. Among the other proposed correlations, that due to Kyte *et al.* (1953) is

$$Nu = \left\{In\left[1 + \frac{7.09}{(GrPr)^{0.37}}\right]\right\}^{-1} \quad \text{... (11)}$$

Churchill and Chu (1975) published the following semi-empirical correlation equation for heat transfer by natural convection from horizontal cylinders:

$$Nu = 0.36 + 0.518\left\{\frac{GrPr}{\left[1+(0.559/Pr)^{9/16}\right]^{16/9}}\right\}^{0.25} \quad \text{... (12)}$$

Churchill and Chu state in their publication that this equation provides a good fit of representative data for all Pr and $10^{-6} \leq GrPr \leq 10^{9}$ • The equation, however, did not match well with the experimental data for very low values of $GrPr \leq 10^{-6}$ which were the experimental data of Collis and Williams (1966). Another correlation, good for $10^{-11} \leq GrPr \leq 10^{9}$, was also developed by Churchill and Chu and is shown to be

$$Nu^{1/2} = 0.60 + 0.387\left(\frac{GrPr}{\left(1+(0.559/Pr)^{9/16}\right)^{16/9}}\right)^{1/2} \quad \text{… (13)}$$

Another correlation equation for horizontal cylinders is due to Raithby and Holland (1976).

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$$Nu^{3.337} = \left\{\frac{2}{In\left[1+\pi 2^{3/4}/_{2.04A\,GrPr^{1/4}}\right]}\right\}^{3.337} + \left[0.72B\,(G_r P_r)^{1/3}\right]^{3.337} \quad .... (14)$$

$Where\ A = \left(\frac{2}{3}\right)/\left[1+(0.49/Pr)^{9/16}\right]^{4/9}$ and $B = 0.14\,Pr^{0.084}\ or\ 0.15,$ whichever is smaller.

Conversely, that for horizontal cylinders due to Kuehn and Goldstein (1980) is,

$$\frac{2}{Nu} = ln\left[1+\frac{2}{\left[\left\{0.518(GrPr)^{1/4}[1+(0.559/Pr)]^{3/5}\right\}^{-5/12}\right]^{15}}\right] \quad \ldots (15)$$

This correlation as stated is valid for any Rayleigh and Prandtl numbers. The average Nusselt number on the cylinder diameter calculated by Jaluri (1980) obtained by an integral method valid for all Prandtl numbers in the range of Grashof number 10^5 and 10^{12} is

$$Nu = \left[\frac{Pr}{1+(0.559/Pr)^{9/16}+10Pr}\right]^{1/5} Ra^{1/4} \quad \ldots (16)$$

For laminar natural convection around the surface of a long cylinder with constant wall temperature according to Fand *et al* (1977), the equation is

$$Nu = 0.47Ra^{0.25}Pr^{0.047} \quad \ldots (17)$$

For the range of Rayleigh numbers 3×10^2 to 2×10^7 and Prandtl numbers 0.7 to 3090.

MATERIALS AND METHODS

Glycerin remains a highly valuable material due to its remarkable versatility. This stems from its unique combination of physical and chemical properties, compatibility with various substances, and ease of use. Additionally, glycerin boasts an excellent safety profile with minimal toxicity (The American Chemistry Council, 2024).

Physically, glycerin is a water-soluble, clear, odorless, viscous liquid with a high boiling point. Chemically, it's a trihydric alcohol, allowing for various reactions while maintaining stability under most conditions. This exceptional blend of properties positions glycerin for a wide range of applications across numerous industries, Yoon and Sin, (2018).

Recent advancements have seen glycerin being explored in exciting new areas: Glycerin can be a valuable platform molecule for producing bio-fuels and other bio-based products, Shafer *et al*., (2010). Its hygroscopic nature makes it a desirable ingredient in drug formulations to maintain moisture content, Clarke and Delgado, (2018). Research is ongoing to explore glycerin's potential role in novel energy storage solutions, Shahid and Al-Sagheer, (2020). With over 1500 known applications, glycerin continues to be a material with significant potential for future exploration and development.

While the terms "glycerin" and "glycerol" are often used interchangeably, a subtle distinction exists. Commercially, "glycerin" typically refers to purified products containing at least 95% glycerol by weight. This concentration is usually determined by converting specific gravity measurements at specific temperatures (e.g., 20/20°C or 25/25°C) (The Society of Chemical Manufacturers and Affiliates, 2024).

However, from a strictly chemical standpoint, "glycerol" refers to the pure compound itself, also known as 1,2,3-propanetriol (CAS Registry Number: 56-81-5; NIOSH Number: MA8050000). This chemical definition emphasizes the specific molecular structure ($CH_2OHCHOHCH_2OH$) of glycerol.

One of glycerin's most prominent characteristics is its high viscosity, Yoon and Sin, (2018). Glycerin's ability to maintain viscosity across a wide temperature range allows it to function effectively in hydraulic systems, Wang and Zhu, (2019). Also in specific situations, glycerin can be a suitable lubricant due to its viscous nature. Researchers often utilize glycerin and its solutions to study fluid flow phenomena in laboratories due to its controllable viscosity range Zhao and Cheng (2020). Furthermore, aqueous solutions of glycerin serve as standard fluids for calibrating viscometers, instruments used to measure fluid viscosity (ASTM International, 2023).

Another noteworthy aspect is glycerin's ability to remain a liquid at high concentrations and normal temperatures, eliminating concerns about crystallization during use, Yoon and Sin, (2018). However, at lower temperatures, concentrated glycerin solutions exhibit supercooling behavior – a state where a liquid remains liquid below its freezing point, Angell (2002). During supercooling, glycerin's viscosity increases gradually at first, then rapidly, ultimately turning glassy around -89°C, Yoon and Sin, (2018).

Viscosities of various concentrations of glycerin in water at various temperatures have been investigated, Cheng, (2008).

This paper reports the investigation of variation of the concentration of glycerol using appropriate correlations. The percentage concentration is graded from 0:100, 20:80, 40:60, 60:40, 80:20 and 100:0 for glycerin : water mixtures. The marked character of the concentration manifests in the Prandtl number varying from 6,66 at zero concentration of glycerin to 11630 at 100% concentration of glycerin.

RESULTS AND DISCUSSION

Determination of free Nusselt numbers often relies on empirical correlations developed by various researchers. Commonly used correlations include those by Churchill and Chu, Raithby and Holland, Kuehn and Goldstein, Fand *et al* and Jaluria, Incropera *et al*, (2018). These correlations relate the Nusselt number (Nu) to the Rayleigh number (Ra), a dimensionless parameter governing buoyancy-driven flow. The Nusselt number is typically plotted against the natural logarithm of the Rayleigh number for easier visualization and analysis , Içen and Öztop, (2018).

First, the Nusselt number is plotted against the Rayleigh number for glycerol of different concentration. This is done in three regimes of Raleigh numbers. Further plots investigate the relationship between the Nusselt number and the concentration of glycerol.

The plots according to Churchill and Chu, Raithby and Holland, Kuehn and Goldstein, Faud *et al*, and Jaluria *et al* are as attached.

The following inferences are arrived at:

a) The plots for glycerin of 100%, 80%, 60%, 40%, 20% and 0% concentration are presented using Nusselt (Nu) and Rayleigh (Ra) numbers. Correlations by Churchill and Chu., Kuehn and Goldstein, Fand *et al*., and Jaluria *et al* predict a slight Nu increase with higher Prandtl (Pr) number) due to glycerin's viscosity. This aligns with observations, except for the Raithby and Holland correlation, which requires further investigation. The analysis also explores Ra number range (10^{-6} to 10^{9}) and finds the Nu enhancement due to higher Pr becomes more pronounced at higher

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Ra values, as expected with stronger buoyancy-driven flow.

b) The plots of the Nusselt number against concentration are hereby presented. Three sets of Rayleigh numbers; 10^{-6}, 10^{0}, 10^{6} were treated for appropriate correlations. The variation of the Nusselt number with concentration increases gradually but markedly at maximum concentration.

This study examined the relationship between heat transfer and concentration in glycerin solutions. We employed established correlations from Churchill and Chu, Raithby and Holland, Kuehn and Goldstein, Fand *et al*, and Jaluria *et al* to calculate the Nusselt number (indicating heat transfer) as a function of Rayleigh number (representing buoyancy forces) for glycerin solutions with varying concentrations (from 0% to 100%, corresponding to Prandtl numbers of 6.66 to 11630). The analysis included plotting Nusselt number against the logarithmic scale of Rayleigh number and then against the concentration of glycerin for a specific Rayleigh number. Interestingly, the initial increase in heat transfer with increasing Rayleigh number (from 10^{-6} to 10^{0}) was minimal. However, a significant rise in heat transfer became evident at higher Rayleigh numbers (10^{9}). Notably, the Raithby and Holland correlation predicted the highest Nusselt number at the largest Rayleigh number (10^{9}). Furthermore, the study revealed a slight enhancement in heat transfer with higher glycerin concentration (which translates to a higher Prandtl number). This trend is consistent with the correlations presented by Churchill and Chu, Raithby and Holland, and Kuehn and Goldstein (as shown in Figures 1a, 1b, and 1c). Additionally, the correlations proposed by Fand *et al* and Jaluria *et al* also demonstrated an increase in heat transfer with increasing concentration. Overall, these findings highlight the influence of concentration on heat transfer behavior in glycerin solutions.

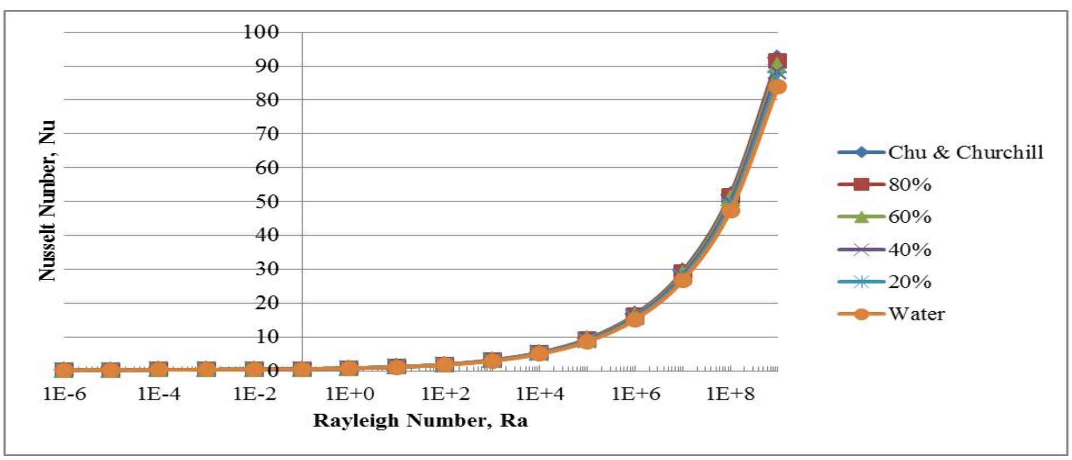

Figure 1a: Nusselt number vs Rayleigh number with varied concentration for glycerin using Churchill and Chu Correlation

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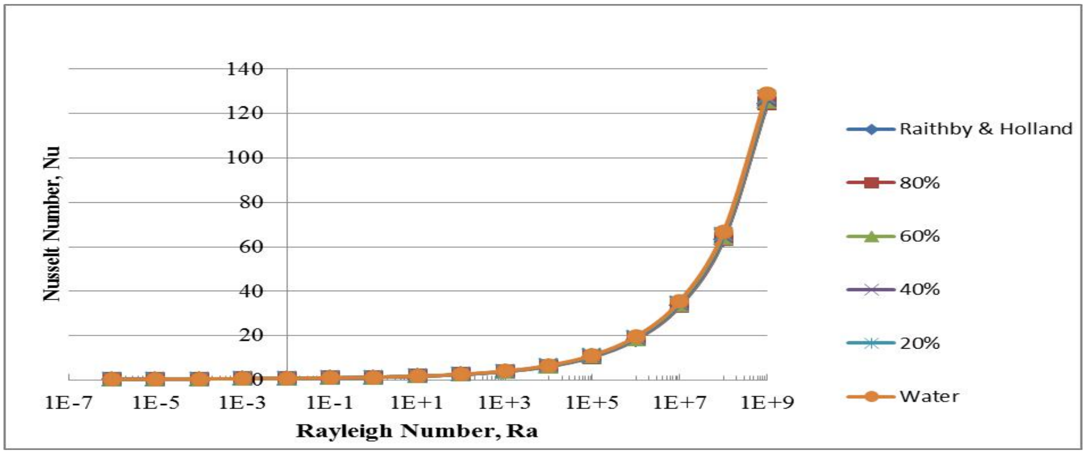

Figure 1b : Nusselt number vs Rayleigh number with varied concentration for glycerin using Raithby and Holland Correlation.

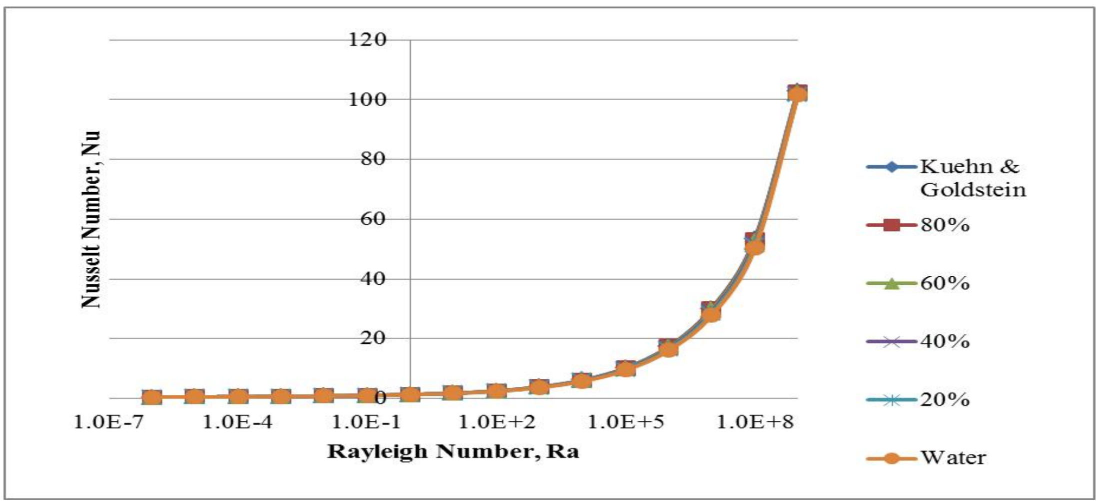

Figure 1c: Nusselt number vs Rayleigh number with varied concentration for glycerin using Kuehn and Goldstein Correlation

To further explore the relationship between heat transfer and glycerin concentration, researchers fixed the Rayleigh number at three different values (10^{-6}, 10^{0} and 10^{9}) and examined how the Nusselt number varied with concentration (Figure 2a, b and c). At lower Rayleigh numbers (10^{-6}), the Nusselt number showed only a small increase with increasing glycerin concentration. This trend became more pronounced at higher Rayleigh numbers (10^{0} and 10^{9}). In other words, the influence of concentration on heat transfer becomes more significant as the driving force for natural convection (represented by Rayleigh number) increases.

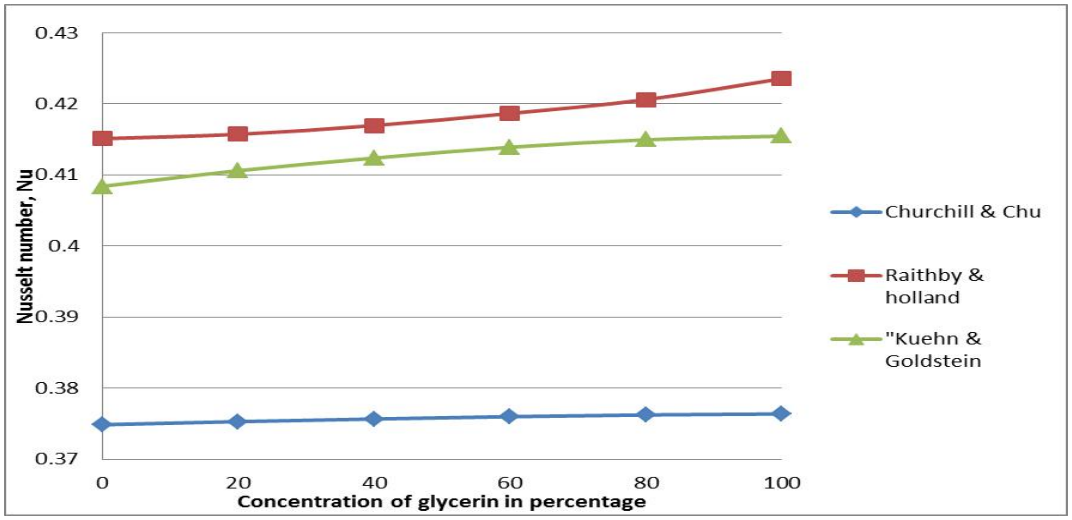

Figure 2a: Nusselt Number vs Concentration of glycerol when Ra = 10^{-6}

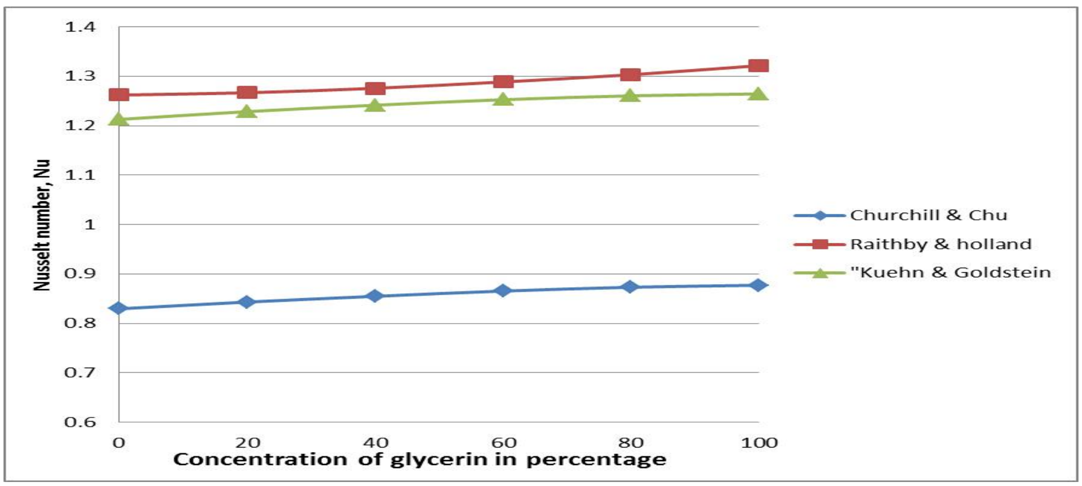

Figure 2b: Nusselt Number vs Concentration of glycerol when Ra = 10^{0}

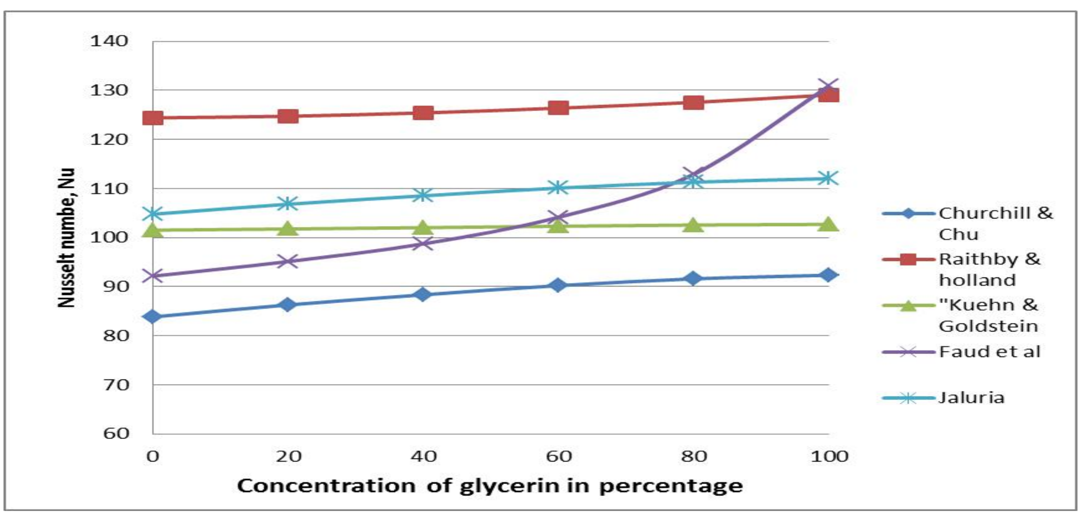

Figure 2c: Nusselt Number vs Concentration of glycerol when Ra = 10^{9}

Our analysis reveals a clear dependence of heat transfer (represented by Nusselt number) on both the concentration of glycerin and the driving force for natural convection (represented by Rayleigh number). As shown in Tables 1a, 1b, and 1c, a negligible increase in Nusselt number (less than 0.01) was observed with increasing glycerin concentration for a low Rayleigh number of 10^{-6}. However, this trend changed significantly at higher Rayleigh numbers. When the Rayleigh number was raised to 10^{0}, a moderate rise in Nusselt number of around 0.2 was observed with increasing concentration. This effect became even more pronounced at an extremely high Rayleigh number of 10^{9}. In this case, increasing the glycerin concentration led to a substantial enhancement in Nusselt number.

Table 1a: Variation of Nusselt Number as a function of concentration with fixed Rayleigh Number (Ra = 10^{-6})

Churchill and Chu	Raithby and Holland	Kuehn and Goldstein	Concentration (%)
0.3748	0.42299	0.40839	0
0.3753	0.4206	0.41059	20
0.3757	0.41865	0.41237	40
0.376	0.41695	0.4139	60
0.3762	0.41573	0.41495	80
0.3764	0.4151	0.41545	100

Table 1b: Variation of Nusselt Number as a function of concentration with fixed Rayleigh Number (Ra = 10^{0})

Churchill and Chu	Raithby and Holland	Kuehn and Goldstein	Faud et al	Jaluria	Concentration (%)
0.8294	1.32142	1.21264	0.51818	0.58916	0
0.8432	1.30314	1.22852	0.53492	0.60064	20
0.8548	1.28844	1.24146	0.55519	0.61028	40
0.8653	1.27568	1.25265	0.58564	0.61912	60
0.8731	1.26662	1.2604	0.63491	0.62591	80
0.8771	1.26193	1.26415	0.73597	0.62991	100

Table 1c: Variation of Nusselt Number as a function of concentration with fixed Rayleigh Number (Ra = 10^{9})

Churchill and Chu	Raithby and Holland	Kuehn and Goldstein	Faud et al	Jaluria	Concentration (%)
83.833	129.065	101.521	92.1471	104.7683	0
86.279	127.56	101.763	95.124	106.8102	20
88.346	126.395	102.029	98.7281	108.5254	40
90.219	125.415	102.322	104.142	110.0971	60
91.596	124.739	102.564	112.905	111.3045	80
92.323	124.395	102.693	130.876	112.0147	100

The influence of glycerin concentration on heat transfer is further quantified by calculating the percentage increase in Nusselt number as concentration goes from 0% (water)

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to 100% (pure glycerin) (Table 2). This percentage change is minimal at very low Rayleigh numbers. For instance, with the Fand *et al* correlation, there's practically no difference in Nusselt number between pure water (Pr = 6.66) and pure glycerin (Pr = 11630) at a Rayleigh number of 10^{-6}. However, the impact of concentration becomes significant at higher Rayleigh numbers. At a Rayleigh number of 10^{9}, the Fand *et al* correlation predicts a substantial increase of up to 42% in Nusselt number with increasing glycerin concentration. This highlights the interplay between concentration and buoyancy forces in affecting heat transfer.

Table 2a: Percentage increase in Nusselt number (Ra = 10^{-6})

Churchill and Chu	Raithby and Holland	Kuehn and Goldstein	Concentration (%)
0	0	0	0
0.1174	0.565	0.5387	20
0.2161	1.026	0.9746	40
0.3041	1.4279	1.3492	60
0.3682	1.7164	1.6063	80
0.4028	1.8653	1.7287	100

Table 2b: Percentage increase in Nusselt number (Ra = 10^{0})

Churchill and Chu	Raithby and Holland	Kuehn and Goldstein	Fand et al	Jaluria	Concentration (%)
0	0	0	0	0	0
1.659	1.38336	1.3095	3.2305	1.9485	20
3.06	2.4958	2.3766	7.1423	3.5848	40
4.3308	3.46143	3.2994	13.019	5.0852	60
5.264	4.14705	3.9385	22.527	6.2377	80
5.756	4.50198	4.2478	42.03	6.9166	100

Table 2c: Percentage increase in Nusselt number (Ra = 10^{9})

Churchill and Chu	Raithby and Holland	Kuehn and Goldstein	Fand et al	Jaluria	Concentration (%)
0	0	0	0	0	0
2.9181	1.1662	0.2385	3.23061	1.948939	20
5.3841	2.0693	0.5009	7.1418	3.58606	40
7.6182	2.828	0.7893	10.0176	5.08623	60
9.2599	3.3522	1.0273	22.5264	6.23871	80
10.127	3.6185	1.155	42.0296	6.91662	100

CONCLUSION

The analysis revealed a characteristic trend for free convection: Nusselt number plotted against the logarithm of Rayleigh number exhibited hyperbolic curves in all concentration categories. This finding aligns with established theories of natural convection. Interestingly, these results suggest that the concentration of a fluid can potentially be determined by analyzing the variation of the Nusselt number with concentration using appropriate correlations. However, the overall impact of concentration on Nusselt number appears to be relatively low. This implies that the ratio of heat transfer via convection compared to conduction in these fluids is negligible, especially at the laminar flow stage.

Even in the turbulent regime, the enhancement in heat transfer due to concentration remains modest, typically around 10%. The Fand *et al* correlation stands out as an exception, predicting a maximum increase of up to 42%. These observations suggest that while concentration plays a role in heat transfer, its influence may be less significant than other factors, particularly at lower Rayleigh numbers and laminar flow conditions.

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