Numerical Investigation of the Effect of Variable Viscosity on Rayleigh-Benard Marangoni Convection in Hydro Dynamic Surface

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Abstract: Buoyancy-driven convection, commonly referred as conventional convection or Rayleigh convection, arises when a fluid is subjected to a temperature gradient in a gravitational field and there is a change in density and viscosity with regard to temperature. Unlike buoyancy-driven convection, Marangoni convection, also known as interfacial tension gradient-driven convection, can occur in a fluid even when no gravitational field exists. The suggested inquiry approach in this study is based on a natural convection analysis combined with a numerical examination of the effect of variable viscosity on Rayleigh-Benard Marangoni convection in a hydrodynamic surface. The effects of viscosity fluctuations in the Rayleigh-Benard-Marangoni convection process, which causes different physical changes, are taken as key objective to analyze. The relationship between viscosity and surface tension, the viscosity and buoyancy values are computed to find their dependence relationship, followed by the temperature dependence of variable viscosity of fluids with high and low molecular spacing. Finally, the density is related with the viscosity. As a result, the impacts of changing viscosity are accounted using the resulting equations to represent the Rayleigh number and Marangoni number effects. Convection are determined using microscopic fluid's dynamic parameters, allowing for a better understanding of fluid dynamics under natural convection.

Keywords: *Rayleigh Benard convection, Marangoni convection, Viscosity, Buoyancy, Surface tension, Density.*

1. Introduction

Evaporation of solutions affects a variety of physical and technological mechanisms including the drying of saline lakes, the drying of paint films, crystal formation, and distillation. Rayleigh-Benard or Benard-Marangoni convection, which is caused by a temperature gradient, is often confronted during the evaporation of pure liquids and has been ubiquitously researched [1]. Convection in multilayer systems is a common occurrence that is of special concern in a wide range of technological fields [2]. Consider a sheet of liquid that is bounded vertically by two horizontal rigid surfaces, one of which is hotter than the other. As the temperature differential exceeds the critical temperature difference, the gravitational instability overcomes the viscous and thermal damping effects, and the fluid is set in motion, resulting in buoyancy-driven convection [3]. When a fluid is subjected to a temperature gradient in a gravitational field and there is a difference in density and viscosity with respect to temperature, buoyancy-driven convection, also known as normal convection or Rayleigh convection, occurs [4]. The kinematic viscosity and thermal diffusivity of the fluid dampen disruptions to the liquid, while buoyancy forces intensify them. Under steady-state conditions, equilibrium between these effects is formed, which is expressed by the dimensionless Rayleigh number [5].

Unlike buoyancy-driven convection, Marangoni convection or Interfacial tension gradient-driven convection may occur in a fluid

even though there is no gravitational field. The thermal diffusivity of the fluid will conduct away the heat faster than the disruption will amplify if the temperature differential through the liquid is minimal enough [6]. The flow would be resisted by the dynamic viscosity, allowing the interface to flatten and the interfacial stress to remain steady [7]. In addition, scaling the equations that model the interfacial momentum equilibrium results in a dimensionless category, that shows a balance between the dissipative effects of viscosity, thermal diffusivity and the promoting effects of interfacial stress gradient. The Marangoni number refers to this dimensionless attribute [8].

For several years, the topic of thermal instability has been studied scientifically, numerically, and experimentally. For stability analyses, most studies assume a steady basic state [9]. Convection, on the other hand, often occurs in evaporative processes until the system enters a steady state. The magnitude of Rayleigh convection or Marangoni convection is largely determined by the fluid depths [10]. Rayleigh convection is proportional to the cube of the fluid depth, and Marangoni convection is directly proportional to the fluid volume, according to previous studies [11]. We may infer that buoyancy-driven convection is more common in deep waters, interfacial tension gradient-driven convection is more common in shallow fluids, and Rayleigh and Marangoni convection can occur at intermediate fluid depths [12]. And, for most convective heat transfer, the corresponding wave number is approximately the same. Even at moderate Rayleigh numbers, the Bow and temperature gelds become unstable in a two-dimensional cavity, exhibiting a fluctuating convective condition similar to that observed for the constant viscosity event [13]. In conclusion, recent research has focused on the volatility of flow and temperature fields induced by changes in viscosity [14]. The variable viscosity effect must be considered when the viscosity of a working fluid is subject to temperature variations or when the temperature differential of the system is high. It may cause a significant error in the heat transfer coefficient if it is ignored [15].

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Since the viscosity have a high influence on the convection process. There is a great need to study the characteristics of the fluid and their reaction based on the variation in the viscosity in Rayleigh-Benard Marangoni Convection.

2. Literature Survey

Varé et al [16] in their paper investigated the context of amplitude equations, Rayleigh–Bénard convection for shear-thinning fluids with temperature-dependent viscosity. The Carreau model describes the fluid's rheological behavior, and the relationship between viscosity and temperature is of the exponential form. Using a multiple scale extension, Ginzburg–Landau equations with non-variational quadratic spatial terms are derived directly from the simple hydrodynamic equations. For various values of the shear-thinning degree, the stability of hexagonal patterns against spatially uniform disturbances (amplitude instabilities) and long wavelength perturbations (phase instabilities) is investigated for different values of the shear-thinning degree α of the fluid and the ratio r of the viscosities between the top and bottom walls. Future work may consider the temperature-dependence of other material properties such as the volumetric thermal expansion coefficient and investigation could be carried out to include side wall effects.

Lopez-Nuñez et al [17], in this article reviews the linear stability of a thermo convective problem in an annular domain. The flow is heated from below, with a linear decreasing horizontal temperature profile from the inner to the outer wall. The top surface of the domain is open to the atmosphere and the two lateral walls are adiabatic. The effects of several parameters in the flow are evaluated. Different kind of competing solutions appear on localized zones of several pairs a dimensional numbers planes appear. The boundaries of these zones are made up of co-dimension two points. Future works to find a new geometry such that the transition between thermos capillarity and thermo-buoyancy would be sharper, in order to better identify the structure coming from these effects.

Chunhui et al [18], in their paper made arithmetical simulations of the thermal–hydraulic performance of the thin metallic layer are carried out to reduce the uncertainties in the heat flux evaluation. Specifically, the Rayleigh-Bénard and Bénard-Marangoni convections are considered in the heat transfer models of the metallic layer. The Trio CFD code is validated for the Bénard-Marangoni convection, then applied into the numerical simulations of the metallic layer with dissimilar top boundary conditions: pure radiative heat transfer, and radiative heat transfer plus positive or negative Marangoni effects. The high temperature profile, mean temperature and focusing effect of the metallic layer are evaluated and compared for various cases. Results show that the Marangoni effects have to be considered for small metallic layer thicknesses. Furthermore, in future work, the layer can be divided into two regions, of which the heat flux correlations can be evaluated independently, giving a better estimation of the heat flux profile.

Yu et al [19], investigated Rayleigh-Bénard convection of a gas-liquid medium near its density maximum was offered in this paper. The influences of the density inversion parameter and Rayleigh number on the flow constancy, flow pattern evolution, and heat transfer ability of Rayleigh Bénard convection were analyzed. The results show that the critical Rayleigh numbers for onsets of a steady convection and an unsteady convection rise with the increase of the density inversion parameter. The flow pattern evolution powerfully relies on the density inversion parameter. As future works the scaling relationship for the average Nusselt number in terms of the density inversion parameter and Rayleigh member is proposed.

Fantuzzi et al [20], in their work showed a new rigorous upper bound on the vertical heat transport for Bénard– Marangoni convection of a two- or three-dimensional fluid layer through infinite Prandtl number. Precisely, for Marangoni number Ma >>1 the Nusselt number Nu is bounded asymptotically by Nu 6 const.

× Ma2/7 (ln Ma) −1/7. In the future, it would be stimulating to investigate logarithmic corrections with negative exponent are provable for other flows, starting with extensions of the basic model considered in this work.

Doering Charles [21], in his paper confounded efforts to discriminate between two competing theories for how boundary layers and interior flows interact to determine transport through the convecting layer asymptotically far beyond onset. In a conceptually new approach, Bouillaut, Lepot, Aumaître and Gallet devised a procedure to radiatively heat a portion of the fluid domain bypassing rigid conductive boundaries and allowing for dissociation of thermal and viscous boundary layers. Their experiments reveal a new level of complexity in the problem suggesting that heat transport scaling predictions of both theories may be realized depending on details of the thermal forcing. As further works new experimental investigations aimed both at independent confirmation and at understanding Prandtl number influence on the empirical scaling function should be stimulated.

[16] the temperature-dependence of other material properties such as the volumetric thermal expansion coefficient and investigation could be considered, for [17] a new geometry such that the transition between thermos capillarity and thermo-buoyancy can be made sharper, in order to better identify the structure, for [18] the layer can be divided into two regions, of which the heat flux correlations can be evaluated independently, giving a better estimation of the heat flux profile, for [19] the scaling relationship for the average Nusselt number in terms of the density inversion parameter and Rayleigh member is only proposed, for [20] it would be stimulating to investigate logarithmic corrections with negative exponent are provable for other flows, starting with extensions of the basic model considered in this work, and for [21] new experimental investigations aimed both at independent confirmation and at understanding Prandtl number influence on the empirical scaling function should be stimulated. To investigate the process in a convection more convincing and detailed evaluation should be developed.

3. Analyzing the Effect of Variable Viscosity on Rayleigh-Benard Marangoni Convection

Rayleigh-Benard-Marangoni convection can occur due to concentration gradients caused by variable viscosity as well as convection caused by temperature variations when the fluid is a binary solution. This difference in viscosity must be taken into account in order to correctly estimate the heat transfer rate. Previous researches have focused solely on the macroscopic roles of viscosity though the real explanation for variations in the majority function is the impact of viscosity on microscopic function. Hence, there is a persuasive and critical need to investigate the impact of viscosity on the different microscopic parameters used to generate Rayleigh-Benard-Marangoni convection and its effects on the fluid in a convection phase. To overcome these issues, the investigation in this research is based on the analysis of natural convection with the numerical Investigation of the Effect of Variable Viscosity on Rayleigh-Benard Marangoni Convection in a Hydro Dynamic Surface. It mainly focuses on the consequences of viscosity variations in the Rayleigh-Benard-Marangoni convection mechanism which induces various physical changes. Initially the relation between the viscosity and surface tension are determined using the Arrhenius equation, which gives the temp dependence on the surface tension, is utilized instead of the Boltzmann constant, and the temperature of viscosity divergence is then equated with the surf temperature. Following that, the viscosity and buoyancy values are related by considering the drag force in Stokes law and using the terminal velocities. Also, the temperature dependence of variable viscosity of fluids with high molecular space is then calculated using Hard-sphere kinetic theory and Power-law force, while that of fluids with low molecular space is determined using Andrade equation and Walther formula, as well as the Wright and Seeton model. The

viscosity is then related to density, and the relationship between them is directly proportional. As a consequence, the effects of variable viscosity are taken into account using the derived equations to describe the effect related to the Rayleigh number and Marangoni number. This study gives a detailed investigation on the effect of variable viscosity on Rayleigh-Benard Marangoni Convection using the fluid dynamic parameters hence an optimum understanding related to the dynamics of the fluid under natural convection can be determined.
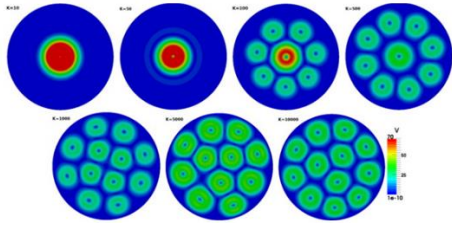
Figure 1: Rayleigh-Benard Marangoni Convection

A temperature difference is imposed normal to the free surface of a thin liquid layer of fluid with unlimited horizontal extension but finite thickness, d. There is no fluid motion in the system's initial steady state and the temperature profile throughout the layer is linear. $U^* = 0$ and $T^* = T_i^* - \beta z^*$ are the simplest expressions for the velocity and temperature. The base flow velocity and temperature are U^* and T^*, respectively, where the asterisk "*" signifies dimensional quantities. The temperature gradient of the base state, is defined as $\beta = \Delta T_d^* / d$ where $\Delta T_d^* = T_i^* - T^*$. The lower surface is stiff and temperature-controlled and the top surface is open to the atmosphere which transfers heat. Although it is widely known that free surface deformation influences the critical temperature differential that leads to fluid motion, this paper focuses on the variable viscosity effect and assumes that the free surface is flat. Because dynamic viscosity is the fluid characteristic that is most affected by temperature, which allows it to fluctuate with temperature, while all other thermo physical variables, like density and surface tension, are also considered.

The Rayleigh–Bénard condition in a liquid is described by the following magneto hydrodynamic equations:

Continuity equation is given by:
$$\nabla . V = 0 \qquad [1]$$

Motion of fluid is given by
$$\rho_0 \left(\frac{\partial v}{\partial t} + V . \nabla V \right) = -\nabla P - \rho(T)g + \mu \nabla^2 v$$
$$[2]$$

Energy equation is given by
$$\rho_0 C_v (\partial T / \partial t + V . \nabla T) = k \nabla^2 T \qquad [3]$$

The velocity vector, temperature, pressure, and time are represented by V, T, P, and t, respectively. The non dimensionalization reference values for length, velocity, temperature, pressure, and time are d, k^*/d, βd, $\rho^* k^*/d^2$, d^2/k^* respectively. The fluid density is ρ^*, while the fluid thermal diffusivity is K^*. The subscript denotes that the characteristics are selected at a lower surface temperature, T. The characteristic value of the fluid's dynamic viscosity, is represented as μ.

Moreover, the study of Rayleigh demonstrates that the mere presence of a temperature gradient is insufficient to assure the initiation of convective movement. The buoyancy created by this gradient must be greater than the dissipative effects of viscous drag and heat diffusion. The buoyant force divided by the product of the viscous drag and the rate of heat diffusion is a dimensionless ratio that describes the relationship between these effects. The Rayleigh number, R, which has the following form:

$$R = \frac{g \, \alpha \Delta T d^3}{\nu \, \kappa} \qquad [4]$$

In the Rayleigh theory, convection begins when the Rayleigh number exceeds a critical value, R_c.

When surface tension is included into the convection equation, a new dimensionless ratio is used in which the surface-tension gradient force is divided by the product of viscous drag and heat diffusion rate. The Marangoni number, M is given by,

$$M = \frac{\gamma \Delta T d}{\rho \nu k} \qquad [5]$$

In the context of this theory, as in the Rayleigh one, convection begins when the Marangoni number exceeds a critical value, Mc.

By dividing both equations, an intriguing link between the Rayleigh number and the Marangoni number can be determined.

$$\frac{R}{M} = \left(\rho \alpha g / \gamma \right) d^2 \qquad [6]$$

Where:

g	acceleration due to gravity
α	coefficient of thermal volume expansion
T	vertical temperature gradient
ν	kinematic viscosity
κ	thermal diffusivity of the fluid
d	thickness of the liquid layer
γ	the temperature derivative of the surface tension
ρ	density at a reference temperature

This equation is taken as a base and the various dependence of the convection microscopic characteristics over the Rayleigh Benard Marangoni convection is determined. The following section elaborates the derivation relating the change of viscosity in the convection process based of four microscopic parameters.

3.1 Relationship of Surface tension and Viscosity

Initially the relation between the viscosity and surface tension are determined. Since there is no direct relationship between the viscosity and surface tension, the Arrhenius equation, which gives the temp dependence on the surface tension, is used instead of the Boltzmann constant, and the temperature of viscosity divergence is then equated with the surf temperature.

The relation between the surface tension and the viscosity proposed by Pelofsky is stated as [22]

$$\ln \sigma = \ln A + B / \eta \qquad [7]$$

where A and B are constants that are substance-dependent. This empirical relationship can be applied to both the organic and inorganic phases of pure and mixed components. Investigations shows that it had Absolute Average Deviation (AAD) values of less than 2% and also more than 20% were discovered for water, oxygen, and deuterium oxide, indicating that the P model is definitely insufficient for these molecules of AAD less than 2% and more than 20%. Instead of which, the MP expression was utilized by which the investigation results can be improved.

$$\ln \sigma = \ln C + D \left[\frac{1}{\eta} \right]^\phi \qquad [8]$$

The substance-dependent coefficients are C, D, and the exponentϕ. This correlation enhanced the outcome over the previous one, owing to the addition of additional adjustable coefficient. The surface tension results were replicated using the MP correlation with AADs of less than 2% and with the worst value being 7.3 percent high.

Also, an alternate version of MP expression can be upgraded in the viscosity calculation:

$$\left(\frac{1}{\eta} \right)^\phi = A_1 + B_1 \ln \sigma \qquad [9]$$

One of the drawbacks of the upgraded formula is that it can't be used simply at the critical point, where the surface tension is zero and the natural logarithm is unknown. As a result, an alternate formulation with a comparable number of adjustable coefficients but omitting the logarithm of the surface tensions is required.

The surface tension-temperature relationship in linear equation can be expressed as

$$\sigma = a + bT \qquad [10]$$

Constants a and b remain substance dependent so it can't be used for wide range fluids. For a wide range of fluids at higher temperatures, the following equation can be used as

$$\sigma = a_1(1 - T_r)^n \qquad [11]$$

The crucial characteristics of fluids, the acentric factor, and the Riedel parameter all can be connected to the coefficient a_1 which can be produced as an adjustable coefficient n.

As a result, the Arrhenius equation is the most widely used equation for explaining the temperature dependence of viscosity which induces the Rayleigh Benard Marangoni effect.

$$\eta = A_0 exp\left[\frac{E_a}{(K_B T)}\right] \qquad [12]$$

Where:

kB   The Boltzmann constant and

Ea   Activation energy for viscous flow

The Vogel-Fulcher-Tamman (VFT) equation is another often used formulation.

$$\eta = \eta_0 exp\left[\frac{DT_0}{(T - T_0)}\right] \qquad [13]$$

Where:

η_0 fluidity constant

D   velocity constant

T_0 Temperature constant.

The ideal glass transition temperature, also known as the temperature of viscosity divergence, is defined as T_0.

When Eq. (10) is substituted for Eqs. (12) and (13), the relationship between surface tension and viscosity is as follows:

$$\ln \eta = A_2 + \frac{B_2}{\sigma + C_2} \qquad [14]$$

This equation, as well as the MP, have three variable coefficients. One of the MP coefficients is an exponential, although only linear coefficients are utilized here. The expression obtained by applying Eq. (11) to Eqs. (12) and (13) is

$$\ln \eta = A_3 + \frac{B_3}{\sigma^{1/n} + C_3} \qquad [15]$$

This equation has four adjustable coefficients, one of which is an exponent n and then A_i, B_i, C_i are coefficients in eq 15. Furthermore, by setting the surface tension to zero at the critical point, they may be utilized to estimate the value of the viscosity at that location. This gives the relationship of surface tension in terms of viscosity. Which can be later on used to derive the changing variable in the Rayleigh Benard Marangoni effect.

3.2 Relationship of buoyancy and Viscosity

Following that, we can relate the viscosity and buoyancy values by considering the drag force in Stokes law and using the terminal velocities.

The following parameters are directly proportional to the viscous force exerted on a sphere:

- The sphere's diameter
- Viscosity coefficient
- The speed of the item

This is expressed mathematically as

$$F \ \alpha \ \eta r \gamma \qquad [16]$$

we get by replacing the proportionality sign with an equality sign.

$$F = k\eta r\gamma \qquad [17]$$

The proportionality constant k is used here. The value of k for a spherical body was found to be 6π in evaluation. As a result, the equation gives the viscous force on a spherical body falling through a liquid.

$$F = 6\pi\eta rv \qquad [18]$$

Which is known as Stokes' law,

where the drag force exerted by a viscous fluid on a sphere of radius r travelling at a velocity of v viscosity in a fluid η. For laminar flow, Stoke's law probably applies in which the drag force on a sphere is proportional to the flow velocity, viscosity of the fluid, and radius of the sphere that can be determined by dimensional analysis.

For example, In the case of droplets, it is gravity that accelerates them at first. The retarding force rises as the velocity increases. Finally, when the viscous and buoyant forces are equal to the gravitational force, the net force and acceleration are both zero. After then, the raindrop falls at a steady speed. As a result, the equation gives the terminal velocity in equilibrium.

$$V_t = \frac{2a^2(\rho - \sigma)g}{9\eta} \qquad [19]$$

where ρ and σ are the sphere and fluid mass densities, respectively. It is clear from the equation that the terminal velocity is proportional to the square of the sphere's radius of fluid and inversely proportional to the medium's viscosity.

Weight downwards, buoyancy upwards, and viscosity upwards are the forces acting on the sphere.

$$Normal\ force\ acting\ downwards = \frac{4}{3}\pi r^3 \rho g \qquad [20]$$

$$Buoyancy\ force = \frac{4}{3}\pi r^3 \sigma g \qquad [21]$$

$$Viscous\ force = 6\pi\eta rv \qquad [22]$$

When the resulting force on the sphere is zero, it reaches its terminal velocity. To find the buoyancy, we need to solve the preceding equation. We get,

$$\frac{4}{3}\pi r^3 \rho g = \frac{4}{3}\pi r^3 \sigma g + 6\pi\eta rv \qquad [23]$$

The velocity at which heat is generated is equal to the rate at which the viscous force does work, which is equal to its power.

$$Buoyancy\ force = \frac{4}{3}\pi r^3 \sigma g + Viscosity \qquad [24]$$

Thus, the relation relating buoyancy and viscosity is derived. This buoyancy changes the viscosity of liquid which in turn reacts with the change in Rayleigh Benard Marangoni convection

3.3 The temperature dependence based on variable viscosity

Temperature has a significant impact on viscosity. In liquids, viscosity typically reduces as temperature rises, but in most gases, viscosity rises as temperature rises. Several models of this dependency are discussed ranging from rigorous first-principles equations for monatomic gases to empirical correlations for fluids.

The molecules crossing layers of flow and transferring momentum across layers cause viscosity in gases. This momentum transfer can be viewed as a frictional force between layers of flow which increases the thermal energy. Increased thermal agitation of the molecules results in a higher viscosity because momentum transfer is generated by free mobility of gas molecules between impacts. As a result, gaseous viscosity rises as temperature rises.

The temperature dependence of variable viscosity of fluids can be different for higher molecular space fluids and lower molecular space fluid. Since the convection process includes both higher and lower molecular space fluids there is a need to predict the value for both the cases. For high molecular space fluid, the dependency is calculated using Hard-sphere kinetic theory and Power-law force, while that of fluids with low molecular space is determined using Andrade equation and Walther formula, as well as the Wright and Seeton model.

The temperature-variation of gaseous viscosity may be accurately calculated using the kinetic theory of gases. The Boltzmann equation and Chapman–Enskog theory provide the theoretical foundation for kinetic theory, allowing for reliable statistical modelling of molecule motions. Given a model for intermolecular interactions, one may determine the viscosity of monatomic and other simple gases with great precision (for more complex gases, such as those composed of polar molecules, additional assumptions must be introduced which reduce the accuracy of the theory).

When gas molecules are modelled as elastic hard spheres (with mass mm and dimension sigma), basic kinetic theory predicts that viscosity rises with the square root of absolute temperature T. The Chapman Enskog Theory defines the temperature dependence as

$$\mu = 1.016 \frac{5}{16\sigma^2} \left[\frac{k_B mT}{\pi} \right]^{1/2} \qquad [25]$$

where k_B is the Boltzmann constant. The $T^{1/2}$ concept, is not accurate in projecting the increase in viscosity of actual gases. More accurate models of molecular interactions, in particular the addition of attractive interactions, which are present in all real gases, are required to capture the true T dependency.

A repulsive inverse power-law force, where the force between two molecules separated by distance r is proportional to $1/_{r^v}$ where v is an empirical parameter, is an improvement of the hard-sphere model. It shows how altering intermolecular interactions changes the anticipated temperature dependence of viscosity.

In this scenario, kinetic theory predicts the temperature rise of Ts, with

$$s = \frac{1}{2} + 2/_{(v-1)} \qquad [26]$$

If μ' is the known viscosity at T', then

$$\mu = \mu' (T/_{T'})^{S} \qquad [27]$$

Where:

μ' Reference Viscosity

T   Static Temperature

The Sutherland model is suggested, which adds weak intermolecular interactions to the hard-sphere model. If the attractions are minor, they can be handled in a perturbative manner, resulting in following equation

$$\mu = \frac{C_1 T^{3/2}}{T + C_2} \qquad [28]$$

C_1, C_2 Coefficient

T   Static Temperature

The coefficient value for air at moderate temperature and pressure can be given as

$C_1 = 1.458 * 10^{-6}$

$C_2 = 110.4$ K

where S, also known as the Sutherland constant, may be defined in terms of the intermolecular attractive force parameters. In other words, if mu' is a known viscosity at temperature T', then

$$\mu = \mu' \left(\frac{T}{T'} \right)^{3/2} \frac{T' + S}{T + S} \qquad [29]$$

μ' Reference value = $1.716 * 10^{-5}$

T' Reference temperature = 273.11 K

S   Sutherland constant = 110.56 K

In general, it has been suggested that the Sutherland model is a poor description of intermolecular interactions, and that it is only effective as a basic interpolation formula for a small number of gases across a small temperature range.

The kinetic theory prediction for μ may be expressed in the form under reasonably broad circumstances on the molecular model.

$$\mu = A \frac{(mk_B T)^{1/2}}{\sigma^2 \Omega T} \qquad [30]$$

σ bonding energy of the molecule

m   mass

kB   Boltzmann constant

T   temperature

where Ω is referred to as the collision integral and is a function of temperature as well as the intermolecular interaction constants. The kinetic theory, which is stated in terms of integrals over collisional trajectories of pairs of molecules, determines it entirely. Ω is a complex function of temperature and molecular characteristics in general; the power-law and Sutherland models are unique in that Ω may be described using simple functions. As a result, the model is optimized for molecules that are spherically symmetric. It is, nevertheless, commonly employed for non-spherically symmetric molecules that do not have a significant dipole moment.

Generally, viscosity is generated by molecules exerting attractive forces on one another across layers of movement in liquids. Because bigger temperatures imply particles have more thermal energy, they are more easily able to overcome the attraction forces holding them together, increasing temperature causes viscosity to drop. Unlike gases, liquid viscosity does not have a systematic microscopic theory. However, based on existing experimental viscosities, some empirical models deduce a temperature relationship.

Andrade equation is a two-parameter exponential which is efficient and commonly used as an empirical correlation for liquid viscosity. It precisely characterizes a wide variety of liquids at various temperatures. Its shape can be explained by modelling molecular momentum transfer as an activated rate process, however the physical assumptions behind the model has been further investigated.

$$\mu = Ae^{B/_T} \qquad [31]$$

The preceding equation is only used for two parameter exponentials, but it may be extended to include more parametric exponentials as

$$\mu = Aexp \left(\frac{B}{T - C} \right) \qquad [32]$$

Furthermore,

$$\mu = Aexp \left(\frac{B}{T} + CT + DT^2 \right) \qquad [33]$$

μ Viscosity

T Temperature Dependence

A, B, C, D Free parameters determined by least square analysis

Thus, the equation gives the derivation for dependence of temperature on viscosity for both high molecular space and higher molecular space fluids.

3.4 The density based on variable viscosity

The viscosity is then related to density, and the relationship between them is directly proportional. A fluid's density is computed by dividing the mass of the fluid by the volume of the fluid. The standard unit of density is kilograms per cubic meter.

$$Density = \frac{mass}{volume} \qquad [34]$$

The resistance to flow of a fluid is described by its viscosity. The rate of shear strain is divided by the shear stress to get dynamic viscosity which is also known as absolute viscosity.

$$Dynamic\ viscosity = \frac{force}{area \times time} \qquad [35]$$

The flow of a known volume of fluid from a viscosity measurement instrument is sometimes used to determine viscosity. The timings can be used with a formula to get the fluid's kinematic viscosity value. The head of fluid is the pushing force that propels the fluid out of the container. This fluid head is also a part of the equation that determines the fluid's volume. When the equations are

rationalized, the fluid head element is removed, leaving the units of Kinematic viscosity as

$$Kinematic\ viscosity = \frac{area}{time} \qquad [36]$$

The relation between the viscosities and density is derived by the following equation

$$Kinematic\ viscosity = \frac{Dynamic\ viscosity}{Density}$$
$$[37]$$

It is clear that the viscosity and density are directly proportional to

$$\frac{area}{time} = \frac{\frac{force}{area \times time}}{\frac{mass}{volume}} \qquad [38]$$

This can also be derived as,

$$\frac{area}{time} = \frac{force}{area \times time} \times \frac{volume}{mass} \qquad [39]$$

As a consequence, the effects of variable viscosity based on surface tension, buoyancy, temperature dependence and density are taken into account using the derived equations. These equations are given to the Rayleigh Benard Marangoni equation thereby the effect related to the Rayleigh number and Marangoni number are obtained and graphs are determined relating the change in convective characteristics.

The study thereby discovered that solutions with a viscosity greater than 10-3 Pa s (water) have either less or the same surface tension as water, and it is assumed that this is due to the fact that the intermolecular bonding (hydrogen bonding) between water molecules remained stable as viscosity increased, causing surface tension. The critical Rayleigh number for the onset of convection has been decreased significantly from its standard estimate. Furthermore, it is discovered that the slip velocities for normal and forced convection are similar. The research has also discovered that the viscoelastic effect can cause an oscillatory instability, while in the absence of it, only a monotonic instability occurs. As a result, the importance of convection is readily apparent. This study gives a detailed investigation on the effect of variable viscosity on Rayleigh-Benard Marangoni Convection using the fluid dynamic parameters hence an optimum understanding related to the dynamics of the fluid under natural convection can be determined.

4. Result and Discussion

This section provides a detailed description of the implementation results as well as the performance of the proposed system and comparison section to ensure that the proposed system analyzes efficiently.

4.1 Experimental Setup

This work has been implemented in the working platform of MATLAB with the following system specification and the simulation results are discussed below,

Platform : Matlab2018b

OS   : Windows 7

Processor: 64-bit Intel processor

RAM   : 8GB RAM

4.2 Implementation Results

This section deals with various results obtained by the evaluation of the Rayleigh Benard- Marangoni convection process due to variable viscosity at different time.
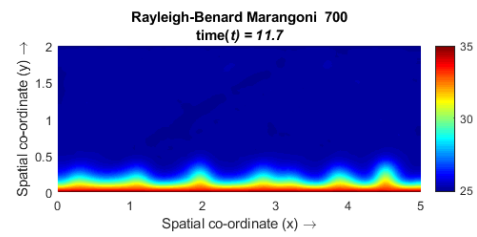

Figure 2: Rayleigh-Benard Marangoni convection at 11.7 secs

The above fig depicts the reaction of a fluid under Rayleigh-Benard Marangoni convection. At 11.7 min the convection process tends to start from the direction of heat flow. The red colour depicts max heat and blue represents minimum heat.
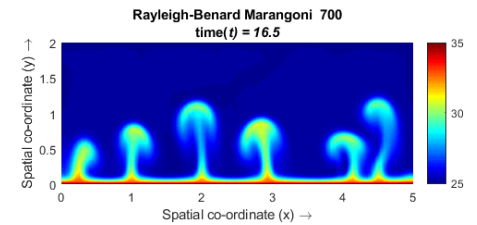

Figure 3: Rayleigh-Benard Marangoni convection at 16.5 secs

The above image depicts the Rayleigh-Benard Marangoni convection at 16.5 secs. The heat is transferred slowly to the upper molecules via conduction process.
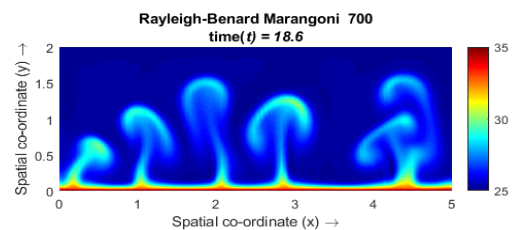

Figure 4: Rayleigh-Benard Marangoni convection at 18.6 secs

The heat is transferred to the upper boundary at 18.6 secs and the changes in the molecules of fluid due to buoyancy, surface tension, temperature gradient and density is clearly visualized in the Rayleigh-Benard Marangoni convection process.
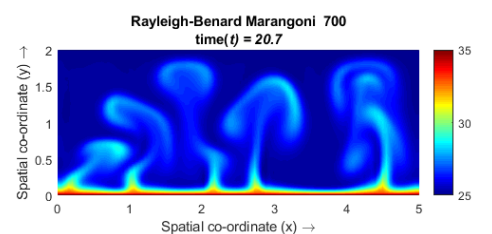

Figure 5: Rayleigh-Benard Marangoni convection at 20.7 secs

The above image shows the transformation in next 2 secs. It is clear that the whole molecules attain a gradual convection structure as time increases.
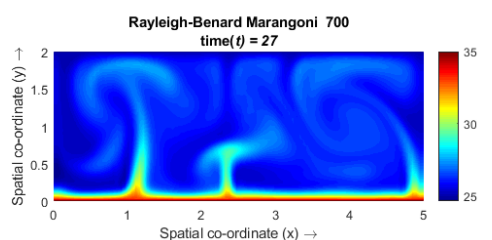

Fig 6: Rayleigh-Benard Marangoni convection at 27 secs

This image depicts the flow of heat in convection in a fluid at 27th sec at constant temperature maintaining the Rayleigh-Benard Marangoni number at 700.
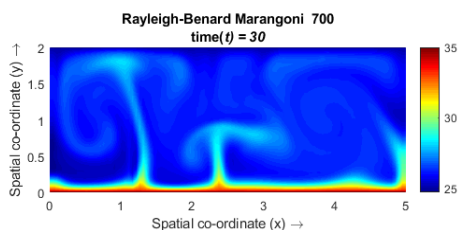

Figure 7: Rayleigh-Benard Marangoni convection at 30 secs

This image depicts the continuous flow of the fluid molecules due to surface tension and buoyancy. The structure is continually makes the whole molecules heated till the equilibrium is attained.
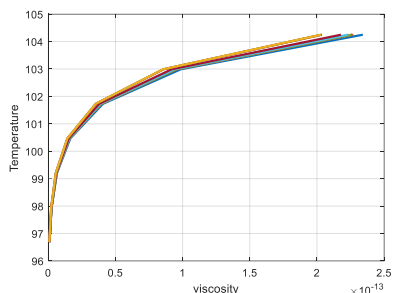

Figure 8: Variation in temperature based on viscosity

Temperature changes as the viscosity changes. The above picture depicts that as the temperature increases the viscosity also increases. Initially the increase is large but as the viscosity attains a limit the viscosity starts to increase gradually.
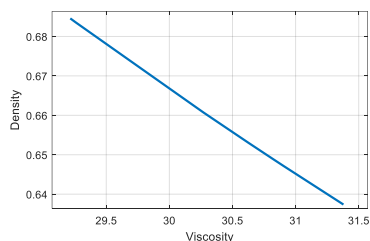
Figure 9: Variation in density based on viscosity

This graph clearly shows that the viscosity drops down so the density is indirectly proportional to viscosity. As density increases the viscosity decreases constantly.
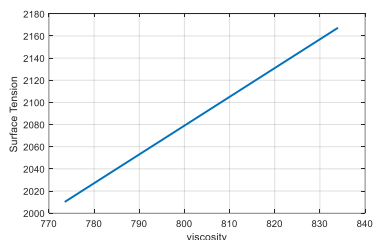

Figure 10: Variation in surface tension based on viscosity

This graph shows that surface tension and viscosity is directly proportional to each other. As the surface tension increases viscosity also increases constantly.
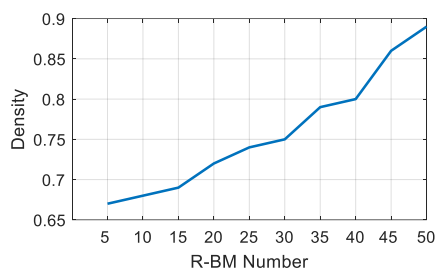

Figure 11: Graph relating density and Rayleigh number

The density of the molecules in fluid is compared with the change in RayleighBénard Marangoni number. The RayleighBénard Marangoni number increases as the density of the fluid is increased.
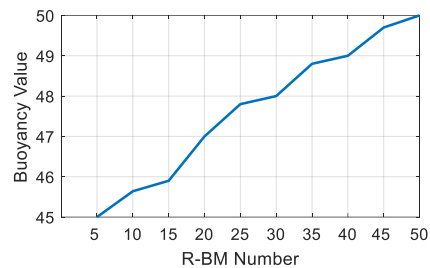

Figure 12: Graph relating buoyancy and Rayleigh number

The change in RayleighBénard Marangoni number is compared to the buoyancy of molecules in fluid. As the buoyancy of the fluid increases, the RayleighBénard Marangoni constant grows.
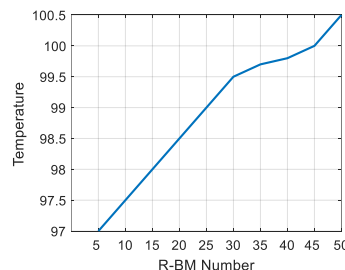

Figure 13: Effect of temperature on Rayleigh-Bénard Marangoni convection

The change in RayleighBénard Marangoni number is compared to the temperature of molecules in fluid. As the temperature of the fluid increases, the RayleighBénard Marangoni constant grows.
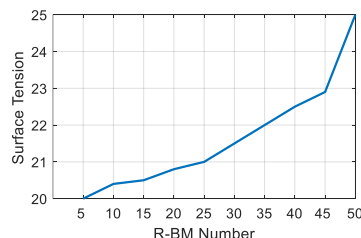

Figure 14: Effect of surface tension on Rayleigh-Bénard Marangoni convection

The RayleighBénard Marangoni number is compared to the surface tension of molecules in fluid. As the surface tension of the fluid rises, the RayleighBénard Marangoni number rises as well.
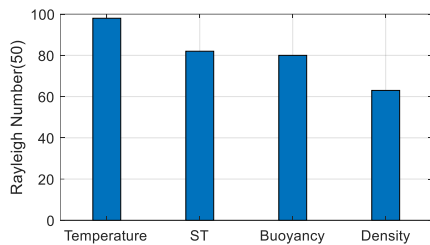
Figure 15: Comparing the parameters affecting convection

The influence of temperature, Surface tension, buoyancy and density on convection process is compared. The results show that temperature affects highly when compared to others and density effects minimum than others.
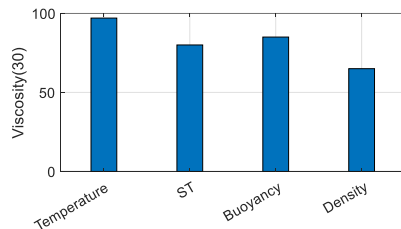

Figure 16: Parameters influence on viscosity

The influence of temperature, Surface tension, buoyancy and density on viscosity is compared. The results show that temperature affects highly when compared to others and density effects minimum than others.

5. Conclusion

In this study, the impact of different indicators on fluid dynamics is explored. The physical properties are mostly concerned with changing viscosity with a flat open boundary condition. The interface between two fluid layers is examined. The study shows that surface tension is exactly proportional to viscosity when evaluating the features of surface tension as viscosity changes. The density, on the other hand, is related to the viscosity indirectly. When examining the temperature gradient, the temperature rises quickly as the viscosity increases, but then gradually shifts and maintains a limit until equilibrium is reached. The buoyancy of a fluid fluctuates with its density as its viscosity changes. Thus, the Rayleigh-Benard and Marangoni convection processes is studied and the intermolecular behavior-based changes are predicted, and the results are displayed. In overall research it is found that with changing viscosity, temperature has the greatest impact of 99% while density has the least of 60%.

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