Experimental Investigation on Natural Convection Heat Transfer Enhancement Using Transformer Oil-TiO_2 Nano Fluid

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Abstract - *Natural convective heat transfer along a vertical cylinder immersed in transformer oil–TiO_2 nanofluids for various concentrations (0, 0.05, 0.1, 0.15, 0.2vol %) under constant heat flux condition was investigated experimentally and presented. Thermal stratification was observed outside the boundary layer in the ambient fluid after steady-state condition is achieved as the fluid temperature goes on increasing along the axial direction. Temperature deviations of the cylinder along the axial direction and temperature variations of fluid in radial direction are shown graphically. It is observed that the temperatures of the cylinder and the fluid increases along the axial direction and the fluid temperature decreases in the radial direction. Experiments were conducted for various heat inputs (30 W, 40 W, 45 W and 50 W) and volume concentrations and observed that the addition of titanium oxide nanoparticles up to 0.15 vol % enhances the thermal performance and then the further addition of nanoparticles leads to deterioration. The maximum enhancement in the natural convection heat transfer performance is observed as 16.8%, i.e., heat transfer coefficient is increased from 356.172 w/m^2k to 670.465 w/m^2k at 0.15vol %.*

***Key Words*: Natural Convection, Heat Transfer, Constant Heat Flux, Thermal Stratification, Transformer Oil-TiO_2, Nanofluids**

1. INTRODUCTION

Conventional heat transfer fluids such as water, engine oil, kerosene, ethanol, transformer oil, ethylene glycol have lower thermal conductivity compared to solids. Lower thermal conductivity of fluid became an obstacle to use in different applications. To overcome this obstacle, a new method such as dispersing Nano sized solid particles in the base fluids, which enhance the thermal conductivity of the base fluids significantly and it is named as Nano fluids. It is a challenge to remove heat efficiently from fast moving devices such as computers, power electronics, automobile engines, refrigerators, air conditions, etc. But in Earlier, researchers dispersed the micro-sized metallic particles (or) Nano particles into the base fluids to enhance the thermal properties of the base fluids but it has many drawbacks such as poor stability, erosion of the equipment, moderate enhancement. Choi et..al [1] Dispersed the nano-sized metallic particles of less than 100 nm size into the base fluid and prepared the nanofluids for the first time and observed the improvement in the thermal performance of it. Buoyancy-induced free convective heat transfer got much interest these days in engineering applications such as electronic cooling, heat ventilation and air conditioning, vapour absorption refrigeration, and nuclear reactor moderation. In order to increase the heat transfer performance of the fluid, nanoparticles in little quantity will be added to the carrier fluid. In various past researches [2–9], Nanofluids consisting of such particles suspended in liquids (typically conventional heat transfer liquids) have been shown to enhance the thermal conductivity and convective heat transfer performance of the base liquids.The thermal conductivities of the particle materials are typically an order-of-magnitude higher than those of the base fluids such as water, ethylene glycol, and light oils, and nanofluids, even at low volume concentrations, resulting in significant increases in thermal performance. Nnanna[10] experimentally investigated the natural convection heat transfer behaviour of Al_2O_3/water nanofluids with various volume fractions ranging from 0 to 8%. In their study, test cell is a 2D rectangular enclosure with heated vertical and cooled horizontal adiabatic walls and performed the steady-state and unsteady-state analysis and observed that trend of temperature profiles is similar for base fluid and nanofluid and also observed the heat transfer enhancement for the smaller volume fractions0.2% ≤ Ø ≤ 2% and the deterioration in the performance at higher volume fractions Ø>2%. Masuda et.al [11] studied the thermo physical properties of the metallic oxide particles (Al_2O_3 and TiO_2) dispersed in water. The transient hot-wire method was used for measuring the thermal conductivity of nanofluids. They reported that the thermal conductivity of nanofluids was significantly larger than the base liquid. For example, the thermal conductivity of Al_2O_3-water nanofluids and TiO_2-water nanofluids at a 4.3vol% were approximately32% and11% higher than that of base liquid, respectively. Wen and Ding [12], Dongsheng [13] formulated the water-based TiO_2 nanofluids by dispersing the nanoparticles in de-ionized water and got the stable suspension with the help of high shear homogenizer and they tested it in the horizontal cylindrical enclosure for determining the natural convective heat transfer at various heat inputs and observed the deterioration in the heat transfer performance in case of nanofluids. Prasad et.al [14] experimentally investigated the natural convection heat transfer performance of water-based Nano-fluids and a dimensionless equation based on the experimental data is suggested for the calculation of Nusselt number with respect to Rayleigh number. Rajesh and Sudhakar [15] performed a study on turbulent natural convection heat transfer in an enclosure for various aspect ratios from 0.3 to 2.5 using Al_2O_3/water nanofluids and it is observed that the augmentation at lower con-cent rations and deterioration at higher concentrations of nanoparticles. Hadi et.al [16] performed the characterization and stability analysis of alumina/water Nano fluid and experimentally invest- gated the natural convective heat transfer at various volume con- cent rations of Nanofluid in a rectangular cavity, which is differentially heated the vertical walls opposite each other and observed an enhancement in the heat transfer up to 15% compared to water at 0.1% volume concentration and after that addition of nanoparticles decreases the performance. Seyyadi et.al [17] estimated the natural convective heat transfer performance using Cu–water Nanofluid in an annulus and results show that the Nusselt number increases with increase in aspect ratio. Xiangyin and Yan [18] Numerically investigated the natural convection heat transfer in a horizontal cylinder filled with Al_2O_3–water Nanofluid in the range of 1–4% volume concentrations and observed the increment in Nusselt number for higher Rayleigh number. Omer et.al [19] Simulated the natural convection heat transfer in a con-centric horizontal annulus using SiO_2 Nanofluid, investigated the effect of Rayleigh number and hydraulic radius, and observed that the average Nusselt number increases with Rayleigh number and hydraulic radius ratio as well. Ravi Babu and G.S.Rao [20] Conducted the experiments to find the natural convective heat transfer performance along a vertical cylinder immersed in water as well as water+ EG blend and also using Al_2O_3–water Nanofluid [21] .

1.1 Synthesis and Characterization of Nanofluids

Two-step method is employed for preparing the titanium Nanofluids. TiO_2 nanoparticles (99.9% purity) were procured from Nano Labs, India and the manufacturer stated that the purchased alumina particles with average size 30–50 nm were having specific surface area of 200–220 m^2/g, bulk density of 0.15-0.25 g/cm^3, and true density of 4.01 g/cm^3. Titanium oxide nanoparticles were dispersed into the transformer oil in the required proportion corresponding to the volume fraction of a Nanofluid and performed the magnetic stirring. The amount of the nanoparticles to be added to the base fluid for making the Nanofluid can be determined from the following equation:

$$\text{Volume fraction} = \frac{V_{np}}{V_{np}+V_{bf}} = \frac{M_{np}/\rho_{np}}{M_{np}/\rho_{np}+M_{bf}/\rho_{bf}}$$

After magnetic stirring, The Nanofluid is then sonicated using an Ultrasonic sonicator (Oscar 179electronics make) at 20 kHz frequency for an optimized sonication time span of 3 h to get the stable suspension.

2. EXPERIMENTAL SETUP

The test setup is having various segments such as test section, which is an Aluminium square prismatic enclosure, which contains the test liquid either base fluid or Nanofluid, Brass tube of 10.2mm diameter and 250mm length, a cartridge type of tubular heater which is having same length as brass tube, Outer galvanized iron shell with cooling water in and out arrangement, Cr–Al type thermocouples of Teflon coated to resist the temperature effects, instrumentation panel with dimmer stat or variac to vary the heat input, voltmeter, ammeter, digital temperature indicator. Photographic and schematic views of the experimental setup are shown in Fig.3. All the thermocouples were calibrated with constant temperature bath at different temperatures and obtained the error less than 0.1% . In order to minimize the loss of heat and to con-duct the full amount of heat from heater to the brass tube, magnesium oxide (MgO) is filled in the gap between the heater and brass tube. Test liquid is filled till the vertical brass tube is completely immersed in it. Thermocouples are mounted by brazing them on the metal tube at uniform intervals and kept open at the same heights in the liquid.

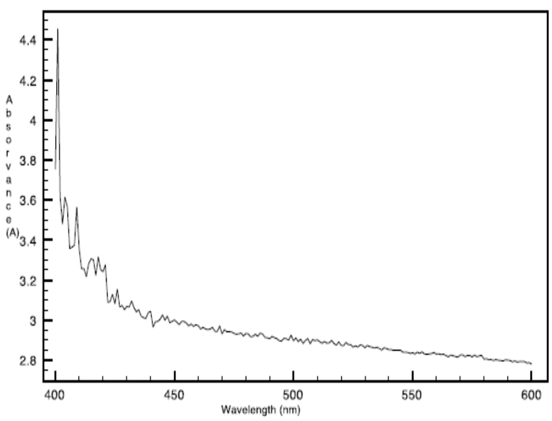

Fig-1: UV-Vis spectrophotometer reading of TiO_2 nanopartcles

All the thermocouples are connected to the digital temperature indicator to indicate the temperature readings before doing the experiments, all the rotating equipment like fans, which cause pressure difference, were switched off. Desire power supply was given to the heater by adjusting the variac so that the vertical cylinder is heated at uniform heat flux. At a certain heat input, the bulk fluid temperature at a point, which is beyond the boundary layer region, was made steady by regulating the flow rate of water in the outer galvanized iron shell. The regulation of cooling water flow rate is done in such a way that the increase in enthalpy of cooling water compensates the heat input, which was giving to the cylinder. For the heat inputs given from 30 W to 50 W, the flow rate of cooling water is varied from 1.43 l pm to 2.23 l pm [20]. All things considered, whatever the heat input is given to the metallic cylinder will be carried away by the cooling water circulation and thereby steady-state condition is achieved. When steady-state condition is occurred, the readings of vertical brass cylinder surface temperatures at different positions and bulk fluid temperatures were noted down [21].

3. RESULTS AND DISCUSSION

Experiments were carried out at different heat inputs by regulating the voltage supply with the help of varies. Heat inputs given to the cylinder are 30 W, 40 W, 45W, and 50W.

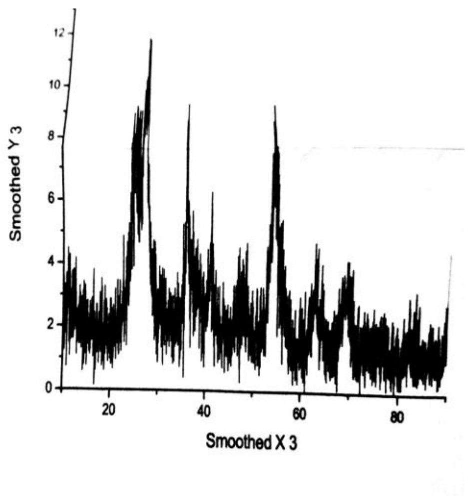

Fig -2: XRD analysis of TiO_2 nanoparticles

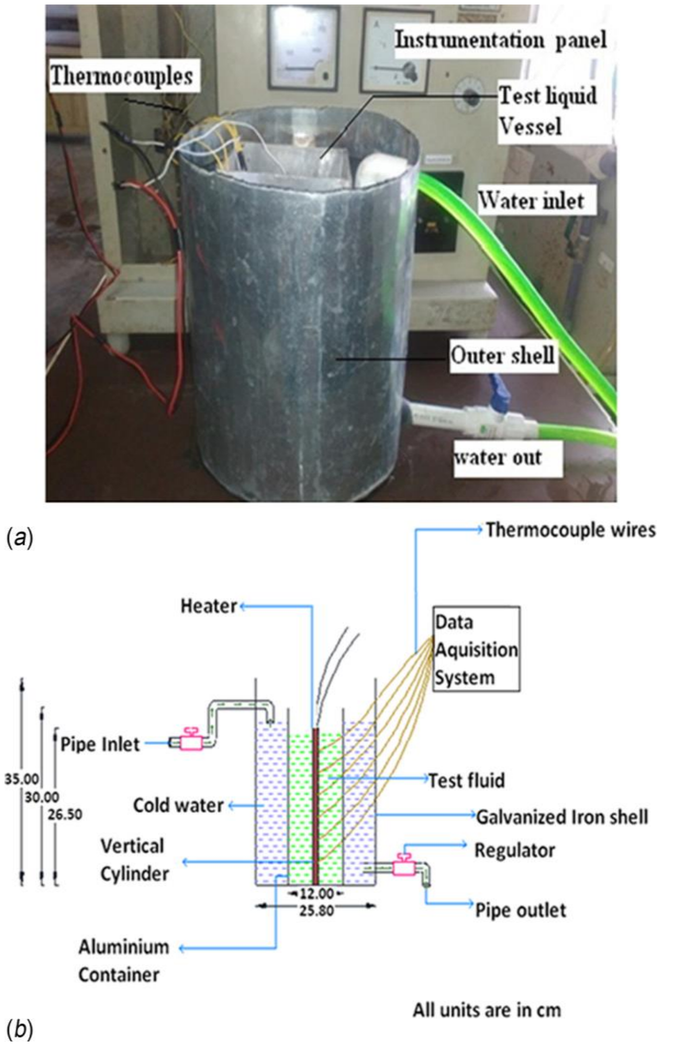

Fig -3: Experimental setup [20]

The surface temperatures of the brass vertical cylinder are measured with the help of thermocouples in the axial direction for transformer oil-TiO_2 nanofluid at 0.15 vol %, nanofluid at 0.15vol % as medium is shown in Figs. It is identified that the surface temperature of the cylinder in the axial direction is increased for any heat input, due to high local heat transfer coefficients occurring at the bottom portions of the cylinder. All the thermo-physical properties of the test fluid are calculated at the film temperature, which is the average surface temperature of the cylinder and the bulk temperature of the fluid and is presented in Eq. Bulk temperature of the fluid is calculated by Fig-1 UV-Vis spectrophotometer reading of TiO_2 nanoparticle XRD Analysis of TiO_2 nanoparticles Fig- 2

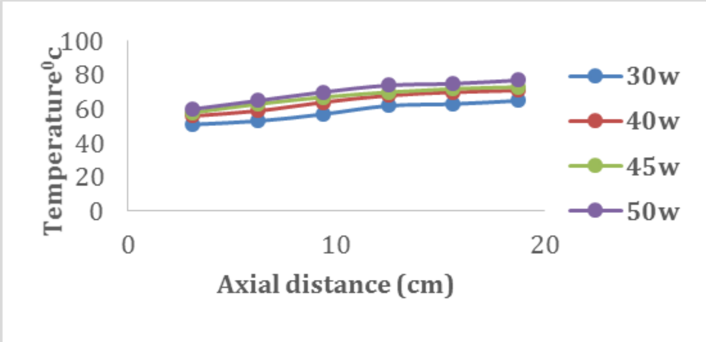

Chart -1: Surface temperature of vertical cylinder along axial direction for transformer oil –TiO_2 at 0.15 vol%

Taking the average temperature of the fluid at the thermocouple locations (which are away from the boundary layer), which are exactly at the same height from the bottom wall of the container compared to the thermocouples attached to the vertical brass cylinder.

$$\text{Film temperature} = \frac{T_s+T_f}{2}$$

Local heat transfer coefficients at different positions are calculated at the points where thermocouples are located. The local heat transfer coefficient is calculated by using Eq. Here, x indicates the position of thermocouple from the bottom of the cylinder.

$$h_x = \frac{Q}{A(\Delta T_x)}$$

T_{s1}, T_{s2}, T_{s3}, T_{s4}, T_{s5}, T_{s6} are the temperatures of the surface at six thermocouple positions and T_{f1}, T_{f2}, T_{f3}, T_{f4}, T_{f5}, and T_{f6} are the temperatures of the fluid at the corresponding height [21].

Local heat transfer coefficient

$$h_{x1} = \frac{Q}{A(T_{s1}-T_{f1})} \qquad h_{x2} = \frac{Q}{A(T_{s2}-T_{f2})} \text{ etc...}$$

Local Nusselt Number $NU_{x1} = \frac{h_{x1} \times x}{k}$

Where T_s is the average surface temperature and T_f is the average fluid temperature. The variation of local heat transfer coefficients in the axial direction is shown in Chart-1. It is understood that the local heat transfer coefficient is higher at the bottom and it is lower at the top of the cylinder. As the boundary layer thickness is very less in the bottom portion, the local heat transfer coefficient will be higher and as it goes ahead to top segment, the thickness of the boundary layer will be more; because of this, lesser heat transfer coefficients might be seen there. Local Nusselt number is calculated from Eq.. The variation of local Nusselt number along the axial direction is depicted in Chart-3.It is identified that the local Nusselt number augments as the length increases and for all the heat contributions to an instance of water as the medium. The thermal stratification is recognized in the mass liquid as the temperature of the liquid at a point which is far from the boundary layer and continues increasing from base part to the top segment. The variation of temperatures along radial direction when the mediums are transformer oil–TiO_2, respectively, is depicted in Chart-2, and it is observed that at the cylinder surface and the wall of the container, there is a precarious change in the temperature on account of the solid and fluid interface and furthermore distinguished the lower temperatures of the fluid in radial directions.

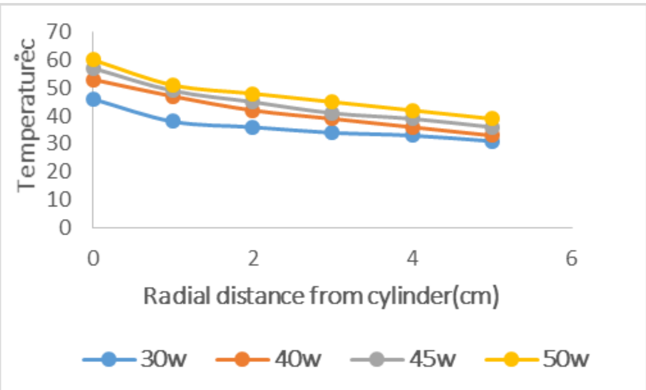

Chart-2: Temperature distribution in the radial direction at mid-die of the cylinder for transformer oil – TiO_2 nanofluid at 0.15 vol%

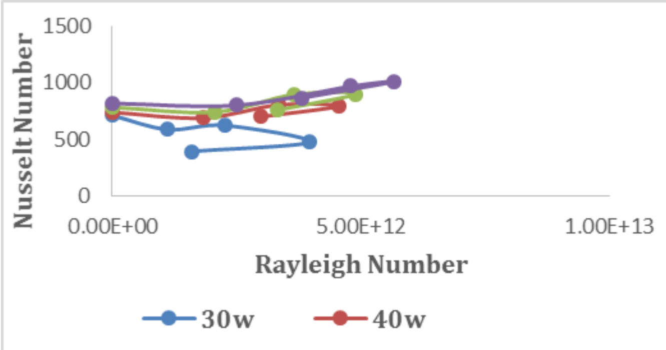

Chart-3: Variation of Nusselt number with Rayleigh number for various heat inputs

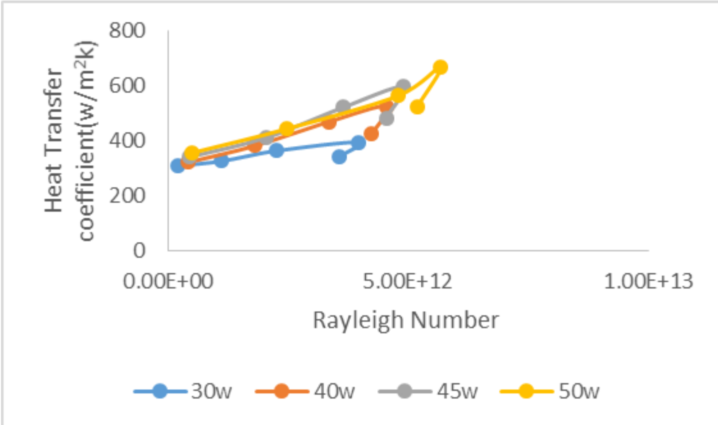

Chart-4: Variation of heat transfer coefficient with Rayleigh number for different heat inputs

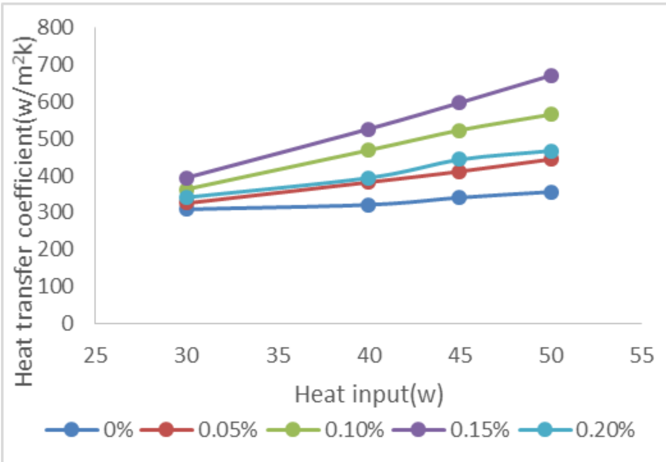

Chart-5: Variation of heat transfer coefficient with heat input various concentration of nano fluid

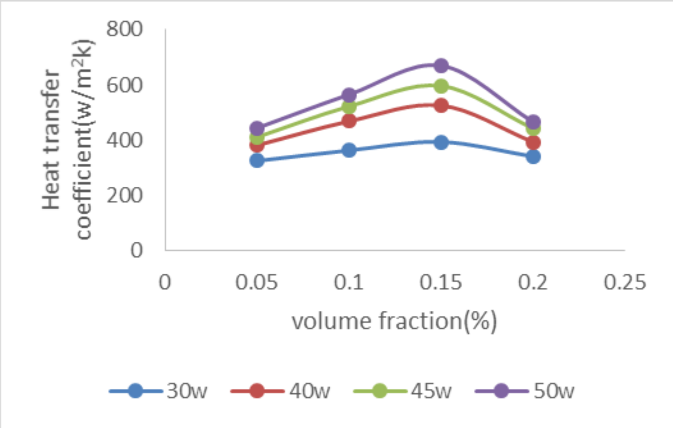

Chart-6: Various heat transfer coefficient with volume fraction of nano fluid for a different heat inputs

After validating the experimental setup, experiments were con-ducted using transformer oil–TiO_2 nanofluid with different concentrations ranging from 0 to 0.2 vol % at various heat inputs such as 30 W, 40 W, 45 W, and 50 W. The variation of the average heat transfer coefficient with respect to volume fraction of TiO_2 nanoparticles is shown in Chart-6, and it is observed that the average heat transfer coefficient is augmented up to 0.15 vol % concentration and then starts decreasing with further addition of nanoparticles. The enhancement in the thermal performance is due to the fact that at lower concentrations, the performance is more dependent on thermal conductivity and at higher concentrations, it will depend on the viscosity rather than thermal conductivity. Rayleigh Number is determined from the following relation

Rayleigh number Ra = Gr.Pr = $\frac{g\beta L^3 \Delta T}{v^2} . \frac{\mu c_p}{K}$

The properties of the nanofluid are determined from the models taken from literature.

Density of nanofluid $\rho_{nf} = \emptyset\rho_p + (1-\emptyset)\rho_f$

Specific heat of nanofluid = $\frac{(1-\emptyset)(\rho c_p)f + \emptyset(\rho c_p)p}{(1-\emptyset)\rho_{nf} + \emptyset\rho_p}$

Dynamic viscosity $\mu_{nf} = \mu_f(1 + 2.5\emptyset)$

Thermal conductivity $k_{nf} = \frac{k_p + 2k_f + 2(k_p - 2k_f)\emptyset}{k_p + 2k_f - (k_p - 2k_f)\emptyset}$

4. CONCLUSIONS

The buoyancy-induced free convection steady-state heat transfer of a vertical cylinder heated uniformly has been explored in this study and presented for various heat fluxes. Surface temperatures of the cylinder along the axial directions in case of transformer oil– TiO_2 nanofluid as mediums are examined and presented

1) It is identified that in case of transformer oil –TiO_2 nanofluid the surface temperatures were recorded 9 to 12% lower than the temperatures when base fluid transformer oil as medium

2) Natural convective heat transfer performance is augmented up to 0.15 vol % concentration of Tio_2 nanopar-ticles and then it is decreased after 0.15 vol % even it worse than the carrier fluid at higher concentrations.

3) The natural convective heat transfer is enhanced by 16.8% at 0.15 vol % concentration compared to transformer oil at 50 W heat input as heat transfer coefficient is increased from 356.172w/m^2k to 670.465w/m^2k.

Nomenclature

C_p = specific heat (J/kgk)

g =acceleration due to gravity (m/s^2)

Gr = Grashof number

h = heat transfer coefficient (w/m^2k)

K = thermal conductivity (w/mk)

L =length of the cylinder (m)

Nu =Nusselt number

Pr = Prandtl number

Ra = Rayleigh number

T = temperature (^{0}C)

V = volume of the fluid (m^3)

β = coefficient of thermal expansion (K^{-1})

μ = dynamic viscosity (Kg/ms)

ρ = density (kg/m^3)

v = kinematic viscosity (m^2 /s)

Ø = nanoparticle volume fraction

Subscripts

bf = base fluid

f = fluid

nf=nanofluid

s = surface

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