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SIMULATION STUDIES IN INTERNAL FLOWS WITH VORTEX GENERATORS AND NANOFLUID

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Abstract: Heat transfer augmentation is the process of improving the rate of heat transfer in industrial applications. In the recent past research attempted for various augment techniques are discussed with emphasis on vortex generators. VGs introduced in the later 1990s, a significant method with introduction of winglet type geometries in internal flow creates vortices and due to turbulence, there are significant change in the heat transfer properties. The state-of-the-art on research and applications of one such type of OVGs are discussed in this study. The present work focuses on the simulation studies with OVGs with their positions are altered to study their influence of OVGs orientation on heat transfer. Thermal analysis is carried out using ANSYS R22 software with air and Graphene dispersed in water as nanofluid with volume concentrations ranging from 2%, 3% and 4% respectively. The fluid flow considered is in the range from (Re = 4000 to 12000) and the results indicates that vortex generator of spacing of 2 mm with 4% volume concentration graphene water nanofluid yielded optimum results as compared with other geometries and volume concentration of nanofluid.

Keywords: *Vortex Generators, Augmentation techniques, Winglet, Graphene.*

Nomenclature

m	Length (meter)	W	Watt
A	Surface Area (m^2)	kW	Kilowatts
P	Pressure (Pa)	K	Kelvin
T	Temperature (K)	D_h	Hydraulic diameter, m
v	Average Velocity of fluid, m/s	Δp	Pressure Drop (Pa)
kg	Kilograms	k	Thermal Conductivity (W/m-K)
h	Heat Transfer Coefficient (W/m^2-K)	Cp	Specific heat (J/kg-K)
Nu	Nusselt number		**Abbreviation**
Re	Reynolds number	VG	Vortex Generator

Gr	Grashoff number
f	Friction Factor

Greek letters

α	Angle of attack (º)
Δ	Delta
μ	viscosity (kg/m-s)
ρ	Density (kg/m^3)
λ	Lambda
Ω	Omega

LVG	Longitudinal Vortex Generator
TVG	Triangular Vortex Generators
OVG	Ogive Vortex Generator
DPHE	Double pipe heat exchangers
Nf	Nano fluids
ARW	Angle winglet pair
RWP	Rectangular winglet pair
CARW	Curved angle rectangular winglet
SST	Shear stress transport
CFD	Computational Fluid Dynamics

1.INTRODUCTION

The study of improved heat transfer performance is referred to as heat transfer *augmentation, enhancement,* or *intensification*. In general, this means an increase in heat transfer coefficient. Attempts to increase "normal" heat transfer coefficients have been recorded for more than a century, and there is a large store of information. A survey [Bergles et al. (1991)] cites 4345 technical publications, excluding patents and manufacturers' literature. Heat transfer augmentation is the process of improving the rate of heat transfer in various industrial applications. Chao Liu et al. [1] experimentally determined the behaviors of improved Heat transfer and the associated higher pressure drop for liquid flow in rectangular microchannel with longitudinal vortex generators (LVGs) were determined experimentally. It was found that the range of critical Reynolds numbers (600–730) were at a much smaller value by adding LVGs than the one without (Re ~ 2300). Anupam Sinha et.al [2] Simulated the air flow through fin-tube type heat exchangers with rectangular winglet pairs (RWP) of half the channel height as vortex generators (VG). The heat transfer characteristics of the heat exchangers with vortex generators located near the tubes have been compared among the cases with varied angles of attack and orientations of tubes. There is an increasing trend of the above for the in-line row of tubes; whereas with the staggered row of tubes, there is slight deviation of this trend. Babak Lotfi et.al [3] numerically investigated a three-dimensional CFD numerical simulation successfully on thermo-hydraulic characteristics of a new smooth wavy finand-elliptical tube (SWFET) heat exchanger with three new types of vortex generators (VGs), namely–rectangular trapezoidal winglet (RTW), angle rectangular winglet (ARW) and curved angle rectangular winglet (CARW). Several parameters have been examined in his study. Results are analyzed from the viewpoint of the field synergy principle which emphasizes that the reduction of the synergy angle between velocity and fluid temperature gradient is the principal mechanism for enhancement of heat transfer performance. Ya-Ling He [4] numerically investigated the heat transfer enhancement and pressure loss penalty for fin-and-tube heat exchangers with rectangular winglet pairs (RWPs) in a relatively low Reynolds number flow. Purpose of his study was to explore the fundamental mechanism between the local flow structure and the heat transfer augmentation. Man-Wen Tian et.al [5] focused his research on the use of two semi longitudinal non central vortex generators (instead of conventional single centrally configuration) as shown in fig 1.1. Triangular-winglet type of vortex generator is selected for 3-D validated numerical study. Sidhartha Das et.al [6] studied the thermophysical properties of graphene nanofluids in thermosyphon at different power inputs, temperatures and angles of inclination. The thermal conductivity of the graphene nanofluid is found to be 29% higher than that of the deionized water at 45°C. The viscosity of the graphene nanofluid increased with the concentration of graphene nanoparticles and decreased with increasing the temperature. Pongjet Promvonge et.al [7] investigated the effect of insertion of louvered V-winglet (LVW) vortex generators on convection heat transfer and pressure loss in a tubular heat exchanger. The investigation reveals that the highest thermo-hydraulic performance from the LVW is about 2.48 at RP = 1 and θ = 30°.yang Li, Chaobin Dang and Eiji Hihara [8] focused his research on a design for a parallel, finless, flat-tube heat exchanger and assessed for high performance in air conditioners. In this design, a longitudinal vortex generator (LVG) plate consisting of thousands of LVGs is placed in front of the finless heat exchanger in the airflow path, thus resulting in improved heat transfer.

2.DESCRIPTION OF GEOMETRY AND DESIGN PARAMETERS

The three-dimensional fluid flow and heat transfer characteristics are studied through a round tube with a set of vortex generators installed in it such that they create vortices and because of turbulence created it results in increasing in heat transfer coefficient.

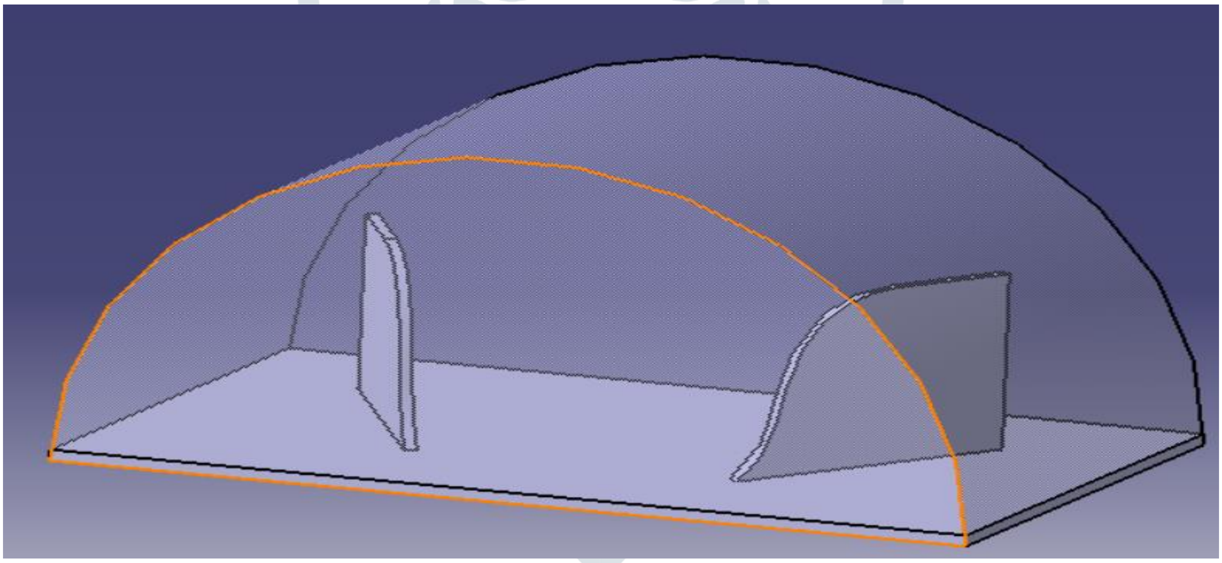

Fig.1 Single module of Ogive Vortex Generator in tube

A tubular smooth plain tube of length 900mm, diameter of 47 mm is designed and imported to simulation software for numerical analysis of different flow and heat transfer related parameters. The simulation was carried out by air fluid as the working fluid with inlet temperature of 300 K. The fluid moves through the tube and the tube wall temperature is constant 500K. The fluid moves through the tube and is heated at the outlet of the tube.

The work from [5] is modified with a novel design structure and CFD analysis is carried out to show the augmented heat transfer parameters. Longitudinal TVGs are installed throughout the length of the pipe in [5] and simulation is carried as air and water as working fluids, which is changed to longitudinal OVGs which are made to installed along the length of the pipe and numerically simulated using software. Further additional lateral spacing is provided to the OVG in the design and tested for the same as shown in Fig.2

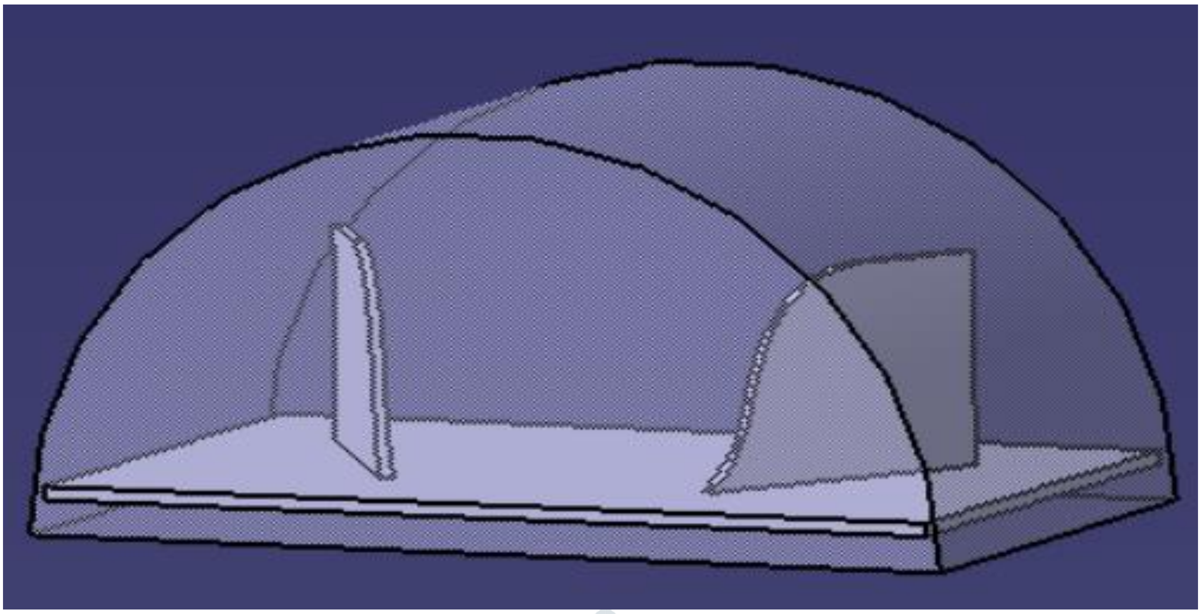

Fig.2 OVGs with a lateral spacing along the length of the tube

3.WORKING FLUIDS

Substance	Density, (kg/m^3)	Viscosity, (kg/m. s)	Specific Heat, (J/kg - K)	Thermal conductivity ($W/m^2 \cdot K$)
Air	1.225	0.000179	1006.44	0.0242
Water	998	0.000855	4182	0.6
Graphene	1028.04	0.000897	4078.83	1.061

Fig. 3 Thermophysical properties of the working fluids

For the entire simulation process, the working fluids taken in this work are air, water and graphene water based nanofluid. Graphene based nanofluid is taken at a volume concentration of 0.02, 0.03 and 0.04 and the same is tested for the found optimized results.

4. NUMERICAL MODELLING AND MESHING

For analyzing different heat transfer parameters and knowing the number of augmented characteristics the above design is modelled numerically in ANSYS R22 Software. ANSYS Fluent is a CFD software that is particularly used for the fluid flow modelling and heat transfer. Fluent was acquired by ANSYS Inc in 2006 for $299 million. The software has undergone various changes and improvements to cater to the needs of the industry. With this CFD software, you can model and simulate all types of fluid processes as well as Fluid structure Multiphysics interactions. ANSYS Fluent also has broad physical modelling capabilities that are needed for fluid flow, heat transfer, turbulence and reactions for industrial applications.

4.1 GOVERNING EQUATIONS

Continuity Equation:

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0$$

Momentum Equation:

$$\frac{\partial}{\partial x_i}(\rho_f u_i u_j) = -\frac{\partial \rho}{\partial x_j} + \frac{\partial}{\partial x_i}\left[\mu_f\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right)\right]$$

Energy Equation:

$$\frac{\partial}{\partial x_i}(\rho_f u_i c_{pf} T) = \frac{\partial}{\partial x_i}\left(k_f \frac{\partial T}{\partial x_i}\right) + \mu_f\left[2\left(\frac{\partial u_i}{\partial x_i}\right)^2 + \left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_i}\right)^2\right]$$

For the solid:

$$\frac{\partial}{\partial x_i}\left(k_f \frac{\partial T}{\partial x_i}\right) = 0$$

Where ρ is density, μ is dynamic viscosity, C_p is specific heat capacity, k is thermal conductivity subscripts f and s refers to fluid and solid, respectively.

4.2 MESHING

Meshing is an integral part of all the analysis systems in ANSYS. Meshing allows the geometries to be broken into small polygons so that each polygon can be processed separately to generate the results. The finer the mesh, the better the results. However, refining mesh too much can lead to high processing times Once the geometry is finished, meshing is the next option. The element size is taken as 0.01 mm phase size. After performing the meshing, hexahedron elements are formed. After meshing is performed, the geometry has 244117 numbers of nodes, and 234000 numbers of elements.

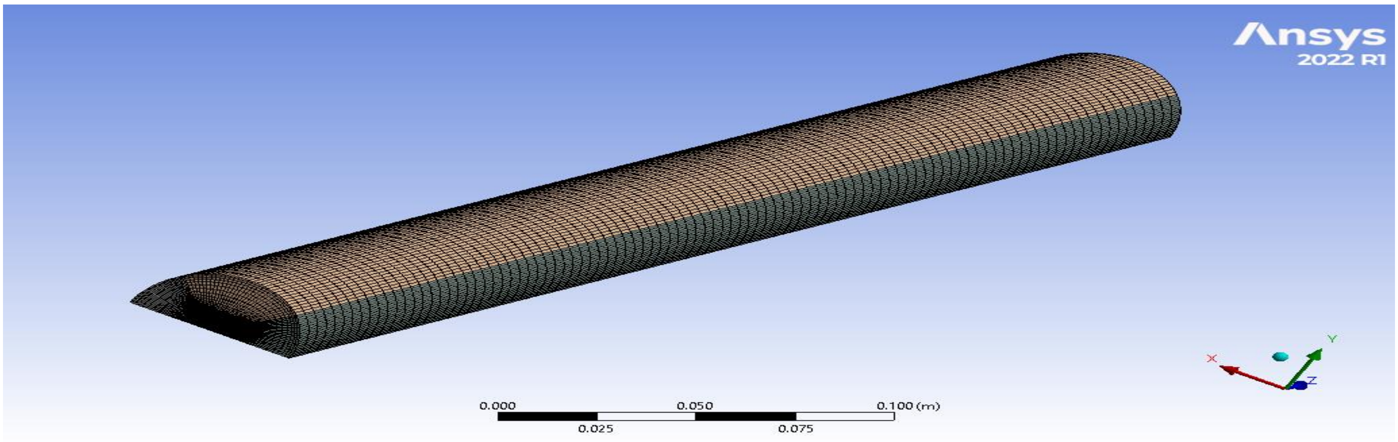

Fig.4 Meshing details

5. RESULTS AND DISCUSSION

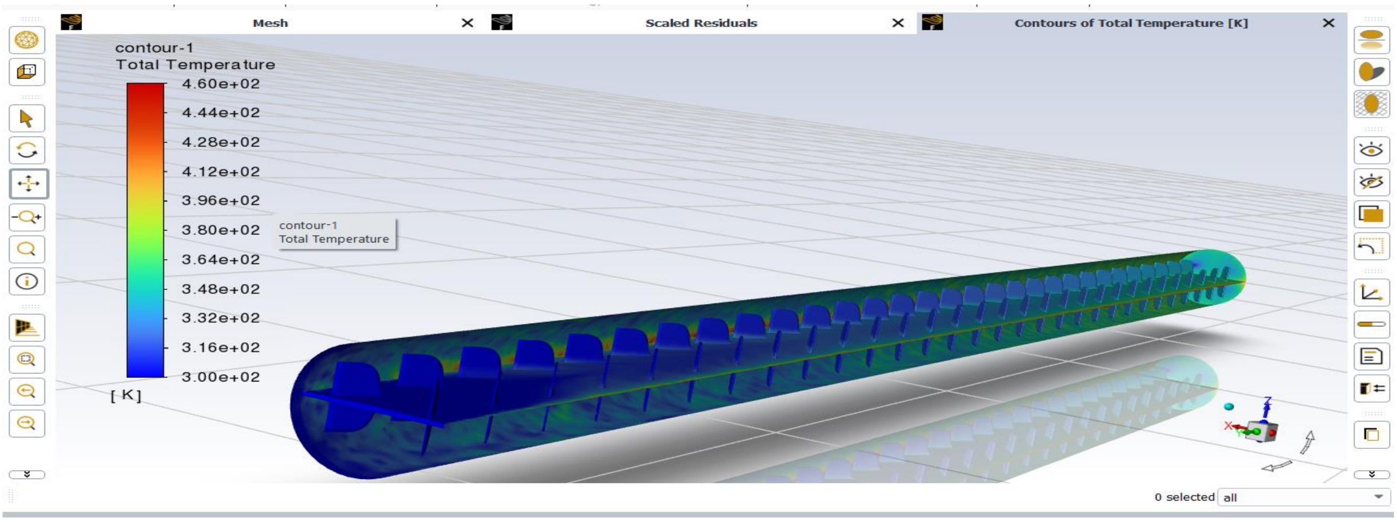

Fig.5 Temperature distribution

The image in the above Fig 5, it shows the temperature distribution of the OVGs skeletal view. The starting portion of the cell is maintaining 300K and the ending cells are having 460 K which is shown in blue and reddish yellow color respectively. At the starting point, the air has a low temperature and it gains heat from the start onwards because the walls of the tube are maintained at a constant wall temperature of 500K. When the air passes further, the temperature will start increasing as the working fluid starts gaining heat from the surface. Additionally, some heat is also added due to increasing friction as the flow is at Re= 12000. It shows turbulent behavior and friction causes this additional effect of heat. So, an increase in temperature at the end cells is shown using graphics by color mapping by the software.

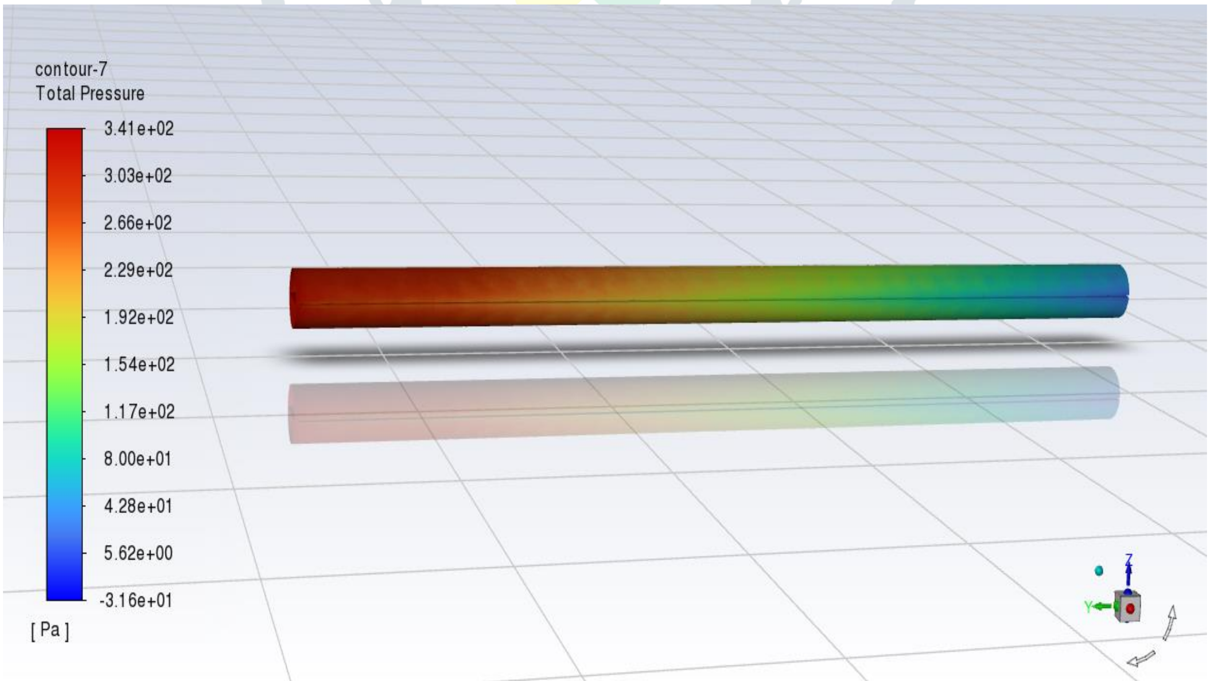

Fig.6 Pressure distribution

The image in the above Fig.6, it shows the pressure distribution contour on the cells when air flows at Re=12000 for the model of round tube where centrally plate is mounted with symmetrical OVGs. At the starting of the cells, there is high pressure being observed and at the ending cells we have a low-pressure region. It is due to the fact that increase in turbulence results in fluid friction with a small amount of consequent heating, the liquid is free to expand slightly. As this expansion occurs, the liquid is flowing down its associated pipe due to pressure gradient, meaning that the pressure is decreasing in the direction of flow. Hence decrease in pressure ending cells is observed. The maximum pressure value is 341 Pa.

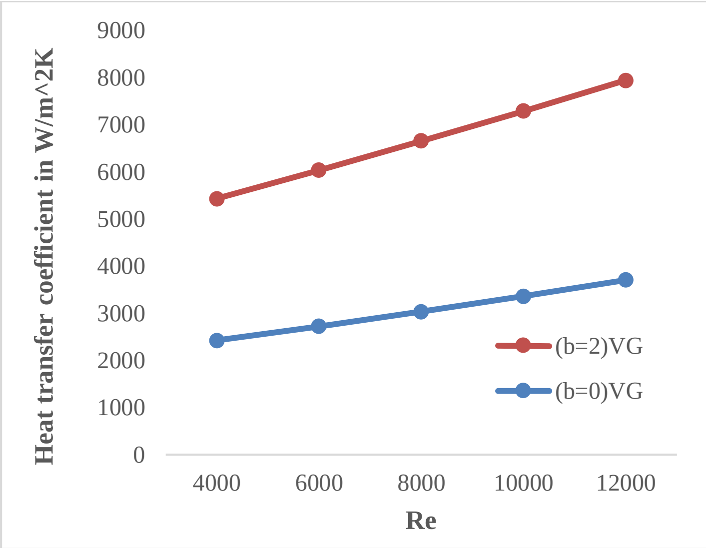

Fig.7 Heat transfer coefficient for 4% of Graphene

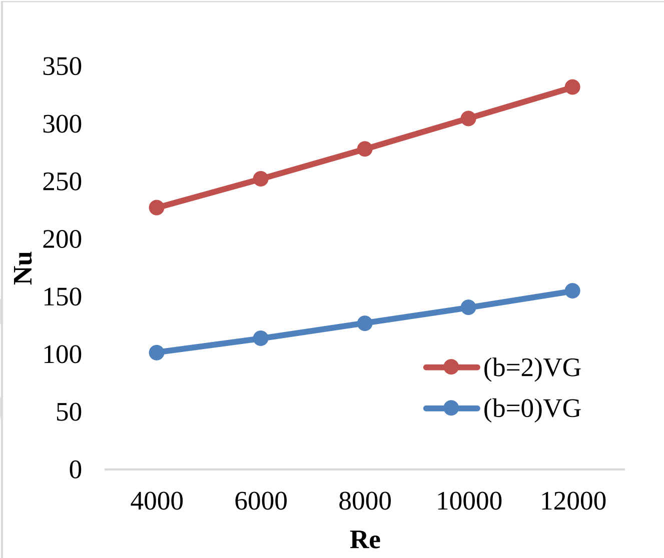

Fig.8 Nusselt Number for 4% of Graphene

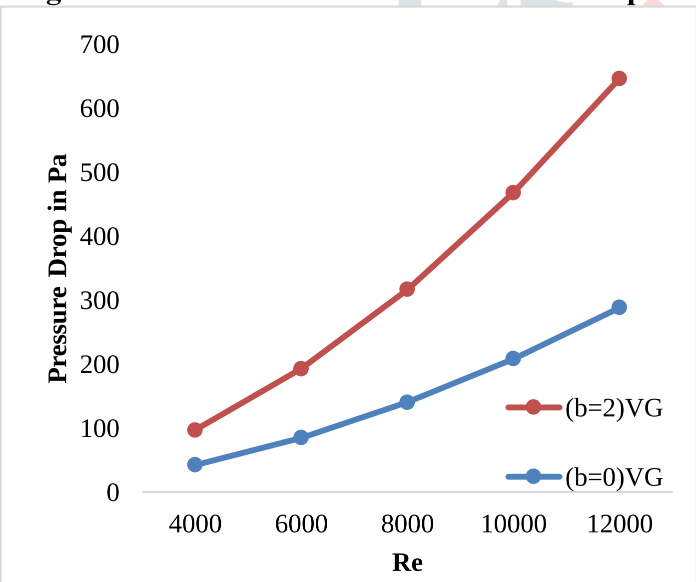

Fig.9 Pressure drop for 4% of Graphene

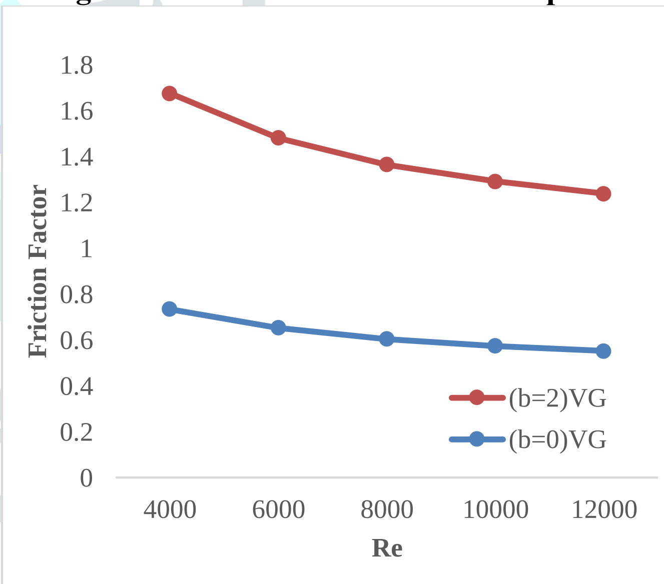

Fig.10 Friction factor for 4% of Graphene

- Definitely, it is very clear from the results about the increasing trend of htc, pressure drop, friction factor and Nu of OVGs with lateral spacing compared to centrally placed OVGs.
- Also, while comparing the working fluids taken which are air , water and graphene based nanofluid at various volume concentration, it is found that because of the high thermal conductivity of graphene solution, it exhibits excellent heat transfer characteristics and 4% volume concentration of graphene when taken shows the best outcomes. Therefore, in this work, all the heat transfer characteristics are calculated and reported based on 4% volume concentration of graphene.

6.CONCLUSIONS

- Heat transfer simulation studies conducted with triangular vortex generator and Ogive vortex generator with air and water as working fluids, it was found that Ogive vortex generator exhibited better performance than triangular vortex generator by 39.7%.
- Simulation studies conducted with Ogive vortex generator with grapheme nanofluid with variable volume concentration, it was found that heat transfer coefficient increased by 38.6% as compared with base fluid water.
- The percentage increase in heat transfer coefficient with increasing volume concentration of graphene nanofluid increased by 38.6% for 2% nanofluid, 40.22% for 3% and 41.73% for 4% volume concentration of graphene nanofluid with Ogive vortex generator.
- The maximum pressure drop offered by centrally placed OVGs was found marginally higher by 4.11% with 4% graphene nanofluid as compared with water.
- The pressure drop was found to increase marginally with increase in volume concentration of graphene nanofluid. The gap between the vortex generator was also found to influence heat transfer characteristics, the average heat transfer rate was also found to increase by 12.35% with increase in lateral spacing of 2mm between the OVGs.

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