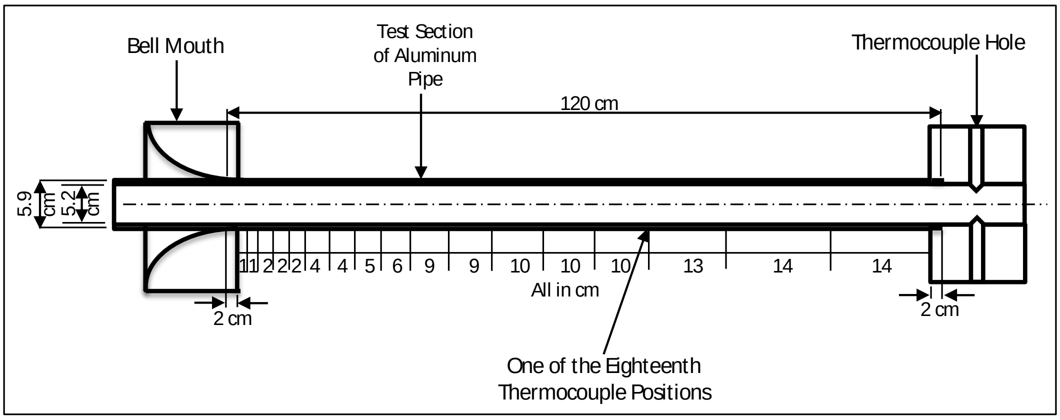


Figure 3: Vertical Projection Showing the pipe and bell mouth (at begin and exit) Thermocouples Positions and Dimensions.

Heat Loss from Test Section Ends

Two thermocouples are fixed in each Teflon piece. The calculation is carried out after measuring the distance between them and the thermal conductivity of the Teflon.

Heater Circuit

The apparatus of heating element and heater circuit consist of a variac type (NATP-6P) to adjust the heater input power as required, while a digital multi-meter type (DM-9020) is used to measure the heater voltage and current, as shown in figure (4).

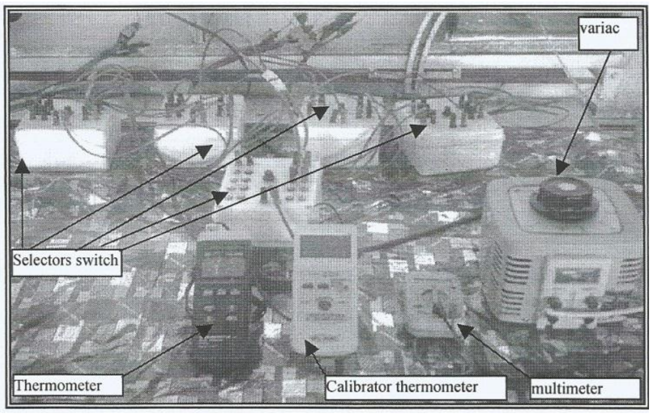


Figure 4: Instruments Used in the Experimental Work.

Thermocouple Circuits

Thermocouple circuits used in the present experimental work are shown in figure (4). They consist of digital electronic thermometer type TM-200. They are connected in parallel to the thermocouples by leads through a selector switch. Digital electronic thermometer calibration is done using calibrator type TM-300.

Orifice Plate

The orifice plate is used to compute the volumetric flow rate through the pipe as shown in figures (5, 6, 7, 8 and 9). It is designed with a diameter of 50 mm and discharge coefficient of (0.6099). Then the flow rate which induced by the centrifugal blower can be found according to the following equation,

$$V^{\circ} = C_d\left(\pi . d_o{}^2/4\right) . \sqrt{2g\Delta h} \qquad \text{... (4)}$$

Where V° is the volume flow rate in (m^3-s^{-1}), C_d is the discharge coefficient, d_o is the orifice diameter in (m) and Δh is the manometer measurement in (m-H_2O).

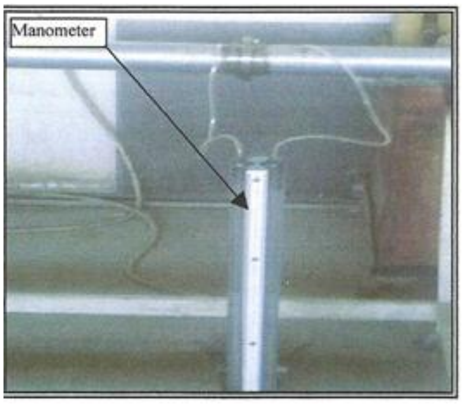


Figure 5: Manometer instrument.

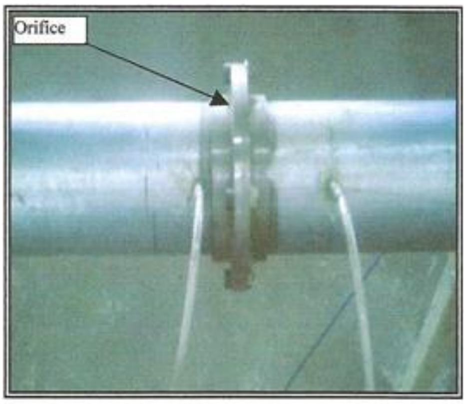


Figure 6: Orifice plate instrument.

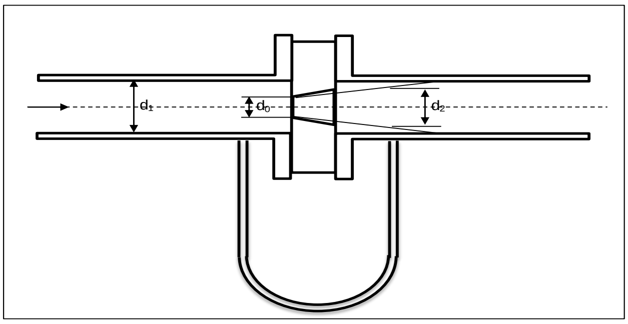


Figure 7: Schematic Diagram of Using Orifice Plate.

Figure 8: Centrifugal Blower and Control Valve.

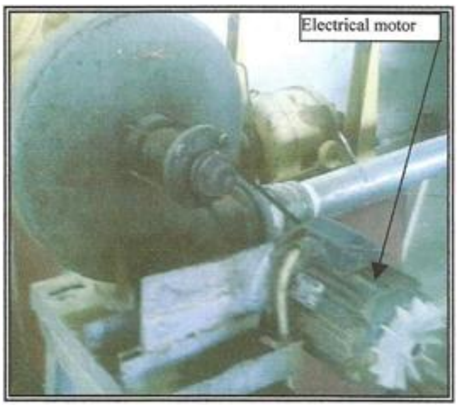


Figure 9: Electrical Motor and Power Transmission to Centrifugal Blower.

Arrangement for DEG

Diesel fuel engine works under load as a prime mover for electrical generation units to produce 500 kVA powers. Its exhaust gas comes from the engine through manifold pass into the silencer. Exhaust gases then passes through the water heat exchanger to cool the gas to be at a temperature identical with that of the air. It is checked by the thermocouple located on the pipe just before leaving to the centrifugal blower. Exhaust gas is assembled inside the reservoir which equipped with a check valve to regulate pressure according to that of air. The gas passes from the reservoir to the centrifugal blower to be after that tested with the same procedure as air, as shown in figure (10).

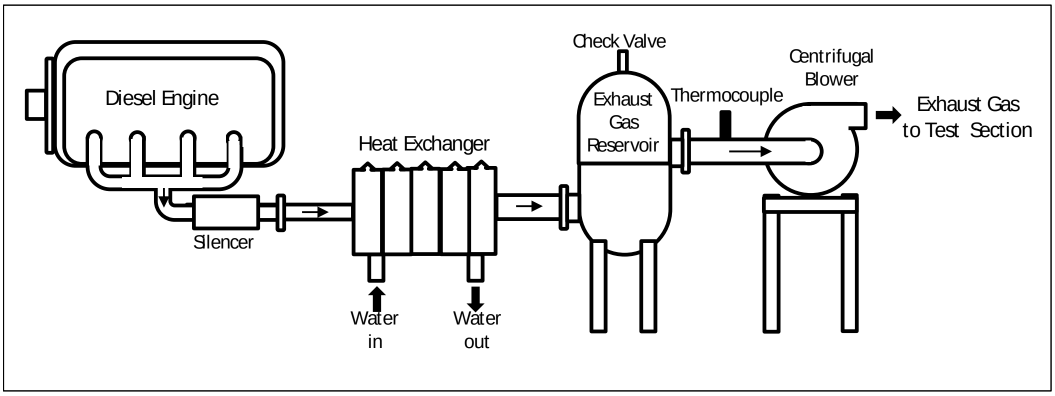


Figure 10: Arrangement of exhaust gas before driving it to blower.

EXPERIMENTAL PROCEDURE

Testing procedure is carried out as follows,

1. Adjusting the inclination angle of the pipe, as shown in figures (11, 12 and 13).
2. Switching the centrifugal power on, to circulate air or gas through the pipe in an open loop.
3. Switching the electrical heater power on and adjusting the specified heat flux. The heat flux is calculated depending on Ammeter and Voltmeter measurements according to the following equation,

$$Q_t = V \times I \qquad \dots (5)$$

Where Q_t, V and I are total heat in Watt, voltage in volt and current in Ampere, respectively.

4. Adjusting the mass-flow-rate by using the control valve and fixing the following measurements on one Reynolds number.
5. Leaving the apparatus under work for at least three

hours to ensure reading the steady state condition.

6. Reading the measured temperature by thermocouples every half an hour until the reading reaches the constant recording after that final reading is recorded.
7. Repeating the articles above 5 and 6 but with the second value of heat flux.
8. Repeating the articles above 5, 6 and 7, but with the second and third inclination angle, respectively.
9. Repeating the articles above 5, 6, 7 and 8 after adjusting a new value of mass-flow-rate according to second value of Reynolds number.
10. Following the same previous procedure when transition to use exhaust gas instead of air.

Figure 11: Experimental Apparatus in Horizontal Position.

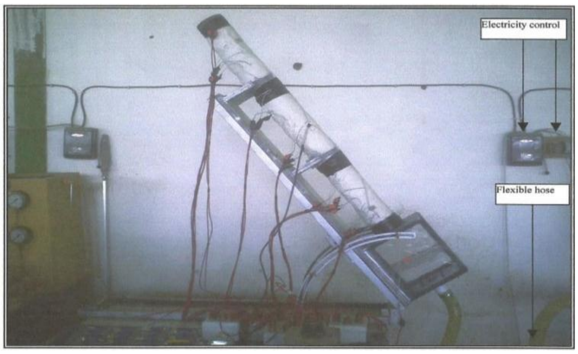


Figure 12: Experimental Apparatus in Inclined 45° Position.

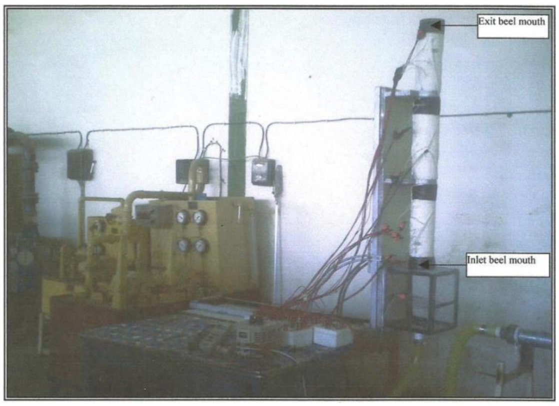


Figure 13: Experimental Apparatus in Vertical Position.

THEORETICAL ANALYSIS

For a uniform heat flux, the analysis of laminar mixed heat transfer is simply carried out using the following equations,

$$Q_{conv.} = Q_t - Q_{cond.} \qquad ...(6)$$

Where, $Q_{conv.}$ and $Q_{cond.}$ are mixed convection and lost conduction heat transfer in Watts, respectively. Conduction heat loss is calculated by using,

$$Q_{cond.} = \frac{\Delta T_{0i}}{\ln(r_0/r_i)/2\pi k_{as} L} \qquad ...(7)$$

$$\Delta T_{0i} = T_0 - T_i \qquad ...(8)$$

Where, T_0, T_i, r_0 and r_i, L and k_{as} are average outer insulation surface temperature, average inner insulation surface temperature, radius from pipe center to outer insulation surface, radius from pipe center to inner insulation surface, length of pipe and thermal conductivity of asbestos (0.161 $W\text{-}m^{-3}\text{-}°C^{-1}$.

The mixed convection heat flux can be represented by,

$$q_{conv.} = Q_{conv.}/A_0 \qquad ...(9)$$

Where, A_0 represents the outer surface area of the pipe. The local radiation heat flux is calculated from,

$$q_r = F_{1-2}\, \varepsilon\, \sigma \left[((T_s)_x + 273)^4 - \left(\left(\overline{T_s}\right)_x + 273\right)^4\right] \qquad ...(10)$$

Where, $(T_s)_x$, $\left(\overline{T_s}\right)_x$, σ , ε and F_{1-2} are the local temperature of pipe, average temperature of pipe, Stephan-Boltzmann constant (5.66×10^{-8} $W\text{-}m^{-2}\text{-}K^{-4}$), emissivity of the aluminum material (0.09) and shape factor (unity value). After calculation of the radiation heat flux, it is found that has very small value compared with the total heat flux.

For more convenience, Raji & Hasnaoui [57] and Li et al. [58] concluded that neglected effect of thermal radiation is mainly justified by the fact that the heat transfer is significantly ensured by mixed or forced convection. Bahlaoui et al. [59] stated that effect of the radiation can be neglected in the case of configurations with nonemissive or weakly emissive boundaries. Tanda G. [60] showed that radiation heat transfer can be small because of the low thermal emittance, which can be measured by a radiometric apparatus. Holman [11] and Incropera & Dewitt [10] treated radiation effects in most of the investigations on natural convection heat transfer between vertical parallel plates according to the following,

1. Assumed negligible and completely ignored.
2. Accounted for, as stray losses.
3. Nullified by techniques such as mass transfer measurement.

Therefore $q_{conv.} = q_t$, and local heat transfer coefficient can be found,

$$h_x = \frac{q_t}{(T_s)_x - (T_b)_x} \qquad ...(11)$$

Where $(T_b)_x$ represents local bulk air or gas temperature.

Table 1: Physical Properties of Air and DEG.

Tempe-rature K	Density (ρ) kg-m^{-3}		Specific Heat (Cp) Kj-kg^{-1}-K^{-1}		Viscosity (μ) Pa-s×10^{-4}		Thermal Conductivity (k) W-m^{-1}-K^{-1}	
	Air	DEG	Air	DEG	Air	DEG	Air	DEG
273	1.2506	1.2950	1.00570	1.0420	0.1715	0.1580	0.02414	0.022180
293	1.1842	1.2260	1.00665	1.0472	0.1815	0.1672	0.02574	0.023650
313	1.1178	1.1570	1.00752	1.0524	0.1909	0.1764	0.02729	0.025578
333	1.0514	1.0880	1.00832	1.0576	0.2002	0.1856	0.02881	0.027046
353	0.9876	1.0190	1.00930	1.0628	0.2093	0.1948	0.03031	0.028053
373	0.9379	0.9500	1.01130	1.0680	0.2181	0.2040	0.03171	0.029533
393	0.8884	0.9096	1.01330	1.0738	0.2269	0.2122	0.03311	0.031012
413	0.8450	0.8692	1.01582	1.0796	0.2355	0.2204	0.04270	0.032492
433	0.8016	0.8288	1.01834	1.0854	0.2440	0.2286	0.05229	0.033972

Both air and diesel exhaust gas properties(ρ, μ and k) are evaluated at the mean film temperature,

$$(T_f)_x = \frac{(T_s)_x + (T_b)_x}{2} \quad \dots (12)$$

Where $(T_f)_x$ represents the local mean film temperature. Table (1) gives these properties at work particular range of temperatures according to DieselNet Technology Guide [61] and Pipe Flow Calculations [62].

The local Nu number (Nu_x), then can be determined from,

$$Nu_x = \frac{h_x\, D_h}{k} \quad \dots (13)$$

Where h_x, D_h and k are the heat transfer coefficient, pipe inside diameter and air or diesel exhaust gas thermal conductivity.

Re number is calculated from,

$$Re = \frac{\rho\, u_i\, D_h}{\mu} \quad \dots (14)$$

Where u_i is the initial velocity of pipe.

Gr number is found from,

$$Gr = \frac{g.\beta.{D_h}^3 (T_s - T_b)}{\vartheta^2} \quad \dots (15)$$

Where g, β and ϑ are gravity constant, reciprocal of average film temperature and kinematic viscosity, respectively.

$$u_i = \frac{V^{\circ}}{A} \quad \dots (16)$$

Where V° and A, are volume flow rate and cross-sectional area, respectively.

$$A = \pi\,(r_o^2 - r_i^2) \quad \dots (17)$$

$$Pr = \frac{\mu\, Cp}{k} \quad \dots (18)$$

$$z = \frac{x/D_h}{Pr.Re} \quad \dots (19)$$

Where z represents the inverse Graetz number, Kurt C. Rolle [63]. The nondimensional length X is represented by,

$$X = \frac{x}{L} \quad \dots (20)$$

Where x and L are the distance from pipe entry and total length, respectively.

According to the same range of temperatures mentioned in table (1), we calculate the Pr number for air and DEG. It is shown in table (2),

RESULTS AND DISCUSSION

Table 2: Pr number values of air and DEG corresponding to temperature range.

Temperature K	Pr number	
	Air	DEG
273	0.715	0.7422
293	0.7098	0.7404
313	0.7051	0.7258
333	0.7006	0.7258
353	0.697	0.738
373	0.6956	0.7377
393	0.6945	0.7347
413	0.5602	0.7323
433	0.4752	0.7304

The values of inverse Graetz number are calculated depending on two values of Pr number. The first one is the average value of higher Pr numbers of air and DEG (0.7286) taken from table (2), and the second is the average of lower Pr numbers (0.6005) within the study range of measured surface temperature.

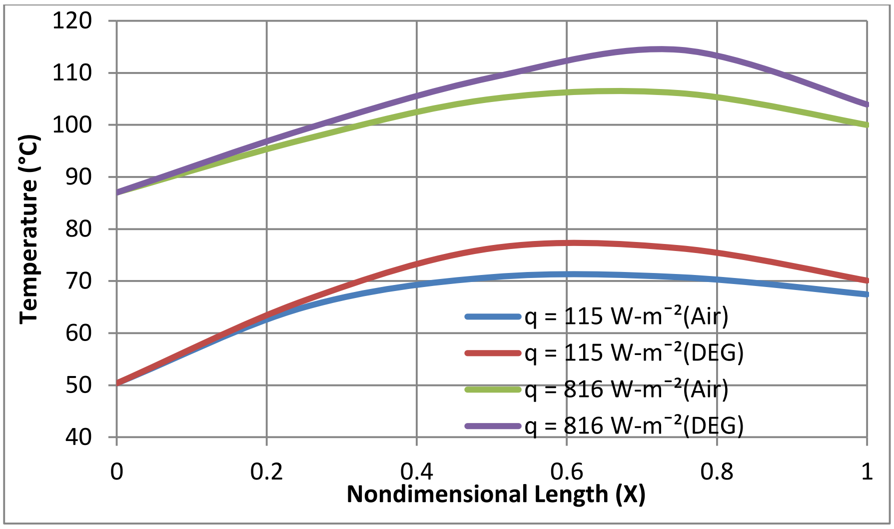


Figure 14: Air and DEG Temperature Distribution along Nondimensional Length (X) for 450 Re number and 0° Inclination.

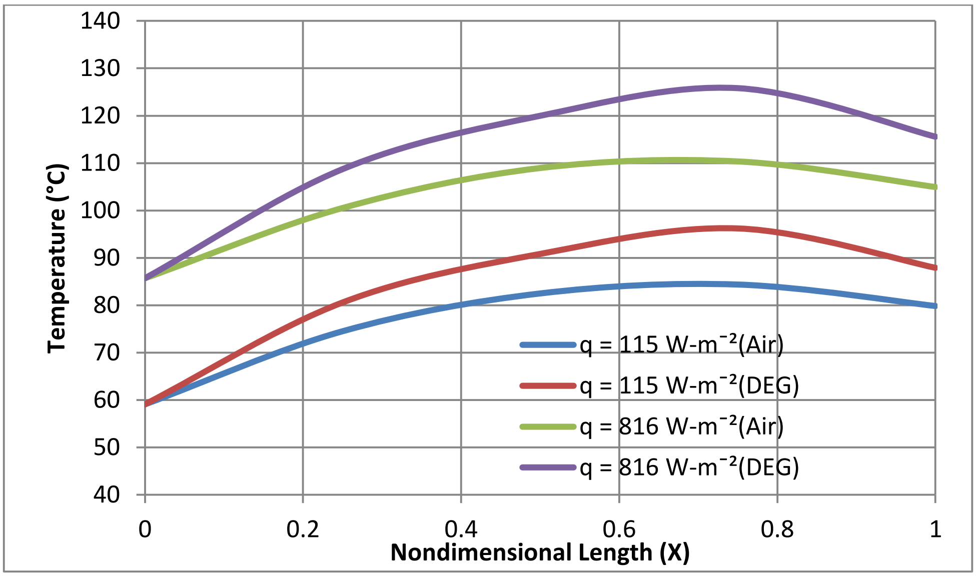


Figure 15: Air and DEG Temperature Distribution along Nondimensional Length (X) for 450 Re number and 45° Inclination.

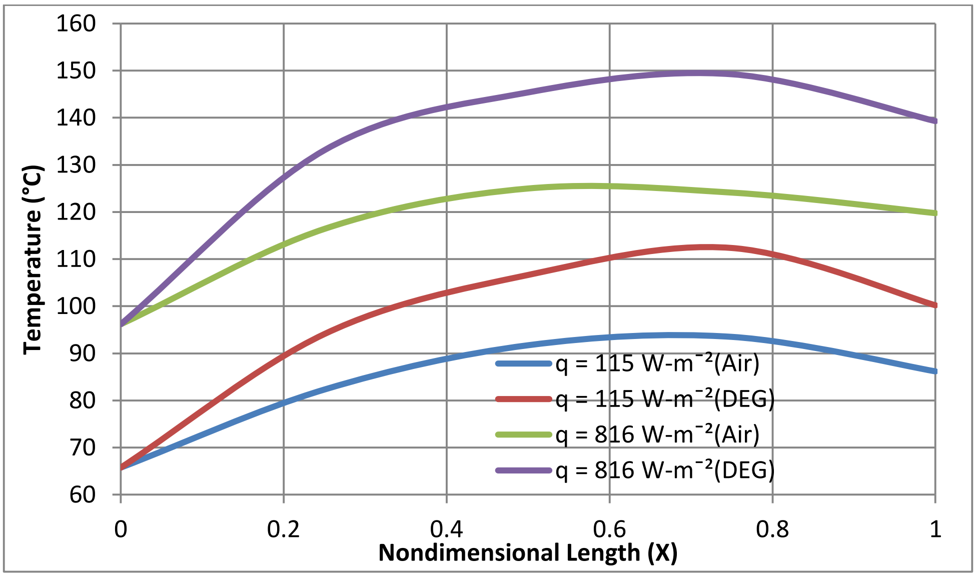


Figure 16: Air and DEG Temperature Distribution along Nondimensional Length (X) for 450 Re number and 90° Inclination.

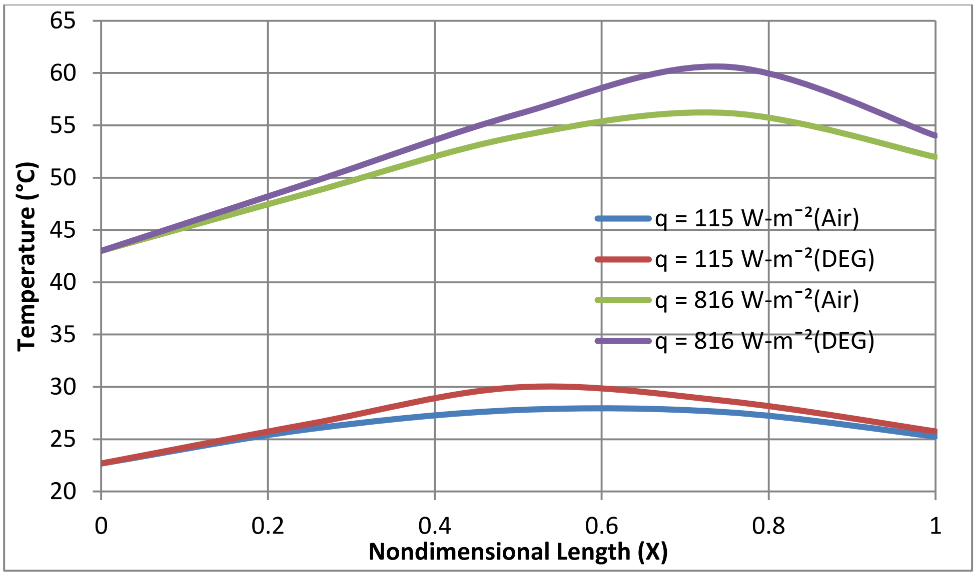


Figure 17: Air and DEG Temperature Distribution along Nondimensional Length (X) for 2008 Re number and 0° Inclination.

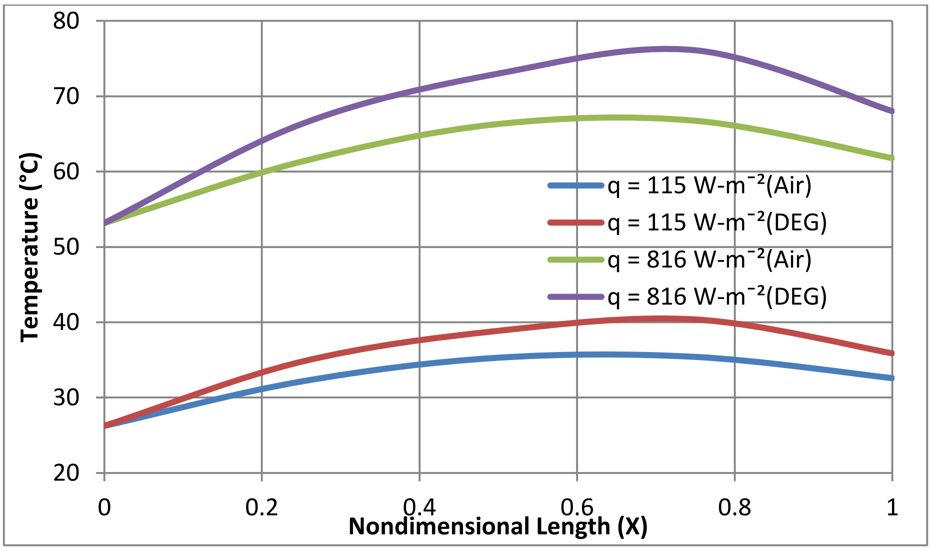


Figure 18: Air and DEG Temperature Distribution along Nondimensional Length (X) for 2008 Re number and 45° Inclination.

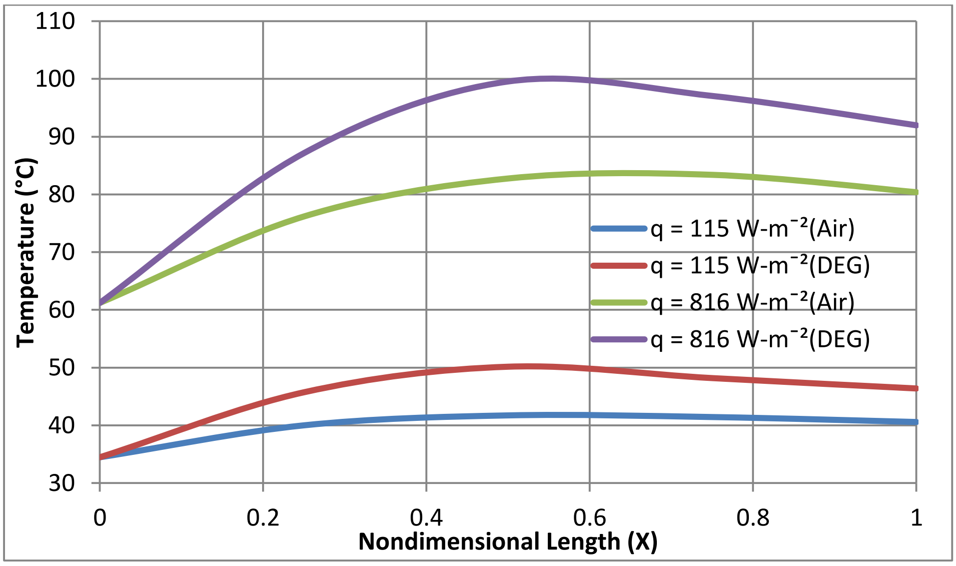
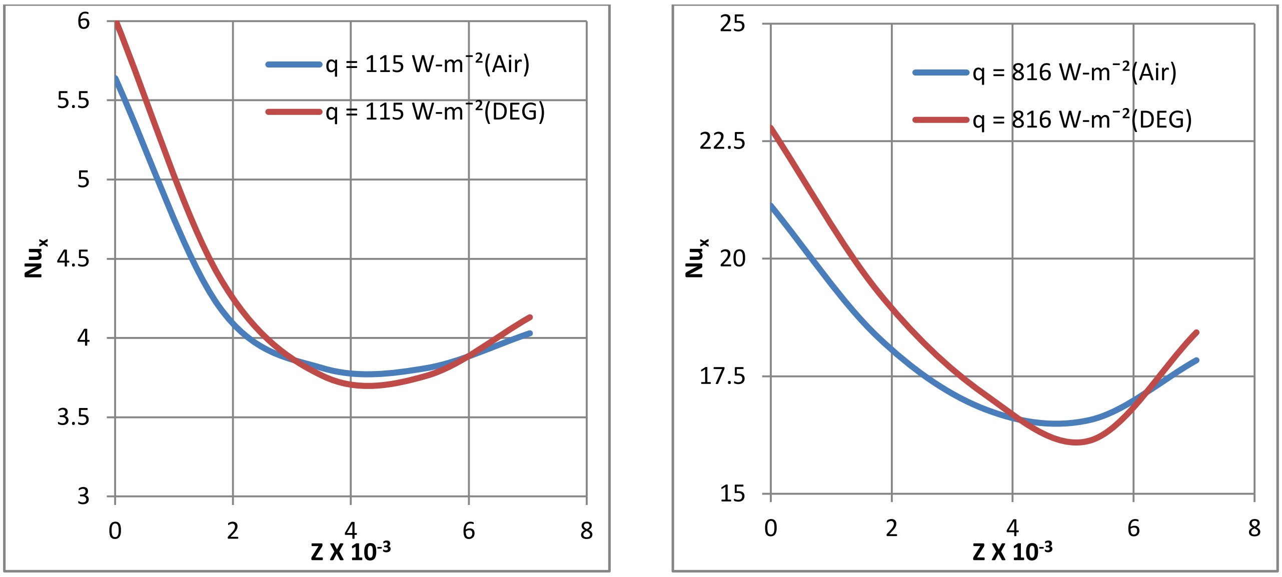
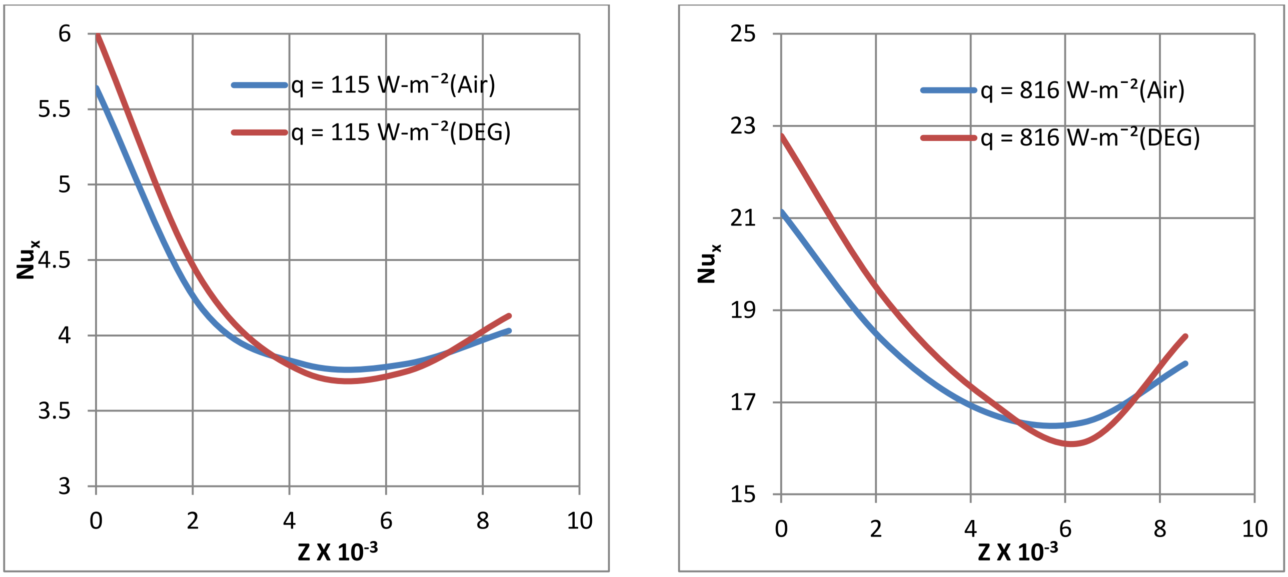


Figure 19: Air and DEG Temperature Distribution along Nondimensional Length (X) for 2008 Re number and 90° Inclination.



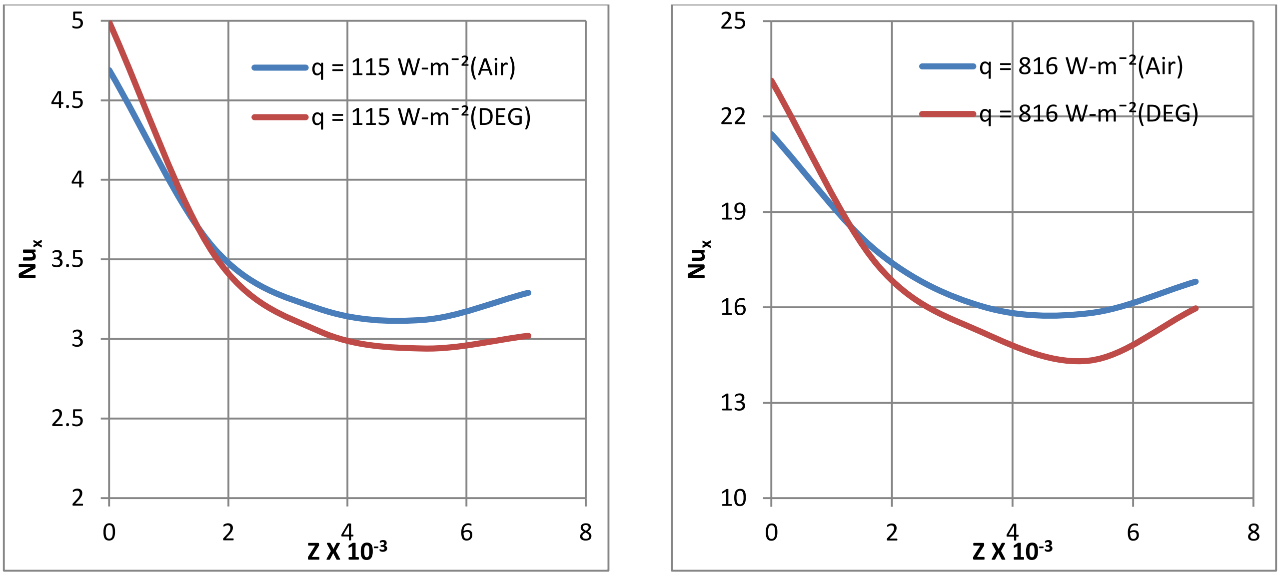
(a) (b)

Figure 20: Air and DEG Local Nu no. Versus Inverse Graetz no. for 0° Inclination Angle, 0.7286 Pr no. and 450 Re no. at (a) 115 W-m^{-2}, (b) 816 W-m^{-2} Heat Flux.



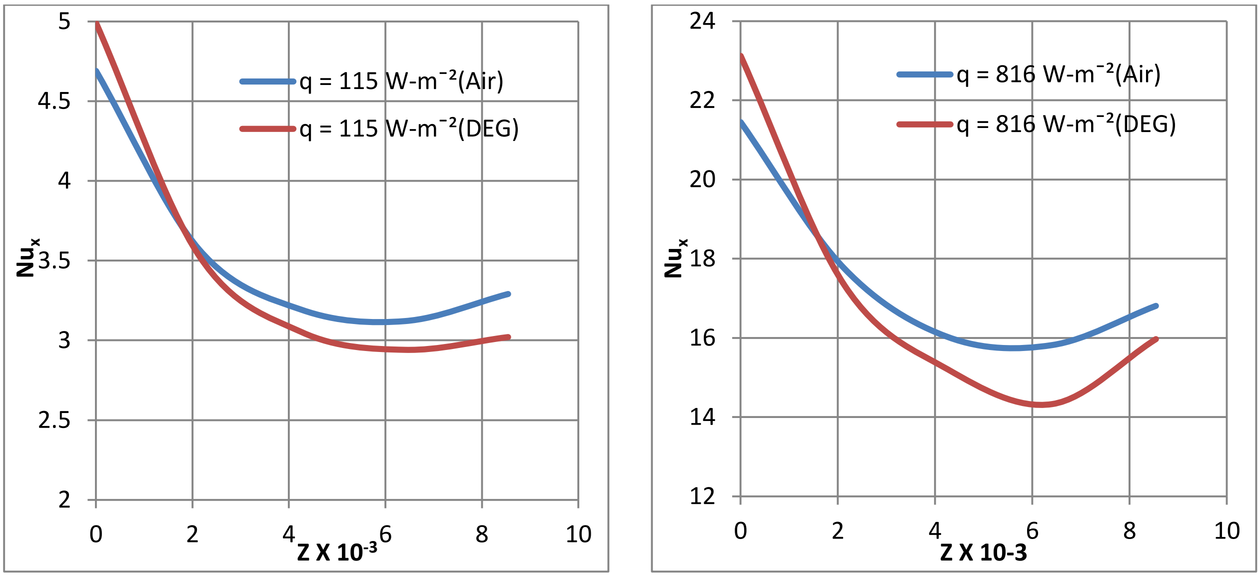
(a) (b)

Figure 21: Air and DEG Local Nu no. Versus Inverse Graetz no. for 0° Inclination Angle, 0.6005 Pr no. and 450 Re no. at (a) 115 W-m^{-2}, (b) 816 W-m^{-2} Heat Flux.



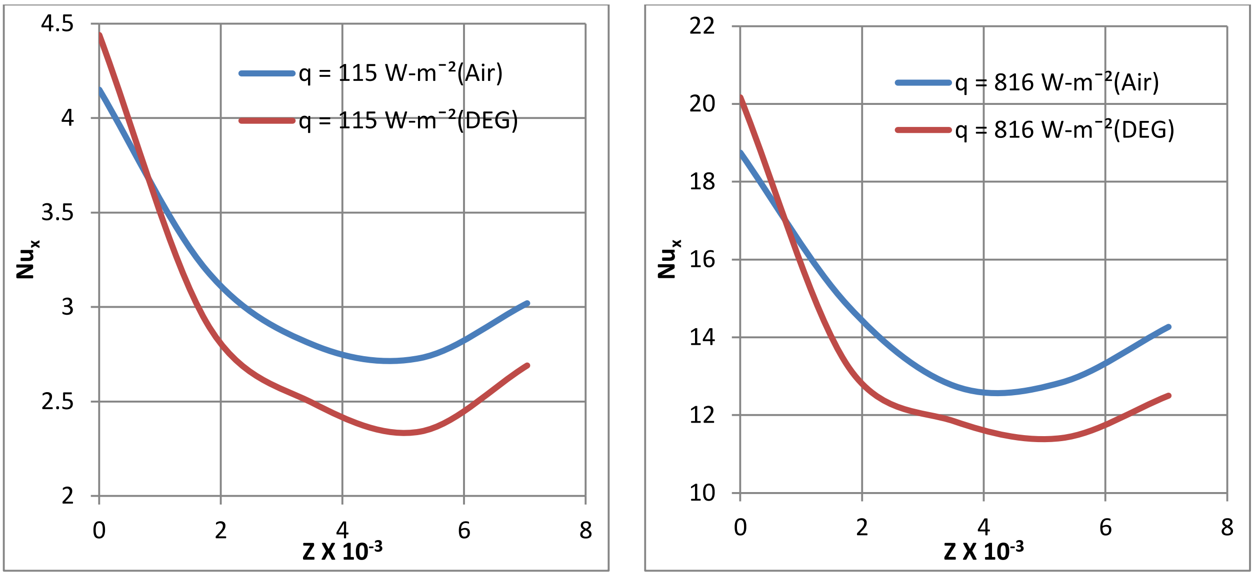
(a) (b)

Figure 22: Air and DEG Local Nu no. Versus Inverse Graetz no. for 45° Inclinaton Angle, 0.7286 Pr no. and 450 Re no. at (a) 115 W-m^{-2}, (b) 816 W-m^{-2} Heat Flux.



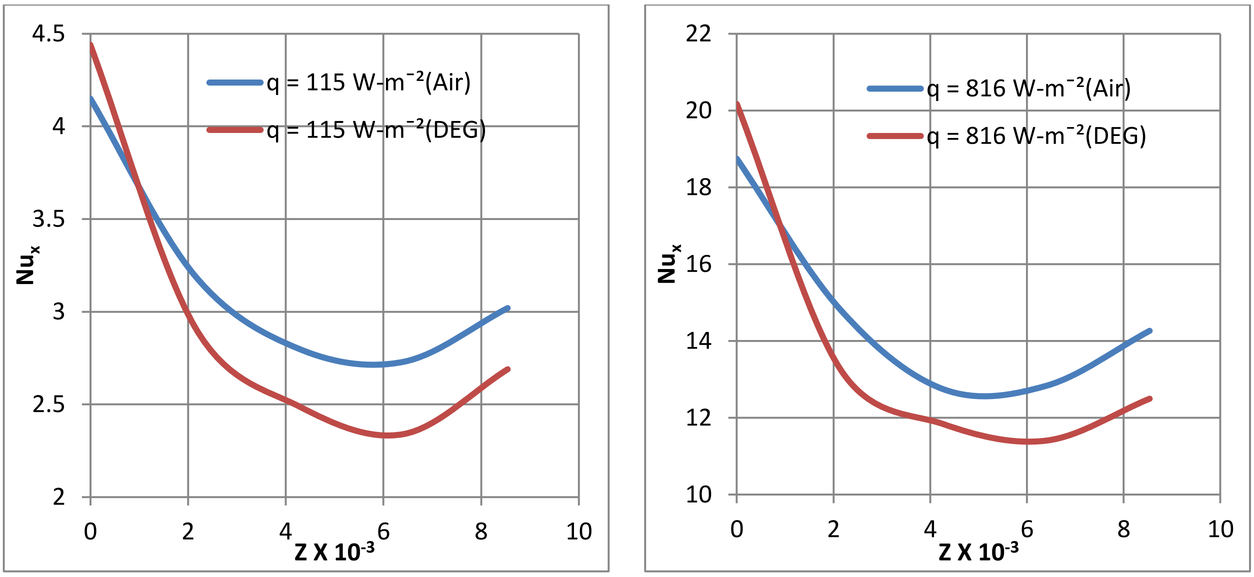
(a) (b)

Figure 23: Air and DEG Local Nu no. Versus Inverse Graetz no. for 45° Inclination Angle, 0.6005 Pr no. and 450 Re no. at (a) 115 W-m^{-2}, (b) 816 W-m^{-2} Heat Flux.



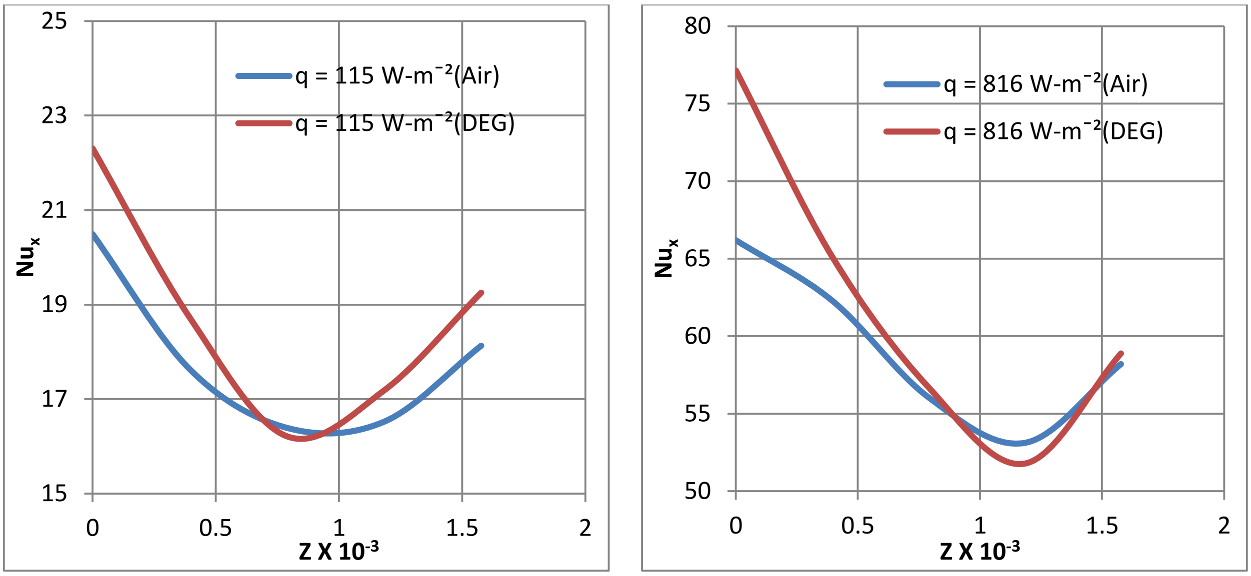
(a) (b)

Figure 24: Air and DEG Local Nu no. Versus Inverse Graetz no. for 90° Inclinaton Angle, 0.7286 Pr no. and 450 Re no. at (a) 115 W-m^{-2}, (b) 816 W-m^{-2} Heat Flux.



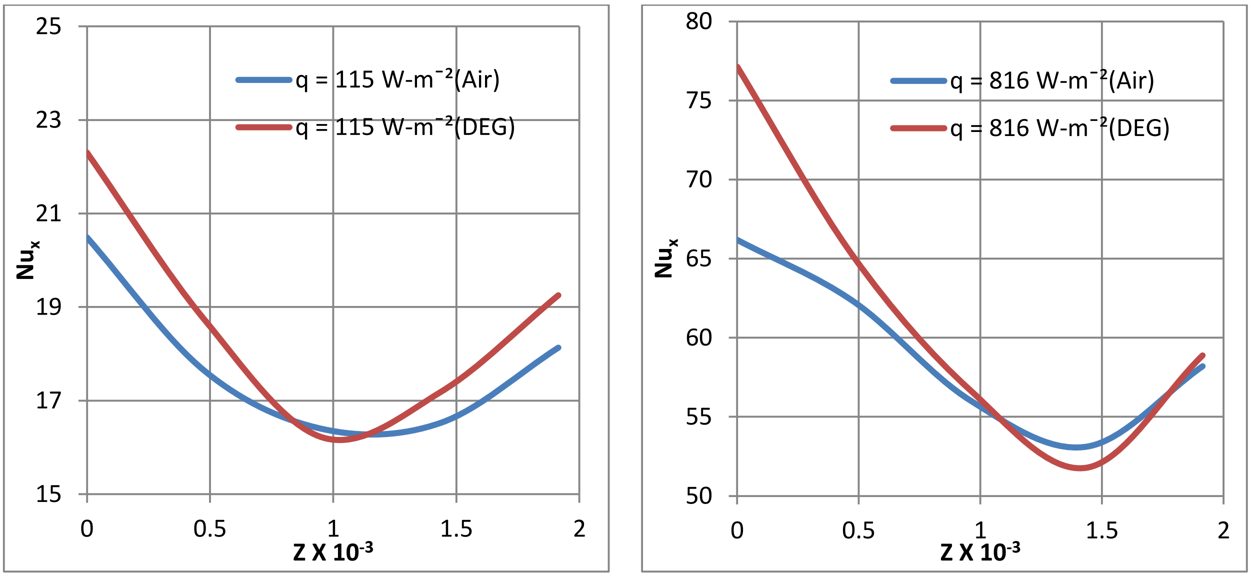
(a) (b)

Figure 25: Air and DEG Local Nu no. Versus Inverse Graetz no. for 90° Inclinaton Angle, 0.6005 Pr no. and 450 Re no. at (a) 115 W-m^{-2}, (b) 816 W-m^{-2} Heat Flux.



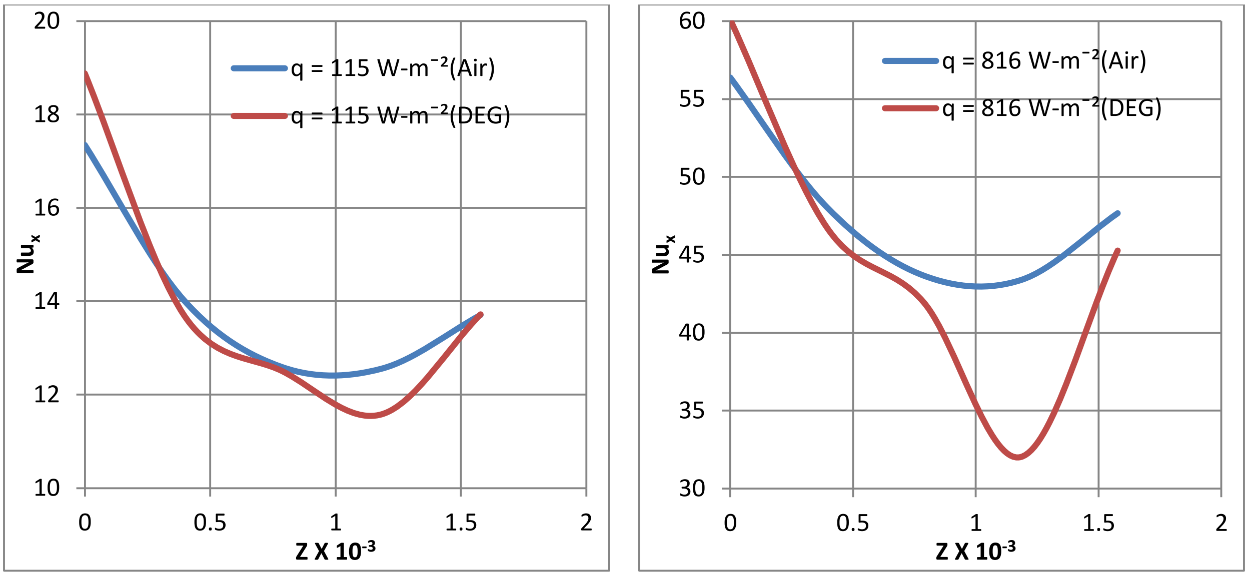
(a) (b)

Figure 26: Air and DEG Local Nu no. Versus Inverse Graetz no. for 0° Inclinaton Angle, 0.7286 Pr no. and 2008 Re no. at (a) 115 W-m^{-2}, (b) 816 W-m^{-2} Heat Flux.



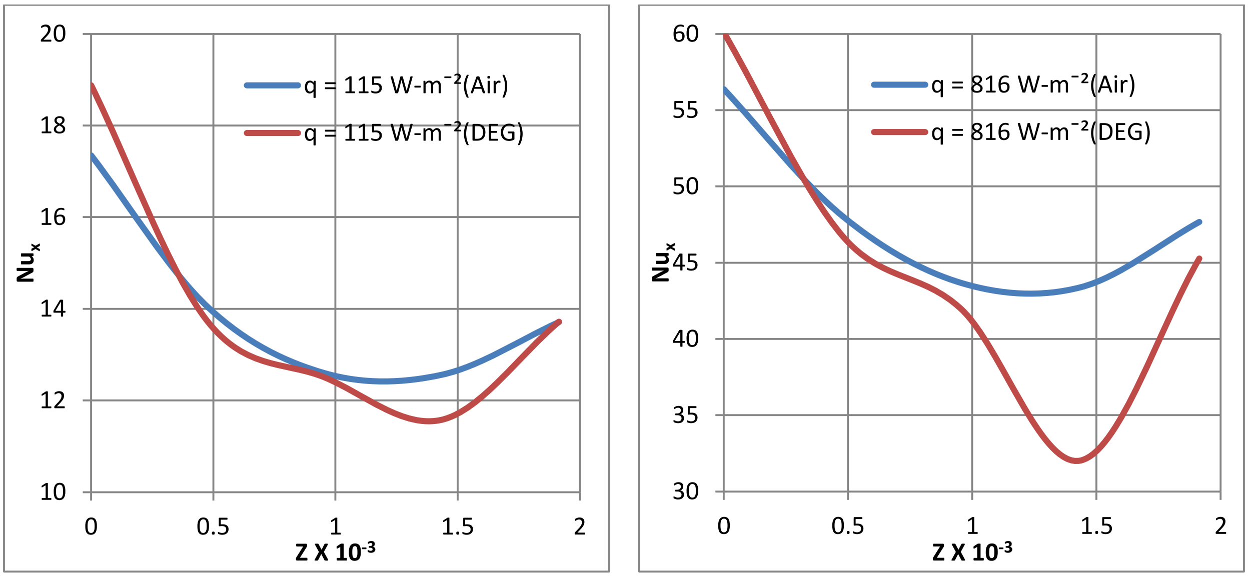
(a) (b)

Figure 27: Air and DEG Local Nu no. Versus Inverse Graetz no. for 0° Inclination Angle, 0.6005 Pr no. and 2008 Re no. at (a) 115 W-m^{-2}, (b) 816 W-m^{-2} Heat Flux.



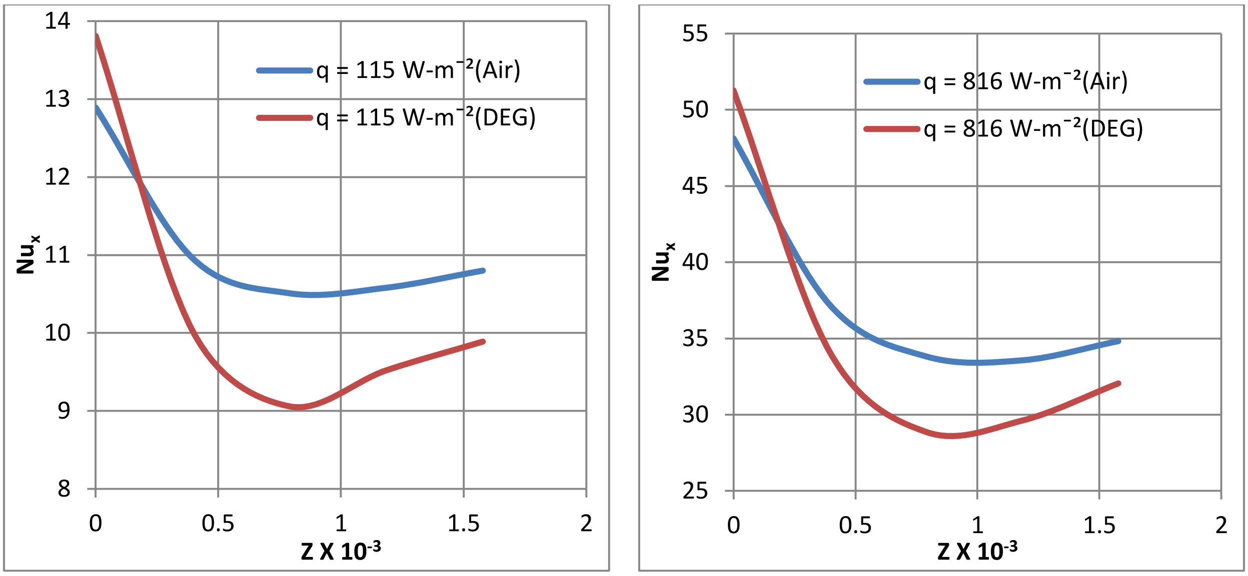
(a) (b)

Figure 28: Air and DEG Local Nu no. Versus Inverse Graetz no. for 45° Inclinaton Angle, 0.7286 Pr no. and 2008 Re no. at (a) 115 W-m^{-2}, (b) 816 W-m^{-2} Heat Flux.



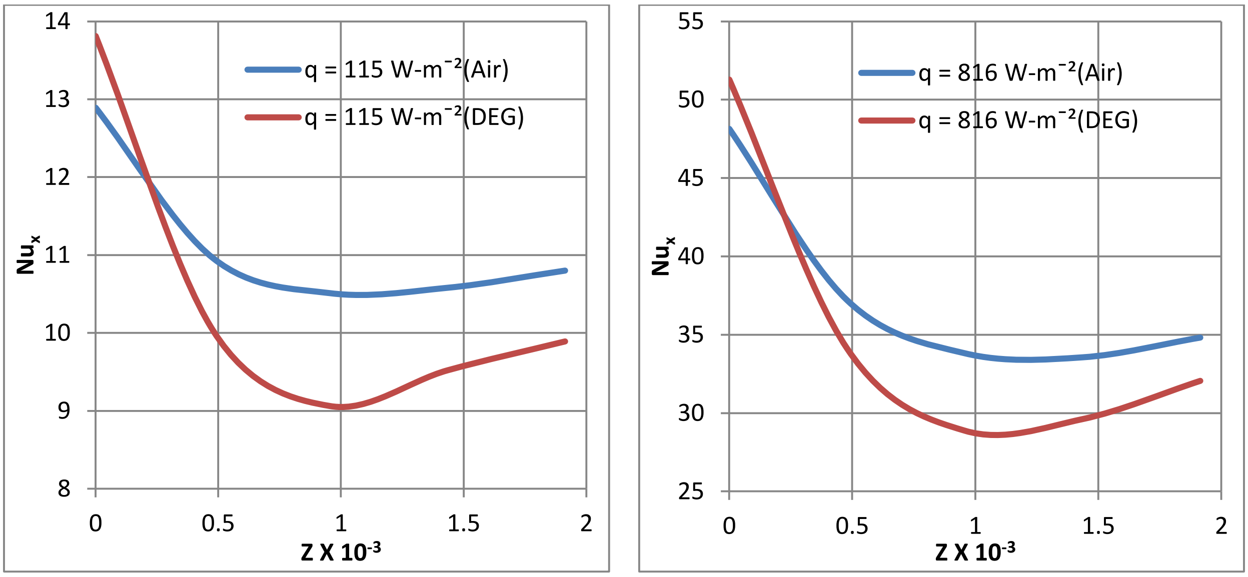
(a) (b)

Figure 29: Air and DEG Local Nu no. Versus Inverse Graetz no. for 45° Inclination Angle, 0.6005 Pr no. and 2008 Re no. at (a) 115 W-m^{-2}, (b) 816 W-m^{-2} Heat Flux.



(a) (b)

Figure 30: Air and DEG Local Nu no. Versus Inverse Graetz no. for 90° Inclinaton Angle, 0.7286 Pr no. and 2008 Re no. at (a) 115 W-m^{-2}, (b) 816 W-m^{-2} Heat Flux.



(a) (b)

Figure 31: Air and DEG Local Nu no. Versus Inverse Graetz no. for 90° Inclination Angle, 0.6005 Pr no. and 2008 Re no. at (a) 115 W-m^{-2}, (b) 816 W-m^{-2} Heat Flux.

(1) Surface Temperature Results

a) General

Results of surface temperature for all cases studied in present paper starts at the same temperature and increases until a maximum value then decreases slightly at pipe end, as shown in figures (14-19). It can be divided into two regions. The first performs the developed region, which starts from pipe inlet till the maximum temperature point. The temperature increase in this region is due to the thermal boundary layer, which starts at zero thickness and ends at maximum thickness. The second region starts from the maximum point till the pipe end. The decrease in this region is due to pipe end heat loss. A rise is clear in the increase and decrease of surface temperature for all cases of DEG upon air. Maximum rise takes place at the maximum point and about half at pipe end. This rise in surface temperature is coming from,

- Lowest DEG gas constant (264.549 J-kg^{-1}-K^{-1}) in comparison to air one (287.1 J-kg^{-1}-K^{-1}) as well as the difference in air and DEG pressure and density property, as shown previously in table (1).

- High buoyancy effect makes to free on forced convection domination. This rise depends on Gr number which in turn depends on air and DEG kinematic viscosity variation (Gr$\propto \frac{1}{\vartheta^2}$).
- Low buoyancy effect makes forced on free domination. The rise depends on velocity, density and dynamic viscosity differences between air and DEG to keep Re constant (T$\propto \frac{1}{v^2}$).
- Free convection reversal flow against air or DEG flow (flow rate reduction) leads to time increase of heat storage (T $\propto$ q).

b) Effect of Heat Flux

The surface temperature for both air and DEG increases as heat flux increases at constant Re number and angle of inclination. A rise in DEG surface temperature above the air one reaches 7.85% at maximum point and reduces to about half at pipe end. This rise percentage does not change with heat flux increase, as shown in figure (14).

c) Effect of Re Number

The surface temperature decreases for both air and DEG as Re number increase at constant heat flux and angle of inclination. Here the forced convection is dominant. Again a rise in DEG on air reaches 7.85% at maximum point and reduces to about half at pipe end. The rise is slightly changed to 7.28% with Re number increase, as shown in figures (14 and 17).

d) Effect of Inclination Angle

Surface temperature increases for both air and DEG as inclination angle increases at constant heat flux and Re number. This is because of buoyancy effect, which induces the reversal flow of free convection. Again a rise in DEG on air reaches 7.85% at 0°for maximum point and reduces to about half at pipe end, as shown in figures (14 and 17). The rise percentage becomes 12.32% at 45° inclination, as shown in figures (15 and 18) and 16.83% at 90° inclination, as shown in figures (16 and 19).

(2) Local Nu_x Number Results

a) General

Figures (20-31) show the local Nu_x number against the inverse Graetz number. It is apparent that for all cases takes place in the study and for both air and DEG, the Nu_x decreases until a minimum point and then increases slightly. The decrease and increase come from the increase and decrease in surface temperature, where heat transfer coefficient is inversely proportional to surface temperature and Nu_x is directly proportional to heat transfer coefficient. In the same manner, the range of Nu_x decrease performs the developing region until the minimum point, while the range of Nu_x increase performs the fully developed region. For all cases studied, the DEG Nu_x values are lower than that of air due to surface temperature rise. It can be seen clearly that they have different values of Nu_x at the initial point the thermal conductivity is dominant (table 1) even they start with the same temperature. Most of Nu_x figures have two intersections between air and DEG curves throughout the pipe dividing it into three regions. The first region from pipe inlet to first intersection, thermal conductivity is dominant. The second region between the intersections, surface temperature is dominant. While the third region between second intersection and pipe end, again k is dominant.

b) Effect of Heat Flux

Figures (20 and 21) show that local Nu_x values for both air and DEG increase as heat flux increases (free convection domination) at constant Re number and angle of inclination, since the heat is directly proportional to heat transfer coefficient. The reduction of DEG from air Nu_x reaches 1.31% and increases to 2.66% at higher heat flux.

c) Effect of Re Number

Figures (20, 21, 26 and 27) show that local Nu_x values for both air and DEG increase as Re number increases (forced convection domination) at constant heat flux and angle of inclination. This is due to surface temperature reduction, which is inversely proportional to heat transfer coefficient. The reduction of DEG from air Nu_x reaches 1.31% and slightly decreases to 1.1% at higher Re number.

d) Effect of Inclination Angle

Figures (20-25) show that local Nu_x values for both air and DEG decrease as the angle of inclination increases (reversal flow growth) at constant heat flux and Re number. The decrease is due to temperature increase because of flow reduction, since it is inversely proportional to heat transfer coefficient. The reduction of DEG from air Nu_x values is 1.31% at 0° angle increases to 5.77% at 45° angle and to 14.29% at 90° angle.

e) Effect of Pr Number

Pr number enters in Graetz number. It has different values at different temperatures. Physical properties of air differ from DEG at constant temperature (table (1)). Table (2) shows values of air and DEG Pr numbers. The average high and low Pr number between air and DEG is chosen. Low values of Pr number make Nu_x slope steeper and reduce entrance distance, while higher values have a non-steeper slope with long entrance distance. Therefore heating time for higher Pr number is greater than that for lowers one (best heating control), as shown in figures (20-31).

CONCLUSIONS

The results measured experimentally or calculated theoretically of temperature distribution and Nu_x shows that this work is worthy. Present study conclusions can be summarized as follows,

(1) DEG stores heat energy when emitted to environment on reverse to fresh air, though it is the main problem of global warming.

(2) This storing phenomenon increase with increasing of source heat and low gas velocity as well as its growth if directed vertically.

(3) The mixed convection comparison shows a domination of

free on forced for DEG on air.

(4) If the DEG is controlled by the aftertreatment system, the before system exhaust pipe should be directed vertically to grow the heat with temperature to not less than 130 °C For first stage (DOC) and 600 °C for second stage (SCR), to be reactive.

(5) The after the treatment system pipe should be directed horizontally, if DEG is injected to environment for heat storing reduction.

(6) If DEG is to be employed for heat exchanging the after system pipe should be directed vertically to invest the heat storing for building air or water heating purposes in stationary engine units.

(7) The after system pipe should be directed vertically also for heat exchanging in big truck engines for air or water heating (stored in a separated tank in a truck) to be emptied for building or industrial uses at tracks parking.

(8) For good environment, the DEG should be heat extracted anyway.

(9) After heat extracting, DEG should be dispersed using velocity in all directions.

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