Chapter - 7

CFD Analysis for Radiator with Proposed Coolants

In this chapter an effort has been made to present the performance of rectangular fin radiator with water and 25% PG brine as radiator coolants and the simulation has been done by considering water, 25% PG brine as radiator coolant and it has been observed that the numerical results for various parameters has been validated with experimental results for the mentioned coolant are within 10% deviation. Based on this confidence the performance parameters using 25% EG brine based Ag nanofluid and 25% EG coolants have been considered for simulation.

7.1 CFD Methodology

Commercial CFD software ANSYS 15.0.7 has been used to perform the CFD analysis for Maruti (800) engine radiator with following assumptions.

(i) Steady state analysis .

(ii) Heat transfer along the length of the heat exchanger for this type of thermodynamic system is negligible.

(iii) Velocity at the entrance of the radiator core for both air and coolant sides are uniform.

(iv) Thermal conductivity of tube material is constant in axial direction.

(v) No internal source exists for energy generation.

(vi) There are no phase changes (condensation or boiling) in all fluid streams.

(vii) There is no thermal expansion /contraction of heat exchanger material.

(a) Description of the radiator geometry

Rectangular fin-tube radiator (Fig.7.1) has been considered in cross flow mode, where the core portion consists of vertical flat coolant tubes with rectangular fins. The detailed dimensions have been presented in Table-7.1. The computational domain has been presented in Fig.7.2, where only a pair of tube and fin combination have been considered for computational case.

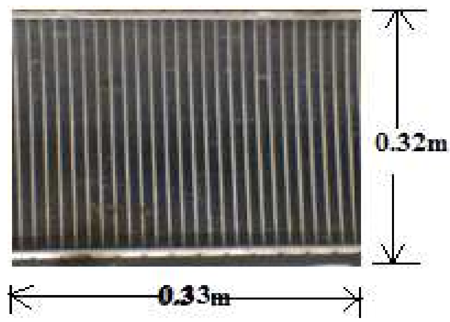

Figure 7.1: Rectangular fin Radiator

Table-7.1: Dimension of the radiator

Parameters	**Fin side**	**Tube side**
Radiator Width, W_c	321mm	
Radiator height, H_c	334mm	
Core depth, F_d	18mm	
Fin width	18mm	
Fin height	9mm	
Fin thickness	0.2mm	
Hydraulic diameter	2mm	2.4mm
Tube thickness		0.35mm
Total heat transfer area/total volume	81.35m^2/m^3	3.41m^2/m^3
Tube dimension		16.2×2×18mm^3
Number of tubes		33

7.2 Meshing

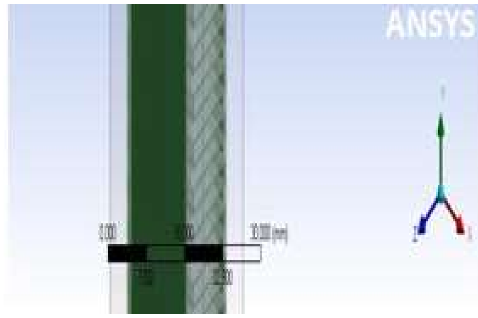

Figure7.2: Design of fin and tube for radiator

The hex dominant method mesh has been generated with mesh matrix of maximum orthogonal quality of 0.99999. In order to check the grid independence, several sets of the mesh size have been adopted and named selection is created for various boundaries with relevance fine of number of nodes 76168 as shown in Figs. 7.3 (a, b). For the further enhancement of the meshing nodes range vary from 80000 to 100000 selected to check the grid independence of the designed radiator simulation, which shows the error within 2%. Thus, the mesh size of 76168 was adopted for the CFD analysis of radiator.

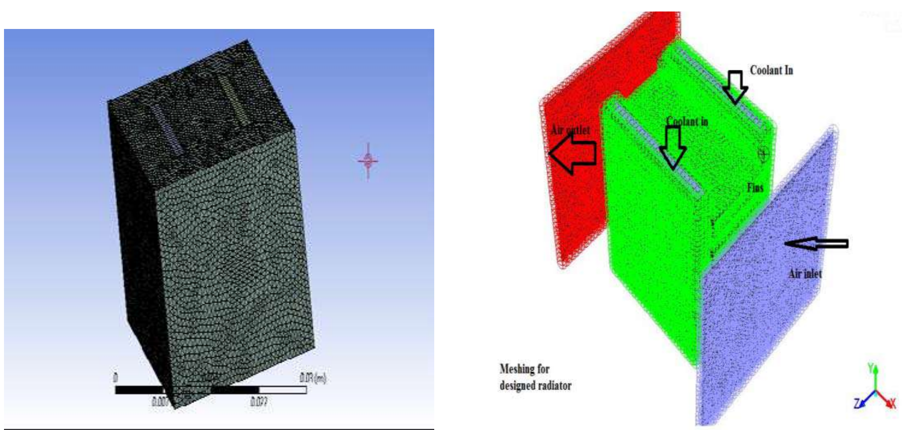

Figure 7.3 (a): Meshing for the radiator geometry

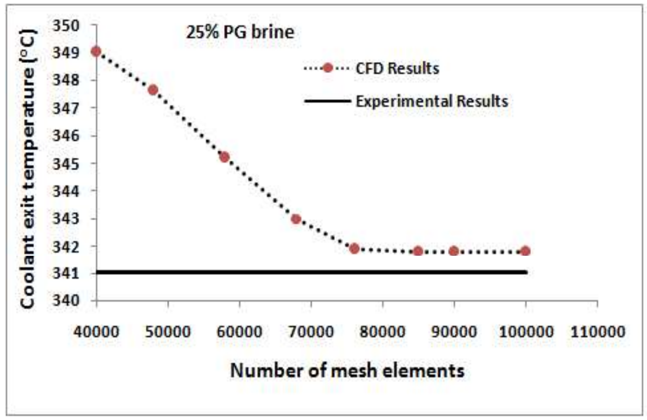

Figure 7.3 (b): Mesh elements variation

7.3 Numerical Schemes

Mass momentum and energy equations have been solved using commercial CFD code ANSYS 15.0.7 Fluent with appropriate boundary condition. The SIMPLE algorithm is used to couple pressure and velocity. A first-order upwind scheme is used for the space discretization of the momentum and energy equations in the simulations. The effect of turbulence on the flow field is implemented by the k-ε model.

7.3.1 Governing Equations and boundary conditions [186]

Continuity Equation: $(\nabla . V) = 0$ (7.1)

Momentum Equations: $(\nabla . V)\ V=\nabla P+\mu\nabla^2 V$ (7.2)

Energy Equations: $\rho C(\nabla . V)T=k\nabla^2 T$ (7.3)

Continuity, momentum and energy equations have been solved using Fluent solver under the following flow and boundary conditions.

Air Side: Since air is come into contact with the fins at outside, the convective boundary condition is taken in analysis.

Air inlet

- Type: Velocity Inlet

- Velocity=3m/s
- Initial Gauge Pressure=150Pa

Air Outlet

- Type: Pressure Outlet, $P_g = 0$
- Backflow Temperature=310.5K

Coolant Inlet

- Type: Velocity Inlet
- Initial Gauge Pressure=150Pa

Coolant Outlet

- Type: Pressure Outlet, $P_g = 0$
- Backflow Temperature=351.6K

Enclosure Walls

Type: Wall

- Momentum: Specified Shear= 0
- Thermal: Heat Flux=0

Tube and fin walls

- Type: Wall
- Momentum: No Slip Condition
- Thermal: Convection h=140 W/m^{2}K (Calculated from EES programme as discussed in chapter 4)

Considering nanofluid as a homogeneous mixture, the following correlations have been used in C based UDF in Fluent, presented in Appendix C.

Thermophysical properties of nanofluids and hybrid nanofluids ,

Density of nanofluid can be expressed as [13]

$$\rho_{nf} = \left(1-\phi\right)\rho_{bf} + \phi\rho_p \tag{7.4}$$

Specific heat of nanofluid can be expressed as[14]

$$c_{p,nf} = \frac{\left(1-\phi\right)\rho_{bf}c_{p,bf} + \phi\rho_p c_{p,p}}{\rho_{nf}} \tag{7.5}$$

Thermal conductivity of nanofluid can be expressed as[18]

$$\frac{k_{nf}}{k_{bf}} = \frac{k_{np} + 2k_{bf} + 2\phi(k_{np} - k_{bf})}{k_{np} + 2k_{bf} - \phi(k_{np} - k_{bf})} \tag{7.6}$$

Viscosity of nanofluid can be expressed as [33]

$$\mu_{nf} = \mu_{bf}\left(1 - 0.19\phi + 306\phi^2\right) \tag{7.7}$$

7.3.2 Material

7.3.2.1 Fin and tube material : Material taken as aluminium for fin and having the properties like density of 2702.0 kg/m^3, and the specific heat of 903.0J/kg-K and thermal conductivity of 205 W/m-K[87]. The properties of the fins remain constants for complete analysis of the radiators. Since, air is come into contact with the fins at outside, the convective boundary condition is taken in analysis [87].The minimum to maximum allowable temperature is given from range of 1000K to 3000K respectively in the analysis. Also, material taken for radiator tube is aluminum.

7.3.2.2 Fluid material

Nanofluid: Considering nanofluid as a homogeneous mixture, the thermophysical properties has been called through UDF.

7.4. Operating conditions

The inlet temperature of the coolant has been taken as 353 K, which is typical for automotive radiators. According to the output requirement the respective inlet boundaries have been considered for the parts in the region. The conservation equations of mass, momentum, and energy mentioned equation (7.1) to (7.3) are nonlinear and coupled systems, which are solved subjected to the above boundary conditions. At the inlet of the flat tube, uniform axial velocity and temperature are prescribed. The uniform axial velocity at the inlet assumed in the present study is an idealization of the actual flow pattern. At the outlet section of the tube, the outflow boundary condition corresponds to fully developed velocity and temperature profiles, so that the axial derivatives of the velocity and the temperature at the exit plane are zero. For a higher Reynolds number, the flow is not fully developed and under such a condition, a pressure outlet boundary condition is adopted. All along the tube wall, a no slip boundary condition is imposed for velocity. For an automobile radiator, a realistic thermal boundary condition on the outside of the wall is a prescribed free stream temperature In the present simulations, an ambient air temperature of 35^{o}C was selected [88].

7.5. Results validation and discussions

Validated results of air exit temperature of PG brine is nearly same with water. Lower coolant exit temperature of PG brine results higher heat transfer rate as radiator coolant as compared to water as shown in Figs.7.4-7.5. Fin wall temperature possess maximum deviation of 2.5% for water as radiator coolant as compared to the above mentioned coolants. The deviation for temperature, velocity magnitude and pressure drop have been shown in Table: 7.2

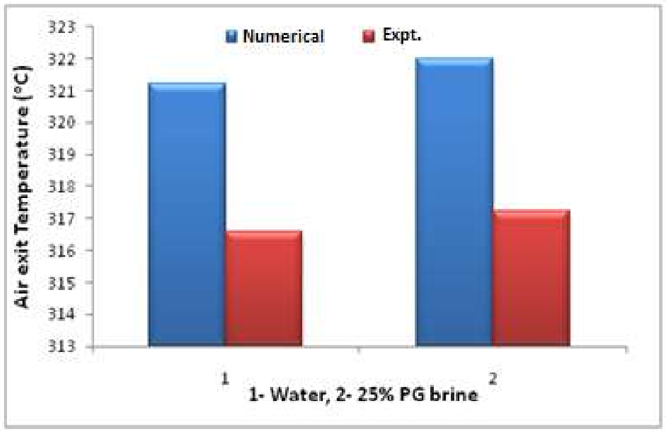

Figure 7.4: Validated results of air exit temperature

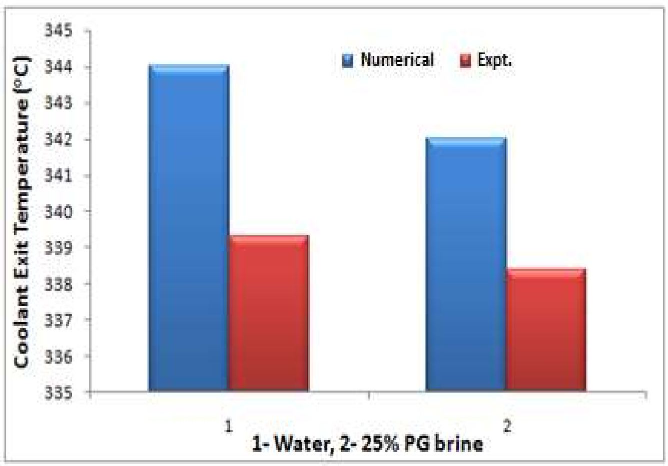

Figure 7.5: Validated results of coolant exit temperature

Table – 7.2 : Validation of Numerical and Experimental Results for water and 25% PG brine

Parameters	**Water Numerical**	**Water Expt.**	**% diff.**	**PG brine Numerical**	**PG brine Expt.**	**% diff.**
Air Outlet Temp. (K)	321.2	316.6	1.6	322.5	317.2	2.2
Coolant outlet Temp.(K)	344	339.3	1.5	342	341.2	1.3
Fin wall Temp.(K)	324	316	2.5	330	322	2.4

Air side Pressure drop (Pa)	18	20	10	16	17.2	7.1
Coolant Pressure drop (Pa)	101	117	5.9	232	250	7.7

7.6 Predicted simulated results for 25% EG and (25% EG+ Ag) nanofluids

7.6.1 Pressure distribution in tube and fins

Numerical analysis of the car radiator is done for volumetric flow rate of 9 l/min for the 25% EG brine and 25% EG brine based Ag nanofluid coolants through a hydraulic diameter of 0.002m tube. Pressure, temperature distribution in tube and fin, temperature distribution at air exit through tube and fins are shown in Figs.(7.6 a, b). Predicted results show that, the pressure drop is maximum in 25% ethylene glycol, which results lower heat transfer performance for the radiator as compared to 25% EG brine based Ag nanofluid and also with the validated result of 25% PG brine.

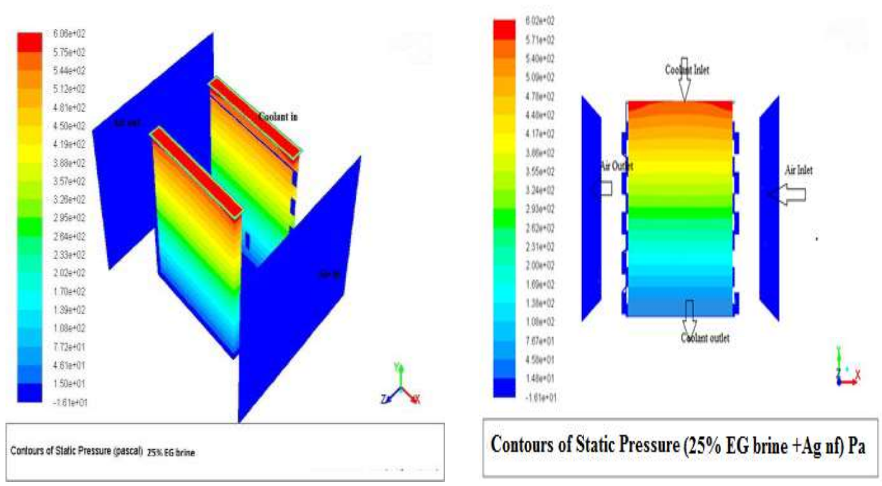

Figure 7.6 (a) Predicted pressure results for 25% EG brine and 25% EG brine based nanofluid

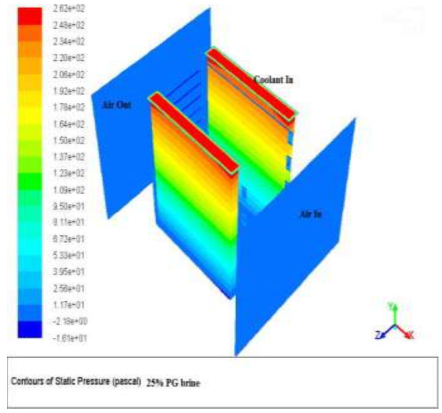

Figure 7.6 (b) Validated pressure results for 25% PG brine

7.6.2 Temperature distribution in tube and fins

Also, the predicted results for the coolant temperature distributions, shown in Figs. (7.7 a, b) through the tube is maximum for 25% EG brine based nanofluid, which results a higher heat transfer performance as compared to 25% EG brine. Similarly, air exit temperature through the fins is maximum for 25% EG brine based nanofluid at inlet frontal velocity of 3m/s through the fins.

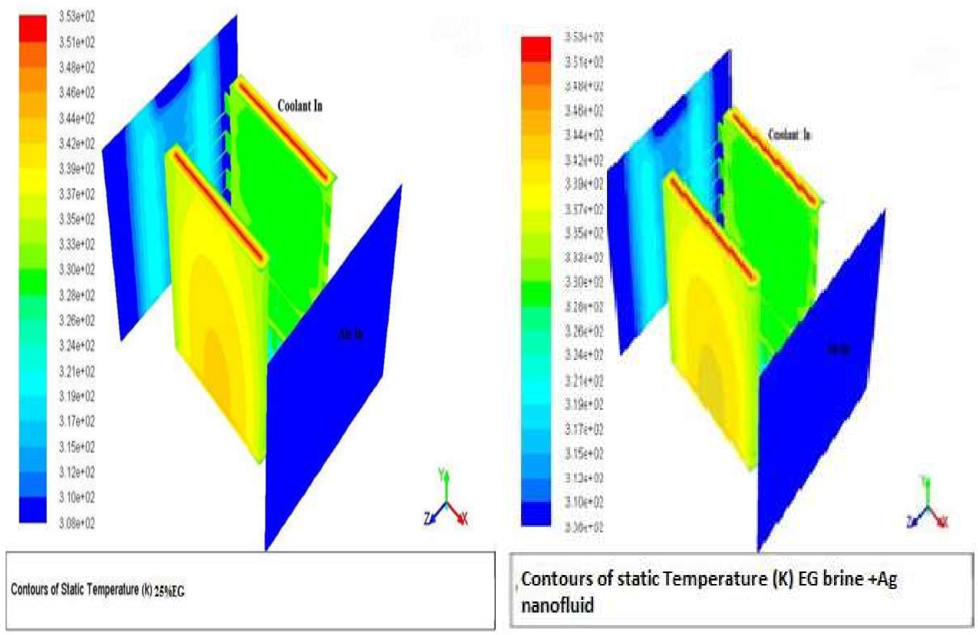

Figure 7.7 (a) Predicted temperature results for 25% EG brine and 25% EG brine based nanofluid

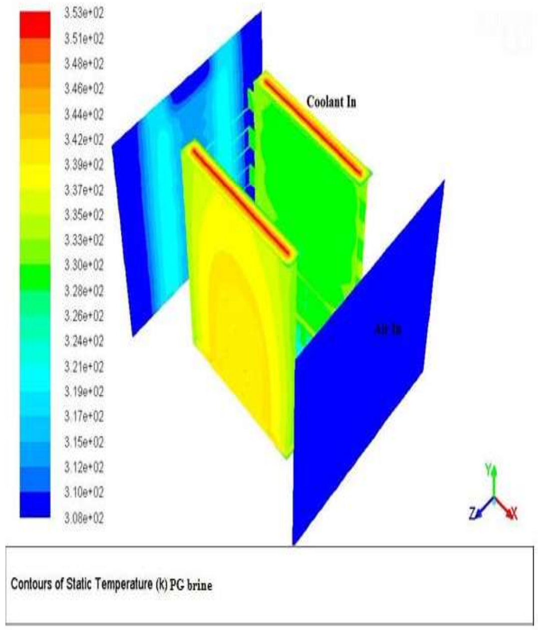

Figure 7.7(b) Validated temperature results for 25% PG brine

7.6.3 Temperature at section plane through the fin

The predicted numerical results of coolant exit temperature through fins and tube section has been shown in Figs.(7.8 a, b). Results show that 25%EG brine based Ag nanofluid having a slightly higher deviation for coolant exit temperature as compared to 25% EG brine as radiator coolants and results higher heat transfer rate. But with comparison to validated result of PG brine the deviation is within 3% for the temperature distribution through tube and fins.

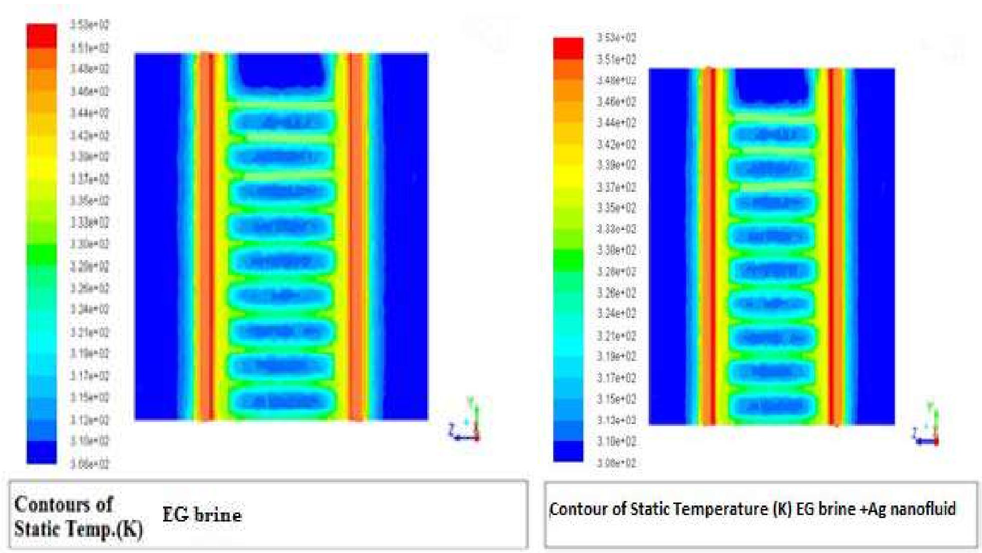

Figure 7.8 (a) Predicted temperature results for 25% EG brine and 25% EG brine based nanofluid

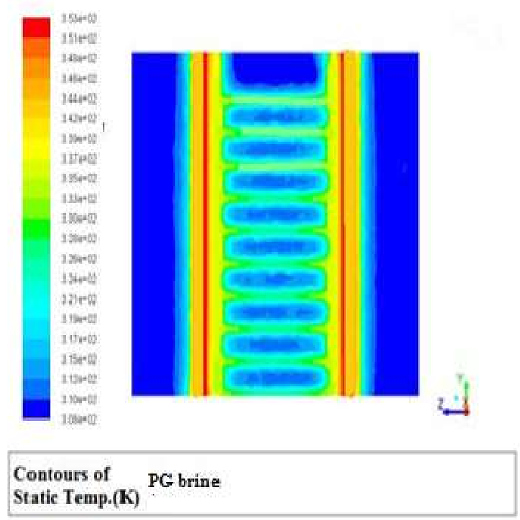

Figure 7.8 (b) Validated temperature results for 25% PG

7.6.4. Velocity Magnitude at a section of fin

However, the predicted velocity magnitude results shown in (Figs.7.9 a, b) are having slightly low deviation for EG brine and EG brine based nanofluid and also validated results of 25% PG brine within 2% deviation through the radiator tubes with a coolant flow rate of 9 l/min.

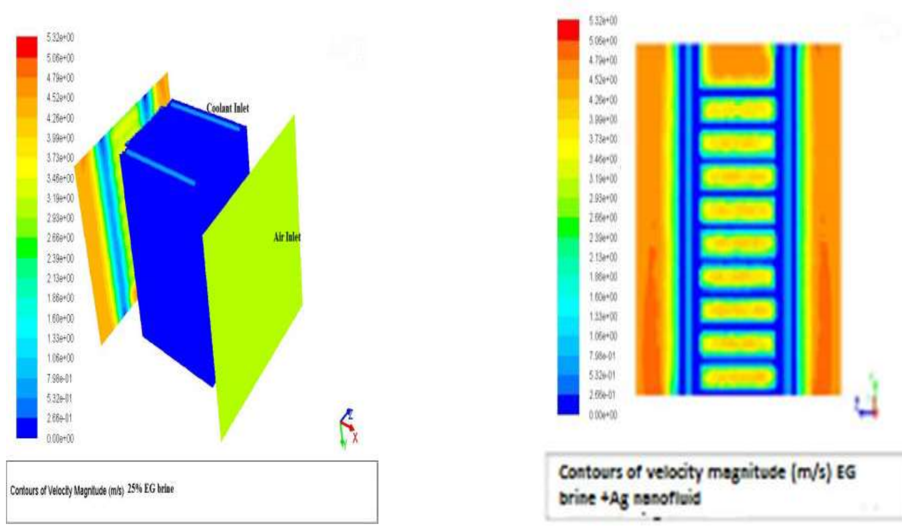

Figure 7.9 (a) Predicted velocity results for 25% EG brine and 25% EG brine based nanofluid

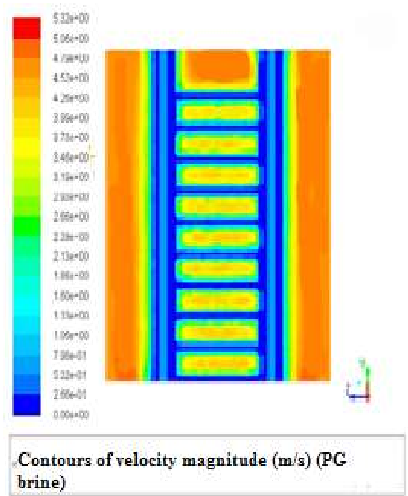

Figure 7.9 (b) Validated velocity results for 25% PG

7.6.5 Air exit section temperature profile for fins

Predicted result of air exit temperature for fins is 2.3% higher in 25% EG brine based nanofluid as compared to EG brine which results a higher heat transfer in radiator at a inlet velocity of 3m/s as shown in Fig 7.10.

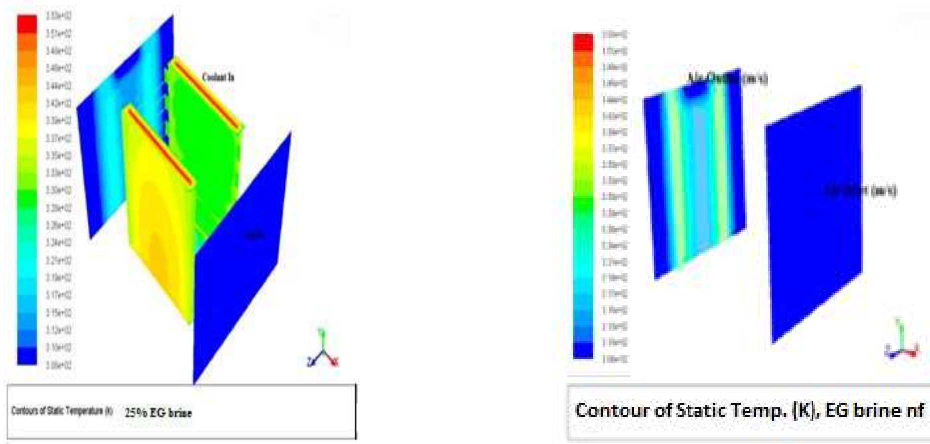

Figure 7.10 : Predicted results for 25% EG brine and 25% EG brine based nanofluid

With comparison to predicted coolant pressure results of 25% EG brine and 25% EG brine based nanofluid with validated coolant pressure of 25% PG brine, 25% EG brine results higher pressure drop as shown in Fig.7.11. Also the comparison results of other parameters are shown in Table : 7.4.

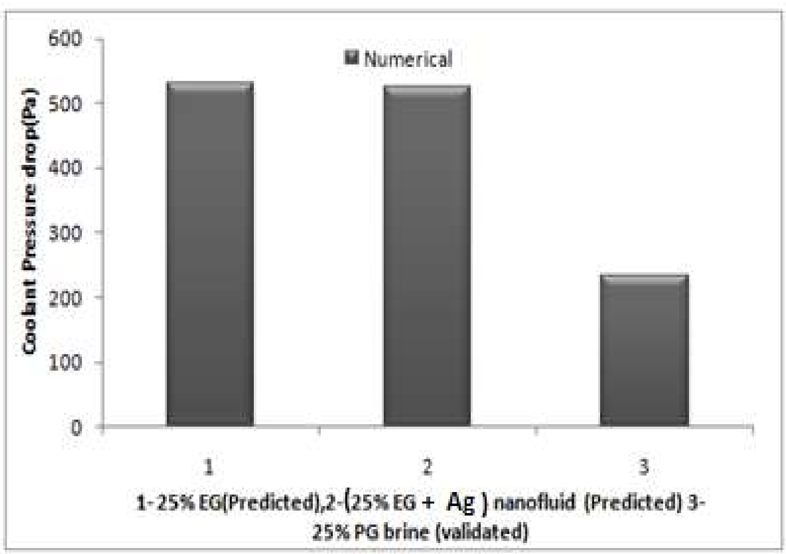

Figure 7.11: Coolant pressure drop for predicted and validated results

Table 7.3 : Comparison of predicted and validated results

Parameters	EG brine Predicted Result	(EG brine + Ag) nanofluid Predicted Results	PG brine Validated Results
Air outlet Temp. (K)	320	322	324
Coolant outlet Temp.(K)	348	347	342
Fin wall Temp. (K)	324	326	330
Air side pressure drop (Pa)	13	14.8	15.4
Coolant pressure drop (Pa)	530	525.5	232