Investigate the thermodynamic performance of Al2O3 nanoparticles suspended in R134a refrigerant in a Capillary Tube

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Abstract- **In the present investigation, an attempt is made to develop mathematical model to determine the flow characteristics of refrigerant inside a straight capillary tube for adiabatic flow conditions. The proposed model can predict the length of the adiabatic straight capillary tube for a given mass flow rate. In the present study R-134a has been used as a working fluid inside the straight capillary tube and used the same model to study the flow characteristics of refrigerant in ANSYS CFX software.**

Investigate the thermodynamic performance of Al2O3 nanoparticles suspended in R134a refrigerant at different concentrations of nanoparticles and at different temperatures in a Capillary Tube

Finally the results of mathematical model are valuated with ANSYS CFX and the results are found to be in fair agreement.

Index Terms- **adiabatic straight capillary tube, refrigerant R134a, ANSYS, simulation.**

I. INTRODUCTION

Refrigeration is the way toward expelling heat, and the reasonable application is to deliver or keep up temperatures underneath the encompassing.

Expansion Devices

A development gadget is another essential segment of a refrigeration framework. The fundamental elements of a development gadget utilized as a part of refrigeration frameworks are to:

1.Reduce weight from condenser weight to evaporator weight, and

2.Regulate the refrigerant spill out of the high-weight fluid line into the evaporator at a rate equivalent to the vanishing rate in the evaporator under perfect conditions; the mass stream rate of refrigerant in the framework ought to be relative to the cooling load.

1.2 Capillary Tube

A slim tube is a long, tight container of steady breadth. "Capillary" is a misnomer since surface strain isn't critical in refrigeration utilization of slim tubes. Normal tube breadths of refrigerant fine tubes extend from 0.5 mm to 3 mm and the length ranges from 1.0 m to 6 m. The weight diminishment in a slim tube happens because of the accompanying two elements:

1. The refrigerant has to stunned the frictional resistance presented via tube walls. This primes to nearly pressure drop, secondly
2. The liquid refrigerant flashes i.e. evaporate with mixture of liquid as well as vapour so its Pressure reduces. The density of vapour is no more than that of the liquid.

II- LITERATURE REVIEW

2.1 Investigation of various geometries of capillary tube

Mutalubi Aremu Akintunde et al reviewed the influences of fields of both helical as well as serpentine-snaked slim tubes on the implementation of a vapor pressure refrigeration outline. He originates the consequences that, on justification of helical-curled geometries the pitch has no enormous influence on the outline implementation yet the circlet distance crossways as of now expected by frequent scientists. On justification of winding geometries both pitch as well as physique impact the framework execution. Execution increments with both increment in the pitch and the tallness.

Akintunde (2004b) revealed the execution of R-12 and R-134a in slender tubes for refrigeration frameworks. In his work, fifty-eight (58) slender containers of various geometries (50 straights and 8 snaked) made of copper-tubes were utilized. The straight tubes were frequently unique lengths (ranges from 1.53 to 2.63 m) and five diverse inward distances across (ranges from 0.72 to 1.62 mm), while the snaked ones were of two straight lengths (1.53 and 2.03 m) with four distinctive looped measurements (50, 100, 150 and 200 mm) yet of the same inner breadth of 1.62 mm.

III- RESEARCH METHODOLOGY

The complete research has been divided into three sections comprising: Model validation, nanofluid side and heat transfer performance for capillary tube. Experimental Analysis has been carried out to validate the FEA model, thus the different refrigerants are applied for find out the performance using the same model.

3.1 Experimental Setup of VCRS

The primary circle of the framework under investigation was made out of five essential segments, i.e., a blower, an evaporator, a condenser, fine tubes and a fluid line filter– drier, as appeared in Fig. The refrigeration setup comprises of a blower of 0.5 tones limit (1411 Kcal/hr), air cooled condenser, a water filled evaporator with electrical radiator and development gadgets as fine or Thermostatic extension valve.

Figure 3.1 (a) Experimental Setup adopted for the Study (GRKIST, Jabalpur)

Figure 3.1 (b) Different parts of Refrigeration system experimental setup (GRKIST, Jabalpur)

The specifications of the experimental setup:

Compressor : Emerson make
Rated cooling capacity : 1411 Kcal/hr
Refrigerant : R-141b
Condenser : Air cooled condenser 3/8" O.D. Copper tube
Expansion Device : A capillary tube with 10 revolution and tube diameter 1.5mm

3.2 Theoretical Background

In the worldwide situation for the environment conservation, it is bringing new challenges to the design of refrigeration systems. The research community are making efforts which focused on improving the energy efficiency of systems (in order to reduce the power consumption) and on replacing the harmful artificial working fluids to environmental friendly refrigerants

Throttling expansion of refrigerant

Like fluids, gases can likewise be extended from high strain to low weight either by utilizing a turbine (isentropic extension) or a throttling gadget (isenthalpic process).

$$\mu_{JT} = \left(\frac{\partial T}{dP}\right)_h \quad \ldots\ldots\ldots\ldots (3.1)$$

3.3The analysis of flow through a capillary tube

In a slim tube the stream is really compressible, three-dimensional and two-stage stream with warm exchange and thermodynamic meta-stable state at the bay of the tube. Be that as it may, in the disentangled examination, the supposition is for consistent, one-dimensional and in single stage or a homogenous blend. Mass and force preservation for a control volume

$$\rho V = Const \quad \ldots\ldots\ldots\ldots (3.3)$$

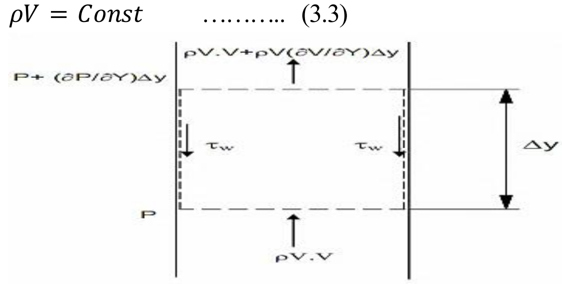


Figure 3.1 A small section of a capillary tube considered for analysis.

Momentum Conservation:

The momentum theorem is applied to the control volume. According to this

[Momentum] $_{out}$ – [Momentum] $_{in}$ = Total forces on control volume

$$\pi R^2\left[\rho V^2 + \rho V\frac{\partial v}{\partial y}\Delta y\right] - \pi R^2[\rho V^2] =$$
$$-\pi R^2\frac{\partial p}{\partial y}\Delta y - \rho_{avg}\, g\pi R^2\Delta y - 2\pi R\Delta y\tau_w \quad \text{………..} \ (3.4)$$

Also, ρavg will tend to ρ since the control volume will clinician to the base face of the control volume where ρ is described. Further, dismissing the effect of gravity, which is nearly nothing we obtain:

$$\rho V.\frac{\partial v}{\partial y} = -\frac{\partial p}{\partial y} - 2\frac{\tau_w}{R} \quad \text{………..} \ (3.5)$$

The divider shear pressure might be composed as far as rubbing factor. hence the frictional pressure drop Δp_f may be obtained from the following equation:

$$\tau_w = R\Delta P_f/2(\Delta y) \quad \text{………..} \ (3.6)$$

The friction factor is defined as

$$\Delta P_f = \rho f - \frac{\Delta y}{D}.\frac{V^2}{2} \quad \text{………..} \ (3.7)$$

Now,

$$\tau_w = \rho f V^2/8 \quad \text{……..} \ (3.8)$$

Substituting for τ_w

$$\rho V.\frac{\partial V}{\partial y} = -\frac{\partial p}{\partial y} - \frac{\rho f V^2}{2D} \quad \text{……..} \ (3.9)$$

For laminar flow the effect of wall roughness in negligible and friction factor is given by

$$f = 64/Re \quad \text{……..} \ (3.10)$$

3.4 CFD Analysis

A CFD analysis has been carried out for the study. The following steps has been followed for the study.

3.4.1 Problem statement

Here the aim of the work is to find out the thermodynamic performance of nano fluid in a capillary tube. Primarily there is the process to define the proper domain for problem to analyse and then apply the boundaries of the problem where conditions are known.

3.4.2 Geometry

The Computational domain of circular micro channel is represented in three dimensional (3D) forms. The geometry consists of a wall, a centreline, and an inlet and outlet boundaries. Geometry is taken as 1.5 mm diameter capillary tube with consider as fluid domain, pitch assume as 3mm coil diameter consider as 25 mm. Figure 3.1 shows the geometry of the capillary tube.

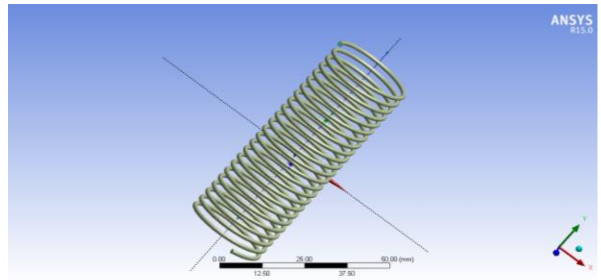


Figure 3.1 Geometry

3.4.3 Discretization process (Meshing)

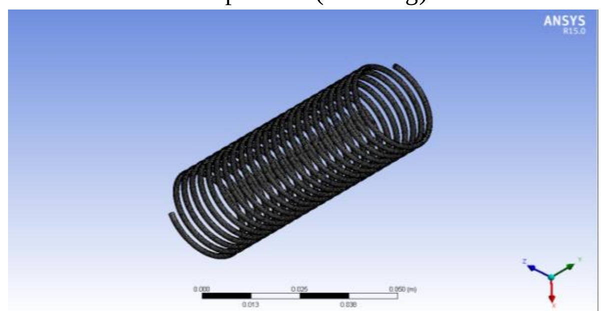


Figure 3.2 Meshing

Structured meshing method done in ANSYS Workbench was used for meshing the geometry. 860260 nodes and 137927 elements were created. The 3D geometry of circular micro channel with structured mesh is shown in Figure 3.2.

3.4.4 Boundary Condition

This step characterizes the material properties.

Table 3.1 Material property used for Investigation (i.e. Refrigerant R141b and R141b+Al_2O_3

Material Property **(I.M. Mahbubula et al; 2013)**					
Material	Nano Particle Conc	Density (kg/m3)	Specific Heat Capacity (j/kgK)	Thermal Conductivity (W/mK)	Viscosity (kg/mS)
R134a		1244	1160	0.093	0.434
R134a+Al_2O_3	0.1	1246	1102	0.094	0.435
	0.2	1249	1046	0.095	0.436
	0.3	1252	994.5	0.096	0.437

Table 3.2 Boundary Conditions

Boundary Condition	R-134a
Inlet Pressure	14 bar
Analysis Type	Steady State Condition
Minimum Volume Fraction (Inlet, Liquid)	0.7
Condition	Turbulence K- Epslone
Surface Tension	0.003 N/m
Inlet Temperature	50° C

IV-RESULT ANALYSIS

4.1 General

This chapter contains the model validation with experimental result. To evaluate the accuracy of the Finite Element Analysis, experimental system was tested with R134a refrigerant before conducting the FEA for R134a based Nano fluid refrigerants with different concentrations.

4.2 Model Validation

4.2.1 Experimental Results

The following results have been found out after the experimental analysis.

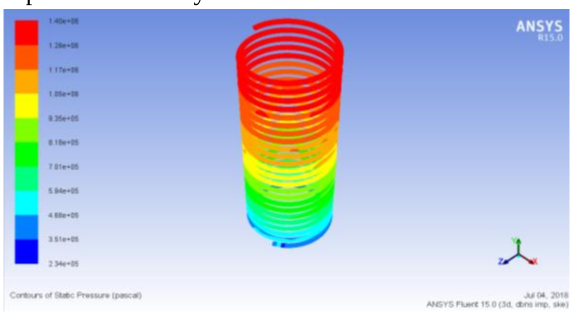


Figure 4.1 Pressure distribution at inlet pressure 14 bar for base fluid R134a

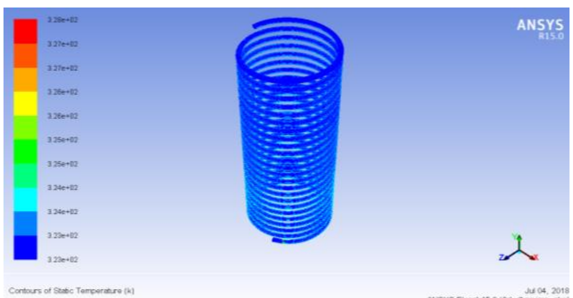


Figure 4.2 Temperature distribution at inlet pressure 14 bar for base fluid R134a

Table 4.1 Comparison of Experimental and CFD results for R134a as a working Fluid

	Experimental Results	CFD Result	Difference (%)
Inlet Pressure (bar)	14	14	
Outlet Pressure (bar)	3	3.28	8.54
Inlet Temperature (K)	326	326	
Outlet Temperature (K)	322.5	323	0.15
Temperature Drop	3.5	3	16.67

Table 4.1 shows the comparison in between Experimental and CFD results for validation the CFD model that can be applied for further analysis for different fluid condition.

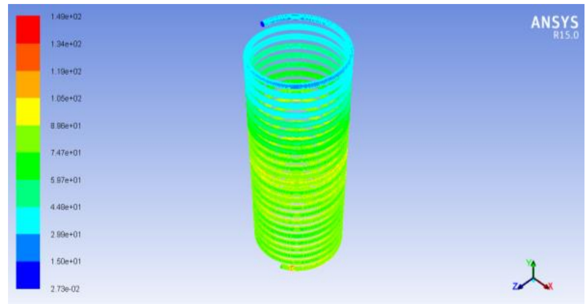


Figure 4.3 Turbulent Kinetic Energy at inlet pressure 14 bar for base fluid R134a

4.3 CFD Analysis for R134a based nano fluid refrigerant

After the model validation the R134a based nano fluid at different volume concentration has been applied for the further analysis.

4.3.1 (R134a+Al_2O_3) Nano refrigerant with 0.1% by volume concentration of Al_2O_3

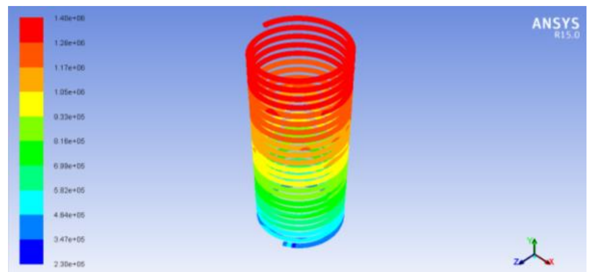


Figure 4.4 Pressure distribution for R134a+Al_2O_3 Nano refrigerant with 0.1% by volume concentration of Al_2O_3

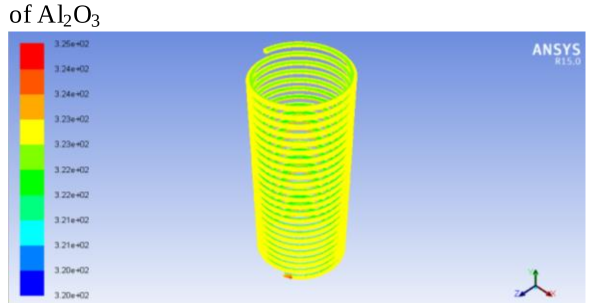


Figure 4.5 Temperature distribution for R134a+Al_2O_3 Nano refrigerant with 0.1% by volume concentration of Al_2O_3

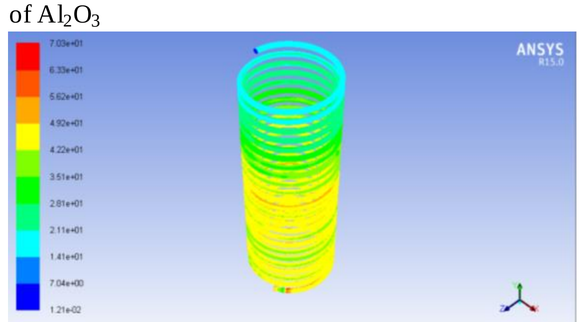


Figure 4.6 Turbulent Kinetic Energy for R134a+Al_2O_3 Nano refrigerant with 0.1% by volume concentration of Al_2O_3

4.3.2 (R134a+Al_2O_3) Nano refrigerant with 0.2% by volume concentration of Al_2O_3

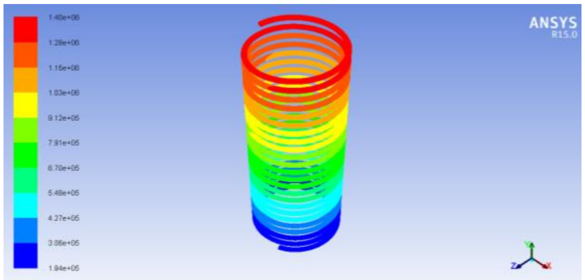


Figure 4.7 Pressure distribution for R134a+Al_2O_3 Nano refrigerant with 0.2% by volume concentration of Al_2O_3

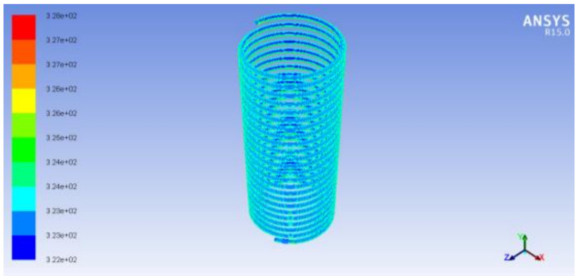


Figure 4.8 Temperature distribution for R134a+Al_2O_3 Nano refrigerant with 0.2% by volume concentration of Al_2O_3

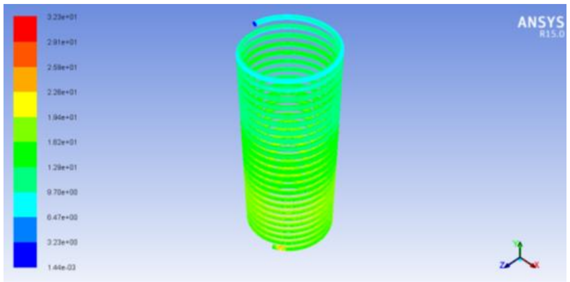


Figure 4.9 Turbulent Kinetic Energy for R134a+Al_2O_3 Nano refrigerant with 0.2% by volume concentration of Al_2O_3

4.3.3 (R134a+Al_2O_3) Nano refrigerant with 0.3% by volume concentration of Al_2O_3

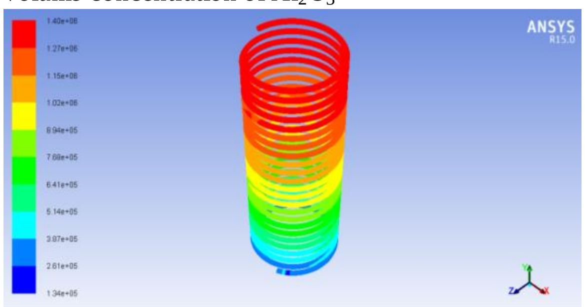


Figure 4.10 Pressure distribution for R134a+Al_2O_3 Nano refrigerant with 0.3% by volume concentration of Al_2O_3

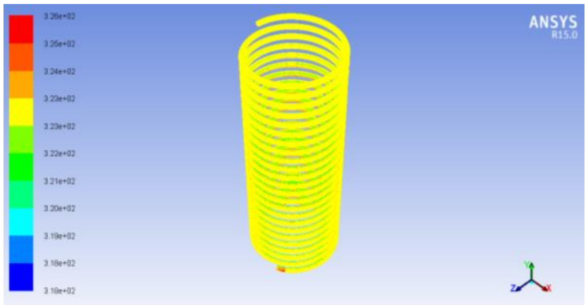


Figure 4.11 Temperature distribution for R134a+Al_2O_3 Nano refrigerant with 0.3% by volume concentration of Al_2O_3

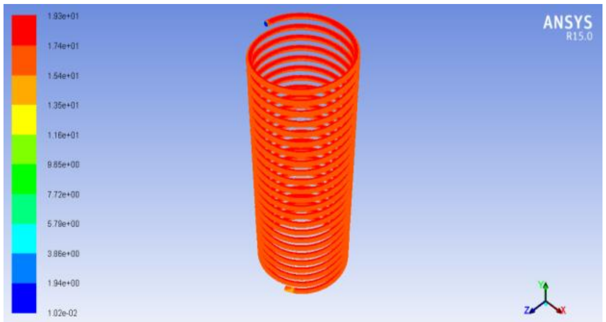
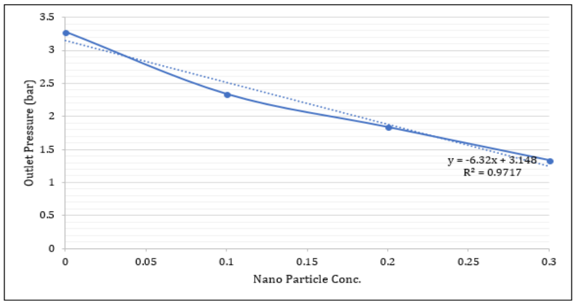


Figure 4.12 Turbulent Kinetic Energy for R134a+Al_2O_3 Nano refrigerant with 0.3% by volume concentration of Al_2O_3

4.4 Discussion

Capillary tube is a small-bore tube, principally used in domestic refrigerators and freezers. The diameter and length of the tube relate to the pressure difference between the condenser and the evaporator and restrict the flow of refrigerant while the compressor is running. Tube of a particular length provides the required pressure drop. When the compressor stops the refrigerant continues to flow until the pressures equalise. The capillary is additionally used as a restrictor to meter refrigerant flow in small, air-cooled, room air conditioning units.



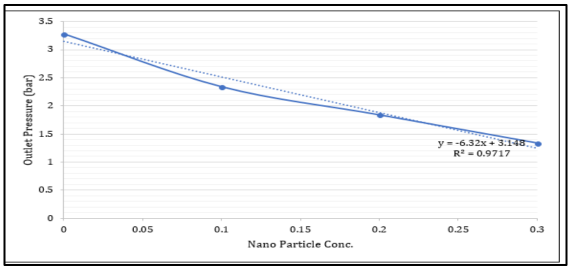


Figure 4.13 Outlet Pressure variation with respect to Nano Particle Concentration

Table 4.2 Inlet and Outlet pressure changes for different Nano Particle Concentration

Material	Nano Particle Conc.	Inlet Pressure (bar)	Outlet Pressure (bar)
R134a	0	14	3.28
	0.1	14	2.34
R134a+ AL_2O_3	0.2	14	1.84
	0.3	14	1.34

Table 4.3 shows the inlet and outlet temperature from the capillary tube at different nano particle concentration.

Table 4.3 Inlet and Outlet temperature changes for different Nano Particle Concentration

MATERIAL	NANO PARTICLE CONC	INLET TEMPERATURE (K)	OUTLET TEMPERATURE (K)	TEMPERATURE DROP
R134A	0	326	323	3
	0.1	325	320	5
R134A+AL_2O_3	0.2	328	322	6
	0.3	326	318	8

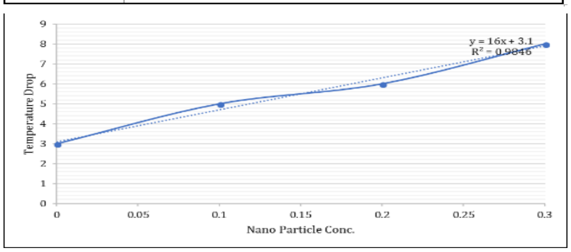


Figure 4.14 Temperature Drop with respect to Nano Particle Concentration

Linear regression has been carried out to understand the behaviour. About 0.9846 value of R^2 can be achieved, which shows the good relation between both the parameters. The relation between both the parameters are as

$$\text{Temperature Drop} = (16 \times \text{Nano Particle Concentration}) + 3.1 \ \ldots.. \ (4.2)$$

Table 4.4 Turbulent Kinetic Energy for different Nano Particle Concentration

MATERIAL	NANO PARTICLE CONC	TURBULENT KINETIC ENERGY (m^2/s^2)
R134A	0	149
	0.1	70.3
R134A+Al_2O_3	0.2	32.3
	0.3	19.2

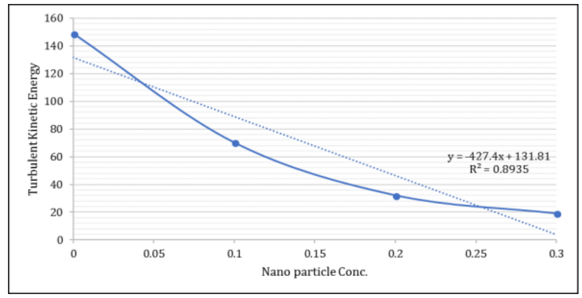


Figure 4.15 Turbulent Kinetic Energy with respect to Nano Particle Concentration

The relation between both the parameters are as

$$\text{Turbulent Kinetic Energy} = (-427.4 \times \text{Nano Particle Concentration}) + 131.81 \ (4.2)$$

V-CONCLUSION

A capillary tube, also sometimes called a restrictor tube, is a fixed length of small-diameter tubing lying between the outlet of the condenser and the inlet of the evaporator. In this work nano refrigerant has been applied for the cooling and capillary tube is considered for the study. The three parameters have been considered for the study i.e. pressure drop, temperature drop and turbulence. The following observations has been made:

- As the Al_2O_3 concentration increases the pressure at outlet decreases, thus maximum pressure drop is achieved. This property helps to increase the overall COP of the system.
- The pressure decrement shows the linear relation with particle concentration
- as the nano particle concentration increases the temperature drop also increases. Maximum of 8-degree temperature drop can be achieved at 0.3 percentage nano particle concentration.
- A decreasing value of Turbulent Kinetic Energy is observed. The function of capillary tube is to provide the flow in laminar condition by controlling the flow. As the concentration of nano particle increases the turbulence in the fluid decreases.

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