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Design, Analysis and Investigation of Solar flat Plate Collector

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Abstract - *Solar is a free source of energy found in nature, and most modern technologies, from vacuum cleaners to electric vehicles, are powered by it. Solar collectors are now being used to develop energy usage in both residential and industrial applications of water heating systems. Despite the fact that solar water heaters come in a variety of configurations, they all use absorber tubes with a circular cross section. This study investigates the effects of different diameters and shapes of absorber plate tubes (zigzag, u-bent double parallel, etc.) on thermal performance. In the analysis, consistent area of cross section along flow channel and constant perimeter of tube flow path will be used as comparison criteria for different designs. This research allows us to create a prescription for the size and shape of various absorber tubes' cross sections.*

Key Words: - **Solar, Flat plate collector, Heat transfer & CFD.**

1. INTRODUCTION

Solar flat plate collector is a device which accumulate available sun energy or rays and transfigure it into required useful energy using water or air as working medium. Solar flat plate collector has main two parts – metal plate , absorber plate and besides which internal tubing structure , size and material of tube are main factors for improving efficiency of solar flat plate collector.

Here, we use water as working medium and by changing tube structure , size and material we are trying to check reliability and performance of Solar collector with the help of ANSYS software – CFD Domain compare with physical model.

2. ANALYSIS

It's Overview to analysis radiation thermal model

Heat transfer is defined as the movement of thermal energy from one region of space to another. Conduction, convection, and radiation are the three primary ways of heat transport. Modeling Conductive and Convective Heat Transfer physical models containing simply conduction and/or convection are the simplest, but buoyancy-driven flow or natural convection Natural Convection and Buoyancy-Driven Flows Theory, and radiation models Modeling Radiation are more complicated.

2.1.1 Procedure for Ansys Workbench CFD analysis

1.The first step in Ansys CFD model is to Import the geometry file, may be STP or IGS file from the created format of software will be required.

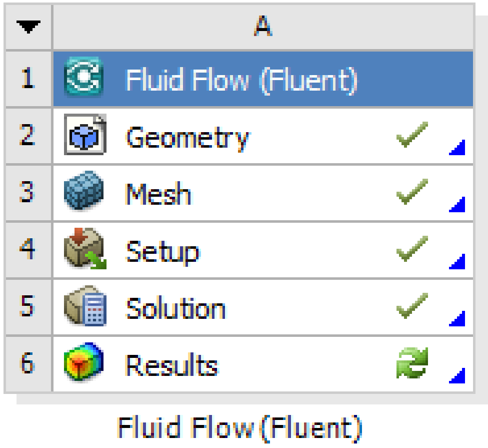

Figure 3 Ansys CFD module – Importation of geometry file

2.1.2 Mesh generation & named selection

Scope	
Scoping Method	Geometry Selection
Geometry	86 Faces
Definition	
Suppressed	No
Type	Element Size
Element Size	25.0 mm
Advanced	
Defeature Size	Default (0.55907 mm)
Influence Volume	No
Behavior	Soft
Growth Rate	Default (1.2)
Capture Curvature	No
Capture Proximity	No

Figure 4 mesh module

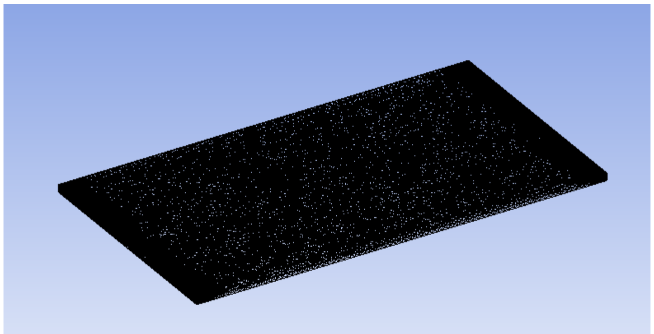

Figure 5 Mesh creation

Statistics	
Nodes	82656
Elements	337578

Figure 6 nodes and elements

2.1.3 Setting up the problem to its boundary condition.

a. After meshing & named selection 3rd process is setup, which means setting up the problem for defined boundary conditions. This process contains several scopes which needs to be set up before solving it. following are the configuration or boundary condition applied while solving.

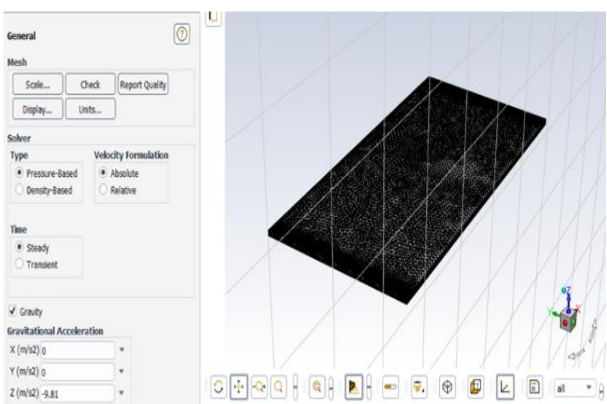

Figure 7 setup 3rd process in CFD

i. Checking for mesh

ii. Turning on energy equation

iii. Describing type of flow

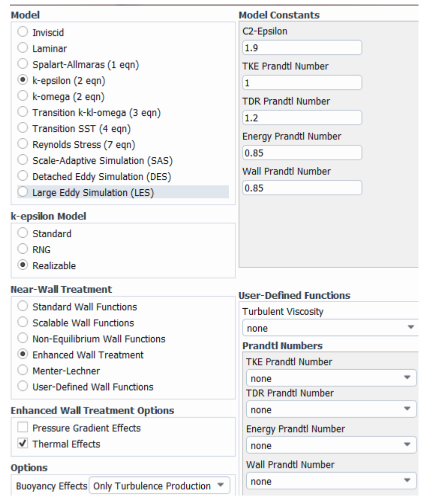

Figure 8 Viscos model

2.1.4 Radiation model

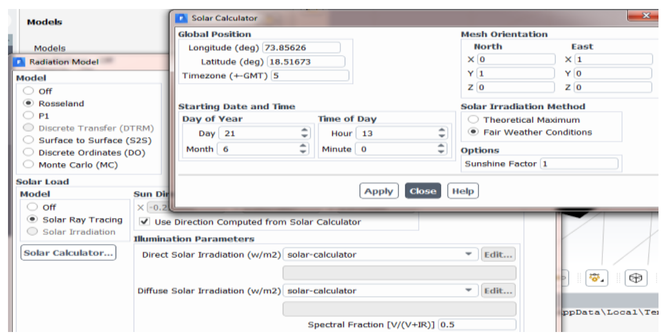

Figure 9 radiation model

2.1.5 Material Creation

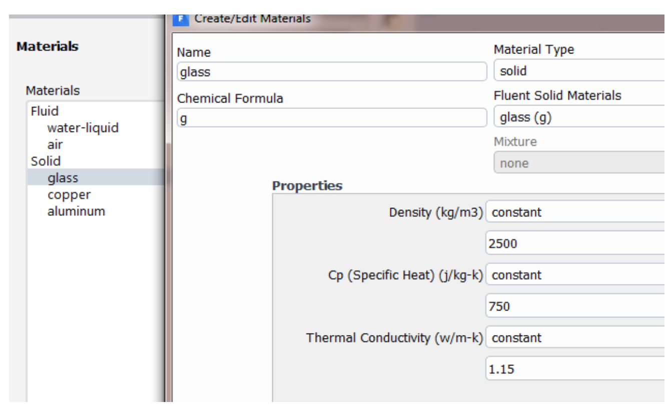

Figure 10 material

2.1.6 Boundary Conditions

1. inlet = 0.05 kg/sec mass flow inlet
2. inlet water temperature = 25 degree Celsius
3. absorber plate = copper material addition + solar tracing turning on
4. walls

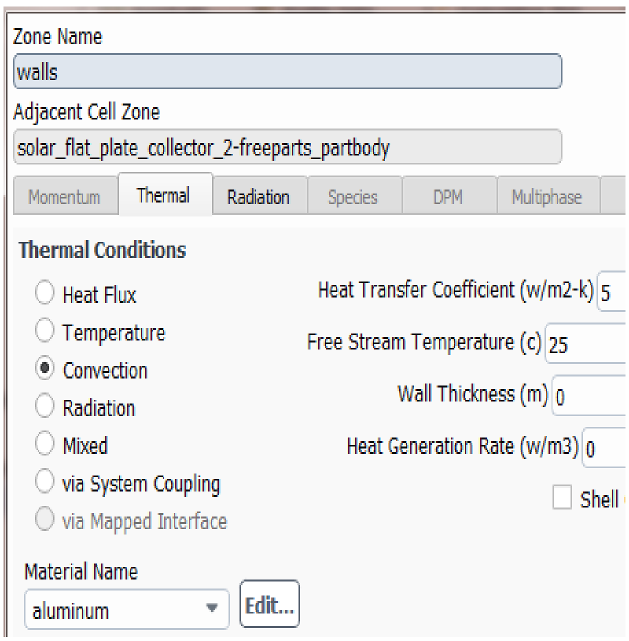

Figure 11 wall scoping

2.1.7 glass

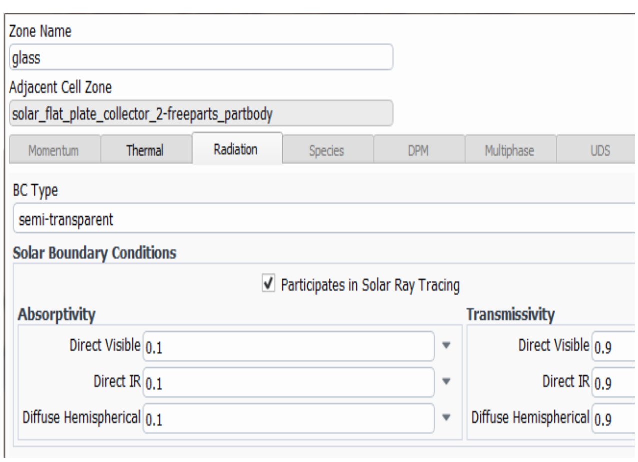

Figure 12 glass scoping

2.1.8 Method for solution

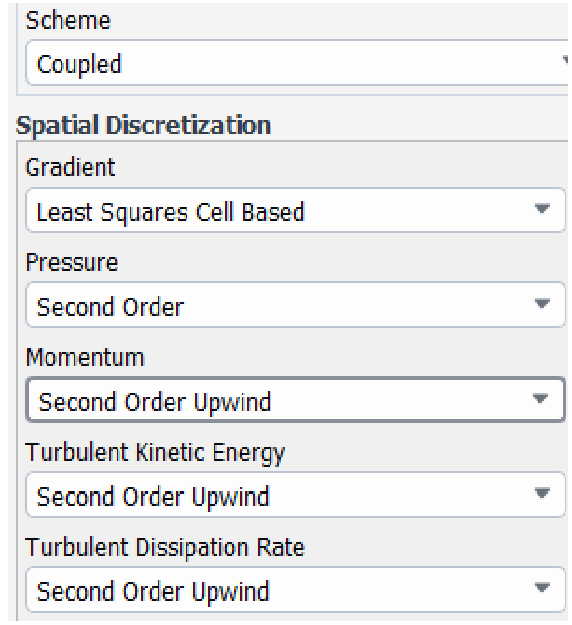

Figure 13solution Type

viii. initialization – Hybrid initialization

ix. solution calculation 50 iteration or steps.

2.1.9 Results

Velocity flow ratio at 0.05 k/sec inlet flow

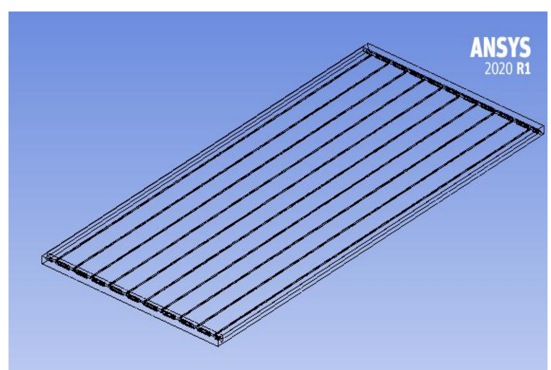

Figure 14 geometry in result mode

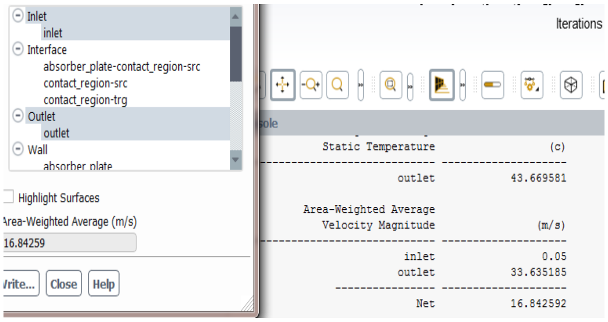

Figure 15 result inlet & outlet velocity

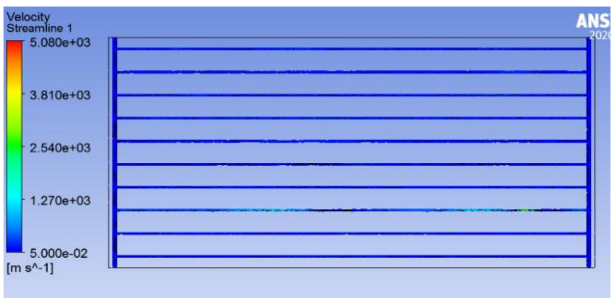

Figure 16 Velocity

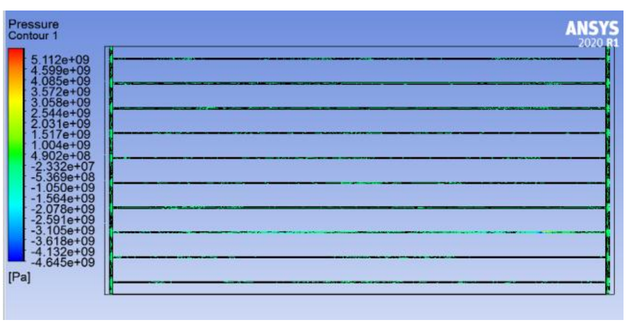

Figure 17 pressure in pascal

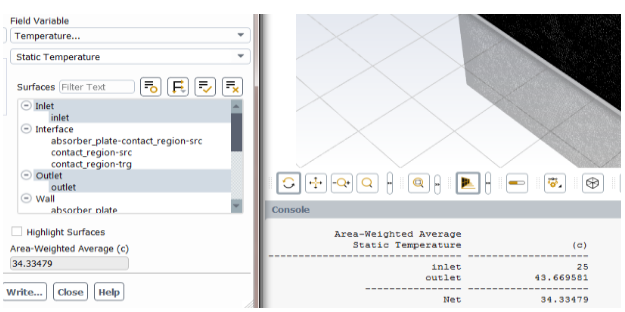

Figure 18 temperature contours

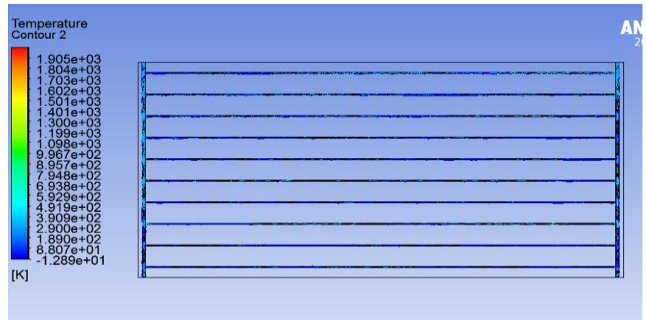

Figure 19 temperature contour

2.1.10 Discussion

In this iteration parallel tube are considered and radiation is applied on top of the glass. The water flowing inside the tube has a temperature of 25 degree Celsius and at outlet 43.66 degree Celsius has been measured.

In next iteration we will calculate the outlet temperature by changing its path from parallel to U-bent.

2.2 Iteration 2

2.2.1 In this iteration

1. boundary conditions
2. material constants
3. solar module
4. energy equations and
5. Number of steps iterations

Have been kept same as to the previous problem

Only tube path has been changed from straight or parallel to u-bent. As we can see in the below figure.

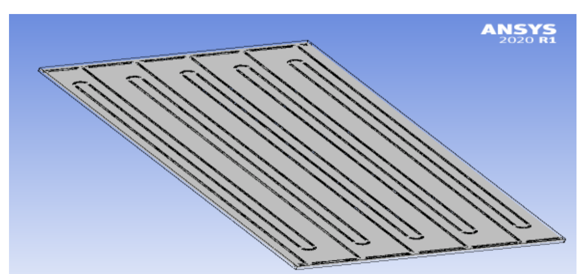

Figure 20 solar flat plate collector with U-Bent tubes

2.2.2 **Results**

1. Velocity

Area-Weighted Average Velocity Magnitude	(m/s)
inlet	0.05
outlet	0.045401586
Net	0.047700802

Figure 21 velocity at parallel path

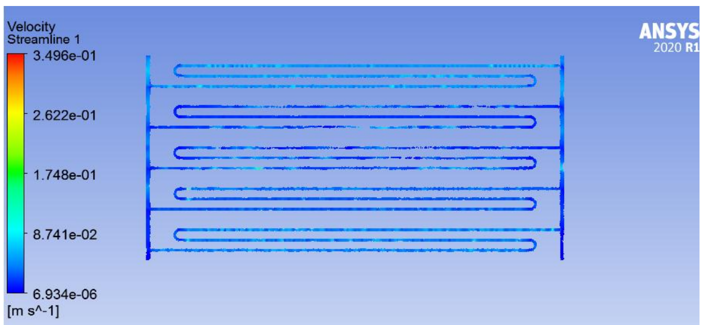

Figure 22 velocity streamline of u bent

2. Pressure

Area-Weighted Average Static Pressure	(pascal)
inlet	327.60909
outlet	0
Net	163.80516

Figure 23 Pressure

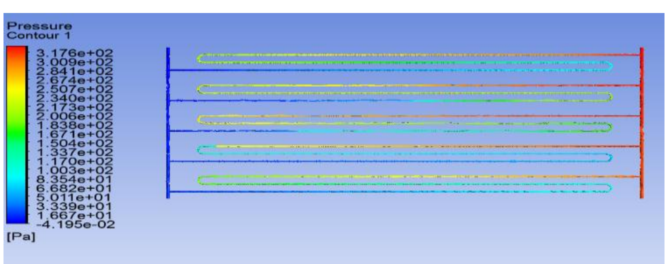

Figure 24 pressure contour

3. Temperature

Area-Weighted Average Static Temperature	(c)
inlet	25
outlet	50.998084
Net	37.998993

Figure 25 Temperature

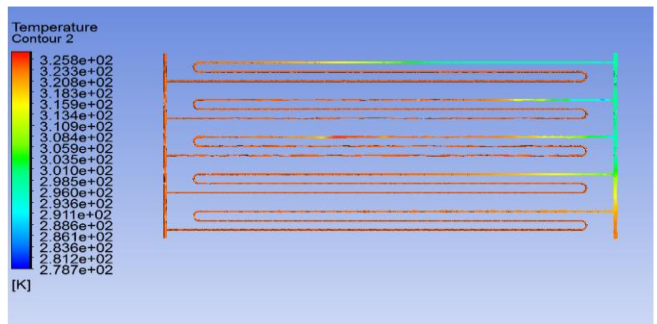

Figure 26 temperature

2.3 Iteration 3

In this iteration the flow path has been changed from u-Bent to Zig-Zag.

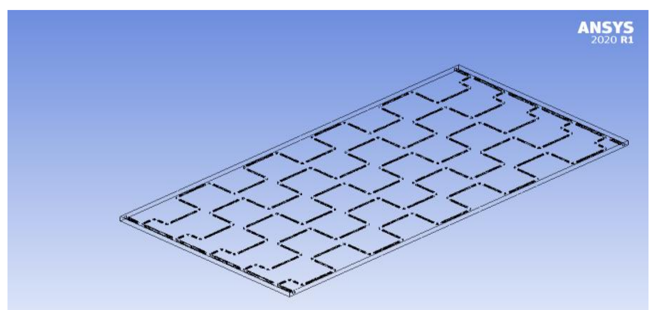

Figure 27 Zig-Zag tubing

1. **Velocity**

Console

Area-Weighted Average Velocity Magnitude	(m/s)
inlet	0.05
outlet	0.049316402
Net	0.049658201

Figure 28 velocity

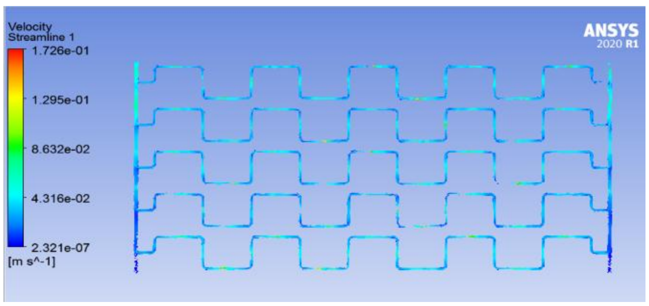

Figure 29 Velocity distribution in the tubing

2. **Pressure**

Console

Area-Weighted Average Static Pressure	(pascal)
inlet	145.9188
outlet	0
Net	72.959275

Figure 30 pressure

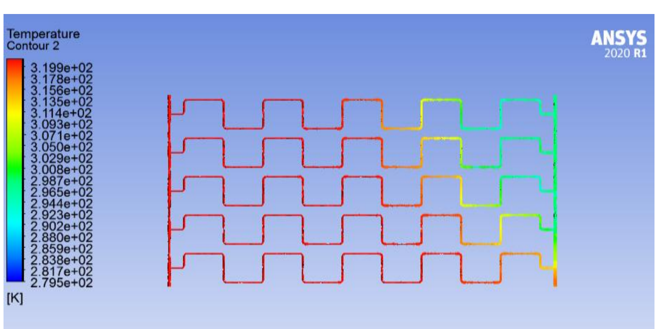

Figure 31 temperature contour of Zig-Zag tubing

2.4 Iteration 4

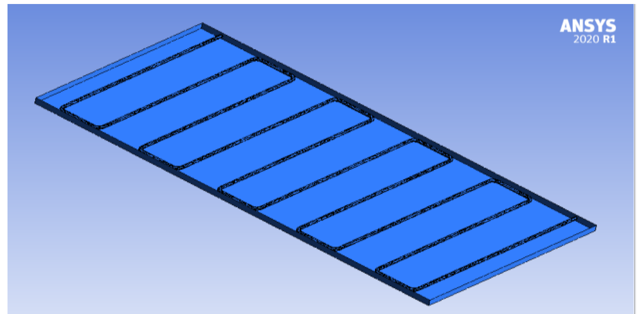

Figure 32 Zig-Zag with single tubing

- Gap between tubes = 200mm
- No of tubes = 10X

1. **Temperature Results.**

Console

Area-Weighted Average Static Temperature	(c)
inlet	24.999994
outlet	49.791294
Net	37.395644

Figure 33 temperature results

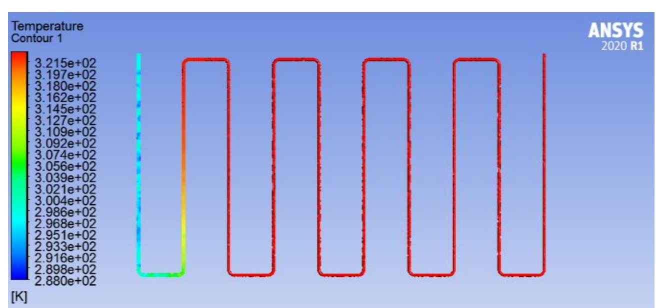

Figure 34 temperature result plot on single tube Zig-zag Path

2. Pressure Results

```
Console

            Area-Weighted Average
               Static Pressure                 (pascal)
-------------------------------- --------------------
                           inlet            95.817464
                          outlet                    0
                ---------------- --------------------
                             Net            47.908732
```

Figure 34 Pressure

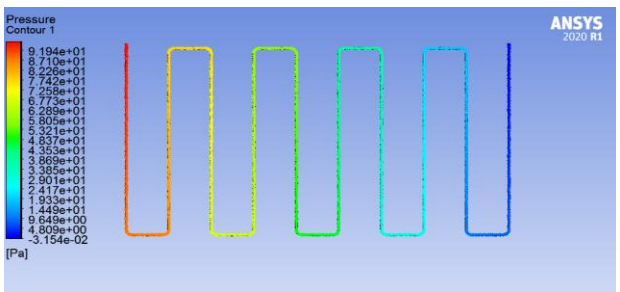

Figure 35 pressure drop at outlet

3. Velocity

```
Console

            Area-Weighted Average
              Velocity Magnitude                  (m/s)
-------------------------------- --------------------
                           inlet          0.050000001
                          outlet           0.02847141
                ---------------- --------------------
                             Net          0.039235706
```

Figure 36 velocity

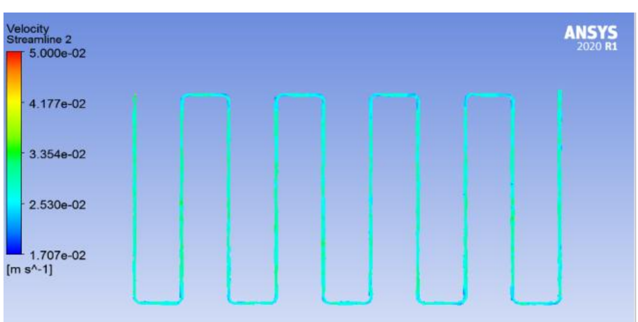

Figure 37 velocity values at defined outlet

- Material Comparison for experimental modal
- Material Steel Collector
- Tube Copper alloy

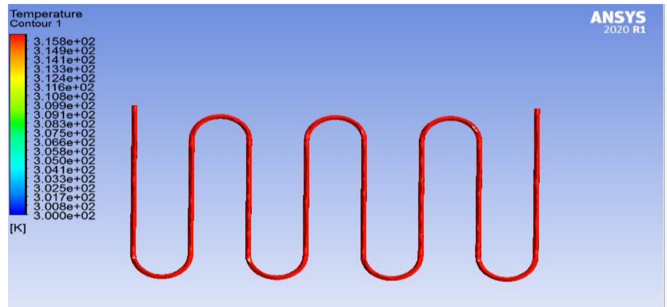

Figure 38 temperature contour

```
            Area-Weighted Average
              Static Temperature                    (c)
-------------------------------- --------------------
                           inlet                26.85
                          outlet            51.566944
                ---------------- --------------------
                             Net            39.208472
```

figure 39 temperature

```
            Area-Weighted Average
               Static Pressure                 (pascal)
-------------------------------- --------------------
                           inlet        -0.0078124998
                          outlet                    0
                ---------------- --------------------
                             Net        -0.0039062499
```

Figure 40 Pressure

```
            Area-Weighted Average
              Velocity Magnitude                  (m/s)
-------------------------------- --------------------
                           inlet                    0
                          outlet       6.5403873e-09
                ---------------- --------------------
                             Net       3.2701937e-09
```

Figure 41 Velocity

III. EXPERIMENTAL MODEL

Figure 42 Experimental Modal Solar flat plate collector single copper tube with steel collector & Figure Water motor

3.1 Parameters

Collector 750*400*30 mm

Glass 750*400*2 mm

Copper tube diameter = 10 mm

Water motor = 6 v powers

Temperature sensor

Black paint = for absorption

3.2 Digital result

Temperature sensor is used to measure the outlet flow of the water flowing inside a steel collector via copper tube.

Figure 43 LCD temperature sensor

Weight	50g
Battery	2 LR44 button batteries (Included)
Size	About 48x28.5x15.2mm/1.88x1.12x0.59''
LCD screen	About 35.7x16.8mm/1.4x0.66''
Wire length	1.5m/4.9ft

Table Specification of temperature sensor

3.3 Water motor

R385 6-12V DC Diaphragm Based Mini Aquarium Water Pump is an ideal non submersible pump for variety of liquid movement application. It has enough pressure to be used with nozzle to make spray system. The pump can handle heated liquids up to a temperature of 80°C and when suitably powered can suck water through the tube from up to 2m and pump water vertically for up to 3m.

1. Model: R385
2. Rated Voltage: DC 6V to 12V (1 amps)
3. Working current: 0.5A to 0.7A (Max)
4. Power: 4W-7W
5. Max Lift: 3m
6. Max Suction: 2m
7. Max Water Temp: 80 °C
8. Pump Size: 90mm * 40mm * 35mm approx.
9. Fluid: 0-100 ° C
10. Input/output tube diameter: outer 8.5mm, inner 6mm approx.
11. Max Current: Up to 2 Amps while starting up
12. Life: up to 2500 Hours
13. The maximum flow rate of up to 1 – 3L/min.

Figure 44 diaphragm Mini Motor

IV. Experiment result

Outlet temperature of water after – minute

Figure 45 temperature of water at outlet after 75 min

Experimental results in tabular form

Sr. No	Time in hours	Temperature T1 in ^{0}C	Temperature T2 in Degree Celsius
1.	**55 min**	**24 ^{0}C**	**50.6 ^{0}C**
2.	75 min	24 ^{0}C	59.5 ^{0}C
	Software Ansys CFD		
1.	**50 Iterations**	**26.85**	**51.566 ^{0}C**

Table 1 Analytical & experimental analysis.

- Hence the value of temperature at 55 min matching the simulation result which was solved for 50 iterations.
- Hence the project is validated as we can see the above readings obtained are matching with the experimental solution.
- The fabricated part has an efficiency to rise the water with an average increment in the temperature radiation of sun energy.
- Future scope
- One can change tube and collector material to know the thermal aspect of properties.

IV. CONCLUSION

- This project helps in determining the design parameter required to enhance the thermal heat transfer between the flat plate solar collector and the working medium passing inside a copper tube.
- 3D model was prepared using Catia v5 3D experience software, & FEA simulation is done using Ansys workbench.
-
- Until now FEM for different iterations have been solved, based on the design criteria & results were noted out as we can see in the result tabular column for below path flow of tubing section.

- Parallel tube flow
- U-bent tube flow
- Zig-zag with 5X tubing &
- Zig-Zag with 1X tubing

- Zig-Zag with steel material process, temperature of water better than any other path, because of zig-zag like structure, water inside the tube rests longer than any other cross-section, but only disadvantage is pressure.
- Hence from all aspect
- Steel is better in strength, as it possesses good thermal & electrical energy, lower in cost. Collector will be made using SS. Tube copper and a thermal glass with absorber plate.
- To validate the project, experimental modal will be prepared by procuring standard materials and fabrication process and will be validated with the Fem solution

Sl No	Type	Boundary Conditions	Result: Temperature In ^{0}c	Result Pressure Outlet in Pascal	Result Velocity In M/Sec
1.	Parallel tube	Inlet temperature T1=25^{0}C Velocity 0.05m/sec	Outlet temperature T2= 43.66^{0}C	P1= 418 P2=0	V2=33.635
2.	U-Bent tube	Inlet temperature T1=25^{0}C Velocity 0.05m/sec	Outlet temperature T2= 50.99^{0}C	P1=327.6 P2=0	V2=0.0454
3.	Zig-zag 5X tube	Inlet temperature T1=25^{0}C Velocity 0.05m/sec	Outlet temperature T2=48.98 ^{0}C	P1= 145 P2=0	V2=0.0493
4.	Zig-zag 1X tube	Inlet temperature T1=25^{0}C Velocity 0.05m/sec	Outlet temperature T2= 49.79 ^{0}C	P1=95 P2=0	V2= 0.0284
5.	Zig-Zag with steel collector	T1 =25^{0}C	T2 =51.566^{o}C	P1 0 P2 =-0.078	V2= 2.481e-8

Table 3 results table

- Hence the analysis done for experiment modal has a temperature of 51.566944 degree Celsius at 50 Sub Iteration.
- In next phase, modal of solar flat plate collector will be prepared with additive manufacturing Process.

5.2 Bill of Material

Sr. No	Components	Specs	Cost
1.	Water Motor	1X 6V	345/-
2.	Copper tube	1x 1 meter	785/-
3.	Collector	Double angle plate 1 meter	345/-
4.	Sheet plates	1-2 mm thickness	645/-
5.	Transparent tube	1 meter	165/-
6.	Glass	2 mm thickness	1200/-
7.	Temperature Sensor	1X	263/-
	Components Total		3748/-
	Fabrication & transportation		3500/-
	Total		6748/-

Table 2 Bill of material

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BIOGRAPHIES

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