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EFFICIENCY OF EVACUATED TUBULAR SOLAR THERMAL COLLECTOR

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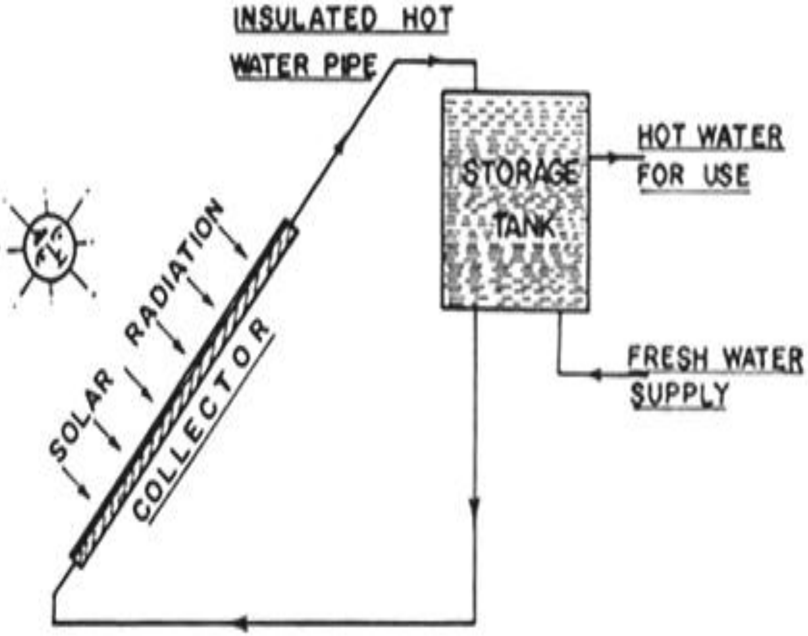
Introduction

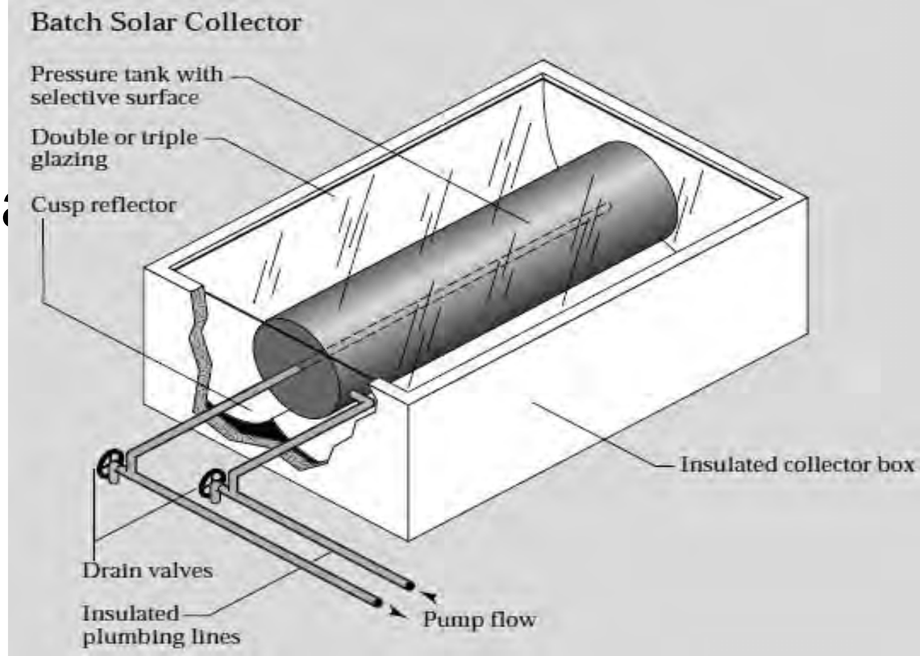
- Solar heating
  - Solar thermal energy for both domestic and commercial applications such as water heating;
  - Composed of solar thermal collectors, storage tank, heat exchanger, and control systems;
  - A thermodynamic process;
  - Passive vs. active systems
  - High efficiency of convertin and utilizing solar energy.



Solar Thermal Collector

- Solar Thermal Collector
  - Captures the sun’s radiation energy;
  - Turns solar energy into thermal energy;
  - Transfers heat to the working fluid.

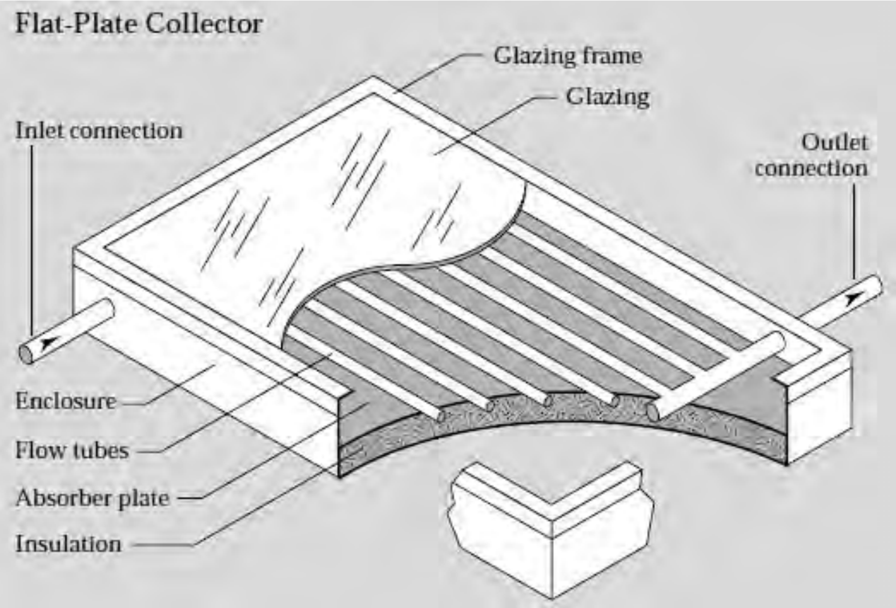
- Batch Collector
  - Easy to design and insta
  - Less energy capture;
  - Inefficient.

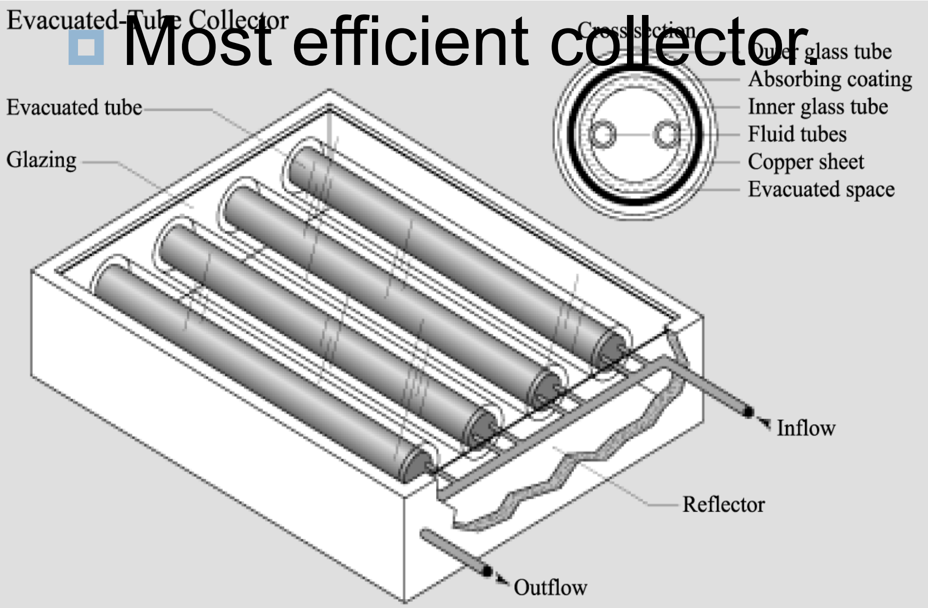


Solar Thermal Collector (continue)

- Flat Plate Collector
  - Weather proofed box;
  - Dark absorber plate;
  - Flow tubes

- Evacuated Tube Collector
  - Two concentric glass tubes;
  - Vacuum in between;
  - Most efficient collector.



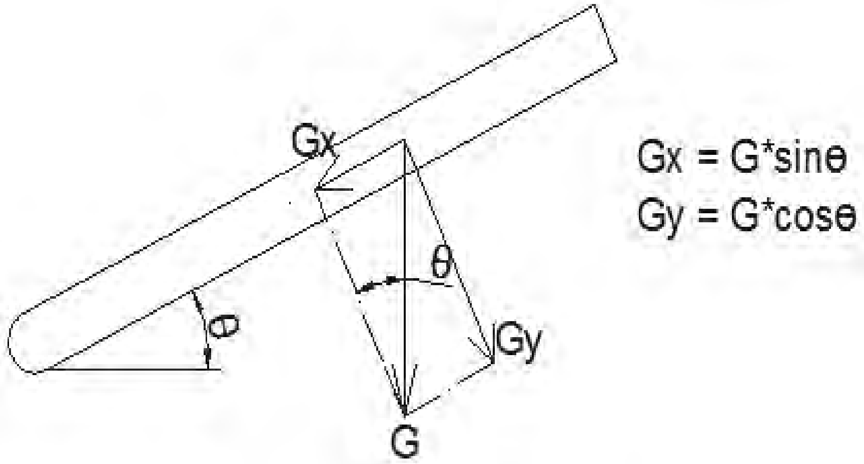


Objectives

- Efficiency of Single Ended Evacuated Tube Collector

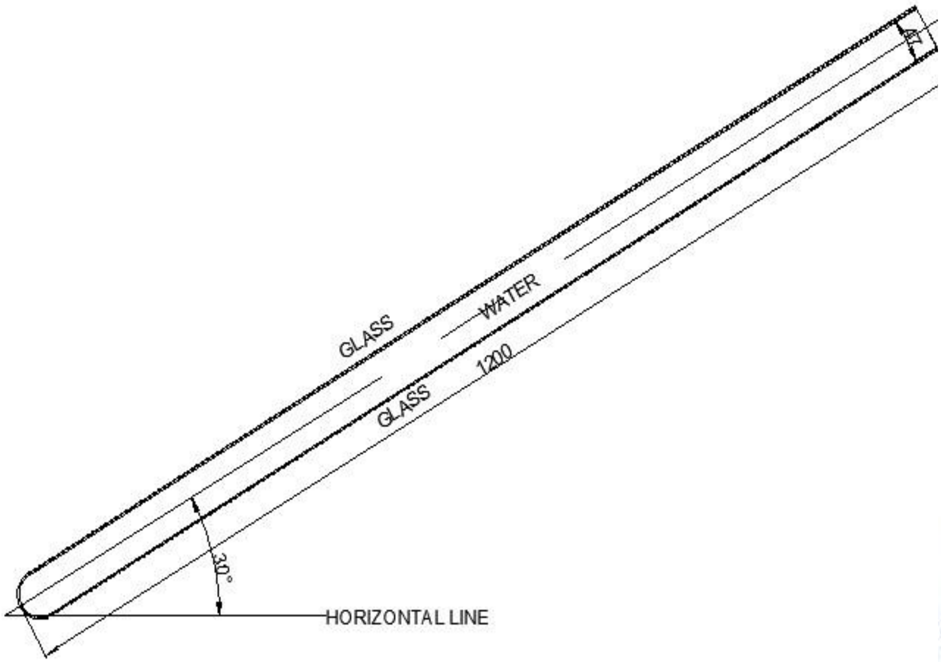
Objectives (continue)

- Mounting Angle
  - Components of gravity
  - Facilitating or impeding
    Efficiency;
  - Range: 15^{o} -90^{o}.
- Aspect Ratio
  - Aspect ratio between tube diameter and length;
  - Longer tube vs. shorter tube (same diameter);
  - Length: 1.2m – 1.8m.



Approaches – Geometry Modeling

- 2D and 3D Geometric Models
  - Length: 1200 mm
  - Inner Tube Diameter: 47 mm
  - External Tube Diameter: 52 mm



Approaches – System Analysis

- Heat Transfer

Heat Conduction in Solid:

$$\nabla \cdot (-k\nabla T) = Q$$

Where,
k: thermal conductivity;
T: absolute temperature;
Q: heat source.

Heat Convection in fluid

$$\nabla \cdot (-k\nabla T) = Q - \rho C_p u \cdot \nabla T$$

Where,
r : density of fluid;
Cp: specific heat capacity;
u: velocity of fluid.

Approaches – System Analysis

- Fluid Dynamics
  - Causes: Temperature difference and density changes

$$\rho u \cdot \nabla u = \nabla[-p\mathbf{I} + \eta(\nabla u + (\nabla u)^{\mathrm{T}}) - (2/3)\eta(\nabla \cdot u)\mathbf{I}] + F$$

$$\nabla \cdot (\rho u) = 0$$

Where:

ρ: density;

u: velocity field;

p: pressure;

I: identity matrix;

η: dynamic viscosity;

F: volume force.

Approaches – System Analysis

- Volume Force - F
  - Acting on a unit volume of water

$$\rho \cdot V = M$$

$$\rho' \cdot V' = M$$

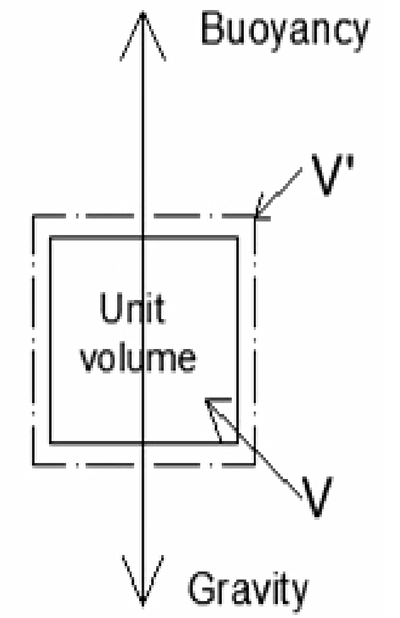
Volume Force = Buoyancy – Gravity

$$F = (B - G)/V$$

$$= (\rho \cdot g \cdot V' - \rho \cdot g \cdot V)/V$$

$$= \rho \cdot g \cdot (V' - V)/V$$

$$= \rho \cdot g \cdot \Delta V/V$$



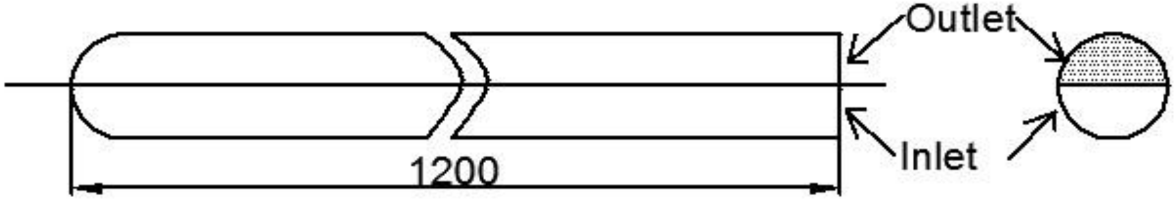
  - Coefficient of Thermal Expansion - α

$$\Delta V/V = \alpha \, (T' - T)$$

$$\longrightarrow F = \rho \cdot g \cdot \alpha \, (T' - T)$$

Approaches – System Analysis

- Simulation Assumptions
  - Inward Heat Flux – 120 W/m^2;
  - Inlet and Outlet



  - Other Assumptions
    - Ignore thermal expansion of glass;
    - Ambient temperature is 298.15 K;
    - Other than natural convection, no other types of dynamic;
    - Ignore effects of water tank.

Approaches – Post Processing

- Energy increment at the Outlet Boundary
  - A certain mass of water (M);
  - Initial temperature (T_0) at the inlet boundary;
  - After being heated over a certain time (t);
  - Final temperature (T) at the outlet boundary;

  Energy Increment:

$$\Delta Q = Cp*M*(T-T_0)$$

$$= Cp*\rho*V*\Delta T$$

ρ is the density of water;

V is the volume of water.

Approaches – Post Processing

- Efficiency Function

$$\Delta Q = Cp * \rho * V * \Delta T$$

Divided by the time ---- t:

$$(\Delta Q/t) = Cp * \rho * (V/t) * \Delta T$$

(ΔQ/t) is the efficiency;

(V/t) is the volume of water flows through per unit time;

Two variables: (V/t) & ΔT

Approaches – Post Processing

- Velocity Field

$$V_{2D} = \int nV dV = \int (nx * u + ny * v) dV$$

$$V_{3D} = \int nV dV = \int (nx * u + ny * v + nz * w) dV$$

- Temperature Difference

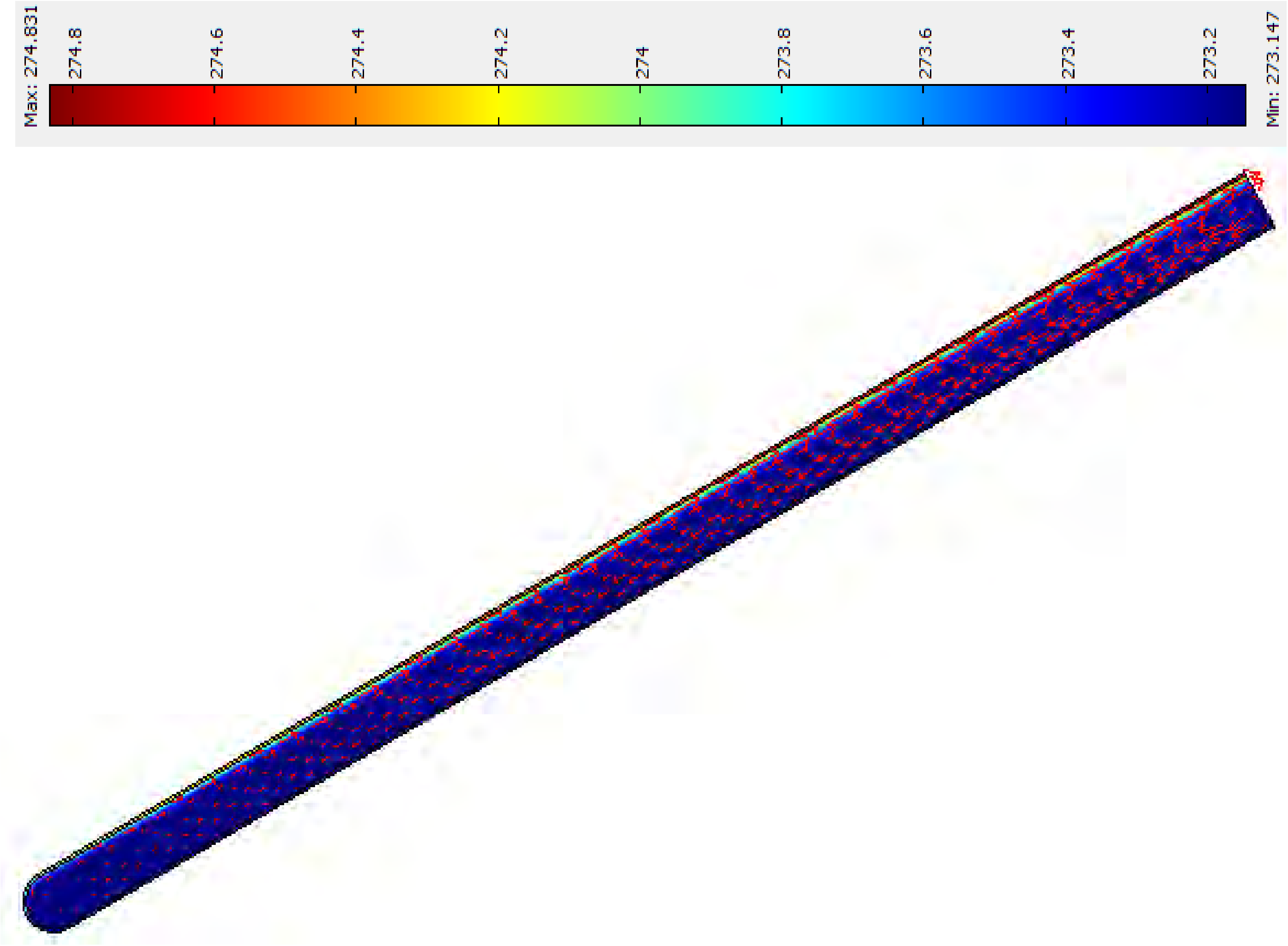
$$\Delta T_{2D} = \int (T - T_0) dT$$

$$\Delta T_{3D} = \int (T - T_0) dT$$

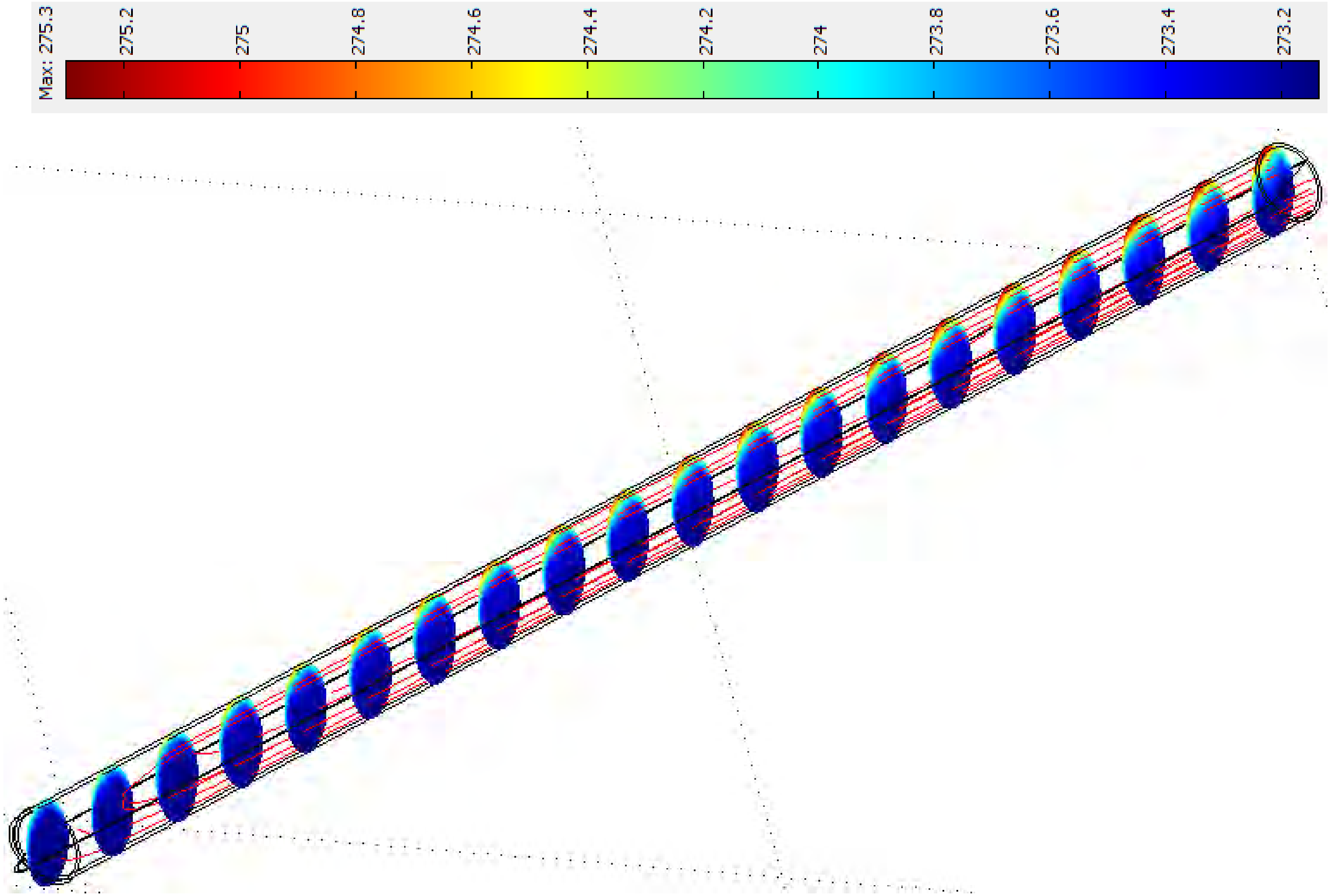
- Thus, $P_{2D} = Cp * \rho \int (nx * u + ny * v)(T - T_0) d(V, T)$

$$P_{3D} = Cp * \rho \int (nx * u + ny * v + nz * w)(T - T_0) d(V, T)$$

Results – 2D Finite Element Model

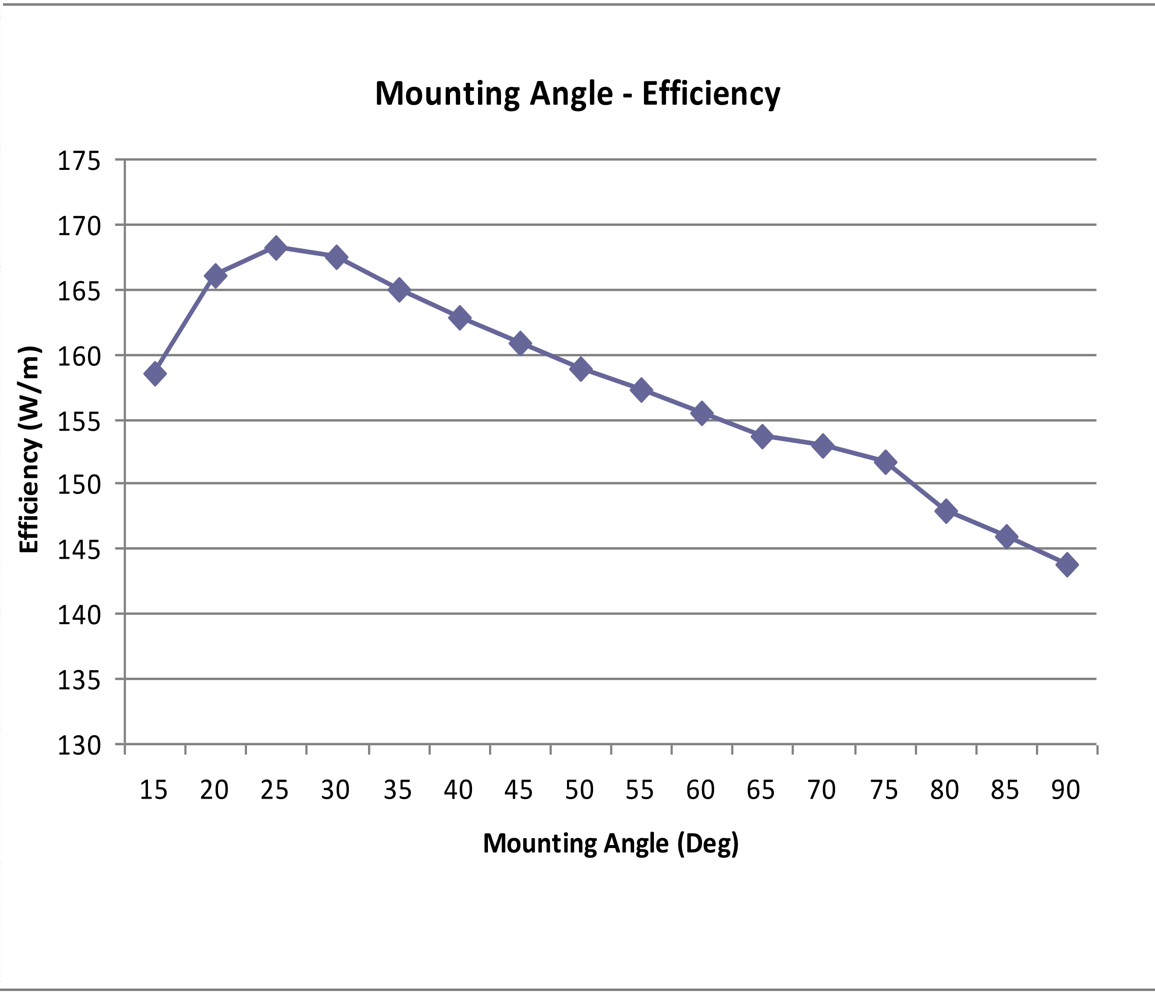


Results – 3D Finite Element Model

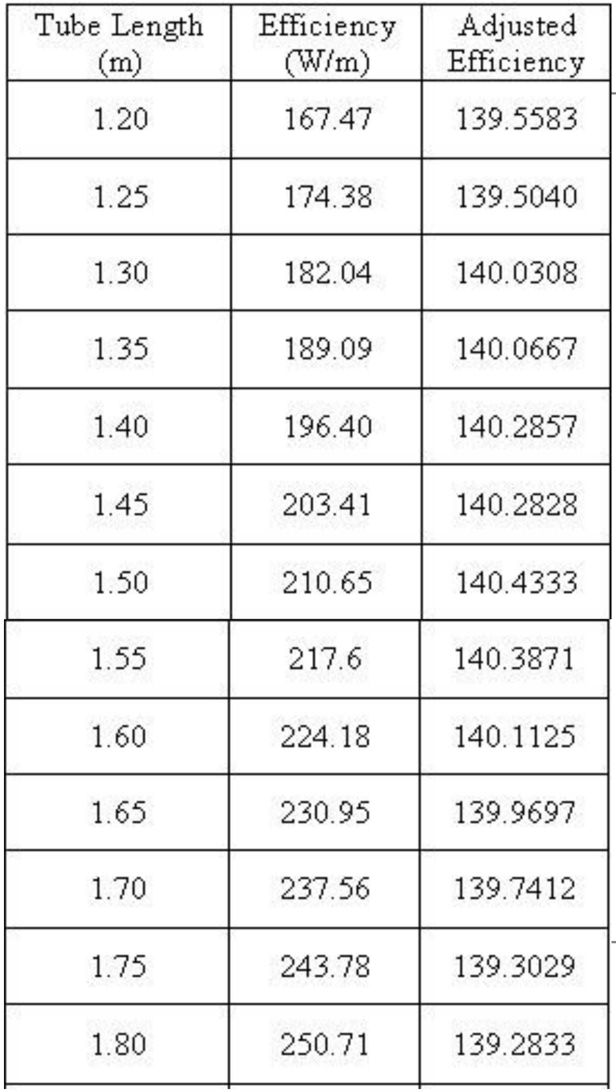


Results – Mounting Angles

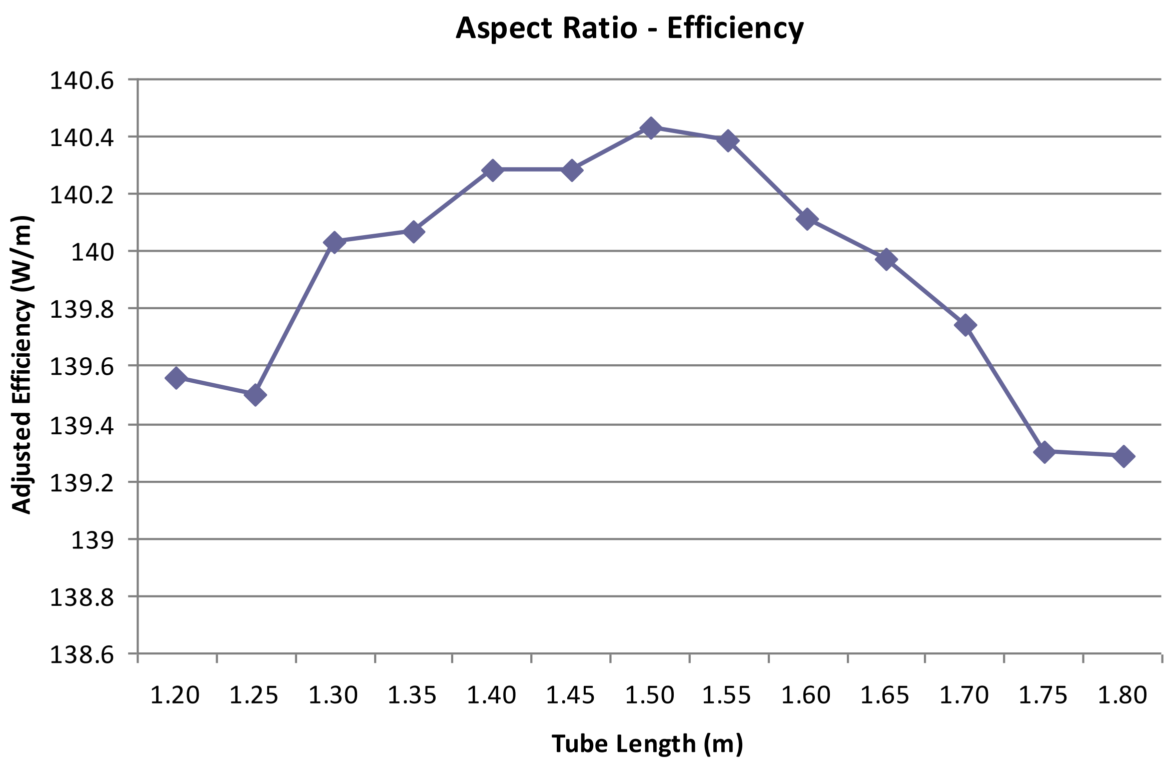
Mounting Angle (Deg)	Efficiency (W/m)
15	158.46
20	166.12
25	168.22
30	167.47
35	165.00
40	162.78
45	160.91
50	158.91
55	157.19
60	155.53
65	153.63
70	152.93
75	151.64
80	147.93
85	145.93
90	143.87



Results – Aspect Ratios



Tube Length (m)	Efficiency (W/m)	Adjusted Efficiency
1.20	167.47	139.5583
1.25	174.38	139.5040
1.30	182.04	140.0308
1.35	189.09	140.0667
1.40	196.40	140.2857
1.45	203.41	140.2828
1.50	210.65	140.4333
1.55	217.6	140.3871
1.60	224.18	140.1125
1.65	230.95	139.9697
1.70	237.56	139.7412
1.75	243.78	139.3029
1.80	250.71	139.2833



Conclusions

- Mounting Angles: Efficiency rises and reaches the maximum at 25^o, then begin falling and reaches the minimum at 90^o.

- Aspect Ratios: As tube diameter maintains as a constant, tube with aspect ratio of (1500/47) has the highest efficiency.

Future Work

- Compare the results with experimental data

Questions?