HEAT TRANSFER INNOVATION PROJECT

Understanding Critical Radius of Insulation

By Group 2

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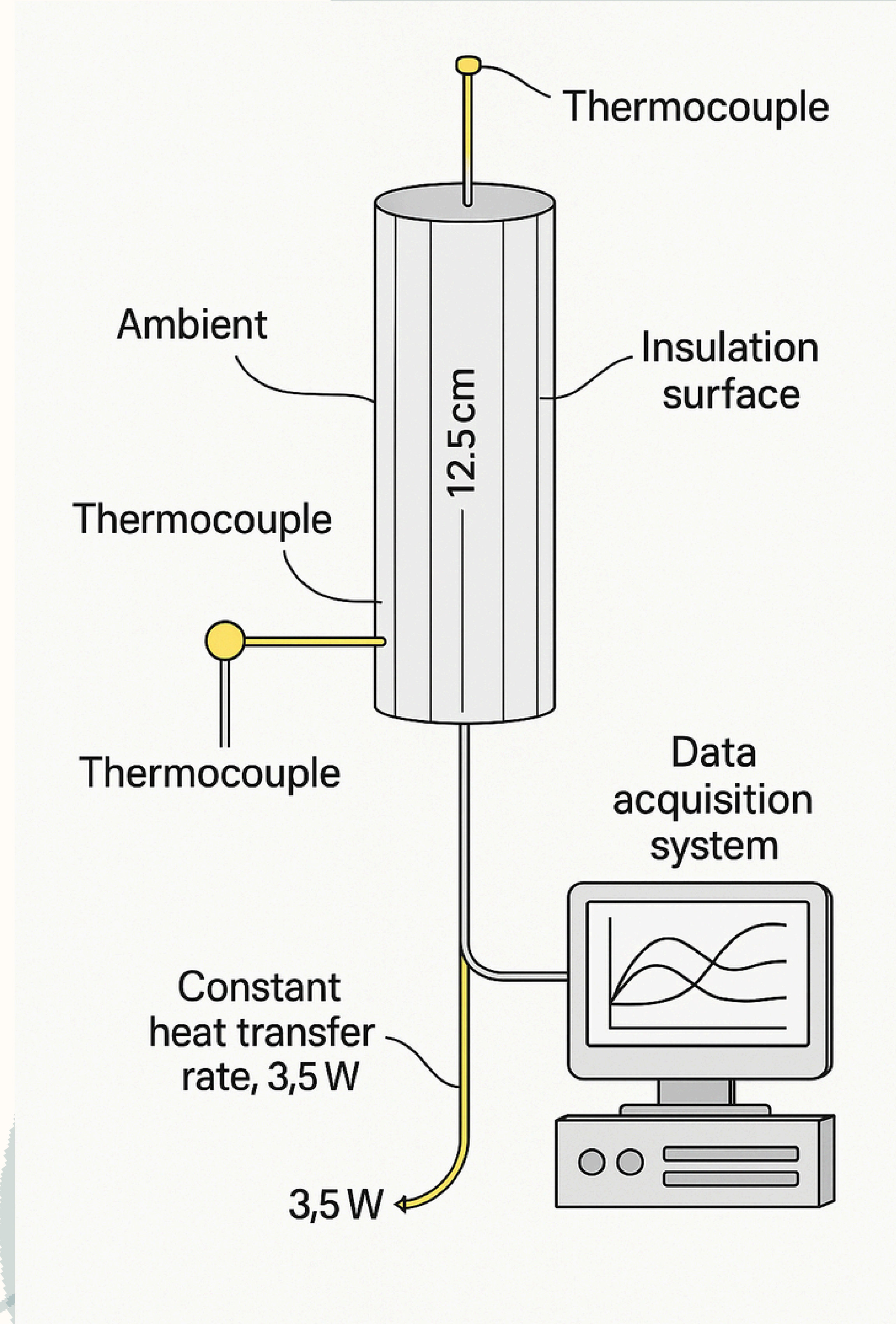
INTRODUCTION

1. Study of critical radius of insulation
2. System: Aluminium Pipe with insulation of double-sided tape.
3. Objective: Compare experimental and theoretical critical radius of insulation.

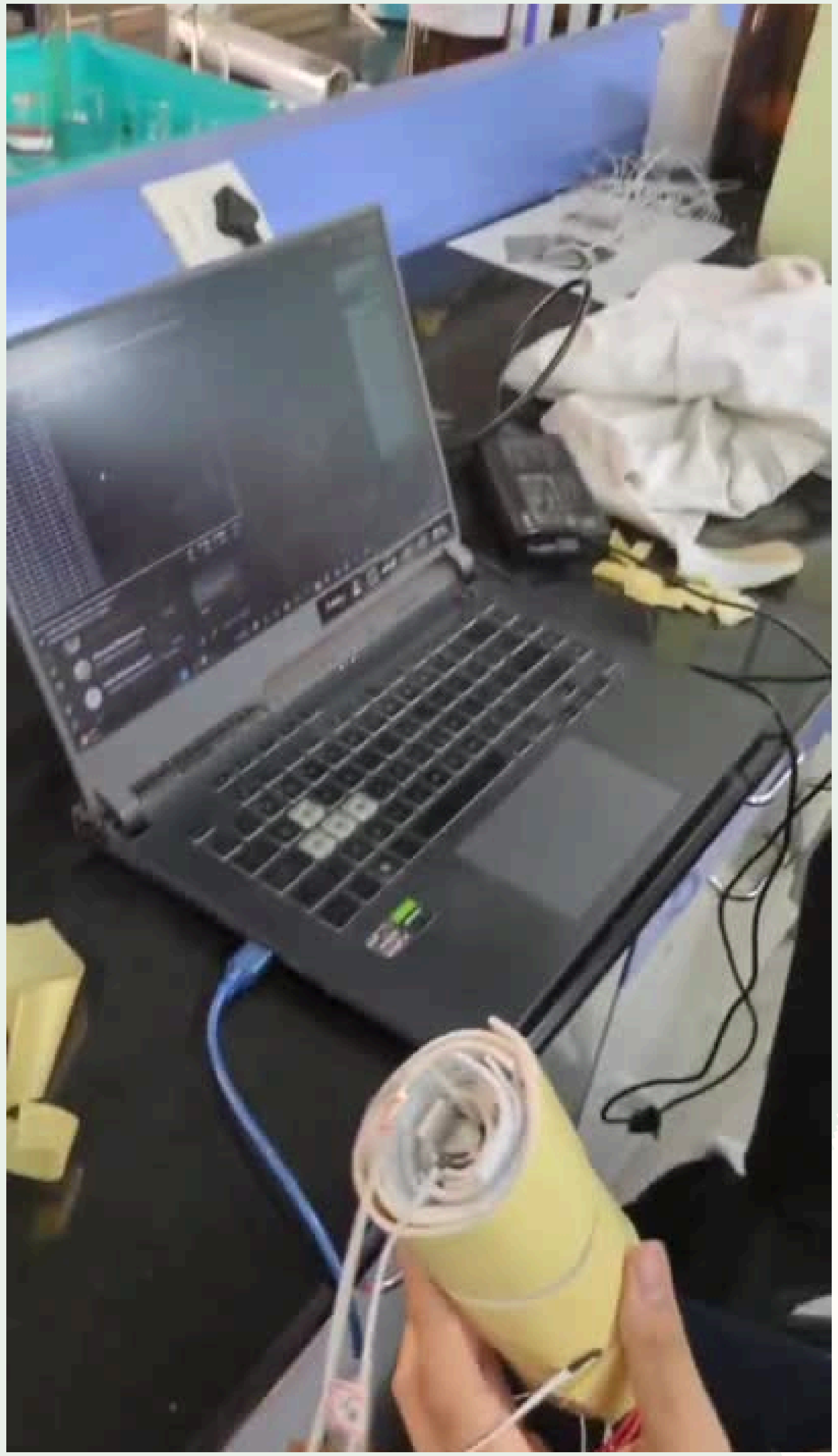
EXPERIMENTAL SETUP

- Experiment focuses on surface temperature measurement of a 12.5 cm long, 3 cm diameter aluminum pipe.
- Double-sided tape used as insulation with a constant heat transfer rate of 3.5 Watts.
- Thermocouples (±0.1°C accuracy) strategically placed to record temperature data on the pipe surface, insulation surface, and ambient environment.
- Data acquisition system analyzes information under controlled conditions to determine optimal insulation performance.



INNOVATIVE ASPECTS

- Traditional insulation methods have limitations which we address in our in-house design.
- We used double-sided tape as the insulation material because, according to our calculations, it was the material with the least critical radius we obtained theoretically.
- These innovations significantly enhance thermal resistance and reduce insulation thickness, offering a more efficient and adaptive solution for heat loss prevention.



EXPERIMENTAL METHODOLGY

- Applying uniform coverage of insulation
- Maintaining constant heat flux for accurate results
- Recording data at various locations and times after the steady state is reached
- After measuring the temperature, the insulation is increased, and the process is repeated till the end of experiment

Theory

- Critical radius is the insulation thickness at which heat loss is maximum.
- Up to this point, added insulation increases surface area more than it resists heat.
- For a cylinder: $R_c = k/h$; (where k = thermal conductivity, h = convective coefficient).
- To reduce heat loss, insulation thickness must be greater than the critical radius.

Simulation

The following simulation code was used (for the calculation of h):

```
L=0.125; N=10; k=0.284; T0=30.6;
W=0.01;
h1=0.01;
delx=L/(N-1);
Ti=30;
g=0;
t = 0.01;
G = 9.8;
Ts = linspace(30 , 40 , 10);
v = 1.5e-5;
Pr = 0.79;
ka = 0.026;
beta = 1/303;
Lc = 0.125;
Ra = (G*beta.*(Ts-Ti)*Lc^3*Pr)/(v*v) ;
nu = 0.59.*Ra.^0.25;
h = (ka.*nu)/Lc;
hsum=sum(h)/10;
```

The value of h so obtained is 3.5601

Taking k of double sided tape to be 0.28

The value of rc so obtained is 7.8 cm

Why Temperature Peaks at Critical Radius (Under Constant Heat Flux)?

- When heat flux is constant, surface temperature Ts must adjust to maintain that same amount of energy transfer:
- $q''=h(Ts-T\infty) \Rightarrow Ts=q''/h+T\infty$. However, when you add insulation (i.e., increase the radius):

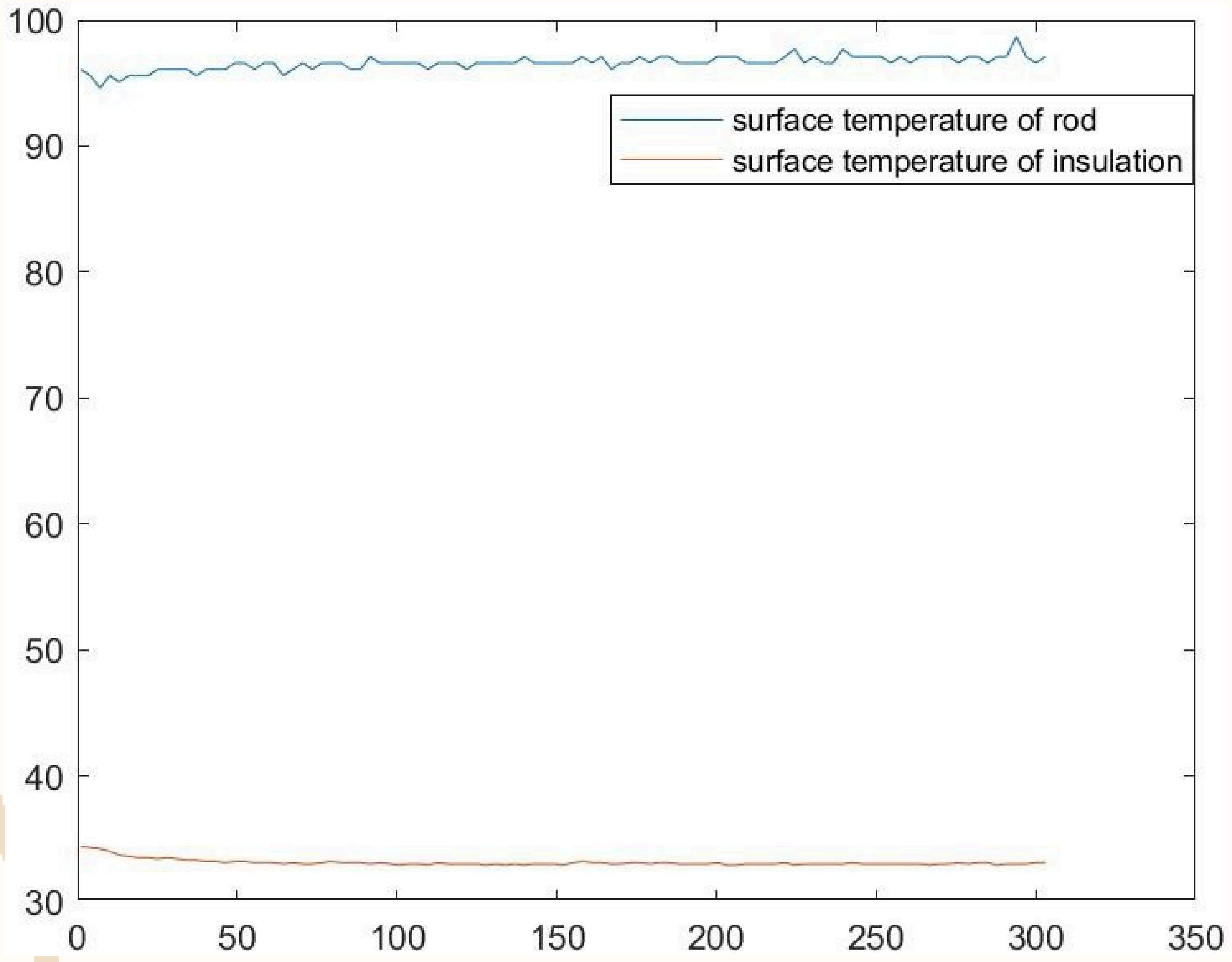
1) Initially, increasing the radius (up to the critical radius) increases the surface temperature.
   - Why? Because you're increasing the thermal resistance due to the thicker insulation, but the outer area is not large enough yet to help dissipate the heat efficiently.
   - So, to keep the same heat flux, the temperature difference must increase — the surface temperature rises.

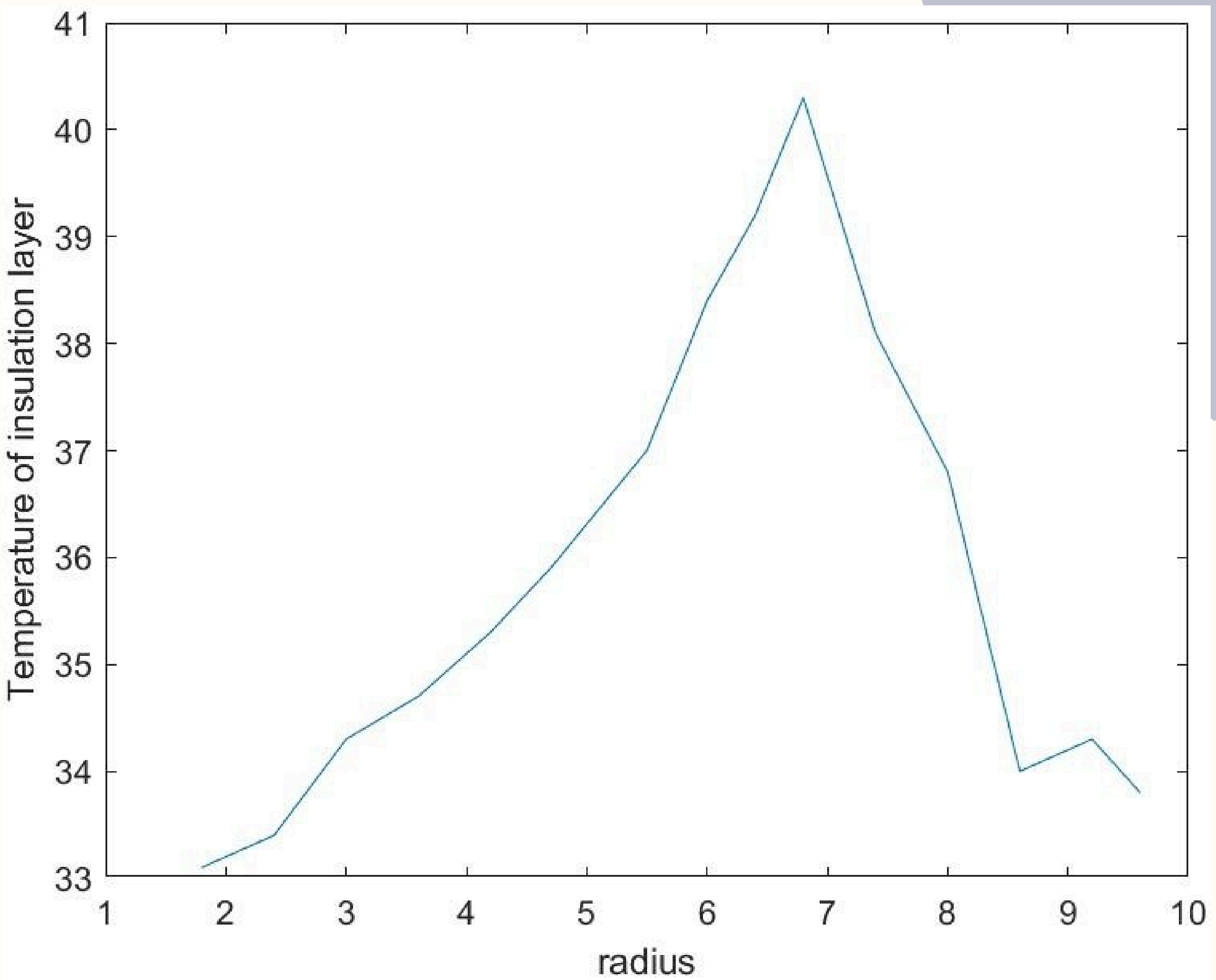
2)At the critical radius, you reach the point where the added surface area begins to outweigh the increased thermal resistance.
   - Here, the surface temperature hits a maximum.

3)Beyond the critical radius, increasing the radius further:
   - Makes the surface area much larger, and
   - The increased area helps dissipate heat more effectively via convection.
   - So now, to maintain the same heat flux, the required surface temperature drops.
   - Basically it is the variation of 1/r and ln r that gives this.

Results

The following plots were obtained:





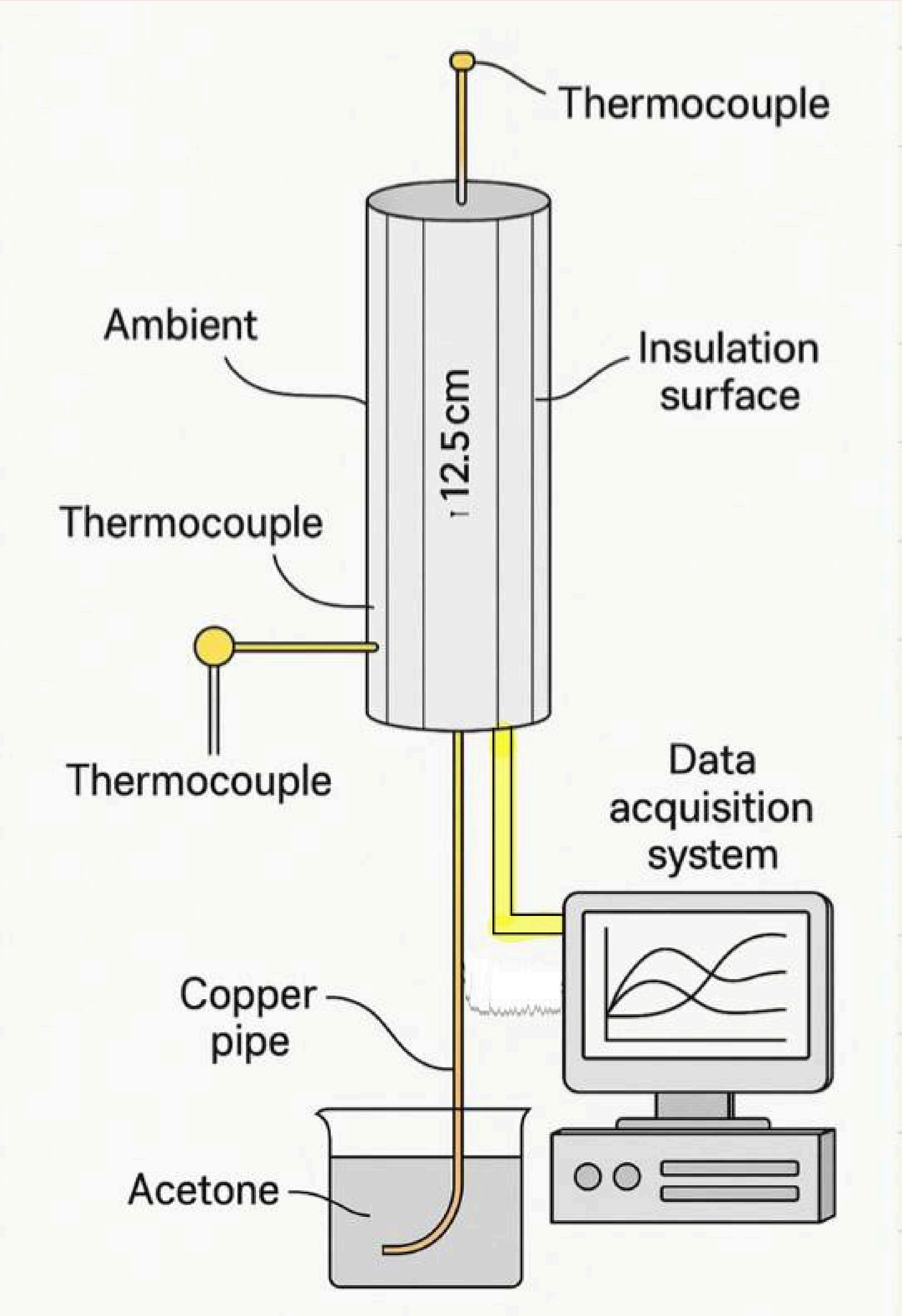
This is the graph we obtained for a particular radius of insulation and it shows how temperatures of the surface of insulation and the surface of the rod varies with time

This graph shows how the temperature of the surface of insulation at steady state varies with the radius of insulation
From graph the value of Rc obtained is 6.8cm

Note- Radius of insulation refers to the radius from the centre of the rod till the surface of the insulation

Conclusion

The theoretical and experimental value matches considerably .
The error encountered is ((7.8 - 6.8)/6.8)*100 = 14.7%



Thermocouple
Ambient
12.5cm
Insulation surface
Thermocouple
Thermocouple
Data acquisition system
Copper pipe
Acetone

Thank you!