DATE

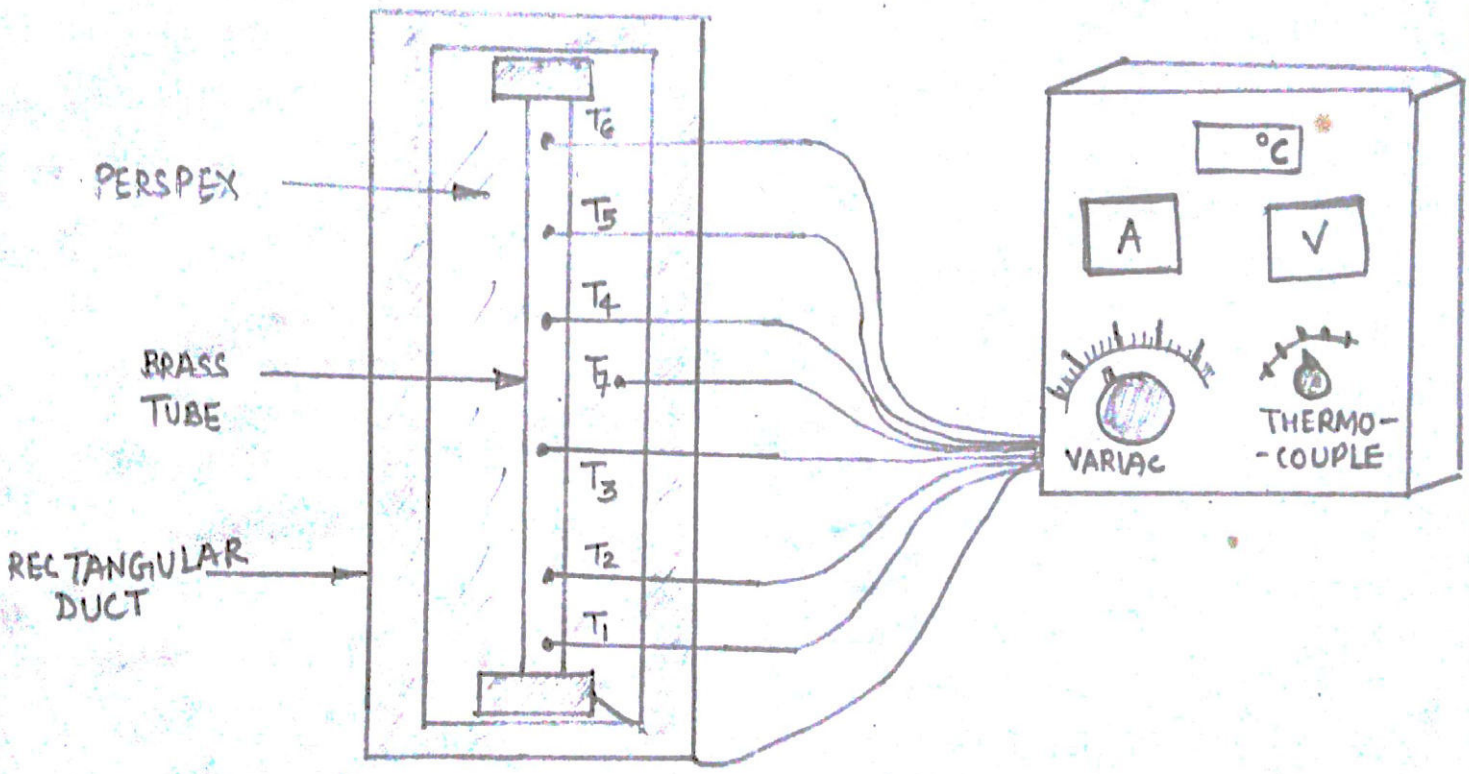
EXPERIMENT NO: 2

SHEET NO.

NATURAL CONVECTION HEAT TRANSFER

- **Objectives:** Determination of local heat transfer coefficients and average Nusselt numbers for free convection from a heated vertical cylinder at various Rayleigh Numbers, and correlation for Nusselts Number.

- **Schematic of the experimental setup:**



● OBSERVATIONS:

▶ OD of cylinder = 38 mm

▶ length of cylinder = 50 cm

ROOM TEMPERATURE = 29°C

RUN No. : 1 (HEATER POWER = 0.669 A × 84.8 V = 56.73 W)

I (A)	V (V)	Time (min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	T_7 (°C)	T_8 (°C)
0.659	83.7	0	36.2	39	39.5	40.6	39.8	39.2	38.6	30.2
0.668	83.9	10	65.5	72.4	73.1	72.7	69.2	67.2	65.3	31.6
0.654	83.3	20	76.4	85.4	87.6	88.5	85.5	83.2	82.2	32.6
0.666	83.8	30	85.4	94.3	97.5	97.7	93.3	91.3	89.5	33.4
0.669	83.9	40	88.9	100.1	102.7	102.8	99.5	95.6	94.6	33.7
0.659	83.8	50	91.8	103.0	106.1	105.8	102.5	99.9	98.5	34.3
0.659	82.7	60	93.2	104.8	107.1	107	104.5	101.8	100.4	34.7
0.647	81.5	70	94.7	105.5	108.2	108.5	105.3	102.8	101.5	35.2
0.653	83.1	80	95.3	106.3	108.6	108.7	105.7	103.1	101.8	35.2
0.661	83.2	90	94.4	106.0	108.6	108.9	105.7	103.3	101.9	35.1

RUN NO. : 2 (HEATER POWER = 0.692 A × 86.6 V = 59.93 W)

I (A)	V (V)	Time (min)	T_1 (°C)	T_2 (°C)	T_3 (°C)	T_4 (°C)	T_5 (°C)	T_6 (°C)	T_7 (°C)	T_8 (°C)
0.692	86.6	0	95	106	109	109	106	104	102	35
0.688	87.8	10	96	107	111	111	107	105	104	35
0.688	87.1	20	97	109	113	113	109	107	105	36
0.708	89.2	30	99	110	114	114	110	108	107	35
0.699	88.4	40	101	112	115	115	112	109	107	35
0.696	88.8	50	101	112	116	116	112	110	108	35

- SAMPLE CALCULATION

⇒ Heat Transfer Rate $Q = VI$

$\therefore Q = 83.2\,V \times 0.661\,A$

$= 55\,W$

⇒ Heat Transfer Area $A_s = \pi D L$

$= \pi \times 38 \times 10^{-3} \times 50 \times 10^{-2}\,m^2 = 0.019\pi\,m^2$

⇒ Heat flux $q = Q/A_s$

$= 921.42\,W/m^2$

⇒ Avg. surface Temperature $T_s = \dfrac{\sum_{i=1}^{7} T_i}{7}$

⇒ $T_s = 104.11°C$

⇒ Ambient temperature of air in enclosure $T_a = T_8$

⇒ $T_a = 35.1\,°C$

⇒ Film Temperature $T_f = (T_s + T_a)/2$

⇒ $T_f = 69.61\,°C$

⇒ Local Heat Transfer coefficients at 7 axial locations

$h_1 = 15.54\,W/m^2K$ $h_4 = 12.49\,W/m^2K$ $h_7 = 13.79\,W/m^2K$

$h_2 = 12.99\,W/m^2K$ $h_5 = 13.05\,W/m^2K$

$h_3 = 12.54\,W/m^2K$ $h_6 = 13.51\,W/m^2K$

⇒ Avg. Heat Transfer coefficient $h_{av} = q/(T_s - T_a)$

⇒ $h_{av} = 13.35\,W/m^2K$

⇒ Avg. Nusselt's Number

$Nu_{av} = \dfrac{h_{av} L}{k}$ ⇒ $Nu_{av} = 231.93$

⇒ $g = 9.81\,m/s$ ⇒ $\beta = 2.919 \times 10^{-3}\,K^{-1}$

⇒ $\nu = 19.91 \times 10^{-6}\,\dfrac{m^2}{s}$ ⇒ $Pr = 0.7178$

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⇒ Grashof Number

$$Gr = \frac{g\beta(T_s - T_a)L^3}{\nu^2}$$

$$= 0.6231 \times 10^9$$

$$Ra = Gr\,Pr$$

$$= 4.4728 \times 10^8$$

◉ TABLE SUMMARIZING THE CALCULATIONS :

	W (w)	$q\ (\frac{w}{m^2})$	T_s (°c)	T_a (°c)	T_f (°c)	h_{av} (w/m²k)	Nu_{av}	$Gr \times 10^{-9}$	$Ra \times 10^{-8}$
RUN 1	52.73	883.40	103.79	35.2	69.5	12.88	223.8	0.6202	4.452
	54.26	909.03	104.21	35.2	69.7	13.17	228.8	0.6224	4.467
	54.99	921.42	104.11	35.1	69.61	13.35	231.9	0.6231	4.4728
RUN 2	63.15	1057.96	108.86	35	71.93	14.32	247.4	0.6471	4.642
	61.79	1035.18	110.14	35	72.57	13.78	237.7	0.6529	4.683
	61.80	1035.34	110.71	35	72.86	13.68	235.8	0.6554	4.7

◉ DETERMINATION OF CORRELATION FOR AVG. NUSSELT NUMBER:

FROM LEAST SQUARE FIT ANALYSIS:

Nu_{av}	Ra	X $\log_{10}(Ra)$	Y $\log_{10}(Nu_{av})$	XY	X^2
223.8	4.452×10^8	8.6486	2.3499	20.3229	74.7975
228.8	4.467×10^8	8.6500	2.3595	20.4093	74.8228
231.9	4.473×10^8	8.6506	2.3653	20.4612	74.8325
247.4	4.642×10^8	8.6667	2.3934	20.7429	75.1118
237.7	4.683×10^8	8.6705	2.3760	20.6014	75.1780
235.8	4.700×10^8	8.6721	2.3725	20.5749	75.2053
	$\bar{Y} = a + b\bar{X}$	$\Sigma X = 51.8585$	$\Sigma Y = 14.2166$	$\Sigma XY = 123.113$	$\Sigma X^2 = 449.948$

where $b = \dfrac{n\Sigma XY - \Sigma X \Sigma Y}{n\Sigma X^2 - (\Sigma X)^2} = 1.01481$ $\quad \therefore a = -6.4186$

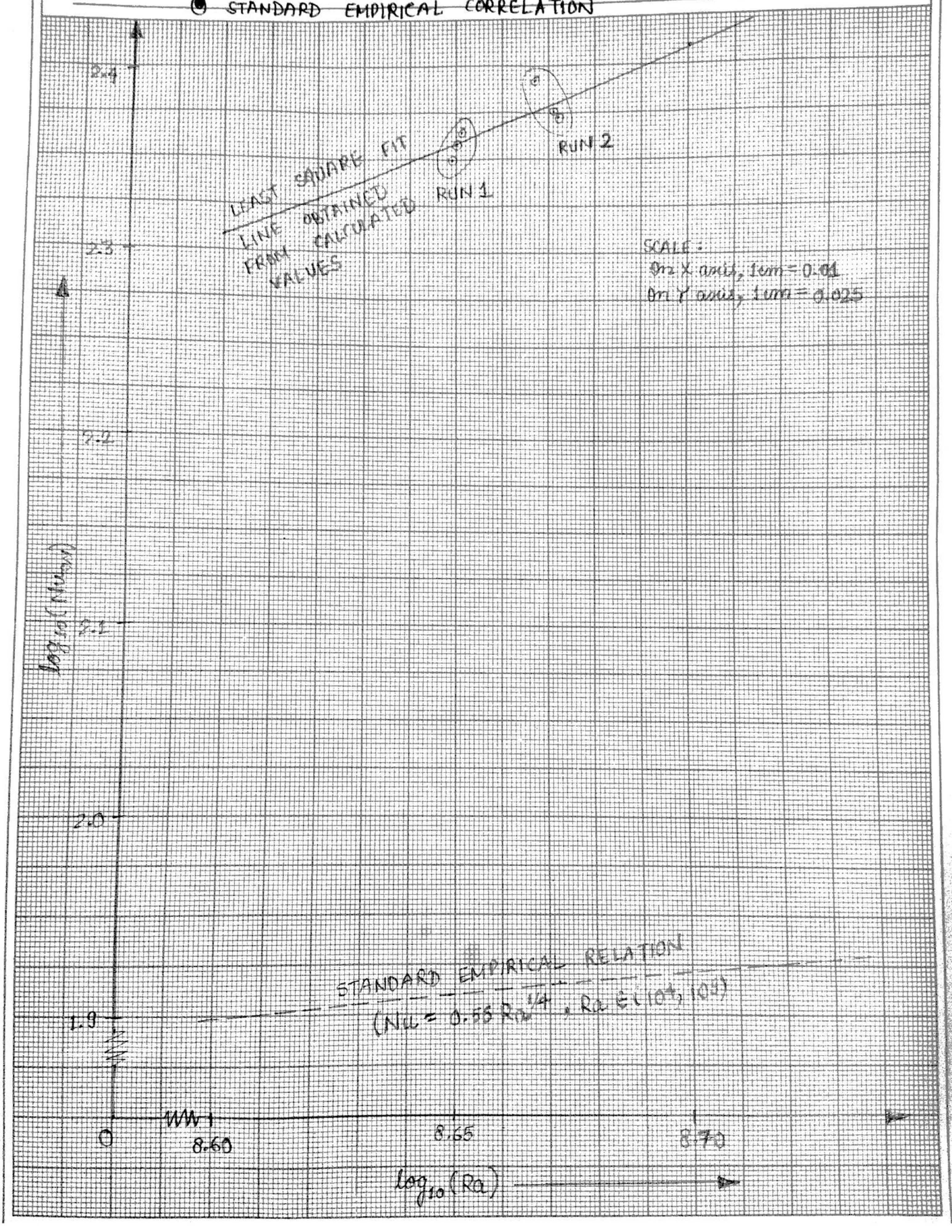
$$\therefore \bar{Y} = -6.4186 + 1.01481\,\bar{X}$$

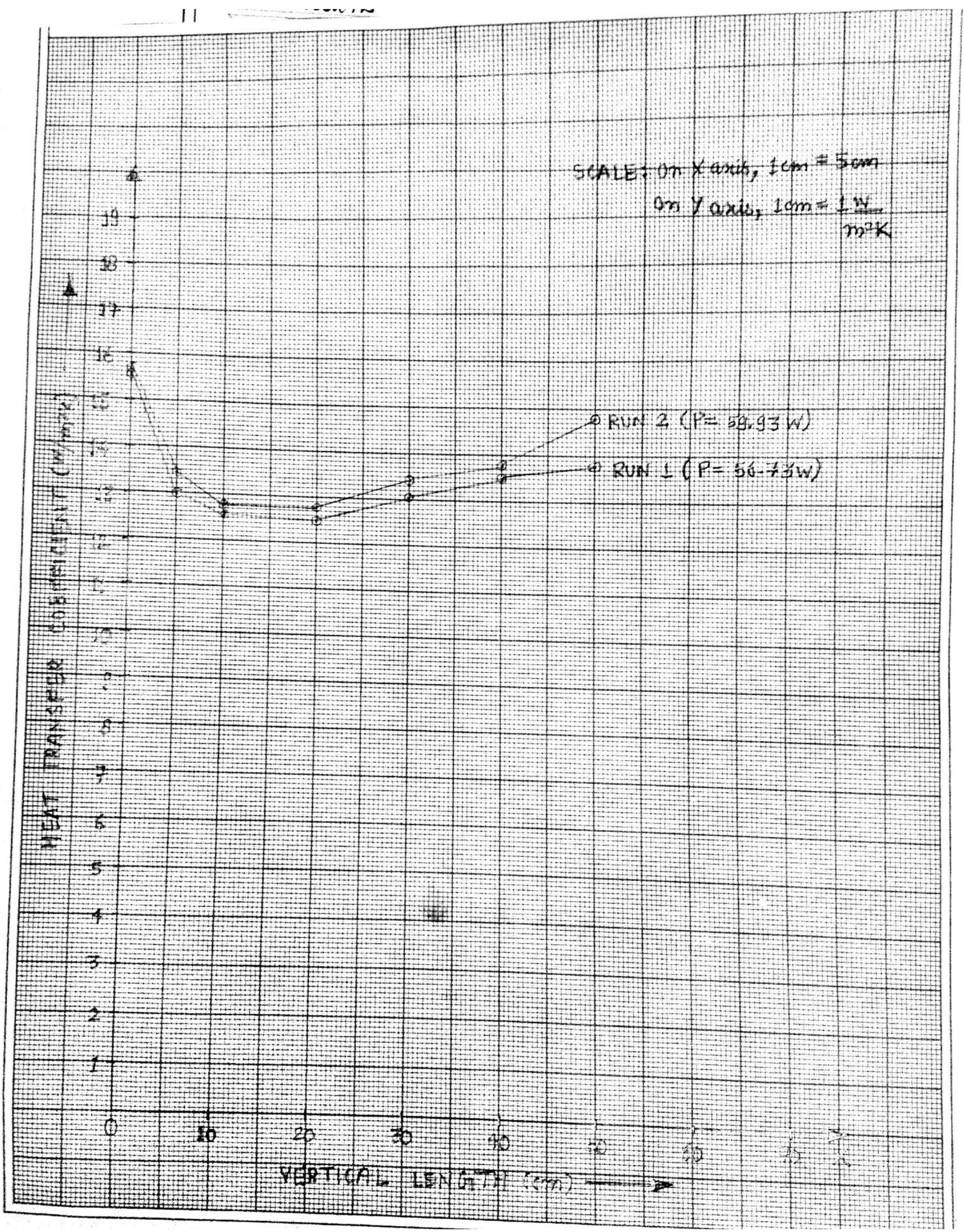
$$\Rightarrow \log_{10}(Nu_{av}) = -6.4186 + 1.01481 \log_{10}(Ra)$$

$$\Rightarrow \log_{10}(Nu_{av}) = \log(3.814 \times 10^{-7}) + \log_{10}(Ra^{1.01481})$$

$$\Rightarrow Nu_{av} = (3.814 \times 10^{-7})\, Ra^{1.015}$$

PLOT OF ● $\log_{10}(Nu_{av})$ VS $\log_{10}(Ra)$ OBTAINED FROM CALCULATED VALUES
● STANDARD EMPIRICAL CORRELATION





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DISCUSSIONS:

As can be observed from the graph, the heat transfer coefficient has a maximum value of almost 15 W/m²K at the starting of the building of the boundary layer (∵ as the temperature gradient is higher)

$\left(-K\frac{dT}{dx} = h_{av} A\Delta T\right)$ so h_{av} is ~~not~~ higher.

But with the thickening of the layer, which is a laminar one, the heat transfer coefficient decreases. This trend is maintained up to half the length up to 3.5m in this case and beyond that there is little variation in the value of local heat transfer coefficient because of the transition and turbulent boundary layers. The last point shows somewhat increase in the value of which is attributed to end loss causing a temperature drop.