School of Nuclear Engineering

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NUCL 355 **Nuclear Thermal-Hydraulics Laboratory**

Lab 11: Forced Convection Heat Transfer

Objectives:

Study forced convection heat transfer in a vertical uniformly heated pipe.

Experimental Apparatus:

The experimental setup is shown in Figure 1. A wrap-around band heater uniformly heats the type 304 stainless pipe. The power supply is a 110 volt, 30 amp Variac (Variable AC power supply). The power input is calculated using voltage and current readings from an instrumentation panel. The band heater voltage V(s) and the current A are measured by panel voltmeter and ammeter.

Air is sucked through the pipe by a vacuum at the outlet. The air flow rate can be controlled by a valve placed between the outlet of the pipe and the vacuum. An orifice meter at the outlet allows for air flow rate measurement. A U-tube manometer gives the pressure differential across the orifice meter.

Figure 1 shows the axial location of the thermocouples. Twenty-five CO3 ("cement-on") E-type (Chromega-constantan) thermocouples from the Omega Engineering company are attached to the outer surface of the pipe to give the temperature distribution along the length of the pipe (Channels 1 through 25). At the inlet and outlet of the pipe two E-type thermocouples are used to measure the air inlet and outlet temperatures (Channels 31 and 32 respectively). Nine E-type thermocouples located inside the pipe measure the axial temperature profile of the air (Channels 26 through 28 and 35 through 40). These thermocouples can also be used to measure the radial temperature distribution of the air at their axial locations.

The pipe is insulated with fiber glass pipe insulation. A thermocouple is suspended near the pipe in the air to measure the ambient temperature. The temperature profiles are read using a digital thermometer on the front panel. The dimensions in Figure 1 are:

Pipe OD = 4.135 cm
Pipe ID = 3.760 cm
Heated tube length, L, = 173.04 cm
Heated length to wall thermocouple 1 = 13.65 cm
Distance between adjacent odd-numbered thermocouples = 9.21 cm
Even-numbered thermocouples are mid-elevation between odd-numbered thermocouples

Orifice diameter = 1.83 cm.

When inserting thermocouples to take radial temperature readings, note the following:
The pipe outer radius = 2.05 in.
The insulation thickness is 2.5 in.
The distance from insulation outer surface to edge of Swagelok nut is 2-5/8 in.

The heat loss from the pipe has already been determined as follows:
1. Plug the two ends of the pipe, set the power supply at a given voltage level and heat the pipe.
2. Let the system reach steady thermal state. The system can be assumed to reach equilibrium state when the temperature change is less than 2^oC in 10 minutes.
3. For several power levels, record the stabilized temperature readings. Record the heating band voltage and current for each setting.
4. Turn off the power and remove end plugs on the pipe.

These data are available in the Heat Loss Figure 2.

Procedure:

1. Set the power in the pipe with the rheostat to the desired value of 30%.
2. Choose five air flow rates to span as wide a range of Reynolds number as possible (i.e., check the scale of the manometer and the maximum flow attainable). Using flow rates for a manometer dP of 16 units, 8, 4, 2 and 1 works well.
3. Starting at the highest flow rate, monitor the temperature for steady state, and when the system has stabilized to a steady state record the temperature readings. Steady state has been achieved when the temperature change is less than 2^oC in 10 minutes for any thermocouple. *Make sure the centerline temperature thermocouples are pulled out when data is taken.*
4. Measure the pipe centerline temperature using thermocouples AR1 to AR10.
5. Locate the thermocouple probe AR5 at various radial positions using a scale and record the radial temperature readings.
6. Change the air flow rate to the next level and repeat steps 3, 4 and 5.
7. Repeat step 6 for other flow rates; at least four sets of data are required (each group will take data at a different flow rate).

Each group will take data for one air flow rate and groups will exchange data after the last session.

Precautions

1. Keep the pipe wall temperature below 200^oC to protect thermocouple wire

insulation.

2. Keep the air exit temperature below 100^{o}C.

Data Analysis

(Some points that should be included in the lab reports.)

1. For each air flow rate, calculate the local heat transfer coefficient from experimental data and the local Nusselt Number at the location of thermocouple #14 based on the ***bulk*** temperature of the fluid.
2. For each flow rate, calculate the Reynolds number from the orifice flow meter data.
3. Plot the data using the dimensionless coordinates of Reynolds number and Nusselt number and compare with the Dittus-Boelter correlation. Note: plot the experimental data as points and the Dittus-Boelter correlation as a line in a log-log scale.
4. Plot one set of axial wall temperatures and centerline temperatures and discuss qualitatively the entrance effect.
5. Plot the radial temperature distribution and explain it qualitatively.

References

1. Incropera and DeWitt, “Fundamentals of Heat Transfer,” 4th Edition, Wiley.

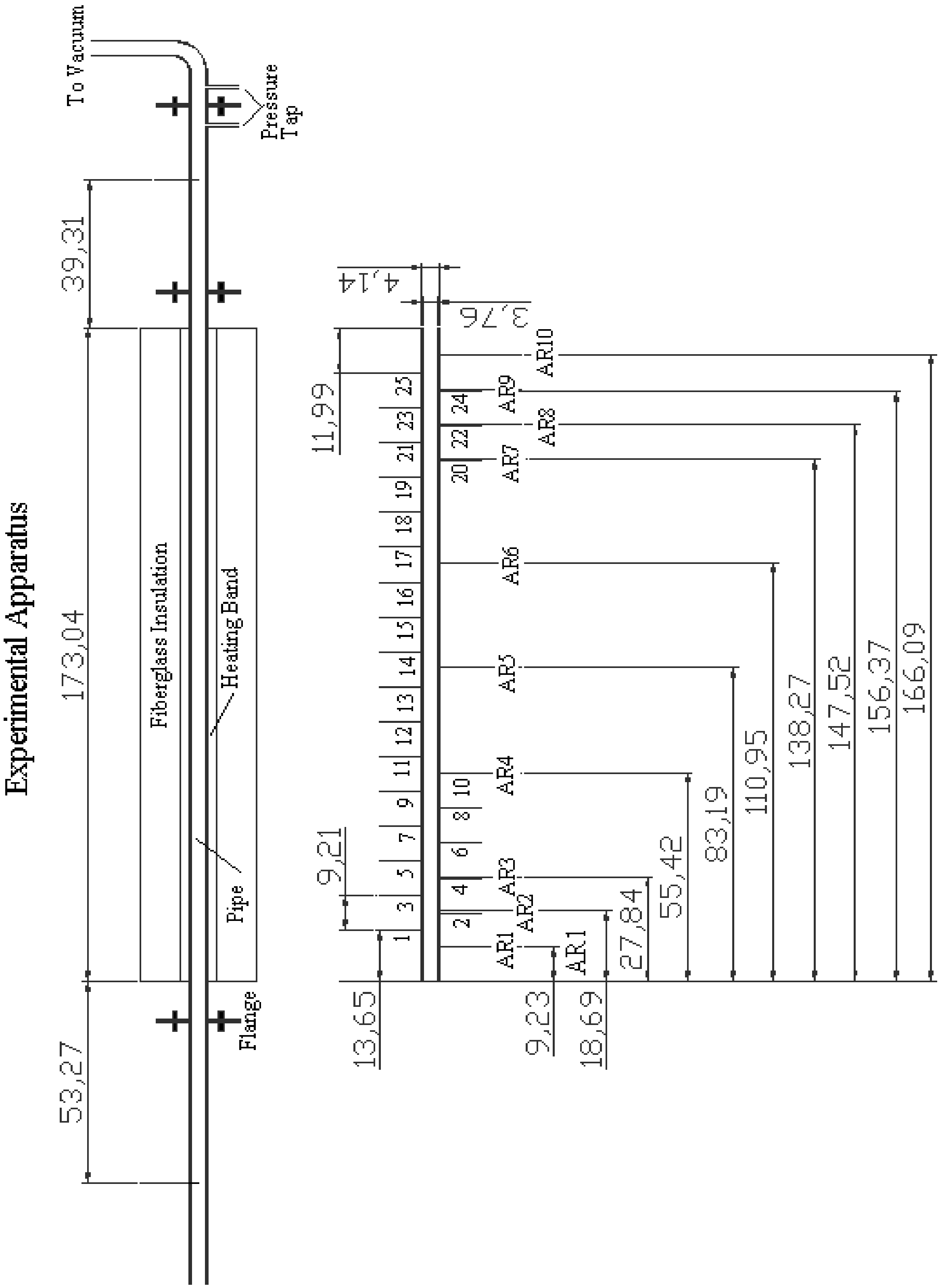

Figure 1 Facility Diagram
(Dimensions in cm)

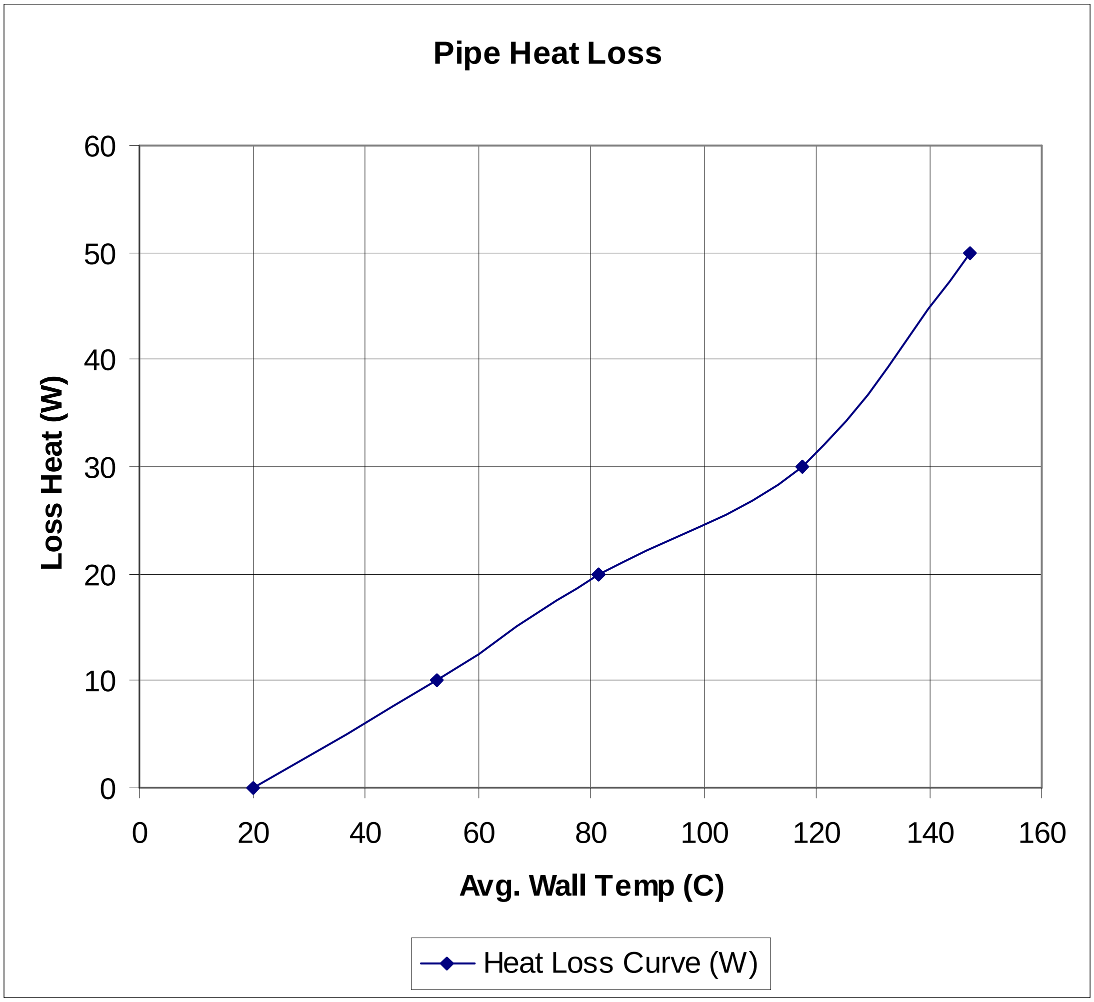

Figure 2 Heat Loss Curve

Table 1 Heat Loss Data

POWER(W)	10	20	30	50	
Wall TC	T (^{0}C)	T (^{0}C)	T (^{0}C)	T (^{0}C)	
1	40	56	79	96	
2	43	64	90	111	
3	46	69	98	122	
4	48	73	104	130	
5	50	76	109	136	
6	51	80	114	142	
7	52	82	117	146	
8	53	83	120	150	
9	54	84	121	152	
10	54	85	122	153	
11	54	85	123	155	
12	56	89	128	161	
13	57	90	130	163	
14	58	90	131	164	
15	58	91	132	166	
16	58	91	132	165	
17	58	90	131	165	
18	58	91	132	167	
19	57	89	130	163	
20	56	87	127	160	
21	55	84	123	155	
22	53	81	118	149	
23	51	77	112	141	
25	46	65	94	118	Ambient
Mean Temp	52.75	81.33	117.38	147.08	20

Note: The heat loss test was done with the pipe closed at both ends.