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AN EXPERIMENTAL STUDY OF TUBE-SIDE HEAT TRANSFER

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ABSTRACT
An experimental investigation was carried out for measuring tube-side heat transfer coefficient of water for turbulent flow in a smooth tube. An experimental set up was designed and fabricated for this purpose. A 914.4 mm long copper tube of 26.6 mm internal diameter and 30 mm outer diameter, of which length of 762 mm was used as the test section. A constant heat flux condition was created by wrapping Nichrome wire around the test section and fiber glass insulation over the wire. Outer surface temperature of the tube was measured at the mid point of the test section by a T-type thermocouple. Two thermometers were used at the inlet and outlet section of the tube for measuring the bulk temperatures. At the outlet section the thermometer was placed in a mixing box. The Reynolds numbers were varied in the range of 5500 to 21000 with heat flux variation 17 to 38 kW/m^2 on the basis of inner surface area of the test section. Experimental Nusselt numbers were found to be in the range of 45 to 159. Data were compared with Dittus and Boelter [1] correlation and error were found between -17% to 25% with r.m.s value of 15%. The authors recommended the coefficient of Dittus Boelter correlation 0.025 to be used instead of 0.023 [1] for this set up. With this predicted coefficient the error between data and predicted Nusselt numbers were found to be in the range of -23% to 15% with r.m.s. value of 11%. Because of the entrance effect the predicted coefficient was found to be somewhat higher than that of Dittus Boelter correlation.

Keywords: Heat transfer coefficient, Nusselt number, Smooth tube, Dittus Boelter correlation.

1. INTRODUCTION
To evaluate the performance of recuperative type heat exchanger it is necessary to know the tube side as well as shell side heat transfer. Although many correlations (Dittus and Boelter [1], Sieder and Tate [2], Petukhov [3] etc.) are available for tube side but frequently it is necessary to modify these correlations to accommodate entrance effect and/or correction for conditions for which these correlations are proposed but difficult to maintain during practical operations.

Eiamsa-ard and Promvonge [4] measured tube side heat transfer coefficient for the purpose of investigating the effects of insertion of a helical screw-tape with or without core rod in a concentric double tube heat exchanger on heat transfer. Naphon [5] reported heat transfer results from the plain tube for comparing with those from coil-wire inserted tube. Eiamsa-ard et al. [6] for experimentally investigating the effect of twisted tape insert on heat transfer in the tube side of a double pipe heat exchanger measured the heat transfer without twisted tape. Ahmed et al. [7] measured the tube side heat transfer coefficient for turbulent flow of air in a smooth tube for the purpose of investigating the heat transfer enhancement using twisted tape inserts. Sarkar et al. [8] also experimentally investigated the convective heat transfer in a smooth tube. Saha and Mallick [9] reported experimental results of heat transfer measurements of laminar flow in rectangular and square plain ducts and ducts with twisted tapes, where the test section was under uniform wall heat flux condition. Pavel and Mohammad [10] reported experimental work of investigating the effect of metallic porous matrix, inserted in a pipe, on the rate of heat transfer, considered also clear flow case where no porous insert was used. Hsieh and Huang [11] experimentally studied heat transfer characteristics of water flow in horizontal tubes with/without longitudinal inserts.

The scope of the present work is to experimentally investigate the tube side heat transfer in a smooth tube in the region of turbulent flow. Data are compared with Dittus and Boelter [1] correlation and modified coefficient of Dittus and Boelter correlation was proposed.

2. EXPERIMENTAL SET UP
The schematic diagram of the experimental set up is shown in Fig. 1. The test section was made from 914.4 mm of copper tube (26.6 mm ID and 30 mm OD), of which 762 mm was considered to be the test section. The nichrome resistance wire was spirally wound uniformly

on the outer surface of the test section to supply the heating power. Mica sheet was used between the tube and heating wire for electrical insulation. The heating wire was covered with mica sheet and fiber glass. The heating wire was connected to 220 Volt main. A T-type thermocouple was placed on the mid point of the test section to measure the outer surface temperature of the tube. Two thermometers were placed at the inlet and outlet of the tube to measure the inlet and outlet water temperatures respectively. To measure the outlet temperature, the thermometer was placed in a mixing chamber. A rotameter (Metric 24G, SS float) of 26 L/min capacity was provided to measure the water flow rate.

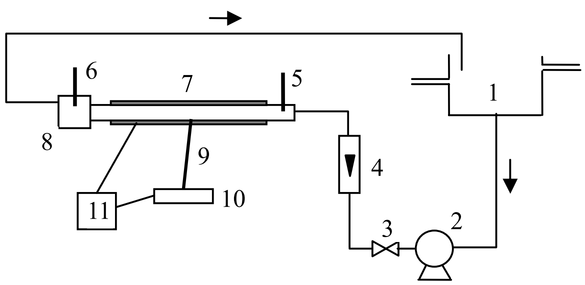

Fig 1: Schematic diagram of experimental apparatus.

1. Reservoir, 2. Pump 3. Gate valve 4. Rotameter 5.6. Thermometers 7. Test section 8. Mixing chamber 9. Thermocouple 10. Temperature reading device 11. Power supply.

Initially water was stored in the reservoir and pumped to the test section through the rotameter. The flow rate of water was varied by the gate valve for different data and kept constant during the experiment. A minimum of 6.2 L/min was used and it was increased up to 21.6 L/min. After switching on the heating power the sufficient time was given to attain the steady state condition. Data were taken for water flow rate, water inlet, outlet, and tube outer surface temperatures.

3. DATA REDUCTION

Heat transfer rate by the heater to water was calculated by measuring heat added to the water. Heat added to water was calculated by,

$$Q = mC_p\left(T_{out} - T_{in}\right) \tag{1}$$

Heat transfer coefficient was calculated from,

$$h = \frac{q}{\left(T_{w,i} - T_b\right)} \tag{2}$$

and heat flux was obtained from,

$$q = \frac{Q}{A} \tag{3}$$

where, $A = \pi d_i L$ (4)

The bulk temperature was obtained from the average of water inlet and outlet temperatures,

$$T_b = \frac{T_{in} + T_{out}}{2} \tag{5}$$

Tube inner surface temperature was calculated from one dimensional radial conduction equation,

$$T_{w,i} = T_{w,o} - Q \cdot \frac{\ln\left(d_o/d_i\right)}{2\pi k_w L} \tag{6}$$

Theoretical Nusselt number was calculated from Dittus Boelter [1] correlation,

$$Nu_{th} = 0.023 Re^{0.8} Pr^{0.4} \tag{7}$$

where

$$Re = \frac{\rho U_m d_i}{\mu} \tag{8}$$

$$Pr = \frac{\mu C_p}{k} \tag{9}$$

$$Nu = \frac{h d_i}{k} \tag{10}$$

Mean water velocity was obtained from,

$$U_m = \frac{m}{A_f} \tag{11}$$

Flow area was obtained from,

$$A_f = \frac{\pi}{4} d_i^{\,2} \tag{12}$$

4. RESULTS AND DISCUSSIONS

Figure 2 shows the variation of the heat flux with the Reynolds number. As shown the heat flux increases with increasing Reynolds number. This is because the heat

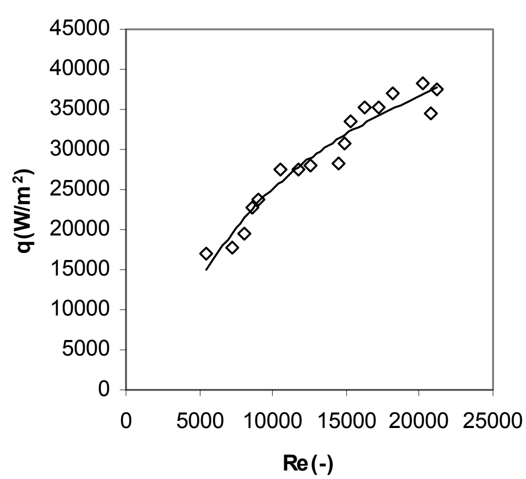

Fig 2: The variation of heat flux with Reynolds number.

transfer rate across the test section depends on the heat absorbing capacity of water. Naphon [5] reported increasing trend of heat transfer rate with increasing Reynolds number.

Variation of experimental Nusselt number with Reynolds number is presented in figure 3. As expected, the Nusselt number increases with increasing Reynolds number.

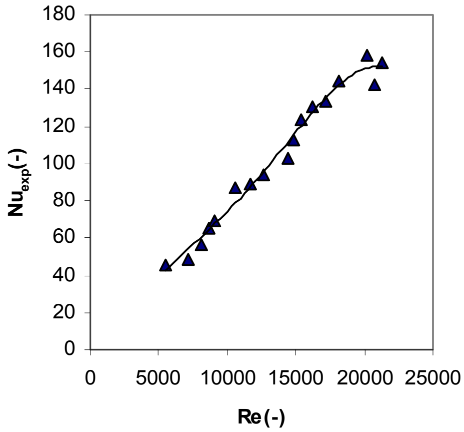

Fig 3: The variation of Nusselt number with Reynolds number.

Figure 4 shows the comparison of experimental Nusselt number with those calculated from Dittus Boelter [1] correlation. Data fall within +25% and -17% of the Dittus Boelter [1] value with r.m.s. value of error 14.7%, table 1. Saha and Mallick [9] compared data for a plain circular duct with the correlation of Bandyopadhyay et al. [12] for the Reynolds number in the range of 30 to 1100. The maximum deviation was 12.8% where as 85% of the data lie within ±6% of the correlation. Eiamsa-ard and Promvonge [4] compared experimental Nusselt number with Dittus Boelter [1] correlation and found within ±15% of the correlation for Reynolds number in the range of 2000 to 12000.

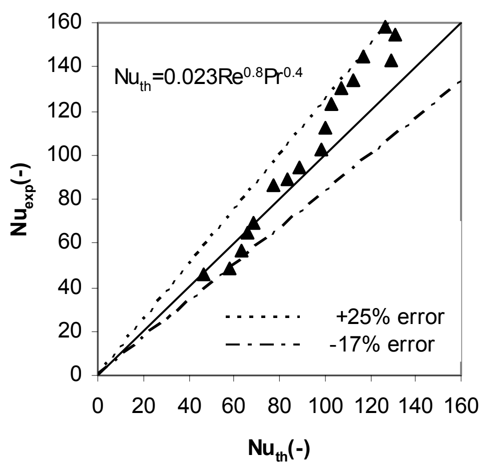

Fig 4: Comparison between experimental and theoretical Nusselt numbers.

Comparison between the Nusselt number obtained from the experiments with those calculated from the proposed correlation is shown in figure 5. Data fall

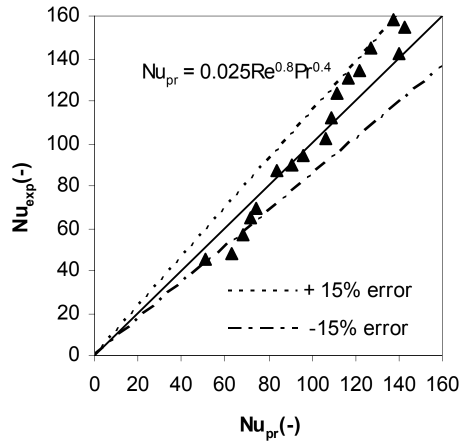

Fig 5: Comparison between experimental and proposed Nusselt numbers.

within 15% to -23% of the proposed correlation with r.m.s. value of error 11%, table 1, where as 88% of data fall within ±15% of the proposed correlation. Table 1 shows the details of error band and r.m.s. value for different values of a, m, and n. Eiamsa-ard and Promvonge [4] correlated their results and gave the value of a, m, and n 0.0054, 0.94, and 0.33 respectively.

Table 1: Error bands and r.m.s. values for different values of a, m, n for $Nu=aRe^mPr^n$

a	m	n	Min %error	Max %error	RMS %error
0.023	0.7	0.4	103	238	185.5
0.023	0.8	0.4	-16.5	25.4	14.7
0.023	0.9	0.4	-65.5	-53.5	57.9
0.023	0.8	0.5	-30.3	5.8	13.3
0.023	0.8	0.6	-41.9	-10.8	24.9
0.024	0.8	0.4	-20	16.4	12
0.025	**0.8**	**0.4**	**-23.2**	**15.4**	**10.8**
0.026	0.8	0.4	-26.1	7.4	11

5. CONCLUSIONS

An experimental study was conducted to investigate the tube side heat transfer. The results of the present study show that:

- The heat flux increases with increasing Reynolds number.
- The Nusselt number increases with the increase of the Reynolds number.
- The experimental Nusselt numbers fall within 25% and -17% of the Dittus Boelter [1] value.

A correlation for Nusselt number is proposed for prediction of turbulent flow heat transfer in a smooth tube with a = 0.025, m = 0.8 and n = 0.4 for $Nu = aRe^mPr^n$.

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7. NOMENCLATURE

Symbol	Meaning	Unit
A	Area of the heated region of tube	(m^2)
A_f	Flow area	(m^2)
C_p	Specific heat of water at constant pressure	(J/kg.K)
d_i	Tube inner diameter	(m)
d_o	Tube outer diameter	(m)
h	Heat transfer coefficient	(w/m.K)
k	Thermal conductivity of water	(W/m.K)
k_w	Thermal conductivity of tube material	(W/m.K)
L	Effective tube length	(m)
m	Mass flow rate of water	(Kg/s)
Q	Heat transfer rate	(W)
q	Heat flux	(W/m^2)
T_b	Bulk temperature	(^oC)
T_{in}	Water inlet temperature	(^oC)
T_{out}	Water outlet temperature	(^oC)
$T_{w,i}$	Tube inner wall temperature	(^oC)
$T_{w,o}$	Tube outer wall temperature	(^oC)
U_m	Mean velocity	(m/s)
Nu_{exp}	Experimental Nusselt number	(-)
Nu_{pr}	Predicted Nusselt number	(-)
Nu_{th}	Nusselt number from Dittus Boelter [1] correlation	(-)
Pr	Prandtl number	(-)
Re	Reynolds number	(-)
ρ	Density of water	(kg/m^3)
μ	Dynamic viscosity of water	(kg/m.s)