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HEAT TRANSFER IN TURBULENT FLOW THROUGH TUBE WITH ROD-PIN INSERTS

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ABSTRACT
An experimental investigation has been carried out to study the pressure drop, turbulent flow heat transfer in a tube with rod-pin inserts. The test section was electrically heated, air was allowed to flow as the working fluid. Air velocity, air inlet, outlet temperature, local wall temperature and the pressure drop were measured to analyze the friction factor, the Nusselt number, the heat transfer coefficient .Heat transfer and friction factor are compared with that of plain tube. The results indicated that as much as threefold improvement might be obtained in the turbulent flow heat transfer coefficient. A correlation was developed for prediction of the heat transfer coefficient.

Keywords: Heat transfer, Inserts.

1. INTRODUCTION
Turbulent flow heat transfer in tubes with inserts has found wide application in heat exchanger used in aerospace, vehicles, refrigeration and air conditioning, cooling of electronic equipments and so on. Improvement in the performance of the above may result in the reduction of the size of heat exchangers or increased heat transfer rate.

The analytical results showed that the local fin heat transfer coefficient varied significantly along fin height, with the smallest value (essentially zero) at the base and the largest value at the tip. Lesser and more gradual variations were exhibits by the local heat transfer coefficient on the wall of the tube or annulus. In general, the fins were found to be as the wall (per unit area).

Heat transfer and pressure drop characteristics in a circular tube fitted with full length strip, short-length strip, and regularly spaced strip elements connected by thin circular rods under uniform heat flux was investigated experimentally by Saha and langille[2]. The strips were crossed-type, rectangular and square in cross-section with different aspect ratio. Laminar flow of water and other viscous liquids was considered. The short-length strip and regularly spaced strip elements had been found to perform better than the full strips. They found that friction factor reduces by 8-58 percent and Nusselt number by 2-40percent for short length strips. For regularly-spaced strips elements friction factors increase by 1-35 percent and Nusselt number increased by 15-75 percent.

Hsieh and Huang [3] experimentally studied the heat transfer and pressure drop characteristics of water flow on horizontal tubes with/without longitudinal inserts. The Reynolds number ranged from 1700 to 4000. The enhancement of heat transfer as compared to a conventional bare tube at the same Reynolds number based on the hydraulic diameter was found to be a factor of 16 at Re≤ 4000, while the friction factor rise was only about a factor of 4.5 at Re≤ 4000.

Uttawar and raja Rao[4] carried out experimentally on isothermal pressure drop and convective heat transfer to servo herm medium grade oil in laminar flow in one smooth and seven wire coil –inserted tubes of varying pitch of wire coil. Their investigation has indicated that, When compared with smooth a plain tube at constant basic geometry, an improvement as high as 350% has been obtained in heat capacity and a reduction in heat exchanger area of about 70 to 80 percent may be achieved using wire –coil-inserted tubes.

Dippery and Sabersky[5] have been experimentally investigated heat and momentum transfer in smooth and rough tubes at various Prandtl numbers. From their experiment, increase in heat transfer coefficient due to roughness of as high as 270% has been conducted.

A longitudinal rectangular plate insert in the tubes of heat exchanger is a good displaceable device and this enhances tube side heat transfer rate. The buoyancy effect on laminar forced convection in a circular tube with longitudinal thin rectangular plate insert was studied by Chen and Hseih.

However the surveys show that very limited data has been published on the thermo hydraulic performance of tubes with rod-pin inserts.

The present study was therefore undertaken:

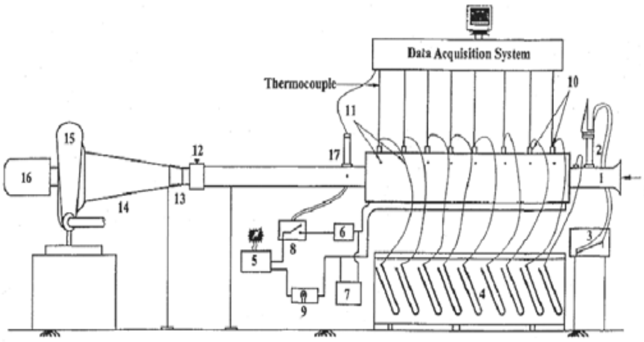
I. To modify the existing experimental facility in thermal engine laboratory for studying turbulent flow heat transfer and fluid friction in a tube with rod-pin inserts

II. To analyze the heat transfer performance.
III. To compare the results with that of plain tube.
IV. To develop a correlation, that may be recommended for prediction of the heat transfer coefficient in a tube with rod-pin inserts.

2. EXPERIMENTAL SETUP AND METHODOLOGY

Experimental Facility

The experimental facility consists of Test section, Inlet section, Air supply system and Heating arrangement. The set up is shown in figure 1.



1. Shaped inlet
2. Traversing pitot tube
3. Inclined tube manometer
4. U-tube manometer
5. Variable voltage Transformer
6. Ammeter
7. Voltmeter
8. Temperature controller
9. Heater on off lamp
10. Pressure tapping
11. Thermocouples
12. Flow control valve
13. Flexible pipe
14. Diffuser
15. Fan
16. Motor
17. Traversing thermocouple

Fig 1: Schematic diagram of Experimental rig

Test Section

The test section was circular tube made of Mild Steel. The test section was wrapped with mica sheet, glass fiber tape and insulation tape. Over mica sheet Nichrome wire was spirally wound uniformly with spacing 4 mm apart. Two heating coils have been used to heat the test section. The Test inserts was placed in the test rig with the help of the bolted flanges. Asbestos sheets were placed which act as heat guards in the longitudinal direction.

Inserts:

Four inserts with different longitudinal pin spacing (x=50mm, 100 mm, 150 mm, and 200 mm) were used as inserts in the experiment. The diameter of the rod was 20 mm and that of pin was 16 mm. The pins were 15 mm long and the number of pin in radial direction was 8.

Inlet Section

The unheated inlet section cast from aluminum was of same diameter as of test section. The pipe shaped inlet,

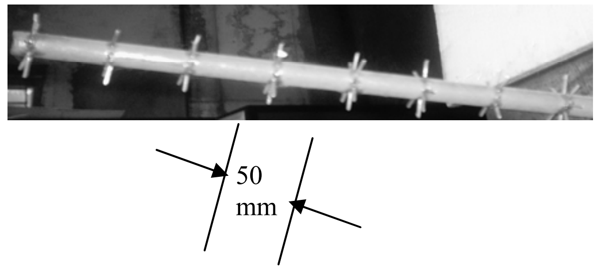


Fig 2: Rod-pin inserts (x=50 mm)

533 long was made integral to avoid section to get fully developed flow in the test section.

Air supply System

Induced draft air flow was created using an electrically operated centrifugal blower. A butterfly type gate valve placed between the test section and the downstream was used to control the air flow rate.

Heating System

Power for heating was supplied by a regulated A-C supply with a 5 KVA variable voltage transformer through a magnetic contractor and a temperature controller. A temperature controller was fixed to sense the outlet air temperature to provide signal for switching the heater off or on automatically.

Experimental Procedure

The Blower was first switched on and allowed to run for about minutes to have the transient characteristics died out. The flow of air through the test section was to set desired value and kept constant with the help of a flow control valve. Then the electric heater was switched on. The electric power was adjusted with the help of a regulating transformer or variac. Steady state condition for temperature at different locations of the test section was defined by Gee and Web (1980) by two measurements. First the variation in wall thermocouples was observed until constant value was attained, and then the outlet air temperature was monitored. Steady state condition was attained when the outlet air temperature did not deviate over 10-15 minutes time. At the steady state condition thermocouple and manometer readings were taken manually.

After each experiment run by the Reynolds number was changed with the help of the flow control valve keeping electrical power input constant. And after waiting for steady state condition, desired data are recorded as per procedure narrated above.

Experimental Data Measurement

Flow of air through the test section was measured using diesel as manometric fluid at the inlet section with the help of a traversing pitot tube. The static pressure tapings were made at the inlet of the test section as well as equally spaced 8 axial locations of the test section. The temperatures at the different axial locations and the air inlet temperature were measured with the help of k-type thermocouples.

3. RESULTS AND DISCUSSION

Tube surface temperature

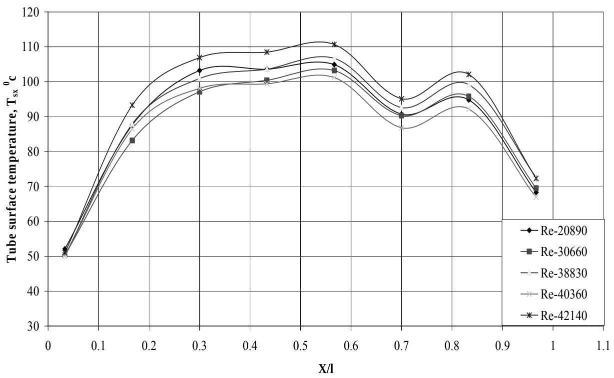


Fig 3: Tube surface temperature along the length of the tube for plain tube.

Figure shows longitudinal variation of tube surface temperature for plain tube. This is plotted for different Reynolds Number. Figure also shows that tube surface temperature is lower for higher Reynolds Number

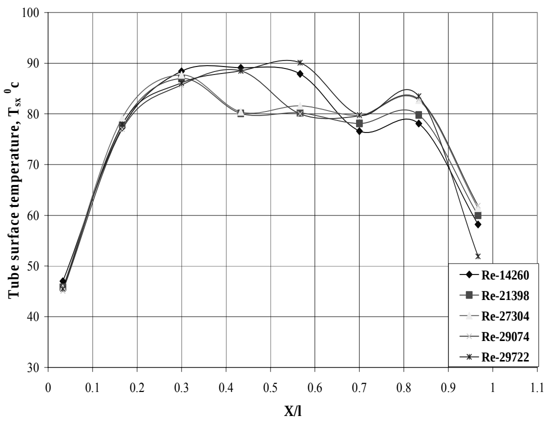


Fig 4: Tube surface temperature along the length of the tube with insert.

Bulk temperature

In figure 5and 6 bulk temperature distribution along the length of the tube is plotted. This is plotted for different Reynolds Number. Figure shows that tube surface temperature increases with axial distance from inlet. Figure also shows as the Reynolds Number increases, bulk temperature decreases

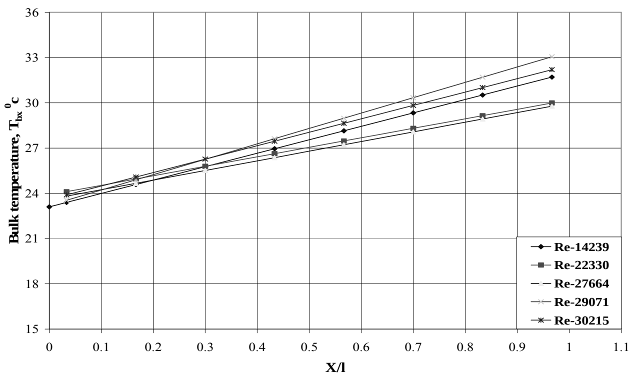


Fig 5: Calculated Bulk temperature along the length of the plain tube

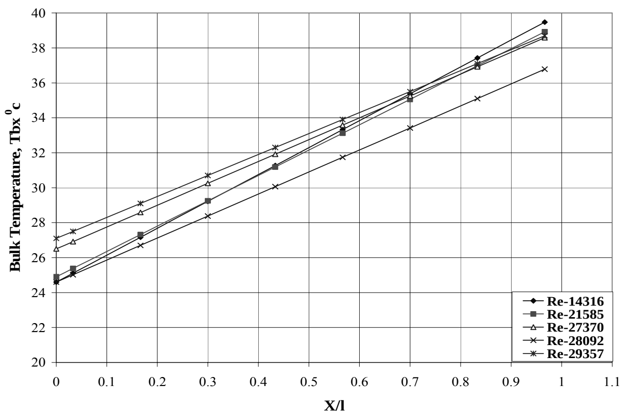


Fig 6: Bulk temperature along the length of the tube with inserts

Nusselt Number

We define the Nusselt number as the ratio of these two:

$$Nu = \frac{q(convection)}{q(conduction)} = \frac{hD_i}{k}$$

In fig 7.local Nusselt number is plotted against X/l for plain tube.

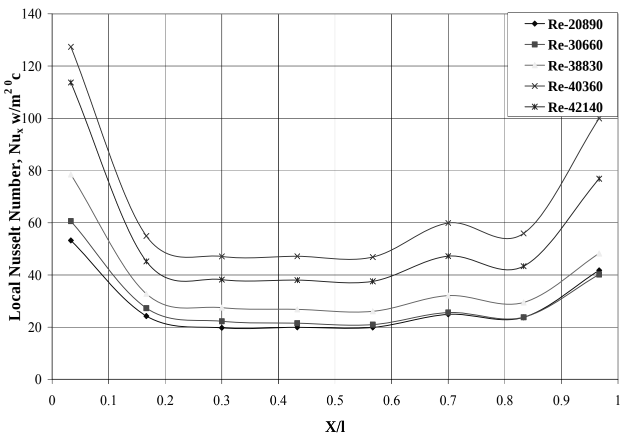


Fig 7: Local Nusselt Number along the length of the plain tube.

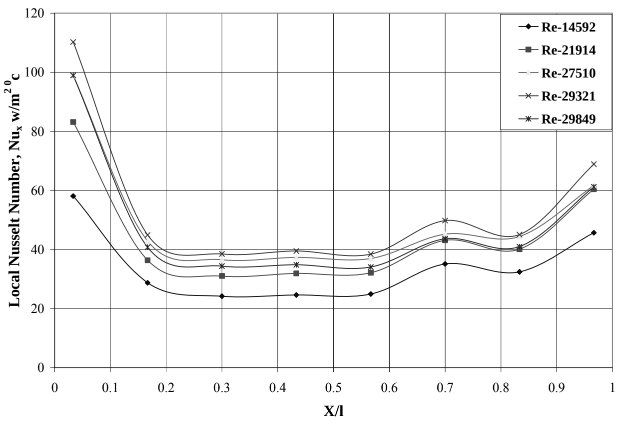


Fig 8: local Nusselt Number along the length of the tube with inserts (when x=50 mm).

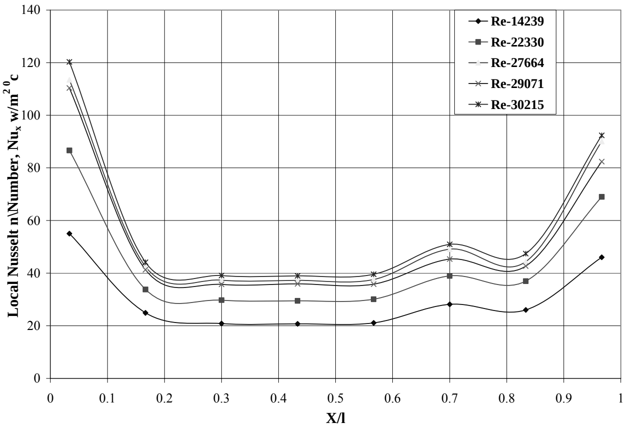


Fig 9: Local Nusselt Number along the length of the tube with inserts (when x=100 mm).

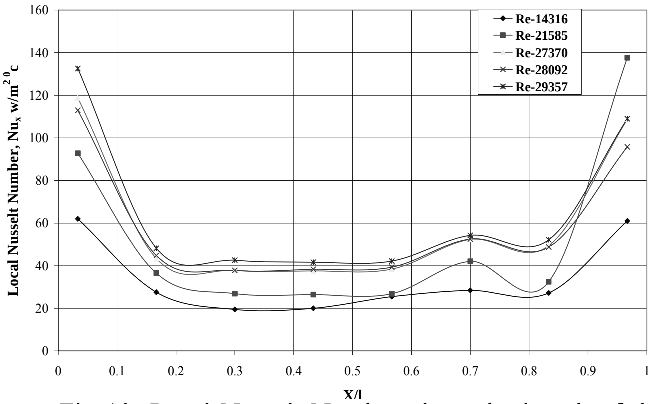


Fig 10: Local Nusselt Number along the length of the tube with inserts (when x =150 mm).

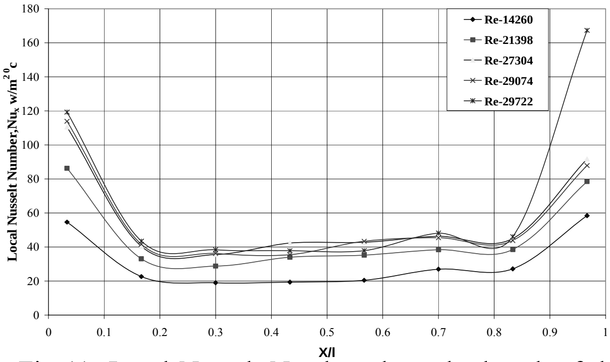


Fig 11: Local Nusselt Number along the length of the tube with inserts (when x= 200 mm).

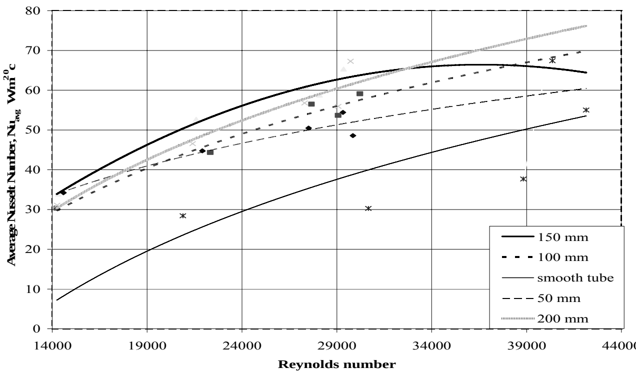


Fig 12: Comparison of avg Nusselt number for plain tube and tube with inserts.

Friction Factor

The local friction factor based on hydraulic diameter is given by

$$f = \frac{(-\Delta P / X)D_i}{2\rho V^2}$$

In fig 13.local friction factor is plotted against X/l for tube with rod-pin insert (x=100 mm). Similar graph may obtain from tube with other rod-pin inserts and plain tube.

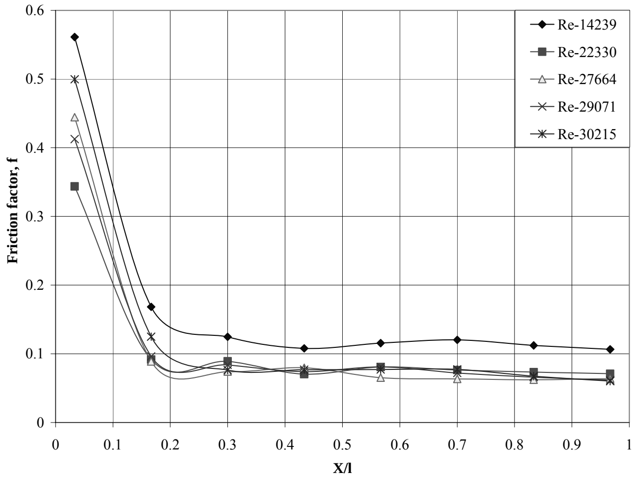


Fig 13: Variation of local Friction factor along the length of the tube for tube with rod-pin inserts (x=100 mm)

Pumping power

Pumping power, Pm can be expressed as

$$P_m = \frac{\Delta p}{\rho} m$$

fig 14 compares blower power for plain tube and tube with rod-pin inserts. It shows that blower power increases with higher Reynolds number for plain tube and tube with rod-pin inserts. Additional blower power needed to overcome increasing pressure drop with decreasing pin distance.

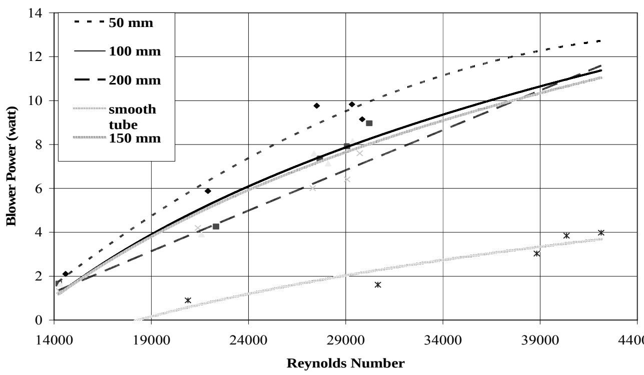


Fig 14: Comparison of pumping power for plain tube and tube with inserts.

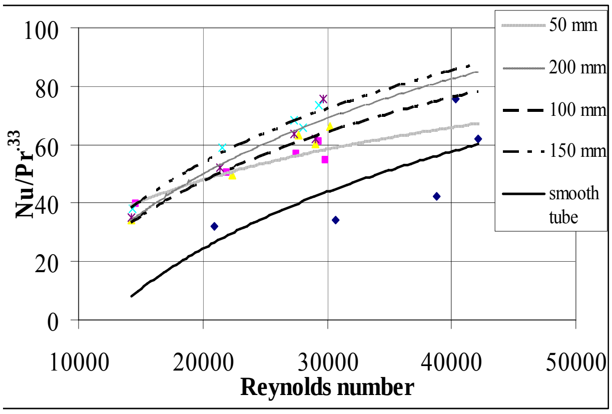


Fig 15: Variation of $Nu/Pr^{.33}$ with Reynolds number plain tube and tube with rod-pin inserts.

Correlations

Then the final correlation was obtained for the Nusselt Number in rod-pin inserts

$$Nu=(2E\text{-}05x2 - 0.0071x + 0.5212) \times Re^{(-9E\text{-}05x2 + 0.0242x - 0.3228)} Pr^{.33} \quad .....(4)$$

The Nusselt numbers predicted from equation (4) agreed well with the experimental values.

4. CONCLUSION

An experimental study has been conducted to investigate the heat transfer augmentation in a tube by means of rod-pin inserts. The study has revealed that the rod-pin inserts in the tube enhances heat transfer rate at the cost of increased pumping power.

The following conclusion can be made

- For comparable Reynolds number heat transfer coefficient for tube with inserts is higher than that of plain tube by
    1. Up to 4.1 times when x=50 mm
    2. Up to 4.2 times when x=100 mm
    3. Up to 4.4 times higher when x=150 mm and
    4. Up to 4 times higher for x=200 mm.
- For comparable Reynolds number local friction factor is higher than that of plain tube by
    1. Up to 3.51 times for tube with inserts when x=50 mm,
    2. Up to 2.916 times for tube with inserts when x=100 mm ,
    3. Up to 2.593 times when x=150 mm and
    4. Up to 2.75 times when x= 200 mm.
- The pumping power required for tubes with rod-pin inserts varies from up to 6 times higher than plain tube.
- The Nusselt number is high in the entrance region and it decreases gradually up to a certain point corresponding to the value of a fully developed flow.
- It was observed that tube with rod-pin insert having pin distance 150 mm performs better.

5. REFERENCES

1. Agarwal S.K. and Raja Rao (1996) M.,"Heat transfer augmentation for the flow of a viscous liquid in circular tubes using twisted tape inserts",International journal, Heat mass transfer , vol. no. 39, paper no. 17;
2. Bergles A.E. and Manglik R.M (1993).,"Heat Transferand Pressure Drop Correlations for Twisted-Tape Inserts in Isothermal Tubes: Part II-Transition and Turbulent Flows" ASME journal vol.115,.
3. Bergles.A.E. Brown. J.S. and Snider (1971),"Heat Transfer Performance of Internally Tubes."ASME paper No.71, HT-31, ASME, New York,
4. Chowdhury.D.andPatankar .V.(1985) , "Analysis of Developing Laminar Flow and Heat Transfer in Tubes with Radial Internal Fins." Proc. ASME National Heat Transfer Conference.pp.57-63,
5. DU PLESSIS J.P. and KROGER D.G.(1987),"Heat transfer correlation for thermally developing twisted-tape inserts",International journal ,Heat mass transfer , paper no.3 vol.3
6. Goldstein L Jr. and Sparrow E.M.,(1976)"Experiments on the Transfer Characteristics of a Corrugated Fin and Tube Heat Exchanger Configuration." J. Heat Transfer (98):26-34.
7. Hong S. W., and Bergles A. E. 1976, "Augmentation of Laminar Flow Heat Transfer in Tubes by Means of Twisted-Tape Inserts,"ASME J. Heat Transfer.98, No. 2, pp.251-256.
8. M.A.rashid Sarkar, M.zaidul Islam, &M.A. Islam,"Heat transfer in turbulent flow through tube with Wire-Coil Inserts",Journal of Enhanced Heat transfer ,12(4) 385-394 (2005).
9. Saha S.K. and Dutta A."Thermohydraulic study of laminar swirl flow through a circular tube fitted with twisted tapes",Journal of heat transfer ASME vol.123,june 2001.
10. Whitham J.M. 1896,"The Effects of retarders in fire tubes of steam boilers. "Street railway journal 12.No.6.p.374.

6. NOMENCLATURE

A_x Cross-sectional area of the tube (m^2)
A_{xt} Cross-sectional area of the wire (m^2)
b Atmospheric Pressure head (mm of Hg)
d Velocity Head at inlet section (inch of water)
D_i Inside diameter of the tube (mm)
D_h Hydraulic Diameter (m)
f Friction factor
Nu Nusselt number
Re Reynolds number
m Mass flow rate (kg/s)
W Wetted perimeter (mm)
l Length of the tube (m)
X Axial distance
μ Fluid dynamic viscosity(Ns/m^2)
Cp Specific heat of air (kj/kg^0C)
k Thermal conductivity of air ($W/m\ ^0C$)
ρ Density (kg/m^3)
ΔP Pressure drop (N/m^2)
t Room temperature (^0C)
T Temperature (^0C)

Q Heat transfer (W)
q Heat flux (W/m^2)
x Longitudinal Pin distance

Subscripts

b Bulk Temperature
i Inlet
o Outlet
s Surface of tube

Dimentionless Parameters

Nu Nusselt Number
Pr Prandlt Number
Re Reynolds Number