Experimental Verification and Validation of Correlation of an Inclined Heated Pipe Using CFD Simulation

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Abstract – Heat transfer coefficient h, determines the rate of heat transfer. The phenomenon of convection with turbulent flow can be solved experimentally and by CFD simulation. The value of h was found by CFD simulation, for a velocity input of 2.5 m/s, for a steel pipe at an inclination of 60º. This h was then compared with the experimental results of Dr. Krishpersad Manohar & Kimberly Ramroop (ref 1). The result was further compared with correlation data obtained using relations given by HILPERT, Fand & Keswani and Morgan. CFD simulation result validated the above correlation.

Further in this study airflow at 0.8,1.35m/s and 2.5 m/s across steel pipe of diameter 0.034m and 0.05mt results with pipe orientation inclined at 0,30,60,90 degrees to the horizontal position will be taken. A comparison of the experimentally determined h (heat transfer co efficient) with cfd simulated h will be done .further we will carry cfd simulation for copper pipe.

The *Nu* number will be calculated by the results obtained by cfd simulations and compared with the test conditions with the commonly used correlations of Hilpert, Fand and Keswani, Zukaukas, Churchill and Bernstein, and Morgan from this we can optimize the exact correlation which can be used for inclined heated pipe.

1. INTRODUCTION

Fluid flow in circular and noncircular pipes is commonly encountered in practice. The hot and cold water that we use in our homes is pumped through pipes. Water in a city is distributed by extensive piping networks. Oil and natural gas are transported hundreds of miles by large pipelines. Blood is carried throughout our bodies by arteries and veins. The cooling water in an engine is transported by hoses to the pipes in the radiator where it is cooled as it flows.

Thermal energy in a hydronic space heating system is transferred to the circulating water in the boiler, and then it is transported to the desired locations through pipes. Fluid flow is classified as external and internal, depending on whether the fluid is forced to flow over a surface or in a conduit. Internal and external flows exhibit very different characteristics. In this chapter we consider internal flow where the conduit is completely filled with the fluid, and flow is driven primarily by a pressure difference. This should not be confused with open-channel flow where the conduit is partially filled by the fluid and thus the flow is partially bounded by solid surfaces, as in an irrigation ditch, and flow is driven by gravity alone. We start this chapter with a general physical description of internal flow and the velocity boundary layer.

2. RELATED WORK

Fluid flow in circular and noncircular pipes is commonly encountered in practice. The hot and cold water that we use in our homes is pumped through pipes. Water in a city is distributed by extensive piping networks. Oil and natural gas are transported hundreds of miles by large pipelines. Blood is carried throughout our bodies by arteries and veins. The cooling water in an engine is transported by hoses to the pipes in the radiator where it is cooled as it flows.

2.1. HILPERT

Hilpert was one of the earliest researchers in the area of forced convection from heated pipe surfaces. He developed the correlation: where the values of C and m, are given on Table I.

Hilpert's calculations were done using integrated mean temperature values, not mean film temperature values, and with inaccurate values for the thermo physical properties of air. The thermal conductivity values of air used by Hilpert were lower (2-3%) than the most recent published results. This resulted in the values of Nusselt number calculated by the Hilpert correlation to be higher than they should be

2.2. FAND AND KESWANI

Fand and Keswani viewed of the work of Hilpert and recalculated the values of the constants C and m in equation 1 using more accurate values for the thermophysical properties of air. The constants proposed by Fand and Keswani are given on Table II.

2.3. ZAKAUKAS

Another correlation proposed by Zukaukas for convective heat transfer over a heated pipe was

$$Nu_f = c\,Re_f^m\,Pr_f^{0.37}\left(\frac{Pr_f}{Pr_w}\right)^{0.25}$$

where the values of c and m are given on Table Except for Prw, all calculations were done at the mean film temperature.

3. PROPOSED MODELLING

Fig. 5.1. Experimental set up

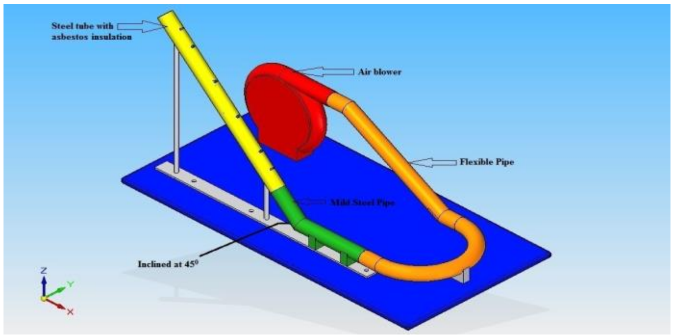

Fig. 5.2. Experimental Set up Model

Calculation of heat transfer coefficient. (MODEL-1) (velocity=14.5m/s)

$Q = \dot{m}C_p\Delta T$

$\dot{m} = \int AV$

$\dot{m} = 1.17 \times \frac{\pi}{4} \times 0.038^2 \times 14.5$

$\dot{m} = 0.01924$ kg/s

$Q = 0.01924 \times 1.005 \times (60 - 35) \times 1000$

Q = 483.405 watts

$Re = \frac{VD}{\nu}$

$T_{surface} = \frac{T_1 + T_2 + T_3 + T_4 + T_5}{5} = \frac{78+83+82+81+74}{5} = 79.6^0C$

$T_{film} = \frac{T_i + T_o}{2} = \frac{35+65}{2} = 47.5$

Properties of air at 47.5^0 of air

$\nu = 17.7025 \times 10^{-6}$

Pr = 0.69825

K = 0.028085

$Re = \frac{14.5 \times 0.038}{17.7025 \times 10^{-6}} = 31125.54$

From Hilpert Correlation for inclined pipe

$Nu_D = \left(\frac{hD}{k}\right) = CRe_D^m Pr^{1/3}$

HILPERT'S CONSTANTS FOR FORCED CONVECTION

Re_D	C	M
0.4 – 4	0.981	0.33
4 – 40	0.911	0.385
40 - 4000	0.683	0.446
4000 - 400,000	0.193	0.618
400,000 - 40,000,000	0.027	0.805

According to the renold's number C & m value are selected

C = 0.193 and m = 0.618

$Nu_D = CRe_D^m Pr^{1/3} = 0.193 \times 31125.54^{0.618} \times 0.69825^{1/3}$

$Nu_D = 102.40$

$Nu_D = \frac{hD}{k}$

Therefore,

$h = \frac{102.4 \times 0.028085}{0.038}$

$h = 75.68$ w/m^{2}k

FAND'S CONSTANTS

Re_D	C	M
1 – 4	-	-
4 – 35	0.795	0.384
35- 5000	0.583	0.471
5000 – 50000	0.148	0.633
50000 – 230000	0.0208	0.814

According to the Reynold's number C & m value are selected

C = 0.148 and m = 0.633

$Nu_D = CRe_D^m Pr^{1/3}$ = 0.148 × 31125.54$^{0.633}$ × 0.69825$^{1/3}$

Nu_D = 91.7

$Nu_D = \frac{hD}{k}$

Therefore,

h = $\frac{91.7 \times 0.028085}{0.038}$ = 67.77 w/m^{2}k

Calculation of heat transfer coefficient. (MODEL-2) (velocity=17.5m/s)

ṁ = ∫AV

ṁ = 1.17 × $\frac{\pi}{4}$ × 0.038^2 × 17.5

ṁ = 0.02322 kg/s

Q = 0.02322 × 1.005 × (58 - 40) × 1000

Q = 419.6 watts

Re = $\frac{VD}{\nu}$

Tsurface = $\frac{T_1 + T_2 + T_3 + T_4 + T_5}{5} = \frac{68+74+71+70+65}{5}$ = 69.60C

Tfilm = $\frac{T_i + T_o}{2} = \frac{40+58}{2}$ = 49 ≈ 50

Properties of air at 500 of air

$\nu = 17.95 \times 10^{-6}$

Pr = 0.698

K = 0.02826

Re = $\frac{17.5 \times 0.038}{17.95 \times 10^{-6}}$ = 37047.35

From Hilpert Correlation for inclined pipe

$Nu_D = \left(\frac{hD}{k}\right) = CRe_D^m Pr^{1/3}$

HILPERT'S CONSTANTS FOR FORCED CONVECTION

Re_D	C	M
0.4 – 4	0.981	0.33
4 – 40	0.911	0.385
40 - 4000	0.683	0.446
4000 - 400,000	0.193	0.618
400,000 - 40,000,000	0.027	0.805

According to the renold's number C & m value are selected

C = 0.193 and m = 0.618

$Nu_D = CRe_D^m Pr^{1/3}$ = 0.193 × 37047.350.618 × .6981/3

Nu_D = 114.02

$Nu_D = \frac{hD}{k}$

Therefore,

h = $\frac{114.02 \times 0.02826}{0.038}$

h = 84.79 w/m2k

FAND'S CONSTANTS

Re_D	C	M
1 – 4	-	-
4 – 35	0.795	0.384
35- 5000	0.583	0.471
5000 – 50000	0.148	0.633
50000 – 230000	0.0208	0.814

According to the renold's number C & m value are selected

C = 0.148 and m = 0.633

$Nu_D = CRe_D^m Pr^{1/3}$ = 0.148 × 37047.350.633 × .6981/3

Nu_D = 102.38

$Nu_D = \frac{hD}{k}$

Therefore, h = $\frac{102.38 \times 0.02826}{0.038}$ = 76.14 w/m2k

(MODEL-2) (velocity=17.5m/s)

4. RESULTS AND DISCUSSIONS

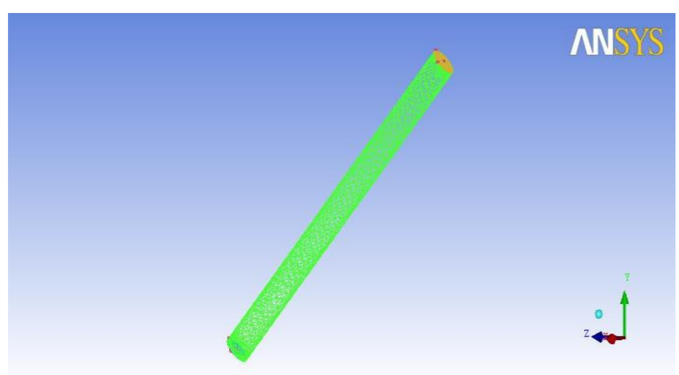

Fig. Modelling and Meshing of Pipe Using ICEM CFD

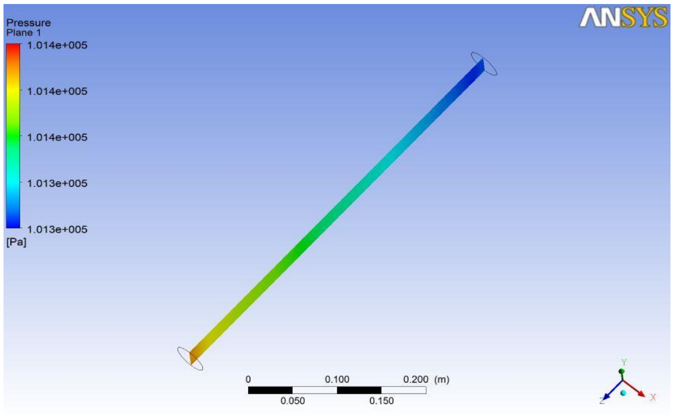

Fig. Pressure Plane

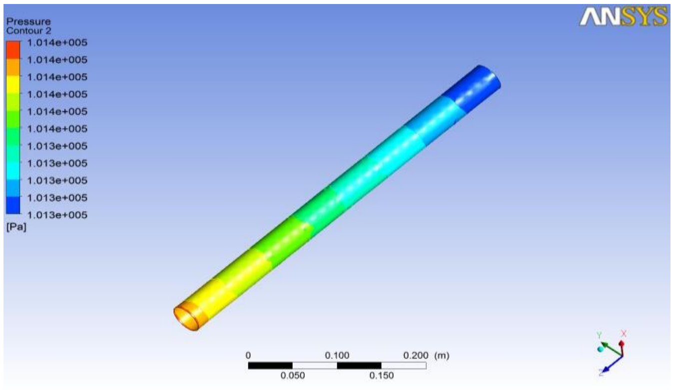

Fig. Pressure Contour

Hilpert correlation experimental and CFD comparison

SL.NO	VELOCITY (m/s)	EXPERIMENTAL h(w/m²k)	CFD h(w/m²k)	% of error
1	14.5	75.68	76.27	0.77
2	17.5	84.75	90.7	6.56

Fand & Keshwani correlation experimental and CFD comparison

SL.NO	VELOCITY (m/s)	EXPERIMENTAL h(w/m²k)	CFD h(w/m²k)	% of error
1	14.5	67.77	76.27	11.14
2	17.5	76.14	90.7	16.05

5. CONCLUSION

- It has been observed that percentage of error for both Hilpert and Fand correlations is within the agreed value (20%)
- Hilpert and Fand correlation is within the agreed value (up to 20%).
- From the above results we can conclude CFD tool is the appropriate tool for verification of experimental results.
- As velocity is increased the heat transfer between the flowing fluid and the surface increases, clearly these results can be observed from the above table.
- As heat flux is increased the heat transfer between the flowing fluid and the surface increases, clearly these results can be observed from the above table.

REFERENCES

[1] Hilpert, & kimberly. "Local Free Convection Around Inclined Cylinders in Air: An
[2] Interferometric Study," Experimental Thermal and Fluid Science, 5:235-242. 1992.
[3] Hilpert, R. "Heat Transfer from Cylinders," Forsch. Geb. Ingenieurwes, 4:215. 1933.
[4] Incropera Fand D. De Witt. Fundamentals of Heat and Mass Transfer, 5th Edition, USA. 2002.
[5] Fand, R. M. and K. K. Keswani. "A Continuous Correlation Equation for Heat Transfer from
[6] Cylinders to Air in Crossflow for Reynold's Numbers from 10-2 to 2(10)5," International Journal of Heat and Mass Transfer, 15:559-562. 1972.
[7] Fand, R.M. and K. K. Keswani. "Recalculation of Hilpert's Constants," Transactions of ASME, pp. 224-226. 1973.
[8] Zukauskas, A. "Heat Transfer From Tubes in Crossflow," Advances in Heat Transfer, 8:87-159. 1987.
[9] Churchill, S.W. and H. H. S. Chu. "Correlating Equations for Laminar and Turbulent Free
[10] Convection From a Horizontal Cylinder," International Journal of Heat And Mass Transfer,
[11] Churchill, S. W. and M. Bernstein. "A correlating Equation for Forced Convection from Gases and Liquids to a Circular Cylinder in Crossflow," J. Heat Transfer, 99:300-306. 1977.
[12] Morgan, V. "Heat Transfer from Cylinders," Advances in Heat Transfer, 11:199-264. 1987
[13] Manohar, K., Yarbrough, D. W. and Booth, J. R. "Measurement of Apparent Thermal
[14] Conductivity by the Thermal Probe Method," Journal of Testing and Evaluation, 28(5):345-351.