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THE CORRELATION OF HEAT TRANSFER COEFFICIENT AND FRICTION FACTOR AT CONSTANT HEAT FLUX IN FORCED CONVECTION FOR HELICAL PIPES

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ABSTRACT
This paper deals with the correlation of the heat transfer coefficient and friction factor at a constant heat flux in forced convection for helical pipes. The study was based on experiments and two correlation equations for heat transfer coefficient and friction factor were developed by using the least square method. The relative errors and the correlation coefficients for both correlation equations were calculated. Air was used in the study. The correlation equations for the heat transfer coefficient and friction factor are in accordance with the experiment results, for intervals given of Reynolds number(17.103<Red<135.103). The relative error and the correlation coefficient for the heat transfer coefficient and friction factor are %3,7, 0,94 ; %9,83 and 0,94 respectively.
Keywords: Turbulent flow, Correlation, Helical pipe, Forced convection

1. INTRODUCTION
Fins in various form are placed to inside the pipes to increase the heat transfer in turbulent flow. These fins spoil the viscos layer and increase the friction losses. This results in an increment of the heat transfer coefficient is seen. The studies on the helical pipes generally consist of four types of fins [1]. There are fins in notch form, ribbed form, groove form and spring form. There are two approaches for the correlation of the heat transfer coefficient. One of them is the analogy between heat and momentum, another one is the empirical method [2,3]. The studies related to heat and momentum generally take into consideration the approaches of Nikuradse [4], Dipprey and Sabersky [5].
There aren't very many experimental correlation, for turbulent flows in finned pipes. Rabas et al [6] obtained a new correlation by collecting the various data. Deng [7] proposed the correlation for intervals of Reynolds number, 5.103<Red<7.104. Water was used in these experiments. Newson and Hodgson [8] offered another correlation for 6.103<Red<7.104 in grooved pipes. Ravigururajan and Bergles [9] developed a new correlation for large Reynolds number, 3.103<Red<5.105 . The fins in grooved, ribbed and spring form were placed inside the pipe. Air, water, hydrogen and n- butil alchool were used in the experiments. Watanabe et al [10], Smithberg and Landis [11], Thorson and Landis [12] developed a correlation for helical pipes. Air was used in their experiments. Xin and Ebadian [13] suggested an empiric equation for the average and the local heat transfer coefficient. In their experiments, air, water and ethylene-glycol were used. Altınışık and etc [14] developed the heat transfer coefficient and friction factor were experimentally examined for constant wall temperature and turbulent forced convection in helical pipes. In this study, each of those correlations for the heat transfer coefficient and friction factor was suggested in turbulent forced convection at a constant heat flux in helical pipes.

2. DEVELOPMENT OF CORRELATION
The variables of convection heat transfer coefficient as a function are,

$$h = f\ (\rho, d, \mu, c_p, k) \tag{1}$$

The convection heat transfer coefficient can be written as follows by utilizing from the Rayleigh method,

$$Nu_d = \frac{q}{T_w - T_b} \cdot \frac{d}{k} = c \,.\, \mathrm{Re}^m \,.\, \mathrm{Pr}^n \tag{2}$$

Dittus – Boelter [15] experimantally obtained as $C = 0{,}023$, $m = 0{,}8$ and $n = 0{,}4$ (for heating) , $n = 0{,}3$ (for cooling) for complete developed turbulent flows in roughness pipes. In this study, the equation developed by Dittus – Boelter was modified; and a new correlation was obtained by employing the least squares method . Dittus – Boelter equation was stated as follows.

$$\overline{Nu}_d = a.\mathrm{Re}^{0,8}.\mathrm{Pr}^{0,4}.\left(1+\frac{s}{h_t}\right)^b.\left(\frac{\mu_b}{\mu_w}\right)^c \tag{3}$$

Here a, b and c are real numbers greater than zero and they are calculated based upon the experimental data. Equation (3) is written as follows in lineer form.

$$\ln \overline{Nu}_d = \ln a + 0{,}8.\ln \mathrm{Re}_d + 0{,}4.\ln \mathrm{Pr} + b.\ln\left(1+\frac{s}{h_t}\right) + c.\ln\left(\frac{\mu_b}{\mu_w}\right) \tag{4}$$

Reynolds and Prandtl numbers are calculated from the experiment results. This point of view, A may be discribed as follws;

$$0{,}8.\ln \mathrm{Re}_d + 0{,}4.\ln \mathrm{Pr} = A \tag{5}$$

In this case equation, (4) can be written given below;

$$\ln \overline{Nu}_d = \ln a + A + b.\ln\left(1+\frac{s}{h_t}\right) + c.\ln\left(\frac{\mu_b}{\mu_w}\right) \tag{6}$$

$$\ln\left(1+\frac{s}{h_t}\right) = X \tag{7}$$

$$\ln\left(\frac{\mu_b}{\mu_w}\right) = Y \tag{8}$$

If X and Y are described and substituted into equation (6), the following expression can be obtained;

$$\ln \overline{Nu}_d = \ln a + A + b.X + c.Y \quad \text{or}$$

$$\ln \overline{Nu}_d - A = \ln a + b.X + c.Y \tag{9}$$

Here, $\ln \overline{Nu}_d$ and A are constant values and can be found from experiment results. The following statement for $\ln \overline{Nu}_d$ and A can be given.

$$\ln \overline{Nu}_d - A = B \tag{10}$$

In this case, the equation (9) is;

$$\ln a + b.X + c.Y = B \tag{11}$$

At the same time, the equation (11) may be given in following form;

$$Y = \frac{B}{c} - \frac{b}{c}.X - \frac{1}{c}.\ln a \tag{12}$$

M, N. and P can be desribed as follows,

$$\frac{B}{c} = M \quad , \quad -\frac{b}{c} = N \quad , \quad -\frac{\ln a}{c} = P$$

From here, the equation (12) changhes into the equation(13)

$$Y = M + N.X + P \tag{13}$$

Due to the least squares method, the experiment number is from $i = 1$ up to n. The total of the squares of the differences between Yi and Y(Xi) should be minimum to approach to the values Yi obtained from the experiments' values Y(Xi) found from equation(13). According to this, the following expression can be written ;

$$\sum_{i=1}^{n} \left[\left(Y_i - Y(X_i)\right)\right]^2 = \min imum$$

$$\sum_{i=1}^{n} \left[\left(Y_i - (M + P + N \cdot X_i)\right)\right]^2 = \min imum \tag{14}$$

If the derivation of this statement is calculated according to M , N *and* P and it equals to zero, the following expressions can be written;

$$M = \frac{\sum_{i=1}^{n} Y_i}{n+1} - \frac{\left(1-2.n+n^2\right).\sum_{i=1}^{n} Y_i}{\left(n+1\right).\left(3-2.n-n^2\right)} \tag{15}$$

$$N = \frac{\left(1-2.n+n^2\right)}{\left(3-2.n-n^2\right)}.\frac{\sum_{i=1}^{n} Y_i}{\sum_{i=1}^{n} X_i} = \left(\frac{1-2.n+n^2}{3-2.n-n^2}\right).\sum_{i=1}^{n}\frac{Y_i}{X_i} \tag{16}$$

$$P = \frac{\sum_{i=1}^{n} Y_i}{n} - \frac{\left(1-2.n+n^2\right)}{n.\left(3-2.n-n^2\right)}.\sum_{i=1}^{n} Y_i - \frac{1}{n}.\left[\frac{\sum_{i=1}^{n} Y_i}{n+1} - \left(\frac{1-2.n+n^2}{3-2.n-n^2}\right).\frac{1}{n+1}.\sum_{i=1}^{n} Y_i\right] \tag{17}$$

All procedures were realized by the Deplhi-VII computer programe and the following equation for the average Nusselt number was found.

$$\overline{Nu}_d = 0,013 . Re_d^{0,8} . Pr^{0,4} . \left(1+\frac{s}{h_t}\right)^{-4,98} . \left(\frac{\mu_b}{\mu_w}\right)^{1,21} \qquad 17.10^3 < Re_d < 135.10^3 \tag{18}$$

Relative error and correlation coefficient for equation (24) are 3,7% and 0,94 .

The friction factor as function may be stated in the following form;

$$f = f(Re_d, s/h_t) \tag{19}$$

Equation (25) may be written as follows,

$$f = a.Re_d^{\,b}.(1+s/h_t)^c \tag{20}$$

Here, a,b and c are real numbers greater than zero.

The correlation equation for the friction factor can be obtained by applying the same method. The equation is,

$$f = 1.56 . Re^{-0,27} . \left(1+\frac{s}{h_t}\right)^{-14,23092} \qquad 17.10^3 < Re_d < 1,35.10^5 \tag{21}$$

Relative error and correlation coefficient for the friction factor are 9,83% and 0,94.

3. RESULTS

Figure 3 shows the equation (18) and the experimental values on the same graphics. The variation according to Reynolds number of the ratio $\overline{Nu}_{experimental}$ and $\overline{Nu}_{emprical}$ isshown in Figure 4. As seen in figure, the deviation changes according to the greatness or smallness of Reynolds number. The reason for this, the rates ρ/μ_b and μ_b/μ_w for low-hight velocities and temperatures denote very small variations.

The variations due to Reynolds number for the friction factor for the experimental and equation (21) are shown in Figure 5. The empirical results are greater than the experimental. values.

Figure 6 and 7 point out the changes according to Nusselt number of the ratio s/h_t . In Figure 6, the helix hight was accepted the constant; but the pitch was changed. As seen in Figure 7, if the helix hight is increased, the ratio s/h_t increases and on the contrary if distance between the two pitches is increased, the ratio s/h_t decreases and the Nusselt number increases. The reason of this, the helix hight is very small according to the pitch and the laminer layer on the inside of the pipe is easly spoilt.

4. CONCLUSION

In this study, helix pipe, of which pitch, helix hight; and diameter are 125 mm, 10 mm and 71 mm respectively. Total data used for correlation are 465.

The experimental studies were conducted under a constant heat flux. The expression given by Dittus-Boelter was modified; and the correlation equations for heat transfer coefficient and friction factor were obtained by employing the least squares method. If the helix hight is kept constant and the pitch is increased; the heat transfer coefficient increases. On the contrary, if the helix hight is increased and the pitch is kept constant, the heat transfer coefficient decreases; and a dead field occurs inside the pipe. The correlation equations obtained for the heat transfer coefficient and friction factor in intervals 17.103<Red<1,35.105 are in accordance with literature. The relative error for heat transfer coefficient is 3,7%; and the correlation coefficient is 0,94. The relative error for friction factor is 9,83%; and the correlation coefficient is 0,94. In this study, air was used. These new correlations may be obtained by using different fluids. Because experiment rig is very convenient to modify.

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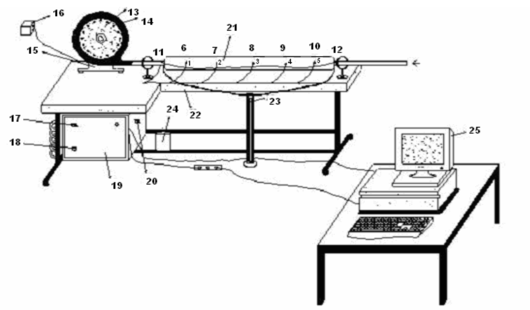

Figure 1. Experiment rig

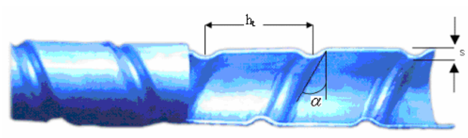

Figure 2. Helical pipe

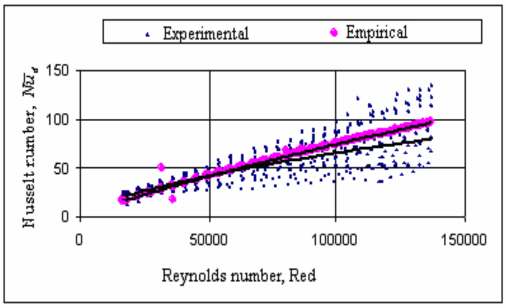

Figure 3. The change according to Nusselt number of Reynolds number for experimental data and equation (18)

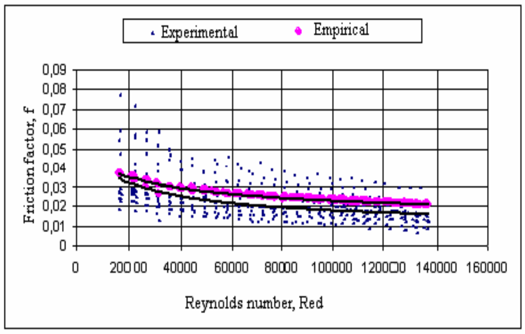

Figure 5. The change according to friction factor of Reynolds number for experimental data and equation (21)

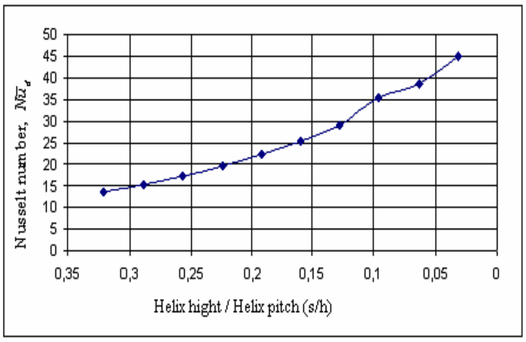

Figure 6. The change of s/h and Nusselt number for equation (18)

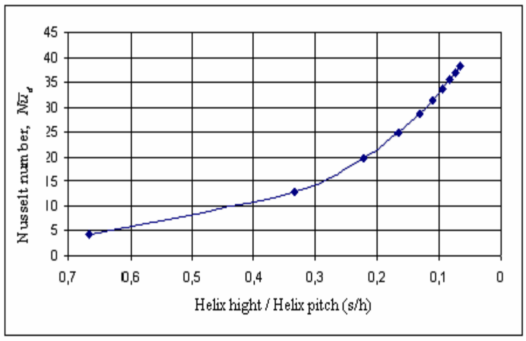

Figure 7. The change of s/h and Nusselt number for equation (18)