COMPUTER AIDED HEAT TRANSFER ANALYSIS IN A LABORATORY SCALED HEAT EXCHANGER UNIT

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Abstract

In this study, an explanation of a laboratory scaled heat exchanger unit and a software which is developed to analyze heat transfer, especially to use it in heat transfer courses, are represented. Analyses carried out in the software through sample values measured in the heat exchanger are: (1)Determination of heat transfer rate, logarithmic mean temperature difference and overall heat transfer coefficient; (2)Determination of convection heat transfer coefficient inside and outside the tube and the effect of fluid velocity on these; (3)Investigation of the relationship between Nusselt Number, Reynolds Number and Prandtl Number by using multiple non-linear regression analysis. Results are displayed on the screen graphically.

Introduction

Modeling studies which are based on experimental data have great importance among the numerical methods used to solve engineering problems. Mathematical difficulties confronted with in these studies are dealt with through computer programs developed for this purpose. In this study, description of a laboratory scaled heat exchanger unit and also a computer program is developed for the heat transfer analysis in the heat exchanger especially to be used in heat transfer courses.

The Heat Exchanger Unit

A schematic diagram of the experimental apparatus is given in Figure 1. The heat exchanger is of the double pipe type with hot water flowing through the central tube while cooling water flows through the annular space. The heat exchanger may be connected to give concurrent or counter-current flow. K-type thermocouples are used to measure the temperature at 6 points(at either ends of the tube surface and entry-exit temperatures of the hot and cold water). Hot water provided by an electrical resistance type water heater is fed into the heat exchanger. Flowmeters are used for measuring the flow rates of hot and cold water. While closed-circuit hot water circulation is obtained through a pump, cooling water is obtained from the main water supply. If the water temperature exceeds a certain value, a temperature control mechanism starts automatically and shuts of the heater.

In the steady-state conditions, by measuring the temperatures and the mass flow rates of both streams, the following may be calculated[1]:

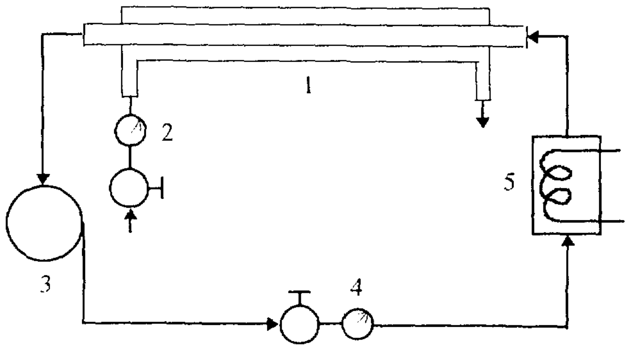

Figure 1. Schematic diagram of experimental apparatus. 1-Heat exchanger, 2-Cold water flow meter 3-Pump, 4-Hot water flow meter, 5-Heater,.

Rate of heat transfer

$$Q = UA_m\theta_{ln} \quad (1)$$

Overall heat transfer coefficient

$$U = \frac{Q}{A_m \dfrac{(T_1 - T_5) - (T_2 - T_6)}{\ln \dfrac{T_1 - T_5}{T_2 - T_6}}} \quad (2)$$

Convection heat transfer coefficient between inner surface of tube and hot stream

$$h_i = \frac{Q}{A_i \dfrac{(T_1 - T_3) - (T_2 - T_4)}{\ln \dfrac{T_1 - T_3}{T_2 - T_4}}} \quad (3)$$

Convection heat transfer coefficient between outer surface of tube and cold stream

$$h_o = \frac{Q}{A_o \dfrac{(T_3 - T_5) - (T_4 - T_6)}{\ln \dfrac{T_3 - T_5}{T_4 - T_6}}} \quad (4)$$

Overall heat balance

$$Q = m_i C_p (T_1 - T_2) = m_o C_p (T_5 - T_6) \quad (5)$$

Through the multi-nonlinear regression analysis; Nusselt, Reynolds and Prandtl non-dimensional numbers used for the derivation of heat transfer coefficient respectively are given below[1]:

$$Nu = \frac{hd}{k} \quad (6)$$

$$Re = \frac{ud\rho}{\mu} = \frac{4m}{\pi d\mu} \quad (7)$$

$$Pr = \frac{C_p \mu}{k} \qquad (8)$$

As seen in these equations; in calculations, physical properties of water in different temperatures are necessary. For this aim, correlations developed through non-linear regression analysis have been used(Table 1). The temperature in these correlations must be set in as °C.

Table 1.Temperature-dependent correlations for the physical properties of water[2].

Density(kg/m^3)

$\rho = 1000.47 - 0.0679468*T - 0.00357872*T^2$

Thermal conductivity (W/mK)

$k = 0.568552+0.0017256*T-5.87414E\text{-}6*T^2$

Viscosity(Ns/m^2)

$\mu = (1762.63 - 47.5729*T+0.587372*T^2 - 0.00261674*T^3)E\text{-}6$

Specific heat capacity (kJ/kgK)

$C_p = 4.21027 - 0.00304996*T+7.93122E\text{-}5*T^2 - 8.23628E\text{-}7*T^3 + 3.34962E\text{-}9*T^4$

Prandtl number(-)

$Pr = 13.3675-0.401211*T+0.00521008*T^2 - 2.37898E\text{-}5*T^3$

The Computer Program

The computer program is developed by using a special mathematics software because of its mathematical capabilities and graphical advantages. The software, designed as menu-driven, consists of four modules one of which is the main module. As the input data of the computer program, only the measured temperatures(T_1, T_2, T_3, T_4, T_5, T_6) and mass flow rates(m_i, m_0) are used. The following analyses are possible to be made in the computer program through a large number of measurements made the such a way to provide certain conditions:

(1) Determination of heat transfer rate, logarithmic mean temperature difference and overall heat transfer coefficient;

(2) Determination of convection heat transfer coefficient inside and outside the tube and the effect of fluid velocity on these;

(3) Investigation of the relationship between Nusselt Number, Reynolds Number and Prandtl Number by using multiple non-linear regression analysis.

Case Studies

Some illustrative applications have been carried out in the heat exchanger unit connected for the counter-current flow to explain the analyses summarized above. In the measurement values obtained after the apparatus reached steady-state operating conditions, deviation from the mean temperature is limited to ±2°C.

Example 1

Through single-measurement set formed for this modules aimed to explain the heat exchanger unit and the software; heat transfer rate, logarithmic mean temperature difference and overall heat transfer coefficients are calculated. The temperature profiles for the hot and cold water are shown as schematically. Screen image obtained from the program for the illustrative measurement is given in Figure 2.

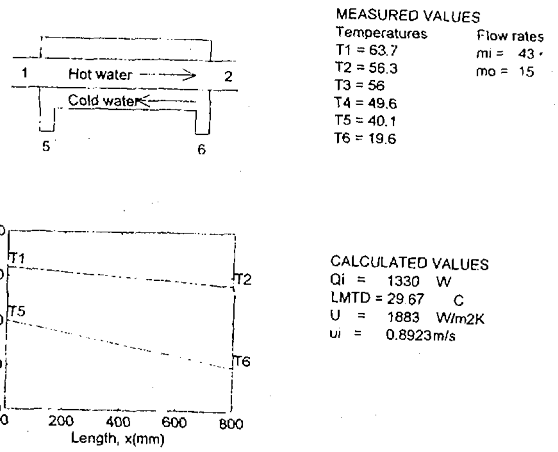

Figure 2. An illustration for the application aimed at explaining the heat exchanger and the software.

Example 2

In this example where measurements are made by reducing hot water flow at a certain rate; the mean temperature of hot water and the flow rate of cold water are fixed. The convection heat transfer coefficients for hot and cold water flows(h_i,h_0), and the overall heat transfer coefficient(U) are determined from equations (1)-(5). The effect of hot water velocity on convection and overall heat transfer coefficients are shown in Figure 3.

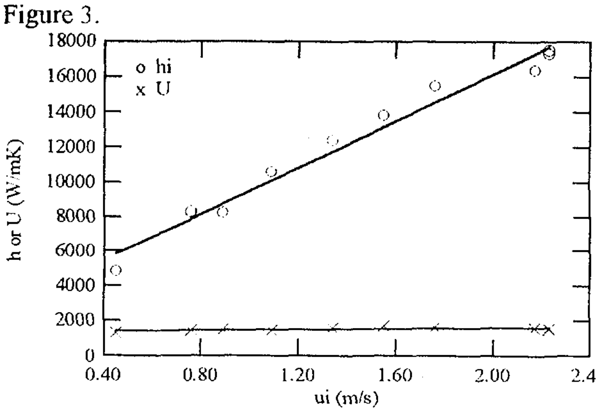

Figure 3. The effect of hot water velocity on heat transfer coefficients.

Example 3

The aim of this module is to show how a correlation to be used for the calculation of the Nusselt number(Nu) is derived through Reynolds number(Re) and Prandtl numbers(Pr). With respect to that, a function like

$$Nu=f(Re,Pr) \qquad (9)$$

is expected to come out. Unsophisticated form of this function is taken as

$$Nu = c\,Re^a\,Pr^b \qquad (10)$$

In the determination of a,b and c coefficients given in equation (10), the methods developed for the multi non-linear regression analysis can be used[3,4]. In this study, logarithmic and linear regression analyses are used.

So, by keeping Pr constant, the dependence of Nu on Re are established. There has been obtained the coefficient as a=0.8 from the logarithmic regression analysis applied to Re and Nu numbers(Figure 4). Similarly, by keeping Re constant, the dependence of Nu on Pr are determined. There has been obtained the coefficient as b=0.6 from the logarithmic regression analysis applied to Pr and Nu numbers(Figure 5). Finally, it has been found as c=0.027 from the linear regression analysis applied to $Re^{0.8}Pr^{0.6}$ and Nu values(Figure 6). The fitted equation is thus

$$Nu = 0.027 Re^{0.8} Pr^{0.6} \qquad (11)$$

Nu numbers derived from the measurements and Nu numbers calculated from the Equation (11) are shown in Figure 7 as compared with each other.

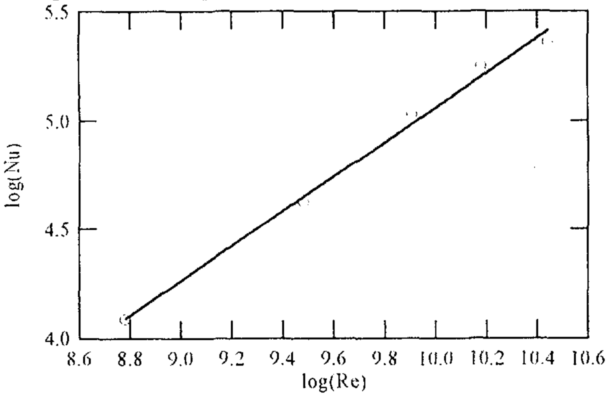

Figure 4. Logarithmic regression analysis between Re and Nu numbers.

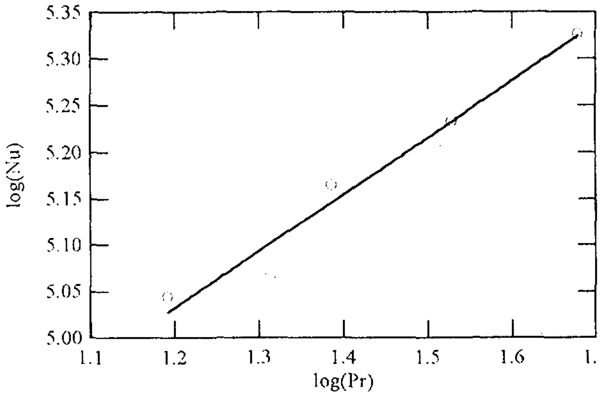

Figure 5. Logarithmic regression analysis between Pr and Nu numbers.

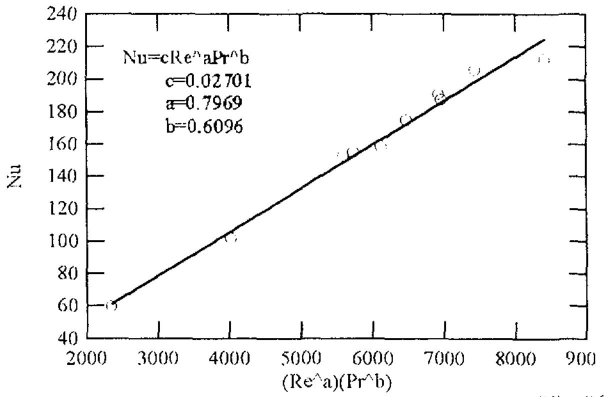

Figure 6. Linear regression analysis between $Re^{0.8}Pr^{0.6}$ and Nu numbers

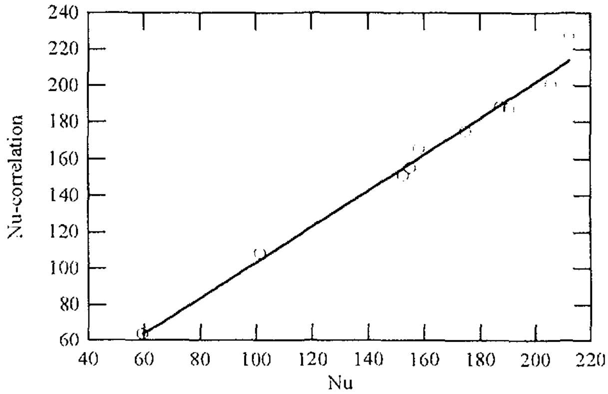

Figure 7. Comparison of Nu numbers obtained from the measurements and calculated from equation (11).

Conclusions

The study given here is prepared especially for undergraduate students studying mechanical engineering. It is aimed to acquaint students with the following subjects, through heat exchanger and software;

- Heat transfer analysis in heat exchanger
- Experimental research methods
- Regression analysis application on measurement values and developing empirical correlations
- Introduction to mathematical softwares
- Modules programming techniques.

References

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