*Proceedings of the Global Engineering, Science and Technology Conference 2012*
*28-29 December 2012, Dhaka, Bangladesh*

# Comprehensive Study on Heat Transfer Co-efficient and Effectiveness for Water Using Spiral Coil Heat Exchanger

Dr M A. Hossain[1], M I. Islam[2], S A. Ratul[2], MT U R. Erin[2]

*Spiral coil heat exchangers play a vital role in cooling high density and high viscous fluids. An experimental study has been conducted to investigate the overall heat transfer co-efficient and effectiveness for water using spiral coil heat exchanger. A physical model of the spiral coil heat exchanger was designed, built, and instrumented for temperature measurements. The mass flow rate of hot fluid was varied from 0.049 kg/sec to 0.298 kg/sec and the mass flow rate of cold fluid was varied from 0.029 kg/sec to 0.225 kg/sec. Experiments have been conducted by varying combination of the mass flow rates of cold and hot water. The effects of relevant parameters on spiral coil heat exchanger are investigated. The result that has been achieved in the research was impressive and encouraging.*

**Field of Research:** Mechanical Engineering

**Keywords:** Spiral Coil Heat exchanger; Reynolds number; Heat transfer coefficient; Effectiveness.

## 1. Introduction

The heat transfer characteristics in spiral coil heat exchangers have received comparatively little attention in literature. It is a very much recent concept. However, most of the studies for compact heat exchangers are carried out with the helical coil heat exchangers and spiral plate heat exchangers. But due to lack of experimental data, the information on spiral coil heat exchangers, in open literature, is limited.

There are some earliest works, regarding spiral coil heat exchangers, were performed by - Seban and McLaughlin (1963) calculated heat transfer in coiled tubes for both laminar and turbulent Flows. Plot of Nusselt *vs*. Graetz numbers were presented for coils with curvature ratios of 17 and 104 with Reynolds numbers ranging from 12 to 5600 for the laminar flow region. Heat transfer and pressure loss in steam heated helically coiled tubes were studied by Rogers (1964). They observed that even for a steam heated apparatus, uniform wall temperature was not obtained, mainly due to the distribution of the steam condensate over the coil surface. Mori (1965) studied the fully developed flow in a curved pipe with a uniform heat flux for large Dean Numbers. Pressure drop and heat transfer for laminar flow of glycerol was presented by Kubair (1950) for different types of coiled pipes, including helical and spiral configurations. Outside-film and inside-film heat transfer coefficients in an

[1]Assistant Professor, Department of Mechanical Engineering,
Military Institute of Science and Technology (MIST)
Email: ahossain@me.mist.ac.bd
[2]Researcher, Department of Mechanical Engineering, MIST

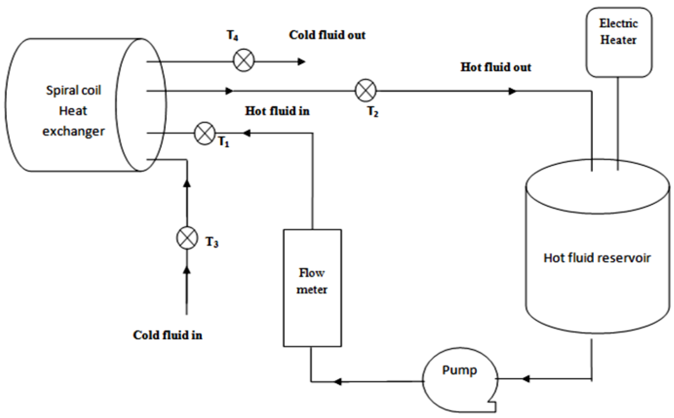
agitated vessel were studied by Jha (1967). Prandtl numbers of 0.005-1600, and curvature ratios of 10 to 100 for fully developed velocity and temperature fields were performed by Kalb (1974 and 1972). The effects of buoyancy forces on fully developed laminar flow with constant heat flux were studied analytically by Yao (1978). Rayleigh number and Dean number were presented for both orientations. Laminar flow and heat transfer were studied numerically by Zapryanov (1980) using a method of fractional steps for a wide range of Dean (10 to 7000) and Prandtl (0.005 to 2000) numbers. Their work focused on the case of constant wall temperature and showed that the Nusselt number increased with increasing Prandtl numbers, even for cases at the same Dean number. Due to the lack of the heat transfer coefficients correlations obtained directly from the spirally coiled configuration, Naphon and Wongwises (2003a and 2003b) proposed a correlation for the average in-tube heat transfer coefficient for a spirally coiled heat exchanger under dehumidifying conditions.

## 2. Methodology

Figure 1 shows the experimental setup line of art schematic diagram that has been used in this research work.

Fig 1: Block Diagram of Experimental Apparatus

The outlet cold water flow rate is kept constant and the inlet hot water flow rate is varied using a gate valve. For the same cold water flow rate, the hot water flow rate is changed for five times. The hot water is circulated in a closed loop and the cold water in an open loop. The experiment starts with raising the temperature of hot




reservoir by an electric heater capacity of around 2 kW. When the temperature of hot reservoir is raised around 50-60$^{\circ}$c, a 0.5 HP centrifugal pump is opened to circulate the hot water through the heat exchanger .At the same time cold water is supplied through the heat exchanger. Thermocouple $T_1$ and $T_2$ are used to measure inlet and outlet temperature of hot water respectively; $T_3$ and $T_4$ are used to measure the inlet and outlet temperatures of cold water respectively. For different hot water flow rates the temperatures at the inlet and outlet of hot and cold water are recorded, after achieving the steady state. The same procedure is repeated for different cold water flow rates and the data related to temperatures, the corresponding temperatures and mass flow rates are recorded. The mass flow rate is noted by using the flowmeter fitted at the outlet of the pump to measure the hot water fluids. The mass flow rate of cold water is measured by bucket method.

Table 1: Material and Dimension of the Setup

| Particulars | Specification |
|---|---|
| Mild Steel Shell | 350 mm dia, 500 mm length |
| Copper tube Coil | 9.5 mm inner dia, 50 m length |
| Water pump | 0.5 hp |
| Flow meter | 18 Lpm |
| Hot Reservoir | 40 liter |
| Thermocouple | K-type |
| Electric Heater | 2 kW |

Table 2: Boundary Conditions for the Experiment

| Variable | Range |
|---|---|
| Hot Water Temperature | 40-60◦c |
| Cold Water Temperature | 25-35◦c |
| Mass flow rate of hot water | 0.049-0.298 kg/sec |
| Mass flow rate of cold water | 0.029-0.225 kg/sec |

## 3. Calculation Methodology

The heat released or absorbed is calculated using the expression,

$$Q= \dot{m}C_p \Delta T \qquad (1)$$

where, $\dot{m}$ is hot or cold water flow rate, $C_p$ is specific heat capacity of water, ΔT is Temperature difference of hot and cold water.

The Nusselt Number of hot water for fully developed turbulent flow inside smooth tube can be determined by using Colburn equation (0.7<Pr<160, Re> 10, 0000):

$$Nu_h = 0.023Re_h0^{.8}Pr^{0.3} \qquad (2)$$

where,

$Re_h=\frac{4\dot{m}}{\pi D_i \mu}$=Reynolds Number of hot water and Pr =Prandtl Number

Empirical relations have been developed for predicting Nusselt Number for laminar flow in the entrance region of a circular tube. One such correlation is given by Hausen as

$$Nu_c= 3.66 + \frac{0.0068Gz}{1+0.04(Gz)^{2/3}} \qquad (3)$$

where, Gz = Gratez Number = $\frac{\mathrm{Re\ Pr}}{L/D_i}$ *(4)*

L and D are the length and inner diameter of the shell respectively.

Heat transfer co-efficient (h) for flow through a circular shell,

$$h= Nu\frac{k}{D_i}. \qquad (5)$$

where, k =thermal conductivity of water (W/m $^0$C)

If, $h_i$ and $h_0$ are heat transfer co-efficient of hot and cold water respectively then overall heat transfer coefficient (U) can be calculated using the following equation,

$$U = \frac{1}{\frac{1}{h_i} + \frac{1}{h_o}} \quad (6)$$

Logarithmic mean temperature difference (LMTD) can be found from the following equation

$$LMTD = \frac{(T_1 - T_4) - (T_2 - T_3)}{log((T_1 - T_4)/(T_2 - T_3))} \quad (7)$$

where, $T_1$=Hot water inlet temperature; $T_2$= Hot water outlet temperature; $T_3$=Cold water inlet temperature; $T_4$=Cold water outlet temperature

Heat transfer area (A) is estimated from the following equation,

$$A = \frac{Q}{LMTD \ x \ U} \quad (8)$$

Effectiveness(ε)of the heat exchanger,

$$\varepsilon = \frac{(T_1 - T_2)}{((T_1 - T_3)} \quad (9)$$

Number of (heat) transfer unit (NTU) which is a dimensionless parameter is defined as,

$$NTU = \frac{1}{\varepsilon} \quad (10)$$

## 4. Result and Discussion

The performance characteristics of spiral coil heat exchanger i.e. heat transfer coefficient (hot water), overall heat transfer coefficient, Nusselt Number, Effectiveness with respect to Reynolds Number and effectiveness, heat transfer coefficient and heat capacity with respect to hot water flow rate for three different cold water flow rates are illustrated from figure 1to 8.

The effects of heat transfer rate on Reynolds number (Re) for three different cold water flow rate is shown in Figure 2. It is observed that the heat transfer rate increases almost linearly with increasing Reynolds number (Re), which is acceptable for the spiral coil heat exchanger. The heat transfer rate is maximum in case of medium cold water flow rate (0.129kg/sec).

Figure 3 shows the variation of the overall heat transfer co-efficient, U ($W/m^2K$) with Reynolds Number (Re) for three different cold water flow. From this plot it is observed that, the overall heat transfer co-efficient, U ($W/m^2K$) is maximum for the highest cold water flow rate (0.225kg/sec) and minimum for the lowest cold water flow rate (0.029kg/sec).

Fig 2: Variation of Heat Transfer Coefficient with Reynolds Number for Different cold water flow rates.

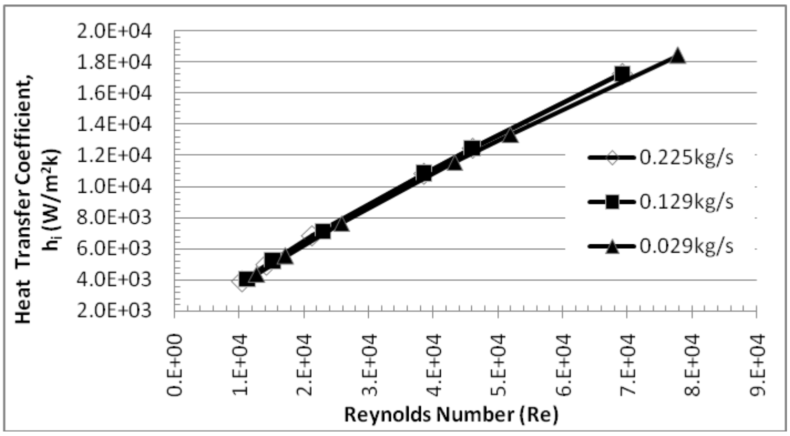



Fig 3: Variation of Overall Heat Transfer Coefficient with Reynolds Number for Different cold water flow rates.

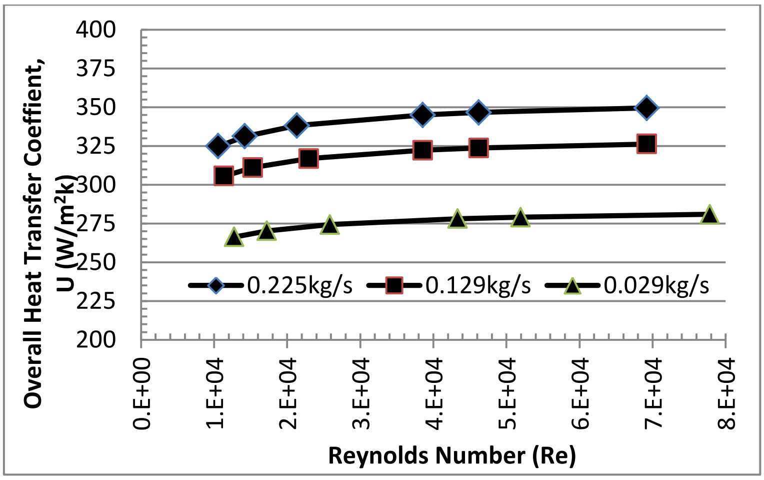



Fig 4: Variation of Nusselt Number with Reynolds Number for Different cold water flow rates.

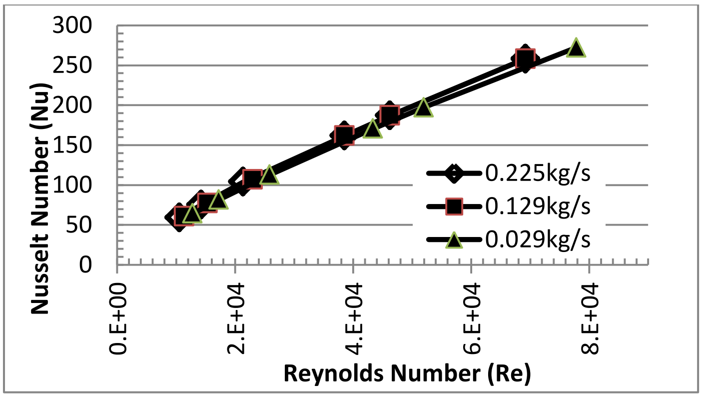



Figure 4 shows the plot of the Nusselt Number (Nu) with Reynolds Number (Re) for three different cold water flow rate. From the experimental result it is shown that the Nusselt number increases linearly with increasing of Reynolds Number for all three cold water flow rate. At 0.129kg/sec cold water flow rate Nu is maximum with respect to Re.

Fig 5: Variation of Effectiveness with Reynolds Number for Different cold water flow rates.

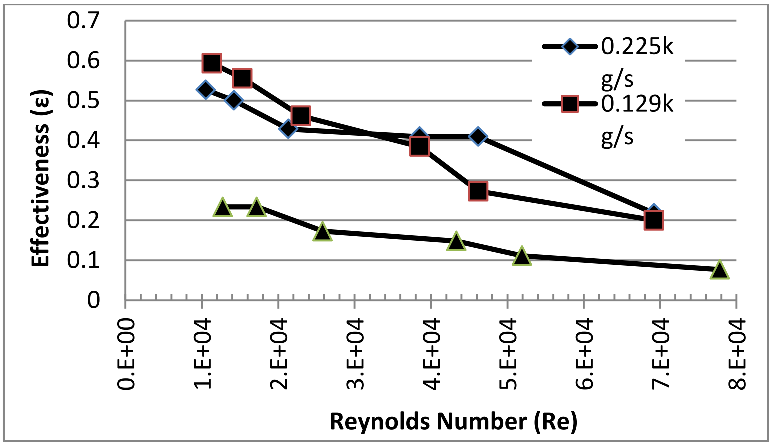



Figure 5 shows the plot of heat transfer effectiveness (ε) with respect to Reynolds Number for three different cold water flow. From this plot it is observed that, the effectiveness (ε) decreases with the increase of Reynolds Number (Re) and the value is maximum for the medium cold water flow. It is occurred because at higher Reynolds Number the hot and cold water get less time to exchange the heat between them. As a result effectiveness is lower for the heat exchanger.

Fig 6: Variation of Effectiveness with Hot Water Flow Rate for Different cold water flow rates.

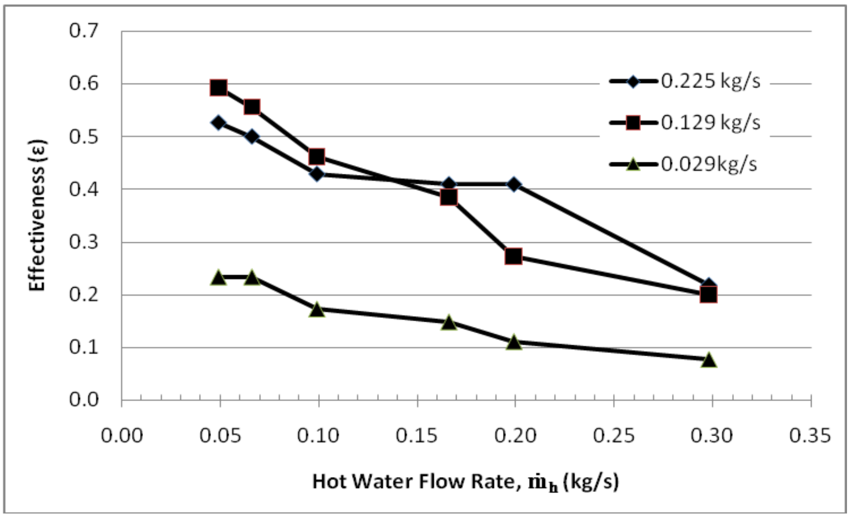



Figure 6 shows the variation of heat transfer effectiveness (ε) with respect to the hot water flow rate for three different cold water flow rate. From this graph we observed that, the effectiveness (ε) decrease with the increase of hot water flow and it is maximum for the medium cold water flow. It is occurred because at higher hot water flow rate the hot and cold water get less time to exchange the heat between them. As a result effectiveness is lower for the heat exchanger.

Figure 7 shows the plot of overall heat transfer co-efficient, U ($W/m^2K$) with respect to the hot water flow rate for three different cold water flow rate. From this plot it is observed that, the overall heat transfer co-efficient, U ($W/m^2K$) is maximum for the highest cold water flow rate (0.225kg/sec) and it is minimum for the lowest cold water flow rate (0.029kg/sec).

Fig 7: Variation of Effectiveness with Hot Water Flow Rate for Different cold water flow rates.

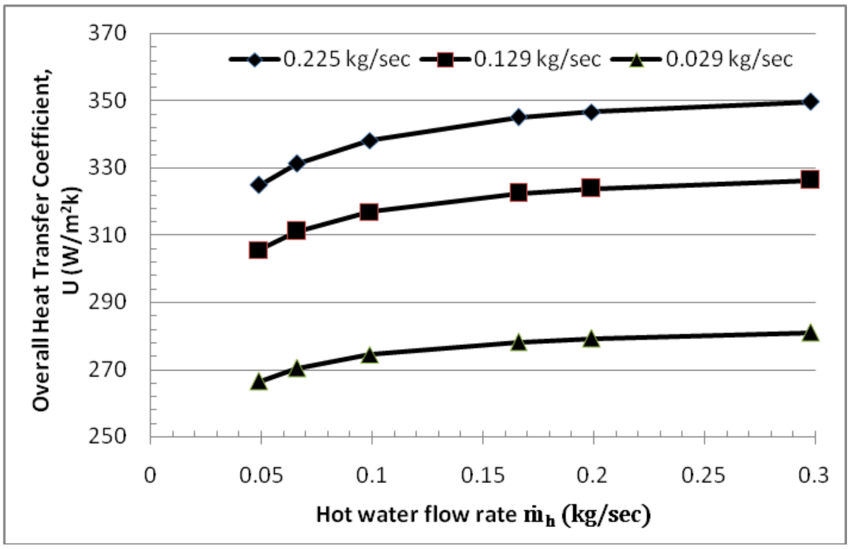



Fig 8: Variation of Heat Absorbed with Hot Water Flow Rate for Different cold water flow rates.

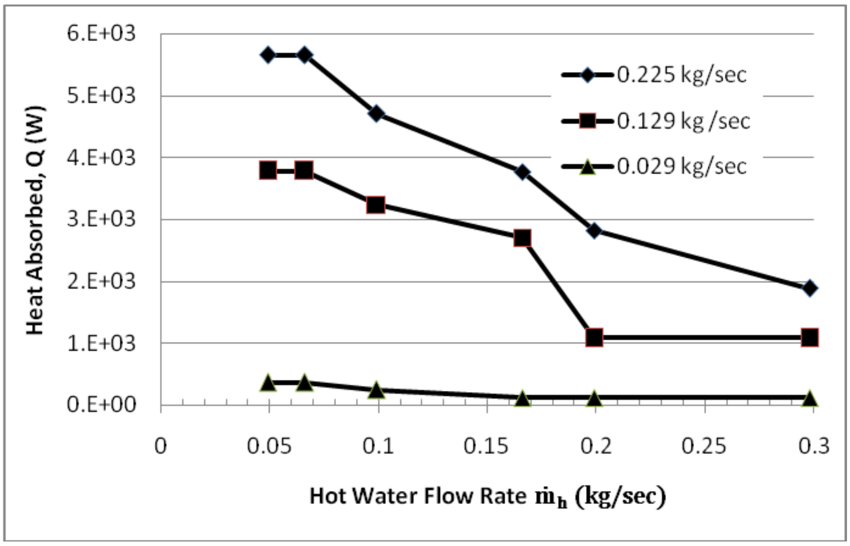
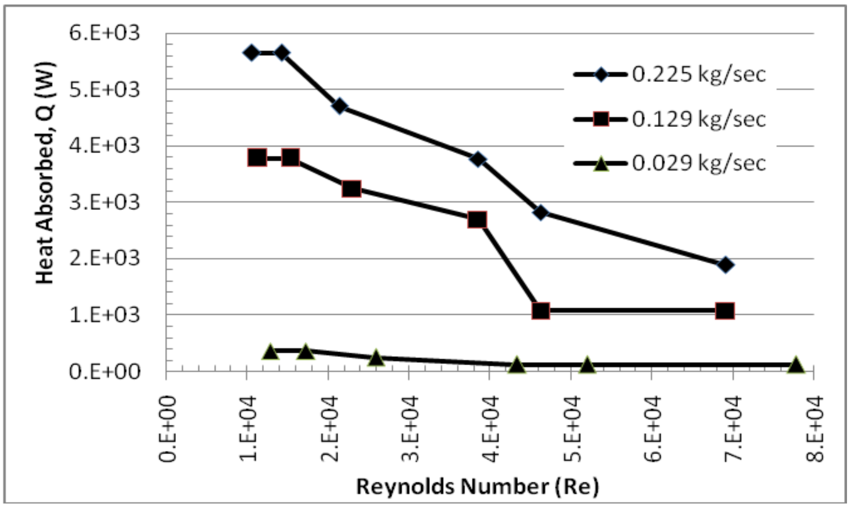



Figure 8 shows the scatter plot of Heat Absorbed by the cold water with respect to Hot water flow rate for three different cold water flow rate. From this graph it is observed that, heat absorbed by the cold water is decreased with the increased of hot water flow rate and heat absorbed is maximum for highest cold water flow rate and minimum for lowest cold water flow rate.

Figure 9 shows the plot of heat absorbed by the cold water with respect to Reynolds Number (Re) for three different cold water flow rate. From this plot it is observed that, heat absorbed by the cold water decreases with the increase of Reynolds Number (Re) and heat absorbed is maximum for higher cold water flow and minimum for lower cold water flow. It is because when Re is high the cold water gets less time to absorbed heat from hot water.

Fig 9: Variation of Heat Absorbed with Reynolds Number for Different cold water flow rates.




## 5. Conclusions

This paper presents the comprehensive study on heat transfer characteristics and the performance of a spiral coiled heat exchanger. The results have explained the better understanding of heat transfer co-efficient and effectiveness of a spiral coil heat exchanger, which is newly attraction for the researcher. The heat transfer rate depends directly on mass flow rate of hot and cold water in which maximum heat transfer rate is obtained at lower hot water flow. The heat transfer coefficient is increased with the increase of both Reynolds Number and hot water flow whereas the effectiveness is inversely proportional to the hot water flow and the optimum effectiveness is obtained when the temperature difference between hot and cold water is maximum. For limited opportunity to survey of previous work on spiral coil heat exchanger, the some degree of judgment was also restricted for the researchers. As this is a newly field of research this work will contribute mostly for further study.

## References

**C.E. Kalb, J.D. Seader.** Fully developed viscous-flowheat transfer in curved circular tubes with uniform wall temperature AIChE Journal, 1974: 20: 340-346.

**C.E. Kalb, J.D. Seader.** *Heat and mass transfer phenomena for viscous flow in curved circular tubes.* International Journal of Heat and Mass Transfer, 1972: 15: 801-817.

**G.F.C. Rogers, Y.R. Mayhew.** *Heat transfer and pressure loss in helically coiled tubes with turbulent flow.* International Journal of Heat and Mass Transfer, 1964: 7: 1207-1216.

**L.-S.Yao, S.A. Berger.** *Flow in heated curved pipes.* Journal of Fluid Mechanics, 1978: 88: 339-354.

**Naphon, P. and Wongwises, S.** Experimental and The theoretical Investigation of the Heat Transfer Characteristics and Performance of a Spiral-Coil Heat Exchanger under Dry-Surface Conditions,. Victoria Falls : s.n., 2nd International Conference on Heat Transfer , Fluid Mechanics,and Thermodynamics. June 2003

**Naphon, P. and Wongwises, S.** Investigation of the Performance of a Spiral-Coil Finned Tube Heat Exchanger under Dehumidifying Conditions. Journal of Engineering Physics and Thermophysics, 2003: 76: 71–79.

**R.A. Seban, E. F. McLaughlin.** Heat transfer in tubecoils with laminar and turbulent flow International Journal of Heat and Mass Transfer. International Journal of Heat and Mass Transfer, 1963: 6: 387-395.

**R.K. Jha, M.R. Rao.** *Heat transfer through coiled tubes in agitated vessels* International Journal of Heat and Mass Transfer, 1967: 10: 395-397.

**R.R. Berg, C.F. Bonilla.** *Trans N.Y. Acad. Sci.* 1950.

**Y. Mori, W. Nakayama.** *Study on forced convectiveheat transfer in curved pipes (1st report, laminarregion).* International Journal of Heat and Mass Transfer, 1965: 8: 67-82.

**Z. Zapryanov, C. Christov, E. Toshev.** *Fully developed laminar flow and heat transfer in curved tubes.* International Journal of Heat and Mass Transfer, 1980: 23: 873-880.