

Effect of flow rate and flow pattern of hot water on Overall Heat Transfer Coefficient for Double Pipe Heat Exchanger

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Received : 27 March, 2017

ABSTRACT

Double pipe multi pass heat exchanger with necessary accessories was designed, developed and evaluated for heat transfer performance. The performance of the heat exchanger for heating of chilled water was evaluated in terms of rate of heat transfer, terminal temperature, effectiveness and U-values, by varying the flow rate of hot water from 5, 10, 15, 20 and 25 lpm keeping flow rate of medium to be heated in inner pipe at 1.0 lpm. The values of maximum temperature rise were in first pass of the HE at all flow rates of hot water in both flow patterns. The actual U values of the heat exchanger ranged from 390.08 to 483.92 W/m² K and 386.21 to 437.90 W/m² K using hot water from solar thermal system in counter current and co-current respectively. It was observed that actual U value increased as the flow rate of service fluid increased up to 20 lpm in both the flow patterns. The actual U values and effectiveness of the heat exchanger were found higher in case of counter current flow pattern than that of co-current flow pattern at all flow rates studied. The regression equations obtained correlating flow rate of hot water and actual U values were $y = 305.1x^{0.1437}$ ($R^2=0.9146$) and $y=338.6 x^{0.0816}$ ($R^2 = 0.9913$) for counter and co-current flow pattern respectively.

Key word: Overall heat transfer coefficient, counter current, co-current, heat exchanger

Double pipe heat exchanger is commonly used for heating or cooling of liquid products in which hot and cold fluids flow through two concentric pipes in the same (co current) or in opposite (counter current) direction. It can be made from pair of single length of pipe or from a number of length arranged in a vertical row with section connected at alternate ends. Smaller diameter pipe is inserted within another pipe and welding of the outer jacket to the inner pipe is done or packed stuffing box is provided to permit different movement and the removal of inner pipe for cleaning or maintenance purpose. The design aspects of double pipe heat exchanger have been described (Arora and Domkundvar, 1990; Yadav, 1994). Double pipe section available commercially range from 5 to 10 cm pipe size outer pipe with inner pipe varying from 1.9 to 6.35 cm size. These are suitable for low flow rates and high temperature range. They can withstand high pressure because of small diameter

pipes and this configuration is also very suitable, when one or both fluids are at high pressure (Mehrabian *et al.*, 2002). Space requirement is normally high as compared to Plate Heat Exchanger. However, it can be ceiling or wall mounted or bulk headed through a wall, thereby saving floor space. Uniform flow distribution and cleaning in place is done very easily. Double-pipe heat exchangers can be arranged in various series and parallel arrangements to meet pressure drop and mean temperature difference requirements. The major use of double-pipes exchangers is for sensible heating or cooling of process fluids where small heat transfer areas (to 50 m²) are required (Devore, *et al.*, 1980).

MATERIALS AND METHODS

The system mainly consists of double pipe 4-pass (each of 2.0 m long) heat exchanger fabricated from AISI 304 grade stainless steel, supply and collecting S.S. tanks, hot water circulating centrifugal pumps and necessary valves and flow metering devices. The hot water was circulated in annular space in a helical

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movement to increase the heat transfer rate by inserting a helical coil on the inner pipe. The arrangement in the design of the heat exchanger (HE) is made in such a way that it is possible to supply hot water in co-current and counter current flow pattern. The microprocessor based data logger having RTD sensors was used to measure the temperature of cold and hot water at various points of the HE. The double pipe multi pass heat exchanger was fabricated as shown in Fig. 1. Argon gas welding was used for joining of pipes and pipe fittings and 140 grit finishing was carried out of all surfaces. All pipe fittings and valves were joined taking upmost care to prevent leakage of the fluids. The pass arrangement is made in such a way that the milk flows successively in each pass

from supply tank to collection tank. The service fluid inlet and outlet were connected in each pass at bottom and upper side of the pass respectively. Necessary valves were connected in service fluids pipes and milk pipes to adjust and control the flow rate. The temperature sensors of data logger were connected at all entry and exit points of milk and hot water in each pass. Rotameters were connected in inlet pipes of service fluid in all passes to measure the flow rates of service fluid. Separate pumps were used with necessary flow control valves in each pass for the supply of the service fluid in the respective pass. The technical specifications of the double pipe heat exchanger are given in Table 1.

Table 1 Technical specifications of double pipe heat exchanger

Part	Material	Inner Dia (mm)	Outer Dia (mm)	Thickness (mm)	Length for each pass (m)
Milk pipe (Inner) and service fluid supply pipe	SS304	21.0	25.0	2.0	2
Service fluid pipe (Outer)	SS304	59.3	62.5	1.6	2
Insulation	Glass wool	62.5	121.0	29.25	2
Cladding for Insulation	SS304	121.0	125.0	2.0	2
Milk tanks	SS304	400.0	404.0	2.0	0.5 m height
Helical coil	SS304	26.0	38.0	Coil rod dia.: 12.0 Pitch: 25.0	2
Service fluid connecting pipes	C-PVC	25.0	27.0	1.0	As per requirement

Operational parameters

To optimize the flow rate and flow pattern for maximum heat transfer, the heat exchanger was evaluated by varying rate of hot water flow as service fluid and chilled water as medium to be heated. The temperatures of chilled water to be supplied in the heat exchanger with Co-current (parallel) and Counter current flow pattern in all pass with 5, 10, 15, 20 and 25 lpm flow rates of service fluid (solar & PNG hot water) were evaluated.

Evaluation of heat transfer performance

In the present design of the double pipe multi-pass heat exchanger, heat transfer takes place from hot water as service fluid to chilled water. The rate of heat transfer in liquid to liquid heat transfer system under various

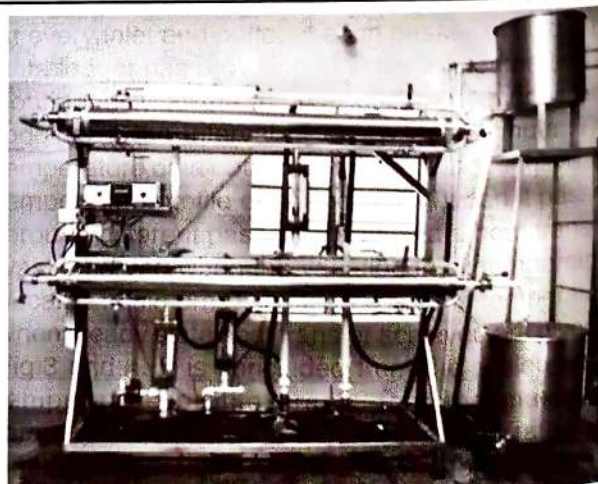


Fig. 1 Experimental four pass double pipe heat exchanger

operating conditions was calculated by using fundamental equations of heat transfer.

Heat transfer area

The heat transfer area in each pass is same and it is estimated by using the following equation.

$$A = \pi \times d_m \times L_p \times \text{No. of passes}$$

Where, d_m = Mean diameter of the milk pipe, m

L_p = Length of each pass, m

Mass flow rate

Volumetric flow rate of hot water measured by rotameter was converted in mass flow rate taking average density of 0.9748 g/cm^3 (974.8 kg.m^{-3}) in the temperature range of 70 to 85°C for theoretical U value calculation. For practical purposes, 1 lpm was taken as 1 kg/m for both milk and water.

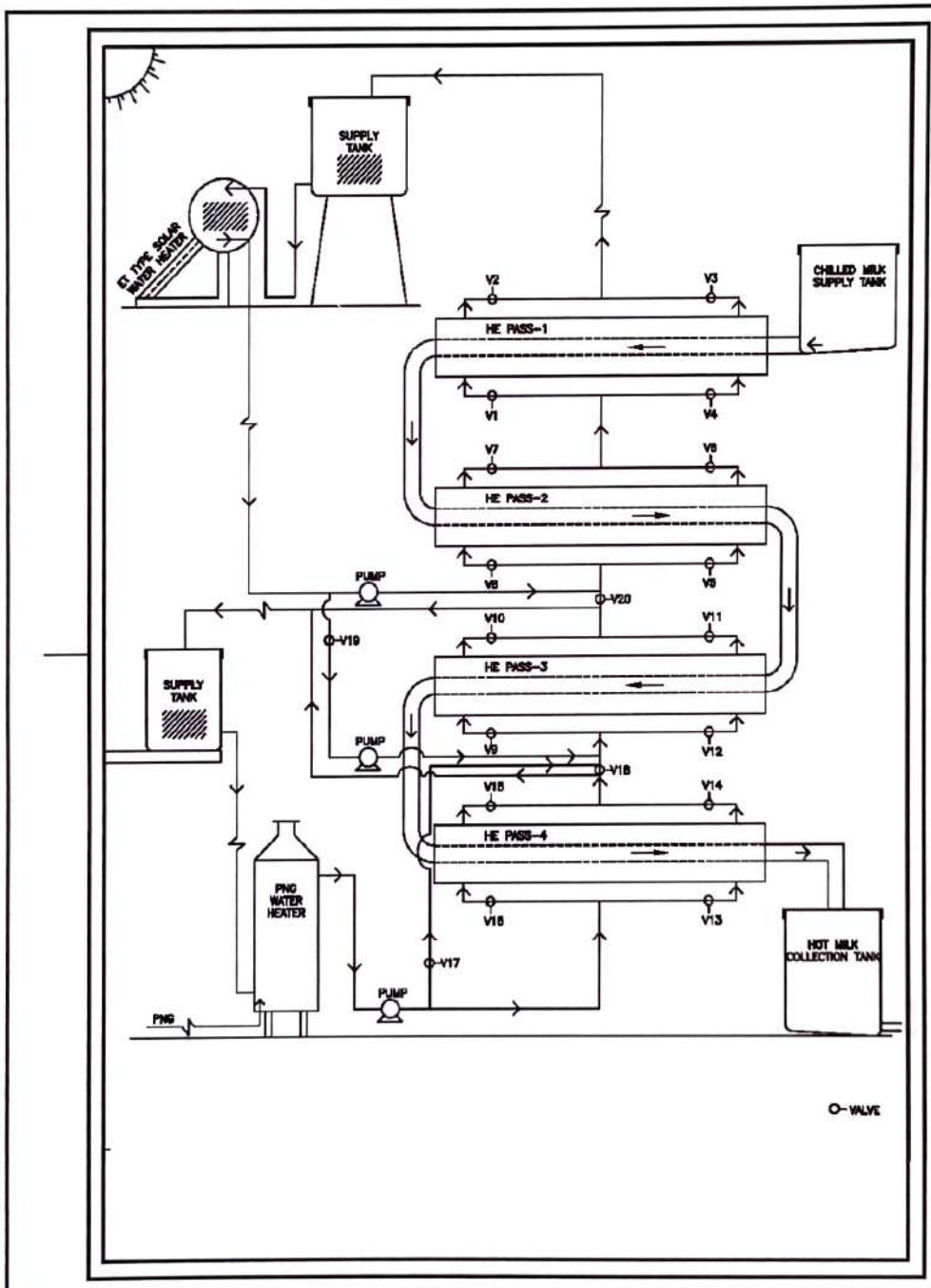


Fig.2 Schematic diagram of experimental heat exchanger

Logarithm mean temperature difference (LMTD)

Logarithm mean temperature difference (LMTD) concept in heat transfer is applied when the temperature difference between the hot and cold fluid is not constant throughout the whole length of the heat exchanger. In the present design of the heat exchanger, the temperature of heating medium drops while the temperature of medium to be heated increases. The LMTD was calculated by measuring inlet and outlet temperature of both the fluids in all the trials.

Co-current (parallel) flow arrangement

Each pass of the heat exchanger has two inlet and two outlet valves in the service fluid pipe. The co-current flow arrangement in each pass is done by keeping the entry and exit of milk and hot water at the same end of the heat exchanger i.e. both fluids move in the same direction. The direction of the milk flow or chilled water flow was in one direction in the order of first pass to last pass. Practically, in the heat exchanger, it is achieved by opening the even number valves and closing the odd number valves as designated in Fig.2 (valve 1 to valve 16). LMTD for co-current (Parallel) flow pattern was calculated by using the following equation.

$$\Delta\theta_m = \frac{\Delta T_i - \Delta T_o}{\ln \frac{\Delta T_i}{\Delta T_o}}$$

Where,

$\Delta\theta_m$ = LMTD, °C

ΔT_i = Temperature difference between hot water and milk at inlet, °C

ΔT_o = Temperature difference between hot water and milk at outlet, °C

Counter current flow arrangement

In the counter current flow, the milk enters in the heat exchanger, while the hot water exits. Thus, the milk and hot water (heating medium) flows in opposite direction. This type of flow was achieved by opening the odd number valves and closing the even number valves as designated in Fig.2 (valve 1 to valve 16). LMTD in counter flow arrangement was calculated using the following equation

$$\Delta\theta_m = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}}$$

Where,

$\Delta\theta_m$ = LMTD, °C

ΔT_1 = Temperature difference between hot water inlet and milk outlet, °C

ΔT_2 = Temperature difference between hot water outlet and milk inlet, °C

Heat transfer rate

This is the amount of heat transferred for the given mass flow rate of milk to raise the temperature to a required level. The amount of heat required to raise the temperature was calculated using the following equation.

$$Q_m = M_m \times C_{pm} \times \Delta t$$

Where,

Q_m = Heat load, kJh⁻¹

M_m = Mass flow rate of chilled water in the heat exchanger, kgh⁻¹

C_{pm} = Specific heat of water, kJ/kg K

Δt = Difference between chilled water outlet and inlet temperature of respective pass, °C

Actual overall heat transfer coefficient

The values of overall heat transfer co-efficient (U-values) were calculated using the following equation.

$$Q_m = Ua \times A \times \Delta\theta_m$$

Where,

Q_m = Heat gain by chilled water, kJh⁻¹ = $Q_m/3.6$ W

Ua = Actual overall heat transfer coefficient, W/m² K

A = Heat transfer area, m²

$\Delta\theta_m$ = LMTD of respective flow pattern, °C

RESULTS AND DISCUSSION**Effect of hot water flow rate on temperature profile of chilled water**

The temperature sensors of data logger were inserted at every inlet and outlet of each passes of fluid. The data logger has provision of scanning temperatures continuously at the interval of three seconds and logging at the interval of every three minute. The temperature data obtained from data logger gave the temperature profile of chilled water, when it passed through different passes. Steady state heat transfer was observed when the variation in all temperature became minimum. The mean values of temperature when steady state heat transfer achieved are given in Fig.3 and 4. It is concluded from the chilled water temperature profile graph, that the maximum temperature rise was in 1st pass in all flow rates and both flow patterns. The chilled water temperature at the end of first pass was observed in the range of

43.10°C to 54°C. Then the rise of temperature was decreased in successive passes. Higher temperature rise of chilled water in first pass is due to the higher temperature difference between hot water and chilled water.

Effect of hot water flow rate on actual U value

The effect of flow rate of hot water on actual U values (U_a) was calculated to obtain optimum value of hot

water flow rate. The actual U values of heat exchanger for two passes in which hot water from solar thermal system was used and in remaining two passes where in PNG fired hot water was used at different flow rates of hot water are shown in Fig. 5. This type of hot water circulation pattern was used in the month of January and February 2016 as the temperature of hot water from ETC was not adequate. The actual U values

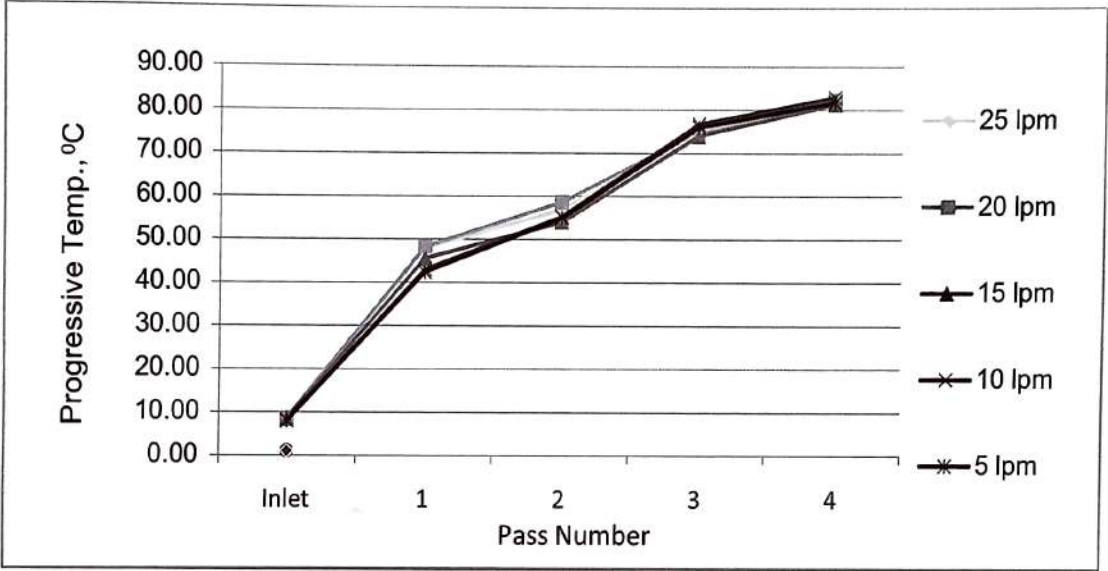


Fig. 3 Progressive terminal temperature of the chilled water (counter current)

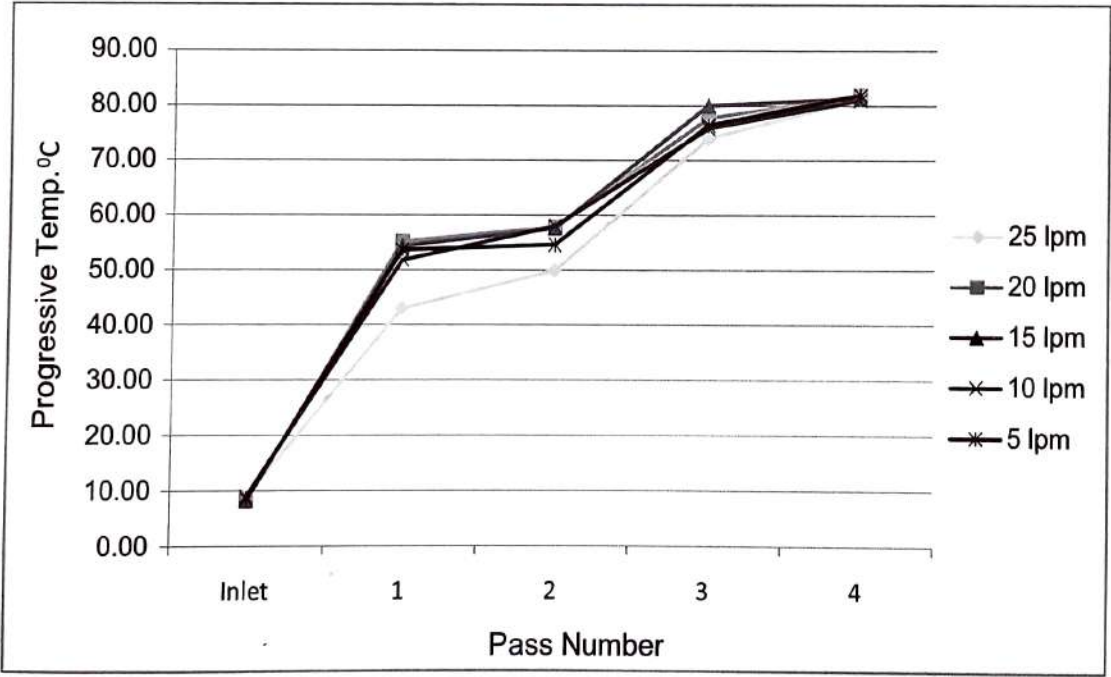


Fig. 4 Progressive terminal temperature of the chilled water(co current)

ranged from 390.08 to 483.92 W/m² K and 386.21 to 437.90 W/m² K for solar thermal heating in counter current and co current respectively. While, the actual U values ranged from 451.05 to 503.29 W/m² K and 429.36 to 479.10 W/m² K for PNG hot water heating in counter current and co current respectively. The

relationship between flow rate of hot water and the actual U values for solar heating and PNG hot water heating revealed that actual U value increased as the flow rate increased up to around 20 lpm. This was in line with observation reported by Desai and Borse (2013).

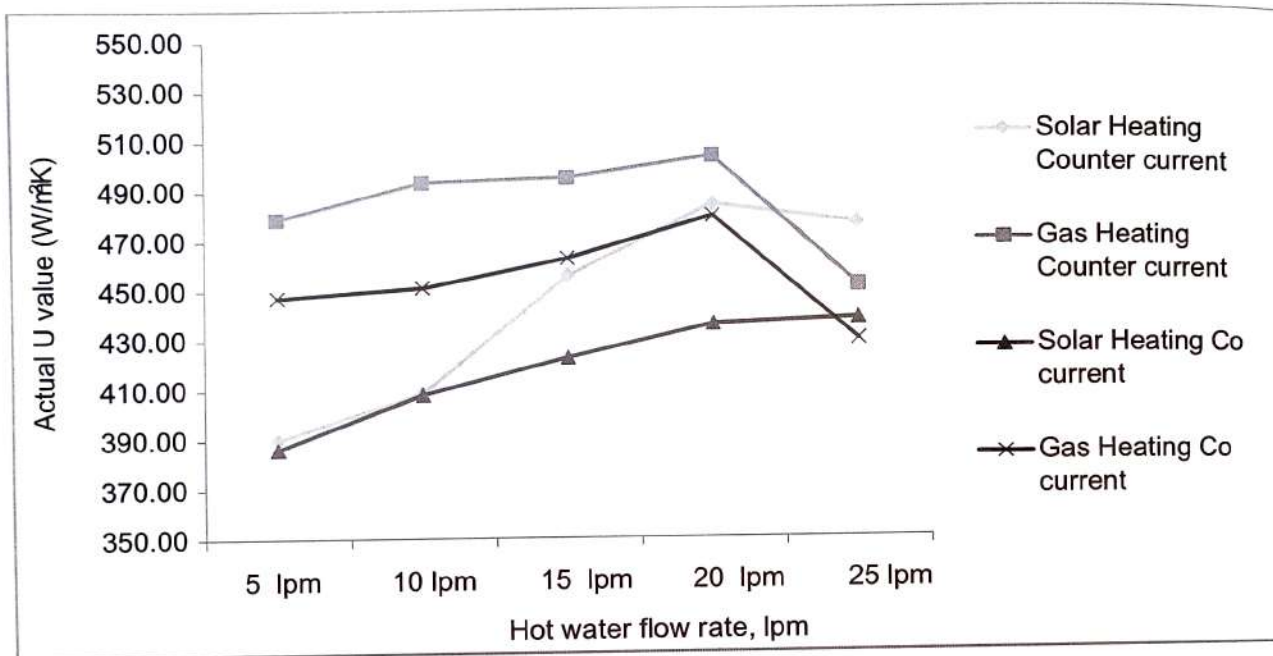


Fig.5 Relationship between hot water flow rate and actual U values for different flow pattern for chilled water heating

Effect of flow pattern on actual U values

The heat exchanger had provision of circulating the hot water in cocurrent and counter current pattern in each pass to evaluate the effect of flow pattern on actual U values. The effect of flow pattern on actual U values for different flow rate is graphically shown in Fig.5. The U values for solar heating as well as PNG hot water heating were found higher in case of counter current flow pattern than that of co current flow pattern at all flow rate studied. Similar observations were reported by Shrigireet *et al.* (2014). Therefore, it is desirable to adopt counter current flow pattern to get higher U values of the heat exchanger which helps in reducing the area requirement of the heat exchanger.

CONCLUSION

At steady state heat transfer conditions, the values of maximum temperature rise were in first pass of the heat exchanger at all flow rates of hot water as well as in both flow patterns. The actual U values of the

heat exchanger ranged from 390.08 to 483.92 W/m² K and 386.21 to 437.90 W/m² K for heating process using hot water from solar thermal system in counter current and co current respectively. While, the actual U values ranged from 451.05 to 503.29 W/m² K and 429.36 to 479.10 W/m² K for PNG fired hot water heating in counter current and co current respectively. It is noticed that actual U value increased as the flow rate of service fluid increased up to 20 lpm in both the flow patterns. The effect of flow rate of hot water on U values of heat exchanger was significant. Beyond 20 lpm flow rate of hot water, U-values of the heat exchanger decreased. The actual U values for solar heating as well as PNG hot water heating were found higher in case of counter current flow pattern than that of co current flow pattern at all flow rates studied. Therefore, it is desirable to adopt counter current flow pattern to get higher U values of the heat exchanger, which helps in reducing the area requirement of the heat exchanger. The equations obtained correlating flow rate of hot water and actual U values were

$y = 305.1x^{0.1437}$ ($R^2=0.9146$) and $y=338.6 x^{0.0816}$ ($R^2 = 0.9913$) for counter and co-current flow pattern respectively.

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