# STUDY OF DOUBLE PIPE HEAT EXCHANGER USING WASHER INSERTS TO IMPROVE HEAT TRANSFER RATE

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***Abstract— Researchers have done several researches on heat transfer enhancement in tube by inserting various tapes in last few years. There is need to improve the thermal performance of heat exchangers, thereby reducing size of heat exchanger and saving of material, effecting energy & cost led to development & use of heat transfer augmentation techniques. This research has been worked out to study the effect of washer inserts with various designs on heat transfer rate in double pipe heat exchanger. The experiment was conducted for hot water temperature up to 70°C using washers having 2, 3 and 4 slots. The experimental results indicate that the pipe with the washer inserts provides considerable improvement of the heat transfer rate over the without washer pipe.***

***Index Terms— Double pipe heat exchanger, washer, heat transfer rate***

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## 1. INTRODUCTION

A heat exchanger is a device to transfer heat from a hot fluid to cold fluid across an impermeable wall. Fundamental of heat exchanger principle is to facilitate an efficient heat flow from hot fluid to cold fluid. Some of the more common applications are found in heating, ventilation and air conditioning (HVAC) systems, radiators on internal combustion engines, boilers, condensers, and as pre-heaters or coolers in fluid systems. In most industrial systems, heat must be transferred from one place to another or from one fluid to another. Reasons for heat transfer include the following:

1. To heat a cooler fluid by means of a hotter fluid
2. To reduce the temperature of a hot fluid by means of a cooler fluid
3. To boil a liquid by means of a hotter fluid
4. To condense a gaseous fluid by means of a cooler fluid
5. To boil a liquid while condensing a hotter gaseous fluid.

This heat flow is a direct function of the temperature difference between the two fluids, the area where heat is transferred, and the conductive/convective properties of the fluid and the flow state. This relation was formulated by Newton and called Newton's law of cooling, which is given in Equation,

$$Q = hA\Delta T_{LMTD} \qquad \text{….. (Eq. 1)}$$

Where h is the heat transfer coefficient [W/m$^2$K], where fluid's conductive/convective properties and the flow state comes in the picture, A is the heat transfer area [m$^2$], and T is the temperature difference [°C].

## 2. METHODOLOGY

The purpose of the current work is to determine the heat transfer rate in double pipe heat exchanger fitted with washer as inserts having different slots. The parameters of interest are Reynolds number (Re) and Prandtl number (Pr) are given by,

$$R_{e=\frac{\rho vD}{\mu}} \qquad \text{….. (Eq. 2)}$$

Where, $\rho$= water density = 1000 (Kg/m$^3$),
D= ID of outer pipe (mm),
$\mu$= viscosity of water (Kg/m-s),
$v$= velocity of water (m/s).

Velocity can be obtain from discharge equation,

$$Q = A_c \times v \qquad \text{….. (Eq. 3)}$$

Where, $A_c$ = cold water flow area

Prandtl number can be given by,

$$P_{r=\frac{c_p\mu}{K}} \qquad \text{….. (Eq. 4)}$$

From above Reynolds number we can find out whether the flow is laminar or turbulent.

i) If Reynolds number below 2000, flow will be laminar.
ii) If Reynolds number lies between 2000-4000, flow will be transitional. For this Nusselt can be given by Gnielinski correlation,

$$N_u = \frac{\left(\frac{f}{8}\right)(R_e - 1000)P_r}{1 + 12.7\left(\frac{f}{8}\right)^{0.5}(P_r{}^{0.667} - 1)} \quad \text{..... (Eq. 5)}$$

iii) If Reynolds number greater than 4000, flow will be turbulent. For this Nusselt number can be given by,

$$N_u = 0.023 R_e{}^{0.8} P_r{}^{0.4} \quad \text{..... (Eq. 6)}$$

Also , $N_u = \frac{hD}{k}$ .....(Eq. 7)

From this $h$= convective heat transfer coeffcient can be obtanied. Now, Heat transfer coeffcient can be obtained from equation,

$$Q = hA_w \Delta T_{LMTD} \quad \text{..... (Eq. 8)}$$

Where, $A_w$= washer surface area

Here, $\Delta T_{LMTD} = \frac{\Delta T_1 - \Delta T_2}{\ln(\frac{\Delta T_1}{\Delta T_2})}$ ..... (Eq. 9)

From this equation heat transfer rate for all four arrangements can be obtained and compared to find out optimum heat transfer rate for double pipe heat exchanger using washer as inserts.

## 3. EXPERIMENTATION AND EVALUATION

### Experimental setup:

- In this double pipe heat exchanger, Inner pipe is passing through outer pipe.
- On inner pipe, washers (30 nos.) are spot welded at an inclination of 45° at 5 cm interval over the length of 1.5 m.
- There are three such arrangement containing different shape of washers.
- Reservoir is fitted with heater. This heater is connected to thermostatic valve which is used to control the temperature of water.

**Fig. 3.1: Actual setup**

**Table no. 3.1: specifications of components**

| ***SR.NO.*** | ***COMPONENT*** | ***SPECIFICATIONS*** |
|---|---|---|
| 1 | OUTER PIPE | ID-32mm, length-1.5m,<br>Thickness-3mm, (Mild steel) |
| 2 | INNER PIPE | OD-12mm,length-1.5m, Thickness-1mm, (Mild steel) |
| 3 | WASHERWITH SLOTS | OD-27mm,ID-13.5mm<br>(Mild Steel)<br>SLOT DIMENSIONS-<br>DIAGRAMME<br>a-4mm<br>b-10mm |
| 4 | THERMOSTATE | 30-110 °C |
| 5 | HEATER | HEATING CAPACITY UPTO 90°C |
| 6 | TEMPRATURE SENSOR | Digital Senor, -30 to 110 °C |
| 7 | RESERVOIR | 35 litre |

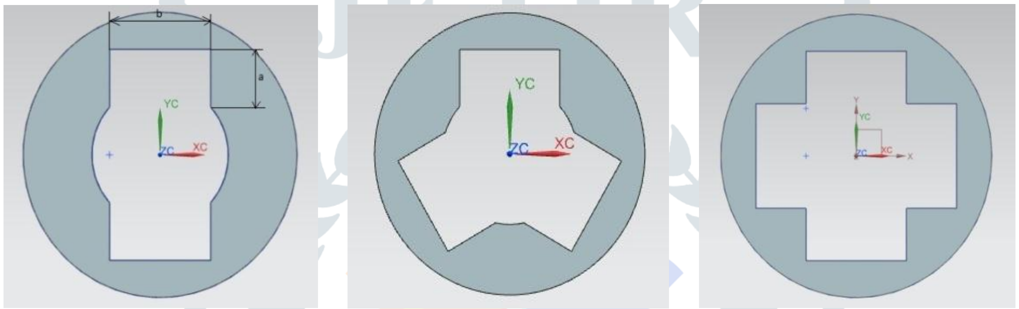


**Fig. 3.2: 2-Slot washer, 3-slot washer and 4-slot washer**
**(Dimension a=4mm and b=10mm)**

**Experimental procedure:**

- Water is filled in reservoir and then heater switched on.
- Temperature of reservoir water increased up to 50°C and controlled by thermostatic valve.
- Pump priming is to be done.
- Hot water is circulated through inner pipe by water pump in counter and parallel flow direction.
- Tap water (at ambient temperature) is circulated through outer pipe.
- Using four temp. sensors temperature of hot and cold water inlet and outlet are to be measured.
- These readings taken over 2 min. span with 30 sec interval.
- Same procedure is repeated for all four arrangements and temperatures obtain for that arrangement.
- Time required for filling the container of 1.25 litre capacity is measured by using stopwatch. By using this, discharge of the flow can be calculated. It will be same for all four.

**Observation:**

**Common parameters:**

- Discharge of cold water
- Time required for 1.25 litre=25 sec
- Time required for 1 litre= $\frac{(25\times1)}{1.25}$= 20 sec
- $Q = \frac{(1\times10^{-3})}{20} = 5\times10^{-5}\,m^3/sec$
- $x = a\times b = 10\times4 = 40mm$ = area of slot
- $D$ = ID of outer pipe = 32mm
- $d_w$ = OD of washer=27mm
- $d$ = OD of inner pipe=12mm

- $A_c$ = cold water flow area
- $A_c = \frac{\pi}{4}\left(D^2 - {d_w}^2\right) + (x \times no.of\ slots)$
- $A_w$ =washer area , $A_w = \frac{\pi}{4}\left({d_w}^2 - d^2\right) - (x \times no.of\ slots)$
- $\mu$ = dynamic viscosity of water, (Pa-sec)
- $\rho$ = density of water = 1000 kg/m$^3$
- $k$ = thermal conductivity water, (W/m-k)
- $f$ = friction factor = 0.008 (from Darcy-Weisbatch equation)
- $P_r$ = Prandtl number

**Observation for parallel flow:**

**Black Pipe (without washer, no slot):**

- Temperature readings:

**Table no. 3.2: Temperature readings for without washer**

| *Sr.no* | *Time (sec)* | *Cold water inlet temp. $T_{ci}$ °C* | *Cold water Outlet temp. $T_{co}$°C* | *Hot water inlet temp. $T_{hi}$°C* | *Hot water outlet temp. $T_{ho}$°C* |
|---|---|---|---|---|---|
| 1 | 30 | 30.3 | 34.2 | 51.4 | 48.8 |
| 2 | 60 | 30.2 | 33.1 | 51.1 | 47.8 |
| 3 | 90 | 30.2 | 34.5 | 50.6 | 48.3 |
| 4 | 120 | 30.4 | 33.9 | 50.1 | 47.3 |
| Average | ----- | 30.2 | 33.92 | 50.8 | 48.05 |

**Blue Pipe (with washer, two slots):**

- Temperature readings:

**Table no. 3.3: Temperature readings for 2-slot washer**

| *Sr.no* | *Time (sec)* | *Cold water inlet temp. $T_{ci}$ °C* | *Cold water Outlet temp. $T_{co}$°C* | *Hot water inlet temp. $T_{hi}$°C* | *Hot water outlet temp. $T_{ho}$°C* |
|---|---|---|---|---|---|
| 1 | 30 | 30.00 | 34.6 | 49.3 | 43.5 |
| 2 | 60 | 29.9 | 34.7 | 49.2 | 43.2 |
| 3 | 90 | 29.9 | 34.5 | 48.9 | 43.1 |
| 4 | 120 | 29.9 | 34.9 | 48.5 | 43.2 |
| Average | ----- | 29.92 | 34.675 | 48.975 | 43.25 |

**Brown Pipe (with washer, three slots):**

**Table no. 3.4: Temperature readings for 3-slot washer**

| *Sr.no* | *Time (sec)* | *Cold water inlet temp. $T_{ci}$ °C* | *Cold water Outlet temp. $T_{co}$°C* | *Hot water inlet temp. $T_{hi}$°C* | *Hot water outlet temp. $T_{ho}$°C* |
|---|---|---|---|---|---|
| 1 | 30 | 30.1 | 34.5 | 50.0 | 43.3 |
| 2 | 60 | 29.9 | 34.9 | 49.5 | 43.2 |
| 3 | 90 | 29.8 | 34.1 | 49.0 | 43.3 |
| 4 | 120 | 29.8 | 34.3 | 47.8 | 42.2 |
| Average | ----- | 29.9 | 34.45 | 49.075 | 43.0 |

**Green Pipe (with washer, four slots):**

**Table no. 3.5: Temperature readings for 4-slot washer**

| ***Sr.no*** | ***Time (sec)*** | ***Cold water inlet temp. $T_{ci}$ °C*** | ***Cold water Outlet temp. $T_{co}$ °C*** | ***Hot water inlet temp. $T_{hi}$ °C*** | ***Hot water outlet temp. $T_{ho}$ °C*** |
|---|---|---|---|---|---|
| 1 | 30 | 29.9 | 33.9 | 48.5 | 43.2 |
| 2 | 60 | 29.9 | 33.8 | 48.0 | 42.8 |
| 3 | 90 | 29.9 | 33.9 | 47.3 | 42.7 |
| 4 | 120 | 29.9 | 33.7 | 46.9 | 42.3 |
| Average | ----- | 29.9 | 33.875 | 47.67 | 42.77 |

**Observation for counter flow:**

**Black Pipe (without washer, no slot):**

- Temperature readings

**Table no. 3.6: Temperature readings for without washer**

| ***Sr.no*** | ***Time (sec)*** | ***Cold water inlet temp. $T_{ci}$ °C*** | ***Cold water Outlet temp. $T_{co}$ °C*** | ***Hot water inlet temp. $T_{hi}$ °C*** | ***Hot water outlet temp. $T_{ho}$ °C*** |
|---|---|---|---|---|---|
| 1 | 30 | 30.9 | 33.3 | 51.2 | 48.0 |
| 2 | 60 | 30.7 | 33.3 | 51.1 | 47.8 |
| 3 | 90 | 30.5 | 33.4 | 51.1 | 47.7 |
| 4 | 120 | 30.3 | 33.1 | 51.0 | 47.6 |
| Average | ----- | 30.6 | 33.275 | 51.1 | 47.8 |

**Blue Pipe (with washer, two slots):**

**Table no. 3.7: Temperature readings for 2-slot washer**

| ***Sr.no*** | ***Time (sec)*** | ***Cold water inlet temp. $T_{ci}$ °C*** | ***Cold water Outlet temp. $T_{co}$ °C*** | ***Hot water inlet temp. $T_{hi}$ °C*** | ***Hot water outlet temp. $T_{ho}$ °C*** |
|---|---|---|---|---|---|
| 1 | 30 | 32.0 | 34.8 | 49.8 | 45.2 |
| 2 | 60 | 31.7 | 34.5 | 49.6 | 45.6 |
| 3 | 90 | 31.3 | 35.5 | 49.1 | 45.2 |
| 4 | 120 | 31.2 | 35.2 | 48.9 | 44.8 |
| Average | ----- | 31.55 | 35 | 49.35 | 45.2 |

**Brown Pipe (with washer, three slots):**

**Table no. 3.8: Temperature readings for 3-slot washer**

| Sr.no | Time (sec) | Cold water inlet temp. $T_{ci}$ °C | Cold water Outlet temp. $T_{co}$ °C | Hot water inlet temp. $T_{hi}$ °C | Hot water outlet temp. $T_{ho}$ °C |
|---|---|---|---|---|---|
| 1 | 30 | 30.4 | 34.2 | 52.7 | 44.3 |
| 2 | 60 | 30.7 | 35.2 | 52.4 | 44.1 |
| 3 | 90 | 31.1 | 35.8 | 52.2 | 45.0 |
| 4 | 120 | 31.5 | 36.2 | 51.9 | 44.5 |
| Average | ----- | 31.025 | 35.35 | 52.3 | 44.475 |

**Green Pipe (with washer, four slots):**

Table no. 3.9: Temperature readings for 4-slot washer

| *Sr.no* | *Time (sec)* | *Cold water inlet temp. $T_{ci}$ °C* | *Cold water Outlet temp. $T_{co}$°C* | *Hot water inlet temp. $T_{hi}$°C* | *Hot water outlet temp. $T_{ho}$°C* |
|---|---|---|---|---|---|
| 1 | 30 | 30.8 | 33.9 | 50.0 | 43.0 |
| 2 | 60 | 30.0 | 35.4 | 51.0 | 44.0 |
| 3 | 90 | 30.2 | 36.9 | 51.7 | 45.7 |
| 4 | 120 | 30.2 | 36.8 | 51.6 | 45.8 |
| Average | ----- | 30.3 | 35.75 | 51.0 | 44.45 |

## 4. RESULTS AND DISCUSSION:

An experimental investigation was carried out mainly for measuring heat transfer rate using various Conditions as mentioned above. Besides that, Reynolds number, prandtl number, Nusselt number, LMTD and convective heat transfer coefficient are required to calculate at that particular temperature conditions. Calculations are done by considering the average of inlet and outlet temperature of respective pipes. The results can be summarized as,

### 4.1 Parallel flow arrangement:

Table no. 4.1: Obtained parameters for Parallel flow

| *No. of slot* | $R_e$ | $P_r$ | $N_u$ | *h (W/m$^2$°C)* | $\Delta T_{LMTD}$ *(°C)* | *Q (W)* |
|---|---|---|---|---|---|---|
| 0 (Black) | 3032 | 4.978 | 5.7144 | 110.93 | 17.16 | 1.3156 |
| 2(Blue) | 6752 | 5.028 | 50.88 | 985.8 | 13.1249 | 4.909 |
| 3(Brown) | 5955 | 4.8787 | 45.39 | 883.0 | 13.155 | 3.943 |
| 4(Green) | 5331 | 4.878 | 41.54 | 800.16 | 12.824 | 3.06 |

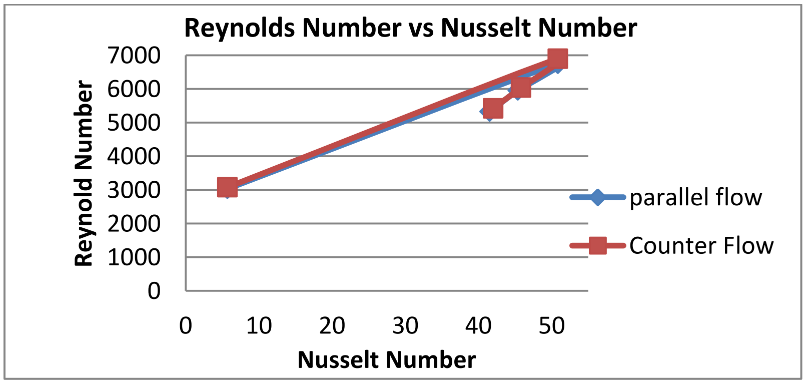
### 4.2 Counter flow arrangement:

Table no. 4.2: Obtained parameters for counter flow

| *No. of slot* | $R_e$ | $P_r$ | $N_u$ | *h (W/m$^2$°C)* | $\Delta T_{LMTD}$ *(°C)* | *Q (W)* |
|---|---|---|---|---|---|---|
| 0 (Black) | 3078 | 5.04 | 5.72 | 111.012 | 17.51 | 1.343 |
| 2(Blue) | 6898 | 4.835 | 50.90 | 986.0 | 14.0 | 5.248 |
| 3(Brown) | 6045 | 4.855 | 45.848 | 892.775 | 13.45 | 4.585 |
| 4(Green) | 5427 | 4.85 | 42.041 | 805.216 | 14.6931 | 3.5438 |

After completion of experimentation all the reading are noted down and comparative graphs can be plotted to find optimum arrangement.

### 4.3 Reynolds Number vs. Nusselt Number for all four arrangements:

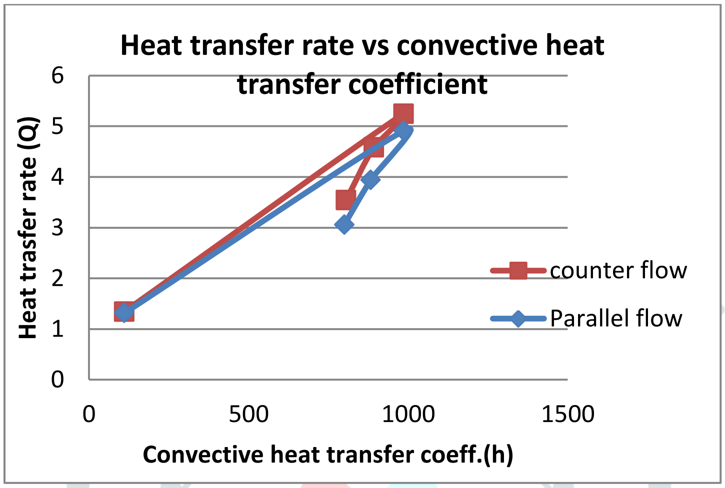


Graph no. 4.3: Re. no. vs. Nu. no. for both parallel flow and counter flow arrangement

- From the above graph conclusion can be drawn that; the washer inserted arrangement yields considerable heat transfer compared with the without washer arrangement.
- The Nu shows the uptrend with raising the Re. The Nu of the washer insert is much higher than that of the without washer pipe.
- From graph it can be concluded that Re and Nu is more for counter flow than the parallel flow arrangement for two slotted washer.

| *Type of heat exchanger* | *Reynolds number* | *Nusselt number* |
|---|---|---|
| 1)Parallel flow | 6752 | 50.88 |
| 2)counter flow | 6898 | 50.87 |

### 4.4 Heat transfer rate vs. convective heat transfer coefficient for all four arrangements:

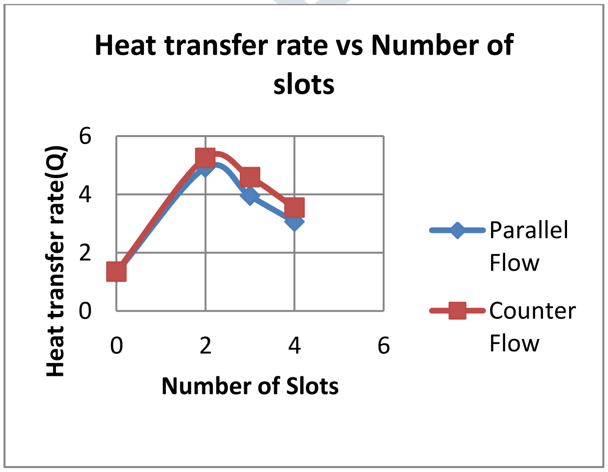


**Graph no. 4.4: Heat transfer rate vs. convective heat transfer coefficient**

- As the convective heat transfer coefficient (h) is directly proportional to area; it implies that there is improvement in 'h' with increase in area.
- Hence from above graph it can be concluded that there is increase in heat transfer rate with respect to the convective heat transfer coefficient
- Further it can be estimated that, both heat transfer coefficient and heat transfer rate is slightly more for counter flow heat exchanger compared parallel flow heat exchanger for two slot washer. And their values are as follow,

| *Type of heat exchanger* | *Heat transfer rate (W)* | *Convective heat transfer coefficient (W/m$^2$-℃)* |
|---|---|---|
| 1)Parallel flow | 4.909 | 985.8 |
| 2)counter flow | 5.248 | 986 |

### 4.5 Heat transfer rate vs. number of slots for all four arrangements:



**Graph no.4.5: Heat transfer rate vs. No. of slots**

- Heat transfer rate is depends on convective heat transfer coefficient, washer's area and logarithmic mean temperature difference.
- As per observation from above graph, it can be concluded that heat transfer rate is maximum for both parallel flow and counter flow heat exchanger; having the washer of two slots.
- This happens, because the surface area for two slot washer is maximum as compared to other washers.
- As the LMTD of counter flow heat exchanger is always more than parallel flow heat exchanger; our graph shows optimum heat transfer rate for counter flow heat exchanger having two slot washer which is 5.248 W.

## 5 CONCLUSION AND FUTURE SCOPE

### 5.1 Conclusions:

This experiment was conducted for double pipe heat exchanger using 2-slot, 3-slot, 4-slot washer and without washer arrangements. From the above experiment it is observed that heat transfer enhancement technique caused an increase in heat transfer rate with increase in Reynolds number and Nusselt number. Heat transfer rate, Reynolds number and Nusselt number are calculated for each arrangement with counter and parallel flow. From that it can be observed, Nusselt number increases with increasing Reynolds number and they are maximum for counter flow 2-slot arrangement.

Heat transfer rate for three arrangement (with washer) are compared with without washer arrangement from that it can be concluded that in parallel flow arrangement it will be maximum for 2-slot washer arrangement. This is increased by 265% than without washer arrangement. In counter flow arrangement heat transfer rate is maximum for 2-slot washer arrangement which is increased by 290% than without washer arrangement.

If we compared the maximum heat transfer rate of parallel flow arrangement with the maximum heat transfer rate of counter flow arrangement, it can be observed that, it is higher for counter flow which is 6.90% more.

### 5.2 Future scope:

- In this experiment washers having rectangular slots are used. But slots having triangular, trapezoidal shapes can also be used in order to check how effectiveness is going to change.
- Perforated washers can also be used and heat absorbing material such as wet cloth can be used.
- Instead of water more heat conducting solution such as brine solution and salt water solution can be used to increase heat transfer rate.
- Alternative materials like Copper having more thermal conductivity can be used instead of Mild Steel.

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