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# Effect on Efficiency of Two-phase Flow Distribution in a Parallel Flow Heat Exchanger with Reverse Upward Flow

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***ABSTRACT:*** *The air and water flow distribution are experimentally studied for a round header – flat tube geometry simulating a parallel flow heat exchanger. The number of branch flat tube is 25. The effects of tube outlet direction, tube protrusion depth and quality are investigated. The flow at the header inlet is identified as annular. For the upward flow configuration, the water flow distribution is significantly affected by the tube protrusion depth. For flush-mounted configuration, most of the water flows through frontal part of the header. As the protrusion depth increases, minimum water is forced to the rear part of the header. Possible explanations are provided based on the flow visualization results.*

***KEYWORDS****: Flow distribution; Parallel flow heat exchanger; Air and water flow measurement; Reverse upward flow; Two-phase; Experimental approach.*

## I. INTRODUCTION

Two-phase flow distribution of Air and water was experimentally investigated in a parallel flow heat exchanger comprised of two horizontal headers and twenty five vertical channels. Most of the flow in the header inlet was identified as stratified flow. The effect of tube protrusion depth was also investigated. It was observed that, For upward flow, significant portion of liquid was forced to rear part of the header. The effect of quality and protrusion depth on the liquid distribution was also investigated.

Aluminum based heat exchangers consist of flat tubes of 5 mm hydraulic diameter. For the vertical header configuration, most of the liquid flowed through the frontal part of the header, and the effect of the inlet pipe direction was not significant. For a horizontal header, the flow distribution was highly dependent on the inlet pipe direction, and better distribution was obtained for the parallel configuration.

## II. EXPERIMENTAL SETUP

The Experimental Setup used for this study is shown in Figure 2.1. The hydraulic diameter of the present flat tube is 5 mm, and the flow cross sectional area is 25 $mm^2$. The test section consists of the 16 mm internal Diameter round upper and lower headers, which are 90 cm apart, and 25 flat tubes inserted at 3 mm pitches. This configuration was chosen to simulate the actual parallel flow heat exchanger. Twenty five flat holes were machined at the bottom for insertion of flat tubes. An aluminum plate, which had matching flat holes, was installed underneath the header as illustrated in Fig. 2.1Flat tubes were secured, and the protrusion depth was adjusted using O-rings between the header and the aluminum plate. Transition blocks were installed in the test section to connect the flat tubes and the 5.0 mm ID round tubes. The round tubes served as flow measurement lines. At the inlet of the header, 1.0 m long aluminum tube having the same internal diameter as the header was attached. The tube served as a flow development section.

Figure 2.1: Experimental setup

Figure 2.2: Water flow meter

Figure 2.3: Flow distribution system

Figure 2.4: Electrical control panel

Table 2.1: Components used in Setup

| Sr.No. | Name of component | Specification |
|---|---|---|
| 1 | Air blower | 15 amp.220 v ac |
| 2 | Water heater | 1000 w |
| 3 | Water pump | 65w |
| 4 | Water flow meter | ½ inch Diameter |
| 5 | Air flow meter | ½ inch Diameter |
| 6 | Air and water Separator | 4 inch Diameter |
| 7 | Flexible pipe | 15 mm Diameter |
| 8 | Thirteen valve | ½ inch Diameter |
| 9 | Vertical square aluminum pipe | Thickness 1.5mm |
| 10 | Vertical circular aluminum pipe | Thickness 1.5mm |
| 11 | Inlet tank | 40Liters |
| 12 | Outlet tank | 25 Liters |
| 13 | Electrical control panel | 15 amp. |

## III. METHODOLOGY

***III.1. UPWARD FLOW:*** An upward flow was observed at the header inlet. The liquid motion in the lower header was unstable and intermittent. Liquid was supplied into the channels by electrical water pump. The Air and water distribution is generally reverse to the liquid distribution. The flow visualization results that the liquid is forced to frontal part of the header as the quality increases. The liquid is forced to frontal part of the header as the quality decreases, yielding better liquid distribution. The explanation at lower quality, more liquid is supplied into the header, supplying more liquid to frontal part may be provided. The annular flow using air and water revealed that more water was forced to frontal part of the header at a higher quality. The reason was attributed to the increased water film thickness at the upper part of the header at increased quality. The part of the incoming water impinges at the first protrusion, separates at the top, reattaches at the bottom of the header due to the action of gravity. The separated water, along with the water from lower part of the header, is forced to the rear end of the header, and starts to fill in the tubes from backward.

## IV. RESULT AND DISCUSSION

***IV.1. Reverse upward flow:*** In reverse upward flow, the air and water are flow in the direction of upward and after that air and water are achieve in separator. Temperature at inlet is 50 °C., Temperature at outlet is 45.8 °C.
Time taken during reading = 10 sec.
Temperature at inlet =50 °C
Temperature at outlet =45.8 °C
H= witch insert in pipe
D= 16mm diameter of pipe

Table 4.1.1: Air flow in different h/d and Reverse upward flow

| Sr. No. | Channel no. | Air flow ($m^3$ /sec) At h/d = 0/16 =0.0 | Air flow ($m^3$ /sec) At h/d = 4/16 =0.25 | Air flow ($m^3$ /sec) At h/d =8/16 =0.5 |
|---|---|---|---|---|
| 1 | 1-5 | 0.5 | 1.5 | 1.5 |
| 2 | 6-10 | 1.2 | 1.4 | 1.2 |
| 3 | 11-15 | 1.3 | 1.2 | 1.0 |
| 4 | 16-20 | 0.5 | 0.5 | 1.0 |
| 5 | 21-25 | 0.2 | 0 | 0.0 |

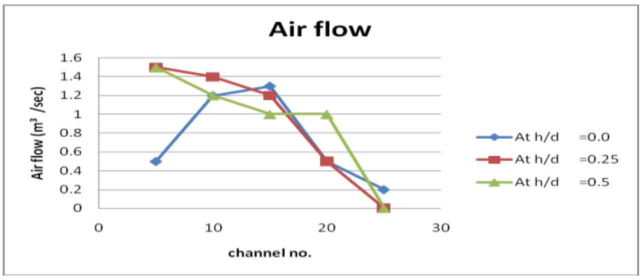


Fig. 4.1.1: Air flow in different h/d and Reverse upward flow

Table 4.1.2 Water flow in different h/d and Reverse upward flow

| Sr. No. | Channel no. | Water flow (L/ sec) At h/d = 0/16 =0.0 | Water flow (L/ sec) At h/d = 4/16 =0.25 | Water flow (L/ sec) At h/d = 8/16 =0.5 |
|---|---|---|---|---|
| 1 | 1-5 | 2.0 | 0.5 | 0.4 |
| 2 | 6-10 | 0.5 | 0.4 | 0.5 |
| 3 | 11-15 | 0.4 | 0.4 | 0.5 |
| 4 | 16-20 | 1.0 | 0.5 | 1.4 |
| 5 | 21-25 | 2.2 | 1.5 | 2.3 |

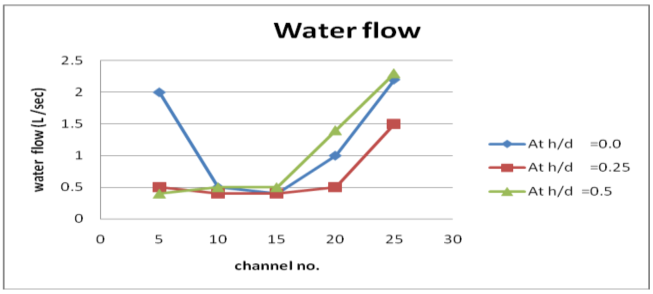


Figure 4.1.2: Water flow in different h/d and Reverse upward flow

## Efficiency:

Temperature at inlet =50 °C
Temperature at outlet =45.8 °C
ή= (Temperature at inlet - Temperature at outlet) / Temperature at inlet
= (50-45.8)/50 =08.40%

***IV.2. REVERSE UPWARD FLOW:*** In reverse upward flow, the air and water are flow in the direction of upward and after that air and water are achieve in separator. Temperature at inlet is 60 °C., Temperature at outlet is 53.6 °C.
Time taken during reading = 10 sec.
Temperature at inlet =60 °C.
Temperature at outlet =53.6 °C
H= witch insert in pipe
D= 16 mm diameter of pipe

Table 4.2.1: Air flow in different h/d and Reverse upward flow

| Sr. No. | Channel no. | Air flow ($m^3$ /sec) At h/d = 0/16 =0.0 | Air flow ($m^3$ /sec) At h/d = 4/16 =0.25 | Air flow ($m^3$ /sec) At h/d =8/16 =0.5 |
|---|---|---|---|---|
| 1 | 1-5 | 0.6 | 1.6 | 1.5 |
| 2 | 6-10 | 1.3 | 1.5 | 1.3 |
| 3 | 11-15 | 1.4 | 1.3 | 1.2 |
| 4 | 16-20 | 0.7 | 0.4 | 1.1 |
| 5 | 21-25 | 0.2 | 0.3 | 0.1 |

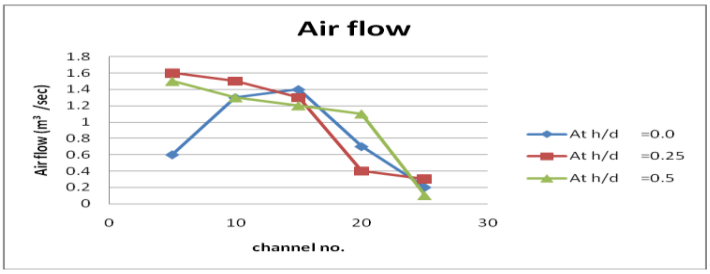


Figure 4.2.1: Air flow in different h/d and Reverse upward flow

Table 4.2.2: Water flow in different h/d and Reverse upward flow

| Sr. No. | Channel no. | Water flow (L/ sec) At h/d = 0/16 =0.0 | Water flow (L/ sec) At h/d = 4/16 =0.25 | Water flow (L/ sec) At h/d = 8/16 =0.5 |
|---|---|---|---|---|
| **1** | 1-5 | 2.1 | 0.5 | 0.4 |
| **2** | 6-10 | 0.6 | 0.4 | 0.5 |
| **3** | 11-15 | 0.5 | 0.4 | 0.6 |
| **4** | 16-20 | 1.2 | 0.5 | 0.9 |
| **5** | 21-25 | 2.4 | 0.9 | 1.6 |

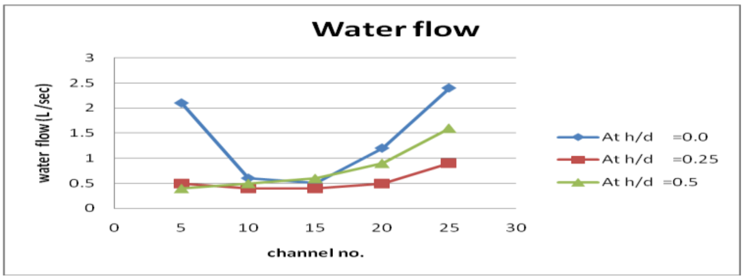


Figure 4.2.2: Water flow in different h/d and Reverse upward flow

## Efficiency

Temperature at inlet =60 °C.
Temperature at outlet =53.6 °C
ή= (Temperature at inlet - Temperature at outlet) / Temperature at inlet
= (60-53.6)/60 =10.66%

***IV.3. REVERSE UPWARD FLOW:*** In reverse upward flow, the air and water are flow in the direction of upward and after that air and water are achieve in separator. Temperature at inlet is 70 °C., Temperature at outlet is 63.8 °C.
Time taken during reading = 10 sec.
Temperature at inlet =70 °C
Temperature at outlet =63.8 °C
H= witch insert in pipe
D= 16mm diameter of pipe

Table 4.3.1: Air flow in different h/d and Reverse upward flow

| Sr. No. | Channel no. | Air flow ($m^3$ /sec) At h/d = 0/16 =0.0 | Air flow ($m^3$ /sec) At h/d = 4/16 =0.25 | Air flow ($m^3$ /sec) At h/d =8/16 =0.5 |
|---|---|---|---|---|
| **1** | 1-5 | 0.7 | 1.7 | 1.6 |
| **2** | 6-10 | 1.4 | 1.6 | 1.3 |
| **3** | 11-15 | 1.6 | 1.4 | 1.2 |
| **4** | 16-20 | 0.8 | 0.5 | 1.2 |
| **5** | 21-25 | 0.1 | 0.9 | 0.2 |

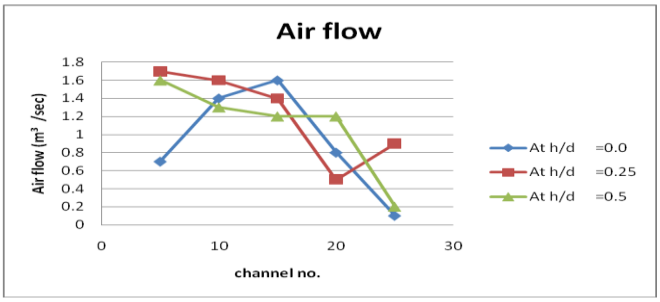


Figure 4.3.1: Air flow in different h/d and Reverse upward flow

Table 4.3.2: Water flow in different h/d and Reverse upward flow

| Sr. No. | Channel no. | Water flow (L/ sec) At h/d = 0/16 =0.0 | Water flow (L/ sec) At h/d = 4/16 =0.25 | Water flow (L/ sec) At h/d = 8/16 =0.5 |
|---|---|---|---|---|
| **1** | 1-5 | 2.3 | 0.5 | 0.5 |
| **2** | 6-10 | 0.7 | 0.4 | 0.6 |
| **3** | 11-15 | 0.6 | 0.4 | 0.7 |
| **4** | 16-20 | 1.3 | 0.5 | 2.2 |
| **5** | 21-25 | 2.4 | 0.9 | 2.4 |

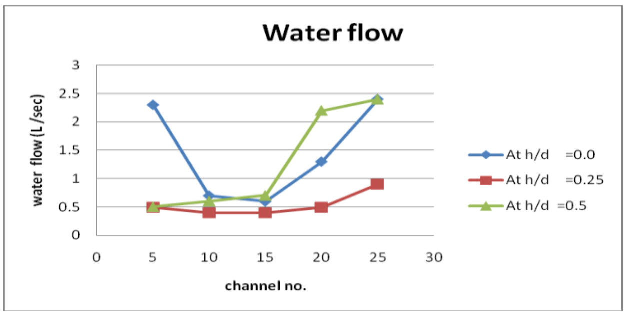


Figure 4.3.2: Water flow in different h/d and Reverse upward flow

**Efficiency**
Temperature at inlet =70 °C
Temperature at outlet =63.8 °C
ή= (Temperature at inlet - Temperature at outlet) / Temperature at inlet
= (70-63.8)/70 =8.85%

***IV.4. REVERSE UPWARD FLOW:*** In reverse upward flow, the air and water are flow in the direction of upward and after that air and water are achieve in separator. Temperature at inlet is 80 °C and temperature at outlet is 73.2 °C.
Time taken during reading = 10 sec.
Temperature at inlet =80°C
Temperature at outlet =73.2 °C
H= witch insert in pipe
D= 16mm diameter of pipe

Table 4.4.1: Air flow in different h/d and Reverse upward flow

| Sr. No. | Channel no. | Air flow ($m^3$/sec) At h/d = 0/16 =0.0 | Air flow ($m^3$/sec) At h/d = 4/16 =0.25 | Air flow ($m^3$/sec) At h/d =8/16 =0.5 |
|---|---|---|---|---|
| **1** | 1-5 | 0.8 | 1.8 | 1.7 |
| **2** | 6-10 | 1.4 | 1.6 | 1.4 |
| **3** | 11-15 | 1.6 | 1.5 | 1.3 |
| **4** | 16-20 | 0.9 | 0.6 | 1.4 |
| **5** | 21-25 | 0.2 | 0.4 | 0.4 |

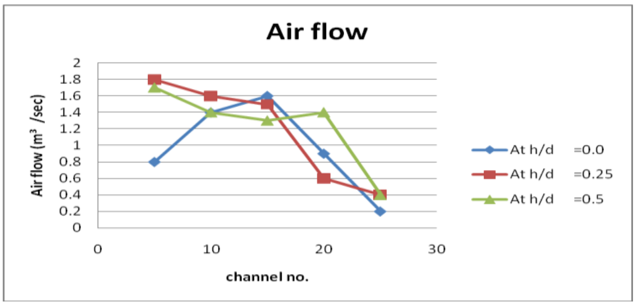


Figure 4.4.1: Air flow in different h/d and Reverse upward flow

Table 4.4.2: Water flow in different h/d and Reverse upward flow

| Sr. No. | Channel no. | Water flow (L/ sec) At h/d = 0/16 =0.0 | Water flow (L/ sec) At h/d = 4/16 =0.25 | Water flow (L/ sec) At h/d = 8/16 =0.5 |
|---|---|---|---|---|
| **1** | 1-5 | 2.4 | 0.6 | 0.5 |
| **2** | 6-10 | 0.8 | 0.5 | 0.6 |
| **3** | 11-15 | 0.7 | 0.5 | 0.8 |
| **4** | 16-20 | 1.4 | 0.6 | 1.6 |
| **5** | 21-25 | 2.3 | 1.2 | 2.5 |

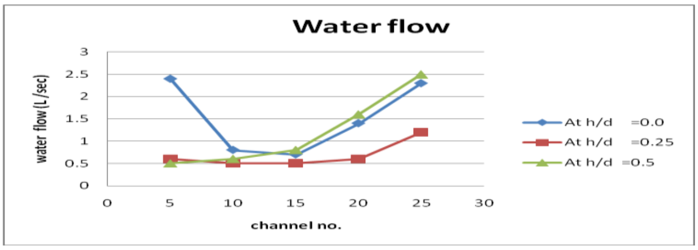


Figure 4.4.2: Water flow in different h/d and Reverse upward flow

## Efficiency:

Temperature at inlet =80°C

Temperature at outlet =73.2 °C

ή= (Temperature at inlet - Temperature at outlet) / Temperature at inlet

= (80-73.2)/80 = 08.50%

## V. CONCLUSION

[1] The effects of tube outlet direction, tube protrusion depth and quality are investigated. It is observed that the incoming water impinges at the protrusions, and the separated water reattaches at the rear part of the header. The reattachment length increases as the protrusion depth increases. The effect of quality is qualitatively the same as that of the protrusion depth. Increase of the mass flux or quality forces the water to rear part of the header.

[2] For the upward flow configuration, most of the water flows through the rear part of the header. The protrusion depth, quality does not significantly alter the flow distribution. Different from the downward flow configuration, the separated water from upper protrusions reattaches at the bottom of the header.

[3] Thus, the variation of reattachment length by the change of protrusion depth, quality is not like to significantly affect the flow distribution. Negligible difference on the water flow distribution was observed between the parallel flow and the reverse flow configuration. Using of Reverse upward flow the obtain maximum efficiency are 10.66% at Temperature at inlet =60 °C and Temperature at outlet =53.6 °C

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