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# Maldistribution of heat exchangers in two-phase flow in open channels

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**Abstract**

Uneven distribution in reduced thermal and dynamic fluid performance can be traced back to heat exchangers. Many papers deal with single-phase flow and flow distribution data, and header design can be done using analytical or numerical models. In this article, the types of heat exchangers are briefly described, and it is clear that each converter can be useful in its proper place due to its efficiency. During the test, two converters were compared with each other for use in the experiment, and the specifications of each converter are also mentioned. Then, according to the experimental and conventional relations and the initial simulation, we obtain the results and compare these results with the results of the second experiment, which is the correct distribution of the converters. Also, due to the existing relationships, we have obtained the additional level between each converter in the open channel during two-phase flow. As a result, according to the types of converters used, we can obtain the correct distribution of converters using two experiments in order to avoid both energy loss and costs for additional converters.

## *1. INTRODUCTION*

Heat exchangers are generally universally utilized in chemical processes, and they may be found in practically every industrial unit. They're devices that allow thermal energy to be transferred between two or more fluids of varying temperatures. This process can be carried out between gas-gas, liquid- liquid, as well as gas- liquid (Guglielmini: 2006). Heat exchangers are utilized to cool or heat a hot fluid to a lower temperature, or to do both.

Heat exchangers are utilized in a variety of implantations. These applications include manufacturing industries, refineries, power plants, petrochemical industries, heating, process industries, food and pharmaceutical industries, metal smelting industries, air conditioning, refrigeration systems and space applications (Taitel and Dukler: 1976). Heat exchangers in different devices like evaporators, boilers, steam generators, evaporators, radiators, cooling towers, condensers, preheaters, fan coils, oil coolers and heaters, furnaces, etc. are widely used. In recent years, the use of compact heat exchangers for single and two-phase applications has increased in the process industry. In the thermodynamic analysis and design of plate heat exchangers, both liquids are considered to be uniformly distributed over all parallel passageways throughout the core of the transducer. Liquid-to-liquid heat transfer is the primary use for plate heat exchangers (Barreras et al.: 2008). As a result, performance in single-phase applications has been documented in the open literature to the point that euro computations can be designed and ranked with confidence. In such experiments, many combinations are possible for each flow, and the flow configuration must be carefully selected to avoid severe current distribution and achieve better performance. Heat exchangers can be classified into different aspects:

- Based on the type and contact surface of hot and cold fluid
- Based on the direction of cold and hot fluid flow
- Based on the heat transfer mechanism between hot and cold fluids
- Based on the mechanical structure and structure of the converters

Many industries are involved in the design of different kinds of heat exchangers, and there are also several courses offered in colleges and universities under various names in the design of heat exchangers. Converter calculations are a long and sometimes tedious task. For example, designing a converter for a particular operation requires a lot of guesswork that can be used to find the right size of a converter according to standards (Trabold et al.: 2008). But with the use of computer programs, all these calculations are performed by the computer, and the designer only has to enter the operating conditions and the properties of the fluids present in operation to design. These include Aspen B-jac and HTFS software. These applications include programs that have the ability to perform such calculations. Many articles have been written about the destructive impacts of current distribution on the heat exchangers performance, but the mother of this article wants to address the effects of distribution and placement of heat exchangers in two-phase current in open channels (Kim et al.: 2010).

## 2. *METHODS*

The experiments were performed in a horizontal channel with a rectangular cross-section with dimensions of 5x10cm2 (hydraulic equivalent diameter / 67.6cm) and a length of 36m (length equivalent to 5400) made of Plexiglas 10. The channel is located on a number of metal supports with adjustable angle and non-conductive heat. For this research, the heat cycle of the two-pipe converter has been used. The inner tube of the copper converter is 12 mm in diameter and 1 mm thick, with a heat exchange length of 70 cm.

Its shell diameter is 8.50 mm. The current inside the converter of non-directional valves is considered. The plate converter is a small and customized example of a conventional home radiator with dimensions of 40 and 60 cm in height and length, respectively, which exchanges heat with the surrounding environment (Basu et al.: 2009).

The fluid used in modelling is water. Heat transfer in frame and plate heat exchangers is simulated in this paper in the form of six models. The transient response of the heat exchangers is investigated by applying a step input to the system. In the initial heat-stable conditions of the converter, the temperature of all points is assumed to be equal to 300K. The step input is entered towards the heat exchanger and is simulated as a step in time 0. 1 second reaches its peak, 350K, along the path of a third-degree curve (Wu & Wang: 2020).

As liquid and gas phases flow through the tube, various flow patterns are created. The interactions between the phases give rise to these different flow patterns. The main factors influencing the flow pattern inside the pipe include fluid parameters such as flow rate and flow direction of each phase of fluid characteristics and geometric parameters such as pipe diameter, pipe slope, pipe geometry and others (Cao et al.: 2020). Momental transfer between two phases, heat transfer and mass transfer in two-phase flow is strongly influenced by current patterns. Therefore, it is necessary to study the flow patterns in order to create proper performance and safety during the process and perform operations in various industries such as refineries, petrochemicals, etc. (Xia et al.: 2020). Given the above, it is natural that many studies have been conducted on biphasic flow patterns so far; however, most studies have focused on biphasic currents. In this experiment, we first compared the two plate heat exchangers with the shell and tube heat exchangers, according to Table 1.

**Table 1.** Comparison of plate heat exchangers with shell and tube heat exchangers

| **Comparison** | **Heat exchangers with welded plates** | **Shell and tube heat exchangers** |
|---|---|---|
| **Number of units** | 1 | 3 |
| **The total heat transfer surface** | 1375 $ft.\ m^2$ | 6013 $ft.\ m^2$ |
| **Materials used** | Avesta pages<br>254 smo | Carbon steel pipes |
| **Type of construction** | Carbon steel frame | Carbon steel shell |
| **Installation costs** | 55000000 $ | 110000000 $ |

Then we use the following equations to investigate how heat is transferred between the converters and how the exchangers are distributed in the open channel during the two phases. From one point of view, the studies performed on pipes can be classified into two categories of experiments performed on large-scale and small-scale pipes (Mahvi & Garimella: 2019). Various criteria are provided for our pipe scaling. We consider small-scale pipes that meet condition 1.

$$d \leq \frac{19}{p_i}\sqrt{\frac{S(P_i - P_g)}{g}} \quad (1)$$

In relation (1), d is the inner diameter of the pipe, S is the surface tension coefficient between the two phases, g is the gravitational acceleration and $P_i$ and $P_g$ the density of the liquid and gas phases, respectively (Zhang et al.: 2017; Zhang et al.: 2020). For phase Liquid water and air gas phase at ambient conditions (temperature 25°C and pressure 1 atmosphere) surface tension coefficient equal to 0.072 N/m, water density equal to 977 $\frac{k}{m^3}$ and air density having a value of 1.184 $\frac{kg}{m^3}$ Are, so the condition is d ≤ 5.15 cm; In other words, pipes with an inner diameter of less than 50 mm are small pipes and pipes with a diameter of more than 50 mm are large pipes (Brenk et al.: 2018).

The coefficient of the heat transfer in a two-pipe heat exchanger is calculated based on the energy balance

$$\boldsymbol{Q_c = (\rho C_p)_c uA\,(T_{c,out} - T_{c,in})} \quad (2)$$

$$\boldsymbol{Q_{nf} = (\rho C_p)_{nf} uA\,(T_{nf,out} - T_{nf,in})} \quad (3)$$

Which is the index related to the flow of cold water inside the shell and nf is related to the nanofluid being tested. $\Delta Q = Q_{nf} - Q_c$ The amount of heat lost is considered to be about 20 to 25% for a two-pipe heat exchanger. On the other hand, we have displacement to transfer heat:

$$\boldsymbol{U_o = \frac{Q}{A_o \Delta T_{lm}}} \quad (4)$$

U is the overall heat transfer coefficient and for bladeless tube heating models, ignoring the transducer deposition, based on the outer surface of the tube, A, by definition, is:

$$U_o = \frac{1}{\frac{A_o}{A_i}\frac{1}{h_i} + \frac{A_o ln(\frac{r_o}{r_i})}{2\pi LK} + \frac{1}{h_o}} \quad (5)$$

By calculating h from the following equation for turbulent flow within the shell (Van Oevelen et al.: 2018):

$$\frac{h_o D_c}{k_{water}} = Nu_o = 0.02Re^{0.8}Pr^{\frac{1}{3}}(\frac{r_o}{r_i})^{0.53} \quad (6)$$

Where D is the equivalent diameter of the converter shell:

$$D_e = \frac{D_i^2 - D_o^2}{D_o} \quad (7)$$

Putting it in the above equation is the only unknown h that is obtained by solving the equation. Nu is then also calculated. The following equation was utilized to calculate the transfer heat transfer coefficient in the plate converter:

$$Q_{nf} = h_{nf}A(T_{amb} - T_w) \quad (8)$$

Where $h_{nf}$ is the heat transfer coefficient of the nanofluid, A is the heat exchange rate of the medium with the environment, $T_{amb}$ is the ambient temperature and $T_w$ is the temperature of the transducer, and is the amount of heat. The loss is calculated as follows:

$$Q_{nf} = \dot{m}_{nf}C_{p,nf}(T_{out} - T_{in}) \quad (9)$$

### *3. RESULTS*

The findings of studies on a horizontal two-phase flow in an open channel are presented in this study. According to the above, it can be seen that each of the plate heat exchangers, depending to the structural characteristics, the number of fluids passing through, the type of flow arrangement, the amount of surface compaction and the type of heat transfer process, can be used for specific applications. The results are summarized in Tables 1 and 2.

Based on these data, targeting can be done using heat transfer improvement methods. In this case, only the use of a torsion tube converter can be done (Yuan et al.: 2016).

**Table 1. Converter simulation results**

| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $E_6$ |
|---|---|---|---|---|---|---|
| $h_t\ (\frac{W}{m^2}.c)$ | 2252 | 1039 | 2253 | 1646 | 853 | 1646 |
| $h_s\ (\frac{W}{m^2}.c)$ | 1932 | 2757 | 1318 | 1686 | 1789 | 1603 |
| $\Delta P_t\ (kpa)$ | 45.589 | 16.051 | 45.589 | 43.420 | 14.964 | 73.816 |
| $\Delta P_s(kpa)$ | 67.591 | 94.372 | 44.624 | 86.868 | 108.177 | 123.052 |

**Table 2. Specifications of available converters**

| | $E_1$ | $E_2$ | $E_3$ | $E_4$ | $E_5$ | $E_6$ |
|---|---|---|---|---|---|---|
| Shell side | KEROSEN E | NAPHTHA | HGO | LGO | BPA | ATB |
| Tube side | CRUDE | CRUDE | CRUDE | CRUDE | CRUDE | CRUDE |
| Area | 280 | 1480 | 280 | 800 | 2760 | 1360 |
| Series - Parallel | 1-1 | 1-1 | 1-1 | 1-2 | 2-3 | 1-4 |
| Shell diameter | 9470 | 1524 | 940 | 1143 | 1219 | 1143 |
| Baffle distance | 255.3 | 1246.4 | 197.3 | 419.3 | 605.1 | 509.1 |
| Number of pipes | 1075 | 2827 | 1075 | 1590 | 1810 | 1590 |
| Number of pipe passes | 2 | 2 | 2 | 2 | 2 | 2 |
| The inner diameter of the pipe | 15.4 | 15.4 | 15.4 | 15.4 | 15.4 | 15.4 |
| Outer diameter of the pipe | 19.1 | 19.1 | 19.1 | 19.1 | 19.1 | 19.1 |
| The distance between the pipes | 25.4 | 25.4 | 25.4 | 25.4 | 25.4 | 25.4 |

In this study, by evaluating the effect of increasing the capacity on the performance of heat exchangers, a range was provided to compensate for the additional level required to increase the capacity using thermal improvement methods. By modifying the distribution of the converters in the open channel, we compare the obtained results with the previous conditions:

**Table 3. Compare the primary network with the modified network**

| Energy saving | Consumption of hot utility | Total level required | | |
|---|---|---|---|---|
| (KJ) | (KJ) | Additional levels $(m^2)$ | Available level $(m^2)$ | |
| 0 | 80.418 | 0 | 6960 | Primary network |
| 23.238 | 80.418 | 3818 | 6960 | Modified network |

The additional level required between each converter for better performance and more economical distribution of converters in the channel is shown in Table 4.

**Table 4. Distribution of additional surface required between converters**

| Converter name | Available level $(m^2)$ | Additional levels $(m^2)$ |
|---|---|---|
| $E_1$ | 280 | 0 |
| $E_2$ | 1480 | 0 |
| $E_3$ | 280 | 345 |
| $E_4$ | 800 | 145 |
| $E_5$ | 2760 | 1323 |
| $E_6$ | 1360 | 2005 |

The temperature distribution is qualitatively comparable to the flow distribution, with the maximum temperature occurring in the heat exchanger's core section (Liu et al.: 2017). Temperature non-uniformity, on the other hand, is more evident than current. Also, the uniformity of temperature and flow in heat exchangers can be observed according to the following table:

**Table 5.** Flow nonuniformity and temperature in the heat exchanger (RE=1010, $\Delta T = 20$℃)

| **Header** | $S_Q$ | $S_T$ | $\eta$ (℃) | $\beta$ |
|---|---|---|---|---|
| **A** | 0.208 | 0.939 | 3.85 | 2.384 |
| **B** | 0.169 | 0.885 | 3.51 | 2.062 |
| **C** | 0.074 | 0.814 | 3.33 | 1.293 |
| **G** | 0.070 | 0.787 | 2.87 | 1.265 |
| **F** | 0.065 | 0.762 | 2.73 | 1.233 |
| **D** | 0.056 | 0.739 | 2.66 | 1.216 |
| **E** | 0.045 | 0.726 | 2.52 | 1.167 |
| **H** | 0.035 | 0.702 | 2.44 | 1.127 |

The distribution in a Kapton heat exchanger is seen in Figure 14. The two-phase output condition of the evaporator at a suitably low vapour percentage is shown in Figure (a). Differentiation is hampered in this condition, and the distribution appears to be excellent. Lower flow rates and higher evaporation temperatures are shown in the figure below (b), indicating distribution issues (Zhang et al.: 2011; Zhang et al.: 2015). This two-phase mixture collides with the heat exchanger's opposing wall and is sprayed into the radius's channels.

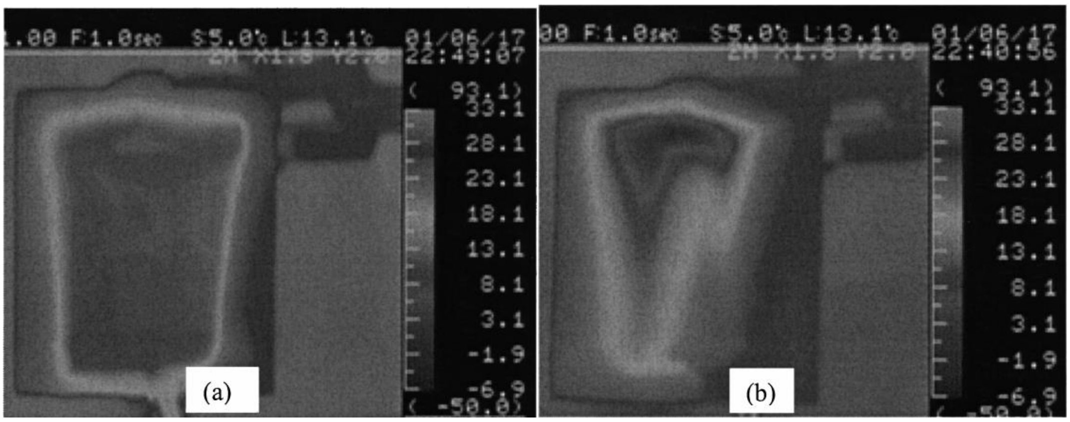

Figure 1. two infrared images of distribution in the heat exchanger

Obtaining a uniform two-phase distribution in two-tube feed headers is very difficult given the laboratory conditions of this experiment. The separation of gravity of the liquid phases in horizontal headers exacerbates the situation (Mao et al.: 2013). Split headers, which might be at the top or bottom of the heat exchanger, have this issue. Horizontal headers are commonly used in melted evaporators to enable condensate drainage. Although projecting the tube's end and middle veins can help with flow distribution, they are insufficient. The effect of the heat exchanger on flow temperature can be seen in the following diagram:

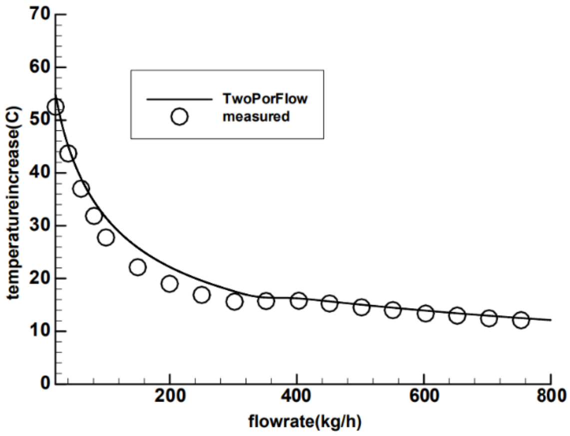


**Figure 2.** The increase in temperature of the cold water inlet of the heat exchanger depends on the flow rate.

The program was applied to three two-phase reciprocating heat exchangers and three counter heat exchangers, both of which work with water. One-dimensional simulation of a simple two-phase flow was made for an electrically heated water evaporator. The results of heat transfer (temperature) are consistent with the experimental findings. More deviations are seen for pressure drop, which is, for example, much more sensitive to the precision of the channel geometry or sediment in the channel wall (Yoon et al.: 2014).

To put it another way, the phenomena is akin to the spread of two-phase currents from a primary vertical branch to two parallel horizontal branches. According to Lee, the volume of liquid flow via the second branch is about equal to that through the first branch, with a fraction of around 0.5-0.7, and the pattern was consistent over three distinct branch (canal) distances. The reason for this is that the liquid film is readily divided at the first junction's entry (i.e. the first branch's entrance), and the leftover liquid film reaches the next junction. The liquid film reaches the next joint without redistribution, resulting in a uniform thickness, and the rate of liquid division to the second branch is lowered as the distance between the smaller branches increases.

## 4. DISCUSSION

According to a survey of the literature on the distribution of two-phase currents in parallel channels, a lot of work has been done in the recent decade. Experimental analysis was used in the majority of the investigations. It is evident that comparing the trials of erroneous heat exchanger distribution in two-phase flow in open channels with the channels described in other experiments and literature has issues. In fact, a considerable quantity of data is collected utilizing various combinations and operating circumstances (total mass flow rate, gas quality, liquid, and so on) as well as geometric settings (header shape and dimensions, feed pipe, number of channels, feed pipe position). Several of these characteristics have been identified as being essential in the erroneous distribution of converters during two-phase flow. As a result, the results of research undertaken in different laboratories varied significantly. The two-phase current distribution is also affected by operating circumstances. The two-phase flow pattern is impacted by the header and channel direction in respect to gravity, as well as the two-phase flow direction, for a particular device shape. A particular two-phase flow pattern in the feed pipe is caused by total mass flow velocity and gas quality. In addition to the proper distribution of converters, geometric corrections can also be used to improve heat transfer during two-phase open channels. These adjustments, on the other hand, may produce issues, such as a larger pressure decrease. More research is needed in this area to look at other potential impacts such as header design, channel shape, and fluid characteristics, as well as to better understand the relevance of feed pipe and outlet conditions. The efficiency of the heat exchanger was determined for different headers based on the trial data. The flow non-uniformity parameter may be used to plot the change in heat exchanger efficiency. Temperature uniformity is greater than it is now, resulting in different degrees of heat exchanger effect loss. By regulating flow unevenness, improvements in header configuration can effectively improve the performance of plate heat exchangers. With the revised header, the degree of temperature non-uniformity can be reduced from 0.939 to 0.702. The experimental study also found a link between the flow non-uniformity parameter and the heat exchanger efficiency drop. Based on current experimental data and two-phase flow models in T-joints, analytical and numerical models can be improved further by considering landing and Weber numbers. With the aim to obtain the best comprehension of the phenomenon of biphasic currents occurring, and the incorrect distribution of transducers in parallel channels, the development of new approaches is needed.

## 5. CONCLUSION

The current paper reports the finding of various experiments performed on a two-phase current in an open channel. The results certain the complexity of the two-phase current distribution phenomenon and the difficulty of how the converters are distributed in a multi-channel channel system. This study shows that severe misalignment of heat exchangers can lead to a loss of economic performance of more than 25%. Improper distribution of fluid flow causes longer fluid coils to form, and the liquid cochlea can eventually occupy the entire canal branch, reducing heat transfer and disrupting the biphasic system. The utilize of a small diameter distribution pipe (or similar) with outlet holes with a small distance along it seems to be a good concept for achieving a good flow distribution. It is found that the current distribution in the channels, furthermore the distribution of header pressure, also depends on factors such as the geometry and the initial flow regime in the header.

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