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Heat Transfer in Two-Phase Unidirectional Flow Regarding Vertical Pipes

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Abstract: *Two-phase flow has been frequently used in industry since long time ago. In most of the processing industries, the flow is biphasic, which is the simultaneous flow of two different fluids through a conduit. Two-phase flow is the method of choice in the majority of the manufacturing processes and different fluid pairs like water-air, oil-water and carbon particles-vapor are simultaneously used in this regard. Gas and liquid phases are the common components of such flows. Accordingly, the optimum use of energy and elevation of the processes' output are the most important issues considered in the majority of the world's industrial processes. In between, direct contact thermal exchangers are being widely applied in processing industries and have many benefits in respect to indirect contact thermal exchangers.*

Keywords: *Two-Phase Flow, Heat Transfer, Direct Contact Thermal Exchanger*

INTRODUCTION

The biphasic flow of gas-liquid in pipes is usually observed in many of the industrial processes, including oil wells and pipelines, chemical and nuclear reactors, oil production installations, condensers and boilers, as well as an array of the others. Reliable designing of such systems needs a thorough knowledge and perception of the biphasic flow mechanism like phase distribution of flow patterns, heat transfer coefficients and pressure drop in various rates of gas-liquid flow. It is well evident that the morphology of the two-phase flow is often playing a vital role in determining the mass and heat transfer during the phase change of heat transfer processes. Thus, it is essentially necessary to conduct a research regarding the properties of the two-phase flow patterns for a better understanding of the main mechanisms of heat transfer in canals.

So far, limited research has been conducted regarding the direct contact heat exchangers in competition with the ordinary heat exchangers. In direct contact type of the thermal exchangers, the heat is transferred between cold and hot fluids via the contact surface between them and there is no wall used between the cold and hot flows.

In a laboratory research on the downward heat transfer of two-phase unidirectional flow in vertical pipes, efforts were made for optimizing the various processes and constructing new devices so that solution could be found for improving the situation in different industries.

In direct contact heat exchangers, the flows are comprised of two non-mixable liquids and/or a pair of gas-liquids. Condensers and the liquid sprayers in the vapor current and the tray condensers wherein the liquid and vapor are in direct contact with one another and the cooling towers are some examples of these exchangers. It is now for years that a part of the energy of the hot and dry gases is being recovered. Energy retrieval from the gas products of combustion, the heat in gases exhausted from water boilers, flow generation and/or processes that need higher temperatures are cases that can work with direct contact exchangers (Fair, 1990). Ghazi et al, (1999) investigated the direct contact heat transfer for water-air systems and concluded that the water temperatures had no or little effect on the overall heat transfer coefficient. Inaba et al. (2002) examined such properties as heat transfer and mass transfer on air bubbles and hot water in direct contact. Chen et al. (2014) performed a study aiming at enhancing heat transfer of two-phase flow in upward vertical pipes using a cylinder made of a porous plate. These writers could observe the bubble, slug, turbulent, spiral and thin spiral patterns in hollow pipes with no porous cylinder. The data related to these patterns were found to be consistent with the maps existent in the prior research.

Klata et al. (1999) offered suggestions for increasing heat transfer current inside the pipes via injecting gas into the liquid for causing turbulence. In laboratory studies carried out by them, a vertical hot pipe was cooled down on the inside part by water, while heat transfer coefficient was being measured with and without air injection. Injection of a little amount of air flow inside the water current was followed by an increase by 20% to 40% in the heat transfer coefficient due to forced convection and, subsequently, caused more increase in the heat transfer for the mixture. Park et al (2004) observed the uniform distribution of water inside the vertical pipes and decomposition of part of the large waves in the form of clusters of indentations in Reynolds numbers equal to and above 40. For 1-meter or longer films in vertical pipes, two relations were obtained for Reynolds numbers in a range between 20 and 40 and between 40 and 400. Using the friction factor's similarity to heat transfer, Tang and Qajar (2011) suggested a mechanical heat transfer relation through estimating the heat transfer coefficient for non-boiling two-phase flows in horizontal pipes, pipes with low slope as well as vertical pipes.

They measured the local heat transfer coefficient, pressure drop and flow parameters for air-water flow inside a pipe, 27.9mm in diameter, and obtained the heat transfer data and pressure drop with a good accuracy using the Reynolds numbers for gas and liquid surfaces. Then, they validated the obtained heat transfer relation based on the laboratory heat transfer data. The comparison of the experimental relation with the heat transfer data indicated that the friction coefficient's similarity to heat transfer coefficient could be applied for a precise prediction of heat transfer of non-boiling two-phase flow inside the pipe.

Shah et al. (2010) numerically simulated the liquefaction of water vapor from an ultrasonic vapor jet through direct contact in sub-cold water. They compared the findings of the calculated fluids dynamics with the laboratory data and concluded that they were in a good match.

Lucas et al. (2005) investigated the pattern development style and important parameters of two-phase flow along with vertical pipes, 51.2mm in diameter and 3m in length. To obtain the volumetric fraction, they utilized wire mesh sensor that provided the volumetric fraction in every cross-section using the voltage difference between the two cross-sections per every unit of time. Jao and Ho (2013) offered an optimum method wherein the intensity of gamma rays was employed for extracting and analyzing some characteristics of flow under any conditions. Shen et al. (2014) explored the downward heat transfer flow's properties inside straight pipes. They showed that the wall temperature was slowly increased with fluid's enthalpy in supercritical pressures when the winglet temperature was below the pseudocritical temperature and that the wall temperature increase was considerable when the winglet temperature was higher than the pseudocritical temperature. Zadrazil and Markides (2014) investigated the liquid film's properties in downward unidirectional flow using laser irradiation and particles' velocity detection. They concluded that the waves formed on the liquid surface played an important role in heat and mass transfer from the region close to the wall towards the gas-liquid contact surface.

Adljoo et al. (2017) simulated the upward two-phase gas-liquid flow patterns in pipes with large diameters. The analysis of the results provided spiral, turbulent, bubble and coagulated as well as two secondary pseudo-spiral and capped-bubbly flow patterns.

In this study, hot water and cold air were in contact inside a vertical pipe with a downward unidirectional flow and the heat transfer from hot water to cold air was examined through measuring the high and low temperatures and humidity. The heat transfer coefficient and Nusselt number were experimentally calculated and compared with the relations existent for the flow developed inside the straight pipes so that a modified relation was eventually offered.

After performing the experiments using such equipments as hot water tank, thermal element, air speedometer, air suction fan, planar laser generator, experimental vertical pipe, digital humidity meter, water and air thermometers, open-head tank, water rotameter, water circulation pump, camera and calculations, it was made clear that the contact surface between air and water inside the pipe had to be computed. Due to the formation of spiral flow inside the pipe, laser device was used for obtaining the contact surface between water and air. In spiral flow, a film of water covered the entire of the pipe's wall and the air existed in the middle of the pipe. The laser light hit the water making it colorful. However, it made no change in the air. The air diameter inside the pipe could be measured through taking photos of the pipe's interior and processing of the images.

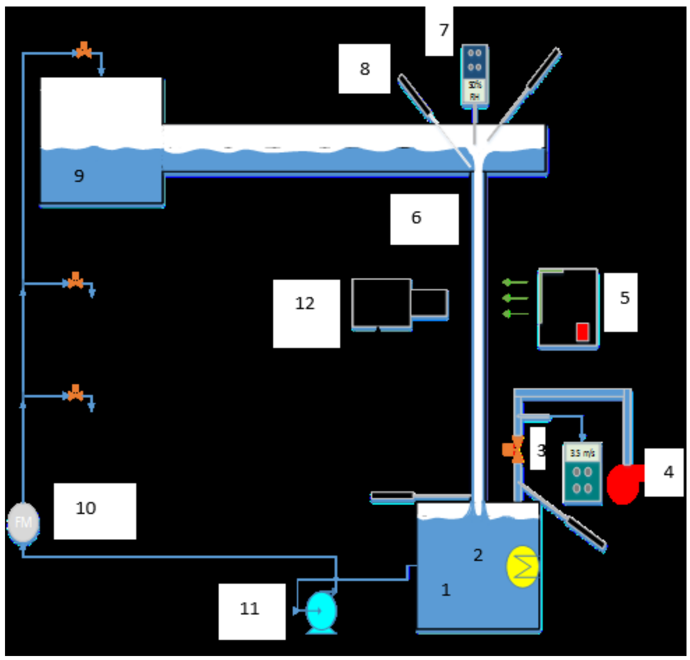

Figure 1: Schematic view of the experimental system

Results and Discussion

The air circulation rate is amongst the most influential parameters on the heat transfer. In this study, the Reynolds numbers of air flow were found undergoing changes in all three studied pipes in a range from 3000 to 20000. One of the most important designing parameters in applying two-phase flow inside the pipes was the heat transfer coefficient that was normally higher for turbulent flows than the calm flows. Therefore, any factor causing turbulence in the flow inside the pipe caused the heat transfer coefficient to be increased. In a given flow rate and for a fixed temperature of the liquid, the increase in the air current rate augmented the fluctuations of the formed liquid film as a result of which the heat transfer coefficient was heightened. Hence, the Nusselt number would also undergo an increase. Nusselt number expressed the ratio between the heat transferred through convection and the heat transferred through conduction.

Having increased the air current in the pipe inlet, the water vapor pressure was partially reduced due to the decrease in the temperature and the resultant reduction in the saturated vapor pressure as well as the relative humidity of the air flow. This partial pressure reduction reduced the absolute humidity of the inflowing air. On the other hand, the reduction in the temperature and absolute humidity of the air in the pipe inlet caused the enthalpy of the air-water mixture to be decreased.

Conversely, the increase in air speed in the pipe outlet increased the temperature and absolute humidity of the air hence increasing the enthalpy of the mixture in the pipe outlet. The total heat transferred from water to air resulted from evaporation and convection that were increased by adding to the air speed. Therefore, the convective heat transfer rate was also increased with the increase in air speed. The convective heat transfer coefficient was a function of the convective heat transfer rate, the water-air contact surface and the temperature differences of the water and air. The increase in the air circulation rate caused a slight enlargement in the heat transfer surface. On the other hand, the decline in the water film's temperature was intensified with the increase in the air circulation rate as a result of which the air temperature increased. Thus, the temperature differences between water and air were reduced. So, the increase in the air circulation rate caused an increase in the convective heat transfer of the air circulation. The physical properties of air were measured in water film's temperature.

Having increased the air circulation, the conductive heat transfer coefficient of the air was decreased. Hence, based on relation (15), the increase in air circulation rate caused an increase in Nusselt number due to the increase in the convective heat transfer coefficient and the air core diameter as well as due to the reduction in the air's coefficient thermal conductivity.

Increasing temperature, as well, played its own role in increasing the convective heat transfer rate and this increase in the heat transfer caused an increase in the convective heat transfer coefficient and the eventual increase in Nusselt number.

The overall rate of the heat transferred from the hot water to the cold air equaled to the sum of the heat transferred through evaporation and the heat transferred through the convection.

Prediction of heat transfer from hot water to cold air through evaporation was developed through correcting the forced convective mass and heat transfer relations of the turbulent flows, according to which the promising results were attained. The water temperature variations were lower than air temperature's. However, the increase in air's Reynolds number caused an increase in the temperature differences of the inflowing and outflowing water. The temperature differences of the inflowing and outflowing air, as well, were increased as the air circulation rate increased.

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