TEMPERATURE PROFILES ON MULTI-LOCATION OF STEAM FLOW CONDENSATION COOLED USING PARALLEL FLOWING WATER IN THE OUTSIDE OF A HORIZONTAL PIPE

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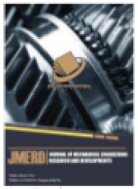

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RESEARCH ARTICLE

TEMPERATURE PROFILES ON MULTI-LOCATION OF STEAM FLOW CONDENSATION COOLED USING PARALLEL FLOWING WATER IN THE OUTSIDE OF A HORIZONTAL PIPE

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ABSTRACT

This paper presents the results of research on temperature profiles on multi-location of condensation of steam flow cooled using parallel flowing water in an outside of a horizontal pipe. The test section consisted of a copper pipe (d_{in}= 17.2 mm, d_o= 19 mm, 1.8 m long) as inner annulus and a galvanized iron pipe (d_{in} = 108.3 mm, d_o = 114. 3 mm, 1.6 m long) as outer annulus. The experiments were conducted at a static pressure (P_s) of 109 kPa. The fluid is water in two phases i.e. steam and liquid. The steam phase flowed inside the inner pipe, while as the cooler, the liquid flowed through the annulus. The flow of steam was then cooled using parallel flowing water in the outside of a horizontal pipe. Data acquisition equipment was used to record data at a sampling rate of 5 Hz. The results showed that a point farther away from the inlet tends to have a lower temperature. The increase of steam mass flow rate (m_{st}) resulted in the larger instability and started to generate wavy slug flow. Therefore, the wavy-slug flow pattern occurred close to the outlet of the pipe.

KEYWORDS

Cross-Section, Instability, Flow Pattern, Wavy-Slug

NOMENCLATURE

din	inner diameter
do	outer diameter
Hz	Hertz
C	Celcius
ṁco	mass flow rate of cooling water
ṁst	mass flow rate of steam
Ps	Absolute Pressure
T	Temperature

1. INTRODUCTION

Condensation is a crucial component of chemical processes, water cycle, and in a nuclear power plan, so that it plays an important role in nature Ghiaasiaan [1]. Another example of the steam condensation is in the distillation of eucalyptus oil. The condensation phenomenon has been studied by so many researchers [2-12]. Another group of research studied steam-air mixture condensation in an annulus channel, for both laminar and turbulent [2]. Dew-point probe was used to locally measure the concentration of steam inside the annulus, while inner tube temperature gradient was used to measure the heat flux. As a result, close to the inlet, the heat flux at the bottom of the tube was slightly higher than that of the top. Contrary, far downstream from the inlet region, the heat transfer at the bottom was lower than that at the top.

Some study presented an analytical model for predicting film condensation of vapor flowing inside a vertical mini triangular channel under the influence of a superimposed pressure [3]. Thome, proposed a new condensation two-phase flow pattern map heat transfer model including both flow pattern and interfacial roughness effects [4]. Grzebielec and Rusowicz presented the heat transfer coefficients for water vapor condensation on horizontal tubes [5]. He also demonstrated the influence of vapor, cooling water and noncondensable gas properties on heat transfer process. A group researcher presented a heat transfer process in liquid spraying heat exchangers placed in a vacuum chamber, and also described the behavior of a falling film evaporation and condensation mode on horizontal tube bundles [6]. The study obtains the heat transfer coefficient and its correlations by means of a mathematical model. Panitapu experimentally investigated the pressure drop and heat transfer coefficient of some refrigerant gas-liquid two-phase flow in a horizontal channel [7]. The research reported that the quality of vapor did not significantly influence on the local heat transfer coefficient for low mass flux, but it was linearly affected for high mass flux. Furthermore, the heat transfer coefficient of R134a and that of R22 were considerably the same. Meanwhile, the heat transfer coefficient of R407C were approximately 13 % lower than that of R22. Moist air around horizontal pipe condensation process was studied theoretically and experimentally to find the heat and mass transfer coefficients, which were influenced by air inlet conditions [8]. As a result, they reported that the increase of air relative humidity and mass flow rate caused the increase of the average mass and heat transfer. Meanwhile, the increase of the temperature difference between the pipe surface temperature and air dew point caused to the decrease of mass and heat transfer coefficient. When compared to the previous theoretical research, their results were in a good agreement. On the other hand, a study presented a mathematical model based on the equilibrium of momentum and energy in the annular flow to predict the heat transfer parameters associated with condensation R-134a in a 5-mm

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ID 950-mm long inclinable tube, and the results correspond to the experiment [9]. Furthermore, a studied the characteristics of pressure drop and condensation heat transfer of R134a inside horizontal smooth and micro fin tubes at saturation temperature of 30oC and 35oC and in the mass velocity range of 50 to 200 kg/m2s [10]. They concluded that the frictional pressure drops gradients and local heat transfer coefficients increase when vapor quality and mass flux were increased. Meanwhile, increasing saturation temperature caused the decrease of the local heat transfer coefficient and frictional pressure drop gradient.

Based on the above description, investigation of steam condensation and two-phase flow has not been deeply studied. Some parameters need to be explored to explain the phenomena of two-phase flow, especially related to condensation, including the geometry, orientation or position of the pipe, and condensation process. Therefore, the objective of present research is to obtain the data of temperature profiles based on multi-location of steam flow condensation cooled using parallel flowing water in the outside of a horizontal pipe. Those data are really important to develop a new model of temperature profiles on two-phase flow for making early warning system of equipments namely boiler, air conditioner, heat exchanger, etc.

1. MATERIALS AND METHODS

The experimental apparatus used in the present study is expressed in Fig. 1 and 2. The test section consisted of inner annulus pipe made from copper (din=17.2 mm, do= 19 mm) with a length of 1.8 m and a galvanized iron pipe as the outer annulus pipe (din=108.3 mm, do=114. 3 mm) with a length of 1.6 m. K type thermocouples were used to detect the spread of temperature in radial or axial direction along the pipe. A data logger of RX 40 series was used to record the temperature with a sampling rate of 10 Hz. In the present experiment, the working fluids were aquades and steam. The aquades was heated using a boiler to generate steam which was then flowed and condensed inside the annulus pipe to form a steam-condensate two-phase flow in the horizontal pipe. The steam static pressure (Ps) was 2.074 absolute atmosphere and the temperature (T) was 119.7 °C. Water was used as a coolant in the out side of annulus pipe.

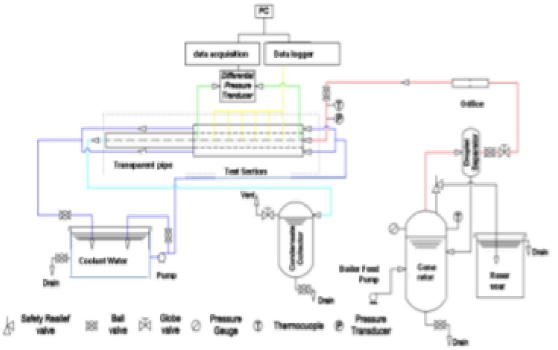

Figure 1: Schematic installation of the experimental apparatus.

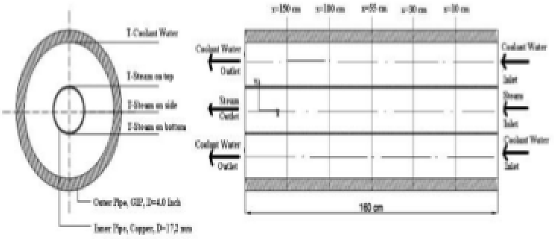

Figure 2: Detail dimension of the test section

2. RESULTS

Axial temperature profiles on the bottom side of test section is shown in Fig. 3. It can be explained that the temperature at the point of 100 cm and 150 cm from the inlet for the three position (bottom, side and top), was still quite high. These data indicate that the vapor dominates the flow rate that occurred in the condenser pipe, resulting in the instability of the flow of steam-condensate, and causing the flow of condensate being wavy. The increase of ṁst caused larger instability or wave and started to form a wavy-slug flow. Cooling water mass flow rate (ṁco) was kept constant at 4.23 10-1kg/s, and its temperature distributions possess the same trend pattern, where the farther from the inlet the temperature decreased linearly, the highest temperature was 24.94°C (at a point 30 cm from the inlet) and the lowest was 17.08 °C (at a point 150 cm from the inlet) and the mean was 19.83°C.

Next, Fig. 4 shows the same tendency for the top, side and bottom, namely at the point of temperature measurement results were approximately constant for a point located at 10 cm to 100 cm from the inlet and were still at a temperature of saturation. This indicates that condensation process was taking place in that location, while the temperature on the side and bottom points are still in saturation temperature. This indicates that condensate is formed at this location. At points located at 100 to 150 cm from the inlet, conditions at the three locations possess the same trend that was downward sharply, this means that there has been a significant additional amount of condensate at this location.

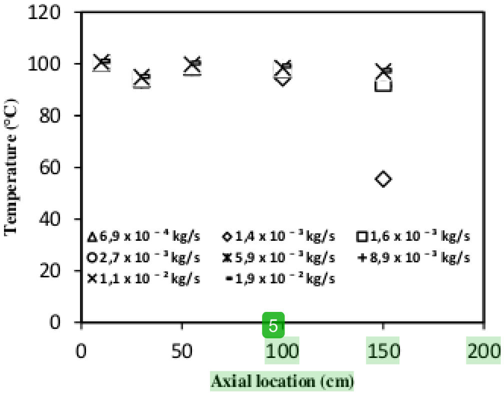

Figure 3: Axially temperature profiles on the bottom side of test section

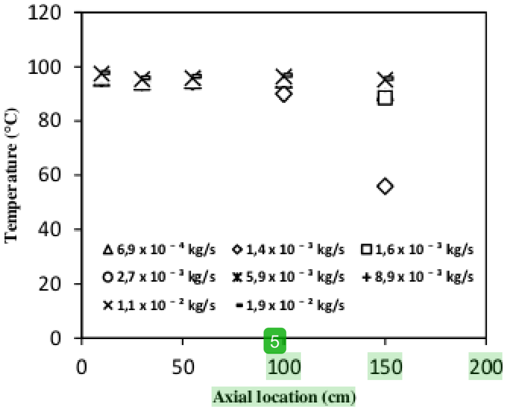

Figure 4: Temperature profile on the right and left side of test section

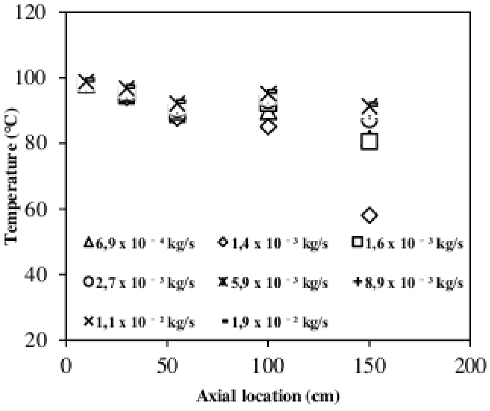

Figure 5: Temperature profiles on the top side of test section

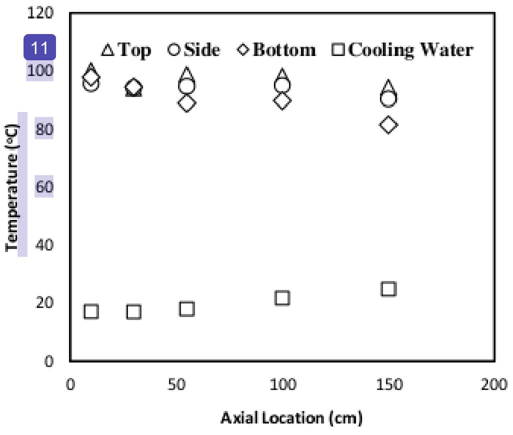

Figure 6: Temperature profiles on the cross-section pipe test (ṁst = 6.9 x 10-4kg/s, ṁco = 4.23 x 10-1 kg/s)

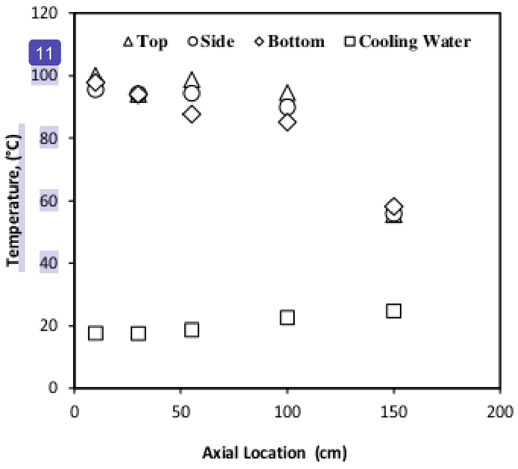

Figure 7: Typical of Temperature profiles on the cross-section pipe test (ṁst= 1.4 x 10-3 kg/s, ṁco = 4.23 x 10-1 kg/s)

Referring to Fig. 5 and 6, it can be explained that the temperature at the point of 100 cm and 150 cm from the inlet for the three positions (bottom, side and top) was still quite high. These data indicate that the vapor dominates the flow rate that occurred in the condenser pipe, resulting in the instability of the flow of steam-condensate, causing the flow of condensate to be wavy. When ṁst is increased, it affects the larger instability and start to form a wavy-slug flow. Furthermore, Fig. 7 shows the same tendency for top, side and bottom, namely at the point of temperature measurement results were approximately constant for a point located at 10 cm to 100 cm from the inlet and were still at a temperature of saturation. This phenomenon indicates that condensation process was taking place in that point. Meanwhile, the temperature on the side and bottom points are also still in saturation condition. This mean that condensate formed at this location. At points located at 100 to 150 cm from the inlet, temperatures at the three locations possess the same trend that was decreased sharply, this means that there has been a significant additional amount of condensate at this location.

Furthermore, Fig. 10 shows that the highest coolant water temperature was 27.45oC (at a point 150 cm from inlet) and the lowest one was 19.33oC (at a point 30 cm from the inlet) and the mean was 22.15oC.

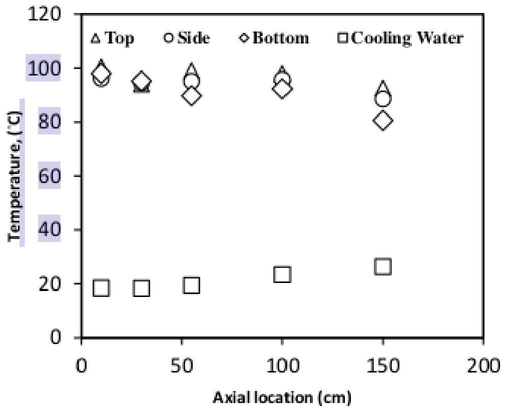

Figure 8: Temperature profiles on the cross-section of test pipe (ṁst= 1.6 x 10-3 kg/s, ṁco = 4.23 x 10-1 kg/s)

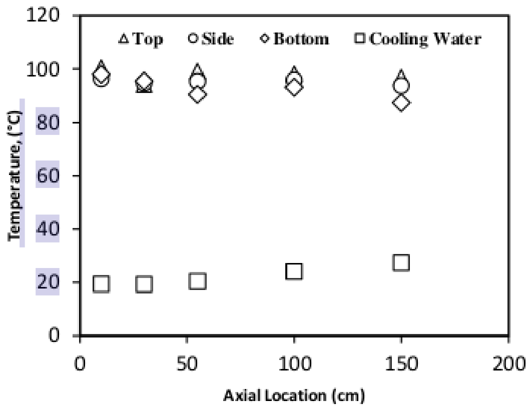

Figure 9: Typical of Temperature profiles on the cross-section pipe test (ṁst= 2.7 x 10-3 kg/s, ṁco = 4.23 x 10-1 kg/s)

Next, Figure 8 shows a slightly different tendency against Fig. 9 at the end, especially at 100 cm to 150 cm from the inlet. It can be explained that the temperature at the point of 100 cm to 150 cm from the inlet for the three positions (top, side and bottom) was still quite high. These data indicate that the vapor dominates the flow rate that occurred in the condenser pipe, resulting in the instability of the flow of steam-condensate, causing the flow of condensate being wavy. In Fig. 9, it is seen that the highest coolant water temperature was 26.35oC (at a point 150 cm from inlet) and the lowest one was 18.31oC (at a point 30 cm from the inlet), while the mean was 21.17oC.

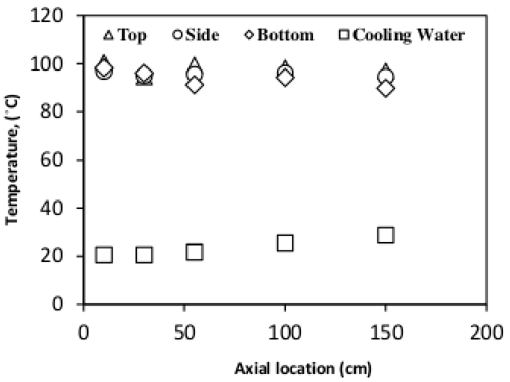

Figure 10: Typical Temperature profiles on the cross-section test pipe (ṁst = 5,9 x 10-3 kg/s, ṁco = 4,23 x 10-1 kg/s)

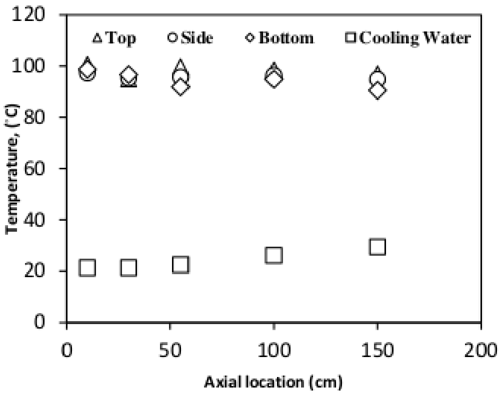

Figure 11: Temperature profiles on the cross-section test pipe (ṁst= 8.9 x 10-3 kg/s, ṁco = 4.23 x 10-1 kg/s)

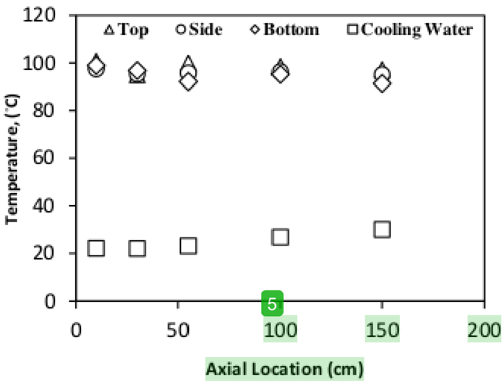

Figure 12: Temperature profiles on the cross-section test pipe (ṁst= 1.1 x 10-2 kg/s, ṁco = 4.23 x 10-1 kg/s)

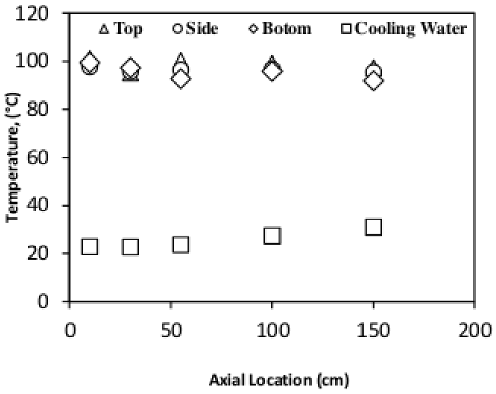

Figure 13: Temperature profiles on the cross-secti on test pipe (ṁst= 1.9 x 10-2 kg/s, ṁco= 4.23 x 10-1 kg/s)

Figures 10, 11, 12, and 13 show that the temperature profiles have a relatively similar trend with those of figures 8 and 9, i.e. the temperature at the points of 100 cm to 150 cm from the inlet for the three position (bottom, side and top) was still quite high. Besides, the cooling-water temperature was still high in the discharge section at the point of 150 cm. These data indicate that the vapor dominates the flow in the condenser pipe, resulting in the instability of the flow of steam-condensate, and cause the flow of condensate being wavy.

3. DISCUSSION

Based on the above results, it was found that the increase of steam mass flow rate (mst) resulted in a larger instability. It was caused by Bernoulli's effect where the increasing steam mass flow rate could increase velocity of steam and make an instability. Then it could start to generate wavy-slug flow. Therefore, the wavy-slug flow pattern occurred close to the outlet of the pipe. In addition, a point farther away from the inlet tends to have about 20 to 50% lower temperature and decreases nonlinearly. This result is in a good agreement with the previous study of Sukamta et al. [11] which stated that the flow pattern area of stratified and wavy flow, wavy-slug flow and slug and large-slug were determined. The transition flow pattern of slug and large-slug is defined as initiating water hammer from ṁco=1x10-1 kg/s to ṁco=6x10-1 kg/s for ṁst=6x10-3 kg/s to ṁst=7.5x10-3 kg/s and ṁco< 3x10-1 kg/s for ṁst=8x10-3 kg/s to ṁst=9x10-3 kg/s. Meanwhile, Lee et al [12] also conducted a similar study and identified several flow patterns ranging from annular-smooth to stratified. The boundary between one flow pattern to another is clearly shown. Where wave flow is found, the film interface displays a series of smaller ripples and larger waves. Large waves appear to join each other into large waves that have a greater mass of liquid, amplitude and speed.

4. CONCLUSION

Reffering to the discussion, it can be concluded that temperature profiles in the events of condensation of steam flow cooled using parallel flowing water in the outside of a horizontal pipe were affected by the radial (cross-sectional) and axial positions along the annulus pipe, where the temperature of the upper radial position tends to be higher while a point farther away from the inlet tends to decrease non linearly and have a 20 to 50% lower temperature. Also, the increase of steam mass flow rate (mst) resulted in the larger instability and start to generate wavy slug flow and other flow pattern, i.e. stratified, stratified-wavy, wavy, and wavy-slug. Both of the results are critical for an input in designing an early warning system of a safe two-phase piping system during steam condensation. This result is consistent with previous studies for steam flow in the opposite direction to cooling flow [11]. Thus, changing the direction of cooling flow from the opposite to the direction of the steam flow does not significantly affect the two-phase flow pattern that occurs. For further research, it is recommended to investigate and analyze about heat and mass transfer occurred in the test section.

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