Visualization of cross-sectional flow structure during condensation of steam in a slightly inclined horizontal tube

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1. Introduction

In the nuclear engineering field, condensation inside tubes is one of the most studied phenomena nowadays. Much of this work has been carried out on two-phase flow condensation systems in order to develop heat transfer models to predict the behavior of such phenomena. These systems are intensively studied due to many numbers of ways in which the liquid/gas interface can be distributed within the flow inside a tube. However, there are a number of flow characteristic for the interfacial distribution, which is a considerable help to predict the type of flow presented in the area of interest. These flow characteristics called flow patterns still depend on a proper visualization technique in order to identify such local distribution [1]. These proper distributions will have a dependence on the inclination of the tube as well, as it was demonstrated by Lips and Mayer [2].

This work is focused on presenting an experimental investigation to visualize the cross-sectional two-phase flow structure for condensation of steam in a horizontal tube and identify the liquid-gas interface using the axial-viewing technique. This innovative technique developed by Hewitt [3] and more recently used in visualization works by Badie [4], permits the achievement to identify those systems in the area of interest by looking directly into the two-phase flow system during condensation of steam inside a pipe with technology such a high speed camera. The local flow pattern is identified from the experimental image based on the flow pattern map developed by J. El Hajal, J.R. Thome and A. Cavallini [1].

2. Methods and Results

The schematic of the experimental setup is seen in Fig. 1. Steam is generated using a steam generator of 2kW capacity in order to give a desired mass flow rate, steam then flows through a superheater in order to make sure of having saturated steam at 100 ℃ and 0.1Mpa at the inlet of the precooler which is a parallel flow heat exchanger with inner tube diameter of 19.0mm, annular tube diameter of 25.4mm and an inclination of 3° with respect to the horizontal. Steam is partially condensed in the precooler to have a desired steam quality at the outlet of the precooler. In order to remove the amount of heat desired to obtain a certain quality at the outlet of the precooler, the mass flow rate of cooling water whose temperature is below the saturation temperature is varied. After cooling water flows through the precooler, it passes through a heat exchanger to remove the heat that was previously taken from the precooler and then deposited to a heating tank where temperature is fixed according to experimental conditions. The local quality at the outlet of the precooler was calculated based on energy balance as follows,

$$x = 1 - \frac{\dot{m}_{CW} * C_p * \Delta T}{\dot{m}_{Steam} * h_{fg}} \quad (1)$$

Where: x is the steam quality at the outlet of the precooler, $\dot{m}_{CW}$ is the mass flow rate for cooling water, C_p is the specific heat at constant pressure, ΔT is the temperature difference between the inlet and outlet parts for the cooling water, $\dot{m}_{Steam}$ is the mass flow rate of steam coming from the steam generator and h_{fg} is the vaporization enthalpy for steam at 100 ℃ and 0.1 Mpa

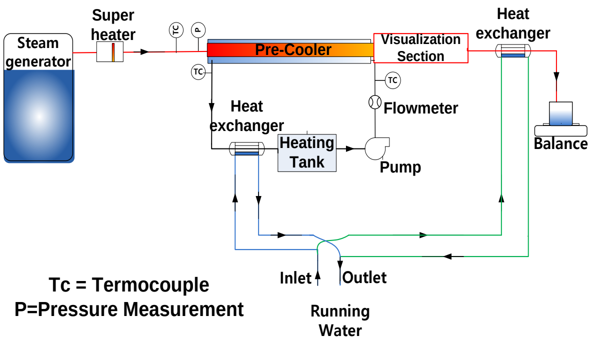

Fig. 1. Schematic of the experimental setup

The steam partially condensed in the precooler to have a desired quality flows into the visualization section, which is composed of an axial viewer and a high speed video camera (Phantom V7.3), as shown in Fig. 2. A short section of the visualization pipe with approximately 10 mm of diameter is illuminated. The illuminated zone is recorded through a window, which is kept free of liquid by passing an air purge system over it and down the viewing tube.

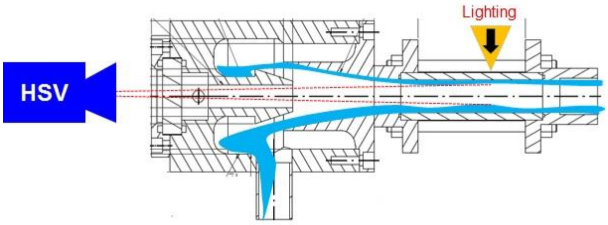

Fig. 2. Schematics of the visualization section

The experimental setup for the visualization section is shown in the Fig 3.

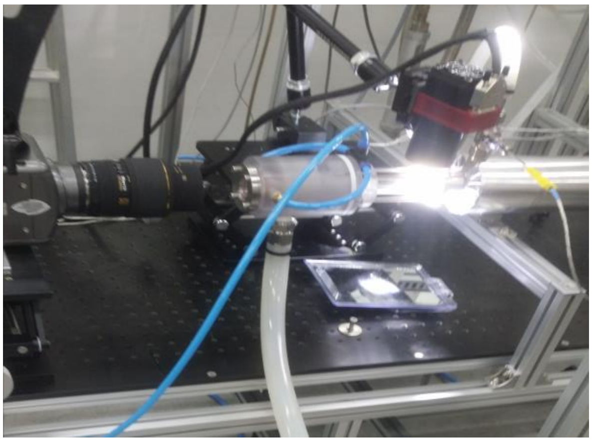

Figure 3. Experimental setup of visualization section

After the visualization section, the steam-liquid mixture goes through a heat exchanger where it gets completely condensed and the condensed liquid flows down to a balance in order to measure the mass flow rate.

Cross-sectional flow structure images were taken during steady state conditions and the representative results are presented in Figs. 4 and 5. The time interval between images is 10 mSec

Figure 4. Shows a stratified flow for the conditions of steam quality of 0.7 and mass velocity of 2.09 $\frac{Kg}{m^2*s}$, when comparing this result with previous studies mentioned above and comparing the type of flow pattern predicted, it is seen that the pattern for this configuration is stratified flow.

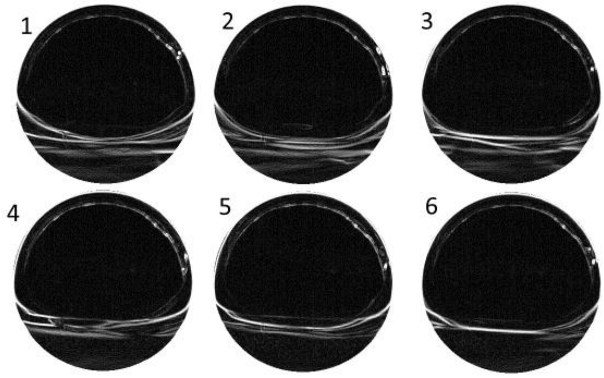

Fig. 4. Cross Sectional image for a steam quality of 0.7 and steam mass velocity of 2.09 $\frac{Kg}{m^2*s}$.

In the Figure 5. The conditions for this configurations were for steam quality 0.6 and steam mass velocity of 2.62 $\frac{Kg}{m^2*s}$, when comparing this results with previous studies it can be seen that the flow pattern obtained with this configuration tends to go to stratified-wavy area, this is due to the increase of the mass velocity for steam.

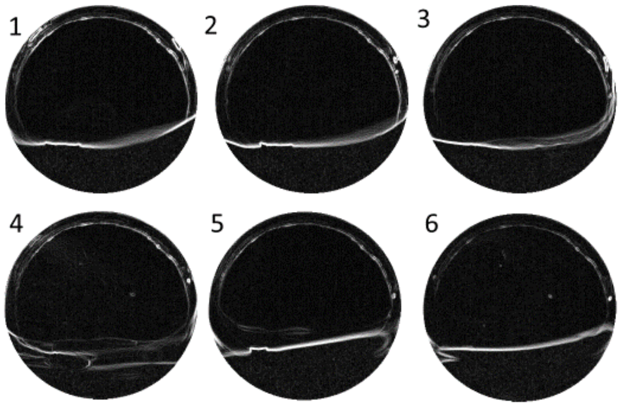

Fig. 5. Cross Sectional image for a steam quality of 0.6 and steam mass velocity of 2.62 $\frac{Kg}{m^2*s}$

3. Conclusions

An experimental work to visualize and locate the liquid-gas interface for steam condensation in horizontal tubes with slightly inclination was developed on this research

The experimental results shows that the axial viewing technique works well with condensation phenomena and can be used for further developments in the field such as determination of liquid film geometry and calculation of void fraction. Specifically, results clearly demonstrate that the axial-viewing technique is able to distinguish the specific liquid-gas interface for steam condensation.

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