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Flow Pattern Map of Steam-Condensate Flow in a Horizontal Double Pipe

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ABSTRACT

There has been some success story in the formulating models for different flow regimes, and a number of coresponding flow maps for horizontal has been developed. Furthermore, most of the maps were generated based on visual observations and are, therefore, subjective in nature. Meanwhile, slugging phenomenon that can be defined as initiation of a water hammer is a very interesting topic because it has a strategic impact on safety factor of the equipment in piping systems i.e. pressurized water reactor (PWR), heat exchanger, steam or gas transportation in chemical industry, air conditioning, etc. The objective of the present research was to investigate the slugging as an initiating water hammer phenomena through non directly contact steam condensing in a horizontal pipe to develop the flow pattern map of steam-condensate flow in a horizontal double pipe.The experimental apparatus used in the present experimental study consisted of an inner annulus pipe made of copper (d_{in} = 17.2 mm, d_o = 19 mm) with a length of 1.8 m. The outer pipe annulus was a galvanized iron pipe (d_{in} = 108.3 mm, d_o = 114. 3 mm) with a length of 1.6 m. The liquid being tested was water. The experiments were conducted at a static pressure of P_s= 108.825 kPa dan the temperature of T = 119.7 °C. The pressure drop in axial direction of the test was directly measured by using a differential pressure tranducer (validyne, accuracy of ±0.25%) with a sampling rate of 7.353 kHz. The obtained experimental data of temperature and differential pressure fluctuations during the steam condensation in a horizontal pipe was analyzed using a statistical analysis.It was found that: 1) the flow pattern map of non slugging (stratified and wavy flow), transition (wavy-slug flow), and slugging (slug and large-slug), were determined, here the transition flow pattern of slug and large-slug is defined as a initiating of water hammer, 2) transition area range of wavy-slug flow pattern are from $\dot{m}_{co}=1\times10^{-1}$ kg/s to $\dot{m}_{co}=6\times10^{-1}$ kg/s for $\dot{m}_{st}=6\times10^{-3}$ kg/s to $\dot{m}_{st}=7.5\times10^{-3}$ kg/s, and $\dot{m}_{co}< 3\times10^{-1}$ kg/s for $\dot{m}_{st}=8\times10^{-3}$ kg/s to $\dot{m}_{st}=9\times10^{-3}$ kg/s. These obtained data are very important in order to develop a database for input in a safe early warning system design of two-phase flow piping installation system during the steam condensation.

Keywords
Flow pattern map, slugging, steam-condensate, horizontal double pipe, water hammer

1. INTRODUCTION

Research in relation to the condensation heat transfer coefficient on a vertical pipe. The test section consisted of a vertical, double-pipe cylinder made of stainless steel SUS304 has been conducted by Nagae T , Murase M, Wu T , Vierow K. [1]. The inner tube was the heat transfer tube with inside diameter of 19.3 mm, wall thickness of 3.04 mm and height of 1.8 m. The mixture of steam and air floweds into the tube from the bottom inlet. The coolant water flows along the outer surface of the heat transfer tube. The temperature distribution in the axial direction under pressure of 0.1 MPa, at an inlet steam flow rate of 1.23g/s is found. Since the steam condenses and its partial pressure drops as it flows downstream, steam–air mixture temperature decreases accordingly. While the enthalpy of the steam is higher near the inlet, and thus the temperature decrease rate is low, the enthalpy decreases with the temperature decrease and the temperature decrease rate tends to grow higher.

More than five decades there have been studies efforts toward better understanding the mechanism of two-phase flow. Meanwhile because of the complex nature of two-phase flow, a complete understanding has not yet been achieved. Many investigations have postulated that the mechanisms are different for each flow regimes or pattern. Accordingly, there has been some success story in the formulating models for different flow regimes, and a number of coresponding flow maps for horizontal has been developed. A well known how pattern map was proposed by Mandane et al. [2]. Furthermore, many of the maps are the product of visual observations and are, therefore, subjective in nature. By far the most commonly used methods to discriminate flow regimes, particularly in early years, were application of visual and high speed cameras. More modern methods use analysis of the time series on experimental data from X-ray, conductance probes, pressure tranducers in attempt to classify the pattern objectively. Matsui [3,4] used differential pressure tranducers, Tutu [5] used absolute pressure tranducers, Brauner D., O. Shaham, and Y. Taitel [6] used conductance probes, Jones and Zuber [7] used an X-ray void measurement system for the vertical upflow in a tube. Elkow and Rezkallah [8] used a capacitance sensor to measure void fluction. In most cases the analysis of the power spectrum density (PSD) function are usually employed to extract the periodic feature of a signal. Matsui [4] calculated the PSD and probability density function (PDF) of the transient pressure drop signal to identify flow pattern of two-phase flow in a vertical pipe. Franca F., Acikgoz M., Lahey R.T. Jr., Clausse A. [9] and Cai, Y., Wambsganss M.W., Jendrzejczyk J.A. [10] employed PSD and other fractal techniques for flow pattern identification as well. Wang [11, 12] used Nonlinear analysis to analyze differential pressure fluctuations of two phase flow through a T-junction with the aim to make clear the two-phase flow behavior splitting at a T-junction. These results may be significant for better understanding the flow structure and also for establishing valid models different from conventional viewpoints.

Based on the above description, an investigation of steam condensation and two phase flow is very wide-ranging. Many things can still be explored to explain the phenomena of two phase flow, especially related to condensation, both in the geometry, orientation or position of the pipe, and condensation process. From those facts, the objectives of this research are to study the two-phase flow pattern map of steam-condensate flow in a horizontal double pipe.

2. METHODOLOGY

The experiment apparatus used in present experimental study is shown in Fig. 1 and the detail of the test pipe is in Fig. 2.

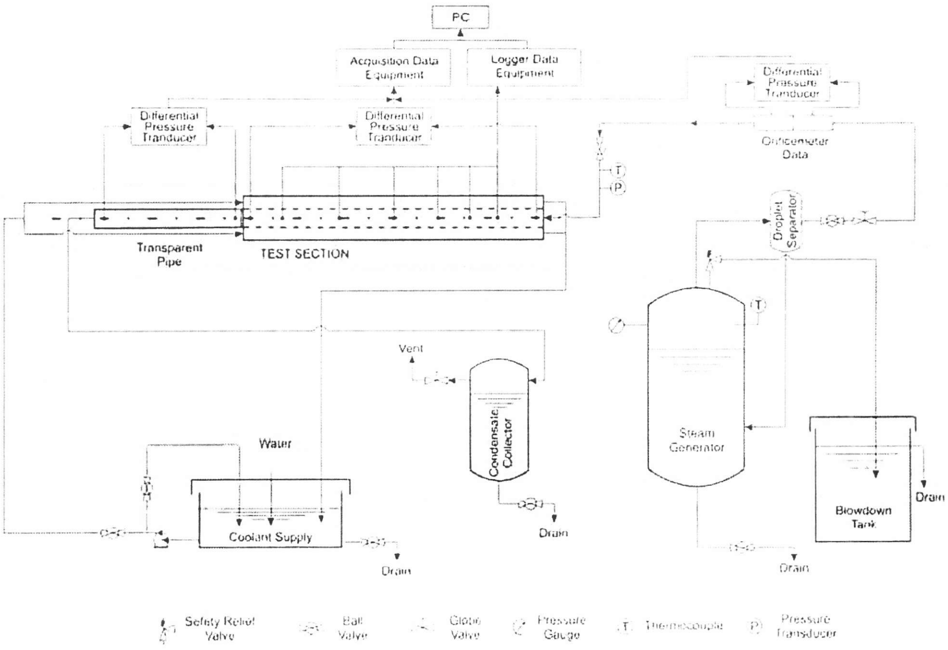


Figure 1: Experiment apparatus used in the present study

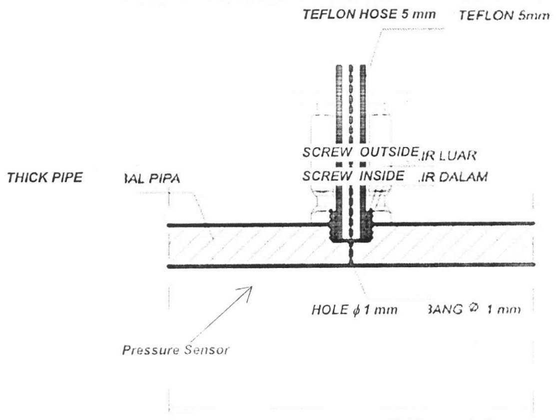


Figure 2: The detail installation of the differential pressure sensor

The Tested liquid was water. The experiment apparatus consisted of the inner annulus pipe made from copper (d_{in} = 17.2 mm, d_o = 19 mm) with a length of 1.8 m. The outer pipe annulus is a galvanized iron pipe (d_{in} = 108.3 mm, d_o = 114. 3 mm) with a length of 1.6 m. In the present experimental study, the water 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 horizontal pipe. The experiments were conducted at a static pressure of P_s= 108.825 kPa dan the temperature of T = 119.7 °C. The water was used as a coolant in the outer of annulus pipe. The pressure drop in the axial direction of the test was directly measured by using a differential pressure tranducer with a sampling rate of 7.353 kHz.

3. RESULTS AND DISCUSSION

Flow pattern transition region map between non-slugging and slugging can be seen in Fig. 3. This map are derived from statistical analysis of pressure difference fluctuation data with the frequency domain (power spectra density) and time domain (root mean square, standard deviation, Skewness, Kurtosis and normal distribution). Based on the results of statistical analysis it can be concluded that at different cooling water mass flow rate ranging from $\dot{m}_{co}$=1.24×10^{-1} kg/s to $\dot{m}_{co}$= 5.78×10^{-1} kg/s for steam mass flow rate less than $\dot{m}_{st}$=6×10^{-3} kg/s, the flow pattern is stratified or wavy flow that categorized as non-slugging. In the same range of cooling water mass flow rate, for steam mass flow rate $\dot{m}_{st}$=6×10^{-3} kg/s to $\dot{m}_{st}$=7,5×10^{-3} kg/s, the flow pattern is Wavy-slug that then classified as transitional. Furthermore, for the small cooling water mass flow rate (less than $\dot{m}_{co}$= 3×10^{-1} kg/s) and for high steam mass flow rate ($\dot{m}_{st}$=8×10^{-3} kg/s to $\dot{m}_{st}$=9×10^{-3} kg/s) re-establish the wavy-slug flow pattern (transition) and stratified (non-slugging). However, for the large cooling water mass flow rate ($\dot{m}_{co}$= 4×10^{-1} kg/s to $\dot{m}_{co}$= 6×10^{-1} kg/s) and the steam mass flow rate ($\dot{m}_{st}$=8×10^{-3} kg/s to $\dot{m}_{st}$=9×10^{-3} kg/s), the flow patterns occurred slug or large-slug.

Next, for the small cooling water mass flow rate (less than $\dot{m}_{co}$= 2×10^{-1} kg/s) and steam mass flow rates between $\dot{m}_{st}$=7×10^{-3} kg/s to $\dot{m}_{st}$=8×10^{-3} kg/s is also slug flow pattern occured. Based on the above description, it can be concluded that the flow pattern that occurs is the start from stratified and Wavy (non-slugging), Wavy-slug (transitions) and slug or large slug (slugging). These data are very important to complete the database that can be used as an input in early warning system design for plant safety piping system. Next, visualization of flow pattern in a horizontal transparent pipe (d_i =17 mm, *plexiglass*) is shown in Fig. 4. Position of the transparent pipe is after the condenser pipe.

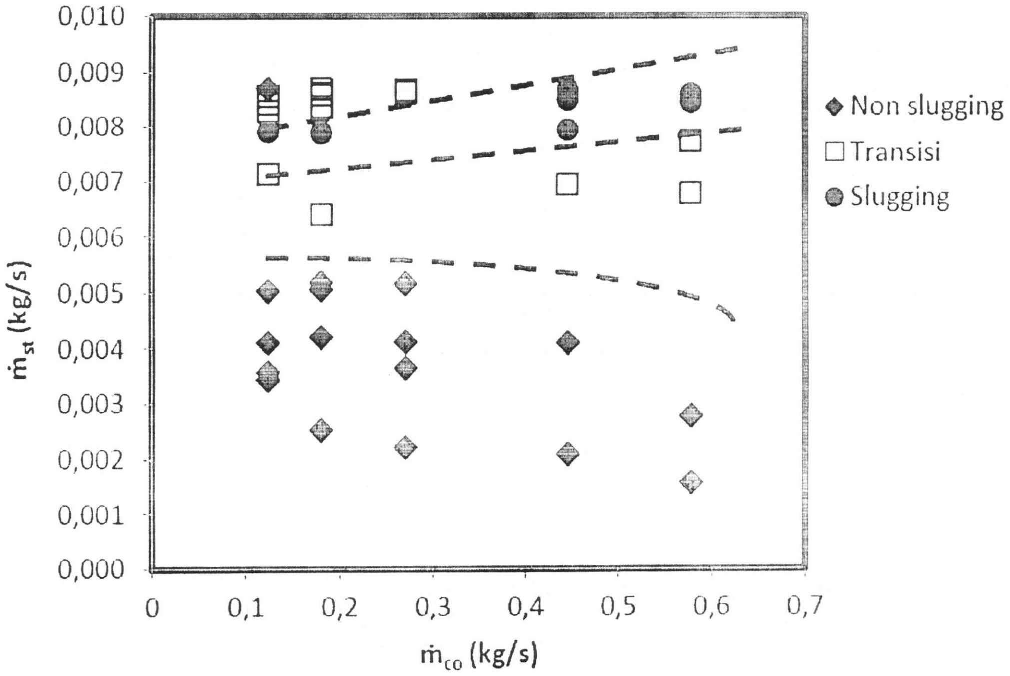
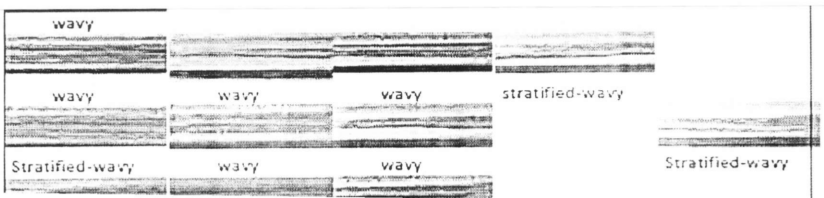


Figure 3: Flow pattern map of slugging and non slugging



NOMENCLATURE

d = diameter (m)
A=area (m^2)
Q_{TS} =Heat transfer rate (kW)
$\dot{m}$=steam mass flow rate (kg/s)
sat=saturated
T = temperature (°C)
h = local heat transfer coefficient ($W/m^2.K$)
k = conduction thermal coefficient (W/m.K)
r = radius (m)
$\dot{m}$ = mass flow rate (kg/m^3)
L = length (m)
s = second
Hz = hertz

Subcript

i = inner
o =outer
w = wall
cl = centerline
co = coolant water
wo= wall-outer
wi=wall-inner
bott=bottom
st=steam
av=average

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