Visualization of Two-Phase Flow in Metallic Pipes Using Neutron Radiographic Technique

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The study of two-phase flow is a matter of great interest both for the engineering and oil industries. The production of oil and natural gas involves the transportation of fluids in their liquid and gaseous states, respectively, to the processing plant for refinement. The forecasting of two-phase flow in oil pipes is of the utmost important yet an extremely difficult task. With the development of the Electronic Imaging System, installed in J-9 irradiation channel of the IEN/CNEN Argonauta Reactor, it is possible to visualize the different types of two phase air-water flows in small-diameter metallic pipes. After developing the captured image the liquid-gas drift flux correlation as well as the void fraction in relation to the injected air outflow for a fixed water outflow can be obtained.

I. INTRODUCTION

In the last few years the study of two-phase flow has been a matter of prime importance for the engineering and oil industries. The production of oil and natural gas involves the transport of fluids in their liquid and gaseous states to the processing plant where they are refined. The prediction of two phase flow in oil pipelines is a notable, yet extremely complicated task. Different modes of two-phase flow can be found in this paper depending on the position of the tube vertical or horizontal. The Standard for determining liquid-gas two-phase system in vertical pipe are: *bubble, slug, churn and anullar flows* [1][6]. In this study the prime aim is to examine two phase flow in the passage of air-water through an aluminum tube with an internal diameter of 6 mm using the Real Time Neutron Radiographic Image technique [2]. We used the Electronic Imaging System (SEI) designed and installed in the irradiation channel of the IEN/CNEN Argonauta reactor [3] and an apparatus which simulates different types of two-phase air-water flows inside the aluminum tube.

II. METODOLOGY

Neutron Radiographic Imaging System

The Neutron Radiographic Imaging System is made up of thermal neutron beams, a device capable of gathering information about the transmission of the beams through the sample. As a source of the neutrons we used a thermal neutron beam of the IEN/CNEN Argonauta reactor operating at a nominal power of 340 W, generating a thermal neutron flux in order of 4.46×10^5 n/cm^2.s, at the exit of the irradiation channel, J-9. The collimation rate of the neutron beam, L/D, was 70 and the rate n/γ of 3×10^6 n/cm^2.mR, with a average neutron energy of 30 meV. Figure 1 shows an external thermal column located in front of the Argonauta reactor and the neutron radiographic system mounted at the irradiation channel, J-9. The visualization of two-phase flows inside metal pipes was only made possible after the development and implementation of the Real Time Electronic Imaging System in the Argonauta reactor. This Real Time image gathering system consists of a scintillator screen for neutrons, NE - 425, with a typical composition of ^{6}LiF + ZnS, which converts the incident neutrons into light photons through the predominant reaction ^{6}Li(n, α)^{3}H, emitting 1.7×10^5 light photons for every detected neutron; a Panasonic video camera model WV - CL 920 with a CCD of 1/2" (inch, main diagonal) with a resolution of 580 lines, operating with a minimal illumination of 0.02 LUX at the lens aperture, *f*, of 1.4. In optical coupling a Canon manufactured MACRO lens, f 1.0, allowing a manual adjustement of the focus was used; besides, a mirror placed at angle of 45^o to reflect the light photons in the direction of the CCD camera.

The components of the Real Time Electronic Imaging System can be found in a hermetically-sealed box though there is an additional shield made of boron paraffin, cadmium and lead in the area where the CCD camera was positioned. The images were digitalized by an external plate from *Pinnacle* (Model PCTV USB 2.0) with a resolution of 720 $\times$ 480 pixels, which records in compressions of 6.0 kbits/sec in the MPEG-2 format through Pinnacle *Vision version 1.0* computer program. A diagram showing the SEI scheme in Real Time and photographs of SEI are show in Figure 2, where one can see the components. The neutron radiographic images were converted to the *AVI* format and developed using the *Image Pro Plus* v.4.0 computer program.

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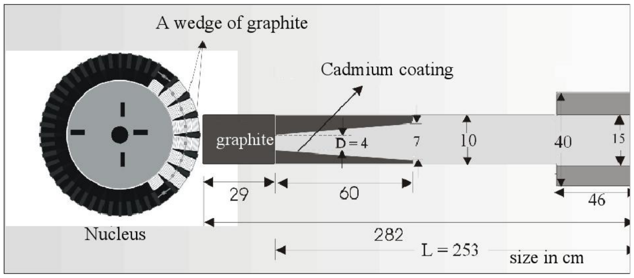


Figure 1: Schematic diagram of collimation the neutron beam in the irradiation channel, J-9, of the IEN/CNEN Argonauta reactor.

The Experimental Apparatus of the Two-Phase Flow

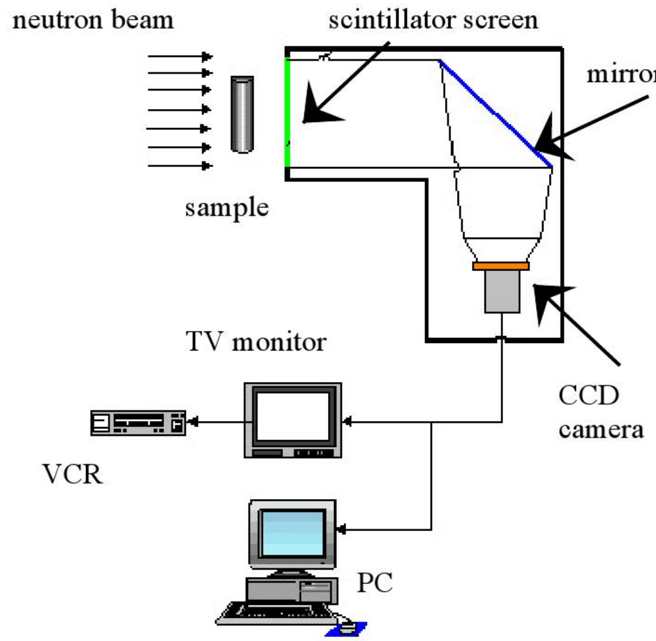
In order to obtain different images of the two-phase flows an apparatus made up of an injector, an aluminum tube with an internal diameter of 6.0 mm, a thickness of 1.0 mm and length of 120 cm; a "separating tank" made of the transparent acrylic, 36.5 cm large and 57.4 cm high; a water leakage metre (R1); an air leakage meter (R2); a hydraulic pump and an air compressor was designed and built at the exit point of the irradiation channel, J-9, of the Argonauta reactor. The water was pumped up by the hydraulic pump while the compressor injected air. The two-phase air-water mixture flowed through the test tube to the separating tank where the air was released into the atmosphere. Figure 3 (a) presents a schematic diagram of this apparatus and Figure 3 (b) shows photos of the apparatus with the Electronic Imaging System installed at the exit point of the irradiation channel, J-9. With the apparatus shown in Figure 3 (b) we have obtained images Neutrongraphic Real Time turbulance model for the default values for desired type of flow. That is, if I want a slug flow, I must enter some values in the flow meters, which only allow these values slug flow. This had already been in the references.

III. RESULTS

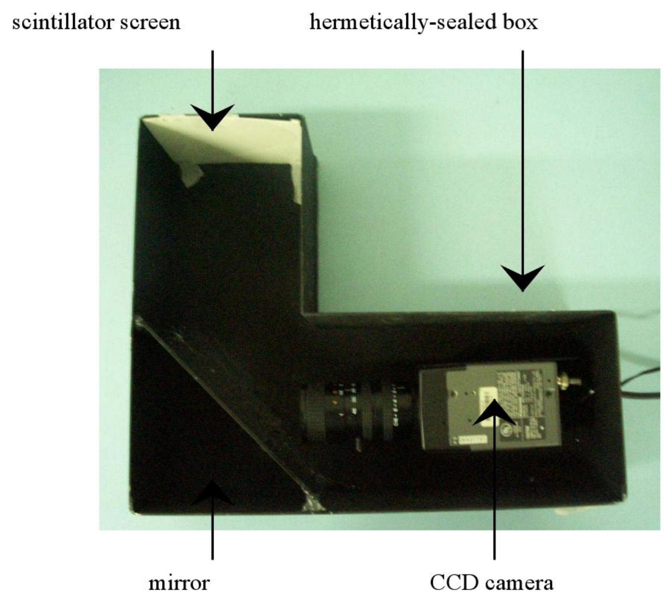
The Real Time Neutron Radiographic imaging technique has made it possible to observe different types of flows, especially the slug flow which is mostly used in engineering [3][8]. In slug flow the diameter of the bubbles are approximately the diameter of the tube, and the top of the bubble has a spherical shape and gas (air) is separated from the tube wall by a thin liquid drops. Figure 4 shows by sequence Real Time two-phase air water flow images taken by the apparatus shown in Figure 3 (b) for water flow velocity (j_L) and of air movement (j_G) of 0.9 m/s and 0.7 m/s respectively.

The *bubbles* flow is somewhat similar to the slug, except for the large amount of water (dark region) that is found inside the supposedly air bubble. As the slug is no water in this region (interior) concludes that this is the flow of bubbles and can be confirmed by the measures set out in the pre-flow meters.

The *churn* flow occurs when the flow mouthful stabilizes and large bubbles are broken leading to a chaotic flow in the center of the tube, displacing the liquid against the walls.



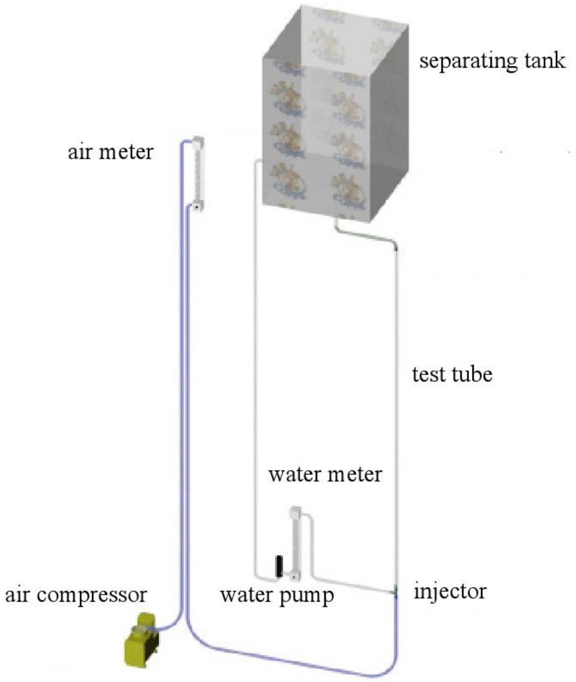
(a) Diagram showing the Electronic Imaging System (SEI) of the Real Time Neutron Radiographic Image installed in the IEN/CNEN Argonauta reactor;



(b) Photographs of the sealed box containing the components of the SEI.

Figure 2

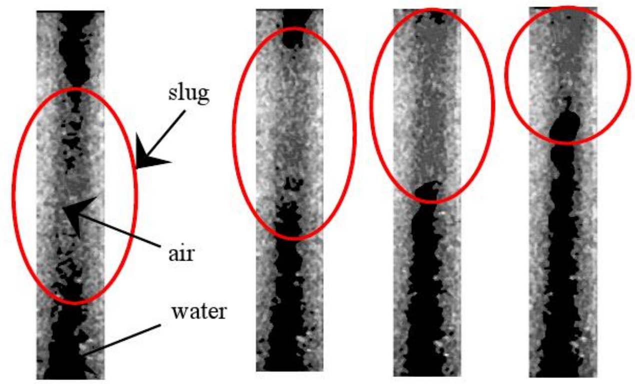
Figure 5 shows two-phase flows types registered by the Neutron Radiographic Imaging System for different water flow speeds and air movement. The images in Figure 5 (a) refers to slug-type two-phase flows; (b) here, the leakage meters were adjusted to allow the formation of bubbles (j_{-1}= 0.2 m/s e j_g= 0.4 m/s); (c) the image here refers to a churn



(a)

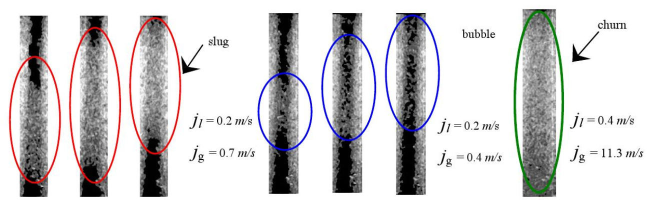
(b)

Figure 3: (a) presents a schematic diagram of this apparatus and Figure 3 (b) shows photos of the apparatus with the Electronic Imaging System installed at the exit point of the irradiation channel, J-9. With the apparatus shown in Figure 3 (b) we obtained Real Time Neutron Radiographic Images of twophase flows relative to pre-established leakage for the desired type of flow.



(a) (b) (c) (d)

Figure 4: Sequence of slug-type two-phase flows.



(a) (b) (c)

Figure 5: Real Time Neutron Radiographic images of different types of a flow: (a) slug, (b) bubble and (c) churn.

flow where the air moves vertically around the center of the tube (j_{-1}= 0.4 m/s e j_g= 11.3 m/s).

Determination of Drift Flux and Void Fraction

With a view to determining the correlation between the drift flux and the void fraction through Real Time Neutron Radiographic image test with regard to the experimental conditions in generating slug-types flows the velocity of the movement of air and that of the water flow will vary. In this case, the correlation between the drift flux based on the Ishii [4] theory model for slug-type flow in a cylindrical tube, diameter 6 mm, can be expressed by equation 1 as follows:

$$\overline{v}_g = \frac{\langle j_g \rangle}{\langle \alpha \rangle} = C_0 \langle j \rangle + \overline{v}_{gi} \,, \qquad (1)$$

where $\overline{v}_g$ is gas velocity in relation to the air movement (j_G) and water flow (j_L); α is void fraction at a particular position of the tube; j the total velocity of the two-phase flow; C_0 the parameter distribution and $\overline{v}_{gi}$ the velocity of drift For the the void fraction tests were conducted under experimental conditions for formation on the types of flow and *slug* and *bubbles*, to which range to the speeds of air displacement and water flow, which were arranged in Table I.

Using the value suggested by Ishii [4] for a flow-type slug

TABLE I: Velocity flow of liquid j_l (water) and velocity gas j_g (air).

j_l (m/s)	j_g (m/s)
0,4	0,7
0,9	0,7
0,4	2,2
0,9	1,4
0,4	11,3
0,3	0,7
0,7	0,7
0,4	0,4
0,9	0,4

quoted in Table II, we obtained a value of 0,08 m/s for speed drag of an air-water two-phase flow in a tube with 6 mm interbal diameter. Substituting this value in equation (1) rearranged:

$$\langle\alpha\rangle = \frac{\langle j_g\rangle}{C_0\langle j\rangle + \bar{v}_{gi}}\,, \qquad (2)$$

and the values of velocities, air drainage, provide in Table I, the equation $j = j_l + j_g$, we obtained the gas velocity relative to each change of speed of air and water, as shown in Table III.

TABLE II: Suggested values for the speed of drag for each scheme [4].

Flow regime	C_0	v_{gi}	**References**
Bobbles	$1,2-0,2\sqrt{\frac{\rho_g}{\rho_f}}$	$1,4\sqrt[4]{\frac{\sigma_g\Delta\rho}{\rho_f^2}}$	Ishii, Zuber [4] and Wallis [10]
Slug	$1,2$	$0,35\sqrt{\frac{gd\Delta\rho}{\rho_l}}$	Ishii [4] and Collier [9]

In Table II, it follows that:
v_{gi} is the speed gas [m/s];
$\Delta\rho$ is the difference between the densities of the two phases [kg/m3];
d is the diameter of the pipe [m];
g is the gravitational acceleration [9,81 m/s2];
ρ_l is the density of the liquid.

Figures 6 and 7 respectively show the correlation between drift flux and the total velocity of the two-phase flow, j, and the void fraction obtained as a result of the velocity of the movement of the injected air for the two water leakage values.

Using the equation (1) we obtain the void fraction as a function of the injected air shown in Figure 7. It is observed that the void fraction increases when the air flow increases, for each water flow, which is consistent with theoretical predictions suggested by Ishii [4].

IV. CONCLUSIONS

The application of the Real Time Imaging System installed in the IEN/CNEN Argonauta reactor has made it possible to

TABLE III: Values obtained experimentally for the total two-phase flow ($j = j_l + j_g$) and gas velocity on various travel speeds of air and water drainage.

j (m/s)	v_g (m/s)
1,1	1,4
1,6	1,9
2,6	3,2
2,3	2,8
11,8	14,1
1,0	1,2
1,4	1,7
0,8	1,1
1,3	1,6

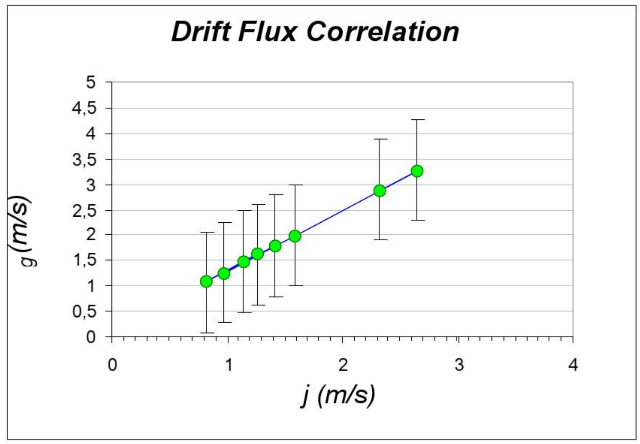


Figure 6: The correlation between drift flux, obtained using the Real Time Neutron Radiographic imaging system for 6 mm diameter aluminium pipes and different velocities of total two-phase flow (j).

visualize two-phase air-water flows in 6 mm diameter aluminium pipes. In the Slug two-phase flow regime and for the different values obtived for air and water leakage it showed that slug flow does not only occur in a straight line as concluded earlier by Shohan [5]. In Figure 5(b) the standard bubble seems to have the same characteristics of slug (Figure 5(a)), as what happens is that the flux of neutrons from the reactor is low and the intensifying screen and CCD camera were already damage, so the task of viewing images neutrongraphic is very careful, we must have techniques for such a view. And similar to a medical radiograph where sometimes see something only after the doctor tells us. In figure 5(c) the pattern churn does not identify the liquid in any region, again this is because the flow of reactor and the resolution of the camera CCD did not help us. It is understood that no water droplets within the large concentration of air and there is a very thin layer of water on the walls, but such a view was not possible for several reasons. As mentioned the reactor is low power and at times the flux of neutrons in quantity and intensity various of operation to operation.

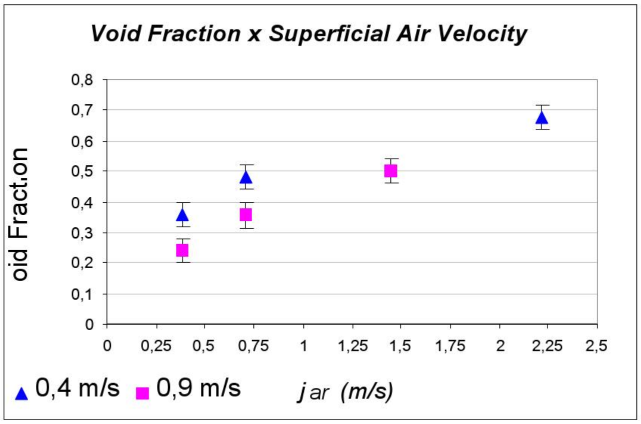


Figure 7: Void Fraction obtained using Real Time Neutron Radiographic Imaging for 6 mm diameter pipe and for different air movement velocities.

The correlation between drift fluxes, shown in Figure 6 resulted in a linear coherent correlation with that obtained by Hibiki et al [6]. The behaviour of the void fraction obtained, using the Real Time Neutron Radiographic Imaging System tests carried out showed that it is well adjusted to the drift flux model.

Although the uncertainties appears to be enormous, the work was done with much accuracy. Many measures were taken and we choose the best. We change the water a few times and we used only distilled water so that no clogging occurred in the water meter and water pump. The problem encountered was related to the conditions of neutron flux, which was low, and also the energy peaks that can occurred at the time of irradiation causing the injector of air and pump varied.

The images obtained showed that the Electronic Imaging System installed at the irradiation channel, J-9, of the IEN/CNEN Argonauta reactor [3] is suitable for performing Real Time Neutron Radiographic Imaging to visualize two-phase flows small-diameter in metallic pipes which is an indispensable tool for the engineering and oil industries.

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