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Systematic investigation of two-phase current in open /special channels

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Abstract

In the present paper, the systematic study of two-phase current in open channels (water-air) has been studied experimentally and numerically. A laboratory device for observation and photography has been built and set up for laboratory examination of this issue. The fluids used were climatic, and the flow results for the selected modes were obtained by changing the velocity and oher parameters and compared with the results of previous research. Also, the effect of pressure drop on the test process can be seen. The energy conservation equation is used to advance the calculations in this paper. As a result, in this paper, the effect of all existing conditions on the flow of the two phases, including velocity and dimensions of the channel, surface pressure and tension, etc., has been investigated.

1. INTRODUCTION

Gas-liquid two-phase flows have many implantations in the gas and oil, petrochemical, nuclear technology, and other industries. Two-phase currents in pipes, which are employed in various slopes from horizontal to vertical, are one of the most common industrial uses. One of the most important natural and unintended phenomena of this interaction is the mixing of water passing through the structures and the surrounding airflow, which in some cases causes severe reactions between the existing climate and causes considerable damage. This type of current is called "two-phase current". One of the most important problems in the analysis of two-phase current in pipes is to determine the exact pattern of flow or distribution of liquid and gas phase inside the pipe (Hansen et al.: 2004). Because many essential engineering and design parameters like heat transfer, mass transfer, pressure drop etc. are strictly related to the distribution of phases, so determining this distribution or in other words determining two-phase flow patterns is one of the critical requirements for two-phase flow analysis that follows all the rules governing fluid mechanics. Two-phase current systems are highly complex (even one-dimensional two-phase currents in ducts) and many characteristics make these types of currents indeterminate and complex compared to single-phase currents (Lee & Mudawar: 2007). To simplify these complexities, various researchers have conducted model experiments to use laboratory and experimental results to obtain simple equations for the analysis of practical and engineering problems, two-phase climate flows in various problems, and Various structures occur - including chemical processes, energy generation and formation, water collection and transmission systems, the oil industry, and offshore hinge lines for oil transportation (Cheng & Mewes: 2006).

It should be noted that despite many attempts to classify the types of biphasic flow regimes, all of these methods are highly qualitative and often conform to the personal views of different researchers. So far, different regimes have been defined, and a wide range of titles have been used for this purpose. These patterns are flow, layer or mould flow, layer flow, wave flow, mixing flow, annular flow, and droplet flow. Methods for predicting two-phase flow patterns within flow transmission pipelines are generally divided into two groups: using experimental and laboratory facilities and using analytical models (O'Neill & Mudawar: 2020). For many years, the prediction of various two-phase air-water flow regimes in pipelines has been considered through experimental experiments. A common method for this purpose is to collect experimental data on the flow rates of the liquid and gas phases and the physical properties of each phase on a section of pipeline under test. Many studies have now been conducted in the fields of experimental, kinematic, and dynamic two-phase flow modelling, but many aspects of this phenomenon remain unknown (Zhang et al.: 2020). Usually, the necessary research is done to identify the types of biphasic flow patterns in the channel and tubular lines of biphasic current transmission using direct current observation method. Among the methods that make these observations possible are "very fast photography" and "X-ray audiography"; So that using the received images, the type of current available can be interpreted to some extent.

The most important possible patterns in horizontal and near-horizontal ducts (tunnels and closed ducts) are floc, wave, and stratigraphic regimes. Especially when the duct length is long, other diets occur in a very small length and very quickly become the main diets mentioned with a limited length transfer, and even if they appear, they generally have many similarities to the three mentioned diets. Typically in large sloping canals, the flow velocity in operation is more than 5 to 10 m/s, and the Reynolds number is in the range of 10^7 *to* $10^9$and surface aeration is almost always on these Structures are observed. Due to the existence of various equations and parameters governing such high velocity and aeration flows, their numerical analysis is not possible, and in most cases to solve many problems related to hydraulics, such flows have to use hypotheses and simplifications. We are the ones who make the results differ from reality (Kopparthy: 2020).

Due to the observed geometric similarities, many researchers consider these regimes as one of the three main regimes mentioned. The stratigraphic regime occurs when water or liquid phase at the bottom of a pipe or channel and close to the floor, and air with The gas-phase transfers in the upper part of the liquid stream and close to the ceiling and two separate layers are formed (Zhang: 2019). Wave regime occurs when the airflow increases relative to the stratigraphic flow and alternating and uniform waves form and move along the tube. As the flow rate or velocity of the air increases relative to the wave current, the waves touch the roof of the tunnel under certain conditions, causing the air layer to rupture, resulting in a clotting regime. An important and significant issue in biphasic currents is that these types of currents have an oscillating and time-dependent nature. Depending on the flow regime, these oscillating characteristics change. This oscillating nature of the current causes special reactions in the biphasic current. In this paper, we try to study the kinematics of two-phase current in open channels using methods (Saisorn & Wongwises: 2015).

2. *METHODS*

The model used in this research, according to Figure 1 is a combination of the main water transmission channel with a diameter of 0.09 and a length of 10 meters. The upstream tank is a metal tank in the shape of a rectangular cube, which is installed in the middle of its longitudinal wall at the height of 5 cm from the bottom of a hole with a diameter of 1.5 m in order to connect the duct to the tank (Trifonov: 2010).

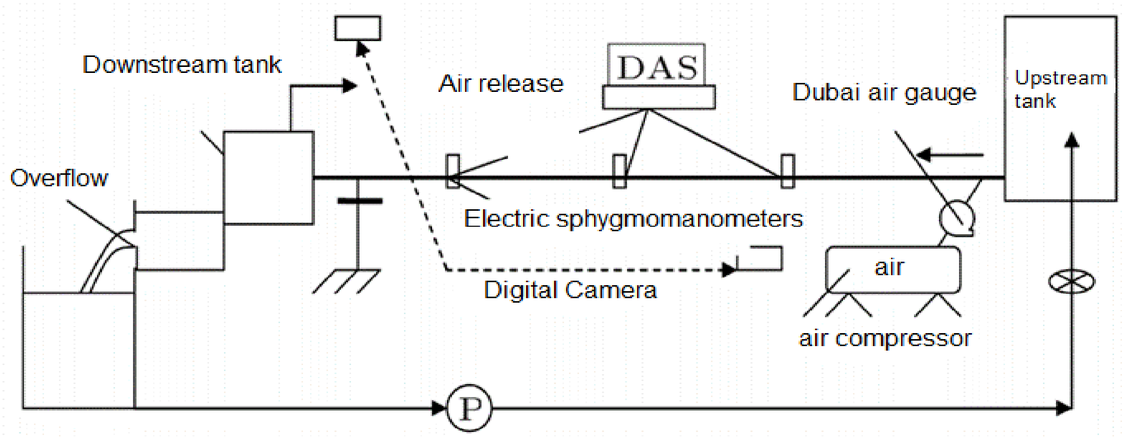


Figure 1. A general overview of parts of the laboratory model

Relationships governing two-phase currents Equations governing two-phase currents, like single-phase currents, include the equations of mass, momentum and energy survival (Banowski et al.: 2018). The energy conservation equation consists of several semesters, which are written separately here. Energy changes over time and the rate of energy input and output of the two-phase control volume is the internal energy of each phase. Rate of work on two-phase control volume:

$$\frac{\partial}{\partial t}\left[\alpha_k \rho_k \left(e_k + \frac{u_k^2}{2}\right) A\delta z\right] + m_k \left(e_k + \frac{u_k^2}{2}\right)\delta z - \left[m_k \left(e_k + \frac{u_k^2}{2}\right) - \delta z \frac{\partial}{\partial z} m_k \left(e_k + \frac{u_k^2}{2}\right)\right] \quad (1)$$

Where *e* is the internal energy of each phase. Also, the rate of work on two-phase control volume is calculated by:

$$\left[\frac{m_k p}{\rho_k} - \left(\frac{m_k p}{\rho_k} + \delta z \frac{\partial}{\partial z}\left(\frac{m_k p}{\rho_k}\right)\right) A\delta z\right] - m_k g.\sin\theta\delta z - pA\delta z \frac{\partial \alpha_k}{\partial z} + \quad {}_k\delta z \frac{p}{\rho_k} + u_k \sum_{1}^{n} \quad \tau_{kn} p_{kn} \delta z \quad (2)$$

Energy rate added to each phase by mass transfer:

$${}_k\delta z = \left(e_k + \frac{u_k^2}{2}\right) \quad (3)$$

Finally, the energy conservation equation for each phase of the steady stream without the presence of a heat source is written in the form of relations (4 and 5):

$$\mathrm{d}\left[m_g \left(i_g + \frac{u_g^2}{2}\right)\right] + m_g g.\sin\theta.\delta z = q_{wg} P_{wg} + q_{gI} P_{gI} \delta z + u_g \tau_{gI} P_{gI} + \quad {}_g\delta z \left(i_g + \frac{u_g^2}{2}\right) \quad (4)$$

$$\mathrm{d}\left[m_I \left(i_I + \frac{u_I^2}{2}\right)\right] + m_I g.\sin\theta.\delta z = q_{wI} P_{wI} + q_{lg} P_{lg} \delta z + u_I \tau_{Ig} P_{Ig} + \quad {}_l\delta z \left(i_l + \frac{u_l^2}{2}\right)$$

$$i_k = u_k + \frac{p}{\rho_k} \quad (5)$$

It should be noted that the phrase of Eg. 6 indicates the input energy rate to each phase:

$$q_{kw} P_{kw} \delta z + \sum_{1}^{n} \quad q_{kn} P_{kn} \delta z + q_k A \alpha_k \delta z \quad (6)$$

Laboratory flow conditions In order to evaluate the turbulence characteristics of the mixed airflow on a physical model of fast water, the range of discharges is between 13 to 38 litres per second. The existing pumping system, the volume of water in the laboratory tanks, the geometric dimensions and the discharge-

Ashle curve of the rapid water model were considered (Sardeshpande et al.: 2016). The design and construction of the physical model were based on the law of landing similarity. It is necessary to mention that in order to ensure that the "scale effect" is insignificant, an attempt was made to provide conditions in the model so that forces that are not large and effective in principle are not effective in the model as well (Betschart: 2015). These conditions were created by selecting the appropriate scale and geometry, controlling the minimum flow depth in the model, controlling the minimum surface roughness, and so on. In this research, the characteristics of the liquid utilized in the experiment are as follows:

Table 1. Physical characteristics of the liquid utilized in the experiment (at 251 ° C).

Liquid	$\rho_L(kg/m^3)$	$\sigma_L(mN/m)$	$\mu_L(cP)$
Water	998.4	74.2	0.896
0.01wt%SDS solution	998.5	45.2	0.884
0.02wt%SDS solution	998.3	36.8	0.881
0.03wt%SDS solution	998.2	28.6	0.880
0.05wt%SDS solution	998.6	29.5	0.880

The flow simulation was performed for the geometry similar to the device made in three dimensions so that the results could be compared well (Lu: 2018). The effect of gravity was also considered, and it was also supposed that there is no transfer of mass between the two phases and that both phases are incompressible; Because the length of the pipe is short and the pressure changes at this length are not large, according to the two-phase flow analysis in the transient state, a time step of 0.001 seconds was used, and the calculations continued until reaching the steady-state (Grabenstein et al.: 2017).

Apparent weather speeds are defined as follows:

$$V_{SL} = \frac{Q_L}{A_p} \tag{7}$$

$$V_{SG} = \frac{Q_G}{A_p} \tag{8}$$

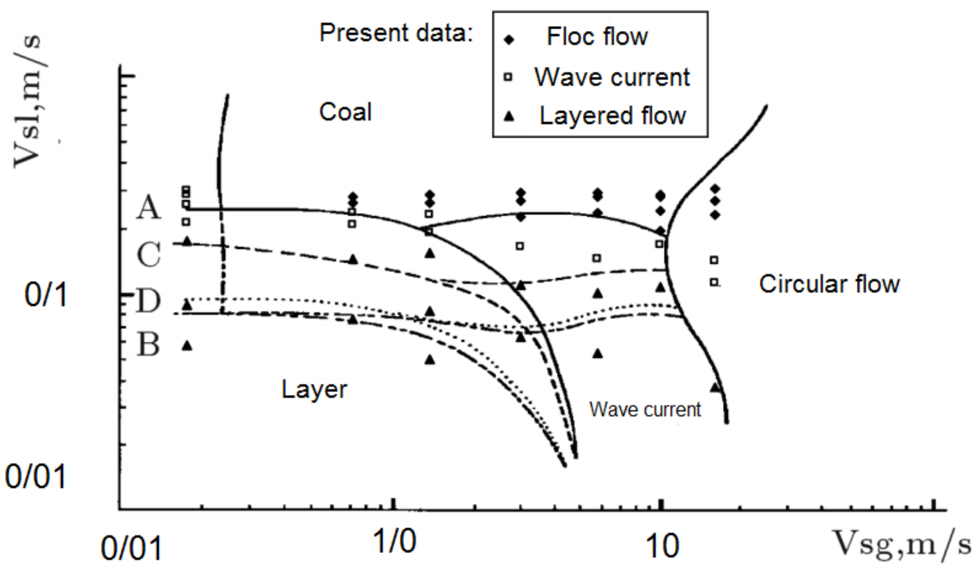
The fluid used is climatic, which in all cases enters the pipe vertically 998 kg/m^3 and the air density on the inlet plate. Water density was set at 225.1 kg/m^3. Speed input limit condition was used for input, and the output current limit condition was used for output (Rysak et al.: 2016).

3. RESULTS

Conclusion There is currently a severe lack of information regarding appropriate standards and design methods for predicting the hydraulic characteristics of biphasic flows, especially in hydraulic structures due to lack of information and insufficient research, whether theoretical or laboratory. In such cases, it is usually based on previous experience or speculation (Wang et al.: 2018).

Carefully in this form, the closeness of the information obtained in this study and the results of previous research can be seen. Therefore, at first glance, the flow pattern map obtained in this research can be a suitable tool for predicting two-phase flow patterns.

Figure 2. Comparison of current test results with previous research



The results of measurements related to the velocity and turbulence characteristics of two-phase airflow were performed completely for a number of dimensionless flow parameters (Spreitzer et al.: 2017). The maximum water load on the inlet opening of the canal is between 25.89 to 95.93 cm and is equivalent to the flow rate of 0.0167 to 0.02 cubic meters per second per unit width. The landing number of the stream approaching the overflow is in the range of 0.663 to 1/007. The results of distribution and dispersion of variable values of climate flow velocity and parameter without turbulence intensity dimension indicate some of the characteristic features of this type of two-phase flow that the conditions of occurrence of two-phase flow patterns were obtained from the flow map according to the table below (Frederix et al.: 2018).

Table 2. Conditions for the occurrence of two-phase flow patterns from the flow map

Flow pattern	$V_{SL}(m/s)$	$V_{SG}(m/s)$
The bottom layer	0.08	0.016
Bubble	0.56	0.008
Coal	0.56	0.6
foamy	0.56	2.5
The bottom layer	0.16	2
Bubble	0.8	0.032
Coal	0.8	0.4
foamy	0.8	2

Reynolds number, $Re = \frac{UD_h}{v}$, where v is the kinetic viscosity, D_h is the hydraulic diameter, U is the mean single velocity of the single-phase liquid. Motion viscosity was calculated from the fluid temperature in the inlet manifold. Table 3. was summarized the test conditions (Vakili-Farahani et al.: 2016).

Table 3. Experimental condition

	Reynolds number	Heat flux (kW/m^3)	Irregularity of the heater temperatures T_{max}/T_{mean}
1	10-40	80-300	1.34-1.68
2	10-42	90-360	1.22-1.32
3	8-42	51-500	1.09-1.21

The two-phase flow pressure drop profiles are shown in Figure 3. In general, channels are hollow media channels that are meant to be contrasted to porous media channels. The decrease in pressure drop followed by a sharp rise is a common feature of these three curves. The reason for this is because the two-phase flow pattern is transferred from stratified flow in one channel to stationary fluid in the other, resulting in stratified currents in both channels.

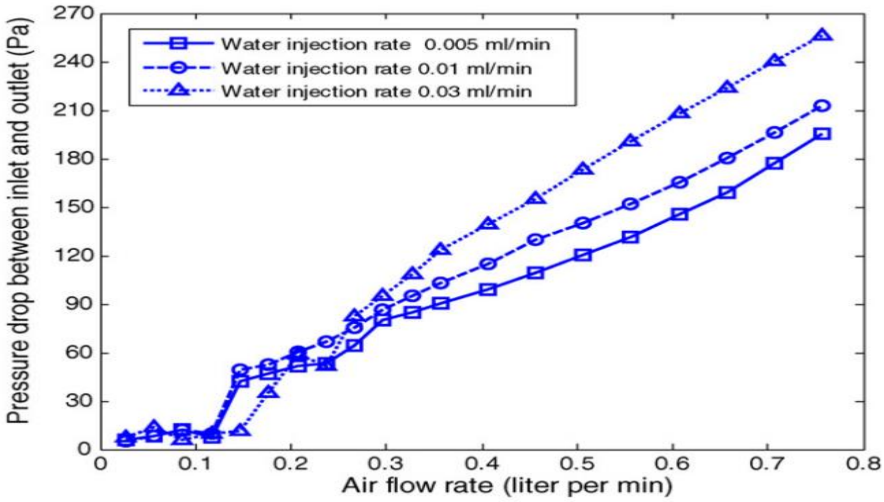


Figure 3. Pressure drop profiles

Figure 4 reveals typical images of two-phase currents obtained in a circular microchannel with various gas flow velocities and low liquid flow rates (Figure 4a), medium liquid flow rates (Figure 4b), and high liquid flow rates (Figure 4c).

Different flow patterns are noticed in a given flow condition, which can be categorized into five different patterns depending on the surface configuration: "liquid alone (or liquid snail)," "gas core with smooth thin liquid film," "Gas core with smooth liquid film," "Gas core with smooth liquid film," "Gas core with ring-shaped liquid film," and "Gas core with deformed interface." "Liquid on its own pattern" In the field, there are no bubbles or liquefied gas interfaces. Under any circumstances, visibility did not display 1 mm and appeared. Smooth liquid films surrounding the gas core are characterized as thin or thick, while wavy liquid films are classed as ring or distorted (Golpanian & Yosipovitch: 2020).

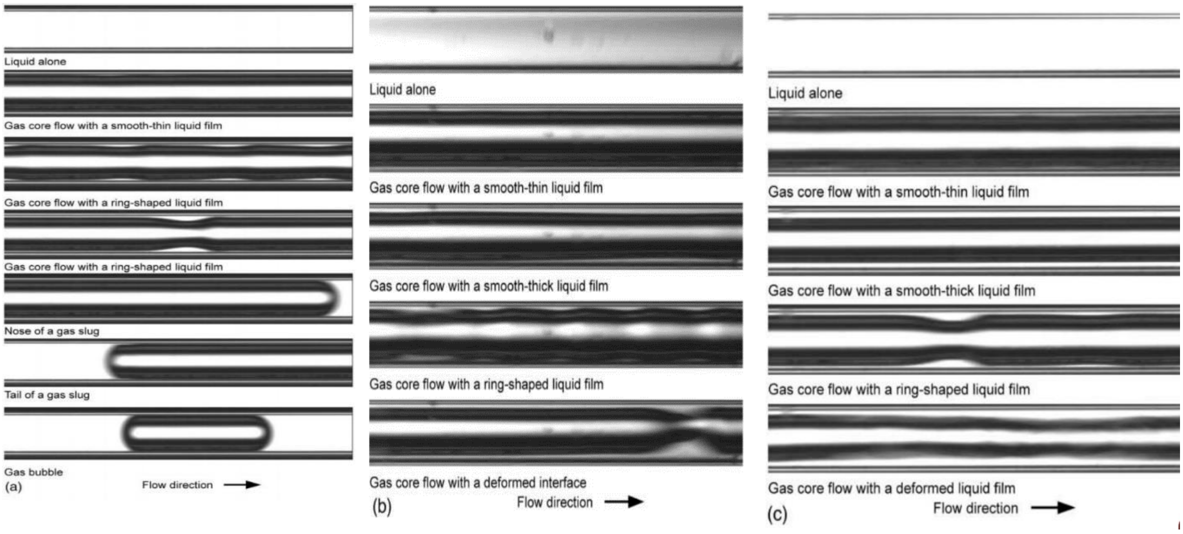


Figure 4. Ideal images of two-phase currents

When the biphasic current from the header is divided into parallel T channels, the surface tension effect becomes more apparent. In the two-phase air/water flow test, we find that all the liquids are divided into partially branched channels, However, alternating air and liquid coils block the rest of the branch channels. As a result, the impact of surface tension must be determined first, and all channels must be dredged.

4. DISCUSSION

Using a self-made and generated transparent assembly, the flow behavior of two phases of air and water in parallel channels of defined width with experimental porous inserts was explored in this work. We developed a two-phase channel flow model in this study. The liquid water saturation, the beginning point of the two-phase flow, and the concentration of species throughout the channel were all calculated using theoretical analysis. Due to the expansion of industrial applications of two-phase downstream flow, its modelling and simulation are of great practical importance for predicting its various conditions in pipes. The impact of these physical properties on the primary operating parameters including air stoichiometry and relative humidity on cell performance is investigated. At full moisture input circumstances, the results demonstrate that liquid water builds quickly in the inlet area, followed by a gradual rise downstream. The liquid saturation rate is expected to approach 30%. Theoretical and numerical simulations of biphasic flows in heterogeneous channels were then performed. The flow pattern of downstream, bubble, coal, and foamy in the downstream flow of the pipe was clearly recognized and photographed in this investigation, and the conditions for the occurrence of two-phase flow patterns were calculated using the flow map acquired from the laboratory study. The results of current research can be summarized as follows. First, in general, the experimental results agree well with the numerical predictions; however, some deviations are obvious when the fluid pressure drop is large. Second, porous channels consisting of spheres with smaller diameters have a greater heat transfer coefficient due to their larger heat transfer area.

5. *CONCLUSION*

The observed biphasic flow patterns were mainly alternating currents, But a closer look at the structure of the liquid film showed that the gas core flows with a smooth or ring-shaped film and a helical gas core flow circled by a deformed liquid. The probability of the emergence of various flow patterns indicates a gradual change in the dominant flow pattern with an elevation of gas and liquid flow velocities. Gas core currents with a thin, smooth liquid film are common at low liquid flow velocities, whereas gas kernel flows with a ring-shaped liquid film are more common at high gas flow velocities. The gas and liquid distribution assume a transitional characteristic for the inlet flow. As the intake gas surface velocity rises, more gas tends to flow into the three middle channels, while the first and end channels become more crowded. Increasing the surface velocity of the inlet fluid does not alter the inlet flow pattern in the header much, so the flow distribution changes somewhat. during the input current changes to a ring, the inhomogeneous distribution of the two phases reaches its maximum. Liquid flows in large numbers to the first and last channels, whereas gas is mostly divided into three intermediate channels. However, in general, the relatively good agreement between the simulation results, especially the flow map and the laboratory flow map, shows the good ability of computational fluid dynamics in predicting low two-phase flow patterns.

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