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Experimental Study and Simulation Principles of An Oil-Gas Multiphase Transportation System *

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Abstract — Presented is an experimental study on the performance of an oil-gas multiphase transportation system, especially on the multiphase flow patterns, multiphase pumping and multiphase metering of the system. A dynamic simulation analysis is conducted to deduce simulation parameters of the system and similarity criteria under simplified conditions are obtained. The reliability and feasibility of two-phase flow experiment with oil and natural gas simulated by water and air are discussed by using the similarity criteria.

Key words: *multiphase flow*; *similarity criteria*; *simulation principle*; *oil-gas multiphase transportation*;

1. Introduction

Current challenges facing offshore oil and gas exploitation require the development of subarine production systems to reduce largely the high cost of facilities of platform systems. In this way, only a single oil pipeline is needed to transport gas and liquid simultaneously to existing offshore platforms or onshore devices. But we are confronted with some new difficulties. Firstly, the pressure at the wellhead will increase and the well output will decrease with the increasing length of the pipeline, therefore, multiphase pumps are needed to boost the mixture, thus, booster stations are needed along the pipeline. Secondly, well effluent is the mixture of oil, gas, water and other matters, so that the most economical and efficient method to measure the well output and control the operation is to use the multiphase metering system. Thirdly, because various flow patterns will occur in a long mixed transportation pipeline, they will affect differently pressure drop, multiphase pumping and multiphase metering at different locations and different time. And lastly, the extension, coalescence, and acceleration of slugs resulting in rapid dynamic fluctuation or even disastrous consequences to the whole system impel people to study the dynamic traits of the multiphase effluent transportation system. Therefore, multiphase pumping, mixture effluent metering and multiphase flow traits become the three key problems in subsea production technology.

As is known, multiphase flow is one of the most difficult branches of fluid mechanics. Its theoretical study, numerical computation and experimental simulation are more complex and

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difficult than single phase flow, since its governing variables are much more than those of single phase flow (Kasturi and Stepanek, 1972). The problems of multiphase pumping, mixture effluent metering, and flow properties can not be properly solved through theoretical analysis and numerical computation; for this reason, laboratory experiments or in-situ tests are compulsory. Economical, convenient and transparent actuating medium should be adopted in experimental simulation to represent and reflect the real phenomena. For an oil-gas transportation system, some problems need to be solved: the way to simulate multiphase flow in laboratory so that the effect of the flow properties and flow patterns on multiphase pumps and meters can be reflected, the scale of the set-up, and the determination of the simulation relation between experimental media and real media. All those problems must be solved before experimental simulation of a multiphase flow.

In order to solve the above-mentioned problems, this paper presents an experimental study on the performance of an oil-gas multiphase transportation system, especially on multiphase flow patterns and pressure drop properties. A dynamic similarity analysis is also presented to deduce simulation parameters of the system and the similarity criteria under simplified conditions are obtained. The reliability and feasibility of two-phase flow experiment with oil and gas simulated by water and air are discussed by use of the similarity criteria.

2. Experimental Study of An Oil-Gas Multiphase Transportation System

Owing to the complexity of the multiphase flow, experimental simulation in a test loop in laboratory becomes a main measure to handle the basic law of oil-gas transportation in submarine pipelines. During the oil-gas mixture transportation in a long pipeline, the effluent should be boosted and metered. Multiphase boosting and multiphase metering are both tough problems in submarine production systems. When an experiment is done on multiphase flow, the development of multiphase pumps and multiphase meters should be taken into account. On the other hand, when the technique of multiphase boosting and multiphase metering is developed, the adaptability of them to various flow patterns of multiphase flow should be considered. Therefore, a set of multiphase flow test loop is designed to simulate the oil-gas mixture transportation system (see Fig. 1). The device, 40 meters in length and 5 cm in inner diameter, is made of transparent plexiglass. The maximum velocity is 1.2 m / s for full water with the Reynolds number about 1.7×10^4, and 30 m / s for full gas with the Reynolds number about 1.7×10^5. By control of the pressure and flow-rate of the gas phase and the liquid phase, various kinds of flow patterns, such as babble flow, stratified flow, plug flow, slug flow, wavy flow and annular flow, can be created in this device. The pressure, pressure difference and velocity are measured with pressure sensors and hot film. The topography of flow pattern is obtained by ERT technique.

A salient feature of two-phase and multiphase flow is the occurrence of certain characteristic flow patterns which show how each phase is distributed in the pipe. For instance, bubble flow, plug flow, stratified flow, wavy flow, slug flow, annular flow will occur in gas-liquid two-phase horizontal pipe flow, and bubble flow, slug or plug flow, churn flow, annular flow, and wispy-annular flow in vertical pipe flow. If the crux of multiphase flow is to be understood, the flow patterns of multiphase flow must be thoroughly studied. By control of the pressure and flow-rate of the gas phase and the liquid phase with jet pumps, various kinds of flow patterns are created in this device. (Li *et al.*, 1998). The experimental results show that the variation of flow pattern along the test loop with different flow fluxes is a continuous procedure. The distinguishing of the critical point of one flow pattern from another is still an unsolved problem. Even

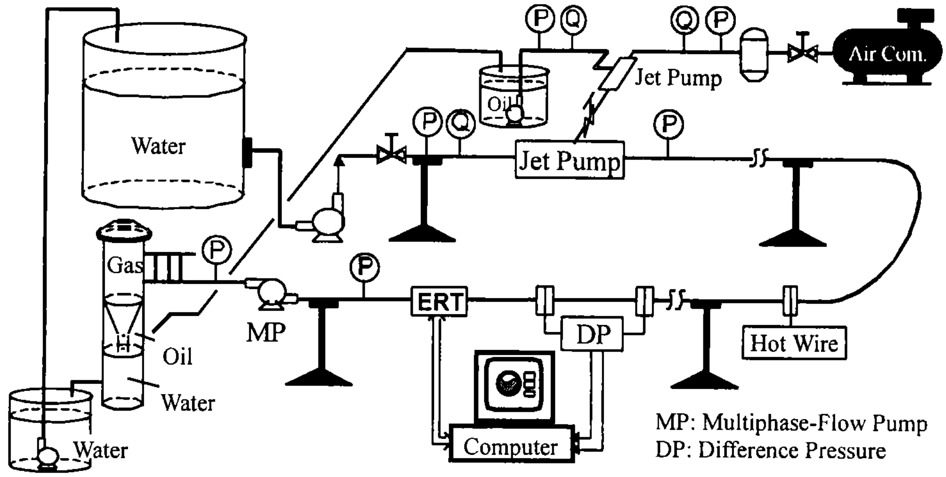


Fig. 1. Experimental simulation system for oil-gas mixture transportation.

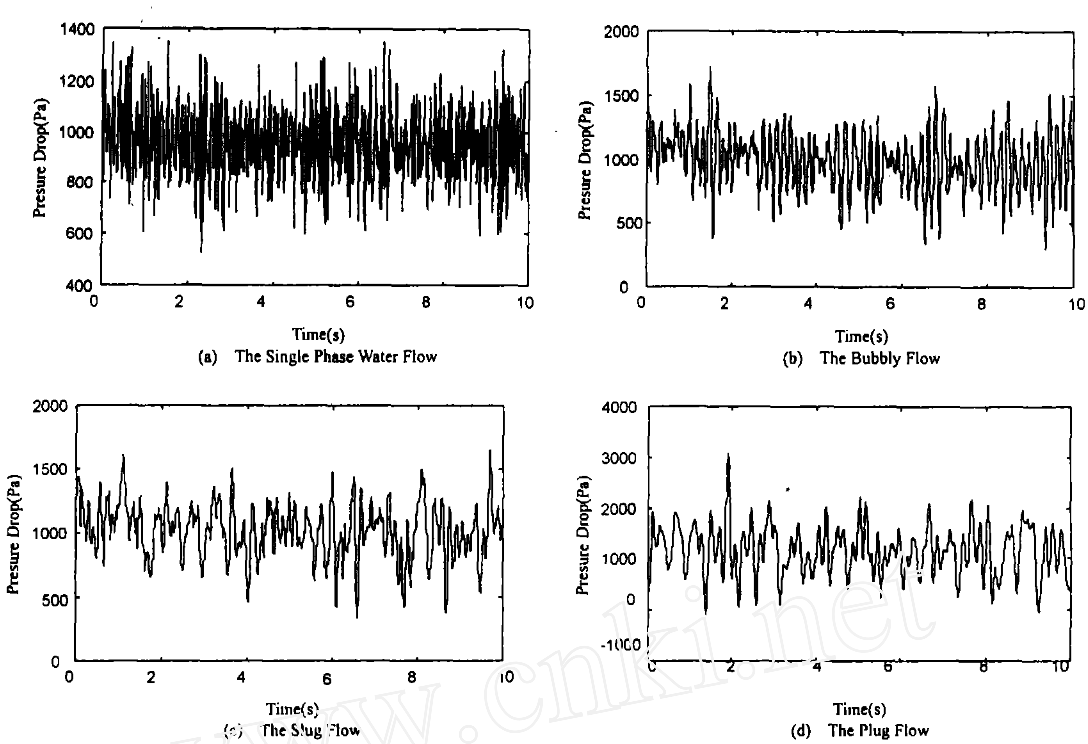
in the so-called same flow pattern, the flow regime will change much with a little change of void-fraction. The transition from one flow pattern to another is just the process from quantitative change to qualitative change of void-fraction and gas-phase and liquid-phase velocities.

The design of oil pipelines requires that a multiphase pressure drop be determined as accurately as possible, as the pressure drop in a pipeline is closely linked with flow patterns. Only a proper method can be adopted which is suitable for the flow pattern, only then can the correct result of pressure drop be obtained and the necessity of booster station be determined and how many. The pressure drops of single-phase water flow, bubble flow, slug flow and wavy flow are compared, as shown Fig. 2. The average pressure drop is 1170 Pa for a single-phase water flow, 1197 Pa for bubbly flow, 1423 Pa for slug flow and 2054 Pa for plug flow. The figures indicate that the pressure drop of bubbly flow is similar to that for single-phase water flow, the pressure drop for slug flow is about 1.7 times of that for bubbly flow. So correct estimation of flow pattern and correct calculation of the pressure drop in a pipeline are very important in the design of an oil-gas transportation pipeline.

Strictly speaking, the pressure distribution on a section of a pipe is not uniform, but changes from point to point. Taking stratified flow as an example, using two-fluid model and neglecting the influence of inertia term in the momentum equation, we can obtain the following governing equation:

$$\frac{1}{\gamma^2}\frac{\partial^2 u_L}{\partial \xi^2}+\frac{\eta^4}{4}\frac{\partial^2 u_L}{\partial \eta^2}+\frac{\eta^3}{4}\frac{\partial u_L}{\partial \eta}$$

$$=\frac{\dfrac{\mathrm{d}P}{\mathrm{d}z}+\rho_L\cdot g\cdot\sin\alpha}{\mu_{eL}}\frac{C^2}{\left[\cosh\left(\dfrac{1-\eta}{\eta}\right)-\cos\left(\pi+\gamma-\gamma\xi\right)\right]^2};$$



(a) The Single Phase Water Flow
(b) The Bubbly Flow
(c) The Slug Flow
(d) The Plug Flow

Fig. 2. Variation of pressure drop with time.

$$\frac{1}{(\pi-\gamma)^2}\frac{\partial^2 u_G}{\partial \xi^2}+\frac{\eta^4}{4}\frac{\partial^2 u_G}{\partial \eta^2}+\frac{\eta^3}{4}\frac{\partial u_G}{\partial \eta}$$

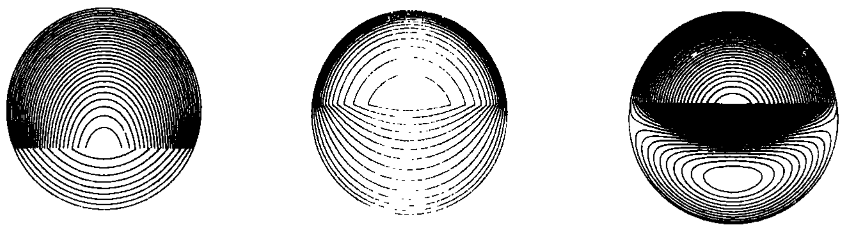
$$=\frac{\frac{\mathrm{d}P}{\mathrm{d}z}+\rho_G\cdot g\cdot\sin\alpha}{\mu_{eG}}\frac{C^2}{\left[\cosh\left(\frac{1-\eta}{\eta}\right)-\cos(\gamma+\pi\xi-\gamma\xi)\right]^2}.$$

The transformation from x, y to ξ, η is

$$x=\frac{C\cdot\sinh\left(\frac{1-\eta}{\eta}\right)}{\cosh\left(\frac{1-\eta}{\eta}\right)-\cos(\gamma+\pi\xi-\gamma\xi)};\quad y=\frac{C\cdot\sin(\gamma+\pi\xi-\gamma\xi)}{\cosh\left(\frac{1-\eta}{\eta}\right)-\cos(\gamma+\pi\xi-\gamma\xi)}.$$

Here $C = D\cdot\sin\gamma/2$ is the half cord of the gas-liquid surface, γ is the half central angle of the surface and D is the diameter of the pipe. From the numerical solution of the above equations, the distribution of iso-velocity can be obtained, as shown in Fig. 3. In the figure, the symbol "H_L" stands for the hold-up of liquid phase in the pipe. The computational conditions are: pipe diameter 25.4 mm; temperature 25℃; ambient pressure 0.1 MPa; superficial velocities u_{LS}= 0.1 m / s, u_{GS}= 1 m / s.

From the results, it can be seen that the variation of velocity distribution on the pipe section is significant, and so is that of pressure. For verification of the pressure distribution on the pipe section, four pressure sensors are mounted on the pipe section, as shown in Fig. 4.



H_L=0.31 — Laminar to laminar

H_L=0.54 — Laminar to turbulent

H_L=0.57 — Turbulent to turbulent

Fig. 3. Velocity distribution on pipe section for different flow states.

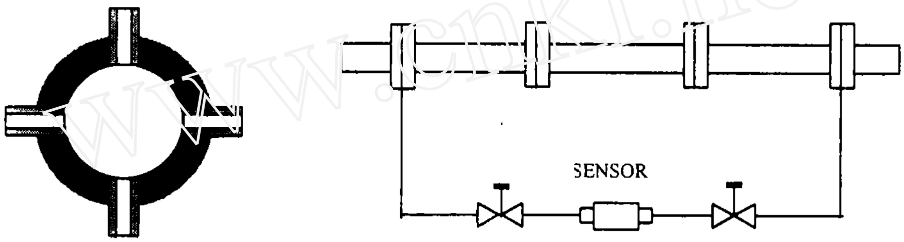


Fig. 4. Pressure measuring system and distribution of pressure sensors.

For the wavy flow, the pressure drop distributions at each position are given in Fig. 5 (the pressure unit is mm water column). The average pressure drop is 16.789 kPa from the top sensor; 21.424 kPa from the bottom sensor; 20.394 kPa and 19.879 kPa from the left and right sensors respectively, the symbols p_T, p_B, p_L, p_R in the figure standing for the pressures at the top, bottom, left and right sensors. So the variation of pressure drop is obvious. Therefore, if more accurate results of pressure drop and drag force are to be obtained, the variation of pressure distribution on the pipe section should be taken into account.

3. Similarity Analysis of Gas-Liquid Two-Phase Flow

Assuming that both gas and liquid phases are Newtonian flows, that the gas phase satisfies the state equation of the perfect gas, that obvious interface exists between the two-phases, and that on the interface, the velocity and tangent stress are continuous, and the normal stress satisfies the Laplace equation, the governing equations of the gas-liquid two-phase flow are as follows:

$$\frac{\partial u_g}{\partial t} + (u_g \cdot \nabla) u_g = \frac{\vec{K}}{F} - \frac{\nabla p}{\rho_g} + \frac{1}{Re_g \cdot \rho_g} \left[\frac{1}{3} \nabla (\nabla \cdot u_g) + \Delta u_g \right];$$

$$\frac{\partial \rho_g}{\partial t} + \nabla \cdot (\rho_g u_g) = 0; \qquad \frac{p_g}{\rho_g} = \frac{RT_c T}{u_c^2} = ET;$$

$$\frac{\partial u_l}{\partial t} + (u_l \cdot \nabla) u_l = \frac{\vec{K}}{F} - \nabla p + \frac{1}{Re_l} \Delta u_l; \qquad \nabla \cdot u_l = 0; \qquad \rho_l = 1;$$

$$\frac{\rho_g}{\rho_l} \left[-p_g + \frac{2}{Re_g} \left(\frac{\partial w_g}{\partial z} - \frac{1}{3} \nabla \cdot u_g \right) \right] - \left[-p_l + \frac{2}{Re_l} \frac{\partial w_l}{\partial z} \right] = \frac{1}{W} \left(\frac{1}{R_g} + \frac{1}{R_l} \right);$$

$$Q = \chi Q_g + (1 - \chi) Q_l .$$

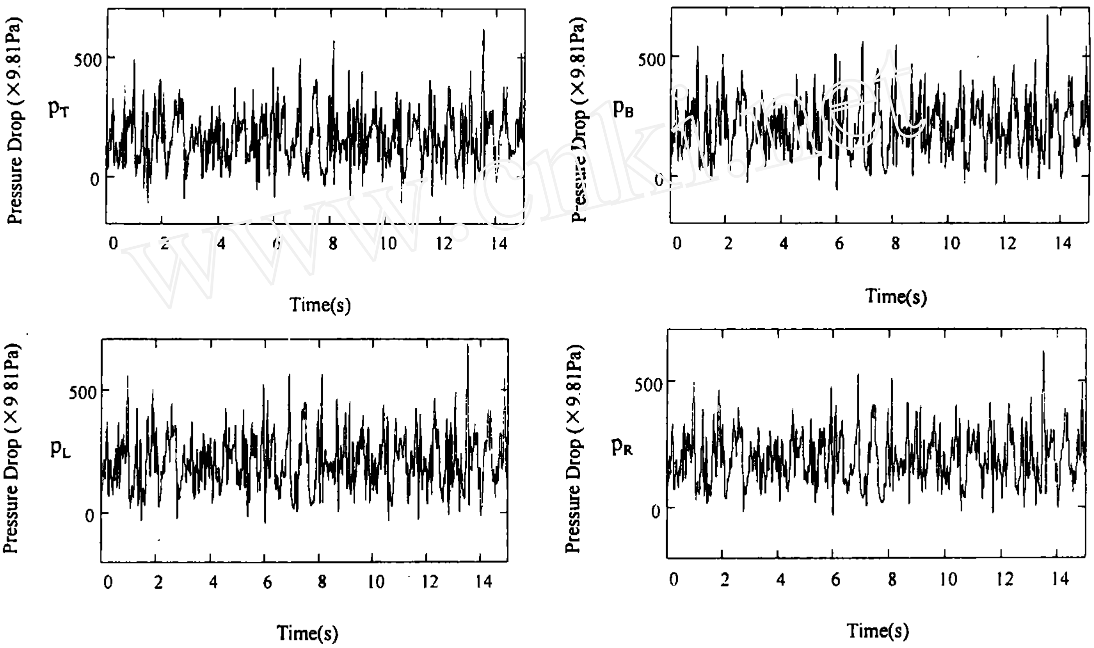


Fig. 5. Variation of pressure drop at different location of pipe section.

All the parameters in the above equations are dimensionless. The reference values of dimensionless variables are taken as length x, velocity u_c, time x_c/u_c, gas-phase density ρ_g, liquid-phase density ρ_l, gas-phase pressure $\rho_g u_c^2$, liquid-phase pressure $\rho_l u_c^2$, gas-phase flux Q_{g0}, liquid-phase flux Q_{l0}, and total flux $Q_0 = Q_{l0} + Q_{g0}$. In the expressions, Re is the Reynolds number, F is the Froude number, E is the Euler number, W is the Weber number, and R is the gas constant, suffix g stands for gas-phase and l liquid-phase, $\vec{K}$ is the unit vector of gravity direction, and R_g and R_l are the surface curvature radii of gas and liquid phases respectively. It is seen that provided that the seven dimensionless constants are equal for two flows, the normalized governing equations are identical.

Equal Froude number $\left(F=\frac{u_c^2}{gx_c}\right)$ (1)

Equal Reynolds numbers $\left(Re_g=\frac{x_c u_c \rho_g}{\mu_g}, \quad Re_l=\frac{x_c u_c \rho_l}{\mu_l}\right)$ (2)

Equal Euler number $\left(E=\frac{RT_c}{u_c^2}\right)$ (3)

Equal Weber number $\left(W=\frac{x_c u_c^2 \rho_l}{\sigma}\right)$ (4)

Equal density ratio $\left(\frac{\rho_g}{\rho_l}\right)$ (5)

Equal ratio or viscous coefficients $\left(\frac{\mu_g}{\mu_l}\right)$ (6)

Equal dryness (χ) (7)

Conditions Eqs. (2), (5) and (6) are not independent, and the equal gas-phase Reynolds number in Eq. (2) can be cancelled.

So the pressure drop coefficient of two-phase flow

$$\varphi_{TP}=\frac{D_{TP}}{D_{SPl}}=\varphi_{TP}\left(Re_l, F, W, E, \frac{\rho_g}{\rho_l}, \frac{\mu_g}{\mu_l}, \chi\right) \tag{8}$$

is a function of 7 dimensionless parameters. Here D_{TP} is the two-phase pressure drop, and D_{SPl} is the single liquid phase pressure drop. Similarly, the drag coefficient, and the void-fraction are also a function of the 7 parameters.

Lockhart-Martinelli (1949) introduced a well-known similarity factor for two-phase flow:

$$X=\left(\frac{D_{PFL}}{D_{PFG}}\right)^{\frac{1}{2}}=\left(\frac{1-\chi}{\chi}\right)^{\frac{2-n}{2}}\left(\frac{\rho_g}{\rho_l}\right)^{\frac{1}{2}}\left(\frac{\mu_g}{\mu_l}\right)^{-\frac{n}{2}}$$

where n is related with wall roughness, and it contains 3 parameters of the seven. Many researchers have done much work on this similarity factor related to flow pattern, pressure drop, drag and void-fraction of two-phase flow, and achieved fruitful results. But its shortcomings of low accuracy and narrow application range remain to be overcome.

4. Simulation Criteria for Two-Phase Flow

From the above analysis, it is seen that, in a normal case, experimental simulation of two- phase flow should meet seven similarity conditions, in addition to the geometrical similarity. This is much more complex than the simulation of single phase flow where only one condition, equal Re_l, needs to be satisfied in the case of a liquid, or two, equal Re_g and M (Mach number) in the case of a gas.

If the gravitational acceleration for the experiment and real flow is the same, the simulation condition of the characteristic scale and velocity should satisfy

$$\frac{(x_c)_1}{(x_c)_2} = \frac{\left(\frac{\sigma}{\rho_l}\right)_1^{1/2}}{\left(\frac{\sigma}{\rho_l}\right)_2^{1/2}}; \qquad \frac{(u_c)_1}{(u_c)_2} = \frac{\left(\frac{\sigma}{\rho_l}\right)_1^{1/4}}{\left(\frac{\sigma}{\rho_l}\right)_2^{1/4}}. \tag{9}$$

And the simulation condition of liquid-phase materiality parameter is:

$$\left(\frac{g\mu_l^4}{\rho_l\sigma^3}\right)_1 = \left(\frac{g\mu_l^4}{\rho_l\sigma^3}\right)_2 = G = \text{constant}. \tag{10}$$

G is called Galileo number. Theoretically, two media with a similar Galileo number can be simulated with each other. Once the two media are determined, the simulation relation of characteristic scale, velocity and temperature can be obtained by Eq. (9).

The reciprocals of Galileo numbers for common liquids are given in Table 1.

From the table, it can be seen that two very severe conditions are needed for an experimental simulation of two fluids as the value of Galileo number of each flow changes very much. One difficulty is that we can hardly find two fluids with nearly the same Galileo number to easily carry out experimental simulation, such as crude oil and water, the difference between their Galileo numbers being as high as 10^{10} times. The other is that even if the two fluids have nearly the same Galileo number, we can hardly use a reduced scale test set-up to simulate large-scale industrial flow. For instance, the Galileo numbers of water and trichloroethylene are very close (two-phase flow with water simulating trichloroethylene), but they require that the length and velocity scale factors be: $(x_c)_{tr}/(x_c)_w \approx 0.52$, and $(u_c)_{tr}/(u_c)_w \approx 0.72$. Those mean that the length scale of the test set-up should be twice that of the real flow and the velocity of the simulated flow should be 1.5 times that of the real flow. This is obviously not suitable for experimental simulation.

If the influence of gravity force on the two-phase flow is dominant, but the influence of surface tension on the two-phase flow is not significant, the condition of the equal Weber number can be discarded. In this case, the length and velocity scale factors should meet the following conditions:

$$\frac{(x_c)_1}{(x_c)_2} = \frac{\left(\frac{\mu_l^2}{g\rho_l^2}\right)_1^{1/3}}{\left(\frac{\mu_l^2}{g\rho_l^2}\right)_2^{1/3}}; \qquad \frac{(u_c)_1}{(u_c)_2} = \frac{\left(\frac{g\mu_l}{\rho_l}\right)_1^{1/3}}{\left(\frac{g\mu_l}{\rho_l}\right)_2^{1/3}}. \tag{11}$$

Table 1 Reciprocals of Galileo numbers of common liquids

Liquid	ρ_l (kg · m^{-3})	σ (kg · s^{-2})	μ_l (kg · m^{-1} · s^{-1})	G^{-1}
Trichloroethylene	1.48×10^3	29×10^{-3}	0.569×10^{-3}	3.51×10^{10}
Water	1.0×10^3	73×10^{-3}	1.02×10^{-3}	3.66×10^{10}
Carbon tetrachloride	1.59×10^3	26×10^{-3}	0.981×10^{-3}	3.08×10^{10}
Methanol	0.786×10^3	22×10^{-3}	0.584×10^{-3}	7.33×10^{10}
Ethanol	0.784×10^3	22×10^{-3}	1.25×10^{-3}	3.49×10^{10}
Glycerol	1.26×10^3	61×10^{-3}	1.6	4.45×10^{10}
Lubricating oil	0.88×10^3	30×10^{-3}	0.36	1.44×10^{10}
Crude oil	$(0.8\sim1.0)\times10^3$	30×10^{-3}	$0.1\sim1$	$2.2\times10^{-3}\sim2.2\times10^1$
Sulphuric acid	1.84×10^3	55×10^{-3}	0.275	5.46

The simulation condition composed of dimensionless parameters is:

$$Re_l^2\, E^3\, F^2 = \frac{R^3\, T_c^3\, \rho_l^2}{g^2\, \mu_l^2} = Q_1 = \text{constant}$$

or

$$\left(\frac{R^3\, T_c^3\, \rho_l^2}{g^2\, \mu_l^2}\right)_1 = \left(\frac{R^3\, T_c^3\, \rho_l^2}{g^2\, \mu_l^2}\right)_2 . \tag{12}$$

Here Q_1 depends not only on the density and viscous coefficient, but also on gas constant. It is much easier to combine the value of Q_1 though the materiality parameters of the two media.

On the other hand, if the influence of gravity force on the two-phase flow is not significant, but the influence of surface tension on the two- phase flow is dominant, the condition of the equal Froude number can be discarded. In this case, the length and velocity scale factors should meet the following conditions:

$$x_c = \frac{Re_l^2\, \mu_l^2}{W\sigma\rho_l}\ ; \qquad u_c = \frac{W\sigma}{Re_l\, \mu_l}\ ; \tag{13}$$

or

$$\frac{(x_c)_1}{(x_c)_2} = \frac{\left(\dfrac{\mu_l^2}{\sigma\rho_l}\right)_1}{\left(\dfrac{\mu_l^2}{\sigma\rho_l}\right)_2}\ ; \qquad \frac{(u_c)_1}{(u_c)_2} = \frac{\left(\dfrac{\sigma}{\mu_l}\right)_1}{\left(\dfrac{\sigma}{\mu_l}\right)_2} . \tag{14}$$

The simulation condition composed of dimensionless parameters is

$$\frac{\mu_l^2 RT}{\sigma^2} = Q_2 = \text{constant}$$

or

$$\left(\frac{\mu_l^2 RT}{\sigma^2}\right)_1 = \left(\frac{\mu_l^2 RT_c}{\sigma^2}\right)_2 = Q_2 . \tag{15}$$

5. Experimental Simulation of Oil-Gas Two-Phase Flow

The above results are applied to the experimental simulation of oil-gas two-phase flow (represented by suffix $o-g$) by water-air two-phase flow (represented by suffix $w-a$).

The density of air is 1.293 kg • m^{-3}, and the viscous coefficient is 1.67 × 10^{-6} kg • m^{-1} • s^{-1}. The density of gas (mainly methane) is 0.72 kg • m^{-3}, and the viscous coefficient is 10.0 × 10^{-6} kg • m^{-1} • s^{-1}.

It is seen from Table 1 that the value of G of oil and water are very different. The experimental simulation taking into account the influence of both gravity and surface tension of the liquid is not reliable.

From Eq. (9), the length and velocity scale factors should meet the conditions of

$$\frac{(x_c)_{o-g}}{(x_x)_{w-a}} \approx 0.6 ; \qquad \frac{(u_c)_{o-g}}{(u_x)_{w-a}} \approx 0.8 .$$

That is to say, the scale of the test set-up should be 1.5 times of that of the real flow device, and the velocity for the experiment 1.2 times of that of real flow.

The density ratio of the simulation is

$$\left(\frac{\rho_g}{\rho_l}\right)_{o-g} = 0.8 \cdot 10^{-3} ; \qquad \left(\frac{\rho_g}{\rho_l}\right)_{w-a} = 1.29 \cdot 10^{-3} .$$

Viscous coefficient ratio is

$$\left(\frac{\mu_g}{\mu_l}\right)_{o-g} \to 10^{-4} \sim 10^{-5} ; \qquad \left(\frac{\mu_g}{\mu_l}\right)_{w-a} = 1.64 \cdot 10^{-2} .$$

The ratio of density of air to that of gas is 1.6, and the ratio of viscous coefficient of air to that of gas is 160. This means that the cause of dissimilarity of flow is the large difference in viscous coefficient ratio. According to the above analysis, if the effects of gravity and surface tension of fluid should be taken into account simultaneously, the simulation of the two-phase flow of oil and natural gas by water and air can be carried out only by changing temperature or gravitational acceleration in the experiment.

Neglecting the surface tension of the liquid phase and the viscosity of the gas phase, from Eq. (11), the length and velocity scale factors should meet the conditions of

$$\frac{(x_c)_{o-g}}{(x_c)_{w-a}} \approx 25, \qquad \frac{(u_c)_{o-g}}{(u_c)_{w-a}} \approx 5.$$

The length scale can be reduced by 25 times and velocity scale by 5 times.

From Eq. (14), if temperature is taken as 300 K, simulation parameters are

$$(Q_1)_{o-g} = 3.01 \times 10^{20}, \qquad (Q_1)_{w-a} = 6.13 \times 10^{23}.$$

They are not very different, which means that when the surface tension of the liquid phase and the viscosity of the gas phase are neglected, the reduced scale simulation of oil and natural gas by water and air can be realized at the same temperature and same gravitational acceleration, and the difference in the simulation parameter is small.

If the gravity effect (not taking into account the effect of viscosity of gas phase) is neglected, from Eqs. (14) and (15), the length and velocity scale factors and Q numbers should meet the conditions of

$$\frac{(x_c)_{o-g}}{(x_c)_{w-a}} \approx 29235; \qquad \frac{(u_c)_{o-g}}{(u_c)_{w-a}} \approx 0.04;$$

$$(Q_2)_{o-g} = 1{,}7 \times 10^{60}; \qquad (Q_2)_{w-a} = 1.7 \times 10^{1};$$

this means that the experimental simulation can be hardly carried out in normal conditions.

According to Quandt's study (Quandt; 1965), if the gas-liquid two-phase flow is governed by gravity, there will be mainly stratified flow, slug, plug flow, and wavy flow. Those flow patterns normally occur in the two-phase flow of oil and natural gas mixed transportation. Therefore, it is workable to simulate oil and natural gas two-phase flow by water and air under the condition that the surface tension of the liquid phase and the viscosity of the gas phase are neglected. Of course, the above analysis is based on the oil of low viscosity ($\mu = 0.1$). For oil of higher viscosity ($\mu > 0.5$), the conclusion is not true and the experimental simulation of oil and natural gas by water and air is not reliable.

6. Conclusions and Discussions

— The experimental simulation set-up of multiphase pipe flow described in this paper has become an efficient test device for simulation of the flow patterns, and pressure drop, and the performance of multiphase pumping, metering and separating of a long oil-gas transportation pipeline on subsea.

— Through a similarity analysis of motion equations, 7 dimensionless parameters are deduced to govern two-phase flow. They are the liquid phase-gas phase viscosity ratio, liquid phase–gas phase density ratio, dryness (or liquid phase–gas phase flux ratio), the Euler number, the Froude number, the Weber number, and the Reynolds number of the liquid phase.

—Under normal conditions, simulation of two-phase flow in laboratory will meet two difficult problems, i. e. the finding of two fluids with a similar Galileo number and the realization of the needed scale.

— If the effects of the surface tension of the liquid phase and the viscosity of the gas phase are neglected, the scaled down simulation of oil and natural two-phase flow can be realized by use of water and air in laboratory under the condition of the same temperature and the same gravity, and the error of the simulation parameter is not large.

— For oil of high viscosity ($\mu > 0.5$), the simulation of oil and natural gas two-phase flow can hardly be realized by use of water and air. For the future, light oil and air, or light oil, water, and air will be used in our laboratory to simulate oil and natural gas, or oil, natural gas and water flow.

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