

A New Multi-phase Flow Calibration Facility and Its Uncertainty Analysis

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Abstract: A new multi-phase flow calibration facility was built at the CIM campus to calibrate single-phase or multi-phase flowmeters of 10 mm to 50 mm in diameter. The flow rate ranges under calibration are 0.08 ~ 50 m³/h for water, 2 ~ 120 m³/h for air and 0.3 ~ 15 m³/h for oil, respectively. The calibration methods are static volumetric method for water and bell prover method for air. To ensure the reliability of the system, some standard flowmeters are added to the pipelines of each phase of media. The design and construction of the system have been discussed in detail. The uncertainty for the calibration facility has also been analyzed.

Keywords: Multi-phase flow, Mixer, Separator, Uncertainty

1. Introduction

While numerous investigations have been made of flow calibrations of the single-phase fluid^[1-4], few studies have been made of flow calibration of multi-phase flow. Nowadays the researches related to multi-phase flow become more and more important. Recently a multi-phase flow calibration facility is built at the CIM campus to calibrate single-phase or multi-phase flowmeters from 10 mm to 50 mm in diameter. The flow rates under calibration are 0.08 ~ 50 m³/h for water, 2 ~ 120 m³/h for air and 0.3 ~ 15 m³/h for oil, respectively. The calibration methods are static volumetric method and master meter method for water, master meter method for air and oil. To ensure the reliability and the uncertainty of the master meters, the master meters for water and air can be calibrated with static volumetric method and bell prover method, respectively. The design and construction of the system have been discussed in detail. The uncertainty for the calibration facility has been analyzed.

2. Construction of the Flow Facility

The CIM Multi-phase Flow Calibration Facility is a closed loop flow system. The schematic of the facility

is shown as Fig. 1. The entire facility is located in two connected rooms. The main facility is installed in a large test room. Additional devices including two pumps for oil and water, an air compressor, an oil-water separator, an oil reservoir and three pressure containers are installed in a pump room. The water pump is located above a water reservoir about 100 m³. Two 15kW frequency converters were used to control the oil and water pumps, respectively, to ensure the two pumps operating at a constant velocity (or constant output pressure). The oil pump is used to pump oil from the oil reservoir into the flow loop through an oil standard flowmeters, while the water pump is used to pump water from the water reservoir into the flow loop through a water standard flowmeters. Similarly, the air compressor pumps gas into the flow loop through a gas standard flowmeter. Passing through the standard flowmeters, the flow is separated into two test pipelines, one for gas and water two-phase flow and another for oil, gas and water three-phase flow. Gas and water flow through a customized manifold into a two-phase or three-phase mixer, and then through another customized manifold into the test pipelines. In the manifold, the flow is split into four separate pipelines of 15 mm, 25 mm, 40 mm and 50mm in diameter. But only one pipeline is used

at a given time. The oil only past through the three-phase mixer to the three-phase flow test pipelines. Each pipeline is fitted with a transparent tube, located upstream of the pipeline, for the convenience of observing. A manual control valve was installed at the downstream of the meter under test to control flow rate. At downstream of the manual control valves, there are two electromotive control valves, which installed at 40mm, 50mm pipelines and 15mm, 25mm pipelines, respectively. These valves will be used for automatic control in the future. There is a longer straight section prior to the testing meter to remove flow asymmetries. The straight section provides an upstream straight length of about 80D for the 50 mm pipeline, and 100D, 160D and 260D for the 40mm, 25mm and 15mm pipelines, respectively. Once the flow in each pipeline passes through the testing meter, the gas is released directly to the test room, the water passing though 2-phase pipelines and the oil passing though 3-phase pipelines will flow into

the water and oil reservoirs, respectively. Fig. 2 shows the picture of the whole facility.

The multi-phase flow facility can be used to calibrate single-phase gas or liquid flowmeters or gas-water two-phase flowmeters on the 2-phase pipelines. It can also be used to calibrate any one of single-phase oil flowmeters, oil-gas-water three-phase flowmeters, and oil-water or oil-gas two-phase flowmeters on the 3-phase pipelines. To calibrate single-phase liquid flowmeters, the static-volumetric method or master meter method can be used. To calibrate single-phase gas or oil flowmeters, only master meter method can be used. In order to ensure the uncertainties of the standard flowmeters, the water standard flowmeters (two Electromagnetic flowmeters) can be calibrated with static-volumetric method and the gas standard flowmeters (two swirl vortex flowmeters) can be calibrated with a 2000L-bell prover.

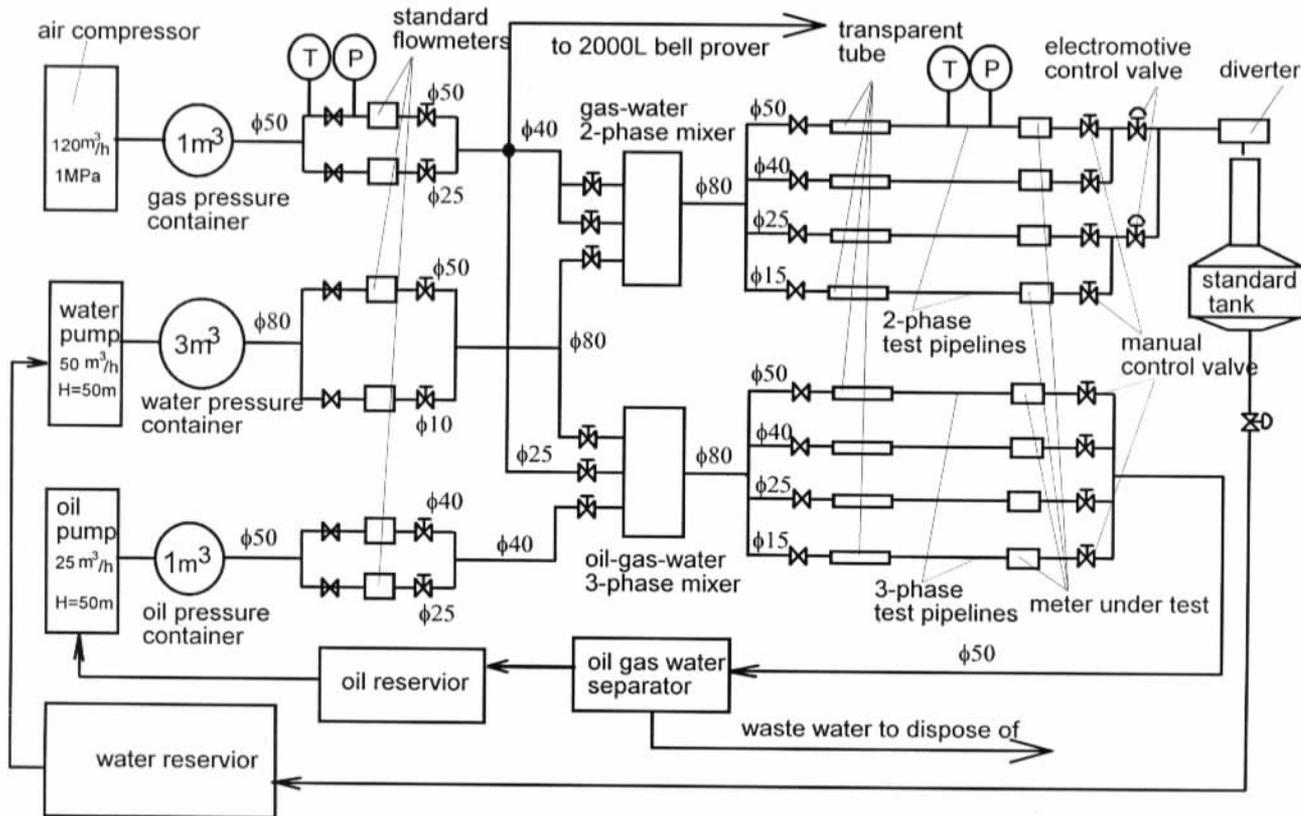


Fig. 1 Schematic of the facility

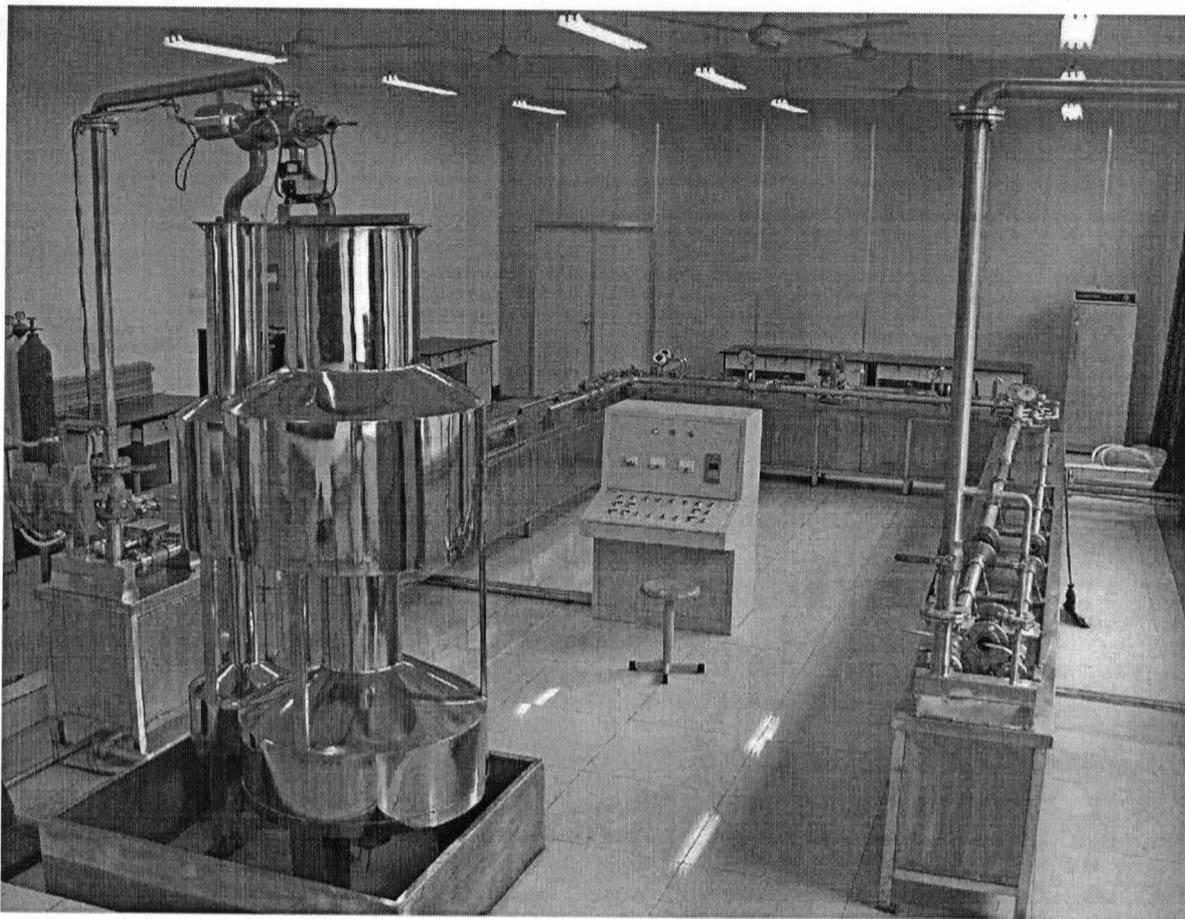


Fig. 2 Picture of the whole facility

3. Multi-phase mixer and separator

The design of the multi-phase mixer and the multi-phase separator is the crucial technique of the facility. The incorporate mixer is used to regulate the multi-phase flow regimes (flow-types). The separator will separate the oil and water from oil-water mixture after testing.

3.1. Multi-phase mixer

There are two multi-phase mixers in the facility. One is used to blend air and water, which called 2-phase mixer. Another is used to blend air, oil and water, which called 3-phase mixer.

There are four inlets in the 2-phase mixer, the main one for water flow is 50mm in diameter, and the other three for gas flow are 25mm, 25mm and 40mm in diameter, respectively. Their configuration diagram is shown in Fig.3. For the air inlets, inlet 1 (25mm in diameter) is

regulated to form water-based slug flow, plug flow and stratifying-annular flow, etc ^[5], inlet 2 (25mm in diameter) is regulated to form water-based bubble flow, uniform flow and stratified/wavy flow, etc ^[5], and inlet 3 (40mm in diameter) is used for single-phase gas flow only.

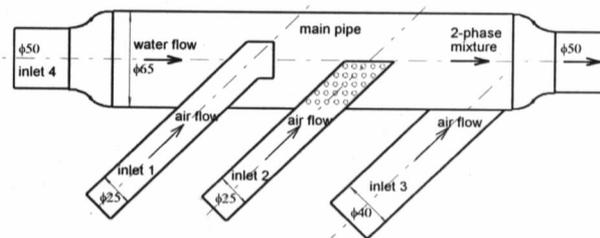


Fig. 3 Configuration diagram of the 2-phase mixer

Similarly, there are four inlets in the 3-phase mixer, shown in fig.4. The main one for water flow is in diameter 50mm, another one for gas flow is in diameter 25mm, other two for oil flows are in diameters 25mm and 40mm, respectively. Air, oil and

water are combined in the three-phase flow mixer. These mixers were built in such a way that the initial base phase (i.e. the phase having the largest volume fraction) and the initial bubble/drop sizes for the other phase could be chosen. In fig.4, inlet 1 (25mm in diameter) is air inlet, which is used to regulate the airflow, and inlet 2 (25mm in diameter) is oil inlet, which is used to regulate the oil flow. Inlet 3 (40mm in diameter) can be used for oil single-phase test or as initial base phase of oil-gas two-phase flow. Obviously, inlet 1 and inlet 4 or inlet 2 and inlet 4 can form the water-based flow regimes; inlet 1 and inlet 3 can form the oil-based flow regimes.

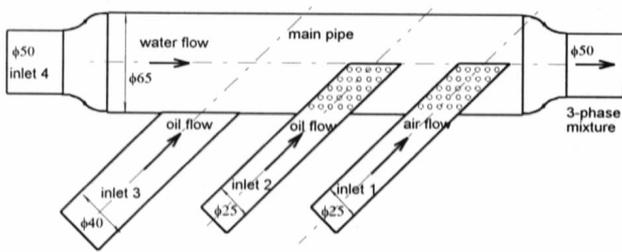


Fig. 4 Configuration diagram of the 3-phase mixer

3.2. Multi-phase separator

Multi-phase separator is used to separate oil from water. The construction of the separator is shown as fig.5. It consists of two-stage separator: a primary separator with $2m^3$ in volume and two secondary separators with $2m^3$ in volume for each. The mixture of oil and water come from the test pipeline goes into the primary separator firstly. In the separator, the mixture gradually becomes oil layer on the top and water layer on the bottom of the separator. The height of the inter-phase boundary of water and oil can be controlled with the water exit valve 1. The water and the oil passing

through primarily separate go into the water separator and oil separator respectively. In these two secondary separators, only a few water remain on the bottom of the oil separator, and only a few oil remain on the top of the water separator. The water on the bottom of oil separator will be pumped to the primary separator to re-separate. The oil on the top of the water separator will flow into the oil separator. The oil in the oil separator will flow back into oil reservoir, but the water in the water separator will flow directly into a disposal water reservoir as wastewater.

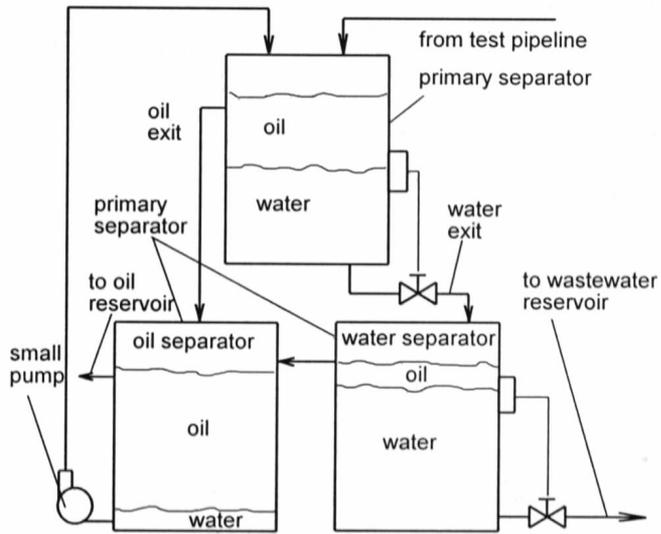


Fig. 5 Schematic diagram of the separator

4. Uncertainty Analysis

The multi-phase flow calibration facility applies static-volumetric method and master meter method. For static-volumetric method, there are four collection tanks. The basic data and uncertainties of tanks, diverter and timer are shown as table 1.

Table 1 Calibration result of the static volumetric method

Volume (L)	30	100	200	500
Height of scale (mm)	142.6	361.7	229.7	281.2
Resolution (ml/mm)	7.8740	24.0673	49.3827	165.2892
Uncertainty A		$S_3=1.66 \times 10^{-4}$		
Uncertainty B		$S_4=2.50 \times 10^{-4}$		
Uncertainty A of diverter		$S_5=1.37 \times 10^{-5}$		
Uncertainty B of diverter		$S_6=1.05 \times 10^{-5}$		
		$U_4=1.71 \times 10^{-5}$		

Uncertainty A of timer	$S_1=9.46 \times 10^{-6}$
Uncertainty B of timer	$S_2=2.50 \times 10^{-5}$
Flow range of the facility (m^3/h)	0.3-50
Uncertainty of the facility (%)	<0.1
Flow stability	5.47×10^{-4}

For master meter method, there are two master meters for each medium: two swirl vortex flowmeters for air, two electromagnetic flowmeters for water and two

oval flowmeters for oil. The basic parameters of the master meters are shown as table 2.

Table 2 Basic parameter of the master meter

	Swirl vortex flowmeter	Electromagnetic flowmeter	Oval flowmeter
Flow range (m^3/h)	2-25 for DN25 8-100 for DN50	0.08-2.5 for DN10 1.0-35 for DN50	0.3-1.5 for DN15 1.5-15 for DN40
Meter coefficient (l/m^3)	172680 20838	100	10000 1000
Basic error (%)	± 0.42 ± 0.28	± 0.2 ± 0.2	± 0.5 ± 0.5
Repeatability error (%)	± 0.02 ± 0.01	0.01	± 0.05

The basic error E of the parallel master meter sets is shown as^[6]

$$E = \pm \frac{\left[\sum_{i=1}^n (q_i E_i)^2 \right]^{1/2}}{\sum_{i=1}^n q_i} \quad (1)$$

where E_i is the basic error of master meter of No. i , q_i is the rated flow rate of master meter of No. i , $i=1, 2, \dots, n$.

If E_{max} is the maximum basic error of all master meters, then:

$$E \leq \frac{E_{max} \left(\sum_{i=1}^n q_i^2 \right)^{1/2}}{\sum_{i=1}^n q_i} \leq E_{max} \quad (2)$$

i.e. the basic error of the parallel master meter sets should never be larger than the maximum basic error of all master meters. That is to say, the parallel master meter sets have the same credibility with the individual master meter at least^[7].

The actual accuracy of pressure and temperature measurement in the facility at the upstream of master

meter and at the meter under test is $\pm 0.4\%$ and $\pm 0.5\%$, respectively. Then, the accuracy of multi-phase flow facility is as follow:

For gas-water 2-phase, $E_{max} = \pm 0.42\%$

$$\delta = \pm \left[0.42^2 + 0.4^2 + 0.5^2 \right]^{1/2} = \pm 0.766\%$$

For oil-gas-water 3-phase, $E_{max} = \pm 0.5\%$

$$\delta = \pm \left[0.5^2 + 0.4^2 + 0.5^2 \right]^{1/2} = \pm 0.812\%$$

5. Conclusion

A detailed description of a recently installed multi-phase flow calibration facility has been made. It is obvious that there are many distinct characteristics in design and construction of new system. These advantages will help the facility to achieve good performance.

Uncertainty and flow stability of the facility for different media are different. For water, performance measurements show that the uncertainty is better than 0.1% and the flow stability is better than 5.5×10^{-4} . For air, the uncertainty is better than 0.5%. For oil, the uncertainty is better than 0.5%, too. For the multi-phase flow calibration, the total uncertainty of system is better than 1%.

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