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Study on Application of Wet Gas Metering Technology in Shale Gas Measurement

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Abstract

The application of wet gas flow meter at shale gas wellhead is of great significance to reduce the investment and operation cost of shale gas extraction. The flow conditions at the wellhead of shale gas and the technical measuring principles of the current wet gas flow meters are briefly analyzed in this paper. A wet gas flow meter was tested on the wet gas flow test facility, and the performance of the wet gas flow meter with the correlation model developed with the air and water as test medium is studied, which is helpful to optimize the wet gas metering process design of shale gas wellhead and to improve the wet gas metering technology. The research shows that the measurement principle of the current wet gas flow meters are workable, however, the wet gas correlations of the wet gas flow meter must be calibrated with wet natural gas according to the working conditions.

1. Introduction

In natural gas industry, the production of natural gas from a well is always accompanied by the water and hydrocarbon. This unprocessed output from gas well is called wet gas, and it is a particular subset of gas and liquid two phase flow. Now, there is no unanimous definition of wet gas in industry, various methods have been used to define and even to classify the wet gas, and it is most commonly defined as when the Lockhart-Martinelli parameter is less than or equal to 0.3[1]. Because of the presence of liquid in the gas flow, single phase gas flow meters fail to work or even damaged when expose to wet gas flows. Now the wet gas flow is measured applying separation technology in most cases in China.

2. Flow conditions of shale Gas wellhead and the demand of wet gas flow metering

Compared with the conventional natural gas extraction, there is no water or light hydrocarbon output produced from the shale gas reservoir. However, in the process of shale gas exploitation, unconventional hydraulic fracturing technology is used to stimulate the reservoir, quantities of fracturing fluid is injected into the reservoir. As a result, a large amount of fracturing fluid accompanied in the shale gas in the process of shale gas extraction. The exploitation of shale gas can generally be divided into four stages according to the wellhead working conditions: drainage exploitation stage, early exploitation stage, middle exploitation stage and late exploitation stage, as it shown in talbe1.

Table 1: Working condition features of shale gas wellhead

Production Stage	Period	Wellhead Pressure（MPa）	Gas Production Rate（$10^4Nm^3/d$）	Liquid Output Rate（m^3/d）
drainage exploitation stage	0-45day	40↘26	25	200-500
early exploitation stage	46day-8month	26↘10	10-15	20-200
	8-10month	10↘7	10	10-20
	11month-3year	7↘2	10↘5	1-10
middle exploitation stage	4year-5year	2↘1	5↘1.5	0.5-1
late exploitation stage	5 year later	1	≤1.5	≤0.5

As can be seen from the table, the gas production, liquid output and the wellhead pressure of shale gas gradually decrease as the extraction time increases. Compared with conventional gas production exploitation, wellhead production of shale gas decline more rapidly, most of the

wellhead production decline about 40% in the first year. Therefore, it is necessary to monitor the shale gas production to get the reservoir information and to evaluate the gas well production capacity, which is essential for the optimization of gas field extraction plans and production decision.

The wet gas can be measured apply separation or non-separation method. The separation method is a traditional technology that recognized by most people, however this method is high cost and low efficient as it requires a complex process pipe system and in most cases the flow of each well is separated and metered alternatively. Compared with the separation technology, the non-separation method or wet gas meter technology can greatly reduce the investment cost and improve the metering efficiency by monitor the well production of each well at the wellhead directly, however the technical maturity of wet gas metering technology has yet need to be tested and verified. Currently, in order to monitor the wellhead output production of shale gas, each wellhead of shale gas on the production platform is equipped with an individual separator and flow measuring meters, which is an expensive investment. The best solution for the shale gas wellhead production measurement is using the wet gas meter whose accuracy could meet the requirement. In this paper, a wet gas meter was tested on the wet gas flow test facility at Chengdu Verification Branch of National large flow rate measurement station, the performance of the wet gas flow meter with the correlation model developed with the air and water as test medium at low pressure is studied, which is helpful to optimize the wet gas metering process design of shale gas wellhead and to improve the wet gas metering technology.

3. Basic principles and technical features of current wet gas flow meters

The wet gas flow meter technology is a new metering technology developed based on single phase flow meters with correlation model in recent few decades. The core of the wet gas flow meter is using the wet gas correlation model created based on large amount experiment data to correct the meter bias caused by the liquid in the gas flow.[2] Most of the available wet gas meters are based on some sort of differential pressure device with wet gas correlations and incorporate some other technologies to determine the liquid fraction of wet gas flow.[3] The metering principles of the most current wet gas meters can generally be summarized into two kinds. One is to use the liquid fraction detecting technology such as gamma ray device or microwave technology to measure the liquid fraction directly and provide this measured liquid fraction information to the correlation models to calculate the gas and liquid flow rates of wet gas flow. The other kind is to use two different gas meters in series, which provide the same flow rate for dry gas but each meter has a different wet gas performance when liquid is present, and use the difference of two meters responses to the wet gas flow conditions to determine the liquid fraction of wet gas flow and then calculate both the gas and liquid flow rates by the correlation models.[4] It is obvious that the gas and liquid flow metering accuracy of wet gas flow meters totally depends on the correlation models.

4. Wet gas flow meter test

4.1 Wet gas flow test facility and the test method

In order to study the performance of wet gas flow meter at the conditions of wet natural gas flow, a wet gas flow meter was tested at the wet gas test facility of Chengdu Verification Branch of National oil and gas large flow rate measurement station of China. This facility is designed for gas-liquid two phase flow studies consisting of water and natural gas. The schematic diagram of the wet gas test facility of CVB is shown figure1. This facility is mainly composed of gas and liquid reference meters, liquid pump injection and regulation system, gas-liquid two phase flow test section and gas-liquid separation system. The gas used for the wet gas facility comes from a high pressure pipeline. The gas reference meter is a high accuracy ultrasonic flow meter which measures the natural gas flow before mixing. The natural gas after is measured by the ultrasonic flow meter and then flows into the test section where the liquid phase is injected and mixed. The flow rate of the liquid is well regulated by the liquid pump injection and regulation system. A 0.5 inch and a 1 inch Coriolis mass flow meters work as liquid reference meters on the liquid injection line to measure the liquid flow rate. The natural gas drives the liquid through the test section and then flow into the gas-liquid separation system where the gas and liquid is separated. The liquid returned via the separator to the water tank and re-circulated by the liquid pump. The separated natural gas after test is discharged into a low pressure pipeline. The test pressure range of the wet gas test facility is from 15bar to 40bar, the gas flow test range is from 8m^3/h to 650m^3/h, and the liquid flow test range is from 0 to 8m^3/h.

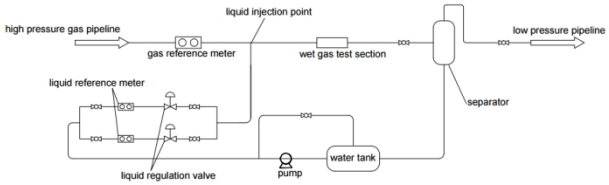

Figure 1: Schematic diagram of CVB wet gas test facility

Figure 2: Wet gas test facility of CVB

According to the flow conditions of wellhead shale gas and the metering range of wet gas flow meter, the experimental test matrix was determined as follows, the test pressure is 22bar, the gas flow rate ranges from 36m³/h to 130 m³/h, the Lockhart-Martinelli parameter ranges from 0 to 0.25, the detailed test conditions are shown in table2.

Table 2: Wet gas flow meter test point

Gas flow rate	36 m³/h	72m³/h	108m³/h	130m³/h
Liquid flow rate (m³/h)	0	0	0	0
	0.19	0.36	0.52	0.74
	0.38	0.71	1.06	1.43
	0.74	1.44	2.16	2.88
	1.1	2.20	3.23	4.49

In the test process, at each gas flow test conditions, the performance of wet gas flow meter at single-phase dry gas is first tested as the base reference for the wet gas flow test. After the dry gas test, the liquid is gradually injected into the natural gas flow from less to more to conduct the wet gas flow test. Figure3 shows the tested wet gas flow meter.

Figure 3: Wet gas flow meter under test

4.2 The test result and analysis

The gas phase test result of wet gas flow test is shown figure4, and the liquid phase test result is shown is figure5. It can be seen from figure4, for the gas flow rate of 72m³/h and 108m³/h, the wet gas flow meter has a decent gas flow measurement result, the relative errors of gas phase flow is approximately within 3%. However, for the other two gas flow rates test condition of 36m³/h and 130m³/h, the gas flow rates measurement of the wet gas flow meter shows obvious positive error except the dry gas test point, and the error increases as the liquid hold up increase which indicated by L-M parameter. The maximum error of gas flow measured by the wet gas flow meter within the test range is 11%. The liquid phase flow measurement results of the wet gas flow meter shows negative error, which means that the liquid flow rates measured by the wet gas flow meter are obvious lower than that measured by the liquid reference meter, and the liquid measurement error of this wet gas flow meter increases as the L-M parameter increases, which has similar trend with the gas flow measurement error. The maximum liquid measurement error at test condition is -37%.

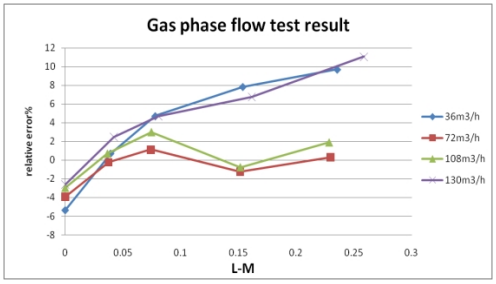

Figure 4: Gas phase flow test result

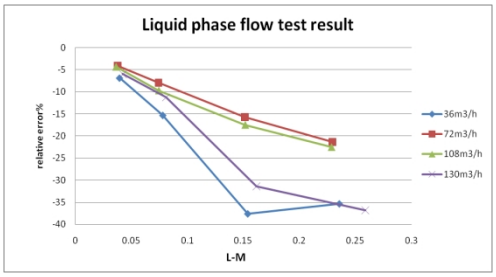

Figure 5: Liquid phase flow test result

As can be seen from the test results, the performance of wet gas flow meter shows the following three features. First, the gas and liquid flow measurement error is related to the liquid hold up of wet gas flow, the higher the liquid holdup of

wet gas flow is, the greater the error will be, and this feature is caused by the metering principles of wet gas flow meter, the measurement of wet gas flow meter relies on the correlation models and the metering algorithm. The correlation model of wet gas flow meter is a complex function that describes the relationship between the wet gas correction factors and liquid holdup and other influential factors. When there is a deviation of the correlation model, the deviation must be shown as a systematic deviation related to liquid holdup and other influential factors such as gas flow rate, gas density, therefore measurement error of wet gas flow meter increase as the liquid holdup of wet gas flow increases. And this is also the main reason why it is more difficult to measure the wet gas flow when the liquid holdup is higher using wet gas flow meters. Second, the gas flow error and liquid flow error of wet gas flow meter are in opposite directions, and this feature of wet gas flow meter is also associated with the metering principle and algorithm the meter, the measurement algorithm of wet gas flow meter firstly analyzes and measures the liquid holdup or liquid fraction of wet gas flow, and then measures the gas flow rate according to the measured liquid fraction and the correlation model. When the measured liquid fraction is smaller than the true value, the correction factor or the over-reading calculated by the liquid fraction and correlation model will also be smaller than the true value, and this will result a higher gas flow rate measurement and cause a positive error of gas flow, and vice versa. Third, the single phase dry gas flow measurement accuracy of wet gas flow meter is lower than that of single phase gas flow meter, this is because the metering algorithm of wet gas flow meter take the dry gas as the wet gas to measure and measures the liquid content first and then the gas flow, the measurement of the gas phase flow includes the measurement result of the liquid phase flow, and the measurement accuracy is lower than that of the simple dry gas measurement using single phase dry gas flow meter.

The above is the direct brief analysis of the test results. The essential reason for the measurement deviation of wet gas flow meter is that the correlation model deviate in the wet natural gas flow, the correlation model of the wet gas flow meter under this test was obtained by data fitting of the data tested with air and water as test medium at the pressure range from 5bar to 15bar. Due to the complexity of wet gas flow, the correlation metering model of current wet gas flow meter is a semi-empirical mathematical model, which is obtained by data fitting, therefore the application scope of the correlations are strictly limited. The current technical reports and related research papers show that the wet gas correlation model will produce uncertain deviation when the wet gas conditions extrapolate the limits of the data range that used to create the correlation model. It can be seen from this study, due to the great difference between the low pressure wet air flow and the flow of high pressure wet natural gas, the correlation models developed with air and water as test medium can not be directly used at wet natural gas flow conditions. When this type of wet gas flow meter used in wet natural gas, the correlation model of the meter must be modified and re-calibrated using wet natural gas test data.

4.3 Wet gas flow meter test after correlation calibration

The wet gas flow meter was tested again after the correlation model was re-calibrated according to the previous wet natural gas test data. The range of the re-test flow condition is consistent with the range of the calibration data, which means the re-test was carried out according to the working condition range of table2. The gas and liquid flow measurement test result after the wet gas meter correlation model calibrated are shown in figure6 and figure7.

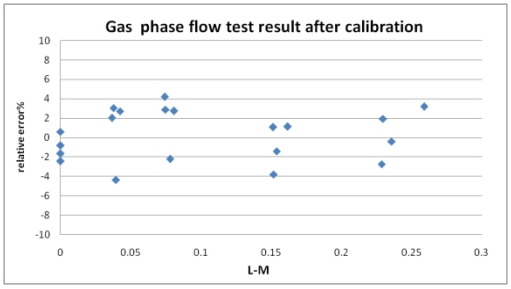

Figure 6: Gas phase flow test result after calibration

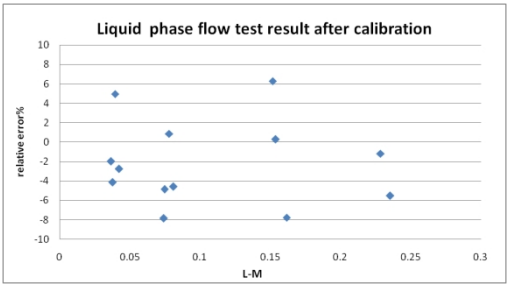

Figure 7: Liquid phase flow test result after calibration

It can be seen from figure6 and figure7 that the gas and liquid flow metering accuracy of the wet

gas flow meter have significantly improved after the correlation model. The gas phase flow rate measurement errors are within the scope between plus and minus 4% and the liquid phase flow rate measurement errors are within the scope between plus and minus 10%. If this wet gas measurement accuracy can be achieved at the wellhead, this wet gas meter can meet the needs of production and management of wellhead metering.

5. Conclusions and Suggestions

It can be seen from the performance test and re-test after calibration that the metering principles and methods of the current wet gas flow meters are workable, however the wet gas correlations of the wet gas flow meter must be re-calibrated with wet natural gas according to the working conditions. There would be an uncertain deviation when the wet gas flow meters that calibrated using air and water at low pressure are directly used at wet natural gas flow, which can not meet the needs of field measurement. Considering this technical feature of current wet gas flow meter, using wet natural gas to calibrate the correlation models according to the flow conditions of wellhead is the necessary mean to ensure the accuracy of wet gas flow meter at the field wellhead. Therefore, the wet gas flow meter should be calibrated under the flow condition as close as possible to the site it will be used.

The wellhead flow conditions of shale gas changes regularly, as the extraction time increase, the wellhead gas pressure and flow rate of shale gas gradually decreases, and the liquid fluid contained in the gas flow gradually decreases as well. According to the analysis of the measuring principles of wet gas flow meters, the difficulty of wet gas measurement reduces as the liquid fraction of wet gas flow decrease. And there is no hydrocarbon contained in the output of shale gas, the components of the gas and liquid of shale gas output are relatively fixed and simple, it is a particular simple case of gas-water two phase flow. Therefore, it is possible to mimic most of flow conditions of shale gas wellhead by wet gas test facility and establish the correlation models for the wet shale gas. The test envelop of the wet gas facility CVB built can cover the flow conditions of shale gas wellhead one year after it put into operation. The next step of wet gas natural gas measurement technology research on shale gas flow should make full use of this wet gas facility to carry out the following several aspects of research work in stages. First, to establish the wet gas correlation model in the test range of the wet gas facility apply wet gas flow test of the facility, and then carry out the shale gas wellhead field test with the flow conditions in the range of the correlations have tested to study the field adaptability of wet gas correlations in the tested ranges and gradually improve the measuring accuracy and adaptability of wet gas correlations, which is helpful to ensure the field metering accuracy of the correlations within the envelope of wet gas test facility. Second, to study the performance of the correlations when extrapolate the flow conditions out of the test range of wet gas facility, to expand the applicable scope of the correlation model. Third, to update the pressure and liquid holdup test range of current wet gas test facility to enhance the test ability that could cover a wider range of test conditions and could able to mimic most of the flow conditions of shale gas wellhead.

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