# Research and Practice of Digital Three-Phase Flowmeter for Complex Oil and Gas Occasion

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**Abstract.** In the development of oil and gas fields, the accurate measurement of oil, gas and water production rate is the basis for calculating the key parameters such as water cut (WCT) and gas-oil ratio (GOR), as well as the important basis for formulating the stimulation measures and field development plans. The traditional surface flowing test is mainly carried out with the help of three-phase Separator or multiple phase flowmeters (MPFM), which is not only complicated operation process and long operating duration time, but also cannot be implemented for environmental protection reasons in some special location. In recent years, with the acceleration of digital oilfield transformation, many wellhead digital multi-phase flowmeters have appeared in the market. However, due to the interference of flow rate, high water cut, high gas content and other factors, the measurement accuracy of most three-phase flowmeters in the market is not good enough, which cannot meet the actual requirement of the customers. In view of the above problems, the design and development of a new on-line three-phase flowmeter is carried out, and the hardware and software system of the flowmeter is upgraded with an iterative and innovative method. Through large-scale field pilot tests to evaluate the performance of equipment, find out the problems during the testing process, and continuously improve the hardware design, software function and core model of the product, so that the instrument can detect the gas and liquid production rate online in real time, and realize real-time data collection and communication through the deep integration with the Internet of Things technology. Present the data to the user in a visual manner in the same time, thus, the whole field data sharing can be realized. The product was put on line in a domestic oilfield after pilot test. The application results show that the product has high stability and the ability


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to work under complex conditions, and can meet the needs of flow measurement under high GOR and high water cut in the oilfield, and has the feasibility to widely expand the application in domestic and foreign oil fields.

**Keywords:** three-phase flowmeter · online detection · The Internet of things · iterative innovation · water content rate · error rate

## 1 Introduction

During oil and gas development, continuous monitoring of wells to obtain pressure, temperature and production data is key to grasping well production status and analyzing reservoir dynamics parameters. Among them, it is particularly important to accurately measure the three-phase flow, which allows calculation of the well's water cut and gas-to-oil ratio. These parameters are a significant basis for formulating oil well stimulation measures and development adjustment plans.

Oil, gas and water are multi-phase flows with complex flow patterns in the well, which increases the difficulty of flow measurement. Normally, truck-mounted three-phase separators are typically used at the wellhead to separate and measure oil, gas and water rate. In addition, stationary three-phase separators at oil and gas processing stations can also be used to separate mixed phases and obtain information such as water cut. However, these processes are laborious, expensive, and do not allow continuous metering. There is an urgent need for reliable online three-phase metering devices for oilfield development and production to reduce investment and improve metering efficiency.

By deploying three-phase flow meters in oil fields, it can realize online automatic collection of oil, gas and water production data from single wells and clusters, optimize the surface process of oil and gas field enterprises, reduce operation costs, improve the accuracy and timeliness of production management and geological reservoir analysis, and provide support for the digital transformation [1–4].

However, due to the oil, gas and water in different flow rates (liquid phase, gas phase flow rate) and gas-liquid ratio to form a variety of flow patterns, the use of three-phase flowmeter for multiphase flow testing is relatively complex [5, 6]. For cross-tube, including laminar flow, bubble flow, segment plug flow, fog flow, etc., by many factors and measurement difficulties, the measurement accuracy of three-phase flowmeter compared with the traditional three-phase separator has a large error, which as a technical bottleneck to limit the three-phase flowmeter large area applications [7, 8]. It is usually conducts continuous field pilot tests on three-phase flowmeters, using iterative innovation to continuously improve the measurement results, so that three-phase flowmeters can more accurately obtain the flow of oil, gas and water to meet the requirements of oilfield production management and reservoir dynamic analysis.

# 2 Online Three-Phase Flowmeter Development Process and Problems

## 2.1 The Test Platform and Development Process of the First Generation Equipment

The online three-phase flowmeter in this study is developed in cooperation with the top multi-phase flow laboratory in China according to the actual needs of the oilfield, breaking the foreign technological monopoly [9–12] and achieving the completely independent research, achieving the scientific goal of domestic replacement of all similar products in the oilfield.

**Fig. 1.** Online three-phase flowmeter appearance structure diagram.

At the end of 2017, the first generation of online three-phase flowmeter product prototype was successfully developed (as shown in Fig. 1). The product, based on a compact integrated measurement solution with multiple sensors, has achieved complete independent development and localization in software and hardware technology. With many advantages such as green and radiation-free measurement process, safety, reliability, high accuracy, modular design and low maintenance cost, it fills the gap of low-cost, non-separated three-phase flow online measurement technology between China and west developed countries in the world. In 2018, the product was completed testing and put on line for the first field pilot test.

After the successful of the maiden voyage, five domestic oilfields were selected for phase II testing at the same time. By deploying 100 sets of three-phase flowmeter equipment in different scenarios such as single well wellhead, inter-meter backdown metering and cluster wells metering, the production of oil, gas and water is automatically collected online without separation, meanwhile, the accuracy of data meets the demand of oilfield.

### 2.2 Technology Principle

The new online three-phase flowmeter consists of four main modules: venturi measurement module, microwave detection module, electro-laminar imaging module, data processing and communication module.

(1) Venturi measurement module

Dual differential pressure venturi flow meters are used to measure the total flow rate in the gas and liquid phases. The differential pressure flowmeter module consists of a venturi with a differential pressure sensor, a pressure sensor and a temperature sensor, connected to a data acquisition and processing module.

(2) Microwave moisture content detection module

The microwave water content module includes a number of microwave sensors with different spatial position directions and angles, which consist of a transmission line set inside a seal, a seal set inside an insulating medium, and an insulating medium set inside a tube. The total circuit module uses the average value of microwave phases to determine the water phase content in the three phases.

By combining the power attenuation and phase angle shift of the detected microwaves in the fluid with a water cut calculation model, the water cut can be calculated as per detected data. This method is more accurate and less influenced by the mineralized content than traditional sensors with RF conductivity technology.

(3) Electromagnetic measurement imaging and display module

Based on the electro-layer imaging technique, the distribution is obtained by applying electrical excitation to the mixed-phase fluid, detecting the boundary value changes, and using mathematical means to invert the distribution of the electrical characteristic parameters inside the mixed-phase fluid. The display module is connected to the data acquisition and processing module and is used to display the results of flow calculations from the output data acquisition and processing module.

(4) Data processing analysis and communication module.

The data processing module is used to receive the differential pressure signal of homogeneous flow output by differential pressure flowmeter, and substitute it and volume flow rate into multi-phase flow empirical model to calculate the average density of homogeneous flow. At the same time, the working gas density can be calculated from the pressure and temperature signals collected by the differential pressure flowmeter and the gas component of the oil-gas-water three-phase flow.

In addition, The data processing module obtains the three-phase flow rates of oil, gas and water by solving a linear system of equations for the interrelationship between the average density, average dielectric constant and phase content of the homogeneous flow, and uploads them to the system through the communication system for use by all relevant departments in the oilfield for queries.

## 3 Performance Enhancement and Product Upgrade

By summarizing the technical problems of the first-generation machine, the researchers conducted countermeasure research in different test bases with the idea of iterative innovation. Through continuous improvement of the hardware design, software functions and core model of the product, the second generation of the product was formed, which has been greatly improved in terms of environmental applicability, working stability and performance index.

**Table 1.** Iterative innovation upgrade content of three-phase flowmeter

| Items | Improvement content | Improvement effect |
|---|---|---|
| Hardware Design | Improved differential pressure transmitter, using a new capillary differential pressure transmitter to replace the traditional pilot pressure differential pressure transmitter | Improved the stability of equipment working for a long time and the consistency between different equipment and different time periods of the same equipment.<br>Improved the applicability to frequently changing well conditions and the feasibility of sensor data, and enhances the robustness of the model.<br>Avoided the problem of signal distortion caused by occasional lead pipe blockage |
| | Improved environmental suitability in terms of equipment differential pressure sensors, interface piping design, etc | The differential pressure transmitter adopts professional capillary pressure to replace the original metal pipe pressure, which improves the adaptability to low temperature.<br>Improved interface and piping design to further reduce the requirement for insulation work |
| | Improved hardware design to facilitate on-site maintenance | Reduced device size for easy transportation, installation, post-operation and maintenance.<br>Improved display to support instant wake-up and reduce energy consumption |
| | .Improved enclosure design, added keys and enhanced site protection | Improved the box design to reduce the difficulty of opening the box for maintenance by reducing the size.<br>Added buttons to facilitate user's on-site operation of inverted wells and data inquiry.<br>Improved the effect of rainproof and dustproof |

(*continued*)

**Table 1.** (*continued*)

| Items | Improvement content | Improvement effect |
|---|---|---|
| Software Features | Support inverted well operation, real-time data query, and historical data query | The device added buttons to support user field operation and reverse well change, and also reserves interfaces to support linkage with automatic well change systems.<br>Supported real-time data and historical data query, including liquid, oil, gas, water, water content, gas-oil ratio by day |
| Core Model | Introduce a new algorithm architecture of artificial intelligence + classical model | Artificial intelligence-based deep learning for real-time classification of flow patterns and flow regimes, and data computation based on classical fluid dynamics models.<br>Fully reuse the existing calibration data of each well to support data migration and assist in AI model classification training.<br>On the basis of achieving consistency among equipment, unify models across ranges and equipment areas to improve the applicability of equipment to new well conditions and significantly reduce error levels |

The second-generation prototype was quickly entered several oilfield plays for field testing and evaluation, targeting single-well metering and covering a wide range of extraction methods, including natural flowing well, rod pump and ESP wells. Test well conditions include high GOR and high water cut wells located in the Northwest field with flow rates from 100 to 350 bbls/d, gas production rates of 0 to 15,000 m3 /day and water cut from 50% to 99%; and low production and high water cut wells located in the Northeast field with flow rates of 50 to 100 bbls/d. Through testing to verify the applicability of the three-phase flowmeter in multiple production ranges, the product supports the provision of second-level online flow data, which can help users more effectively determine the trends and changes in oil and gas well production, providing a reliable basis for oilfield production management.

## 4 Field Applications

After the new online three-phase flowmeter product was put on line, a pilot test was conducted in a domestic E&P company of China National Petroleum Corporation, which mainly included the following four purposes.

(1) Verify the performance of real-time online three-phase flowmeter in oilfield environment.
(2) Obtain data on the applicable working condition range and metering accuracy of the real-time online three-phase flowmeter.
(3) Verify the stability of real-time online three-phase flowmeter under extreme environmental conditions.
(4) Update and iterate on the equipment to meet the needs of each oilfield technology promotion in response to the product usage effect.

Fifteen units are deployed for block metering and single well metering in the X field owned by the exploration company, involving various well types such as pumping and electric submersible pump wells, with liquid volumes ranging from 100–1500 bbls/day, gas volumes ranging from 2000–10000 m3/day, and water cut ranging from 0–100%, basically covering all metering scenarios and well conditions in the field.

Combined with the existing metering and verification vehicle, tipping bucket meter, mass flow meter, vortex flowmeter and other equipment, the well station gas-liquid two-phase accuracy comparison and verification in a flexible manner can be carried out.

Among the 12 devices used for liquid phase validation, five had relative errors below 3% and seven had relative errors below 5%. During the period, a one-month continuous monitoring comparison was done in X-121, and the comparison data are shown in Fig. 2. The daily production trends measured by the three-phase flowmeter and mass flowmeter were basically the same, and the performance and stability of the equipment were verified.

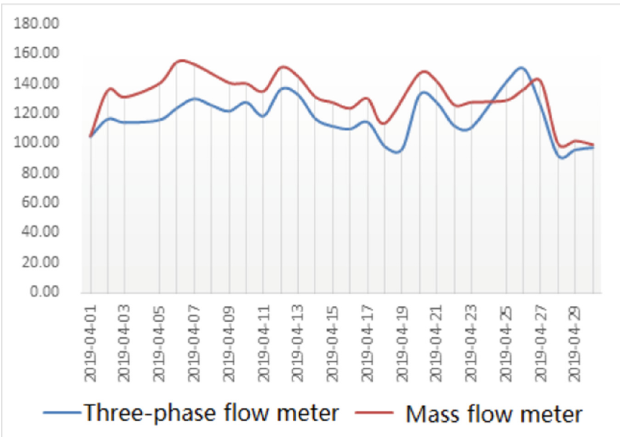


**Fig. 2.** Comparison of daily fluid production from wells at station X-121

The gas phase verification results of the 10 devices showed that the relative errors of the devices were all less than 5%. Moreover, the water content validation of 8 of the above devices showed good performance. Specifically, the absolute error of 6 devices are less than 3%, and the absolute error of 2 devices is less than 5%.

The test results show that the accuracy of the new three-phase flowmeter in the three measurement indexes of liquid volume, gas volume and water content can meet the needs of oilfield production, while combined with its higher stability can fully meet the actual production needs of the oilfield.

## 5 Conclusions

(1) The new online three-phase flowmeter has a novel design and reliable performance, and supports second-level real-time online access to oil, gas and water flow data functions, which can help oilfield users more effectively determine the trend and changes in oil and gas well production and provide a reliable basis for oilfield production management.
(2) Three phase flowmeter through the continuous field test test, find the problem, put forward solutions, and constantly improve the reliability and measurement accuracy of the product, and gradually completed the upgrade from the first generation to the second generation. Achieved a typical domestic oil field 0–100 tons / day flow detection, comprehensive coverage from high gas content low water content to low gas content high water content conditions, and the detection accuracy from 15% error rate to within 10% of the error rate.
(3) Field accuracy verification results show that the new online three-phase flowmeter can fully meet the demand of oilfield production in terms of the accuracy of liquid volume, gas volume, water content and other parameters measurement. In addition, the product has high stability and the ability to work under complex conditions, and can complete the flow measurement in various conditions in the oilfield, which is suitable for expanding applications in oil fields at home and abroad.

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