The last few years have seen oil production industry and state regulators bring forward increasingly strict requirements regarding well yield measurements. Conventional metering technologies, based on gas/liquid separation, do not necessarily meet the most recent requirements concerning accuracy, efficiency and validity of measuring data. This can be especially significant when applying modern “smart oil field” concepts, where a close interaction between instant measurement data, layer models and real-time control is pivotal. Furthermore, the old technologies require high levels of maintenance which means a high TCO (Total Cost of Ownership). Some alternative new technologies utilize radiation sources. These systems retain relatively high costs and attract even more rigorous safety requirements.

Given the current state of play, a relatively new multi-phase metering technology which avoids separation and which utilizes conventional industrial sensors such as Coriolis flow meters, water cut meters, and temperature and pressure sensors, is drawing widespread interest from the industry.

**NetOil&Gas measuring skid**

The NetOil&Gas measuring skid (from here on referred to as the Skid) is intended to measure the oil and gas flow rates and accompanying water in a three-phase well fluid. The Skid core technology has been developed by the Invensys Technology Centre located at Oxford University and now is commercially produced by Invensys Foxboro. The Skid is intended to replace three-phase separator measuring systems conventionally used for well testing and production monitoring in the field.

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1Печатается в авторской редакции.
Fig. 1 shows the design of the Skid. The pipework dimensions and internal diameter (50 mm) are the same for a range of Skid (Coriolis flow tube) DNs from 15 to 50 mm. The Skid with flow tube DN80 has an 80 mm pipework. The well fluid flow is conditioned to minimize slip through the rising and falling of the Skid pipework. The Coriolis meter is installed in the downward and outward leg of the Skid. The design has been developed through field experience with low pressure well applications, and helps to ensure that with low flow rates liquid passes through the Coriolis meter in relatively substantial slugs, which provides better measurement performance.

It is commonly believed that Coriolis meters are not applicable for liquid/gas mixtures. However, researchers at the Invensys Technology Centre have been studying this issue for over two decades, and developed a new fully digital Coriolis meter for liquid/gas operation. The first commercial version of the digital Coriolis meter was launched by Foxboro in 2002. Since then, this innovative Coriolis meter has found hundreds of successful two-phase applications in the chemical, oil and gas, food and beverage and other industries, and has become the heart of the NetOil&Gas Skid. While other vendors are now offering Coriolis meters with claimed two-phase performance capabilities, Foxboro are the market leaders in this field, as demonstrated by the introduction of this new, non-separating three-phase Coriolis-based metering system.

In addition to the Coriolis flow meter, the instrumentation on the Skid consists of a water cut meter and a multivariable pressure and temperature transmitter. The water cut meter is placed immediately below the Coriolis meter. The multivariable transmitter reads the fluid pressure at the inlet to the Coriolis meter and the temperature at the top of the Skid. The control unit, called the Net Oil Computer, acts as communication master for all the devices, using the Modbus RTU industrial communication protocol. The control unit performs three-phase flow measurement calculations based on the data received, provides a human-machine interface (HMI) and also archives well test data files. Real-time data is available to the user’s control system via a Modbus interface, with an update rate of 1 second.

Several water cut meter technologies have been evaluated for measurement accuracy when gas is present in the well fluid. The water cut meter operates using near-infrared absorption spectroscopy with several bands of infrared wavelengths measured simultaneously to distinguish water, oil, gas and other components. Recently an oleophobic and hydrophobic non-stick lens coating has become standard for the NetOil&Gas Skid water cut meter.

The hardware/software architecture of the Skid is shown in Fig. 2. The Display Computer provides three communication interfaces: an internal Modbus for the Skid instrumentation, an external Modbus to provide the user with final measurement values, and an Ethernet interface to enable remote configuration, monitoring and archival data retrieval. The Display Computer further provides a touch screen HMI to enable local configuration, data display, etc. Fig. 2 further shows an overview of the flow calculations. The uncorrected data from the instruments is gathered via the Modbus interface. Here, ‘uncorrected’ refers to the effect of multi-phase flow: the mass flow, density and water cut readings are calculated based on their single-phase calibration characteristics. The liquid and gas densities are calculated based on the temperature, pressure and water cut readings and configuration parameters provided by the user. Corrections are applied to the Coriolis meter mass flow and density readings based on the three-phase flow measurement models. Finally, the oil, gas and water measurements are calculated from the corrected mass flow, density and water cut readings.
The primary technical challenge is to correct for the potentially large errors induced in the mass flow and density measurements of a Coriolis meter by the effect of a gas/liquid mixture. Error functions depend on flow tube geometry and orientation. For a fixed flow tube position, the most significant dynamic parameters are the liquid flow rate and the Gas Volume Fraction (GVF). Previous works, e.g., [1], describe how these errors can be modelled so that corrections can be applied based solely on parameters observable within the Coriolis meter itself. While a number of approaches are possible, here Neural Nets have been used for modelling purposes. A series of experiments have been carried out to create a range of mass flow, GVF and water cut conditions, where the resulting mass flow and density errors have been modelled based on internally observed parameters. Further details of the techniques used to model the multi-phase error surfaces are given in [2], such as handling the interaction between models of the Coriolis meter errors and the water cut meter error. This patent further includes the use of superficial velocity to model flow meter behavior where slip is significant.

NetOil&Gas Skid is specified for use with relatively light oils up to 870 kg/m³ density and 50 cP viscosity. Accuracy specifications are in full correspondence with GOST R 8.615-2005 Standard amended 2010 in the full 0-100% water cut range and 0-50% GVF range. The Skid has passed a number of laboratory tests in TUV NEL (Glasgow) and VNIIR (Kazan). NetOil&Gas Skid was certified as multi-phase flow meter in 2012. Fig. 3 shows some test results obtained for NetOil&Gas 1½” at VNIIR multi-phase testing rig in 2013 [3].

**MERA-MR industrial measuring unit**

Industrial unit MERA-MR utilizing NetOil&Gas technology has been developed and certified by Invensys’ business partner HMS Neftemash OJSC, part of HMS Group, with its plant located in Tyumen. The unit has two versions: stationary and mobile. The stationary unit is intended for multi-well
measurements at extracting pads. This version is designed as a technological block with a multi-well switch inside and can serve up to 14 wells. The mobile version is mounted on a trailer or truck and is suitable for testing, monitoring, supervision, calibration, geophysical research, etc. The State Metrology Institute VNIIR has recognized the mobile MERA-MR unit as a suitable basis for field calibration in accordance with the State metrological traceability chain. As an example, Fig.4 shows a mobile MERA-MR unit carrying out a field test.

For GFVs higher than 50 %, which may occur in some green field applications, both the stationary and mobile units can be equipped with an optional gas separator. This removes excessive gas into a separate measuring line while the residual fluid (possibly with moderate levels of gas present) flows to the NetOil&Gas skid. This separator is usually a cyclone-type gas diverter, which is smaller, lighter and cheaper than the conventional gravity-type devices, as it does not have to remove all of the gas. The MERA-MR unit is equipped with all required safety and life-support systems. By request it can be adapted to different specific conditions and regulations, or equipped with optional systems and tools, e.g. air conditioning or heating system, heat insulation, fluid heating system, electric generator, specific tools, pipe adapters, etc. MERA-MR unit passed Type Approval examination in 2013 and now has a full set of necessary approvals and permissions to be used in oil and gas industry.

**MERA-MR field trial results**

HMS Neftemash and Invensys Foxboro have carried out a number of field tests in partnership with interested oil companies. The test results have confirmed the accuracy specifications, the high level of performance of MERA-MR unit and the reliability of measurement data.

The first field tests were carried out oil fields in the Western Siberia and Southern Volga regions in 2012. The NetOil&Gas skid was tested together with conventional separator-based measuring units. Field test confirmed general performance, reliability, ease to use, HMI, operability, features and other qualities of NetOil&Gas technology despite (as was expected and then explained in the report) full correspondence between different measuring technologies was not obtained.

In 2013 the first industrial mobile unit based on the NetOil&Gas skid, MERA-MR ser. No2603, was ready for field testing. The first MERA-MR field trip was launched in June-July of 2013 in an oil field in the Southern Volga region. Ten tests on 7 different wells were carried out following the test schedule. Comparative tests against conventional measuring separator-based units showed that the MERA-MR gave a much more detailed profile of well behavior, better oil and gas measurement stability and better data reliability. A key conclusion made by the customer was that the NetOil&Gas technology with real-time and full-fluid-composition readings provides extremely valuable data for geophysical research and oil layer control. Another proven benefit of the technology, which is especially important for mobile measuring units, is the significantly decreased test duration.

A further field test in a ‘Brownfield’ oil reservoir located in central Russia, which was carried out in October 2013, demonstrated another NetOil&Gas proven benefit. Because of the outstanding sensitivity of the technology, the usual methods of well productivity testing such as Level/Pressure build-up can be replaced by Pressure transient tests. The customer believes this can improve oil output from their well stock by as much as tens of thousands of tons per year.

The general advantages of NetOil&Gas technology underlined by all customers are:

- Real-time well flow readings (once per second) including full fluid composition: oil, water, free gas and dissolved gas;
- Minimal pressure drop and minimal impact on the pattern of fluid flow. This leads to extremely reliable data, because the measured flow is exactly the same as the free fluid flow;
- Advanced communication capabilities. Measurement data can be transmitted to a control room or data logging centre by any accessible data channel in real-time;
- Advanced reporting tools. The full test report, including totalized data and graphs for liquid, oil, water, free and dissolved gas, can be obtained remotely minutes after the test is finished. Fig. 5 shows an example of a three-phase flow time series graph from a typical well test report.

![Fig. 4. Mobile measuring unit MERA-MR in the field](image)

**Fig. 5. An example of field test report**
Prospects

Today NetOil&Gas technology and industrial measuring unit can be considered as fully developed, tested and proved technology ready for industrial applications. Accuracy specifications are proved by number of laboratory tests and performance has been demonstrated by initial field trials. Despite slightly higher purchase cost comparing to conventional skids the NetOil&Gas technology secures lower TCO during full life cycle as shown on Fig. 6.

Today HMS Group is taking its first commercial orders for stationary and mobile measuring units. We would welcome enquiries from all who are interested in this new state-of-the-art multi-phase measuring technology.

References