ABSTRACT

Over the last 20 years, a number of multiphase flow measurement techniques have been developed for metering oil (or condensate) / water / gas commingled streams. The available techniques can be characterized as those that operate inline or with partial separation. The inline variety typically consists of several meters or measurements and a central computer to interpret the signals and calculate individual phase flow rates. Techniques that employ some element of separation typically use a compact, continuous mode gas-liquid separator with subsequent metering on the gas rich and liquid rich flow streams. This paper will review some of the more common techniques being used with a focus on the application of GLCC®s (gas-liquid cylindrical cyclones) in multiphase flow measurement.

INTRODUCTION

The options today for measuring condensate, water, and gas production from individual wells or group production range from full three phase separation to online measurement, and a variety of partial separation techniques in between.1 While “multiphase measurement” has been generally understood to mean instruments or systems that do not require phase separation prior to measurement, the category has grown to include a number of partial separation techniques. These partial separation techniques typically involve some type of gas-liquid separation into two streams for subsequent measurement. The key distinction governing the classification of the technique as “Multiphase Metering” (MPM) or “Conventional Metering” appears to be whether the gas-liquid separation is done on a continuous basis or in a batch mode. For our purposes we will define Multiphase Metering as the continuous measurement of oil (or condensate), water, and gas.

It the area of gas well metering, there is another class of meters. These meters are classified as “wet gas” meters, which are designed to measure the amount of gas and “total liquid” in a high Gas Void Fraction (GVF) stream. These meters do not determine the ratio of condensate and water in the liquid stream, and have a limited GVF operating range. They are really designed to tell the customer how much gas is flowing in a “wet gas” stream.

FLOW REGIME

When considering conventional or multiphase metering for well testing it is important to understand that the incoming “flow regime” affects the performance of the equipment. The condensate/water/gas stream enters under different conditions based on both the rates and ratio of the oil, water, and gas. These combinations produce different flow regimes, which can have instantaneous flow rates significantly different from the “daily average rates” commonly used to size the equipment. The flow regimes are: Mist, Annular, Wavy, Slug, Plug, and Bubble.2 Most gas applications fall into the “annular” or “mist” flow regimes. A flow pattern map is shown in Figure 1, which displays the relationship between superficial gas velocity (x-axis) and the superficial liquid velocity (y-axis). In addition to the different flow patterns that can be created by the well, there is the condition of “terrain slugging.” This slugging condition is caused by the rise and fall of the pipeline due to the terrain, or the orientation of the process piping. In this case, there are places that trap liquid and allow it to build up until the liquid volume becomes sufficient to be captured by the passing gas, which creates a solid liquid slug.

FIGURE 1.
Flow Pattern Map for Horizontal Pipe Multiphase Flow

These different flow conditions can affect the performance of all metering equipment, because the instantaneous flow rates can well exceed the operating ranges of the metering. It is important to note that some of the “partial separation” Multiphase Meters can actually condition the incoming flow and reduce the size of the equipment downstream of the meter.

THE CASE FOR MULTIPHASE METERING

Multiphase Meters are not approved for custody transfer in the U.S.A.; however, the Minerals Management Service has approved Solartron ISA’s Subsea Dualstream II wet
The most common reasons for considering MPM near the well site are: allocation, reservoir management, early detection of water, and to optimize the injection of hydrate inhibitor. The premise is that by “instrumenting” the wells, the producer can truly optimize the process of producing gas. Producers would be able to monitor production and reservoir conditions and detect any changes in production immediately. In addition they would be able to update their reservoir models and reduce the risk of incorrectly defining the reservoir and its characteristics.

Accuracy. Based on the early performance of MPM in the 1990s it is difficult to consider MPM as more accurate then conventional three-phase test separators. This past performance is somewhat to be expected with the development of new technologies.

Multiphase Metering equipment has continued to improve over the years and many systems now perform as well or better then the traditional three-phase test separators in some applications. These product advancements continue to improve MPM performance, and it is quite reasonable to expect multiphase metering systems to surpass conventional testing accuracies for almost all applications.

Costs. Cost comparisons are not straightforward due to the large number of variables that can all have a significant cost impact for a specific application. Furthermore, the price range of commercially available multiphase meters can differ by a factor of 10:1. Some general guidelines follow:

- Vessel type separator pricing is a much stronger function of pressure, flow rate, and material (corrosion handling) than multiphase metering pricing is. As conditions get more challenging, multiphase meters become more competitive.

- Most multiphase meters have fewer moving parts than comparable vessel type separator systems. This translates into less maintenance. Conversely, the parts for multiphase meters are typically more complicated so when a problem does exist, highly trained service personnel are usually required.

- Multiphase meters for individual well monitoring can eliminate the need for test lines. In some offshore and remote onshore locations, this savings can more than offset the cost of the multiphase meter.

- Some multiphase meter designs fall under piping guidelines and as such may eliminate the need for safety inspections that are often required for pressure vessels.

Safety. Pressure vessels represent a significant safety risk due largely to their size. While multiphase meters handle the same fluids and pressures, the consequences of a large vessel failure are far more serious. Partial separation Multiphase meters have a significantly lower amount of “hydrocarbon storage” which is much safer then the large separation vessels. In addition, the partial separation systems can be fabricated to meet the same design pressures as the piping, so they can be protected by the existing pressure relief valves on the manifold. Most in-line multiphase meters, however, introduce their own significant safety threat with their use of radioactive materials.

WET GAS METERS

Wet gas meters are designed to tell the operator the amount of gas and total liquid that is passing through the line. They do not tell the operator the ratio of condensate and water in the liquid.

Solartron ISA Dualstream II

The Dualstream II is based on technology developed by the British Gas R&D division, and is capable of measuring wet gas without the need for sampling or tracer measurements. The meter uses a venturi meter and a “second differential pressure flow meter” to determine the gas and liquid rates. (GVF 90 – 100%) (Design pressure ≤ API 15000)

Agar Wet Gas Meter

This metering determines the gas and liquid fractions in real-time without the need for knowing densities. The Meter is comprised of a dual venturi run that measures the GVF; and a vortex shedding meter that provides the additional flow information for the correction of the flows without any density input. (GVF 90 – 100%) (Design pressure ≤ 10,000 psi)

Multiphase Meters

Multiphase meters are designed to measure all three phases of the wells production; oil (or condensate), water, and gas. Some of these meters may have a limit in the GVF range that they can handle; therefore, the GVF range has been listed with each description. New companies and products continue to be introduced into the market so the following list of manufactures is not a complete list, but is the best list that could be compiled at the time.

Inline Multiphase Meters

A number of manufacturers offer inline multiphase meters that do not call for any phase separation. A sample of the offerings with a brief description of the measurement principle follows. Where possible, the description is paraphrased from the product brochure. This list of inline meters is not intended to be all-inclusive.
GLCC© (Gas-Liquid Cylindrical Cyclone) style compact

The Premier multiphase metering system employs a Premier Instruments of metering systems is not intended to be all-inclusive. A partial list with a brief description follows. Where possible, the description is taken from the product brochure. This list of metering systems is not intended to be all-inclusive.

A number of manufacturers now offer multiphase metering systems that use compact gas liquid separators to either concentrate the gas and liquid legs or completely separate them before subsequent measurement. In some cases, manufacturers use compact separation in conjunction with their inline devices to extend the operating range or improve performance. One of the added advantages of the partial separation approach is that some manufactures can permanently split the flow, allowing the operator to remove the liquid at the point of metering. A partial list with a brief description follows. Where possible, the description is taken from the product brochure. This list of metering systems is not intended to be all-inclusive.

Partial Separation Multiphase Meters

Premier Instruments

The Premier multiphase metering system employs a GLCC© (Gas-Liquid Cylindrical Cyclone) style compact separator to split the gas and liquid streams. Then conventional gas and liquid flow meters are used to determine the volumetric flow, and Premier’s infrared water cut meter is used to establish the oil/water ratio. For many customers the use of conventional metering provides a significant advantage over the use of specialized systems, allowing them to troubleshoot and repair them in the field. The GLCC© may or may not include control valves on the gas and or liquid leg depending on the range of gas and liquid rates the system must handle.10

Premier MPFM 1900VII

This meter utilizes electrical impedance measurements and gamma densitometry signals to establish oil, gas, and water fractions. Then the cross-correlation of the signals is used to measure individual component flow rates.6

Kvaerner Duet

This meter uses dual gamma ray densitometers to measure the condensate, water, and gas. It calculates the velocity by using the cross-correlation technique on the densitometer signals. In addition, Kvaerner can add a venturi meter to the system, to enable it to achieve GVF ranges from 97 – 100%.8, 9

Schlumberger VX /(Framo)

This meter employs a mixer-flow conditioner followed by a venturi mass measurement coupled with a dual-energy gamma ray phase holdup measurement.7

Roxar MPFM 1900VI

This meter utilizes electrical impedance measurements and gamma densitometry signals to establish oil, gas, and water fractions. Then the cross-correlation of the signals is used to measure individual component flow rates.6

AGAR MPFM 400 (High Gas Volume)

The MPFM 400 Series extends the dynamic range of the gas and void fraction capacity of the MPFM 300 Series by using a Fluidic Flow Diverter (FFD™). The solid state FFD™ uses the difference in flow momentum of the gas and the liquid to divert most of the free gas in the stream into an ancillary measurement loop around the MPFM 300. The remaining fluids flow through the MPFM 300 Series. The gas in the bypass loop is metered and added to the oil, water and gas measured by the MPFM 300 unit.4, 5

Phase Dynamics & Kvaerner CCM

The CCM (compact cyclone multiphase meter) developed by Kvaerner and Phase Dynamics employs a proprietary compact separator, conventional gas and liquid flow meters and a microwave-based water cut meter.11, 12

Daniel Industries MEGRA

This meter uses a GLCC© style separator to split off the main portion of the gas. The gas is then measured using a coriolis or vortex shedding meter. A MEGRA MPM (GVF ≤ 25%) is installed on the liquid leg to measure the condensate, water, and remaining gas. The MEGRA is a venturi meter for bulk flow rate and Multiple Energy Gamma Ray Absorption (MEGRA) for phase fraction measurement. For GVF greater than 25%, the manufacturer suggests upstream compact separation.13, 14

Daniel Industries Micromotion

This meter uses GLCC© partial separator to completely split the gas and liquid flows. Both the gas and liquid legs have coriolis meters to measure the gas, condensate, and water.13, 14

GLCC© Compact Separator

The Gas Liquid Cylindrical Separator has gained in popularity over the last ten years as an alternative to vessel separators. The GLCC© is an integral part of several commercially available multiphase meters as well as dozens of “home made” systems developed by ChevronTexaco, and others. Today there are over 350 special cases...
GLCCs in operation throughout the world with the vast majority being used in multiphase metering applications. They range in size from 3 in. to 5 ft. in diameter and 5 ft. to 30 ft. tall.1

Principle of Operation. A GLCC has a vertically mounted pipe with an inclined tangential inlet (Figure 2). The inlet is designed so that the incoming three-phase flow generates a swirling action (Figure 3). The centrifugal force pushes the denser liquid phases out toward the wall and down to the liquid leg. The lighter gas phase is forced to the center and out through the upper gas leg. The resulting gas and liquid legs are then metered and the flow streams are recombined to provide a hydrodynamic balance to the system.

![FIGURE 2. Basic GLCC](image)

![FIGURE 3. GLCC Top View](image)

In the simplest configuration, there are no moving parts and “off the shelf” gas, liquid, and water cut meters are used to measure the three-phase production. More elaborate configurations can include a level transmitter, a gas leg control valve, a liquid leg control valve, and an inline multiphase meter on the liquid leg.

Design considerations. The operational envelope of a GLCC is defined by the permissible gas carry over (GCO) and liquid carry under (LCU) allowed by the application. GLCCs can be designed to provide near zero GCO and LCU but simpler and lower cost designs are achievable if some level of GCO and LCU is tolerable. In multiphase metering applications, the target accuracies and the metering instruments dictate these allowable limits. The design objective is to match a body design to the particular incoming multiphase flow conditions and select metering equipment to provide the desired overall accuracy given the anticipated GCO and LCU.

Determining the appropriate body designs for a particular multiphase flow condition is a difficult task and may be the most significant reason GLCC use has not been more prevalent. This task has been made much easier by the recent development of a GLCC simulator. The simulator was developed at Tulsa University under the auspices of the Tusla University Separation Technology Projects (TUSTP), a joint industry project (JIP) created in 1994 to further the development of separation technology for the oil and gas industry. The simulator essentially predicts gas carry under, liquid carry over, and overall pressure drop for a given set of process parameters and GLCC design characteristics. The important process parameters include: anticipated flow rates, temperature, pressure, and fluid viscosity. Flow rates must be considered in terms of instantaneous values rather than daily averages. It is also very important to understand the resulting flow regime (e.g., mist, slug, churn, bubble, liquid ribbon, etc.) as it will impact the design and even determine the suitability of a GLCC.

The body design characteristics include the main section diameter and height, gas and liquid leg diameters, inlet configuration, and recombination height. The inlet configuration consists of several parameters including diameter, port opening, single or dual (Figure 3), and height relative to the vertical pipe section. The port opening refers to the actual opening into the vertical pipe. Restricting the opening will increase the stream velocity, which may be needed to facilitate separation.

The simulator includes a “Design Wizard” that will suggest recommended body design features based on the flow conditions. This simulator program is made available to all contributing members of the JIP but successful application of the simulator requires a skilled operator. An iterative process is almost always required.
The second phase of design involves selection of appropriate metering instruments. While the GLCC© style system allows for the use of conventional gas and liquid metering with proven track records, the potential for wet gas and gassy liquid can cause problems for otherwise robust technologies. In general, detailed performance specifications in non-ideal flow streams are not available from meter manufacturers. Work is underway at Texas A&M under Dr. Stuart Scott's direction to characterize common metering technologies in terms of the added uncertainty resulting from wet gas and gassy liquid. Water cut meter performance in gassy liquid may also be a concern especially as the water cut increases. The impact of erroneous water cut measurements on net oil calculations increases dramatically at high water cuts.

In some cases, GLCC©s are used in conjunction with inline multiphase meters to improve performance. Clearly, the tolerable level of gas carry under far exceeds that for conventional liquid metering resulting in a simpler GLCC©.

EXAMPLES

Figures 5-7 represent a small sample of the GLCC©s in the field. Figure 5 shows an early Chevron prototype in Oklahoma. Figure 6 shows the world’s largest GLCC© at

FIGURE 5. Early Chevron Prototype in Oklahoma

FIGURE 6. Bulk Separation, Minas, CPI, Indonesia

5 ft. in diameter and 20 ft. high. The unit is located in Minas, Indonesia. Figure 7 shows a unit that was used to replace a three-phase test separator for well testing.

FUTURE GLCC© DEVELOPMENT

As more and more GLCC© based systems are implemented, actual field results will allow refinement of the simulator. Work is also being started on connecting Gas-Liquid separators with Liquid-Liquid and Gas scrubbers to build an overall system that will meter and separate oil (or condensate), water, and gas streams.

CONCLUSIONS

There are now a variety of metering systems available on the market. They range from inline or partial separation systems and both have their advantages and disadvantages, but they all offer continuous measurement capabilities. Continued testing and product improvements are advancing the industry as a whole, and the desire of producers to implement this technology continues to grow. If the current trends continue, the producers will shift to using MPM instead of the old three-phase test separators.
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