**Determination of Net Oil for Well Performance Measurement**
Class LM2100

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**Abstract**
Although there are several techniques for measuring net oil and water cut from a producing oil well, each method has its particular requirements and limitations. Various technologies have been used in this application and their characteristics are briefly discussed. Coriolis meters have been used successfully in over 4000 sites to date. Their popularity indicates that their requirements and limitations are not overly restrictive, and that their applications as net oil computers are not too complicated for field personnel. This paper details the use of Coriolis meters in this application and explains how their requirements for well performance measurement can be met by using a new electronics platform.

**Definitions**
Net oil is the volume of oil, corrected to a reference temperature that is contained within a gross volume of produced fluid. In order to determine net oil, it is necessary to determine the water cut of the produced fluid. Water cut is the volume fraction of production fluid that is produced water.

**Measurement Methods**
Oil well performance was first measured by flowing into tanks. Although simple in concept, tank testing does not lend itself to accurate water cut measurement, temperature compensation for volume, or compensation for evaporation and backpressure. Test times can also be unreasonably long for low producers.

To overcome these limitations, vessel type separators were introduced. These test separators are connected to a manifold where all of the wells in a nearby area are tied in. The wells are tested one at a time, while the other wells in the manifold flow to the production separator.

A three-phase separator attempts to separate the oil, water, and gas into separate streams, where flow measurements are made on these individual streams. Typically, turbine meters are used to measure the oil and water streams, called "legs" coming off of the separator. The oil leg usually has some water entrained in it and capacitance probes are used to measure the water cut of this oil stream. The gas, coming off of the top of the separator, is usually measured with an orifice plate. The flow meters and probe are connected to a net oil computer that calculates "net oil" and water cut at actual temperature.

The problem with this system is that it is unreliable. The major weakness is the water-oil interface level control on the separator. It relies on an electronic detector or a mechanical displacer that floats between the oil and water interface. Paraffin, foamy crude, tight emulsions, well surges, and other common oilfield phenomena, cause problems with interface level controllers and allow water to escape through the oil leg, and oil to escape through the water leg. If the water cut exceeds about 10% on the oil leg, the capacitance probe becomes saturated and reads 100% water cut. Another weak component is the turbine meter. The bearings are susceptible to accelerated wear from the sandy liquids, and the blades are vulnerable to damage from gas and liquid slugs during upset conditions. Vane-type positive displacement meters don't fare any better in this type of service, and are also prone to failure.

**Two-Phase Separators**
Being much simpler, a two-phase separator is much more reliable, since all it has to do is separate the liquid from the gas. Now the trick is to differentiate the water from the oil. You would think that with two liquids having such different physical characteristics that this would be easy. Think again.

Oil and water mixtures exist in one of three types of phase regimes: oil continuous, water continuous, and emulsion. Oil continuous is a matrix of oil with water droplets dispersed. Water continuous is a matrix of water with oil droplets dispersed. An emulsion is a homogenous mixture of oil and water that looks like a milk shake. Under a microscope it appears like tiny spheres of water and oil packed together like black and white marbles in a jar. Tight emulsions can be very tenacious, not separating even after months of stationary captivity.

These oil and water mixtures, exiting the liquid leg of a two-phase separator were first measured for water cut using capacitance probes. This worked fairly well until water cuts rose high enough to cause the produced fluid to shift from oil continuous to water continuous. When this happens, there is a free electrical path through the water (usually saline, a good conductor) between the capacitance plates. This results in a short circuit and causes the meter to read 100% water cut. This transition from oil continuous to water continuous can occur anywhere between 10% to 50% water cut, with 30% being an average dividing line.

Early microwave and radio frequency water cut probes, also utilizing the 60 to1 difference in dielectric constant between oil and water, had a similar problem. Like the capacitance probes, they had good accuracy at the low water cuts, but when the mixture became water continuous the devices were overwhelmed by the massive attenuation of the water phase. Recent improvements to this technology have made the devices capable of operating throughout the water continuous and oil continuous phase regimes. Although capable of operating from 0 to 100% water cut, their accuracy at higher water cuts diminishes. Most microwave probes are also affected by changes in water salinity and oil density, and must be calibrated on the individual well fluids.

Very recently, near infrared (NIR) water cut probes have been introduced to the well performance measurement application. These devices have exhibited very good performance in high water cut environments. The commercially available model on the market today utilizes an infrared wavelength that is attenuated by oil. It has particularly good application in mature oil fields with active water floods where water cuts are normally above about 70%. Their simplicity of operation, low installed cost, and tolerance for entrained gas makes them a promising alternative to dielectric water cut devices.

**Coriolis Net Oil Measurement**

Since about 1986, Coriolis meters have been used in well performance measurement on two-phase separators. These meters measure mass flow, density, and temperature directly. The operator is required to enter the individual oil and water densities for each well. The on-line density measurement from the Coriolis meter determines the water cut of the produced fluid. A net oil computer is then used to calculate net oil, using the mass flow and density measurements. Using the internal temperature measurement in the Coriolis sensor, the net oil computer is able to give results at standard temperatures: 60 deg F, 15 deg C, or 20 deg C.

The limitation of Coriolis meters for water cut is that there can be no free gas bubbles in the liquid. Free gas causes the bulk density of the liquid to decrease. This causes the water cut to read too low and net oil to read too high. The requirements of the Coriolis net oil system are that the oil and water densities are known and entered at reference temperature into the net oil computer. These densities are usually measured and recorded when the well is completed, or obtained by grabbing liquid samples, and measuring the density in a laboratory. The oil density is complicated by the fact that it must be sampled and measured at the same pressure as the Coriolis sensor. This is because the light hydrocarbon molecules in crude oil will immediately evaporate to the atmosphere if exposed even briefly. This leaves behind heavier oil that has a higher density than that which is being measured in the line.

**In-line Density Determination**

Recently, one Coriolis manufacturer has made the determination of the individual oil and water densities much easier for field operators. The operator first purges the two-phase separator of the previous well's contents by flowing the well to be measured into the separator for a pre-determined purge time. Following this, the operator fills the separator, and then traps the fluid by manually closing the dump valve, and bypassing the inflow to the separator. The well fluids are allowed to sit still and stratify into oil and water layers. This usually takes about 10 to 15 minutes. The operator zeroes a totalizer on the net oil computer so he can keep track of how much fluid is left in the separator. He then opens the dump valve manually, and pure, produced water flows through the Coriolis sensor. When the density and temperature are stable, the microprocessor-based net oil computer gets an average of the water density and temperature. The net oil computer corrects the density to standard temperature and stores it in memory.

As the separator continues to drain, the operator can see the density change and "flutter" as the rag layer, or emulsion layer, passes through the sensor. Eventually, the oil layer drains from the separator, through the Coriolis sensor, and the operator can see this on his screen as a stable density in the approximate range of his crude oil. He initiates another temperature and density average, and if desired, grabs an oil sample from the line to do a shake out. A shake out is a liquid sample centrifuge to separate water from oil. The net oil computer then prompts him to enter the water cut from the shake out. Entering this, and knowing the water density from before, the net oil computer calculates the oil density at standard temperature, and enters it into memory.

By using the Coriolis sensor to determine the individual oil and water densities, operators are freed from grabbing samples under pressure, and doing laboratory densitometry also under pressure. Results from the field indicate that this technique can give extremely accurate net oil and water cut results in most cases.

**Transient Bubble Remediation**

A limitation of Coriolis meters mentioned earlier was that gas bubbles can ruin water cut readings by lowering the measured density. In fact, just 15 to 20 minutes of bubbles passing through the sensor can cause a 6-hour well test to be inaccurate. The same Coriolis manufacturer has invented a clever way of remediating the water cut values to get a good well test when there are transient bubbles passing through the sensor. Here's how it works:

A Coriolis sensor vibrates its sensor tubes at their natural frequency in order to get the tubes to vibrate with enough amplitude to make the Coriolis forces twist the tubes. When single-phase fluids (gases or liquids) flow through these sensor tubes, the system is relatively undamped and it requires minimal power to vibrate the tubes at their natural frequency. If two-phase fluids (bubbles in liquid or mist in gasses) pass through the sensor, the sensor tubes become damped as if a shock absorber were absorbing the vibrational energy. As the amplitude of the moving tubes decreases, the Coriolis transmitter compensates by increasing the drive energy. This increase can indicate when bubbles are passing through the Coriolis sensor.

A new Coriolis net oil computer has taken advantage of this effect, and has implemented a technique whereby if the drive energy exceeds a preset value, the computer looks back in time some number of seconds at the liquid density. It uses this density in the water cut equation until the drive energy returns back to normal. Some logic has been incorporated that will not allow it to use a density that has a high drive energy associated with it. Early results from the field indicate that this is a very effective technique for determining water cut when transient bubbles pass through the Coriolis sensor.

**No Separator?**

In some cases, a Coriolis meter can be used for net oil and water cut measurement, directly at the wellhead with no separator at all. Typically, these are electric submersible pumped (ESP) wells producing more than 2000 bpd. By applying a slight amount of backpressure downstream of a Coriolis sensor, the fluids are kept above the bubble point pressure, and no gas is evolved. The main advantage of this technique is the savings in capital cost by eliminating test separators and manifolds from the gathering station. Major savings in surface piping are also realized by using trunk lines rather than individual flow lines from each well to the gathering station. In almost all cases, these savings are more than enough to justify individual metering and telemetry at each well, sometimes saving millions of dollars. From an operational standpoint, it is also better to have full-time measurement on all wells simultaneously, increasing surveillance for problems. Not having to switch wells in and out of the test manifold, operate a net oil computer, or record well tests, saves some labor costs as well.

**Multiphase Metering**

No discussion of net oil and water cut measurement would be complete without mentioning multiphase meters. Multiphase flow meters attempt to measure the individual flow rates of oil, water, and gas with a single system. Most of these devices use a variety of instrumentation like: nuclear densitometers, microwave probes, inductance probes, differential pressure flowmeters, ultrasonic flowmeters, mechanical flowmeters, pressure and temperature transmitters, etc. These systems can be quite complicated, involving the simultaneous measurement of several physical phenomena, and the processing of the data by a fast computer. At the present time, these systems are also somewhat expensive as well, commanding up to a quarter million dollar price tag. Since there are several versions of multiphase meter designs, all with their particular requirements and complex limitations, we will not discuss the relative merits of each.

Instead, the author will describe the simplest and least costly of the multiphase metering systems. This system, known as the Accuflow™ Multiphase Measurement System, incorporates an innovative separation technology that maximizes gas-liquid separation while minimizing volume, weight, footprint, and complexity.

The inlet section of the Accuflow utilizes an angled, tangential entry into a vertical standpipe. This section effectively separates medium to large gas bubbles from the liquid, and prevents gas slugs from re-aerating the liquid in the stilling section. The liquid moves down the standpipe while the gas exits the top. The liquid then flows upward through a U-shaped member and into a horizontal stilling section. In this section, the liquid moves slowly through a half-filled pipe. A throttling-type level control is used to maintain the level in this section by modulating the backpressure on the exiting gas. By having only 3 to 12 inches of liquid level in this horizontal section, the small gas bubbles remaining in the liquid have only a short distance to float to the surface and be released.

The liquid continues to flow through 20 to 40 feet of this horizontal stilling section, which is U-shaped in plan form, like the slide section of a slide trombone. After releasing all of the gas bubbles, the liquid flows down to a Coriolis meter where net oil and water cut are measured. From here, the liquid flows up to be re-combined with the gas. The gas is typically measured with a vortex meter, but occasionally the gas leg is measured with a Coriolis meter. The advantage of using a Coriolis meter on the gas leg is that the density can be monitored to detect carbon dioxide content when a $CO_2$ flood is active. The drive energy can also be monitored to detect mist in the gas should an upset condition cause liquid carry-over.

Accuflow Multiphase Metering Systems have been successfully installed at 65 sites in six countries. These systems have delivered excellent accuracy at flow rates up to 30,000 bpd, and at water cuts and gas fractions up to 99%. With minimal moving parts and oilfield-proven components, they have demonstrated low maintenance and easy operation. The low liquid volume of this system means shorter purge and test times, resulting in more frequent well tests. Since the Accuflow is not classified as a pressure vessel, some savings in capital cost as well as less liability and environmental impact can also be realized.

**Conclusion**

The determination of net oil and water cut for well performance measurement has evolved from tank testing to multiphase metering systems. Every method has its particular limitations and requirements, and each application needs to be studied to determine which method is best for the various well conditions. The application of Coriolis meters at test separators, wellheads, and as components of multiphase metering systems, deserves serious consideration due to the sheer number of successful installations. Recent innovations in the net oil computer electronics of these Coriolis systems have made it easier for operators to overcome some of the requirements and limitations of this equipment.