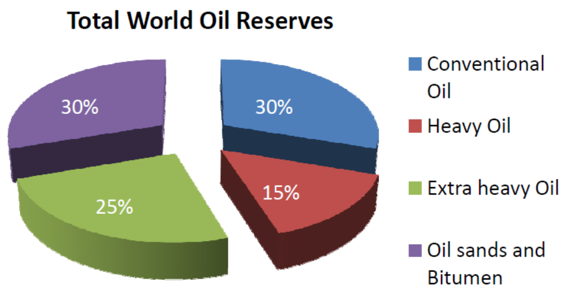
Measuring Produced Reserves of Heavy Oil by use of MPFM

1. Introduction

The demand for hydrocarbons is growing - based on the demand worldwide and the replacement rate necessary to compensate the decline of the current field, it is estimated that more than the equivalent of 5 times Saudi Arabia production (~60 MMbopd with 15 MMbopd due to purely to the increase of energy worldwide driven by emerging country and large countries such as China and India) is required by 2030. In addition to the challenge of meeting this demand, it is a fact that most of the reserves of hydrocarbons on earth (70%) are unconventional - i.e., Heavy Oil, Extra heavy oil, Oil sands or Bitumen. This article will give you a brief description of existing and proven technology for accurately measuring produced reserves of conventional as well as unconventional forms of hydrocarbons.

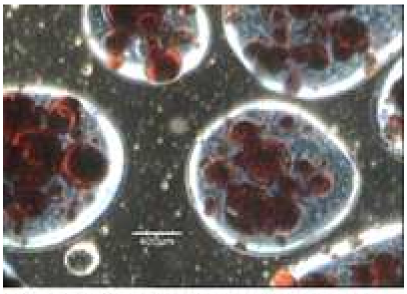


The figure above is based on information from the www.w2os.com. This article is based on the fact that the need for addressing the market of heavy oil is important and that it can be beneficial for players in the oil and gas market to know that there are technologies already in place to meet the challenge of increased demand for hydrocarbons tied up in an unconventional form.

The technology described in this paper is well known to the Multiphase Community; however the benefit of experience, by using multi- energy gamma in combination with a venturi to measure unconventional oil, is explained in section 4 of this article.

2. The Challenge

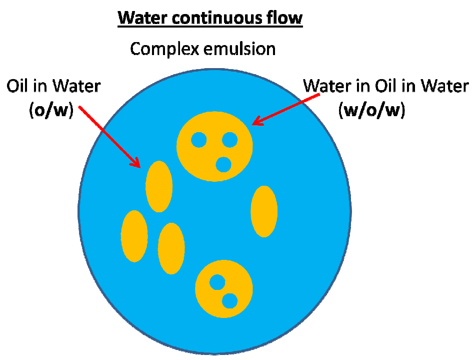
Unconventional oil can be defined in three categories: heavy oil, extra heavy oil and oil sand/Bitumen. The difference between these three sub-categories and conventional hydrocarbons is the variation not only in density (kg/m3) but also in: viscosity (cP), and composition, with various challenging components, where sulphur is a known contribution in many heavy oil fields around the world. Another challenging situation is the liquid viscosity which is the combination of the oil and water mix. When this is changing and the amount of water increases significantly (factor 3 to 10), the viscosity reaches its inversion point. The inversion point is characterized by a competition of forces and other phenomena at extremely low scale, and the carrying medium changing from water in oil (oil continuous) to oil in water (water continuous). These phenomena will appear in any well, with time, when they become aqueous. This zone around the inversion point is the challenging situation where emulsions are forming. Unfortunately, emulsions are non-predictable and flexible shapes of viscous liquid and appear as a non-predictive flow pattern/regime. The use of equipment not affected by this versatile behavior is instrumental to the quality of the measurement; blind tees and Venturi are among the list.

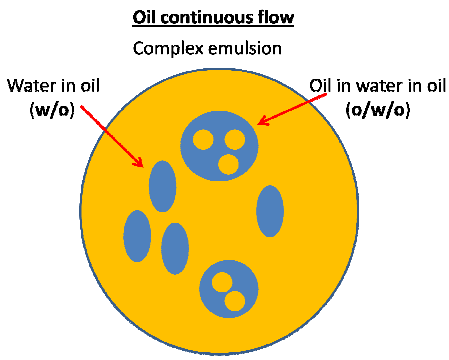


Water continuous emulsion with oil droplets enclosing (red dyed) water droplets

In order to understand how complex the structure of emulsions can be, we have added a picture of water continuous emulsions with oil droplets, to the left. A measurement technology that can measure this structure is compulsory.

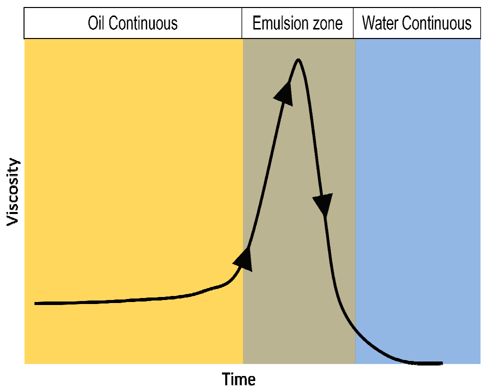
The figures below illustrate how complex emulsions can look, for both oil and water continuous flow regimes.





The main challenge for any measurement system is to capture the total volume or mass flow rate of what is being produced and then splitting out the hydrocarbons (Oil, Gas) from the water. With the flow structure scenario described in figure above, which is common for unconventional oil, it is clear that a measurement system must be able to capture the w/o/w situation for water continuous flow as well as o/w/o for oil continuous flow. Otherwise both water and oil measurement will be incorrect. The flow structure can also make the situation even more demanding in cases where production evolves from oil to water continuous over the years, as the well waters out. In these cases a measurement system must be able to cope with both scenarios as well as the Emulsion zone.

The figure below shows an illustrated plot of a typical viscosity evolution versus time. The shift from oil continuous flow to water continuous flow causes the viscosity of the mixture to increase. The mid section of the plot where the viscosity increases up to the inversion point is what we can call the Emulsion zone.



This is the most challenging situation for any technology, the purpose of which is to measure the three phases of oil water and gas. With the changing conditions, going from oil to water continuous, as described, an measurement approach that is not affected by the change must be taken.

The advantage of the multi-energy gamma ray technique is that this can be used with the same level of quality measurement in any type of water/liquid ratio. By definition, it is independent of the structure of the flow because the gamma rays interact with the atoms and do not interact with the macro structure. The multi-energy gamma interaction is defined as a sub Nano-metric Measurement (10^{-12} to 10^{-15} m) smaller than the size of the molecules.

3. Technology

Several technologies exist on the market which claims multiphase measurement within certain performance with respect to accuracy. For the purpose of measuring heavy oil wells, multi-energy gamma in combination with a venturi has been proved to be very effective. This combination has been on the market since 1998 (References are listed in section 4 of this article), and measures accurately the three phases: Oil, Water and Gas for the full GVF range from 0 to 100% and WLR from 0 to 100%.

Multi-energy gamma fraction meter consists of single radioactive source, Barium 133, which emits gamma rays at numerous energy (multi) levels and a scintillation detector that detects the gamma rays that have passed through the flowing medium inside the throat of the venturi. The scintillation detector is capturing gamma photons from 3 out of the multi-energy levels that are emitted from the source. The three energy levels that are currently in use are: 32 Kilo electron volt (keV), 81(keV) and 356 (keV) The interpretation of the three energy levels reading from the gamma detector can be simplified as follows:

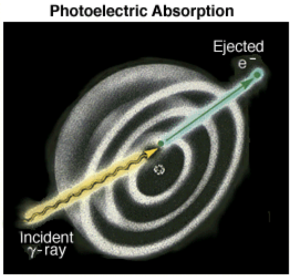
32 keV – *Photo electric effect* – Detects the produced reserves composition, which distinguishes the water from the oil and gas (hydrocarbons)

81 keV – *Compton scattering* and photo electric – Combines a density measurement providing the split between the gas and the liquid with some compositional effects providing contrast.

356 keV – *Compton scattering* – Density measurement used as a check of calculated densities from the other two energy levels. This enables interpretation of additional components such as H2S, and sand burst measurement.

The techniques which are used in the interpretation of the gamma ray counting and observations are:

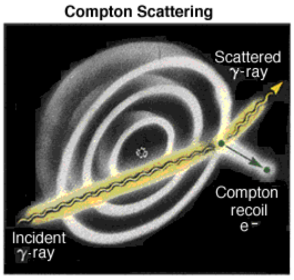
Photoelectric effect:



The disappearance of a low-energy gamma ray as it interacts with an atom’s electron shell, causing the ejection of an orbital electron, is called photoelectric absorption. When the electron returns to its original state a gamma ray is emitted, which is detected by the gamma ray detector.

It is a factor at gamma ray energies below 100 keV and predominates at energies below 75 keV.

Compton Scattering:



This phenomenon, discovered in 1923 by the American physicist Arthur Holly Compton, is the scattering of a gamma ray by an orbital electron. As a result of this interaction, the gamma ray looses energy and an electron is ejected from its orbit. Compton scattering predominates in the 75 keV to 10 MeV energy range.

To further explain the benefit by using multiple energy gamma ray measurement it is essential to explain the difference between multiple energy gamma ray to single gamma ray, or what is known in the industry as gamma densitometer.

A gamma densitometer uses normally a high energy gamma source, > 120kEv. Cesium is one of the most commonly used sources for this purpose (i.e. energy level ~ 662 keV). The high energy gamma rays interact with the matter through Compton scattering and thus the denser the material, the greater the effect and less gamma rays to be detected on the other side (within the gamma detector).

Single high energy gamma ray in combination with a venturi, can provide total mass flow rate, but not the fractions of oil water and gas. For this kind of measurement the fractions are normally defined by an additional measurement, like electromagnetism, which is flow regime dependent, due to its required conductive path through the flow. Or it can be defined by additional input providing the split between the phases, like GVF or GOR input, or utilizing additional energy levels to obtain the necessary composition information.

In the light of the explanation above, the benefit by using multiple energy gamma ray becomes clearer. Multi-energy provides not only density measurement but also compositional measurement. This enables amongst many benefits, the ability to distinguish between liquids with identical or close to identical density. In heavy oil this is important when the density of the oil increases to the same level as the water. In this case a single gamma ray measurement will not be able to distinguish the oil from the water.

It is also of high importance to highlight the benefit by a sub Nano-metric Measurement mentioned in the end of chapter 2. The number of gamma rays actually interact with the atom's, ensuring the capturing all components of the matter, and also components in complex structures like emulsions. This is the basis of the accurate WLR measurement provided by the dual gamma fraction system.

With a high accurate WLR as input to a viscosity model, an accurate actual viscosity can be provided. The accurately measured and modeled viscosity form the basis of a *multiphase Reynolds* number which is used to calculate the discharge coefficient or the friction factor from the pipe wall in the venturi. The discharge coefficient goes into the flow rate equations which can be calculated very accurately.

4. Experience with Multi-energy Gamma Ray Measurement in Heavy Oil

The first installation utilizing the unique combination of a venturi and the multi-energy gamma system described in this article was installed for Perenco in the Yombo field in Congo in 2005. Since the initial deployment, approximately 120 meters with this technology have been installed worldwide.

The list below is to illustrate the experience this technology has gained in heavy oil application in the last 14 years. The list is made up by successful test and field installations.

Field Experience

- 98-99 First extensive flow loop test to qualify venturi in combination with multi-energy gamma – (Cepro) SPE 63118
- 2000 Commercialization of venturi sizes of 52mm and 88 mm – Viscosity up 2000 cP@lc
- 00-05 Considerable experience in Chad, Brazil, Mexico and Venezuela
- 03-04 Multi-energy gamma and venturi size 29mm tested at Cepro and Atalaia
- 04-05 Re qualified the full technological platform for 3000 cP@lc
- 2006 Metrology qualification of the commercialized product for Inmetro in Atatlaia
- 05-08 Considerable field experience and publications with viscous oil from 5000 cP to 27000 cP@lc
- 07-08 Joint Industry Project (Schlumberger – NEL) with UK government (DTI)
- 09-10 SAGD Operation
- 2011 SAGD Commercial sale of 76 Units
- 2012 CHOPS

Flow loop experience heavy Oil

- 98 Cepro
- NEL Multiphase JIP
- Humble Heavy Oil
- National Engineering Laboratory
- DOD China
- Atalaia, Brazil, Petrobras
- NEL Emulsion Testing for BHP<
- NEL High Viscosity & DTI
- NEL Multiflow3 & Veritas

Relevant technical papers for Multiphase Measurement in heavy oil:

[1] THEUVENY B.C., SEGERAL G. and PINGUET B.: "Multiphase Flow Meters in Well Testing Applications" paper SPE 71475 at the 2001 Annual Technical Conference and Exhibition, New Orleans, Sep. 30th-Oct. 3rd.

[2] PINGUET B., GUIEZE P., DELVAUX E.: "Criticality of the PVT Model in Multiphase Flow Meters to ensure accurate volumetric flow rate reporting" paper Multiphase Pumping & Technologies Conference in Abu Dhabi, February 22nd-25th 2004.

[3] PINGUET B.G, DESTARAC P: "Importance of the fluid properties and predictable measurement in Multiphase flow metering to ensure accurate reporting in high water cut conditions and/or high CO2

concentration” at 1st International Jornadas sobre Medicin de Gas, Petroleo y Derivados South America Instituto Argentino de Petroleo y Gas

[4] ATKINSON D.I., BERARD M., and SEGERAL G.: “Qualification of a Nonintrusive Multiphase Flow Meter in Viscous Flows” paper SPE 63118 presented at the 2000 Annual Technical Conference and Exhibition, Dallas, Oct. 1-4.

[5] THEUVENY B.C., SEGERAL G. and PINGUET B.: “Multiphase Flow Meters in Well Testing Applications” paper SPE 71475 presented at the 2001 Annual Technical Conference and Exhibition, New Orleans, Sep. 30th- Oct. 3rd.

[6] PINGUET B.G., BARRETO W.: “Multiphase Flow experience in Brazil: An artificial lift Focus”, South East Asia Conference, Singapore, March 9th-11th.

[7] KANE, M and ATKINSON, I, Documents related to work in Heavy Oil based on CEPRO facilities, Schlumberger Internal Information.

[8] Flow Program NEL DTI “Guidance Notice for Heavy Oil”

[9] BLOUIN. E, FAILLENET. E, HUSSENET. JP, PINGUET. B, BARDIN. D: “Real Case in Heavy Oil: Production Optimization with Vx Multiphase Flow Meter” Multiphase Pumping and Technology Feb 2007, Abu Dhabi, UAE

[10] GUERRA E, “Multiphase Flow Metering Technology Qualification for PDVSA – Venezuela” 2005, Schlumberger Library.

[11] BENNISON. T,”Prediction of Heavy Oil viscosity”, IBC Heavy Oil Field Development Conference, London, December 1998.

[12] PINGUET. B, GUERRA. E, HOLMES. H, ANGULO. W, KANE. M “Outstanding Performance in Heavy Oil application with Vx Technology (Part 1: Flow loop Validation)”, 6th International South East Asia Flow Measurement Workshop, March 2007.

[13] PINGUET. B, BLOUIN. E, FAILLENET. E, BARDIN. D, HUSSENET. JP,"Production optimization in Heavy Oil: Field Experience with Vx", 26th International Conference on Offshore Mechanics and Arctic Engineering OAME2007 29666 June2007.

[14] PINGUET. B, GUERRA. E, HOLMES. H, ANGULO. W, RIBEIRO. C "Outstanding Performance in Heavy Oil application with Vx Technology (Part 2: Field Validation)", Testing Oil Sands & Heavy Oil Technology -July 18-20, 2007

Additional references used in this article:

Fundamentals of Multiphase Metering B Pinguet – Schlumberger 2010

SPE 63118 Qualification of a Nonintrusive Multiphase Flow Meter in Viscous Flows: Atkinson 2000

http://w2os.com/pdfs/Heavyoil05.pdf

Schlumberger Internal presentations (Bruno Pinguet)

Eivind Vethe - Schlumberger

Bruno Pinguet - Schlumberger