

1. Multiphase metering and allocation

The subject of multiphase metering and allocation has been a hot topic for the last decades. The need for an accurate measurement to replace dedicated test lines and topside test separators has been discussed for many years. This article will look into the principle of conducting multiphase measurement by use of Multiphase Flow meters in different allocation regimes. Framo Engineering and Schlumberger have jointly developed the PhaseWatcher Vx technology which is used as an example throughout this article. Different aspects of allocation measurement have been identified as important and are highlighted in this article. The different aspects are the subject of the sub sections of the article.

As an Introduction to the main subject we have searched for a definition of the word “allocation”.

The web page: <http://www.thefreedictionary.com/Allocation> defines allocation as earmarking. I.e. allocation/earmarked could mean: Set aside for a particular purpose; allocated for use in specified ways; marked so as to be recognized.

This expression, dating from the 1500s, alludes to the practice of marking the ears of cattle and sheep to show ownership. An even older example of “earmarking” comes from Exodus 21:6 “His master shall bore his ear through with an awl; and he shall serve him forever”.

For all practical purposes a definition is useful and we would like to point to the Norwegian Petroleum Directorate (NPD) and the regulation: *Regulations relating to measurement of petroleum for fiscal purposes and for calculation of CO2 tax* also known as [*The measurement regulations*](#).

Allocation: Apportionment of petroleum between various owner groups and owner companies.

The multiphase measurement is also used to nominate the cost associated with producing the reserves; this is called nomination but is not a focus of this article.

When multiphase meters entered the market there was an expectation that these instruments, with their game-changing technology, should be able to replace the test lines and test separators. This expectation cannot be said to be met fully in the Norwegian sector, but if we take the multiphase flow meters performance specifications into account, there are technologies in the market that are able to outperform test separators.

One of these is the PhaseWatcher Vx technology, which has been in the market since 1997. Some operators use this technology and have a 100% confidence in it (knowing the limitations), while others have taken a more cautious approach, still relying on the test separator, while still others have embraced a combination of technologies, such as virtual metering combined with multiphase flow meters or test separators. The question then becomes; why haven't multiphase flow meters replaced the test separators in the whole market after 16 years?

An answer to this question that covers all reasons is not possible to give, but some reasons based on experience, can be given.

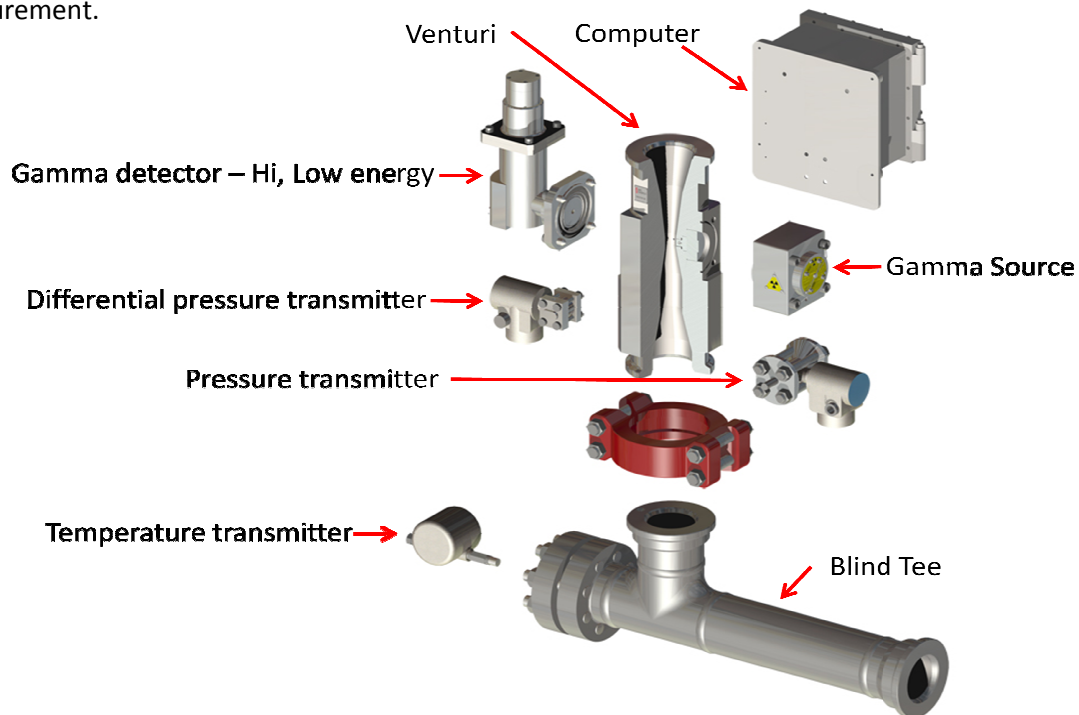
The use and trust in any product must be based on a positive experience for the user. This can also be said to be perceived quality. ISO 9000 defines quality like this: *The totality of characteristics of a device that affect its ability to satisfy stated or implied needs*.

Quality, which is basis for trust, implies more than just the product itself (Product quality). It involves the whole aspect of using the product correctly, maintaining it and not exceeding its boundaries in any way. This can also be summarized as: Use and maintenance.

As this article is covering revenue earned by producing oil and gas, and even more importantly, the earmarking of revenue, it becomes very clear that trust or quality is an important factor and that this is achieved not only through product quality, but by use and maintenance.

2. The PhaseWatcher Vx and its sensors

Figure 1 is a separated view of a topside PhaseWatcher Vx. The picture serves as a graphical contribution to the text below where we explain each instrument and their role in flow measurement.



The measurement principle of the PhaseWatcher Vx requires 5 individual measurements which are being provided by 4 instruments. These instruments are identified in Figure 1 above.

1. Dual energy Gamma detector that reads 2 (+1) energy levels (Hi, Low, 3rd energy level)
This should not be misunderstood to be a gamma densitometer only, which reads only 1 energy level (Required empty pipe reference) Redundant detector
2. Differential Pressure transmitter (Factory calibrated) Redundant transmitter
3. Line pressure transmitter (Factory calibrated) Redundant transmitter
4. Line temperature transmitter (Factory calibrated) redundant transmitter
5. ISO standard venturi. Manufactured according to ISO requirements, hence no need to determine the discharge coefficients, as is required for venturis which do not follow the ISO standard.
6. Blind Tee. Requirement for hydraulic design to serve as an inlet conditioner.
7. Flow computer

Can this (Multiphase) Metering system, that consists of a mechanical part, an instrumentation part and a computer part, as well as documentation and procedures, be 'calibrated' by establishing a relationship between measured value and reference value with known uncertainty? Yes, the system can be 'calibrated' by use of the definition in the Norwegian measurement regulations, which require the multiphase meter to be 'calibrated' against a test separator or another reference. But is this sufficient?

It is known that test separator uncertainty is largely dependent on perfect separation as the instruments require PURE single phase fluids to maintain their stated uncertainty. On many occasions, stated uncertainty of the test separator is higher than the multiphase meter it is supposed to 'calibrate'. In the Norwegian sector there are many cases where the test separator is the only method of comparison for a multiphase meter.

3. Calibration and traceability

The International Bureau of Weights and Measures (BIPM) located in Paris have, since its establishment in 1875, had the role of establishing and maintaining international metrological references level and standards. This work has been essential for the development of trade and science. Today the organization gives a solid foundation for traceability in measurement and cooperation for the establishment and development of measurement science and a common reference level for measurements.

There are several important terms in metrology, and BIPM, in cooperation with the international organizations for standardization and legal metrology, has developed an “International Vocabulary of Basic and General terms in Metrology” (VIM). This document is available at the website of BIPM (www.bipm.org). In relation to this article there are at least two terms that should be pointed out as critical for the discussion.

2.39 (6.11)

calibration

operation that, under specified conditions, in a first step, establishes a relation between the **quantity values** with **measurement uncertainties** provided by **measurement standards** and corresponding **indications** with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a **measurement result** from an indication.

NOTE 1 A calibration may be expressed by a statement, calibration function, **calibration diagram**, **calibration curve**, or calibration table. In some cases, it may consist of an additive or multiplicative **correction** of the indication with associated measurement uncertainty.

NOTE 2 Calibration should not be confused with **adjustment of a measuring system**, often mistakenly called “self-calibration”, nor with **verification** of calibration.

NOTE 3 Often, the first step alone in the above definition is perceived as being calibration.

The definition of “Calibration” above gives the definition to the word that clearly states the need for a comparison of a measurement instrument against a reference. It is important to look at Note 2 to understand that the often misleading term “self calibration” misguides and confuses the understanding of the need for comparing the measurement instrument/system with another instrument/reference. It is therefore, in the same context, a need for understanding the term “metrological traceability” (2,41). This term refers to an unbroken chain of comparisons up to a measurement standard. This should ideally be an international measurement standard.

2.41 (6.10)

metrological traceability

property of a **measurement result** whereby the result can be related to a reference through a documented unbroken chain of **calibrations**, each contributing to the **measurement uncertainty**

NOTE 1 For this definition, a 'reference' can be a definition of a **measurement unit** through its practical realization, or a **measurement procedure** including the measurement unit for a non-ordinal quantity, or a **measurement standard**.

NOTE 2 Metrological traceability requires an established **calibration hierarchy**.

NOTE 3 Specification of the reference must include the time at which this reference was used in establishing the calibration hierarchy, along with any other relevant metrological information about the reference, such as when the first calibration in the calibration hierarchy was performed.

NOTE 4 For **measurements** with more than one **input quantity in the measurement model**, each of the input **quantity values** should itself be metrologically traceable and the calibration hierarchy involved may form a branched structure or a network. The effort involved in establishing metrological traceability for each input quantity value should be commensurate with its relative contribution to the measurement result.

NOTE 5 Metrological traceability of a measurement result does not ensure that the measurement uncertainty is adequate for a given purpose or that there is an absence of mistakes.

NOTE 6 A comparison between two measurement standards may be viewed as a calibration if the comparison is used to check and, if necessary, correct the quantity value and measurement uncertainty attributed to one of the measurement standards.

NOTE 7 The ILAC considers the elements for confirming metrological traceability to be an unbroken **metrological traceability chain** to an **international measurement standard** or a **national measurement standard**, a documented measurement uncertainty, a documented measurement procedure, accredited technical competence, metrological traceability to the SI, and calibration intervals (see ILAC P-10:2002).

NOTE 8 (omitted)

Justervesenet (www.justervesenet.no) is appointed to support the activities related to national standards/metrological references in Norway. It is therefore important for Justervesenet to increase the knowledge of how to obtain trust to measurement results.

For challenging metering methods/technologies like multiphase flow measurements, there is a clear need for development in the traceability chain. A robust international reference level should be supported by measurement inter-comparisons between testing facilities to have an acceptance of the reference levels and the calibrations methods.

Measurements made for obtaining relative knowledge may also be of importance, but may not need the same level of trust to the absolute level of the measurement result. Such measurements can, when proved stable during time, play a role for monitoring stability in processes. They may also, by comparisons with other systems, be lifted formally to obtain trust between trading partners.

4. Multiphase measurement uncertainty for allocation

After all, allocation for multiphase metering is about achieving the lowest possible measurement uncertainty. To obtain the best condition it is necessary to address two topics.

1. The need for input for the individual measurement principle.
2. PVT (Pressure Volume Temperature) for converting line condition data to standard condition (15°C, 101.325kPa) to allow comparison between measurements (fiscal meters, production separator instruments, etc)

Different measurement principles require different setup of the meter in order to achieve high performance/low uncertainty. Examples of how meters are set up or updated through field life time based on a variation of the measured fluid can be as follows:

1. Manually set up by downloading values into a Interpretation model
2. Semi automatic download of required input data by a computer in a surrounding network.
3. Automatic feedback (Self calibration) of input data based on own measured values

The need for PVT for the purpose of achieving high accuracy data at standard condition is driven by

the infrastructure of the production system. If allocation per well in a system with commingled flow is a requirement, measurements performed at line conditions require use of a PVT package to calculate the amount of production in the right format for earmarking the revenue, typically referred to as 'Standard conditions'.

This article will focus on the input data and the meter performance at line conditions. The PVT discussion has already been addressed - please refer to technical paper: OTC OTV-23340-PP. (This paper looks at how to reduce 15% error in the PVT, by use of representative subsea samples and combining the data from an analysis, with raw data from the MPFM in a post processing procedure).

The main multiphase flow meter vendors on the market use a venturi based measurement where density input is required to solve the venturi equation. Besides this, the measurement principles vary between these vendors and different input might be required. To describe the manual set up of a Multiphase Flow meter there is need for an example; for this purpose the PhaseWatcher Vx (Figure 1) is used.

The required inputs for the Vx are :

Venturi - Total Mass flow rate: Density of all three phases.

Multi-Energy Gamma: Mass attenuation of all three phases for the High, Low and highest energy levels.

(All mass attenuations coefficients for hydrocarbons and water are available in National Institute of Standards and technology (NIST)). If the correct parameters have been downloaded to the computer hosting the flow model which performs an interpretation of the readings from the 4 instruments, a correct measurement will be the output.



Figure 1 SS PhaseWatcher Vx

Other measurement principles in use are based on electromagnetism and require the conductivity or permittivity of the water and oil as an input.

Framo Engineering and Schlumberger recommend this instrument to be maintained as described below. The need for updated inputs is driven by changes in the properties of the fluid that are being measured. The ideal and recommended ways to obtain correct densities and mass attenuation coefficients are as follows:

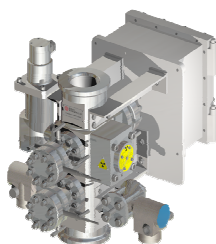


Figure 2 Insitu by TS PhaseWatcher Vx

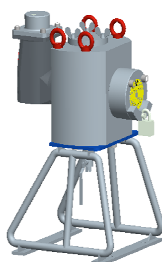


Figure 3 Mass attenuation test cell



Figure 4 Lab analysis of a representative sample

In reality most of the subsea PhaseWatcher Vx meters in the field is set up using Lab analysis as the source of data. In fact it is only in a few fields where the use of the direct attenuation measurement methods has been implemented. Interestingly these fields are all where the meters are used for allocation purposes. Please refer to reference 3 (BC10).

The operator for the field in the referenced paper, Shell, has invested time and money to gain understanding of the technology they have put in place to measure their production and enable their allocation scheme. This has resulted in the deployment of a subsea sampling system to secure most accurate input data to the meter. There is a regulatory requirement to the oil measurement uncertainty of 1% for allocation from the Brazilian government, ANP, this being met with the PhaseWatcher Vx using inputs from the samples.

To summarize this section it is important to highlight the need which all multiphase flow meters have, which is the density of the fluids passing through the venturi. All differential pressure based measurements (venturi, v-cone, wedge, orifice plate) require density input in order to solve the equation for mass flow through the device. In addition the different measurement principles that are used to split the phases or the water from hydrocarbons requires: Mass attenuation for oil, water and gas for different energy levels. Likewise, for measurement principles based on electromagnetism, it is essential to get conductivity or permittivity of the water, as well as the permittivity of the oil. With reference to section three and the definition of calibration and note about self calibration, it is recommended that we, as an industry and measurement community, follow the international definitions and do not consider using this terminology for multiphase flow meters. Rather a term such as ‘verification’ or ‘adjustment’ can be used to describe a feature which uses additional measurements to determine if the unit is set-up correctly. The PhaseWatcher Vx has several such features, like the H2S measurement and the third energy verification. Calling these features a self calibration is in direct conflict with international standard terminology.

5. Multiphase metering in allocation regimes

With the information provided in section 1 – 4 where strong indications are given that there is need for an active ownership around multiphase meters ; this section we will try to come up with some indications and advice as to what ‘active ownership’ to multiphase flow meters could be.

This implies the understanding of how the measurement principle works and the resultant set up of the meter along with obtaining inputs with the lowest possible uncertainty.

Multiphase flow meters are used in what is arguably the most difficult conditions in which a flow measurement device can be deployed ie, that of an unprocessed well stream with multiple components (oil, water, gas, sand, H2S, injected chemicals, etc) in which it is expected to measure accurately the oil, water and gas flow rates with little to no maintenance or support over the field life. Typically the amounts of sand and other ‘contaminants’ are small enough to not impact the uncertainty of multiphase meters, but if they are present in considerable quantities they will impact uncertainty. At the same time, changing fluid properties in each well are often poorly tracked and not updated in the meter set-up.

It should be pretty clear that instruments working in conditions like the ones described above, need proactive maintenance/updates. This is where the active ownership comes in and a close follow up of these instruments is required.

As mentioned in the introduction, in Norway NPD regulates the multiphase metering for allocation purposes by use of the measurement regulations. Multiphase measurement may be used if traditional single phase measurement of hydrocarbons is not possible for financial reasons. The multiphase meter can then be used as a fiscal meter for allocation purposes. An example of this is the Trym field, which is operated by Dong energy. Dong have taken a very active ownership to this meter which is measuring gas and condensate production from the Norwegian side of the continental shelf which is produced back to the Harald platform on the Danish side. This means that the meter is operating in a Fiscal allocation – cross boarder regime. Please refer to section 7 for more information.

As a responsible vendor of multiphase flow meter systems, Schlumberger and Framo Engineering have developed different corresponding tools and system that are purposely made for enhancing measurement quality. These should be used particularly for allocation systems. Examples of such tools and systems are topside Phase sampler that can provide online feedback of PVT data directly into the set up of a PhaseWatcher Vx. Subsea sampling that addresses the need for establishing a correct equation of state for PVT conversion of measurement from line to standard conditions, topside PC/measurement stations that can store raw data as well provide OPC interfaces, remote monitoring system that enables an expert to handle your proactive maintenance as well as problem solving remotely. These services are all available and are regularly promoted in the market, but the tendency is that the operators follow different strategies, which sometimes involves an active ownership, but in too many cases offers the complex and important measurement too little attention. It is important to note that the additional tools and services do directly address the requirements for multiphase metering in the: The Measurement Regulations.

One additional service is the remote monitoring of multiphase flow meters. By adding the meter to a network and opening up for remote monitoring, the measurement, and challenges are moved closer to the experts. There are many additional benefits that increase the total value to the owner of multiphase flow meters and enabling this feature is easy. Especially for subsea flow meters, it is a major benefit. Another aspect of this tool is that it removes the veil, demystifying the measurements and eliminating the ‘black box’ concern that some operators still feel. It does this by visualizing the measurement and allowing operators to see the meter plots in real-time or trend the historical at high resolution. Clients who use these tools get a deeper understanding of the technology and are able to perform more first line diagnostics themselves, thereby driving an active ownership.

It also enables the service of storing raw data that can be used for post processing at a later stage if needed; this is maybe one of the most important services that should be in place for all allocation meters. The additional cost for storing raw data is very low and should be considered the most cost effective insurance any operator can have for a multiphase flow meter in an allocation regime!

To summarize this section it can be said that there are many ways of keeping the performance of a multiphase flow meter at the highest possible level, as it should be when it is an integral part of an allocation regime. As the adoption of multiphase meters for allocation continues, it is necessary to take steps to ensure the measurements are maintained at the lowest possible uncertainties to ensure a fair and equitable allocation scheme for all partners. Besides the meters themselves, there are tools available to assist the operator to take an active ownership/management approach to these meters as they are required by law for their fiscal meters.

6. Regulation of fiscal measurement in Norway: Måle forskriften

This is a section of: *The measurement regulations*, which contains regulations for use of multiphase flow meters in fiscal regimes.

Multiphase measurement may be used if traditional single phase measurement of hydrocarbons is not possible for financial reasons. The multiphase meter can then be used as a fiscal meter.

The following elements shall be satisfactorily documented to allow use of a concept based on multiphase measurement, cf. Chapter VII and Section 18:

- *The operator shall present a concept to the Norwegian Petroleum Directorate for comments and formal processing well before submitting the Plan for Development*

and Operation (PDO). An estimate of the **expected measurement uncertainty** shall be presented, combined with financial figures for the risk of loss between production licenses (cf. NORSOK I-105), Annex C).

- The main principles of the **operations and maintenance philosophy** shall be described.
- Possibility to **calibrate meters against test separator** or other reference.
- **Redundancy in sensors and robustness** in the design of the measurement concept.
- Relevant **PVT (equation of state) model and representative sampling** opportunity to be able to perform a sound PVT calculation.
- Design of inlet pipes to ensure similar conditions if multiple meters are used in parallel.
- Flexibility in the system for handling varying GVF (gas volume fraction).
- The planned method for **condition monitoring** and/or planned **calibration interval** shall be described.
- The planned **method and interval for sampling and updating PVT** data shall be described.

When the multiphase meters are part of the fiscal measurement system, they shall be treated as other fiscal measurement equipment and the administrative requirements which apply pursuant to these Regulations shall therefore be fulfilled.

Note to § 14 – there is a requirement for the Instrumentation on a test separator to be upgraded when used to calibrate multiphase meters in fiscal allocation regimes.

The highlighted words/sentences above are already discussed in this article. It shows a consistency between the law and the suggested active ownership of multiphase flow meters.

7. Examples of Fiscal allocation with PhaseWatcher Vx

The pictures below are taken from technical papers that have previously been presented. They are both describing how the PhaseWatcher Vx technology is being used for allocation measurement. The picture 6 below is taken from the technical paper: *Shell Successful application of MPFMs on BC10* Presented by Jaco Bronz, Shell at the Americas workshop in 2012. This paper shows how the PhaseWatcher Vx is being used to allocate the produced reserves from the BC 10 field to the different Brazilian states Espito Santo and part of Rio de Janeiro. Please refer to the full paper for further information.

The picture 7 below is taken from the technical paper: *Fiscal Allocation: A New Endeavour for Multiphase Flow meter*. This paper is written by Dr Bruno Pinguet, Schlumberger and was presented for the South East Asia Flow Measurement Conference, 2012. The paper gives a full introduction to the important features that a multiphase meter has to meet for allocation purposes as well as good overview of what has been achieved in this different allocation regimes already.

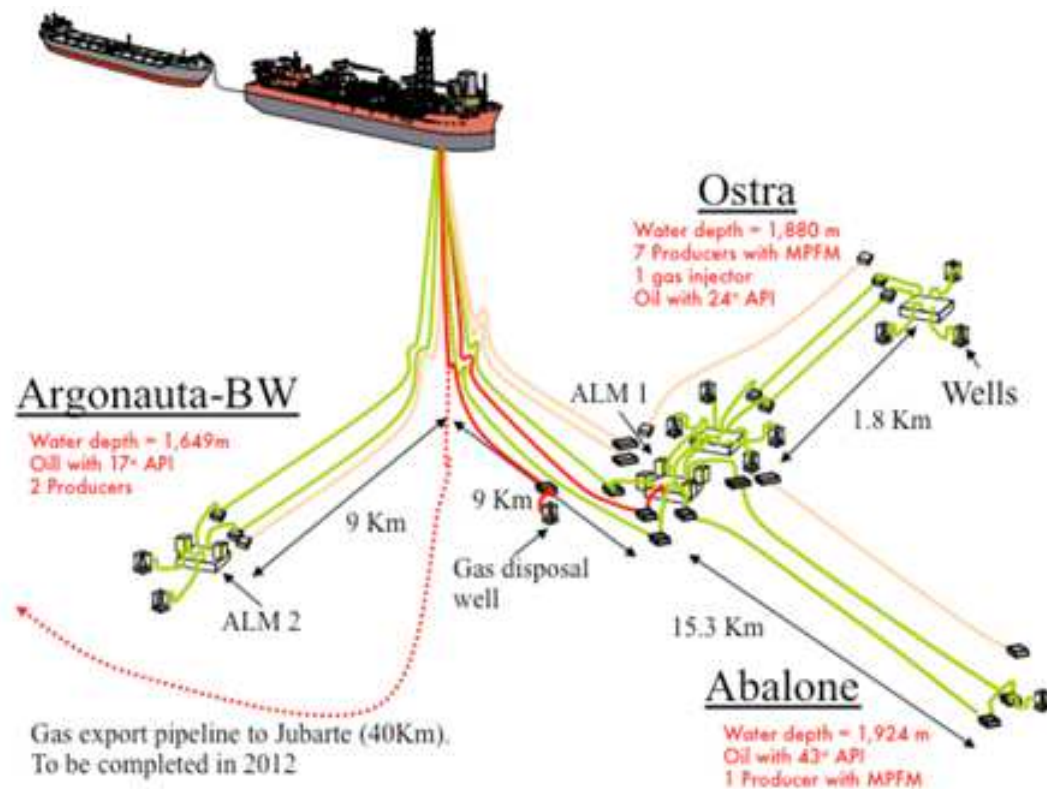


Figure 2 - Schematic overview of the BC10 phase 1 development.

Figure 5: Picture from technical paper: *Shell Successful application of MPFMs on BC10*

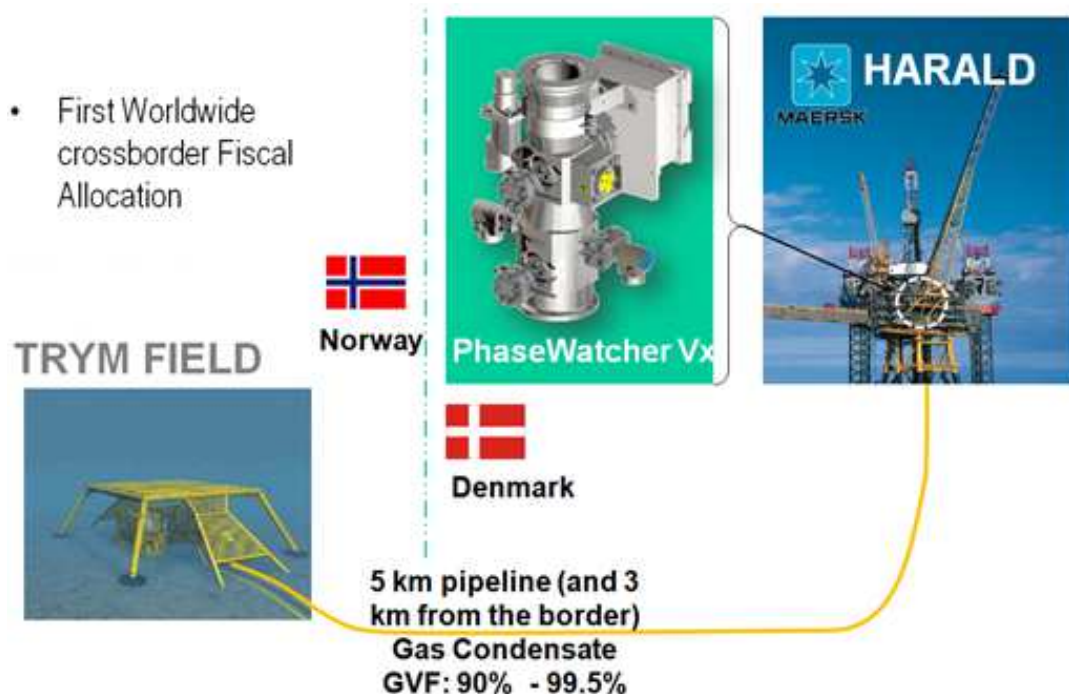


Figure 6: Picture from technical paper: *Fiscal Allocation: A New Endeavour for Multiphase Flow meter*

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