

## **Using Multiphase Meters for fiscal purposes - A field experience**

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### **1. INTRODUCTION**

During the last decade there has been a trend that more and more marginal fields have been put into production. Typical characteristics for these fields are that the economy does not defend a standalone development. These fields require an existing installation that can act as a host. Normally, modifications to the host installation are required. Both weight limitations and economic issues will be normative for the chosen design.

Traditional metering systems which measure the different phases out of a large separator may not be feasible. The projects are challenged to come up with a solution that is smaller, lighter and cheaper. Multiphase flow meter (MPFM) has then often been introduced to achieve such requirements in the project (Thorn, et al., 2012).

Accordingly, the need for measuring multiphase flow has increased. However, the industry is still facing challenges related to accurate measurement of multiphase flow. When talking about tie-back developments to a host installation, the metering system will be essential for field allocation and thereby the income to the owners of the fields involved. Uncertainty in the measurement system is then critical to secure correct income, tariffs, taxes and in some cases also fees to the government.

Irrespective the challenges related to multiphase measurement and multiphase flow meters, the oil and gas industry has over the last few years installed more and more multiphase flow meters for fiscal services.

DONG E&P Norge (DONG) is the operator of the Trym field which is located in the southern part of the Norwegian sector of the North Sea, close to the Danish border. The field was developed during a period of two years from 2009 to 2011 as a tie-back to a Maersk Oil (Maersk) operated platform and it uses multiphase flow meter for fiscal metering. After more than two years in production, DONG has, together with Maersk gathered valuable experience on how to operate a tie-back field with multiphase flow meter as the fiscal meter.

This paper discusses the metering system, how it has been operated and its performance. The failures and the successes are included. In addition it includes what may be looked at as best practices. Two oil & gas operators and two Authorities, Norwegian Petroleum Directorate (NPD) and Danish Energy Agency (DEA) have been involved in both the development and the operation phase. Both the role of the Authorities and their experience from the development and operation are considered herein.



Figure 1: Trym tie-back to Harald

## 2. METERING FOR FISCAL AND ALLOCATION PURPOSES – THE USE OF MULTIPHASE METERS

Before going any further it is crucial to have a common understanding of the term "metering for fiscal and allocation purposes". This paper is dealing with a field that is subject to Norwegian regulations. The fiscal metering system covered herein is within the scope of The Measurement Regulations (Last amendment 8.3.2012) (Norwegian Petroleum Directorate, 2001). The Scope for the Measurement Regulations are among other things described as:

*These regulations are applicable to the petroleum activities in areas ... relating to petroleum activities and ... relating to tax on discharge of CO<sub>2</sub> in connection with petroleum activities on the continental shelf, specifically:*

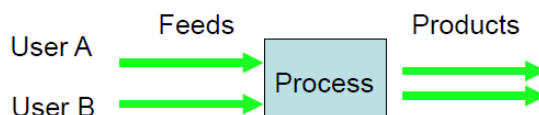
*a) in planning, design, construction and operation of metering systems for measuring produced, transported and sold quantities of oil and gas (fiscal measurement systems)...*

Furthermore, there are some important definitions to be aware of (Norwegian Petroleum Directorate, 2001):

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

*Fiscal metering: Metering carried out in connection with purchase and sale and the calculation of taxes and royalties.*

Allocation is also defined by Energy Institute (Energy Institute, 2012) and is included here to give a graphical definition on the term:



Allocation is the determination of the quantity of products belonging to each user when processed together in a commingled system.

Figure 2: Definition of allocation (Energy Institute, 2012)

The Measurement Regulations are valid for both fiscal and allocation measurement systems and fiscal metering or fiscal measurement is used as common terms. In general the same requirements for measurement uncertainty apply for both fiscal- and allocation metering systems. But there is an opening in the regulations to argue for a higher uncertainty based on cost-benefit analysis. If the metering system is by their tasks defined as fiscal, it should be designed and operated according to the Measurement Regulations.

### Section 8 Allowable measurement uncertainty

Measurement system	Uncertainty limit at 95 percent (%) confidence level <i>(expanded uncertainty with coverage factor k=2)</i>
Oil metering for sale and allocation purposes	0,30 % of standard volume
Gas metering for sale and allocation purposes	1,0 % of mass

Figure 3: Accepted measurement uncertainty

Measurement systems that are subject to the Measurement Regulations shall be accepted by NPD. There is a requirement to obtain consent from the NPD prior to start-up of the metering system. As part of both the processes described above there shall be information related to the chosen solution including uncertainty figures. If the proposed measuring solution does not fulfil the requirements in the Measurement Regulations it is important to involve the authorities as early as possible.

Several fields have been developed by use of MPFM as the fiscal meter during the last years. On Norwegian continental shelf there are currently installed 14 fiscal metering systems that are using MPFMs and several more are under development. For UK the similar number are approximately 15 fields<sup>1</sup> and for Denmark it is 4<sup>2</sup>. Most of the mentioned systems in use in Norway have an estimated uncertainty of 2-5% of total hydrocarbon mass according to the Plan for Development and Operation (PDO).

The introduction of MPFM for purposes related to fiscal and allocation metering has not been without problems. In 2012 NPD started a project related to MPFMs which are subject to the Measurement Regulations. The reason for the project was to summarize the experiences during the last years. NPD realised that for several of the developments, the metering systems based on MPFM

<sup>1</sup> Source: DECC

<sup>2</sup> Source: DEA

did not work as expected and caused disputes between the licenses. In some cases the owners of the different licenses ended up in arbitration tribunal (Norwegian Petroleum Directorate, 2012).

The Measurement Regulations were revised in 2012 partly as a consequence of the increased use of MPFM in fiscal metering systems. NPD wanted to formalise the use of MPFMs in such systems, both to increase the awareness of critical factors to succeed, and to avoid dispute related to the measurement system after production start-up.

### 3. THE TRYM FIELD

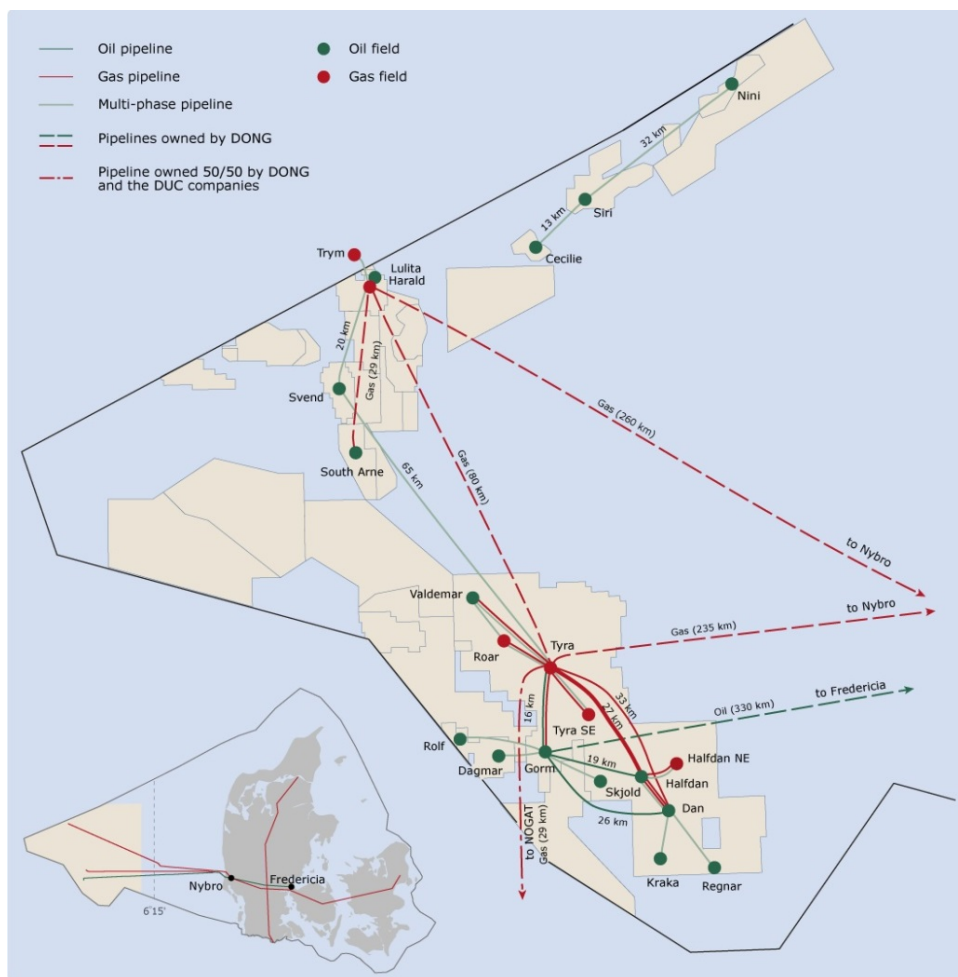


Figure 4: Location of production facilities ([www.ens.dk](http://www.ens.dk))

The Trym field is located in block 3/7 (Production License 147) in the southernmost area of the Norwegian part of the North Sea. It is located just 3 kilometres from the border against Denmark, with the Harald installation as the closest installation. The water depth in the area is around 65 metres. The discovery was done in 1990 by A/S Norske Shell, and together with their partners they started to plan for development and operation in 2005. In 2008 Shell decided to sell their ownership in Trym without being granted an accepted PDO. There were also some other changes in the ownership and it all ended up with DONG E&P Norge as the operator (50% share) with Bayerngas Norge as the only partner (50%) (Norwegian Ministry of Petroleum and Energy, 2013).

The Trym reservoir contains gas and condensate at a depth of about 3400 metres and the recoverable reserves were originally estimated to 1.5 million Sm<sup>3</sup> of condensate and 4.3 billion Sm<sup>3</sup> of gas. Development was done by a four slot subsea template and a 5 kilometre pipeline to the Harald platform. The reserves are produced solely by natural depletion via two horizontal wells and the production started in February 2011.

	Trym	DUC	Lulita
DONG E&P Norge	50,0 %		
Bayerngas	50,0 %		
Maersk Olie og Gas		31,2 %	
Shell		36,8 %	
Chevron		12,0 %	
Danish North Sea Fund		20,0 %	
DONG E&P Danmark			21,8 %
Noreco			28,2 %
<b>DUC</b>			<b>50,0 %</b>

Table 1. Ownership interests of the involved Licences

The Harald platform is part of the Dansk Undergrunds Consortium (DUC) and is operated by Maersk. The installation consists of a production platform and a living quarter platform. It has been producing since 1998 from both the Harald field and a neighbour field called Lulita. The Lulita field is 50% owned by DUC (Danish Energy Agency, 2012).

One important issue with the Harald platform is the operation philosophy. There are only a few persons working on the installation and the offshore installation manager is shared with the Tyra field centre located approximately 60 kilometres away. There are 16 beds on the installation and with a regular crew of 13, there are only a few beds available for other personnel. There are also limited numbers of helicopter flights to the platform. The consequence is that it may be a challenge to send service personnel to the installation when needed, and the operation and maintenance philosophy has to reflect this.



Figure 5: The Harald installation

#### 4. CROSS BORDER PRODUCTION AND THE AUTHORITIES

The Trym development is the first cross border development between Norwegian and Danish continental shelf. Before the development was approved an agreement between Norway (Ministry of Petroleum and Energy) and Denmark (Danish Ministry of Climate, Energy and Building) that described the production of oil and gas resources from Norwegian sector via Danish infrastructure (platforms, pipelines and terminals) needed to be in place (Norwegian Ministry of Petroleum and Energy, 2010). An obstacle before the agreement could be signed was a 5% tax for use of oil pipeline in Denmark. The result after negotiations was that produced oil from foreign countries was not subject to pay the above mentioned tax for use of Danish pipeline infrastructure.

As a part of the agreement there was issued a cooperation agreement between NPD and DEA regarding fiscal metering issues.

The selected development solution for Trym as a cross border to a Danish installation gives the outcome that both Norwegian and Danish authorities are involved in the fiscal metering system. Regulations related to fiscal metering for both countries have to be taken into account. Practically, it means that Trym metering system shall be in compliance with both NPD and DEA's regulations for fiscal metering. As there are no specific regulations in place in Denmark that covers fiscal metering in detail, a common practice is that compliance with Norwegian regulations fulfils the Danish requirements.

Another result is that both NPD and DEA are involved in metering audits. There is also a yearly cooperation meeting between the parties involved (DONG, Maersk, NPD and DEA) where the status for Trym metering system is closely covered. Until now there have been three government audits and three cooperation meetings, so the performance of the Trym metering system has been under close surveillance from the authorities after start-up.

## 5. TRYM FISCAL METERING

The Trym fiscal metering system consists of a MPFM and a Test Separator both installed at the Harald platform. The MPFM is defined as the fiscal metering point and its output provides the input to the allocation system and in the end a monetary value.

Maersk as the Harald operator is responsible for the day-to-day operation and maintenance. DONG is, as the operator of the Trym field, responsible for compliance with Measurement Regulations and also the focal point for all authority communications related to Trym.

The MPFM is installed downstream the Trym inlet choke and is calibrated and adjusted against the Test Separator regularly in accordance with the agreements between the parties. The MPFM and meter runs installed on the Test Separator gas and oil outlets with its instrumentation, are all part of the fiscal metering system and are therefore subject to the Measurement Regulations.

The Gas Volume Fraction (GVF) for Trym field was estimated to be from 92% to 98% during the field lifetime. The change between gas and oil mode is planned to be done at a GVF of approximately 95%. From start-up of the field until now the GVF has increased from 92% to 94%.

The Test Separator metering system was upgraded as part of the Trym field tie-in project. The upgrade was needed to improve the overall measurement uncertainties that were specified in the PDO to be  $\pm 4 - 9\%$  of total hydrocarbon mass (95% confidence level). The upgrade of the Test Separator involved a new 4" liquid meter run with Coriolis meter, water cut meter and sampling point, additional differential pressure, pressure and temperature transmitters at the orifice gas meter. Finally the flow computers were upgraded from Emerson S500 to S600 model.

The supervisory system consists of:

- DMS (Daniel metering system) computer.
- Data communication to/from Harald Distributed Control System (DCS) and Plant Server system.

The multiphase metering station consists of:

- Flow computer
- Multiphase Flow Meter.

The installation is prepared for a second Multiphase Flow Meter.

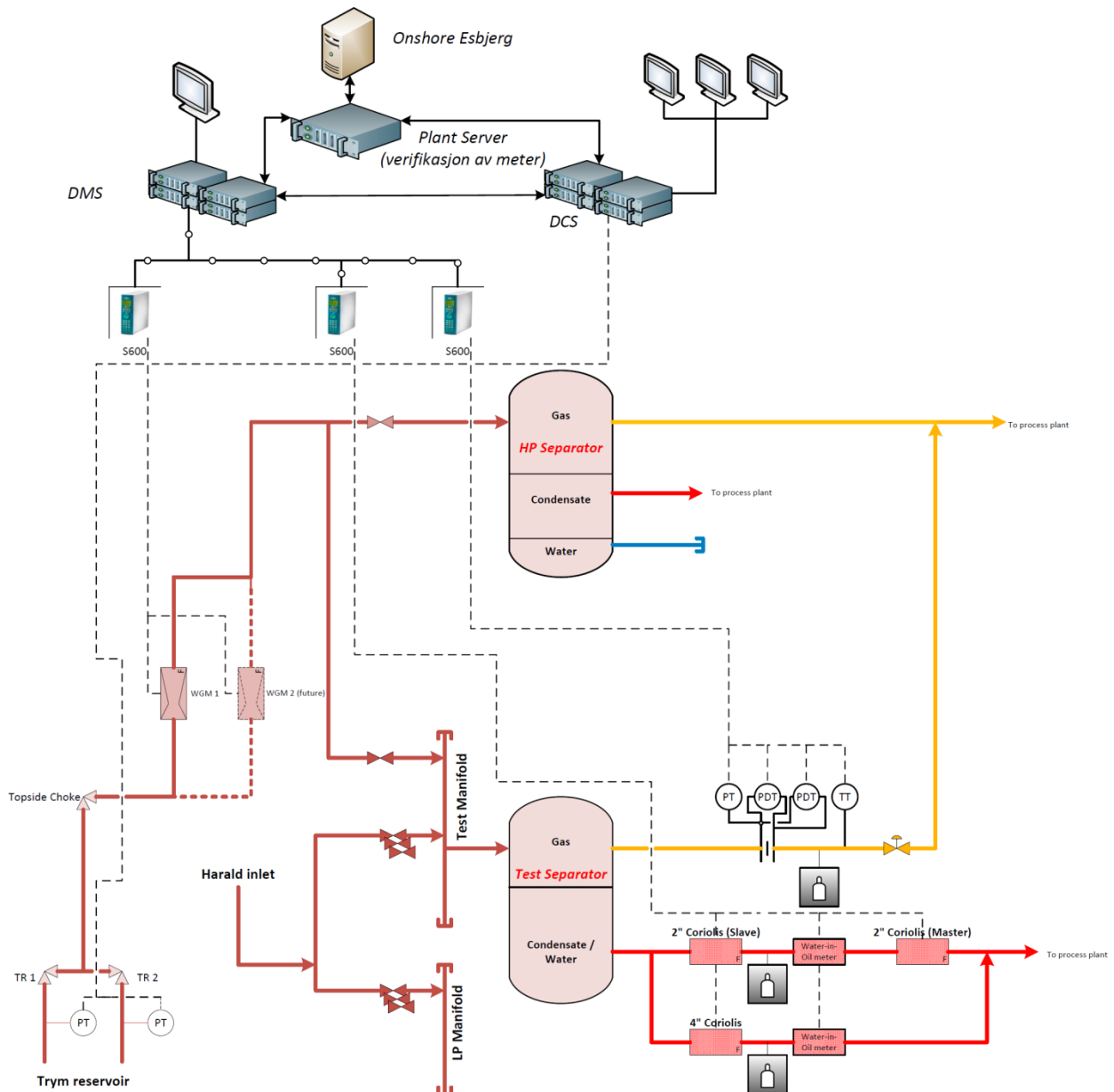


Figure 6. Trym metering system

The Test Separator liquid metering station consists of one 2" meter run and one 4" meter run. The test separator liquid meter station is equipped with:

- Flow computer
- 2" meter run (2 off Coriolis meter installed in series (master/slave))
- 4" meter run (1 off Coriolis meter)
- Water in oil meter on each meter run.
- Pressure transmitter.
- Temperature transmitter.
- Spot sampling outlet.



The Test Separator gas metering station consists of one 12" meter tube with a senior orifice fitting and orifice plate. The test separator gas metering station is equipped with:

- Flow computer, with AGA 8 calculations for density.
- Orifice meter.
- 2 off Differential Pressure transmitter
- Pressure transmitter
- Temperature transmitter
- Spot sampling outlet

There are no automatic sampling systems installed on the Test Separator outlets. Pressurised manual spot samples of oil and gas are retrieved at separator pressure and used as representative samples. These are analysed and recombined to a fluid composition at an approved laboratory. The results are evaluated and used as input to the metering and allocation system, process simulation model for DUC and, if found necessary, as PVT input to the MPFM.

There is a high-capacity network connection between the Harald installation and Maersk offices in Esbjerg that enables for remote surveillance and operation of the metering system. This is an absolute requirement because of the operation philosophy of the Harald field. In addition there is a system established for transfer of essential real time metering data from the Harald installation to DONG's premises in Norway.

The verification, also called proving, of Trym MPFM is as earlier mentioned done by routing the Trym production through the Test Separator. There are routines that define flushing time to ensure representative Trym fluid in the vessel. The proving lasts for approximately 24 hours and all data during this sequence is stored on a dedicated part of the Harald Distributed Control System (DCS). Further on, the proving of the MPFM is thorough documented and all vital information is stored in a historical database. If, in the future, the result of a proving should be questioned, it will be possible to do a proper verification and if necessary a correction.

After the proving is completed, meter factors for the MPFM are calculated, evaluated and uploaded to the flow computer. All uploading is initiated by a Maersk metering engineer after the results have been evaluated and accepted.

31<sup>st</sup> International North Sea Flow Measurement Workshop  
22<sup>nd</sup> - 25<sup>th</sup> October 2013

WGM: WGM 1  
Status: Uploading  
Created by: MOGIOAND03  
Uploaded by: NA

## Proving calculation report

Start of Proving: 2013-04-25 09:00:58  
End of Proving: 2013-04-25 22:01:00

### HC reporting

End of hourly value	HC mass flow rate [t / hr]			
	WGM Raw	WGM Corrected	TS	% Deviation
2013-04-25 09:00:58	105.644	105.625	105.052	0.6
2013-04-25 10:00:59	105.424	105.415	104.761	0.6
2013-04-25 11:00:59	104.067	104.043	103.423	0.6
2013-04-25 12:00:59	104.243	104.199	103.360	0.9
2013-04-25 13:01:00	105.561	105.515	104.828	0.7
2013-04-25 14:00:57	105.374	105.332	104.680	0.7
2013-04-25 15:00:59	105.077	105.043	104.951	0.1
2013-04-25 16:01:00	105.450	105.406	105.031	0.4
2013-04-25 17:00:57	105.188	105.151	104.765	0.4
2013-04-25 18:00:59	106.834	106.796	106.155	0.6
2013-04-25 19:01:00	108.235	108.214	107.731	0.5
2013-04-25 20:00:57	109.321	109.306	108.875	0.4
2013-04-25 21:00:58	109.591	109.575	108.841	0.7
2013-04-25 22:01:00	109.337	109.327	108.982	0.3
Sum / Avg	1,489.346	1,488.947	1,481.435	0.5

### Oil reporting

End of hourly value	Pressure [barq]		Temperature [°C]		Oil mass flow rate [t / hr]				Oil density [kg / m3]			Oil volume flow [m3 / hr]		
	WGM	TS	WGM	TS	WGM Raw	WGM Corrected	TS	% Deviation	WGM	TS	% Deviation	WGM	TS	% Deviation
2013-04-25 09:00:58	97.8	94.6	43.7	44.5	30.930	30.219	29.941	3.3	655.5	635.1	3.2	46.104	47.148	-2.2
2013-04-25 10:00:59	97.7	94.6	43.8	44.0	30.580	29.875	29.514	3.6	655.6	635.5	3.2	45.565	46.444	-1.9
2013-04-25 11:00:59	97.4	94.5	43.7	43.9	30.635	29.928	29.386	4.3	655.8	635.8	3.2	45.634	46.222	-1.3
2013-04-25 12:00:59	97.0	94.5	43.7	43.8	31.306	30.584	29.403	6.5	656.1	635.9	3.2	46.620	46.237	0.8
2013-04-25 13:01:00	97.0	94.6	43.7	43.8	31.795	31.062	29.784	6.8	656.1	635.7	3.2	47.349	46.851	1.1
2013-04-25 14:00:57	96.8	94.6	43.7	43.6	31.578	30.851	29.700	6.3	656.2	635.4	3.3	47.017	46.744	0.6
2013-04-25 15:00:59	96.8	94.6	43.7	43.5	31.235	30.514	29.924	4.4	656.2	635.5	3.3	46.498	47.083	-1.2
2013-04-25 16:01:00	96.7	94.6	43.6	43.4	31.669	30.941	29.891	5.9	656.2	634.6	3.4	47.145	47.104	0.1
2013-04-25 17:00:57	96.8	94.6	43.7	43.5	31.359	30.636	29.822	5.2	656.2	634.1	3.5	46.687	47.032	-0.7
2013-04-25 18:00:59	97.4	94.7	43.7	43.7	31.898	31.162	30.184	5.7	655.8	634.4	3.4	47.513	47.577	-0.1
2013-04-25 19:01:00	97.7	94.7	43.8	43.8	31.711	30.978	30.493	4.0	655.6	633.8	3.4	47.249	48.112	-1.8
2013-04-25 20:00:57	97.9	94.8	43.7	43.8	31.856	31.122	30.912	3.1	655.4	633.1	3.5	47.483	48.823	-2.7
2013-04-25 21:00:58	98.1	94.9	43.6	43.7	32.002	31.266	30.883	3.6	655.3	633.3	3.5	47.712	48.765	-2.2
2013-04-25 22:01:00	98.0	94.8	43.7	43.6	31.721	30.991	30.916	2.6	655.3	633.0	3.5	47.289	48.838	-3.2
Sum / Avg	97.4	94.6	43.7	43.7	440.275	430.129	420.753	4.0	655.8	634.7	3.3	46.848	47.350	-1.1

Figure 7: Part of report issued after verification, showing HC mass and oil mass

## 6. ALLOCATION OF PRODUCTION FROM TRYM

The production from Trym is processed and introduced to an infrastructure that was established decades ago, the DUC infrastructure. Compared with similar infrastructure systems in Norway and UK there is one significant difference. Namely that there is only one ownership structure for all of the production entering the system. Consequently, ownership allocation has not been an issue before the Trym tie-back.

Producing the Trym field via the DUC infrastructure has introduced the need for allocation between different ownerships. The allocation (and metering) has a direct impact on the taxable income to Denmark and Norway. So without doubt, the quality of the metering and allocation is of high importance for both the licenses and the countries involved.

A common way of doing allocation when exporting through a pipeline is to allocate the different components on a mass basis. This is also the case for allocation of Trym. It is also worth mentioning that the DUC is allocated by difference. This can be described by the following equation:

$$Q_{DUC} = Q_{Total} - Q_{Trym}$$

When doing allocation by difference, it is essential to consider the relative quantities provided by each user. Measuring the minor stream will keep the uncertainty relatively low (Energy Institute, 2012) as done in this specific case.

The metering system determines the quantities produced from the field. However, what really counts is the allocated final sales products which are dry gas to the market and stabilised oil. This is a process that happens downstream the fiscal meter, and for Trym the dry gas is delivered at gas export points at either Tyra West or Tyra East while the stabilised oil is delivered at the oil terminal in Fredericia, Denmark.

## 7. OPERATIONAL EXPERIENCE

Trym has been in production for more than two years and the production has been as expected. The metering system has been working quite well, however, a close follow up has been a premise to achieve this. Some of our experiences from the operation are discussed below.

### 7.1 Preparation before first-oil

Based on the context that Trym is a marginal field and was developed exclusively for natural deployment, most of its values would be produced during the first years of production. The PDO profile was indicating that 50 % of the condensate and 31 % of the gas would be produced during the first two years in operation.

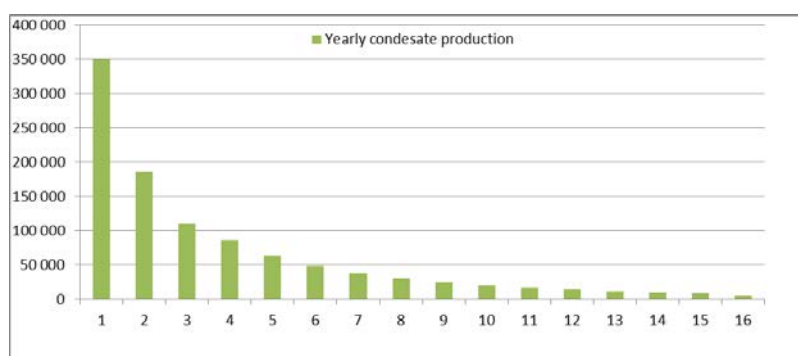


Figure 8: Expected yearly condensate production from PDO

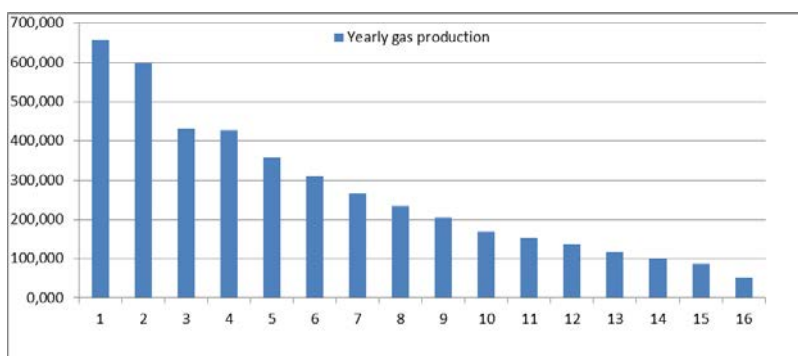


Figure 9: Expected yearly gas production from PDO

As a result of this there was no time to try and fail. Best practice for operation of the multiphase meter as fiscal meter had to be in place before first-oil. To achieve this ambitious goal both the metering system, the organisations and the quality management system needed to be prepared. Proper communication with both Norwegian and Danish authorities was also an important part from day one.

But what if the metering system failed?

No matter how well prepared everything was it could happen that the system did not work as provided. There are many parts in the metering system that may fail during start-up and operation. The system was vulnerable because of only one MPFM installed, without a back-up meter available. Worst case scenario was a failure to the multiphase meter that resulted in the need of replacement. A contingency plan on how to utilize the Test Separator and still have acceptable measurements was prepared.

The metering system was implemented into the existing metering system on the Harald platform. A third party verification of Trym metering system was done. This included also verification of the calculations done in the flow computers and the computer system for proving of MPFM.

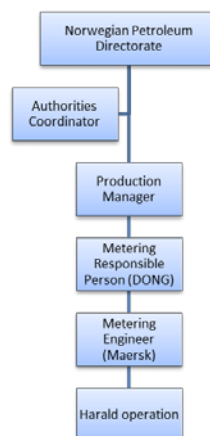


Figure 10: Trym Metering System - Reporting lines

Trym metering organisation is quite simple with a metering responsible person at DONG and an onshore metering engineer at Maersk, responsible for daily operation. In addition to this the Harald crew supports the metering engineer with offshore tasks. Awareness to the Trym metering system is a key factor, and all of the Harald crew went through an introduction course covering Trym metering system and the NPD regulations. The importance of the MPFM and how to deal with metering upsets was pointed out. However, as previously mentioned, the manning on Harald is very limited and it is not realistic to maintain a competent fiscal trained manning on Harald. All data evaluations, verifications, flow computer maintenance and parameter changes are therefore done by the onshore metering department. This has been possible due to the fact that all computers taking part of the Trym Metering System are fully accessible from onshore. All calibration and adjustment of equipment taking part of the fiscal reference is also done onshore.

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Document no.	Document rev.	Document title
TFMS-001	2	Measurement Manual.
TFMS-100	4	QA-QC Document list
TFMS-101	2	Procedure for documentation and archiving
TFMS-102	4	QA and QC deviation document
TFMS-103	3	Personnel functions and related competences
TFMS-104	1	Trym Metering Overview - Instrument/computer block diagram
TFMS-105	1	List of Trym flow computer calculation flow charts
TFMS-106	1	List of Trym flow computer functional specifications
TFMS-107	1	Trym meter system. 3 <sup>rd</sup> part verification
TFMS-108	1	Uncertainty calculation and evaluation
<b>Operational Procedures:</b>		
TFMS-200	2	Procedure for Proving
TFMS-201	1	Procedure for selection of Trym in use meter
TFMS-202	1	Procedure for selection and shift of TS gas orifice
TFMS-203	1	Procedure for selection of in use TS liquid coriolis meters
TFMS-204	1	Procedure for alarm handling

Figure 11: Some of the procedures established by Maersk for Trym Metering

Maersk established a metering quality management system containing operational and maintenance procedures. Detailed procedures for different main tasks were established in addition to procedure regarding corrective actions to be taken in event of a measurement malfunctions.

## 7.2 The Multiphase Flow Meter and Allocation

Originally multiphase flow meters were used to replace separators, and measuring the different phases was of high importance. E.g. measuring of well streams for well allocation is a common use of multiphase meters (Pinguet, et al., 2012). The multiphase flow meter is a high-tech instrument that has a significant amount of information available for the end user. Trym MPFM has about 80 different outputs available.

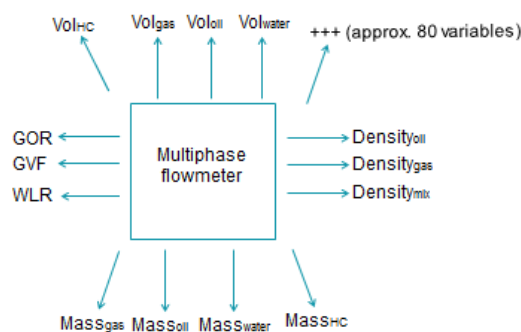


Figure 12: Available data from MPFM

Using the MPFMs for fiscal metering is different from other applications that MPFMs are used for. The main objective for the fiscal meter is to measure the produced quantities that generate an input to the allocation system. It is of high importance to have knowledge about the allocation system.

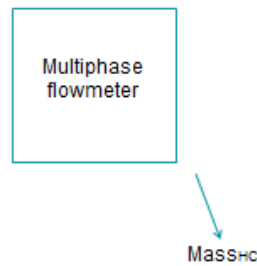


Figure 13: The only output that matters when it comes to fiscal purposes for Trym.

The only important input from the metering system required for the allocation system, is the total hydrocarbon mass (HC mass).

This means that the measured quantities of oil and gas phases are not important for the main purpose of the fiscal meter. This is important information that those responsible for the metering system should be aware of, from planning to operating the metering system.

But how is the amount of oil and gas then decided when the measured phases from the MPFM are not used? The answer to this is in the allocation system. The example below is a quite common way of designing an allocation system:

- The total HC mass from the metering system is entered into the allocation system.
- Hydrocarbon composition is entered into the allocation system.
- Calculate the mass of each component in the total HC stream.
- Calculate the Process Allocation Factors (PAF).
  - There is a PAF for each component and it is a ratio number that tells how much of the total amount of a component that is delivered as gas. The rest is delivered as liquid. The PAFs are calculated by use of the process simulation model for the DUC system.
- Calculate the split between exported gas and exported liquid by use of PAFs.
- Some of the gas is allocated to fuel and flare and is deducted from the gas stream.

By learning about the allocation system before first-oil from Trym, it was easy to focus on the most important output from the MPFM. All follow up of the MPFM afterward has been done with the total HC mass in mind. However, optimising the system for the total HC mass has also given some challenges. Other disciplines within the organisations may use other data from the metering system and it is important to identify this to avoid the use of inaccurate data that may give consequences for e.g. reservoir management or financial reporting.

It is also worth mentioning that Trym has been producing oil and gas with very low water content. That makes it easier to calculate total HC mass. If and when Trym starts producing a higher content of water, there might be challenges that have not been seen so far. However, significant amount of water is not expected from Trym.

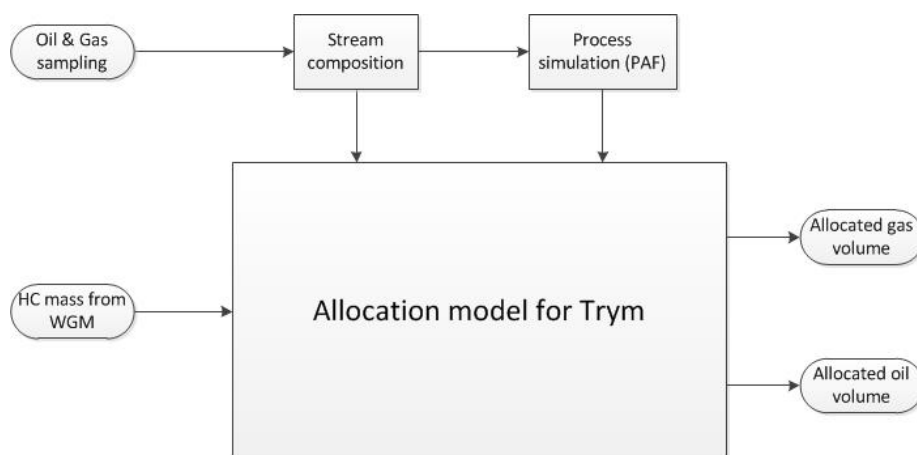


Figure 14: Allocation model

### 7.3 Verification of Multiphase Flow Meter against Test Separator

Verification of the MPFM against the test separator was agreed between the Trym and Harald owners to be done frequently and on regular basis. So far it has been done monthly, given that the field has a stable production. The verification, also called proving, takes all in all about 24 hours to perform. This includes necessary work to route the production from the HP separator to the Test Separator, flush through the Test Separator with Trym fluid, perform the proving, and route the production back to the HP separator.

All the data during the proving sequence is stored in a dedicated proving system which is part of the DCS system. It is then possible to review the data after the test is finished and define the stable and representative period which shall be used to calculate new meter factors (MF). There are several meter factors in use for the MPFM, one for oil ( $MF_{oil}$ ), one for gas ( $MF_{gas}$ ) and one for water ( $MF_{water}$ ). The proving application calculates new meter factors which then have to be manually verified and approved. Approved MFs are downloaded to the Flow Computer and will be used until new MFs are established.

The regular access to Test Separator and proving of the MPFM has been a key factor for the confidence to the Trym metering system, both from the operators and the authorities. Experience from other fields using multiphase meters as fiscal meter is that commercial agreements may limit the access to test the multiphase meter against a reference, or it may involve a relative high cost in form of compensating for other field's deferred production. That may cause mismeasurement over a significant period with the need for fiscal corrections afterwards. Missing access to Test Separators (as reference) may be caused by the host platform using this separator to optimise own production.

As mentioned above, proving of the MPFM against the Test Separator has been done monthly. In addition there have been done ad-hoc tests due to irregularities in either the operation or the performance of the MPFM. Results from the proving of the MPFM from Trym start-up until April 2013 are shown in Figure 15.

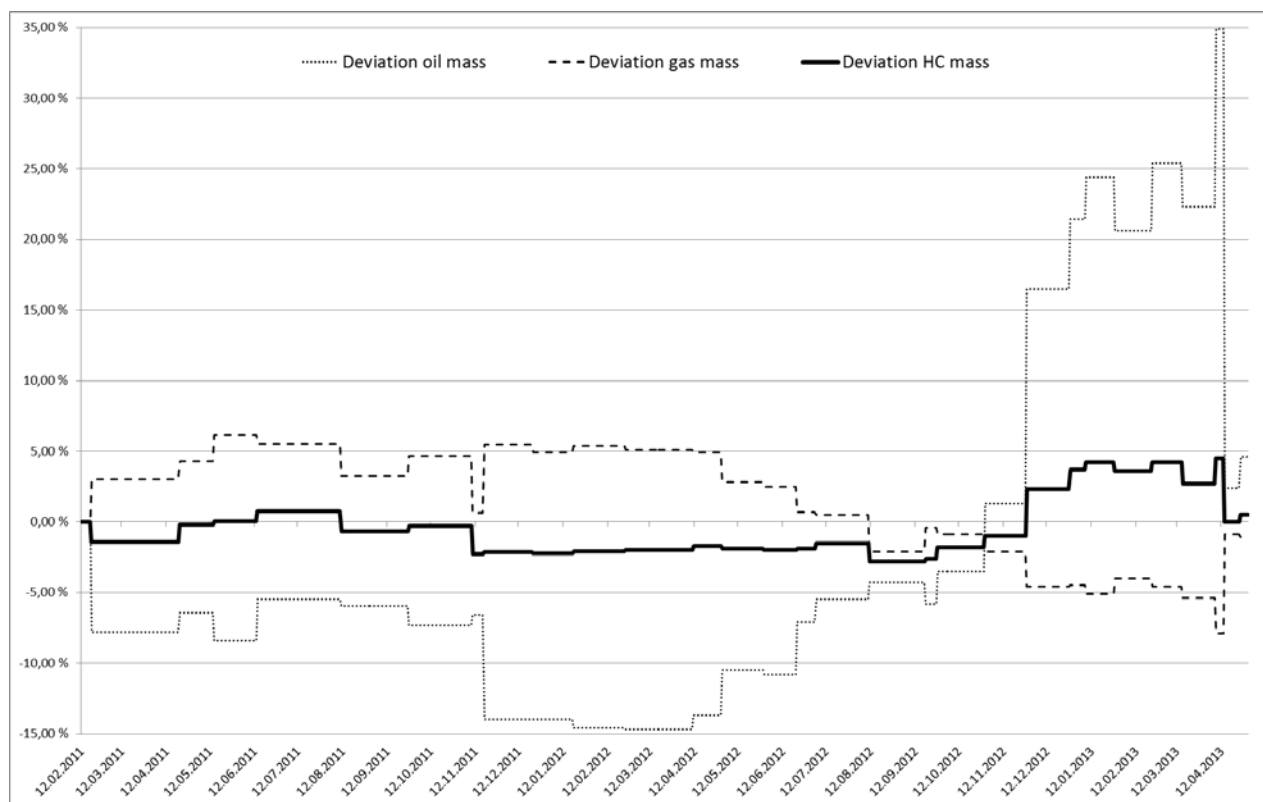


Figure 15: Deviation between Wet Gas Meter and Test Separator

One interesting and important result is that the total HC mass does not differ much. When it comes to the separate phases the results are not that promising. As earlier stated regarding the input to the allocation system the total HC mass is the most important parameter. The trend gives a confidence to the measurement of Trym even with significant deviations for both oil and gas phase. However, it is essential not to underestimate the importance of the phases and how they behave. During the two years of operation they have been used as an important quality indicator for the MPFM. Investigations have been started when the deviations have exceeded given threshold values. The observed difference in phase measurement between Test Separator and MPFM has been useful to identify actual problems with the MPFM.

A requirement in the Measurement Regulations is that "all valves of significance to the integrity of the metering station shall be accessible for inspection to secure against leakage". Just a short time before first-oil it was realised that there were several possible leakage points around the Test Separator during proving of MPFM. The reason for the possible leakage was that Trym is producing at 90 bar while Harald and Lulita is producing at 30 bar, and unfortunately there are not a single valve isolating the Test Separator from the test manifold. During one of the first verifications of MPFM it was confirmed that leakage was a problem and had to be dealt with. Compared to the Trym flow rates and the overall system uncertainty the leakage rate was very small ( $< 0.1\%$ ) but because it is a custody transfer system such a systematic error cannot be neglected but have to be compensated for. A procedure was made and the principle was to perform a test and calculate leakage rate before and after the proving.



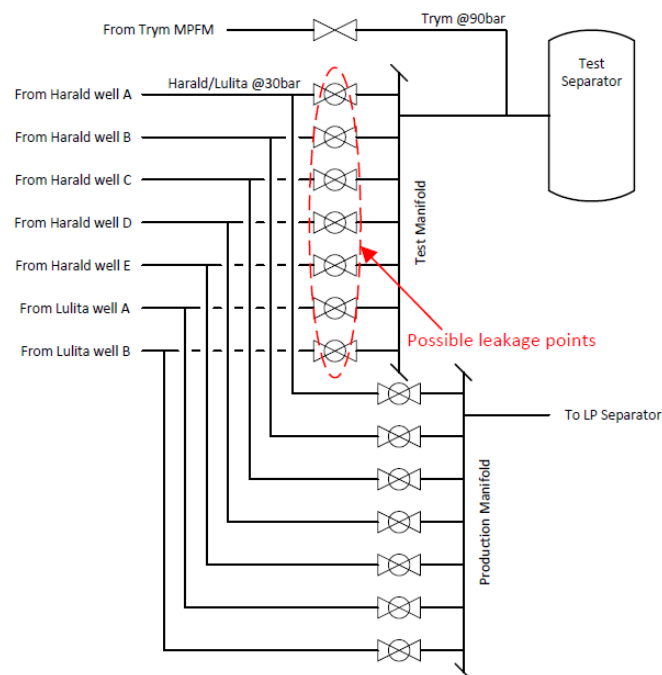


Figure 16: Possibility for leakage during proving of Trym MPFM

Coriolis meters are used on the liquid outlet from the Test Separator and the use of such meters has been thoroughly follow-up by NPD the last years. It has been experienced that tests of the meter at line conditions are necessary to confirm its suitability (Fosse, et al., 2013). As the production pressure from Trym has been 90-95 bar, it may have a significant impact on the Coriolis meters. The manufacturer of the Coriolis meters are quoting the pressure effect on flow rate accuracy to be -0.016% per bar, giving a correction of -1.44% at 90 bar. Early 2013 it was discovered that the pressure effect was not included in the flow calculations for the meters and a fiscal correction will be carried out. The Coriolis meter will be tested to confirm the pressure effect.

## 7.4 Sampling

As for traditional metering systems, sampling is important to determine the quality of the hydrocarbon stream when using MPFM. For Trym the results from the samples are used as input to the allocation system and the process simulation model.

Sampling is a great challenge when it comes to multiphase flow and the decision for Trym was to do sampling during proving. Both the oil and gas outlet from the Test Separator are equipped with sampling points for manual sampling. An external company is responsible for performing the sampling and there are procedures in place to secure as representative samples as possible. A report summarizing the sampling is issued after each sampling campaign. It contains vital information about time, pressure, temperature, measured rates etc., and it is a part of the quality assurance system. The report is also part of the final documentation for the specific sampling campaign.

For Trym the sampling is carried out every second month in combination with proving. One master and one backup sample are secured from both the oil stream and the gas stream. The samples are sent to a laboratory in the UK for analysis. It has been experienced that there is a long lead time

from the sampling is performed until the final analysis report is issued. This causes some problems related to the allocation process and therefore also some financial issues.

The PVT model in the MPFM has been updated three times since start-up. The updates have only had minor impact on the measured total HC mass. The oil and gas phases have shown more significant changes. The conclusion is that for Trym, the PVT model in the MPFM is not very sensitive for the fiscal use of the meter.

## 7.5 Analysis results and the need for re-allocation

The laboratory in UK is accepted by all parties and is responsible for doing the analysis of the Trym samples. Oil and gas samples are analysed. Oil rates, gas rates and the two analyses are used to calculate a recombined total HC stream.

The analysis report is evaluated by both Maersk and DONG before it is finally approved and used. There have been a couple of instances where the results have been questionable, with the results that the backup samples have been analysed and used. There are procedures in place both at Maersk, the sampling company and the laboratory on how to perform the different tasks related to sampling, analysis, reporting and validation.

In the agreement for producing Trym it is described how the recombined composition shall be handled in the allocation. Since there is a time delay from a sample is taken and until the new recombined composition can be implemented, a bias in the allocation will occur. When a new composition is available, it will be used to re-allocate the production from the time the sample was implemented, and back to the time halfway between the time the last sample was taken and the time the second last sample was taken. This is called the mid ranging principle and has shown to give some challenges.

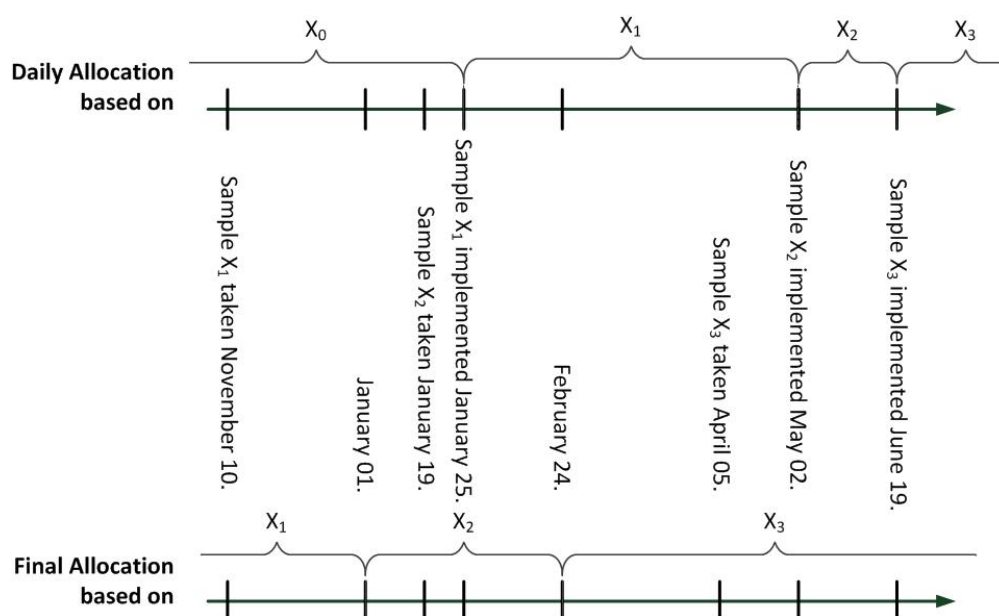


Figure 17: Mid ranging principle

As long as the field is producing, the Gas Liquid Ratio (GLR) will increase gradually over time. The principles in the allocation system do not reflect this gradual change. The allocation system uses the last available composition with its static GLR, until it is updated. As the GLR will increase over time the reallocation will change the amount of oil and gas allocated to the Trym owners. The gas is under-allocated until a new composition is available and reallocating is done, and the DUC owners have to return gas to Trym. It is the opposite situation for condensate. The total BOE (Barrels of Oil Equivalent) is almost conserved, but because of the difference in value for a BOE of gas compared with a BOE of condensate this will cause some financial implications. It has also shown to be a challenge when forecasting the production and performing daily nominating of gas production.

## **7.6 The Authorities**

The Norwegian Petroleum Directorate has confirmed that the good dialogue between Dong/Maersk and the authorities both in Norway and Denmark had been maintained during the design, testing and operation of this metering application.

The Danish Energy Agency has followed the good collaboration between the Maersk and DONG and their approach and dedication through the design phase to operation, and do appreciate and value the good understanding and dialogue between the DEA and NPD. The DEA has confirmed that it finds that despite of the complexity of the whole downstream allocation system, that the parties have found a good robust metering- and allocation system that with continuous focus, proper adjustments and improvements is a satisfactory solution for a metering system for marginal fields<sup>3</sup>.

## **7.7 What could have made the metering system even better?**

Even if the overall experience from operation of the Trym metering station is positive, there are things that could have been done differently. Listed below are some main items that could have made the metering system even better.

- A service agreement with the supplier of the MPFM that includes remote access and frequently performance checks would have been beneficial for this application. The workload on the Maersk engineer following-up the Trym metering system would have been relieved and it would have added more expertise to judge the performance of the system. Based on the experience from the operation of Trym and other MPFM's on the DUC installations, Maersk is about to sign a service agreement with the supplier regarding remote access and surveillance of MPFM's.
- Trym consist of two wells and the compositions of the fluids from the wells are comparable. Changes in flow rates from the different wells will not have a significant influence on the composition of the HC stream. This may change over time, and will then cause a higher uncertainty in the metering and allocation. One subsea MPFM on each well would, based on

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<sup>3</sup> Source: DEA

each wells composition and the wells flow rate, make it possible to calculate a dynamic composition to use in the allocation.

- The Test Separator was upgraded as part of the Trym project but still it carries a relative high uncertainty (approx. 1.8% on total HC mass). A reduced uncertainty for the Test Separator would give a better confidence to the reference measurements.
- Possible solution to reduce the Test Separator overall uncertainty is to install a pump in front of the Coriolis meters to reduce the risk of flashing in the Coriolis meters. Change out of the orifice meter on the gas outlet to an ultrasonic meter will reduce the risk for errors during operation of the meter.

## 7.8 Best practice

Best practices in operation of MPFM have been described in several publications before (Couput, 2011) (American Petroleum Institute, 2013) (Norwegian Society for Oil and Gas Measurement (NFOGM), 2005). However, below is a list of what is considered as best practice based on the experience done after operation of MPFM for Trym.

- Be prepared before start-up of the metering system (Quality management system, organisation, back-up solutions, etc.).
- Close cooperation with the authorities during both planning and operation phase.
- Metering and allocation specialist involved in preparation of commercial agreements to secure the possibility to operate the metering system in a proper and decent way.
- Frequent verification of the multiphase meter against the reference.
- Establish service agreements including remote access solutions for the MPFM supplier.
- Periodic maintenance of the multiphase meter by use of the MPFM supplier.
- Establish check parameters and accept criteria
- Storage of all vital data
- Use of supplier if mismeasurement occurs.
- Close follow-up of metering system by dedicated personnel.

## 8. CONCLUSIONS

The use of the multiphase flow meter as the fiscal meter for the Trym field has been a success, given the conditions approved by the authorities and the licenses. There are several reasons for this success, but most important was the awareness to the metering system and its properties during the project phase and further into the operation phase.

Commercial agreements between the licenses have also been a factor for success as they are describing a regular and frequent verification of the multiphase flow meter against the Test

Separator. Such agreements may also serve as an obstacle that makes it impossible to operate the metering system in accordance with the regulations.

The quality management system prepared for Trym metering gives a proper foundation in operating the system. The quality management system is custom made for Trym metering system and includes all main tasks that are performed. Preparation of the organisation so it is ready for operation before first oil is vital.

The results from verification of the MPFM against the test separator shows that the total HC mass does not differ more than approximately 4%. That gives a confidence to the metering system and its suitability in this application.

During operation the experience may be summarised as this: A simplified metering system that is based on the use of MPFM needs a thorough follow up by dedicated personnel with the right competences. It is also important to prepare for a fall back plan in case of failures to the MPFM. It also takes a long time to rectify in case of failures. Proactivity is therefore needed up front to avoid mismeasurement or shut-in of the production due to lack of measuring.

Using MPFM as fiscal meter is possible, but it needs to be done with a high attention to the complete system to avoid situations that may require corrections afterwards.

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