# Subsea multiphase measurements: where we are and what 's next from an oil & gas operator perspective

**Jean-Paul Couput, TOTAL**

---

## 1 INTRODUCTION

Access to oil & gas reserves is becoming more and more complex and difficult. This is resulting for operators in more and more technical and economical constraints to develop fields and produce hydrocarbon in an safer way .
Technical solutions developed so far rely more and more on multiphase schemes which obviously do require measurements & monitoring solutions usable in multiphase conditions to give data users and customers the information they require .

This situation is particularly true for subsea developments where conventional developments schemes using well head platforms or clusters, separation station , processing systems cannot be easily deployed .

Consequently , operators and measurements industry started to deploy and use multiphase measurements techniques like multiphase metering in subsea shallow water applications more than 10 years ago .

For high water depth development which of course are more challenging, TOTAL installed one of the first subsea multiphase meter at 1500 water depth early 2000 on GIRASSOL field located in Angola.
Since then,multiphase metering solutions have been considerably deployed within TOTAL subsea assets on different location & fields including Gulf of Mexico ( Canyon Express ) , North Sea and West Africa .

This paper will give some status on subsea needs & operational feedback gained so far in subsea multiphase metering implementation and use .Based on existing experiences and on expected future developments, our vision as operator on multiphase measurements systems for subsea applications is described.
.

## 2 SUBSEA DEVELOPMENTS CHALLENGES

Available statistics indicate that worldwide subsea oil resources are estimated to be around 300 billions barrels . For deep offshore i.e water depths higher than 400 m , oil reserves represent 200 billions barrels .
On the other side , deep offshore production is expected to double on the next 10 years from 10 Mboepd to 20 with a large increase in capital spent.

In term of subsea development challenges , industry will have to develop large fields but also remote and/or small reservoirs.
We need also to anticipate :

a drive for increased oil recovery from existing fields with higher water cuts
an increase in gas developments
an increase in measurement demand for contractual and fiscal allocation .

Deeper waters, complex fluids and reservoirs (high temperature / high pressure, heavy oil, gas condensates ) associated with more safety and environmental constraints will dictate coming developments.
With longer subsea tie–back and distances from well to process facilities, reliability, operability & maintainability of equipment will be an issue with an increasing need of multiphase data to monitor flows , sand , hydrates , water production and provide valuable flow assurance information .

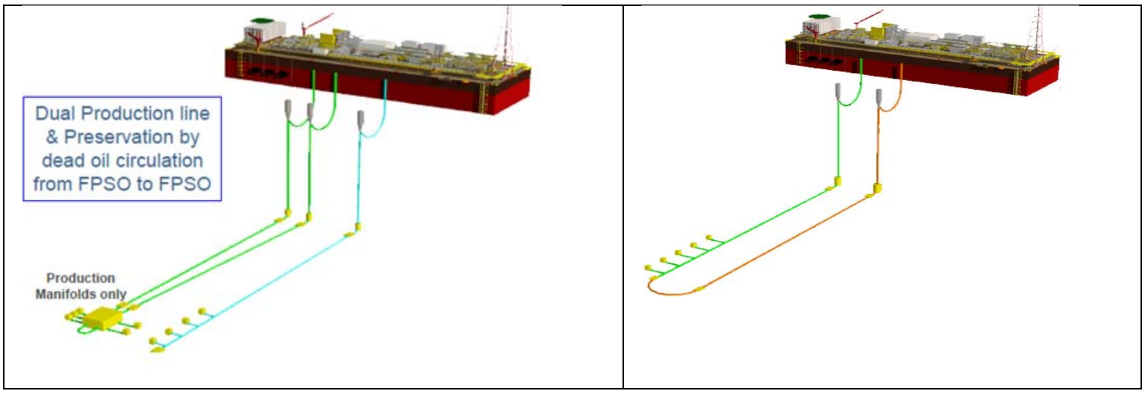
In term of economics there will be a drive for cost effective developments through optimized architecture concepts , subsea boosting & processing , new floating systems and also Innovative & reliable measurement & monitoring solution

## 3 SUBSEA NETWORKS AND FACILITIES

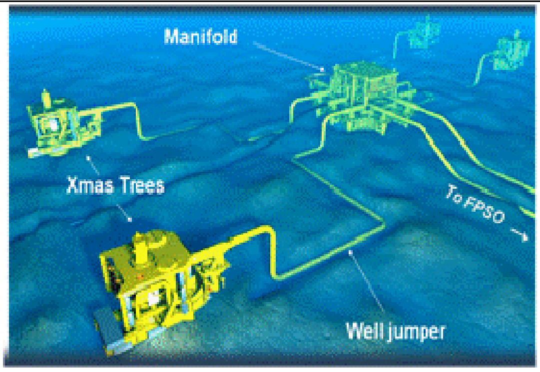
### 3.1 Subsea systems architecture

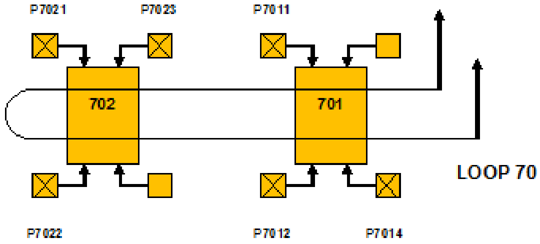
In first subsea developments at high water depths , daisy chains consisting in two branch flow lines were use to connect wells to the surface by riser flowlines .
Such a system was making possible to switch wells from one line to the other and consequently to test wells directly or by difference using test facilities located on surface .
Such a system may also allow to verify subsea instrumentation by connecting mulmtiphase metering systems with topside installations .

Subsea architecture have been simplified and optimised through the use of hybrid lines or even single lines with several production wells per line and several injection wells per line.



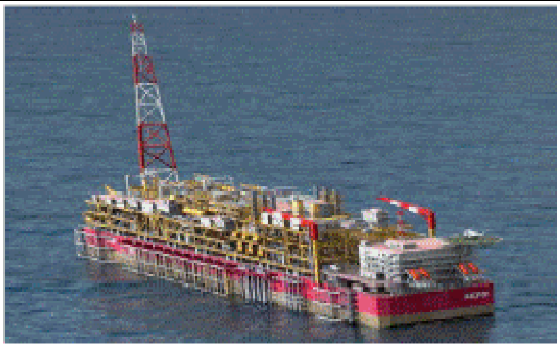

In most of the time they will not be specific test line to test individual subsea wells test line.
Such situation make individual well testing and individual multiphase systems verification quite difficult due to deferred production generated by closing N-1 wells to test Well N .




### 3.2 Surface facilities and FPSO

Subsea wells and fields may be produced through offshore installations like FPSO or production may be sent directly to shore . TOTAL is operating some of the largest FPSO units with oil capacity above 250 000 bbls per day .



## 4 MULTIPHASE FLOW MEASUREMENT CHALLENGES FOR SUBSEA DEVELOPMENTS

As for topside, subsea measurement solutions shall be implemented to give all information required to operate subsea installations safely and to provide all users with needed information like :

- Well and flowline flow rates
- Water salinity
- Sand content .

The trend has been to rely on in line subsea measuring systems like multiphase meters, wet gas meters , sand detectors … .
Subsea sampling of multiphase flows has not been largely developed so far.

### 4.1 Achieve and guarantee quality of information

Data accuracy is obviously one of the issue for subsea measurements which cannot be verified & calibrated easily due to limited access . Accuracy targets must be specified according applications which may be :

- reservoir and well monitoring
- contractual and fiscal allocation
- production optimization

Access to real time information for well behaviour diagnostic , equipment trouble checking and measurements interpretation ( sand detector for instance ) is also a challenge in subsea due to data transmission complexity .
Subsea measuring system communicate with topside through proprietary systems developed by subsea systems suppliers ( Subsea Electrical Modules and Subsea Control Modules ..)

### 4.2 Comply with constraints related to subsea operations

Verification of subsea systems using topside installation may be a constraint due to technical feasibility and also to deferred production.
Suppliers recommendations applicable to topside MPFM or eventually to Subsea are not easily applicable .
Doing empty pipes or calibrating electrical systems ( capacitance , microwaves ..) with known fluids is not straightforward.
Even calibration of a differential pressure measurements using reference pressure generators is not applicable.

### 4.3 Provide reliability and robustness

Reliability is obviously a key point . It concerns meter assembly, measuring sensors , measurement electronics and computers which may be designed and QA/QC in order to avoid problems .
Should we have failure risks, minimum redundancy shall be implemented in systems .

### 4.4 Tolerance to fluid properties & flow regimes change

Systems robustness which means capability to maintain performance in case of failure or in case of process changes like fluid properties or flow regimes changes constitutes one functionality

### 4.5 Compliance with water salinity changes

This aspect need to be considered seriously as multiphase meters and wet gas meters may be submitted to random water salinity changes along field life in case of formation reservoir production for gas and also in case of water breakthrough in case of water injection .

### 4.6 Satisfy integration & installation constraints

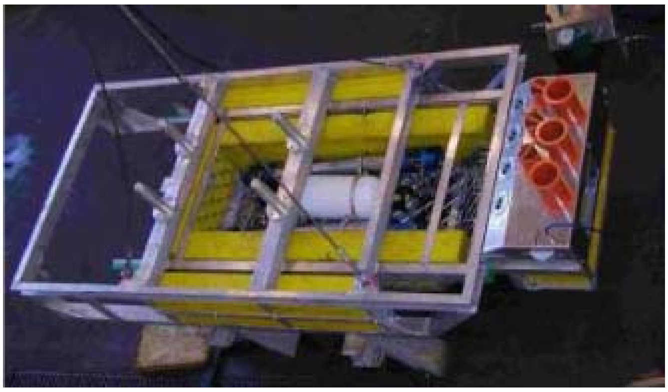
In subsea designs, measuring systems are part of larger systems provided by subsea modules and systems manufacturers. This may result in potential under estimation of metering problems and constraints by subsea integrators and also lead to conflict between manufacturers ( flow meters , acoustic sand detectors ..) requirements and subsea assembly design.
Power and size may also be a constraint for subsea flow meter integration , installation and removal .

### 4.7 Retrievability

Standard practice is to have fully retrievable systems in case of major sensor or electronics failure due to hardware or process . Redundancy may help but in some cases is not enough .

### 4.8 Difficult access to fluid sample

Subsea sampling including sampling probe and sample retrieval back to surface is costly and a very few reliable and safe systems have been developed and implemented so far to sample multiphase streams which today makes accessibility to fluid property difficult.



ROV sampling skid

## 5 SUBSEA MULTIPHASE MEASURING SYSTEMS IN TOTAL OPERATED ASSETS

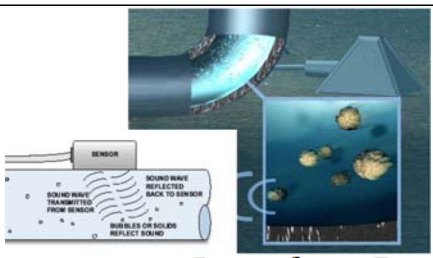
### 5.1 Subsea multiphase and wet gas meters

TOTAL has a significant operational experience gained so far with most of subsea multiphase and wet gas meters suppliers including Framo , Roxar , MPM & ISA Solartron .
More and more, the standard practice within TOTAL is to install one individual multiphase meter or wet gas meters on each well for well metering and testing .
More than 100 subsea multiphase meters are now in operation since several years . Most of them are installed at high water depths ( > 1000 m WD ) .
Up to now, we have been using both fully retrievable systems or systems with only electronic retrievable .
Depending on subsea production system suppliers , subsea architecture and X- tree solutions , subsea MPFM have been installed for well metering on X-tree upstream choke , on jumpers or on manifolds .



### 5.2 Subsea sand detectors

Standard practice is also consisting in installing sand detectors mainly based on acoustic signal processing on wells and flow lines to detect well sand production if any.



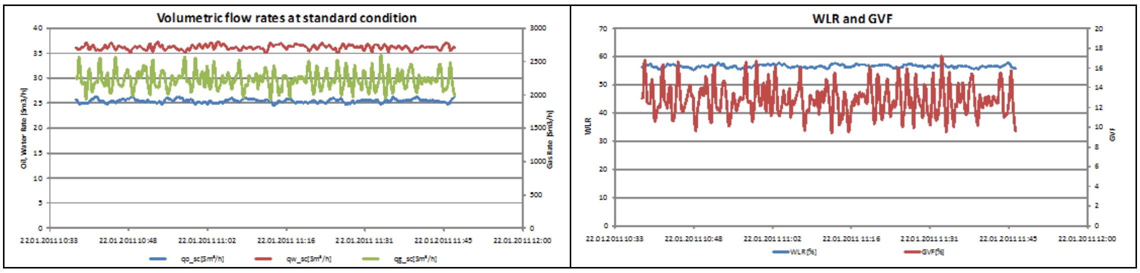

$$Sand\ rate = \frac{Raw\ value - Zero}{Step}$$

## 6 OPERATIONAL FEEDBACK with SUBSEA MULTIPHASE MEASUREMENTS

### 6.1 General multiphase meters performance

General performance is established by comparing multiphase meter flow measurements with total oil production measured topside and estimated flow rates based on flow models .
For a couple of oil fields , total liquid flow (water + oil) deviates less than 5% from topside measurements but oil deviations may be up to 10 % .

## 6.2 Real time flow data




Most of data are made available to users through subsea communication links and real time data base historian for well monitoring and metering.

## 6.3 PVT data and water salinity

Incorrect properties of hydrocarbon gas and liquid ( density , attenuation ) as well as water density and conductivity have been found to affect significantly dual gamma and gamma / electrical technology measurements.
Periodic verification of PVT combined with fluid property assessment like water conductivity is still a key point in subsea MPFM maintenance and operation.

## 6.4 Sensors & measurements failures

We have experienced a numbers of failures on sensors , electronics & computers which have been fixed or partially solved

- by retrieving full meters or electronics in case of systems with canisters
- by using defaut values when information is missing or is invalid

The following table give some statistics obtained on a TOTAL West Africa field producing 200 000 bopd .

| | |
|---|---|
| % subsea MPFM retrieved | 10 % |
| % subsea MPFM considered as fully functional | 70 % to 85% |
| % of subsea MPFM out of range | 5 % |

The following table lists main failures experienced so far with subsea multiphase meters .

| Type of equipment | Type of failure | % of meters affected |
|---|---|---|
| Gamma measuring systems | Insufficient number of counts – peak loss – offsets | 20 % |
| Electrical systems | Capacitance electrodes " contamination " - wrong permittivity | Up to 30% at beginning with improvement versus time |
| Differential pressure | Hydrates or out of ranges | 5 % |
| Pressure & temperatures | Data acquisition or transmission | Measurements may be available 80% of time |
| Subsea Computer failures | | 2 % |
| Communication | Low speed / data loss | A solution to data loss may be to power- |

| | | |
|---|---|---|
| | | cycle the flow meter power supply |

### 6.5 QA/QC during subsea MPFM manufacturing & integration

For different reasons , QA/QC has been found to be insufficient between MPFM manufacturing & start up . This may concern both the supplier itself or the subsea integrator .

Here after are listed a couple of things which may happen and affect meter performance when put in operation :

- deposits on sensors during manufacturing & storage
- un reliable communication

- insufficient testing before start up
- bad instrument calibration
- wrong PVT data inputs

## 7 MANAGEMENT OF SUBSEA MULTIPHASE MEASUREMENTS IN TOTAL

To fix reliability and performance issues and develop confidence in subsea flow data , we have been developing guidelines and approaches which are summarized below .

### 7.1 Cooperations with suppliers

Of course , periodic meetings and discussions between users and most of suppliers have been set up with a record of status and interventions in order to

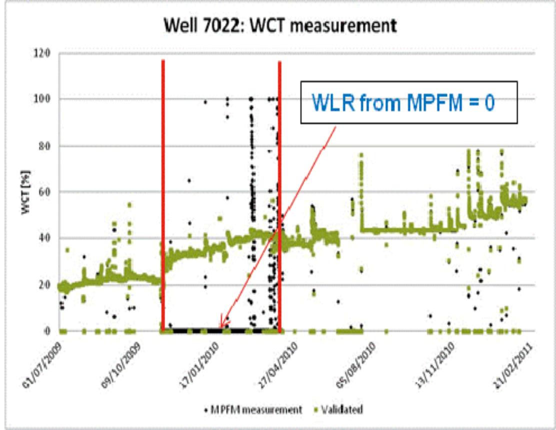
- solve problems and avoid replication
- access to raw data for internal diagnostic
- share operational feedback
- develop verification practices ( in situ verification )
- anticipate future needs both for mpfm and wet gas
- develop meter qualification and knowledge ( sand ? )

### 7.2 Best practices

Some of practices in place for subsea multiphase measurements are :

- Periodic maintenance through supplier contracts
- in line calibration development
- remote follow up
- comparison with topside measurements through deviation coefficients ( Figure )
- unbalances follow up
- extensive flow loop testing
- back up and trending of meters using virtual metering .

| Wells | Coef Oil MFM | Coef Water MFM | Coef Liq MFM | Coef Gas MFM |
|---|---|---|---|---|
| WELL 1 | 0,7244 | 0,9725 | 0,8198 | 1,0561 |
| WELL 2 | 1,1321 | 1,3043 | 1,1769 | 1,5183 |
| WELL 3 | 0,9190 | 1,0739 | 0,9647 | 0,9403 |
| WELL 4 | 0,9138 | 1,0000 | 0,9138 | 1,1557 |
| WELL 5 | 0,6941 | 1,0559 | 0,9004 | 0,9434 |
| WELL 6 | 0,8851 | 1,2431 | 0,9187 | 1,2653 |
| WELL 7 | 0,9219 | 1,0000 | 0,9219 | 1,2259 |
| WELL 8 | 1,0357 | 1,0000 | 1,0357 | 1,0081 |
| WELL 9 | 0,7476 | 1,0000 | 0,9716 | 1,0261 |
| WELL 10 | 0,7731 | 0,8610 | 0,8060 | 0,9513 |
| WELL 11 | 1,1035 | 1,7612 | 1,2023 | 1,102 |
| WELL 12 | 0,8443 | 1,2508 | 0,9264 | 1,0519 |




### 7.3 Subsea flow meter surveillance & validation

Data Validation & Reconciliation ( DVR ) methodology , is applied to subsea system surveillance in which flow measurement and flow data accuracy and validation are an issue . The DVR approach is used to enhance the existing physical metering system and to provide backup in case of subsea instrumentation failure. (Ref 1 )

### 7.4 Subsea meter specifications

Through internal specification , fully retrievability , redundancy and water conductivity measurements are now required .

### 7.5 People training

As multiphase metering acceptance rely on people , extensive technical training has been initiated between TOTAL assets and headquarters with Supplier assistance .

## 8 FUTURE NEEDS , WAY FORWARD AND CONCLUSIONS

All operators and data users are dreaming about the magic subsea flow measuring system which should give all required data with good accuracy , minimum calibration and operational constraints and cost .
Easy integration in subsea design is also a must .

Getting such a meter could take very long time and is not necessary realistic but at the same time as operators and others stakes holders , we need to express clearly our needs , our bad records and expectations in order to push industry and competition to improve and come up with improved solutions and new ideas.

We need also to explain what will be the coming subsea challenges to have the technology ready .

Here after are listed a couple of points to be addressed seriously for the design , the installation & the operation of meters .

### 8.1 Subsea meter performance and accuracy

Present specifications which are addressing gas , liquid and water liquid ratio may turns into high uncertainty for oil which are insufficient for contractual allocation or oil production estimation at high water content .
Revision of existing standards or guidelines may help in describing new performances which should be for instance lower than +/-1% for WLR and +/- 2.5 % for oil in given GVF range .

### 8.2 Fluid property and process conditions tolerance

For subsea , priority should be put on technologies which are less sensitive to fluid property variations as well as insensitive to problems experienced with process fluids .

### 8.3 Sensor and system reliability

Reliability experienced so far is not fully satisfactory. This must be improved as soon as possible as this could be detrimental for some technologies

### 8.4 In situ verification and calibration

Any advanced functionality allowing users to develop confidence in meters should be developped and implemented .
A standard may help to improve situation by describing minimum requirements to be provided

### 8.5 Technology

Most of multiphase flow metering technology installed a few years ago rely on measuring principles developed 15 years ago , so we encourage all industry and manufacturers to propose new approaches like recent players which are using tri dimensional measurements like MPM or optics like Weatherford .

### 8.6 Water salinity function

Access to water salinity shall be part of multiphase and wet gas supply both for reservoir follow up and also to maintain accuracy of flow meters when needed .

### 8.7 Sand measurements in multiphase

Industry has not considered limitation of acoustic sand detectors especially when used both in subsea and in multiphase streams , there is once again a specific domain which shall be investigated and improved .

### 8.8 Subsea integration and QA / QC

Clearly , QA/QC has shown some weakness both within manufacturers but also during assembly and integration should be improved , reviewed and audited .
In addition , close relationship should be established between subsea systems integrators and users on measurement topics to avoid problems.

### 8.9 Third party flow loop test

It seems to be difficult to have access to third party flow loop tests able to run oil , gas and water flow rates at different conditions including different water salinity and viscosity.

As users , we suggest industry to think to such loops which of course should be accredited by regulatory bodies according ISO standards.

### 8.10 Operation and back up

If most of problems are related to hardware itself , it is clear that operators shall develop their own practice and expertise to verify , validate and back up subsea flow measurements in case of failure .

### 8.11 Subsea sampling

Even if sampling will not be extensively developed and used for safety reasons in subsea environment , capability to get samples for fluid property analysis or allocation is an issue which need to be addressed .

**ACKNOWLEDGEMENTS**

The author would like to thank all people from headquarters and assets who have contributed directly or indirectly to this operational feedback . Specific mention to Vincent Arendo from TOTAL Operations who has provided part of feedbacks on subsea multiphase meters.