Offshore Liquid FPSO Measurement Systems

Class # 2450

By

T. Cousins

Cameron Caldon

1000 Mcclaren Woods Drive

Coraopolis, PA 15108, USA

INTRODUCTION

Floating production, storage, and offloading systems (FPSO's) receive crude oil from deepwater wells and store it in their hull tanks until the crude can be pumped into shuttle tankers or oceangoing barges for transport to shore. They may also process the oil and in some later FPSO's to be used for Gas distribution.
Floating productions systems have been utilized in remote offshore areas without a pipeline infrastructure for many years. However, they have become even more important with the push by the offshore industry into ever deeper waters. Floating production, storage, and offloading/floating storage and offloading (FPSO/FSO) systems have now become one of most commercially viable concepts for remote or deep-water oilfield developments. They also allow a company to develop offshore resources quickly between discovery and production. They have been shown to reduce this time as much as two to four years. Further there can be significant cost savings in developing marginal fields.

.HOW THEY WORK

An FPSO system is an offshore production facility that is typically ship-shaped and stores crude oil in tanks located in the hull of the vessel. The crude oil is periodically offloaded to shuttle tankers or ocean-going barges for transport to shore. Gas may be piped directly to a shore facility. A typical FPSO is shown in Fig. 1, with a typical operational setup, shown in Fig. 2. The ship is likely to be taking oil from a number of drilling platforms, connected by a series of subsea pipes. Further, they may take several oil types, and carry out mixing to produce a more commercially viable oil grade.

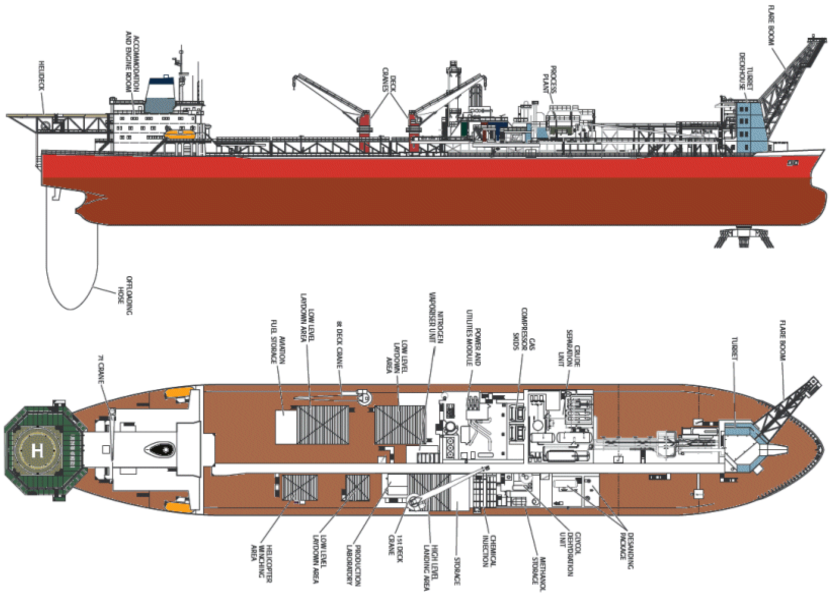

Fig 1 TYPICAL FPSO

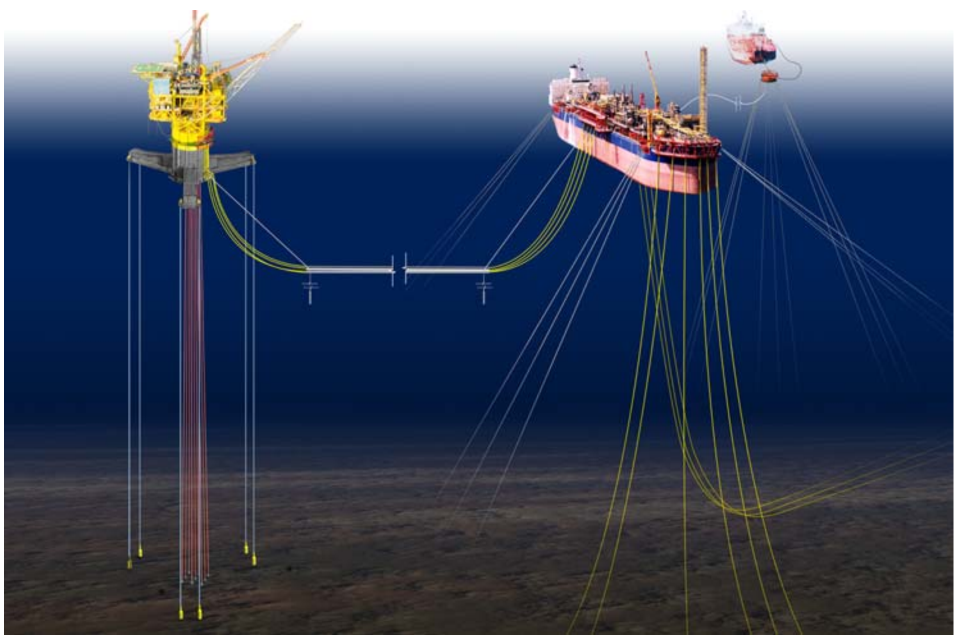

Fig 2 OPERATION OF FPSO

An essential part of the design of an FPSO is the Turret. The turret is the connecting point between the FPSO and the subsea systems and is the pathway for getting oil and gas from the reservoir into the vessel. In conjunction with the correct anchoring, the turret permits the FPSO to weathervane freely to minimize the impact of sea state conditions on the vessel. Collected oil and gas as well as water and gas injection, used to maintain reservoir pressure, arrive and leave the vessel through pipes in the turret.The world's largest FPSO is the Kizomba A, with a storage capacity of 2.2 million barrels (350,000 m^3). Built at a cost of over US$800 million, it is operated by Esso Exploration Angola (ExxonMobil). Located in 1200 meters (3,940 ft) of water at Deepwater block 200 statute miles (320 km) offshore in the Atlantic Ocean from Angola, West Africa, it weighs 81,000 tonnes and is 285 meters long, 63 meters wide, and 32 meters high (935 ft by 207 ft (63 m) by 105 ft).

METHOD OF OPERATION

A typical operating cycle of an FPSO is as follows:

- The normal operating cycle encompasses up to 10 days of production
- The FPSO will have enough storage for this amount of oil
- Off loads by shuttle ships are usually on a seven day basis (allowing 3 days in the cycle for the advent of bad weather conditions.

The shuttle ships unload the oil from the FPSO and may be dedicated shuttles whose only purpose is to take the oil to a local terminal, or to ships that take the oil from the FPSO direct to a customer. In the former case the metering requirement is likely to allocation metering, although there may tax implications that require the level to be full custody transfer. In the second method the level of performance will be custody transfer.

METER REQUIREMENTS

Metering on an FPSO is a function of a number of competing requirements, each of which may fight the other requirements. For example weight and size limitations may make capacity difficult to achieve, or the need for capacity may mean some sacrifices in uncertainty by not using a prover.

Weight & Size

While the uncertainty requirements of metering on an FPSO are clearly the same for any custody transfer/ fiscal allocation system, the really big issues are not so much in the level of measurement, but are more related to the weight and volume. Early FPSO’s had no processing modules on the ship. There was plenty of space for a metering skid and weight was not an issue. The prover section of an FPSO used in Yemen is shown in Fig. 3. This is a 42” prover, mounted completely separately from the five 14” turbine meter skid. The total footprint area of the skid was made up of the two separate sections. Not only was the footprint large but the maintenance was difficult, with the size and weight of the ball and its position making maintenance a big issue. When a ball burst on one occasion it took over 2 days to remove and replace it. A further issue was calibration, waterdraw of such a large prover. In the picture a smaller prover can just be seen inside the main prover. Calibration was achieved by water drawing the small 8” prover, calibrating a positive displacement meter, also in the skid, and finally calibrating the main prover with the PD meter.

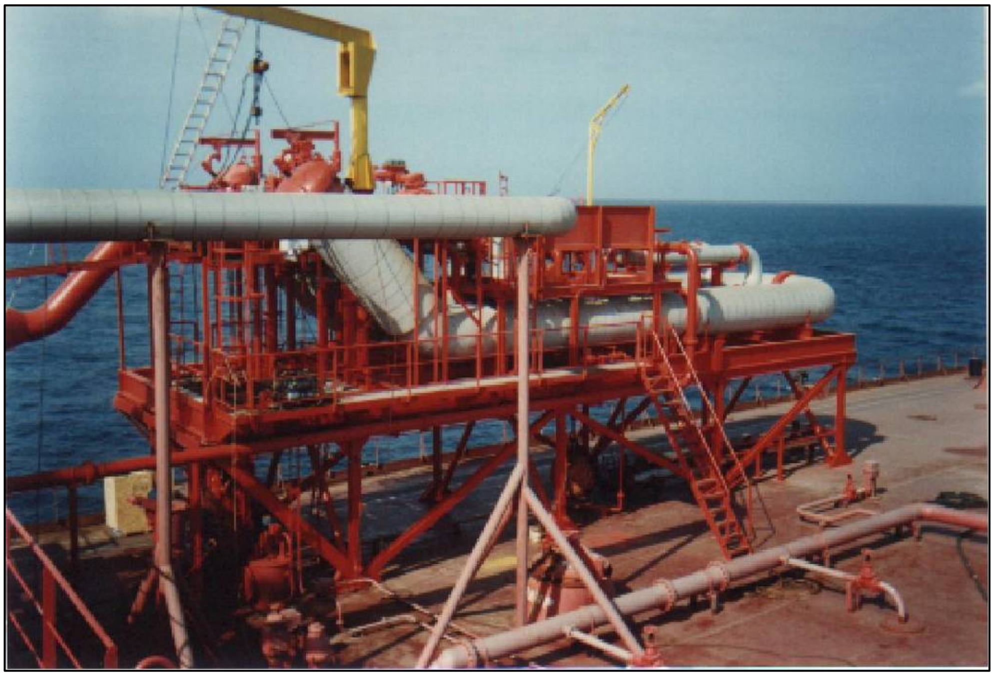

Fig 3 42" Prover on an FPSO

New FPSO's not only store oil but also carry out processing and even refining. The space is now a premium, as is the weight. A typical, modern, ship is shown in Fig 4, giving little space for metering. The previously described skid could not be used, and so metering engineers are looking for smaller footprint solutions with easier or less maintenance.

Fig 4 Modern Processing FPSO

In a recent example of an FPSO, the ship was redesigned four times due to over weight and capacity problems. As can be seen from Fig 6, the room available for any item is minimal. The flow measurement on the ship is subject to the same pressures as the rest of the equipment. This has required different design configurations and methods of measurement. In the example below, the prover has now been wrapped under the meter skid to give a smaller footprint.

Fig 5 Compact Meter Skid

The skid can be seen on the ship, Fig. 6, perched on the side.

Fig. 6 The Meter Skid on a Vessel

A ball prover is typically large in volume and requires some very innovative engineering, other solutions available are to use a small volume prover, or master metering, both of which can reduce the footprint considerably.

Capacity

Another major feature of flow measurement on an FPSO is the need to be able to load shuttles as fast as possible. To quote an old Northern English expression “Time is money”. This is very true of loading tankers. The faster the turn round of the oil, the faster the inflow of cash. A further reason is the need to load quickly in the event of bad weather. Prover capacity, for example, limits the size and flowrate of individual Meters. To compensate for this the meters are conventionally set in banks of up to 5 or more small meters.

This allows the prover capacity to be minimised but enables the total throughput to be large by bringing on line a number of meters and proving one at a time.

Pressure drop must also be considered when designing for capacity, balanced against size and weight. Pumping capacity and cavitation can cause significant errors in measurement, as well as increased running costs. Any meter that has parts in the fluid will cause some extra pressure drop dependent on the meter type. This will become an increasing problem as the viscosity of the oil increases.

Previously meter skids had used Turbine meters as their basic method of measurement, and in the event of high viscosity even the use of Positive Displacement meters were countenanced. However, to achieve the capacity the skids can become large and weighty. Furthermore, extra pump capacity is needed to overcome the pressure drop through such skids and maintain the flow rates necessary to load ships at the required rates. There has been a move to other methods of measurement, notably time of Flight Ultrasonic flowmeters, where the low pressure drop has helped. In particular, rather than having a bank of meters, with all the associated manifolds, valves etc. an ultrasonic meter can sized such that only one, or one meter and a check meter is needed, reducing cost, footprint, with smaller skids, and pressure drop.

Reliability

A further requirement, made more important by space constraints and remoteness, is reliability. Under ideal conditions and with good lubricating oils turbine and positive displacement meters will last for years without failure. But heavy production oils can contain gas and particles that can reduce the life of these meters, particularly the positive displacement meters. They both need some form of strainer to protect them, which raises the pressure drop. The need for moving parts and slightly delicate components such as bearings will always leave the possibility of component failure. Newer flow meter designs, such as ultrasonic meters, with “solid” state components essentially untouched by the fluid are generally more robust, and easier to repair.

Uncertainty

It is often difficult to quantify uncertainty requirements, custody transfer is often a contractual agreement between two organizations the buyer and seller. It may be that they agree to a wider specification if circumstances make it sensible. API is not clear about uncertainty requirements. It does specify issues with proving, however, these are primarily targeted at repeatability.
OIML 117 is specific in the matter of uncertainty for custody transfer. In general the accuracy requirements for a custody transfer require that the total system uncertainty will be less than 0.3%. This allows the meter to have a total uncertainty, including repeatability, of between 0.15 and 0.2%

To Prove or Not to Prove?

Custody Transfer has lived by the use of provers to “calibrate” the meters on site and take out the effects of installation. The problem this presents for FPSO, especially with line provers, is the extra size and weight. Small volume provers are a possible solution, as by their very nature they are compact and light. However, when used with ultrasonic flowmeters, there are currently some questions as to the validity of this method. Further, if the large meter solution is taken the size of prover required is so large as to be impractical. The solution for a number of FPSOs is to use a master meter concept, with one meter kept as a master meter for checking one or more operational meters. This is a very similar concept to that used in gas measurement with a good deal of success. In the case shown in Fig. 7, two 24” ultrasonic flow meters have been used. To reduce the common mode problem, where two similar meters would be affected by the fluid effects, such as waxing, one meter can be held offline, usually in a diesel mix to keep it clean, and then brought on-line at agreed intervals to check the operational meter. The meters are also sent annually for calibration. This still leaves a possible doubt over the transfer of the calibration to the operational installation. As the two meters have different installation conditions, if they initially agree then this increases the confidence in the performance. Further confidence can be gained by using a meter such as the two plane ultrasonic meters, which have an extra immunity to installation effects.

Fig 7 Offline Master Meter Installation

The issues that have to be considered when choosing non-proving are:

- How to ensure that a laboratory calibration can be transferred to the operational conditions?
- Are there methods of ensuring the transfer of the calibration?
- Is there any other method of checking the performance?

The first issue is to choose the appropriate measurement facility that gives traceability and ensuring calibration at appropriate conditions. There are a limited number of facilities in the world that offer this:

- SPSE & Trapil in France for multi-viscosity oil calibration to ISO 17025
- NEL in the UK to ISO 17025
- Delft Hydraulics in the Netherlands ISO 17025
- Cameron Facility in Pittsburgh NMI certified to ISO 17025, Fig 8.

Fig. 8 Cameron Flow Laboratory

To ensure that the meter calibration is valid when installed insensitivity to changes in fluid properties relative to the calibration conditions is essential. Essential features such as:

- Choosing the right pipework for calibration to reduce the effect and calibrate out f local installation errors, such as step changes
- Insensitivity to installation effects caused by upstream bends and valves etc.,
    - All meters are sensitive to some form of installation conditions,
    - A major issue with most flowmeters is profile
    - The actual flow profile as produced by pipe fittings
    - This may be alleviated by use of flow conditioners.

Positive Displacement meters and certain designs of Ultrasonic flow meters are very insensitive to flow induced variations due to installation. Turbine meters would be a poor choice for this type of measurement.

THE FUTURE OF FPSO's

While this paper is largely about Liquid measurement, it should be noted that the latest FPSO's also now act as floating gas terminals, usually with a direct pipeline to the shore, rather than shuttles. In this case the flow measurement is usually by multi-path ultrasonic flow meters, although some orifice systems are still used. Perhaps the major development is the use of an FPSO to produce LNG and load LNG tankers. In this case the flow measurement is still developing. At present it appears that Ultrasonic and Coriolis meters are taking the lead. Ultrasonic meters in this case have an advantage that they represent little or no pressure drop, a very important feature in LNG measurement.

A further development is the use of multi-phase meters on FPSO's. sometimes for sub-sea operation. Fig. 8.

Fig 8 Sub-Sea Multiphase Meter

Multiphase meters are today a vital component of operators' development and field production plans. They can be used for production monitoring, individual well testing, production allocation and reservoir monitoring and they provide the operator with critical information on a well's capabilities – information such as water saturation and break through, gas coning, permeability and flow characteristics. As the wells get poorer in their quality there is more water and gas mixing with the oil. Often the water is used to keep pressure up in the well, and as a consequence mixes with the oil. Using separators is difficult on a FPSO due to their bulk and complexity. The benefits to the operator are clear, including no separation requirements; no need for costly test separators; the instantaneous and continuous measurement of three phase rates – not just at a discrete point in time and not just for one well; and limited maintenance requirements. The result can be substantial CAPEX/OPEX savings, increased well control, and enhanced production from the fields.

Uncertainty is an issue, in the rest of the paper we have been talking about 0.15-0.3% devices, these flowmeters are 5-15% meters. But because of the savings these uncertainties are acceptable, particularly for well testing and even allocation metering. The development of these meter types is so concentrated that improvements in performance are bound to come in time.