FMC EnergySystems

FMC Measurement Solutions

High Capacity Liquid Flow Metering and Proving Equipment for Offshore Crude Oil Storage and Transfer Vessels

Technical Paper

Bulletin TP0A003

Peter P. Jakubenas

Summary

Offshore exploration, drilling, and field development represent a large investment. It often is a 3 to 5 year effort. Payback on the investment is not achieved until custody transfer of the produced crude oil is accomplished. This is most quickly achieved by use of an offshore crude oil storage and transfer vessel, often termed a floating production storage off-loading system (FPSO); rather than pipelines, on-shore tank terminals, land based measurement systems, and SBM loading facilities, which not only take extensive time to construct, but also become rather permanent facilities, and which cannot be justified for a small to medium size field.

Crude oil storage and transfer vessels are normally constructed from refurbished crude carriers in the 150,000 DWT size range. The crude oil from the multitude of well heads is piped to the semi-permanently moored vessel. The crude may be stabilized and measured prior to receipt aboard the vessel, or stabilization and measurement may occur aboard the vessel. The vessel is usually sized to accommodate 20 to 60 days' production. When the vessel is filled, arrangements are made to transfer the cargo to ocean going crude carriers. This transfer must usually occur at rates high enough to accomplish the complete unloading of the storage vessel into the crude carrier in 10 to 20 hours. Because of the problems associated with accurately gaging tanks under these circumstances, a high flow rate liquid metering system is often used.

Note the use of the word "system" when describing the measuring equipment. It is essential when applying meters and associated measurement equipment that the systems concept be used. In order to attain the ultimate in accuracy and reliability, all of the measurement elements must be properly selected for the application, and designed to work together. It is desirable for the equipment to be assembled and tested as a prefabricated unit prior to installation aboard ship. The subject of this paper is concerned with specification and design of the above described measurement systems.

Applicable Standards and Specifications

Codes, standards, and specifications for the systems described above are extensive due to the hazardous materials, severe environments, and degree of accuracy required. In addition, requirements for shipboard equipment must be met. Consultation with a number of interested parties is required to establish basic specification applicability. This may include producers, sellers, buyers, governmental authorities associated with royalties, customs, safety and environment, and equipment operations people. The codes are categorized and are listed in the following section.

General Design Standards - Measurement Accuracy Requirements

API Manual of Petroleum Measurement Standards

- Chapter 5, Section 2 - Displacement Meters
- Chapter 5, Section 3 - Turbine Meters
- Chapter 5, Section 4 - Instrumentation or Accessory Equipment
- Chapter 4 - Proving Systems
- Chapter 12 - Calculation of Petroleum Quantities
- Chapter 6, Section 5 - Metering Systems for Loading and Unloading Marine Bulk Carriers
- Chapter 8, Section 2 - Automatic Sampling

Requirements of National and Local Customs, Weights and Measures, and Governmental Authorities

Pressure Retention Safety and Construction Codes

ANSI/ASME B31.3

ANSI/ASME B31.4

ASTM Material Specifications

ASME Boiler and Pressure Vessel Codes

Construction and Inspection Requirements of the Ship Certification Agent, such as:

- American Bureau of Shipping
- U.S. Coast Guard
- Lloyds
- Bureau Veritas
- Det Norske Veritas
- Vincotte

"Solas" (Safety of Life at Sea) Standards

NACE (National Association of Corrosion Engineers) Specifications

Electrical Safety Codes

National Electric Code

API-RP-500B "Classification of Areas for Electrical Installations at Drilling Rigs and Production Facilities on Land and on Marine Fixed and Mobile Platforms"

Electrical Codes of Ship Certification Agents noted above

Structural Codes

AWS D1.1 - Structural Welding Code

AISC - Steel Construction Code

Structural Codes of Ship Certification Agents noted above

Operational Considerations

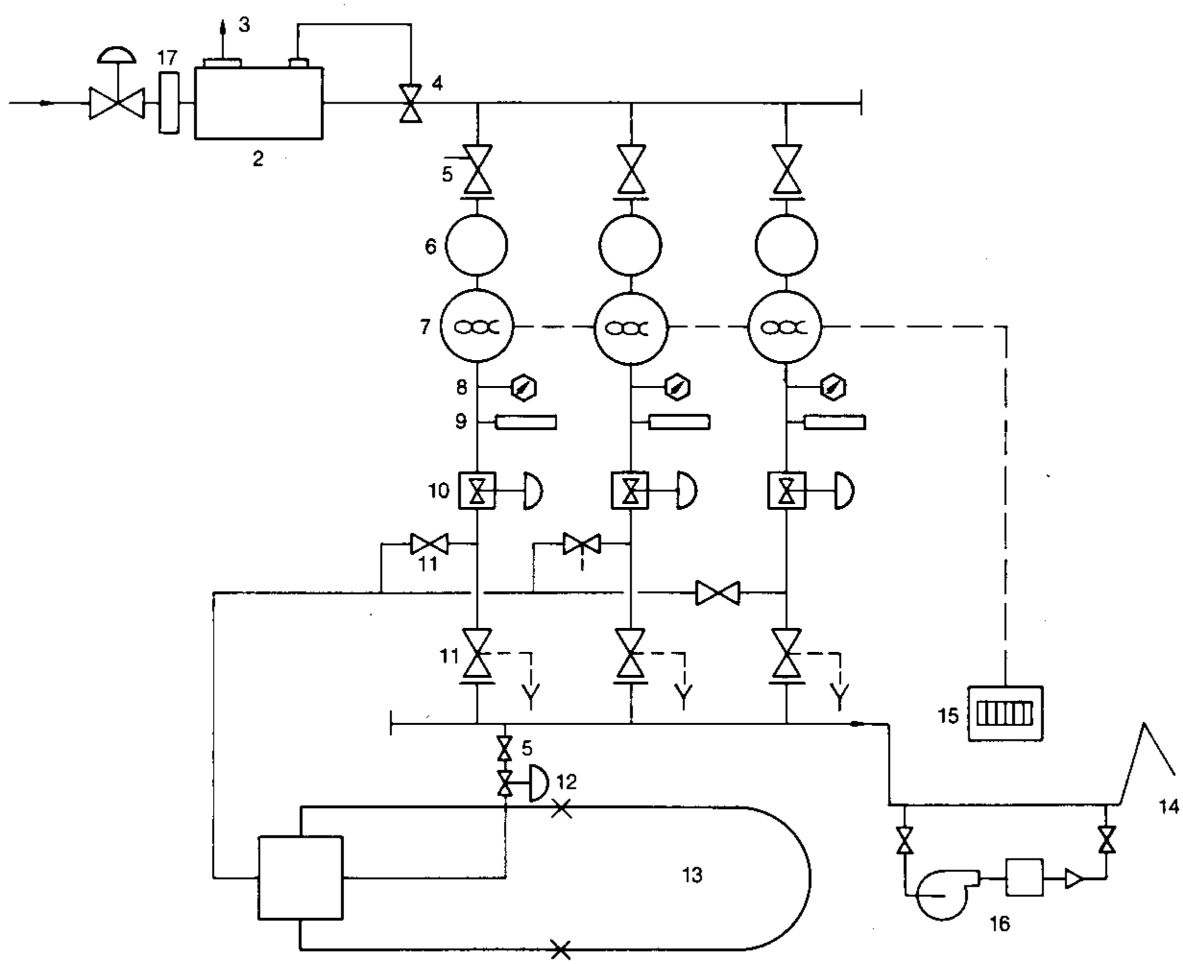
Measurement of crude oil by metering instead of gaging of vessel storage tanks is preferable for a number of reasons:

1. It is considerably more accurate. Metering can be accurate to 0.2% or better on an overall basis. It is traceable to measurement standards. Vessel tank gaging is considerably less accurate (see References 1, 2, and 3). Tank gaging on a vessel is complicated by irregular shaped tanks, movement of the ship, possible inclement weather contributing to operator error, etc.

2. It is more convenient for the operator.
3. Results are completely auditable and traceable to standards. With modern automation equipment recording is automatic.
4. A high degree of security and integrity can be built into the system if required.
5. Readout of final corrected data is available immediately upon completion of loading. This saves ship demurrage costs.

Operation of the system should be somewhat intuitive, because it is not done everyday. Today's microprocessor control systems, with color graphic CRT terminals, are ideal for this application.

Automation of the function required for metering is important from the standpoint of reducing manpower required for the loading operation, and the necessity for operating personnel to physically be on the metering skid. For this reason, the following operations should be automated: valve control, sampling, proving and readout of temperature, pressure, and gravity.



1. Pressure Reducing Valve
2. Air/Gas Separator
3. Air/Gas Release
4. Throttle Valve, Air/Gas Sensed
5. Isolation Valve
6. Strainer
7. Meter
8. Pressure Gage and Transmitter
9. Thermometer and RTD
10. Flow Control Valve
11. Block and Bleed Valve
12. Back Pressure Valve
13. Prover
14. Loading Arm
15. Remote Meter Readout
16. Sampler (Automatic) with Circulating Pump
17. Basic Sediment & Water Monitor

Figure 1 — Schematic Arrangement of a Loading Marine Bulk Carrier Meter Station With Three Meters and a Prover

Equipment Description

Basic equipment requirements for FPSO metering systems is similar to that required for other high flow rate vessel loading or unloading systems; however, consideration must be made for the specific application.

Figure 1 shows a typical schematic arrangement of a metering system, sampler, prover, and loading arm. Various loading arm arrangements are used depending on the mooring configuration and the FPSO mooring.

Note that virtually all of the components described interact with each other to a high degree. The components must be selected for functionality in themselves, and compatibility with one another. It is necessary that the entire system be integrated by a multi-disciplined project engineering team. Delineation of all applicable specifications prior to start of design is essential.

Major Design Considerations

Flow Rate

System flow rate is determined by storage batch size and desired off-loading time. For example, if one million barrels of oil is to be off-loaded in 20 hours, a system flow rate of 50,000 BPH is required. Obviously the higher the flow rate, the more costly the system will be.

Pumping Arrangement and Pressure Drop

Installing a flow measurement system in an off-loading line adds pressure drop. Coordination of loading pump design with meter system design is essential as certain tradeoffs are possible. In general, lower pressure drop meter skids are more costly; but this cost is typically recovered by the use of smaller loading pumps and less pumping energy. If possible, the system should be 150 ANSI pressure rating. Variable speed pumps and skid inlet pressure controls are preferable.

Multiple Meter Arrangement

Virtually all high capacity meter systems have multiple meter runs. These are desirable to achieve flow rangeability, maintenance flexibility, and to keep the meter prover to a reasonable size. Multiple meters are particularly needed for unloading tanker compartments, where tank stripping is done at a much lower flow rate than full flow unloading. The meters used during stripping are usually smaller in size than the main meters.

Water Elimination Equipment and Sampling

Accurate oil measurement cannot be accomplished when large amounts of BS&W are present in the flowing stream. Water separation and sensing equipment may be necessary upstream of the metering station to limit BS&W into the meters. Most of the sensing devices available are adequate to provide a high BS&W alarm and/or shutdown or a diversion of flow back to water elimination equipment; but they are not sufficiently accurate to provide on line correction of precisely measured volumes. This is best accomplished by use of a properly designed sampling system (Reference API Manual of Petroleum Measurement Standards, Chapter 8, Section 2) and laboratory analysis of the samples for percentage of water using methods described in API Manual of Petroleum Measurement Standards, Chapter 10, Sections 1 through 4.

Air Elimination Equipment

For proper measurement, air and/or gas must be eliminated from the flow stream ahead of the meter. This is normally accomplished by air eliminators installed ahead of the meter runs. These are essential for most unloading systems. Air elimination may be done on the common inlet header or on each meter run. Air release heads on the strainers are useful to help remove air trapped after strainer or meter run servicing.

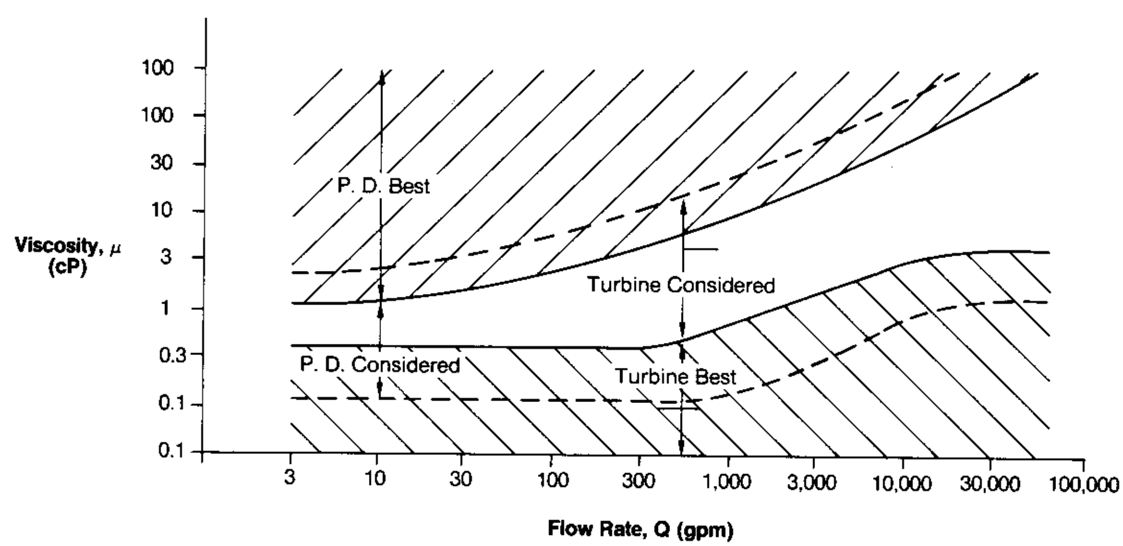


Figure 2 — P.D. and Turbine Meter Selection Guide

Systems Location

In order to meet the majority of the ship certification codes, FPSO measurement systems must be located on a platform approximately 10 feet above the ship deck. If this is not part of the original measurement system planning, it can result in costs which were originally not anticipated. To keep the cost of the structure down, the measuring system should be made as compact as possible, and the structure should be an integral part of the metering system design.

Selection of Meter Type and Size

Criteria for selection of positive displacement meters versus turbine meters is identical to that required for most other applications. Properties of the fluid must be known. If the fluid is sour, special materials may be required. If fluid properties are not completely known (this will be quite normal), a positive displacement metering system will usually be the best choice.

This is thoroughly discussed in Reference 4. Figure 2 from Reference 4 presents basic selection data. Positive displacement meters for this application have two additional advantages over turbine meters: (1) they take up less space and (2) they are not subject to the unknown effects of sea motion on turbine meters and the swirl of the approaching fluid stream.

Meter size is determined by taking the total flow rate desired and dividing by a number from 3 to 5. Where space is a major consideration, normally a larger number of smaller meters is desirable because the prover size is considerably smaller. This is particularly true if a small volume prover is used.

Selection of Prover Type and Size

Historically, folded bi-directional provers have been used on FPSO systems. However, many times system size influences overall system cost, as mentioned in the Multiple Meter Arrangement and Selection of Meter

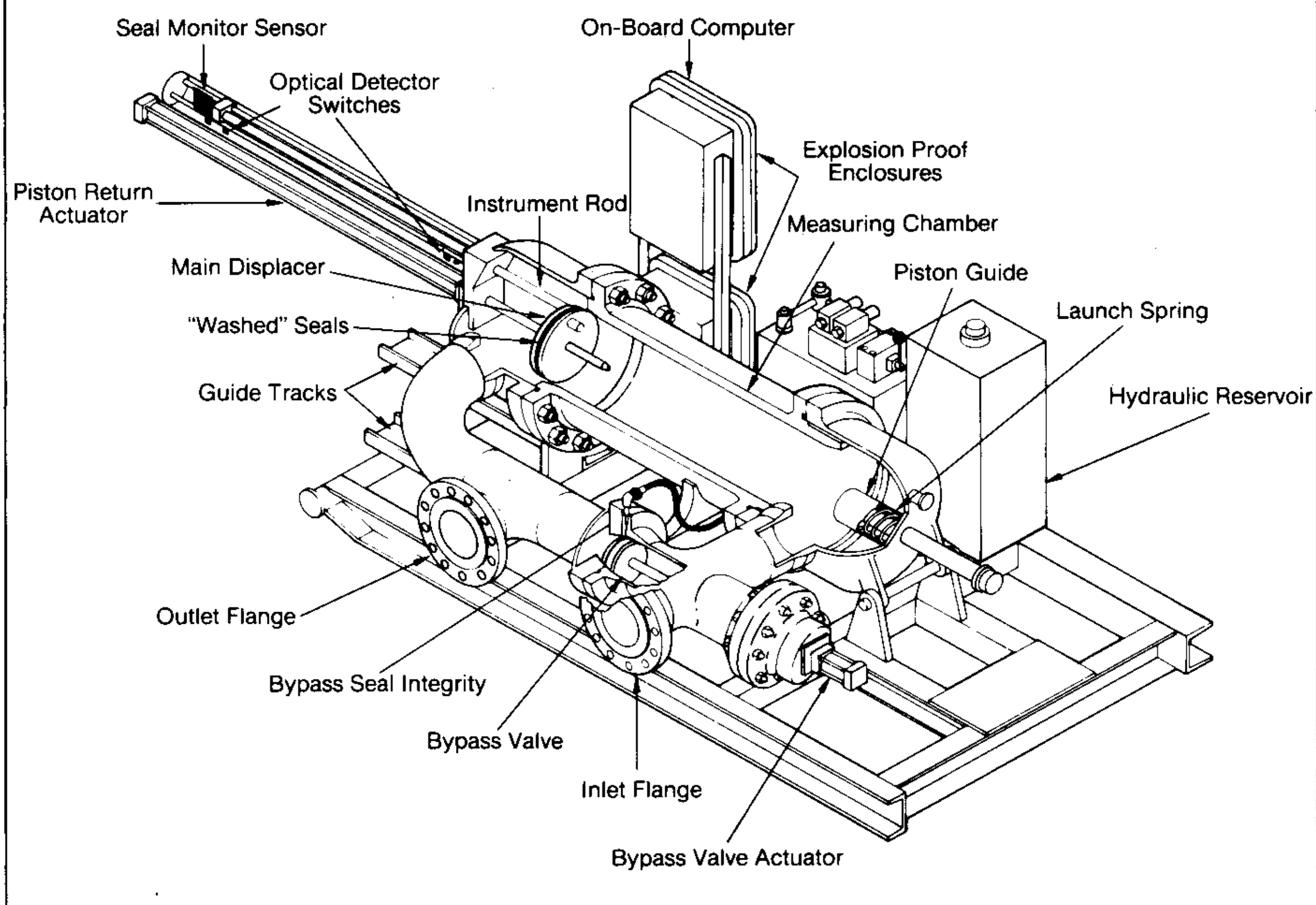


Figure 3 — Small Volume Prover

Type and Size sections. When this is a factor, a small volume prover should be considered. Figure 3 shows a typical small volume prover. Figure 4 shows a system with a bi-directional prover.

Electrical Code Considerations

Often the electrical codes applicable to systems covered by the scope of this paper do not allow any high voltage electrical power on the measurement skid. When this is the case, valve actuators, pumps, etc., must be operated pneumatically or hydraulically with intrinsically safe and/or low voltage explosion proof signals and controls. This normally adds to the complexity and cost of the system. It is important that this restriction be known at the outset, as actuator type can strongly influence valve type selection.

In addition, marine construction codes may specify particular wiring materials, cables, conduits, etc. It is important that these applicable codes also be part of the initial system specifications. Junction boxes, instrument enclosures, and wiring devices must be watertight, corrosion resistant, and explosion proof to withstand the severe shipboard environment.

Flow Control and/or Back Pressure Control

Flow control, using a butterfly or ball type control valve on each meter run and prover, is essential for FPSO systems. These valves allow for establishing meter factors at fixed flow rates. In the case of turbine meter systems, they also provide the 20 to 30 PSI back pressure required for accurate measurement. The prover outlet flow control valve assures that the prover is always packed. Flow control valves also prevent over speeding of the meters.

Block Valves

Valves upstream of the meters and strainers are required for shutdown for maintenance. They need not be bubbletight shutoff, and motor operators may not be required. The two downstream valves must be high integrity double block and bleed valves, as they influence the integrity of the meter factor obtained during proving. In order to perform automatic proving, they must be motor operated.

Instrumentation

Shipboard control room equipment, while normally protected from the harsh marine atmosphere by an environmentally controlled control room, can be expected to be subjected to loss of power and environmental control. For this reason equipment should be tropicalized and have backup power supply capability.

The specifying engineer needs to make basic system decisions regarding degree of operator convenience, degree of redundancy or backup, and data recording

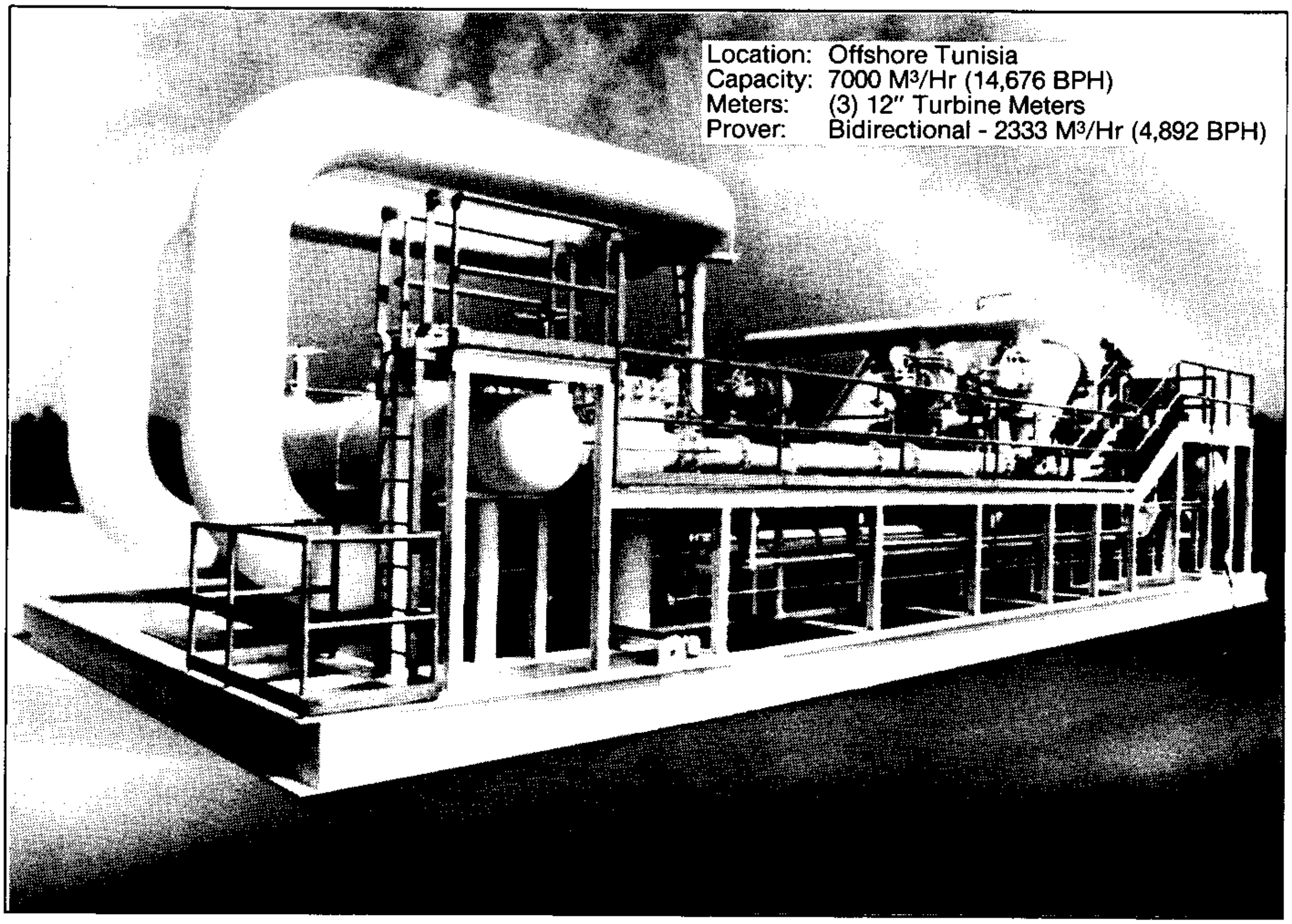


Figure 4 — Typical FPSO Metering Skid

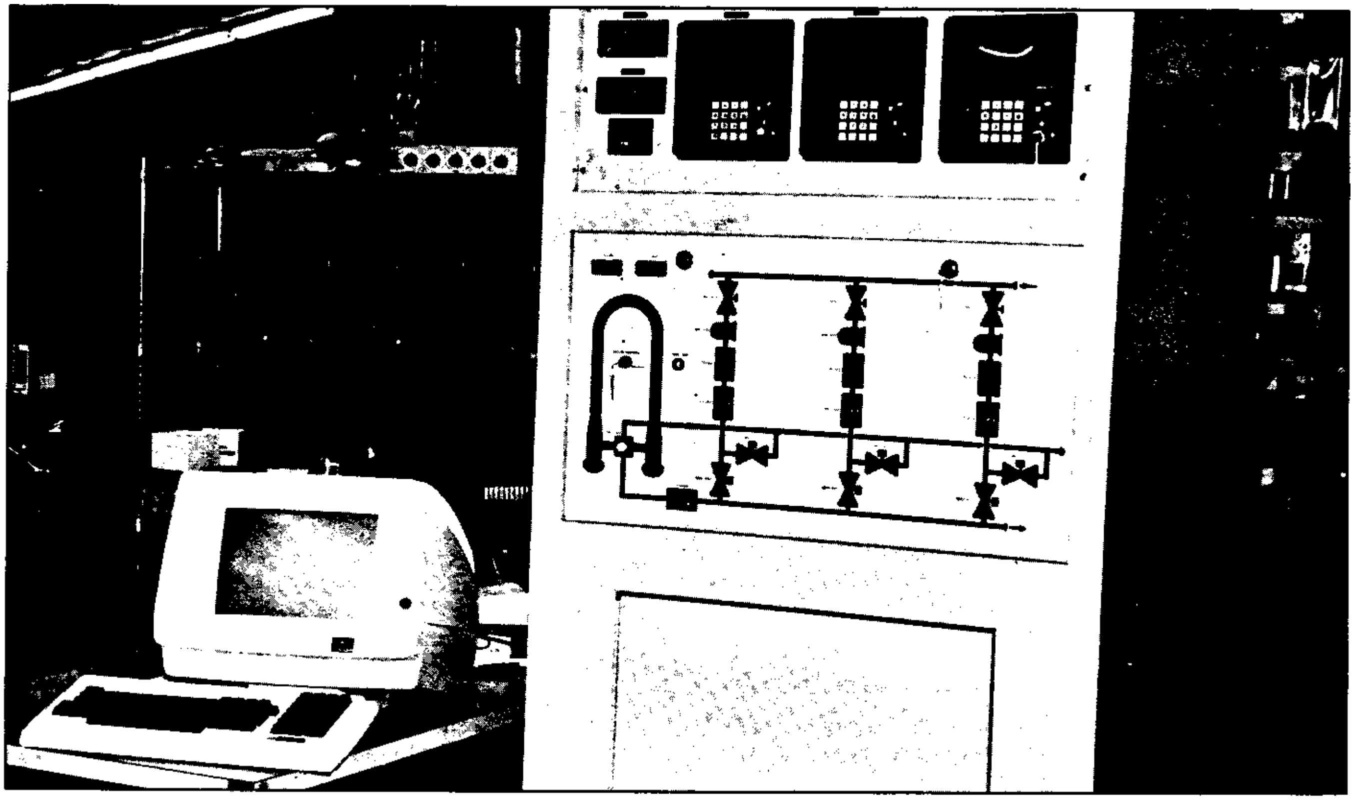
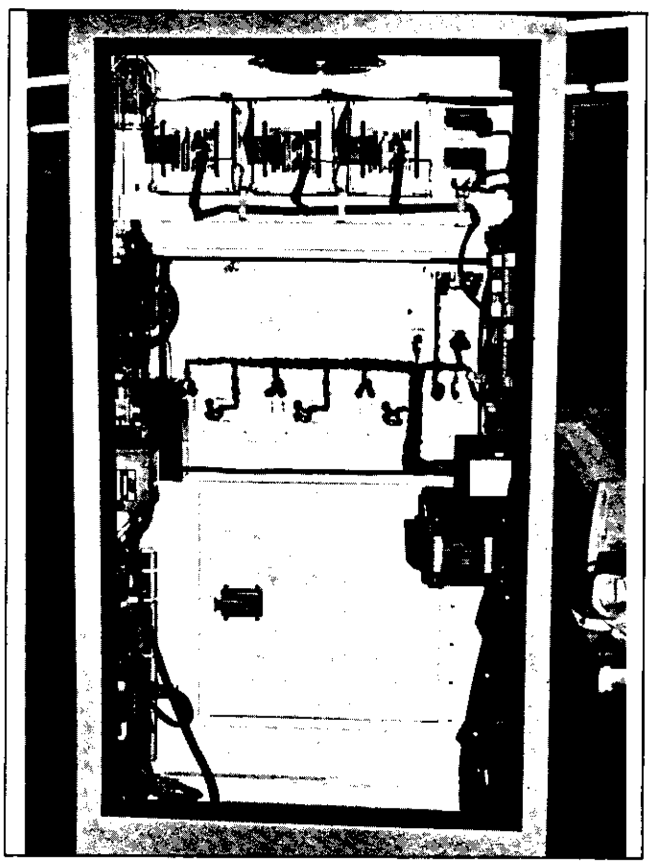
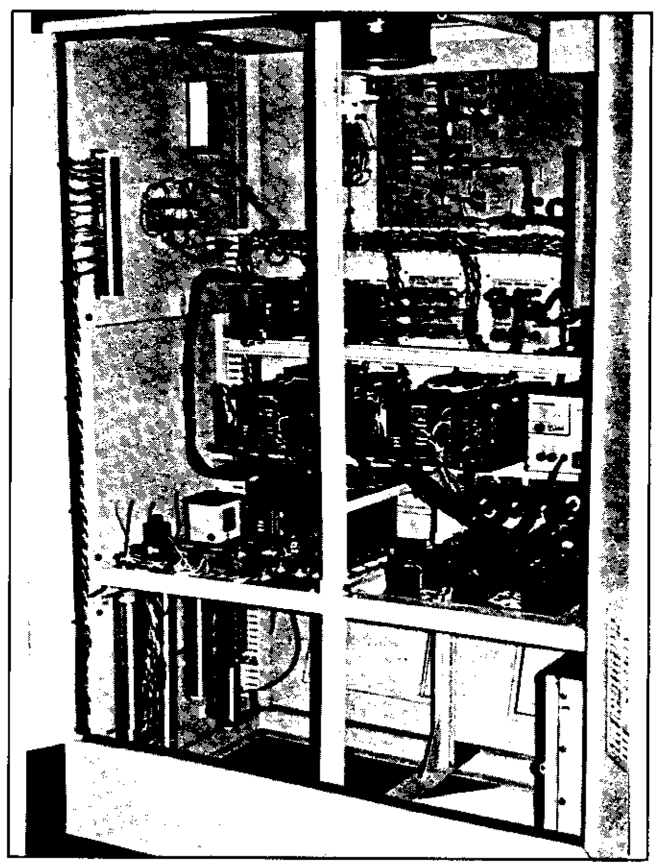


Figure 5 — Typical Microprocessor Console With Color Graphic CRT Control



Microprocessor Instrument Console Interior View
(Note Compactness of Installation)



Non-Microprocessor Instrument Console

Figure 6 — Console Comparison

requirements. Sophisticated microprocessor instrumentation systems available today offer the advantage of full automation, full back-up, ultra low power consumption, small size and high value compared to older style discrete instrumentation systems. This is ideally suited to the FPSO environment. Figure 5 shows the control console for a three meter run system. Figure 6 shows a comparison of the inside rear of a previous generation panel with a new generation instrumentation console. Note the simplicity of wiring and access space in the newer generation console.

In order to achieve optimum measurement accuracy, precise temperature, gravity, and pressure signals must be sent from the meters and prover to the control room. These signals must be isolated from power and control lines by separate junction boxes and conduit or cable systems.

Conclusion

Precise measurement of crude oil from early production floating vessels to ocean going crude carriers is technically and economically feasible using properly designed metering and loading systems. Effective and efficient design and fabrication of this equipment is dependent on knowing all of the applicable code and standard requirements up front. Also, the fluid properties and volumes to be transferred must be known. Modern instrumentation provides operator ease and convenience. Printed reports of throughput, with traceability to measurement standards, are available from the equipment.

References

1. "Calibration of Tanks on Tankers and Oil Barges" by R. Carter Norrell - Marine Technology, Vol. 21, No. 2, April 1984.
2. "Accuracy of Metering Versus Tank Gauging of Vessel Delivered Petroleum Liquids" by P. E. Swanson - Smith Meter Technical Paper 107.
3. "An Assessment of Shipboard Tank Level Indicating Systems" by James E. Johnson, A. C. Rogers, and Robert L. Bass - Marine Technology, Vol. 21, No. 3, July 1984.
4. "Improving Petroleum Custody Transfer Measurement Accuracy" by P. D. Baker, The Fifth API Petroleum Measurement Seminar, Tulsa, Oklahoma, March 10, 1985.

Acknowledgement

The author wishes to thank Mr. Richard Keating of Smith Sytems Operation of Smith Meter Inc., A Moorco Company for permission to prepare and present the above paper.

This paper was prepared for and presented at the 41st Petroleum Mechanical Engineering Workshop and Conference on Facilities, Pipelines, and Measurement sponsored by The Petroleum Division of The American Society of Mechanical Engineers. The Workshop and Conference was held in Kansas City, Missouri, USA on September 15, 16, and 17, 1985.

Headquarters:
6677 North Gessner Road, Suite 315, Houston, TX 77040 USA, Phone: 713/510-6970, Fax: 713/510-6972

Locations:
Erie, PA USA Phone 814/898-5000, Fax 814/899-8927
Corpus Christi, TX USA Phone 361/289-3400, Fax 361/289-1115
Stephenville, TX USA Phone 254/968-2181, Fax 254/977-1627
Longmont, CO USA Phone 303/702-7400, Fax 303/702-1608
Los Angeles, CA USA Phone 661/296-7711, Fax 661/296-5166
Eunice, LA USA Phone 337/550-7133, Fax 337/550-7134
Thetford, England Phone (44) 1842-82-2900, Fax (44) 1842-76-5402
Slough, England Phone (44) 1753-57-1515, Fax (44) 1753-52-9966
Ellerbek, Germany Phone (49) 4101-3040, Fax (49) 4101-304133
Kongsberg, Norway Phone (47) 32/286-700, Fax (47) 32/289-590
Barcelona, Spain Phone (34) 93/201-0989, Fax (34) 93/201-0576
Moscow, Russia Phone (7) 095/564-8705, Fax (7) 095/926-5066
Singapore Phone (65) 869-0605, Fax (65) 861-2401
Beijing, China Phone (86) 10/6500-2251, Fax (86) 10/6512-6857
Chennai, India Phone (91) 44/496-0455, Fax (91) 44/496-0114
San Juan, Puerto Rico Phone 787/274-3760, Fax 787/274-1020

Visit our website at www.smithmeter.com