**MARINE CRUDE OIL MEASUREMENT SYSTEMS**
Class # 2240

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**Abstract**

The accurate determination of quantity and quality of crude oil or refined products transferred from shore to tanker; or tanker to shore, or FPSO or FSO to transport tanker is the function of Marine Crude Oil Terminal Measuring Systems. From the measurement data, a Bill of Lading can be prepared and transport costs, taxes, royalties, and customs fees can be computed. Low uncertainty of measurement is essential as each tanker load represents a value of 80 to 100 million dollars. Even errors of ± 0.1% represent a significant amount of revenue. In addition to low uncertainty, meter systems offer several other advantages over older more traditional tank gauging methods. Compared to pipeline measurement, these systems tend to be much larger; as high intermittent flow rates are required to keep ship loading times reasonable. Specification guidelines for meter systems and associated equipment are presented in this paper.

**Introduction**

Marine Crude Oil Measuring Systems are necessitated by agreements between petroleum buyers, sellers, and transporters along with customs and/or governmental authorities. The agreements outline how the fluid is to be measured and how the results of measurement will be traceable to recognized standards. Most Marine Tanker loading terminals are supplied by shore based tanks. Usually three measurement figures are compared, in order for the final volume to be certified: shore tank quantities, the metered quantities, and the ship captain's quantities. Normally meter quantities are an order of magnitude more accurate, on an overall basis, than tank gauging quantities. Proper determination of the quality of the crude oil, through accurate sampling and analysis for BS&W, is also required. In addition to meeting the requirements for measurement, systems must meet numerous safety and construction codes and standards as the fluids are hazardous. Operation of the measurement station must be relatively simple; and a user friendly operator interface is highly desirable. The task of the system designer is to transform these requirements into engineering specifications, drawings, and bills of materials for procurement, manufacture, test, and delivery to the end user of a cadre of components specifically selected and assembled to work together to meet the requirements of the measurement agreement and applicable codes.

**System Considerations**

High performance marine crude oil terminal measuring systems offer state of the art solutions to high accuracy liquid measurement requirements; however, for achievement of ultimate performance, it is important that the primary measurement elements be surrounded by carefully selected ancillary components and all items be integrated into an accurate well designed, easy to operate system. This necessitates a systems approach to the procurement of meter stations, usually with a turn key contract to an experienced component and system supplier. Overall accuracy on the order of ± 0.25% or better is achievable with properly designed systems and under some circumstances the accuracy may approach ± 0.1%.

**System Economic Justification**

Measurement system initial purchase and operation costs may be somewhat more than that for tank gauging equipment, however if decreased uncertainty of 0.5% (0.7%- 0.2%) is achieved compared to tank gauging, for oil that is $100/bbl; a potential savings of $0.50 per barrel is achieved or $500,000.00 per million barrel tanker loaded. Keep in mind that if the difference is in the favor of the buyer, the seller is depriving himself of deserved revenue. If the difference is in the favor of the seller, he may be opening himself up to potential lawsuits and retroactive charges. For this reason the truth in measurement with traceability to a world recognized standard is being sought. In addition, with metering "live" tanks can be used with potential capital savings for 50% fewer tanks. Live tanks allow flow into them and out of them at the same time, which is not possible with tank gauging systems.

## Fluid Properties

In order to optimize the system cost and performance, and avoid changes as the system is designed, it is desirable to have complete fluid and system environmental information (reference Table 1) at the outset. At times, it is impossible for the user to define all of the parameters. If reasons why a particular parameter are not available or definable to the designer, he can allow flexibility in certain component choices. For example; if viscosity is unknown, a meter with a wide viscosity range can be selected. It is also important that the station designer be fully informed of the system configuration upstream and downstream of the measurement station. Pressure drop and flow control requirements must be fully understood for properly designing a system and it's associated operational and control hardware and software. Note that for export terminals the properties of crude oil to be measured is usually known, as they are tied to specific producing fields. For import terminals more flexibility is required as ships could arrive for offloading crude from virtually any field in the world.

**TABLE 1**

Typical System Data

Requirements
Project Name:______________________Location:________________
Site Conditions:__________________________________________

| | Maximum | Normal | Minimum |
|---|---|---|---|
| Ambient Temperature: | | | |
| Relative Humidity: | | | |
| Precipitation: | | | |
| Air Quality: | | | |
| Wind: | | | |
| Elevation: | | | |
| Solar Radiation: | | | |

Product Data Product Name:______________________________________

| | Maximum | Normal | Minimum |
|---|---|---|---|
| Flow Rate Per Meter: | | | |
| Flow Rate For System: | | | |
| Pressure: | | | |
| Temperature: | | | |
| Specific Gravity: | | | |
| Viscosity: | | | |
| Pour Point: | | | |
| Reid Vapor Pressure: | | | |
| $H^2$s Content: | | | |

Applicable Codes:
ANSI Class : ____________________________________
Piping Code: ____________________________________

Electrical Area Classification____________________________________

Electrical Voltages Available:
Skid Power ______Vac @______ Hz.
Console Power ______Vac @______ Hz.

Approvals Required:
Weights And Measures ________________________________
Electrical Safety ___________________________________
Ship Certifications (If Applic.) _______________________

## Environmental Considerations

Since the measurement stations are subjected to marine environments, equipment must be selected with this in mind as well as any extremes of ambient temperature that will be encountered. In earthquake prone areas seismic effects must be considered. Space available for the system, which is usually installed on a jetty or offshore platform, is a primary consideration, as platform cost per square foot of deck is very high. Shipping size and weight limitations must also be incorporated into the system design.

## Codes and Standards

Selection of appropriate and applicable standards and codes is essential in order that the system be accurate, safe, convenient to operate and maintain, and reliable. The standards most often used are listed by category in Table 2.

**TABLE 2**

**DESIGN CODE SPECIFICATIONS**

I. General design standards-measurement accuracy requirements

- API-Manual of petroleum measurement standards

  Chapter 4 – Proving Systems

  Chapter 5 – Section 2 – Displacement Meters

  Chapter 5 – Section 3 – Turbine Meters

  Chapter 5 – Section 4 – Instrumentation or Accessory Equipment

  Chapter 5- Section 8- Ultrasonic Meters

  Chapter 6 – Section 5 – Metering Systems for Loading and Unloading Marine Bulk Carriers

  Chapter 12 – Calculation of Petroleum Quantities

  Chapter 21- Flow Measurement Using Electronic Metering Systems

- Requirements of national and local customs, weights and measures, and government authorities.

II. Pressure retention safety and construction codes

- ANSI / ASME B31.3 Chemical Plant and Petroleum Refinery Piping
- ANSI / ASME B31.4 Liquid Petroleum Transportation Piping Systems
- ASTM material specifications
- ASME boiler and pressure vessel codes
- NACE – National Association of Corrosion Engineers specifications

III. Electrical safety codes

- National Electric Code – NFPA – 70
- Electrical codes of ship certification agents (if shipboard equipment)
- Local or regional electrical codes

IV. Structural codes

- AWS D1.1 – Structural Welding Code
- AISC – Steel Construction Code
- Structural codes of ship or offshore platform certification agents (if shipboard equipment)

## System Pressure Rating

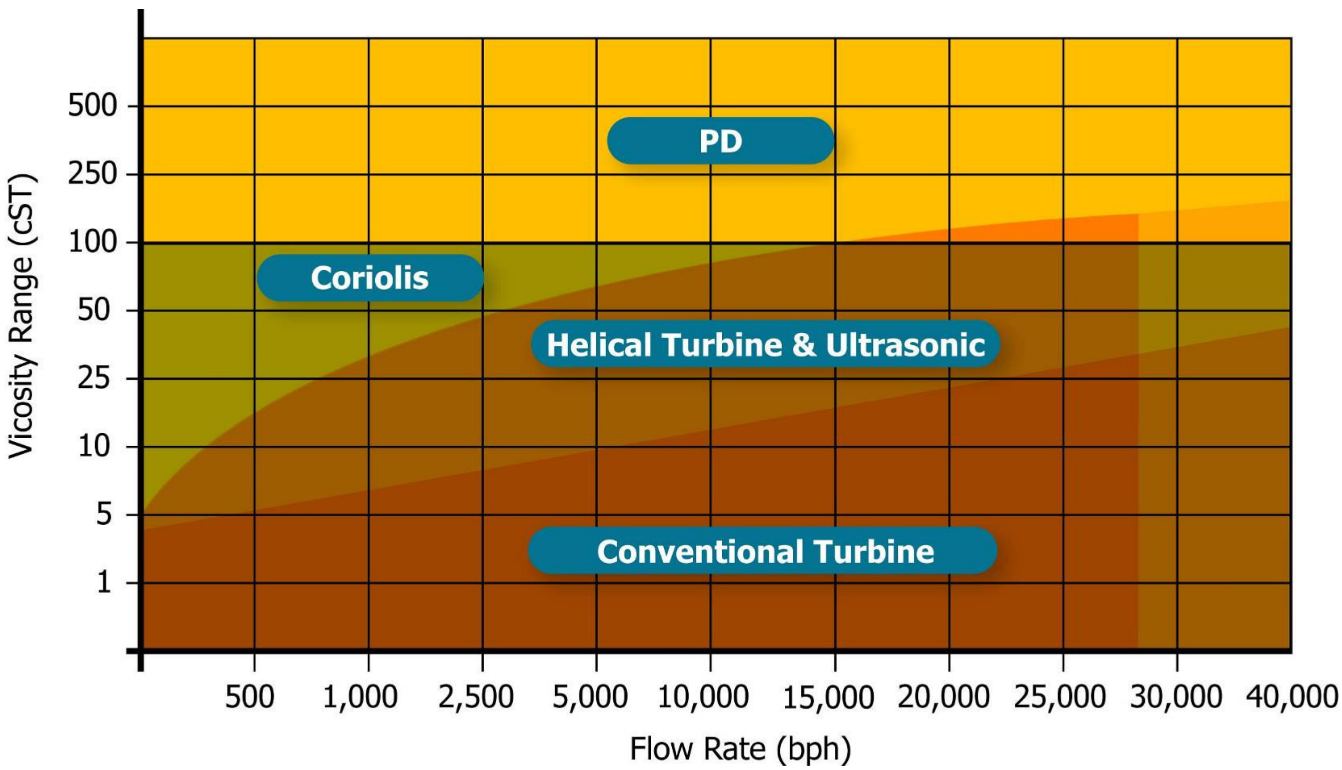
It is usually desirable from an overall economics stand point to design the pressure rating of the measurement system as low as possible, usually 150 ANSI. This necessitates surge relief and pressure reduction equipment upstream of the meter equipment. This equipment is required also for protection of the tanker piping and equipment for the loading systems.

## Meter Selection

Selection of meters is primarily influenced by flow rate, rangeability or turn down, fluid viscosity, pressure drop, wax content, and corrosive properties of the fluid stream. For multi-fluid streams, the worst case fluid must be considered. We now have four technologies to choose from; Positive Displacement, Conventional Turbine, Helical Turbine and Ultrasonic. Coriolis meters are not normally used in these applications. Each technology has it advantages and disadvantages for an application and they must be carefully considered. For more information on this subject refer to Figure 1 and also References 1 and 2. One important item to note is that most meter capacity ratings vary with density and viscosity of the fluids to be measured.

**FIGURE 1**

**FLOW RATE/VISCOSITY REGIMES FOR METER APPLICATIONS**




In the case of tanker loading and/or unloading facility design, the station flow rate is determined by tanker capacity divided by desired maximum loading time. For very large tankers load times of 20 hours maximum are often used. This would result in a 50,000 BBL/HR system flow rate for loading a 1,000,000 BBL Tanker in 20 hours. These are high intermittent flow applications. Most ships need to be in port for a maximum of 30 hours; after that demurrage fees would apply.

The size and quantity of meters for a particular station is determined by a balance between rangeability, prover economics, maintainability, and overall system economics. For additional details see Reference 3. A single large meter requires a large prover, results in limited rangeability, and would require complete shutdown of the station if any critical component in the meter run malfunctions. A large number of smaller meters would result in a much smaller prover, wide rangeability, and standby capacity in the event of a malfunctioning component. However a station with too many small meters has a large number of valves, and the cost of instrumentation, which is fixed per meter run, becomes very high.

Most system designers recommend a design with a complete spare meter run. This allows a great deal of flexibility in that full system capacity is not compromised should one meter or critical component in a meter run become inoperable. It also allows a method of increasing total station flow rate either temporarily or permanently and allows use of all runs at a rate below their maximum which results in lower pressure drops and longer meter life.

As a result of the above, the normal multi-meter run station usually has a minimum of two meter runs and a maximum of 5 or 6 meter runs. The exact number is usually determined based on dividing the total station flow rate desired by a number from 2 to 6 until the rate per meter run is close to the maximum rate of a standard size meter as obtained from a typical manufacturers meter size vs. capacity chart (reference Tables 3, 4 & 5). Note that typically these charts cover a certain density and viscosity range and they may need to be corrected before the meter size is selected. Selection of meter type, size, and quantity is usually the first and most important step of station design.

**Table 3 Turbine Meter Size vs. Capacity**

**SENTRY SERIES***

| Size Inches (mm) | Max. Flow Rate BPH ($m^3/h$) |
|---|---|
| 4 (100) | 1,500 (240) |
| LF6 | 2,500 (400) |
| 6 (150) | 4,000 (635) |
| 8 (200) | 7,500 (1,195) |
| 10 (250) | 12,000 (1,910) |
| 12 (300) | 18,000 (2,860) |
| 16 (400) | 27,000 (4,295) |
| 18 (450) | 35,000 (5,565) |
| 20 (500) | 42,000 (6,680) |

* Available with Class 150, 300, 600 and 900 ANSI flanges.

**MV SERIES TURBINE METERS***

| Size Inches (mm) | Flow Range+ BPH ($m^3/h$) | Flange to Flange Inches (mm) |
|---|---|---|
| 3 (75) | 90-900 (14-140) | 10.0 (254) |
| 4 (100) | 190-1,900 (30-300) | 12.0 (305) |
| 6 (150) | 400-4,000 (64-640) | 14.0 (356) |
| 8 (200) | 750-7,500 (119-1,190) | 16.0 (406) |
| 10 (250) | 1,250-12,500 (199-1,990) | 20.0 (508) |
| 12 (300) | 1,900-19,000 (302-3,020) | 24.0 (610) |
| 16 (400) | 2,700-27,000 (429-4,290) | 32.0 (813) |

* Available with Class 150 and 300 ANSI flanges. Other types of end connection and flange ratings are available.
+ Minimum and maximum values indicated.

**Table 4 PD Meter Size vs. Capacity**

**DOUBLE CASE METERS**

| Model | Size Inches (mm) | Max. Flow Rate GPM++ (L/min)+ |
|---|---|---|
| C2 | 2 (50) | 150 (570) |
| E3 | 3 (75) | 500 (1,900) |
| E4 | 4 (100) | 600 (2,250) |
| F4 | 4 (100) | 725 (2,750) |
| G6 | 6 (150) | 1,200 (4,600) |
| | | BPH++ $m^3/h$++ |
| H8 | 8 (200) | 2,285 (365) |
| JA10 | 10 (250) | 3,500 (550) |
| JB10 | 10 (250) | 4,700 (740) |
| K12 | 12 (300) | 7,200 (1,140) |
| M16 | 16 (400) | 12,500 (2,000) |

+ Maximum flow rate on intermittent service.
++ Maximum flow rate on continuous service.

**Table 5 Ultrasonic Meter Size vs. Capacity**

**ULTRA SERIES MAXIMUM FLOW CHART**

| Size Inches (mm) | Max. Flow Rate BPH ($m^3/h$) |
|---|---|
| 6 (150) | 4,500 (720) |
| 8 (200) | 8,000 (1,270) |
| 10 (250) | 12,500 (1,990) |
| 12 (300) | 19,000 (3,020) |
| 16 (400) | 28,000 (4,450) |
| 20 (500) | 43,000 (6,835) |

**Flow Conditioners**

When turbine or ultrasonic meters are used, special upstream and downstream flow conditioners are usually required to prevent fluid swirl and non-uniform velocity profiles. Also bores of upstream and downstream sections must be properly aligned.

**Prover Sizing and Selection of Prover Type**

The next most important step is the selection of the prover. The prover is a device that enables, on line, absolute volumetric calibration of the meters; with traceability to national or world recognized volumetric standards. Provers are calibrated by a "Water Draw" procedure to establish base volume at a reference temperature and pressure, usually 60$^{o}$F and 0 PSIG using calibrated measures. They are then used, "on the fly" to calibrate the meters using the exact fluid being measured. For large high capacity systems each meter is proven at each flow rate at which it is used for each tender, batch or tanker load. These proving requirements are specified in the appropriate API Manual of Petroleum Measurement Standards.

Provers may be bi-directional, uni-directional, piston type, or small volume. Bi-directional provers are the most widely used and tend to be the best choice for most applications. For fluid temperatures below -20$^{o}$F a piston type prover is usually used. Where space is very limited and time to accomplish a series of proves is to be kept to a minimum; small volume provers may be used. Figure 2 shows a typical bi-directional prover.

Prover design, sizing and calibration are standardized by API. A prover is sized for a minimum number of pulses from the meter, normally 10,000 pulses. For more information on detailed prover design see References 4 and 5.

Normally the prover for a measurement station is designed for the maximum flow rate per meter run, thus 50,000 BPH station with four meter runs would have a 12,500 BPH prover. The maximum prover flow rate may or may not be the maximum capacity of the meter itself. For maximum system expansion capability it is usually recommended that the prover have the capacity to prove at the maximum meter rate.

**Block Valves**

Properly selected valves are of utmost importance for accurate proving. (Reference Typical System P&ID Figure 3). When the meter run to be proven is aligned with the prover, no fluid must be added or allowed to escape from between the meter inlet and the prover outlet. This can only be assured by using double block and bleed, high integrity valves in this portion of the system. In addition, since proving is done rather frequently, these valves must endure many open and close cycles with positive sealing after each closure. Some systems require devices to monitor the valve integrity automatically. Any drain or vent valves in this portion of the system must also have means of monitoring seal integrity.

Provers may be arranged upstream or downstream of the meters. When the prover is upstream, the high integrity valves must be upstream, when it is downstream, the high integrity valves are located downstream of the meters.

Other block valves are desirable for isolation of the meter run, however these are not required to be of high integrity design as they are normally left in the open position.

If a prover is shared with multiple outlet headers a block and bleed valve is required between the prover outlet and each header.

**Control Valves**

When multi-meter runs are used, flow control valves are required to balance flow among the parallel runs and control flow for proving. Due to the prover pressure drop being added to the meter run pressure drop when proving, the control valves in the meter runs not being proved must be pinched down to force the desired flow rate through the prover and meter being proved. In addition, if turbine meters are being used, downstream back pressure must be kept on the turbine meters for proper operation. Minimum back pressure is higher for liquids with higher vapor pressure. In order to accomplish the above, a combination back pressure and flow control system is commonly used.

It is important to note that the control valves mentioned above may also be used to drop excessive upstream pressure and control on and off for batching. If this added function is required of these valves, it must be known before they are selected, as valves with these added functions are normally more costly than those selected for merely balancing. Consideration must also be made of failure mode on loss of air or signal for the valves. Usually, failure in last position is most desirable.

**Figure 2 Bi-Directional Pipe Prover and P&ID for Prover**

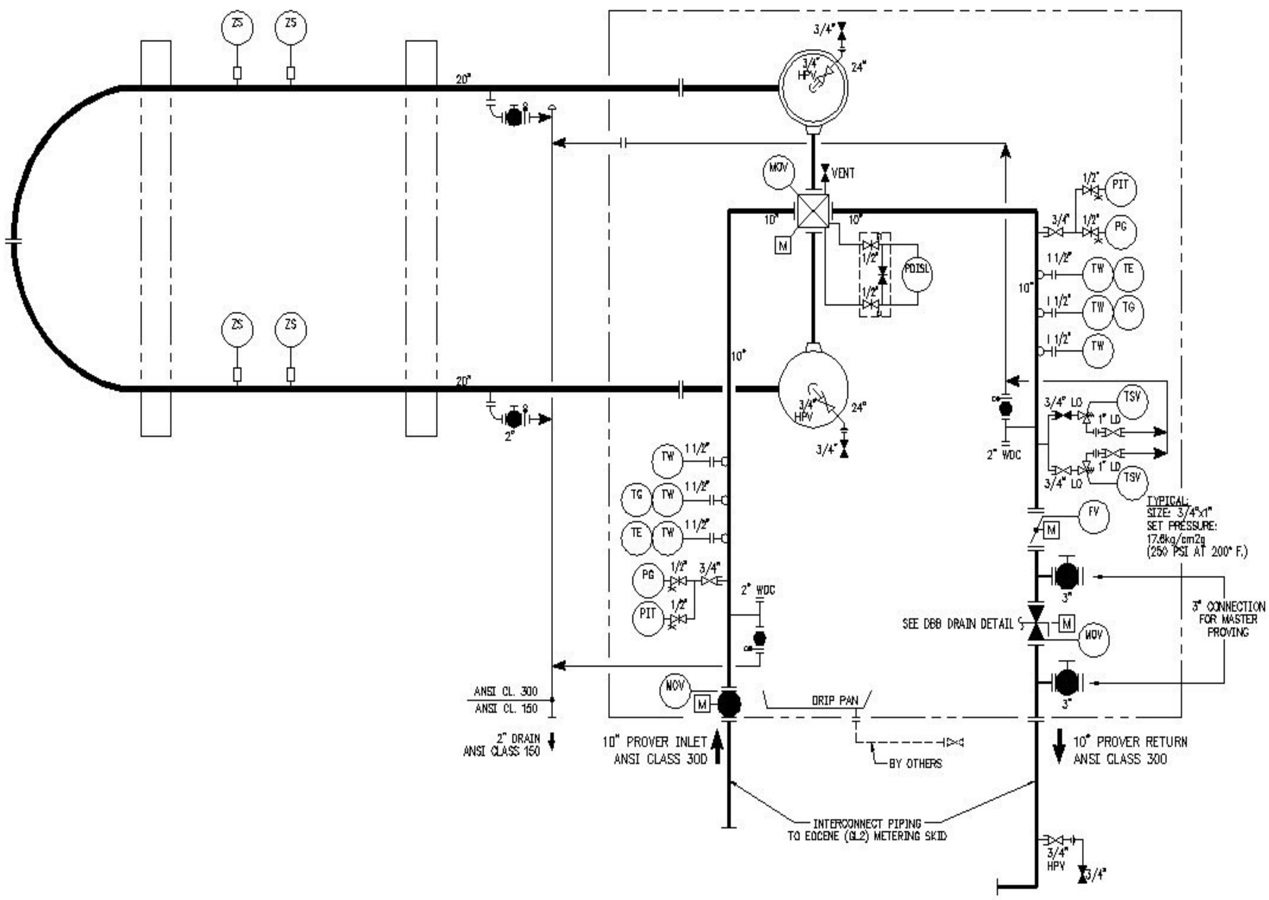
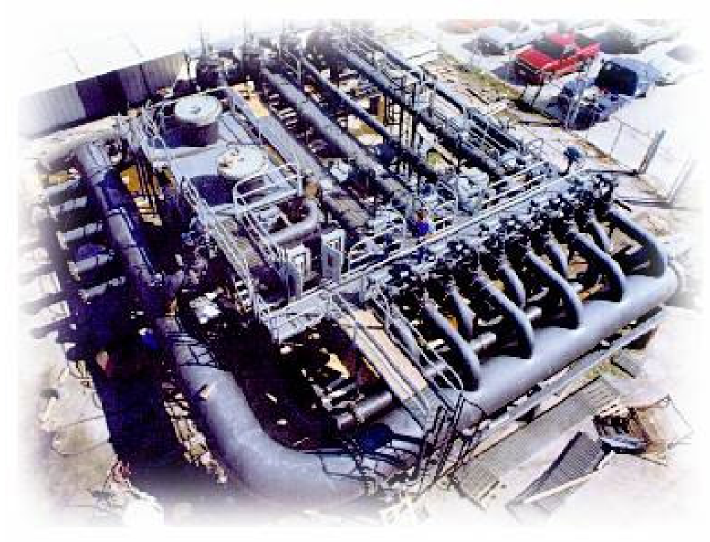
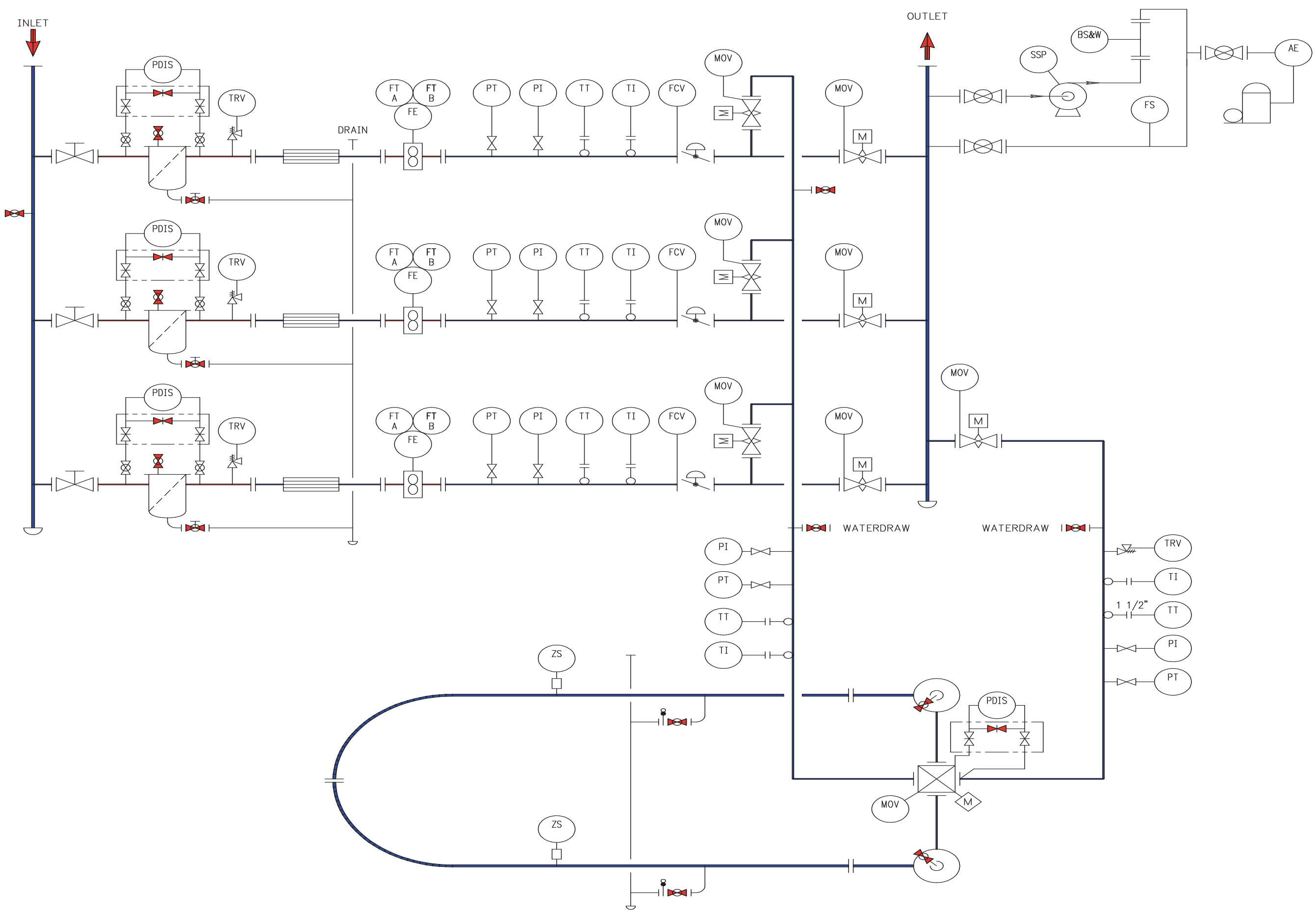


**Figure 3 Typical System and P&ID for System**






## Strainers

Meters -except for ultrasonic- and provers must be protected from harmful debris and particulate matter that may come from the inlet lines in the form of pipe rouge, loosened internal lining from pipe or storage tanks, “grass”, remains from construction, slag, weld rods, etc. This is normally done using large basket type strainers. Each is usually equipped with differential pressure switches and/or indicators to indicate a clogged condition. For use with turbine meter systems, special high capacity, low pressure drop designs are available. Monitoring of the strainer differential pressure at all times is important to prevent the baskets from rupturing and destroying the equipment they are meant to protect.

**Skid Instrumentation**

Meter skids can be operated completely locally using manual and/or motor operated valves, meter mounted registers, local prover counters, pressure indicators and temperature indicators; however because offshore facilities usually have limited manpower, most skids are equipped with the above mentioned items as back up for a remote control panel. In addition, skids are usually equipped with equipment for determination of fluid quality, i.e., gravity, BS%W content and viscosity. These instruments include sampling conditioning equipment such as mixers, samplers, densitometers, viscometers and BS&W measurement devices. For details on instrumentation consult Reference 6.

**Control Room Instrumentation**

Control room instrumentation varies widely from very rudimentary readout devices and control push buttons to completely automated systems. It is up to the system end user and operator to determine the degree of sophistication required and/or desired. Today's flow computers and supervisory computers offer touch screen graphic displays, personal computer based data collection, extensive reporting capabilities, condition base monitoring of field inputs, automated proving, meter factor analysis and operator ease. For more information see Reference 6. They offer extreme value due to ease of operation, redundancy, and field proven reliability.

Two operationally diverse systems are usually available. One is for batch type loading or unloading of vessels,or barges; in which case a target volume is preset and the system starts up each meter run in turn, brings all runs on line, proves them, delivers the prescribed quantity, and shuts itself off with "ramped down" flow rate control followed by printout of complete reports.

The other type of system is strictly a recorder of events and is primarily used for facilities where flow rate, start, and stop is controlled elsewhere. Periodic reports are logged out and meters are proved when predetermined parameter changes occur. It is necessary for the specifier and designer to choose an appropriate mode for each specific system.

Valve control and interlock both on and off the meter skid are often required as a part of the control system. This is done using compact programmable logic controllers. A typical system block diagram is shown in Figure 4.

Flow computations normally follow API Manual of Petroleum Measurement Standards Chapter 12 guidelines; however various petroleum companies and government weights and measures authorities have special provisions and or methods of doing certain portions of the calculation. The newest API tables are not universally used and many "new" systems still are contractually required to do calculations using older tables. These requirements must be known and defined prior to finalizing system software.

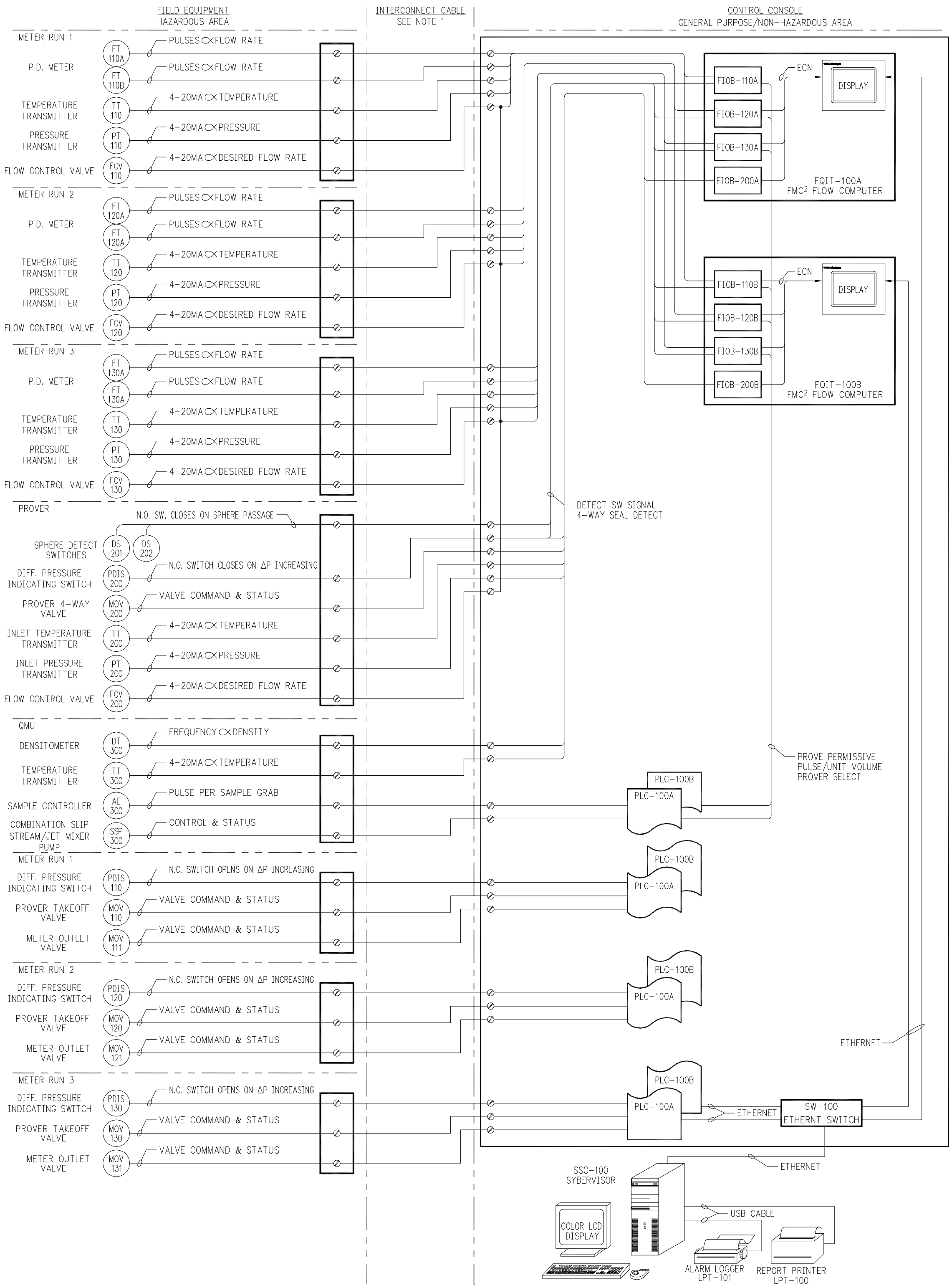
**System Data Concentration and Transmission**

Many measurement systems are tied via microwave or telephone lines to large accounting and/or master control computers. If this is required, the measurement flow supervisory computer then must also act as a data concentrator and communication device to the larger "host" computer. The protocol required for these two machines to talk (hardware, software, and power source) must be carefully defined so the systems can properly communicate.

**Conclusions**

Marine Crude Oil Terminal Liquid measurement station design involves a multi-disciplined engineering approach to proper selection of a large number of interacting components to achieve function, low uncertainty, dependability, ease of operation, reliability, safety, conformance to prescribed standards, and economy. Selection of a competent vendor experienced in all aspects of such systems is essential to achieve the end result on schedule and within budget. The vendor must be provided with complete information regarding system fluids and performance requirements prior to starting design in order to efficiently and effectively achieve the end result.

# Figure 4 Control System Block Diagram



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**References**

1. “Improving Petroleum Custody Transfer Measurement Accuracy” P. D. Baker – Smith Technical Paper 111 http://info.smithmeter.com/literature/docs/tp01001.pdf

2. “A Comparison of Liquid Petroleum Meters for Custody Transfer Measurement”- Smith Technical Paper 104 http://info.smithmeter.com/literature/docs/tp0a014.pdf

3. “High Capacity Liquid Measurement Systems”– Smith Technical Paper 102. http://info.smithmeter.com/literature/docs/tp0a011.pdf

4. “Liquid Flow Provers (Conventional) B.S. Ryan – Proceedings of the Seventy Fourth International School of Hydrocarbon Measurement – 1999 P. 471. http://info.smithmeter.com/literature/docs/liquid%20flow%20provers.pdf

5. “Liquid Meter Proving Techniques” P. P. Jakubenas- Proceedings of the Eighty Fourth International School of Hydrocarbon Measurement- 2009 P. 692

6. “ On Line Flow Computers for Custody Transfer” P. P. Jakubenas – Proceedings of the Eighty Sixth International School of Hydrocarbon Measurement- 2011