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Basics of Flow, Gas Metering and Control Systems for Custody Transfer Measurement

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Dan Hackett is Business Development Director – Ultrasonics for the Daniel Measurement & Control Division of Emerson Process Management based in Houston, Texas. Dan develops key business opportunities for Daniel's gas and liquid ultrasonic meter business and provides technical sales training to the Daniel sales channel as well as conducting measurement seminars throughout the world. He has extensive experience in custody transfer measurement of oil and gas.

Dan has authored numerous papers presented at various API, AGA, ISA and NEL conferences. He has participated on several committees and working groups of the API Committee on Petroleum Measurement, most recently Chapter 5.8 Measurement of Liquid Hydrocarbons by Ultrasonic Flow Meters. Dan is a member of the AGA Transmission Measurement Committee which is responsible for AGA 9 Measurement of Gas by Multipath Ultrasonic Meters. Dan is a 1980 graduate of Texas A&M University.

Overview of Flow Metering

Why the need to Meter Flow

Figure 1-2 Flow measurement has probably existed in some form since man started handling fluids.

- Over 4000 years ago, Romans measured water flow to household to control allocation.
- Early Chinese measured salt water flow to brine pots used to produce salt used as seasoning.
- Early practice in U.S. was to charge for natural gas on a per-light basis.

- The reason for fluid measurement - know how much fluid has flowed .
- The purpose is to determine billings for consumption based on flow.

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Overview of Flow Metering

Type of fluids

- Gas
  - Natural Gas, Produced Gas
  - Air
  - Industrial Gas (eg. Nitrogen, Oxygen, CO_2, etc.)
  - Produced Gas
- Liquid
  - Crude Oil, Condensate
  - Refined Hydrocarbons
  - LPG
  - Water
  - Aromatics, Olefins, Chemicals
- Steam

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Overview of Flow Metering

Custody and Non-Custody Transfer

Custody Transfer

Q = $

For custody transfer, flow measurement equals dollars

Measurement Contract Requirements for Custody Transfer

- **Quantity of Material**
- **Point of Delivery**
- **Material Properties**
- **Measurement Station Design**
- **Measurements**
- **Material Quality**
- **Billing**
- **Summary of Contract Requirements**

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Overview of Flow Metering

Other Factors in Custody Transfer
- Accuracy
- Uncertainty
- Maintenance of Meter Equipment
- Proving Meters, if required
- Operation Considerations
- Custody Transfer Auditing

Non-Custody Transfer Measurement
- Control Signal
- Check Metering
- Allocation
- Process Measurement

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Measurement Standards

Development of Flow Measurement Standards
- In 1797 Giovanni Venturi performed the first work using orifices in fluid flow measurement.
- 1890 Professor Robinson of Ohio State University designed the first orifice meter
- Between 1924 and 1935 research & experimental work was conducted by the American Gas Association (AGA) / American Society of Mechanical Engineers(ASME)
- AGA & ASME Developed Orifice Meter Coefficients & Standards
- In late 80's, API developed Measurement Manual, specifically to Petroleum products.
- Other organizations involved in writing standards :-
  - Gas Processors Association (GPA), Instrument Society of America (ISA), American National Standards (ANSI), American Society of Testing Materials (ASTM), Institute of Petroleum (IP), British Standards Institute (BSI), International Organization for Standardization (ISO), and International Organization for Legal Metrology (OIML).

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Measurement Standards

AGA (American Gas Association)

AGA Report No. 3 /API MPMS Ch. 14.3/GPA 8185/ANSI 2530
Natural Gas Measurement using Concentric, Square-Edged Orifice Meters

AGA Report No. 5
Fuel Gas Energy Metering

AGA Report No. 7
Measurement of Gas Turbine Meters

AGA Report No. 8/API MPMS Ch. 14.2
Compressibility Factors of Natural Gas and Other Related Hydrocarbon Gases

AGA Report No. 9
Measurement of Gas by Multipath Ultrasonic Meters

AGA Report No. 10
Speed of Sound in Natural Gas and Other Related Hydrocarbon Gases

AGA Report No. 11
Coriolis Flow Measurement for Natural Gas Applications

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Measurement Standards

ISO (International Organization for Standardization)

- ISO 12213-1:1997
  - Natural gas -- Calculation of compression factor -- Part 1: Introduction and guidelines
- ISO 12213-2:1997
  - Natural gas -- Calculation of compression factor -- Part 2: Calculation using molar-composition analysis
- ISO 12213-3:1997
  - Natural gas -- Calculation of compression factor -- Part 3: Calculation using physical properties
- ISO/DIS 17089:2010
  - Measurement of fluid flow in Closed Conduits - Methods using transit time ultrasonic flowmeters
- ISO/TR 12767:1998
  - Measurement of fluid flow by means of pressure-differential devices -- Guidelines to the effect of departure from the specifications and operating conditions given in ISO 5167-1

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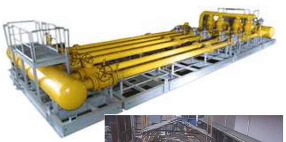
Measurement Standards

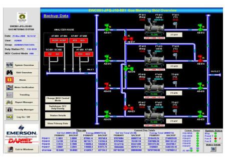
GPA (Gas Processors Association)

- GPA 2145-03
  - Physical Constants for Hydrocarbons & Other Compounds of Interest to the Natural Gas Industry
- GPA 2166-86
  - Obtaining Natural Gas Samples
- GPA 2172-96
  - Calculation of Gross Heating Value, Compressibility, and Relative Density
- GPA 2174-93
  - Obtaining Liquid Hydrocarbon Samples
- GPA 2177-03
  - Analysis of Natural Gas Liquid Mixtures Containing Nitrogen and Carbon Dioxide by Gas Chromatography
- GPA 2261
  - Analysis for Natural Gas & Similar Gaseous Mixtures by Gas Chromatography
- GPA 2265-68
  - Determination of Hydrogen Sulfide and Mercaptan in Natural Gas
- GPA 2286-95
  - Tentative Method of Extended Analysis of Natural Gas

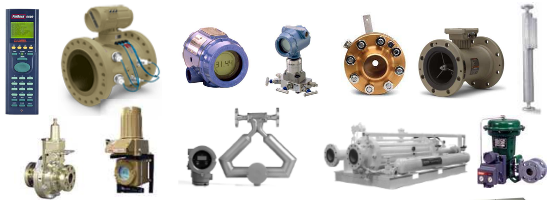
Systems Overview

- Equipment Supplied
  - Metering Systems – Liquid & Gas
  - Provers – Pipe and Compact
  - Quality Measurement Units
  - Control Panels - DanPac
  - Custom Operator Interface



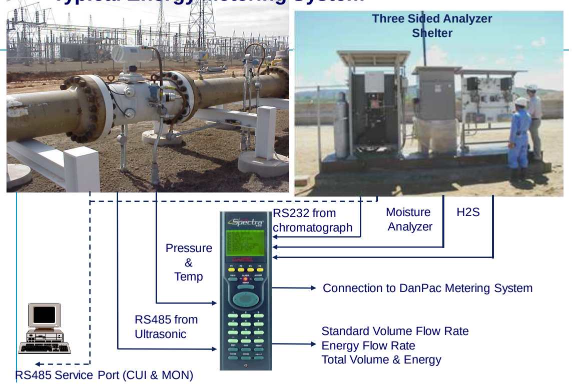


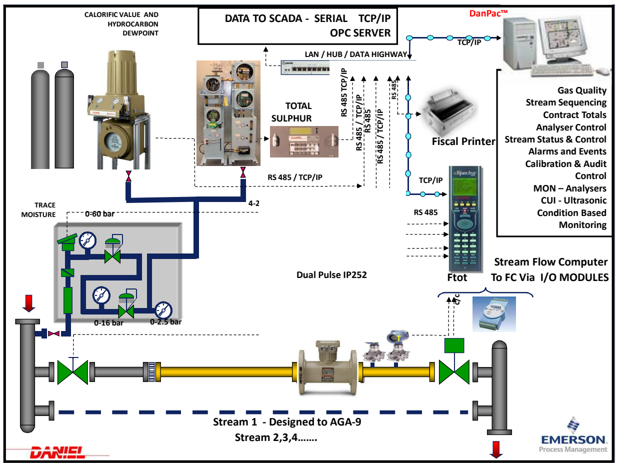
Flow Measurement Equipment



- Flow Meter
- Analysis
- Controlling
- Measurement
- Metering and Computing

Typical Energy Metering System





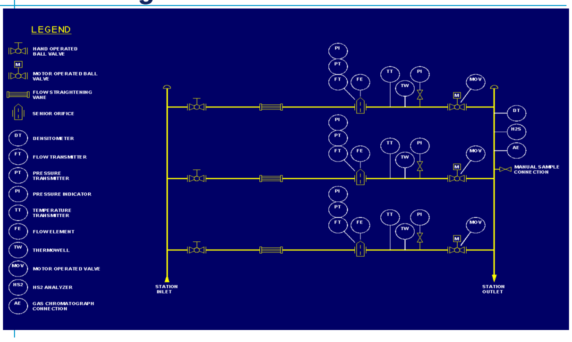
Primary Components

- Inlet block valves
- Conditioning
- Meter or meters
- Downstream block valves
- Pressure reduction
- Instrumentation

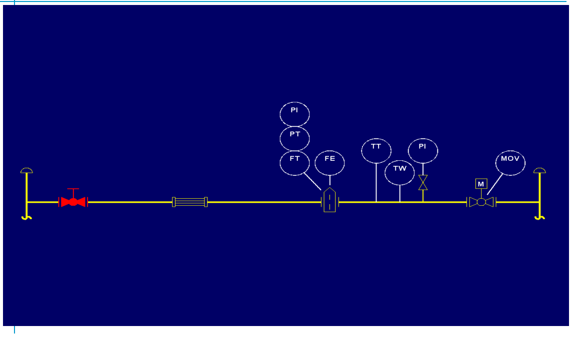
Skid Mounted Instruments

- Temperature transmitters
- Pressure transmitters
- Differential pressure transmitters
- H2S Analyzer
- Dewpoint Analyzer
- Densitometer
- Chromatograph
- Automatic sampling

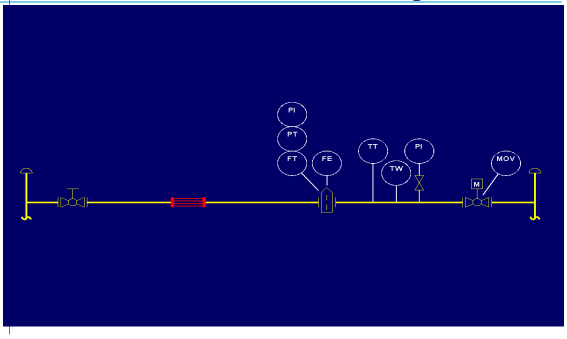
Flow Diagram



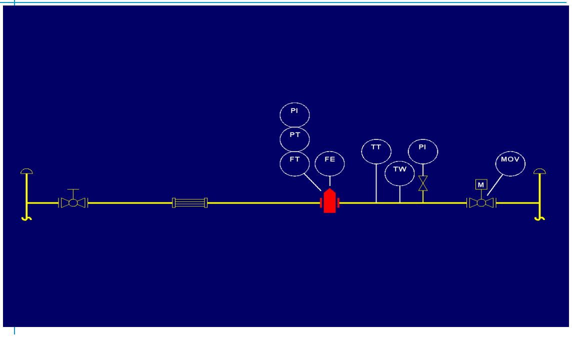
Meter Skid -- Inlet Block Valve



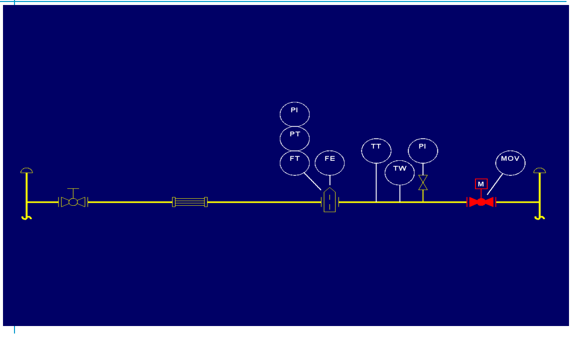
Meter Skid – Flow Conditioning



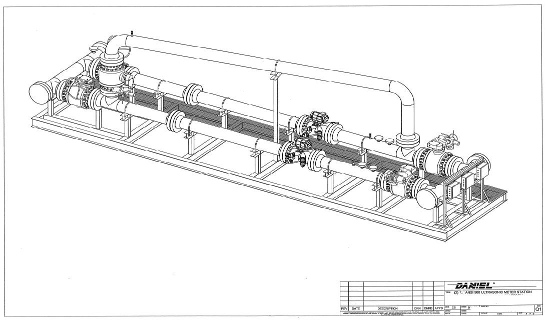
Meter Skid -- Flow Element



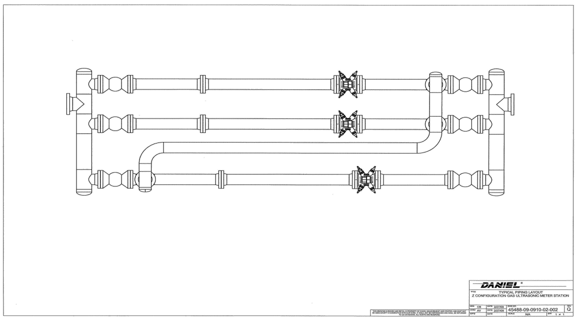
Meter Skid – Outlet Block Valve



Two Meter Run Z-Configuration

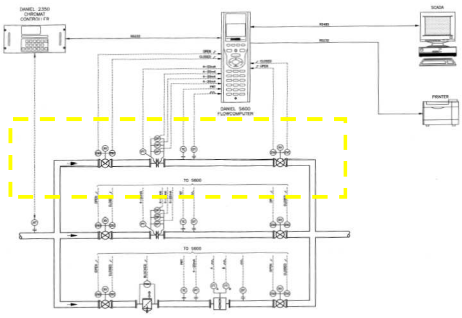


Two Duty Meters with Spare/Master

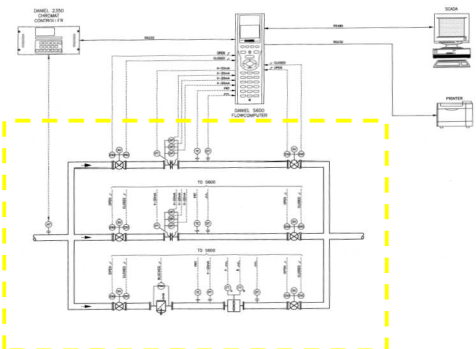


Gas Chromatograph

Typical Gas Metering Stream



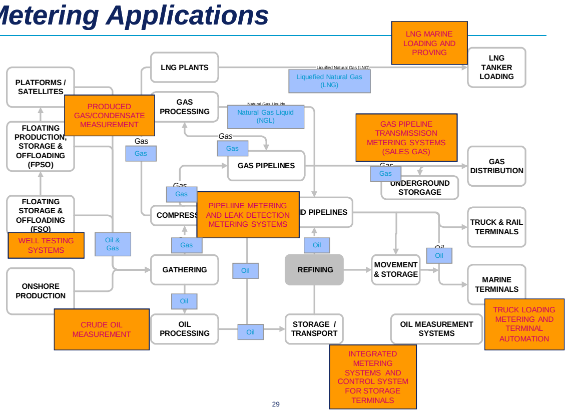
Typical Gas Metering Station



Typical Uncertainties

- Liquid
  - Fiscal/ Custody 0.25%
  - Allocation 0.25% to 2%
    - Revenue Tax or Shared Pipeline – reduced uncertainty
- Gas
  - Fiscal/ Custody 1.0%
    - Orifice Calculated uncertainty typically 0.6 to 0.7%
  - Allocation 2% to 5%
- Well Test 10%
- Wet Gas – Multiphase 5% to 20%
- Flow Computer calculation uncertainty 0.001%

Metering Applications



Multi-Stream vs. Single Stream

- **Traditional approach**
  - **redundancy on each stream with single stream FC's**
  - **Metering supervisory handled station summation, flow balancing, gas composition etc.**
- **Multi-stream approach**
  - **technology became more reliable**
  - **capability & functionality grew with in flow computers**
- **US approach adopted multi stream FC's**
  - **Have a spare in the stores – hope no failure**
  - **If install unit from stores – prove results/batch data not updated**
- **Latin America, some caution wanted multi stream redundancy**
  - **Hot Duty standby born**

Metering Applications

- Types of Meters
  - Head Meters
    - Orifice
    - Flow Nozzles
    - Venturi
  - Linear Meters
    - Turbine Meter
    - PD Meter
    - Vortex Meter
    - Ultrasonic Meter
    - Coriolis Meter

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Metering Applications

- Orifice Measurement
  - **Construction and installation of orifice meter are extremely important**
  - **Reynolds Numbers and Beta Ratios are keys to accuracy limits of these plates.**
    - **Beta ratio of roughly 0.1 to 0.75**
    - **Reynolds no. below 1,000,000 - uncertainty of 0.5% increases. Once below 4000 - practical measurement is no longer possible.**
  - **Standards covered for orifice :-**
    - **AGA -3/API MPMS 14.3/GPA 8185**
      - **Part 1 - General Equations and Uncertainty Guidelines**
      - **Part 2 - Specification and Installation Requirements**
      - **Part 3 - Natural Gas Applications**
      - **Part 4 - Background, Developments and Implementation Procedure and Subroutine Documentation for Empirical Flange-Tapped Discharge Coefficient Equation**
    - **ISO 5167 - Measurement of fluid flow by means of pressure differential devices inserted in circular cross-section conduits running full**
      - **ISO 5167-1:2003 - Part 1 - General Principles and Requirements**
      - **ISO 5167-2:2003 - Part 2 - Orifice Plates**
      - **ISO 5167-3:2003 - Part 3 - Nozzles and Venturi Nozzles**
      - **ISO 5167-4:2003 - Part 4 - Venturi tubes**

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Metering Applications

- Orifice Measurement
  - **ASME-MFC-3M is similar to previous version of ISO 5167**
  - **Basic orifice mass flow equation is as follows :-**
    - $q_m = C_d * E_v * Y * (\Pi /4) * d^2 * (2 * g_c * \rho_f * \Delta P)^{0.5}$
  - Advantage of orifice meter
    - **Well-documented in standards**
    - **Enjoys wide acceptance; personnel knowledge across the industry about requirements for use and maintenance**
    - **Relatively low cost to purchase and install**
    - **No moving parts in the flow stream**
    - **When built to standards requirements, does not require calibration beyond confirming mechanical tolerances when purchased and periodically in use**
  - Disadvantages of orifice meter
    - **Low rangeability with a single readout**
    - **Relatively high pressure loss for a given flow rate, particularly at lower beta ratios**
    - **More sensitive to flow disturbances at higher beta ratios than some meters**
    - **Flow pattern in the meter does not make meter self-cleaning**

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Metering Applications

- Turbine Measurement
  - **Similarly to orifice, widely used in both gas and liquid measurement**
  - **Installation of gas turbine meter must be in accordance to AGA-7 or ISO 9951:1993(E). The equation is found in both standards :-**
    - $q_b = q_f * M_f * (P_f/P_b) * (T_b/T_f) * (Z_b/Z_f)$
  - **For installation of liquid turbine meter, it is covered under API MPMS Ch. 5.3 - Measurement of Liquid Hydrocarbons by Turbine Meters.**
  - **Use of Pulse Security, eg. Level A or B, API MPMS Ch. 5.5 - Fidelity and Security of Flow Measurement Pulsed-data Transmission Systems**
  - **The calculation is defined in Ch. 12.2 - Calculation of Liquid Petroleum Quantities Measured by Turbine or Displacement Meters. The general equation :-**
    - $q_{gross\ std} = q_{gross} * M_{cf} * CTL * CPL$
    - **CTL is the Volume Correction Factors as described in API MPMS Ch. 11.1 (also known as ANSI/ASTM D 1250, IP 200, or API Std 2540). The various table covers 5A/5B/5D, 6A/6B/6C/5D, 23A/23B/23E, 24A/24B/24C/24E, 53A/53B/53D, and 54A/54B/54C/54D.**
    - **CPL is the compressibility factors for hydrocarbons described in API MPMS Ch. 11.2.1/11.2.1M or 11.2.2/11.2.2M**

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Metering Applications

- Turbine Measurement
  - Advantages of turbine meter
    - **Good accuracy over full linear range of meter (accuracy is percent of flow rate, and not percent of full scale)**
    - **Electronic output available directly at high resolution rate that makes proving possible in a short period of time**
    - **Meter cost is medium, but total meter station is low-to-medium cost because of high flow rate for given line size**
    - **Has pressure and temperature limits, but can handle normal flow conditions very well**
    - **Excellent rangeability on gas meters at high pressure**
  - Disadvantages of turbine meter
    - **Require throughput proving to establish most accurate use**
    - **Viscosity effects liquid meters that may require separate proof curves for different viscosities**
    - **Rangeability at low pressures about the same as other gas meters**
    - **Require upstream flow pattern to be non-swirling, which necessitates straightening vanes or very long inlet pipe.**

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Metering Applications

- Ultrasonic Measurement
  - **Ultrasonic meters for gas measurement covered by AGA 9 or ISO 17089**
  - **Ultrasonic meters for liquid measurement covered by API MPMS Chapter 5.8**
  - **Installation of gas ultrasonic meter must be in accordance to AGA-9 or ISO 17089.**
  - **The equation for transit time is :**
    - $V = (L^2 / (2 * X))* ((t_1 - t_2) / (t_1 * t_2))$
    - $q_f = V * (\Pi * D^2) / 4$
    - $q_b = q_f * M_f * (P_f/P_b) * (T_b/T_f) * (Z_b/Z_f)$

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Metering Applications

- Ultrasonic Measurement
  - Advantages of ultrasonic meter
    - **No pressure drop, since meters are same diameter as adjacent piping**
    - **High frequency pulse rate of output minimizes errors from effects of pulsation and fluctuating flow**
    - **Installation can be simple and inexpensive**
    - **High rangeability**
    - **No moving parts in contact with flowing fluid**
    - **Simple mechanical calibration easily checked without a throughput test**
  - Disadvantages of ultrasonic meter
    - **Power required for operation**
    - **Flow profile must be fully developed for an average velocity to be determined from a single path or reflection unit. (Note : multiple-path units average disturbed flow patterns, including swirl to minimize flow profile problems)**
    - **High initial cost**
    - **Close proximity of control valve may effect the meter's performance**

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Metering Solution

Typical Gas System Requirements

- Filters
- Flow transducers - Orifice, Ultrasonic
- Isolation Valves (Motorized or Manual)
- Temperature and pressure Transmitters
- Gas Chromatographs
- H2S Analyzers
- Moisture Analyzers
- Analyzer Shelters
- Density Meters
- Flow computers / Supervisory system/Control Panel
- Gas Samplers

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Metering Solution

Conditioning

- Inlet Header - Where inlet of the customer pipe gets connected. Manifold acts as a distribution chamber for take off of streams (meter runs).
- Inlet Block Valve -Typically manually operated Ball or Gate Valve. Provides isolation to the meter run for maintenance or standby.
- Meter Run - Consists of
  - Strainer/Air-Eliminator - Eliminates debris & air from entering the flow meter - protects internals. DP transmitter for monitoring of DP across the strainer - cleaning purpose. Usually a combination, however separate vessels can be provided

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Metering Solution

Measurement

- Measuring Element -
  - Selected based on applications, ease of maintenance
  - Coriolis meters for mass or volume measurement
  - Generally Turbine Meters & PD Meters are used for volumetric measurement.
  - Turbines are good for low viscosity, higher flow handling and less weight. Requires straight runs.
  - PDs are good for high viscosity
- Instrument Spool Piece - Normally includes Pressure & Temperature measurement and P & T gauges. P & T signals are also available at Flow Computer for monitoring & correction. Also includes additional Thermowell for spot temperature measurement during third party calibration.

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Metering Solution

Control

- Outlet Block Valve - At the outlet of each meter stream. Used for blocking the flow when required and to establish required flow through the operational meter. In the downstream of Flow control valve. DBBs with means to verify seal integrity are used
- Flow Control Valve - Normally does the function of equalizing the flow in all meters. Used for flow adjustments/balancing between parallel streams and during proving operation. Can be designed for open, close or remain in current position

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Metering Solution

Other Components

- Outlet Header - Where outlet of the metering skid gets connected to customer's pipe.
- Sampling System - Normally consists of sampling grabber & sampling containers . Establishes the quality measurement accuracy of crude oil (water in oil) or hydrocarbons (composition analysis)

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Metering Solution

Other Components

- MCCS System - Includes Flow Computers, PLC and MMI package allowing operators to interface with the system in the field. MCCS system provides final control of the valves, proving, temperature compensation. Provides Delivery report, Alarm & Event Printing.
- Cables, Cable Trays, Insulation, Lighting, 10% Radiography of piping work, Thermal Relief Valves, Junction Boxes, MOV distribution boxes etc.

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Additional Gas Components

Moisture Analyzer

Consists of sample handling system and retrievable sample probe with pressure regulator. Flow is regulated before passed through the detector.

On certain applications heated regulator or heat traced tubing is required to avoid condensation.

All devices are field mounted and provides 4-20mA output for the given range and can be connected to DCS or Flow computer.

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Additional Gas Components

Hydrocarbon Dew Point Analyzer

For monitoring of hydrocarbon dew point in the gas. Provides 4-20 mA output for DCS or Flow Computer. It has three stage operation - purging, cooling and warming.

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Metering Solution

Total Solution

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Metering Solution

System Components

- Flow computer is used as one multi-function device providing measurement, control & communication. Functions are
  - Multi run totalizing & combining the data
  - Prover calculations & controls
  - Batch schedules & presetting batch sizes
  - Sampler control
  - Flow & Pressure control
  - Batch start & stop ramping
  - Data averaging & archiving
  - Generates alarms and logs alarms & Records Transactions
  - Provide customized reports
- PLC is used to provide I/O configuration algorithms

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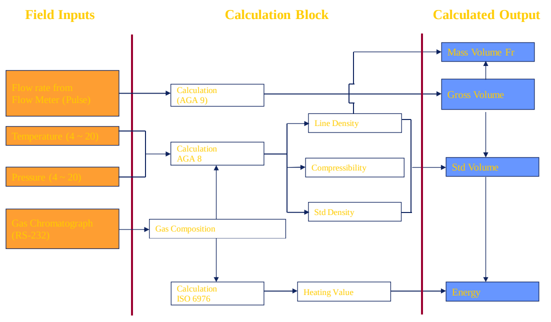
Inside the Flow Computer



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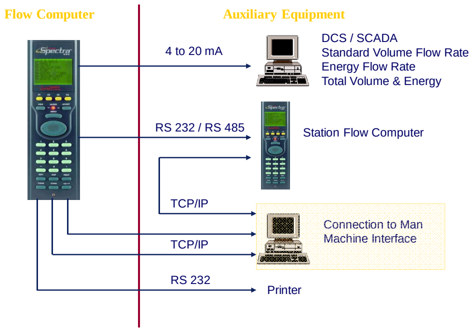
Communication to the Outside World



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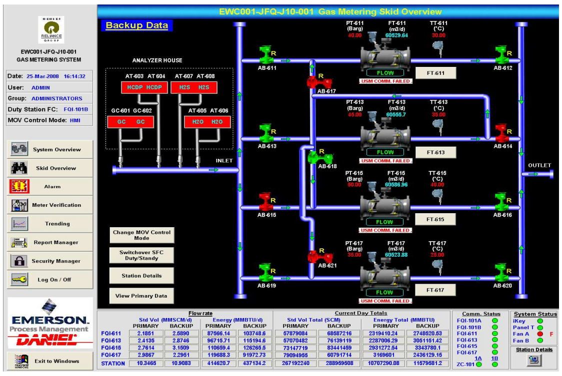
Control System Features

- Single Software Package for Screens, Communications etc.
- User Interface: trending, reporting and data entry
- Alarming
- Archiving
- Communications
  - SCADA
  - Network
- Monitor the entire metering process
  - Graphical
  - Text
- View historical trends of metering process
- View metering process alarms
  - Alarm detection based on configuration criteria defined in database
- Input quality data from laboratory analysis for correction of delivery data (if necessary)
- Generation of reports
  - Print meter delivery tickets, proving reports, summary reports etc.
- Enter manual override values for failed instruments
- Meter run totalization
- Data archiving

Control System Metrology Features

- Fiscal Measurement
- Meter Proving, Master Metering
- All metering calculations are performed using 64 bit (double) precision floating point numbers for the highest accuracy.
- Batch totalization and correction
- Flow balancing
- Flow scheduling
- K factor linearization
- Valve monitor/control
- Sampler control
- Station densitometer
- Station gas chromatograph

Man – Machine Interface Module
Gas Metering



Summary

- For custody transfer, flow measurement equals dollars
- Measurement Contract Requirements for Custody Transfer
  - Quantity of Material
  - Point of Delivery
  - Material Properties
  - Measurement Station Design
  - Measurements
  - Material Quality
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Thank You

Questions?

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