

2.1 Overview

The Agar MPFM-50 is a multiphase flow meter that continues the long tradition of excellent multiphase meters provided by Agar for over 15 years which includes the 300, 401 and 408/408E series.

Agar's research into Coriolis flow meter technology has extended typical coriolis metering into multiphase flow conditions up to 100% gas in the flow stream. The combination of this new generation coriolis flow meter, Agar Dual Venturi and the Agar microwave water cut meter provides a reduced-cost and accurate multiphase flow meter that can measure oil, water and gas without separation of the production stream. The Agar oil/water meter with microwave technology provides the capability for measuring water cuts from 0-100% even in the presence of changing salinities.

Additionally, by adding the High GVF Water Cut Measurement option, MPFM-50 meters can be customized to include cost effective and practical solutions for measurement of well streams that feature large multiphase flow rates and high void fractions.

Also in consideration to mature oil fields where some wells might exhibit extremely low flow, Agar offers the Low Flow option which allows effective measurement of extremely low instantaneous flow rates without diminishing the overall measurement accuracy.

The Agar MPFM-50 Series is a true multiphase flow meter that provides on-line, real-time well production information for the entire production flow stream. There is no longer a need for expensive, secondary equipment such as phase separators and pumps. Following its startup, it does not require further field calibration or detailed knowledge by operator of the fluid properties such as density and salinity to attain the specified accuracy. The MPFM-50 Series is fully self-contained and compact for use in rugged field conditions and can easily be trailer mounted for portable service. The principles of operation of each of these components and their functions are described in this section.

This section of the manual describes the principles of operation of each component and how the operator can use the computer to verify that the instrument is operating properly. Actual operation of the system is detailed in Section 5.

The Agar MPFM-50 consists of the following components as shown in Figure 2-1:

- A. Coriolis mass flow meter
- B. Agar OW-200 water cut meter
- C. Dual Venturi Meter
- D. RTD
- E. ID-201 Interface
- F. DAS
- G. Pressure Transmitter
- H. Purge Pump

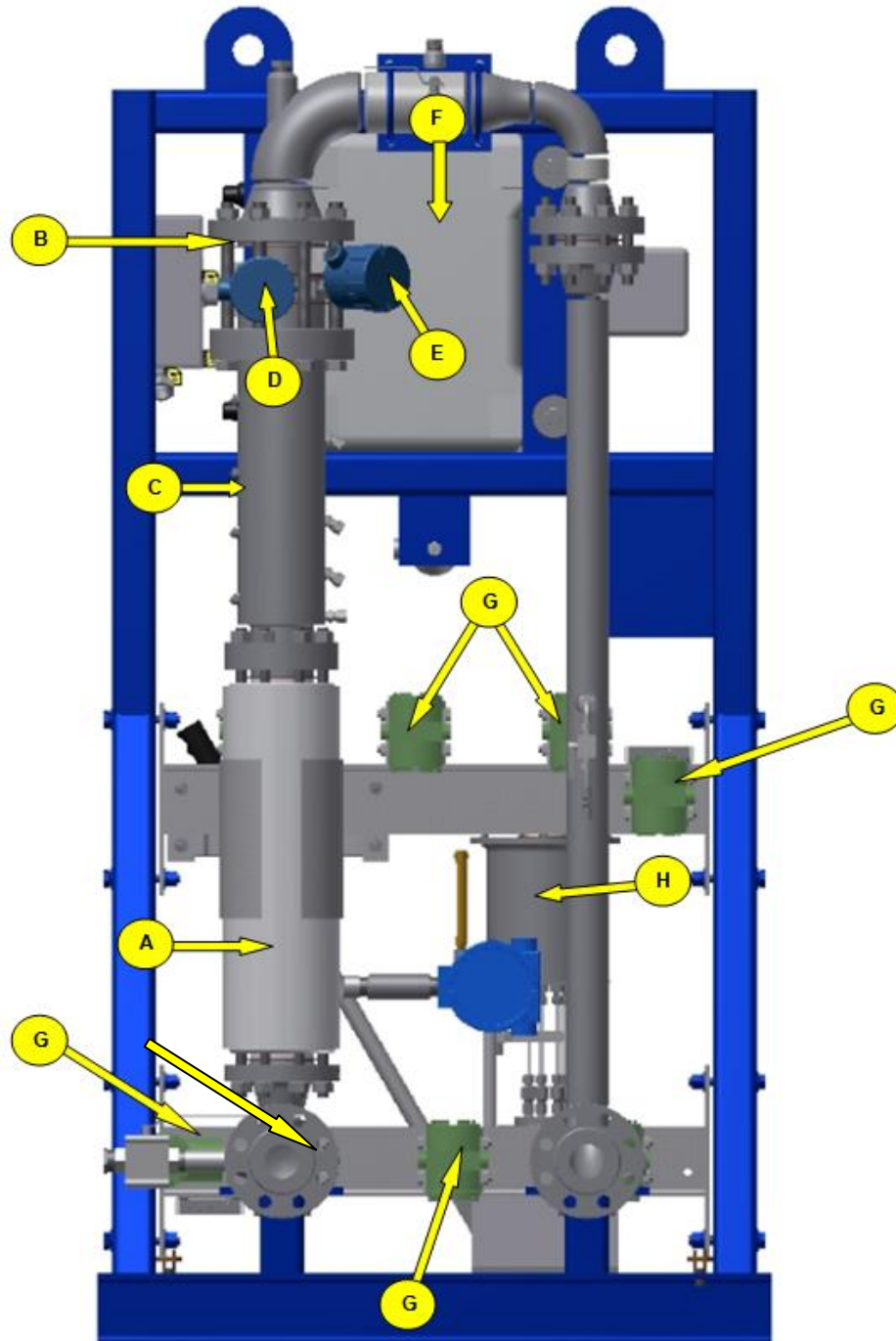


Figure 2-1 Agar MPFM-50

The electronic enclosure consists of the OW-200 electronics Phase Amplitude Measurement System (PAMS) and the flow computer also referred as Data Acquisition System (DAS); it is usually called PAMS/DAS assembly. The MPFM's transmitters and sensors continuously measure pressure, mass flow, density, temperature, and dielectric properties of the flow stream. The process temperature is measured with an RTD sensor which is part of the OW-200 system. The signals from the sensors are connected to the analog inputs of the PAMS/DAS enclosure. The DAS computer determines the gas, water, and oil flow rates from the raw data. The result is a real-time measurement of stream flow conditions.

The combination of the Coriolis flow meter and the venturi meter measures the fluid mixture density ρ_m and the mass flow M_t . The OW-200 measures the fraction of the water in the fluid wc (Figure 2-2 provides a simplified view of the MPFM-50 calculation model). Volumetric flow rate of oil, water and gas is then determined by the following equations:

$$\alpha = \frac{\rho_m - \rho_o - C_w(\rho_w - \rho_o)}{\rho_g - \rho_o}$$

$$wc = (1 - \alpha)C_w$$

$$M_m = \sqrt{p_d \rho_m}$$

$$Q_m = \frac{M_m}{\rho_m}$$

$$Q_l = (1 - \alpha)Q_m$$

$$Q_g = \alpha Q_m$$

$$Q_w = wc Q_l$$

$$Q_o = (1 - wc)Q_l$$

Where: α — Calculated gas void fraction

ρ_m — Fluid density measured by the coriolis meter

M_m — Fluid mass flow rate measured by the coriolis meter

C_w — Water concentration in the fluid measured by the OW200

p_d — Pressure differential between the venturi inlet and the venturi throat.

wc — Calculated water cut

ρ_w, ρ_o, ρ_g — Water, oil and gas densities at the meter condition

Q_l, Q_g, Q_o, Q_w — Calculated liquid, gas, oil and water volumetric flowrates

The above equations are in a simplified form, but in real application, the liquid viscosity, slip ratio, and flow patterns are changing all the time. The effect of these properties must be taken into account by collecting more measurements. The additional measurements to be included are: the secondary venturi measurement, the differential pressure measurement across the coriolis meter, and the differential measurement across the entire meter.

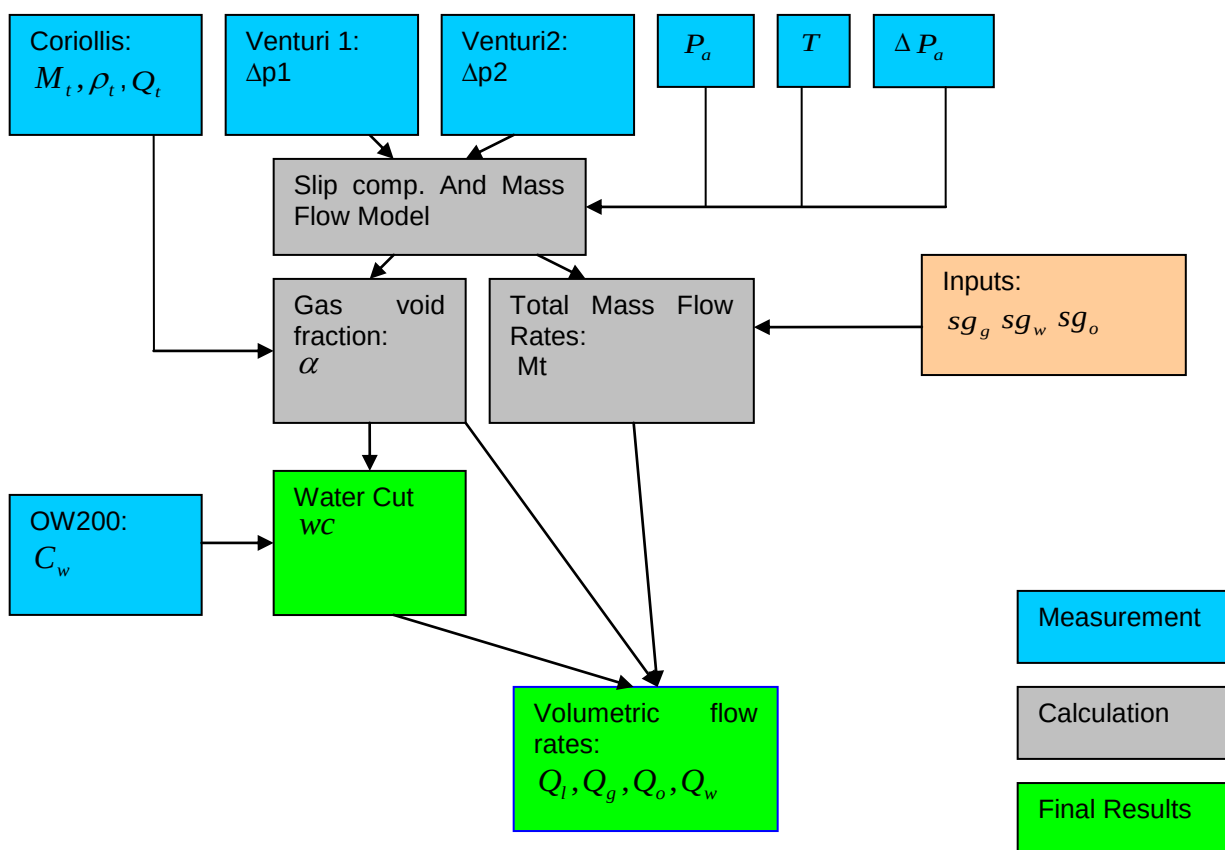


Figure 2-2 MPFM-50 Calculations

2.2 Coriolis Flow Meter

Coriolis flow meters are relatively new compared to other flow meters. The most popular configuration consists of one or two U-shaped, horseshoe-shaped, or tennis-racket-shaped (generalized U-shaped) flow tube.

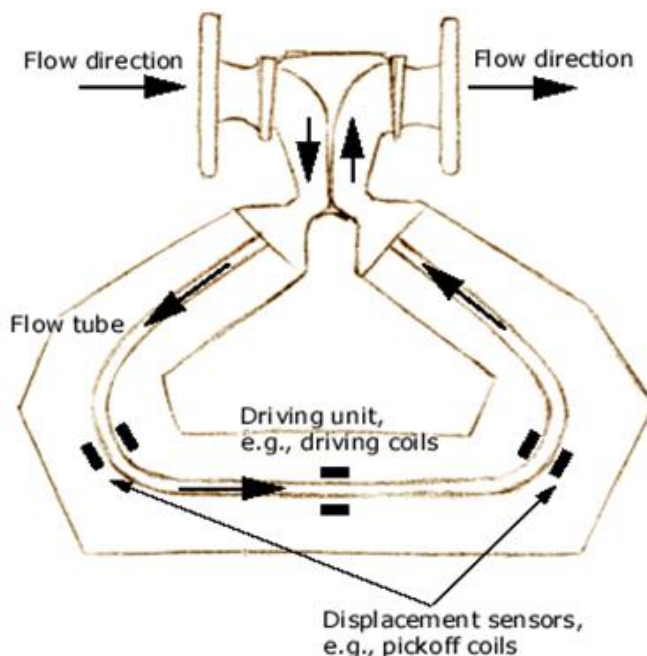


Figure 2-3 Conventional Cc

he flow passes into the U-shaped tube as shown in Figure 2-3. As an oscillating excitation force is applied to the tube; it vibrates at its natural frequency which depends upon the linear density. By measuring the vibrating frequency the density of the fluid stream can be accurately obtained. The fluid flowing through the tube induce a deformation or twist to the tube because of the coriolis acceleration acting in opposite directions as the oscillating radius of the tubes changes from zero to a maximum and back to zero. When the tube moves upward during the first half of an isolation cycle, the fluid flowing through it resists being forced up and pushes down on the tube. On the opposite side, the liquid flowing out of the meter resists having its oscillating radius decreased and pushes up on the tube. This opposite pushing action causes the tube to twist. Similar twist but in the opposite direction takes place during the second half of an isolation cycle. This continuous twisting of the tube results in a phase difference (time lag) in the vibrations between the inlet and the outlet sides. This phase difference is directly affected by the amount of mass flowing through the tube. Conventional U-shaped design coriolis meters may easily clog with some dirty and/or abrasive liquids and dampening of the vibration takes place for multiphase stream.

By combining unique proprietary electromechanical and firmware engineering advancements, Agar has developed an enhanced straight tube design capable of operating correctly in both single and multiphase flow streams. Contrary to conventional coriolis flow meters, the Agar coriolis meter operates effectively over the full range of 0%-100% Gas Void Fraction, it does not have the high pressure drop that is common to most of the coriolis meters and its design is compact. An advantage of the coriolis flow meter is that it measures the mass flow rate directly which eliminates the need to compensate for changing temperature, viscosity, and pressure conditions. Note also that the vibration of coriolis meters has very small amplitude, usually less than 2.5 mm (0.1 in), and the frequency is near the natural frequency of the device, usually

between 100 to 700 Hz. Finally, the vibration is commonly introduced by electric coils and measured by magnetic pickup sensors.

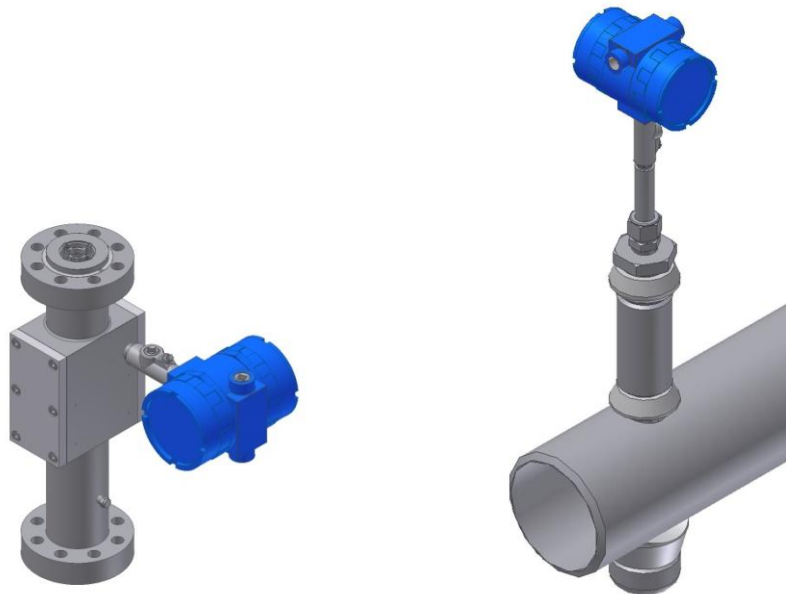


Figure 2-4 In-line Coriolis and Agar Insertion Coriolis meters

2.3 Agar Momentum Meter (Dual Venturi Meter)

The Agar momentum meter consists of a venturi section to determine real-time flow rates of liquid and gas. Its principle of operation uses fundamental knowledge of fluid mechanics and state-of-the-art numerical methods. The venturi section has pressure taps at its inlet and at the throat, plus an additional tap between the inlet and the throat which makes it a “dual venturi”. The venturi section has a fourth tap at the outlet to measure the viscous losses. The differential pressures are measured relative to their corresponding inlet pressures. The high range and low range throat differential pressures are displayed as P2 and P3 respectively.

The data from the momentum meter is used by the MPFM DAS, which calculates flow parameters such as fluid viscosity and slip ratio, as well as, other dynamic properties. Combining these parameters with those measured from the coriolis meter enables the MPFM to obtain volumetric flow rates for liquid and gas, and can be operated in the field without input by the operator on fluid properties such as density and salinity.

2.4 Agar OW-201 Oil/Water Meter

The OW-201 is a second generation oil/water analyzer. It consists of a microwave transmitter broadcasting at 2.45 Gigahertz and a receiver. Advances in microwave engineering and dielectric modeling of the oil/water emulsion enable the OW-201 to measure the water content accurately over the full range of 0-100% in oil or water continuous phases. The percent water is established by measuring the bulk dielectric properties of the fluid. The accuracy of the OW-201 is independent of changes in fluid velocity, salinity, pH, viscosity, temperature, or density.

The water cut data from the OW-201 is used by the MPFM's DAS during the three-phase flow calculations.

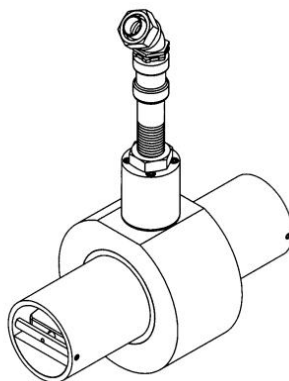


Figure 2-5 OW-201 Water Cut Meter

2.5 Oil/Water Determination

The oil/water measurement subsystem determines the respective amounts of oil and water in the liquid fraction of the fluid stream. The system works over the full range of 0-100%, regardless of whether the fluid is oil-continuous (OC) or water-continuous(WC) (i.e., if there are small water droplets in an oil medium or small droplets of oil embedded in a water medium). The effects of changes in fluid velocity, salinity, pH, viscosity, temperature and density are modeled in the data processing software.

The major components of the oil/water system are the Agar OW-201 water cut meter and the Agar ID-201 interface detector.

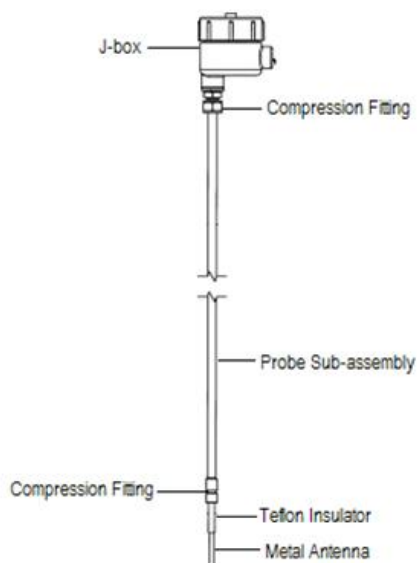


Figure 2-6 ID-201 Interface Detector

The OW-201 continually transmits around 2.5 Gigahertz microwave signal through a cross section of the flow stream. The fluid's electrical properties are derived from the flow's effects on this signal (phase shift and amplitude loss), and the fluid's dielectric is the result of this calculation (see Figure 2-7). The ID-201 is an interface detector that assists in determining the continuity state of the fluid (whether WC or OC) and is required for the computer model to calculate the correct water and oil concentrations. The presence of gas is taken into account by the model, and the oil/water determination is combined with pressure transmitter data from the other subsystems to complete the calculation.

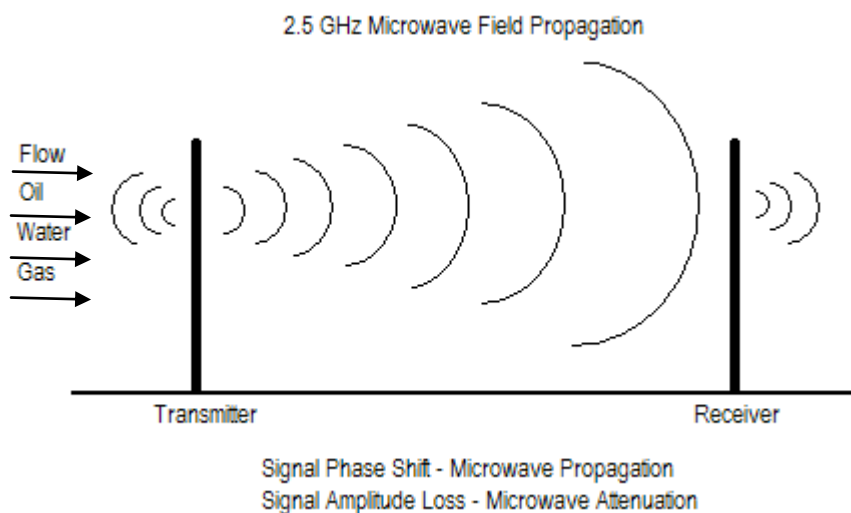


Figure 2-7 PAMS Microwave Flow

2.6 OW-301 Oil/Water Meter

For low water cut applications, where the water cut is less than 30%, the Agar OW-301 water cut meter can be used. The principle of OW-301 operation is based on measuring the complex permittivity properties of the flow stream using the energy absorption of multiple high-frequency wave method. The fluid permittivity is a unique monotonic function of WC that the instrument uses to calculate WC. The energy absorption of multiple high- frequency wave method allows compensation for the effect of changing hydrocarbon composition (different types of crude oils) and for water salinity. The OW-301 measures the volumetric water concentration over the low water cut range in the oil-continuous phase. The accuracy of the OW-301 is not affected by changes in the fluid velocity, salinity, pressure and pH, and provides temperature compensation.

2.7 OW-201 Extreme High-Temperature Sensor

For extreme high temperature process applications up to 572°F (300°C) the EHT version of the OW-201 sensor can be used.

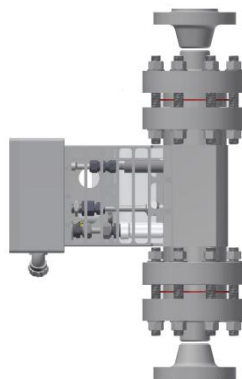


Figure 2-8 OW-201 EHT - Extreme High Temperature Sensor

2.8 Data Handling

Raw data coming from the MPFM instrumentation is collected by the Data Acquisition System (DAS) where the analog signals are received and digitalized. See Figure 2-9 for the Piping and Instrumentation Diagram (P&ID).

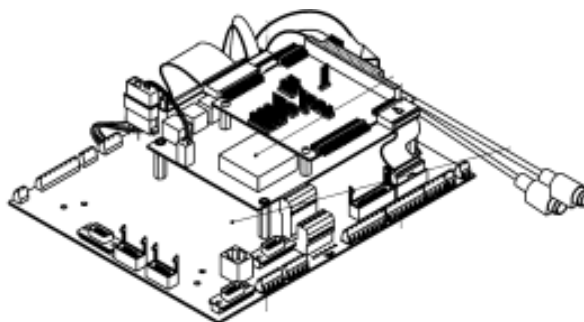


Figure 2-9 Data Acquisition System (DAS)

Raw data from the PAMS is collected and averaged locally by the DAS computer approximately every one second which is represented as one cycle. Flow calculations are performed for each measurement cycle. In most flow patterns, a single set of transmitted flow data represents the instantaneous true flow, and the reported flow is a continuous average of all the individual cycles.

Flow data and volumetric totals can be reported by the DAS computer as:

- RS-232 output
- The computer's main storage media (hard disk or compact flash card)
- Analog outputs
- Pulse outputs
- SCADA system data through a MODBUS protocol
- HMI interface proprietary software run at a local or remote work station computer (AgarDAS)

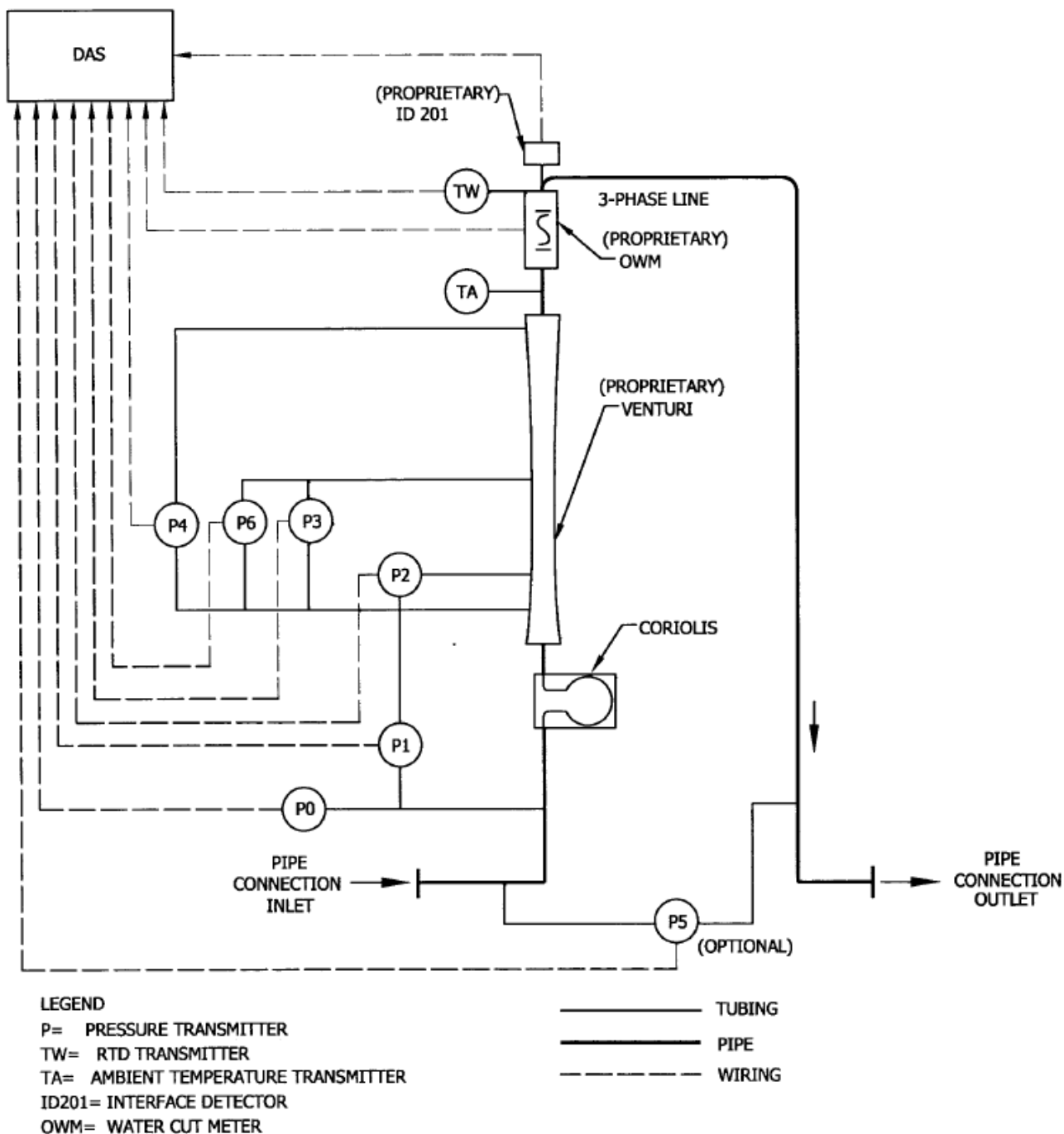


Figure 2-10 MPFM-50 Piping & Instrumentation Diagram (P&ID)

2.9 High GVF Oil/Water MPFM-50 (HGOW) option

At High GVF flow where the amount of liquid is very small compared to the amount of gas, it is necessary to partially separate the liquid in order to get good accuracy in the water cut measurement. The partial separation can be done in two ways. At high flow and large pipe diameter the MPFM-50 uses the High GVF OW measurement option as described further below in this section. For small pipe diameter the Low Flow MPFM-50 (FFD) option is used as described in section 2.9.

Figure 2-10 shows the general assembly of the High GVF OW option where a multi-stream splitting manifold and a 1" FFD gas diverter are used to connect the 2" High GVF OW measurement skid in parallel with the main large diameter MPFM-50 leg. The diameter of the main line can go from 3" to 36". The High GVF OW measurement skid will be accurately measuring the water cut content of the multiphase stream using the Agar microwave and Coriolis measurement techniques described previously. Measurement of the flow rates in the main leg is accomplished by combining density and mass flow measurements, from an orifice plate and the Agar insertion Coriolis meter, with the water cut measurement inputs from the High GVF OW skid section. From the calculated GVF in the main leg (MPFM-50 side) and the accurate water cut measurement from the HGOW skid, the total fluid mixture density is determined. Mixture density, orifice differential pressure, water cut and GVF are the parameters used to calculate the individual oil, water and gas flow rates in the main line. Additional pressure drop measurements in the main leg are used to account for slippage and high viscosity losses where applicable. Total flow rates for each phase are then determined by adding the phase flow rates measured by both, the main and split stream legs.

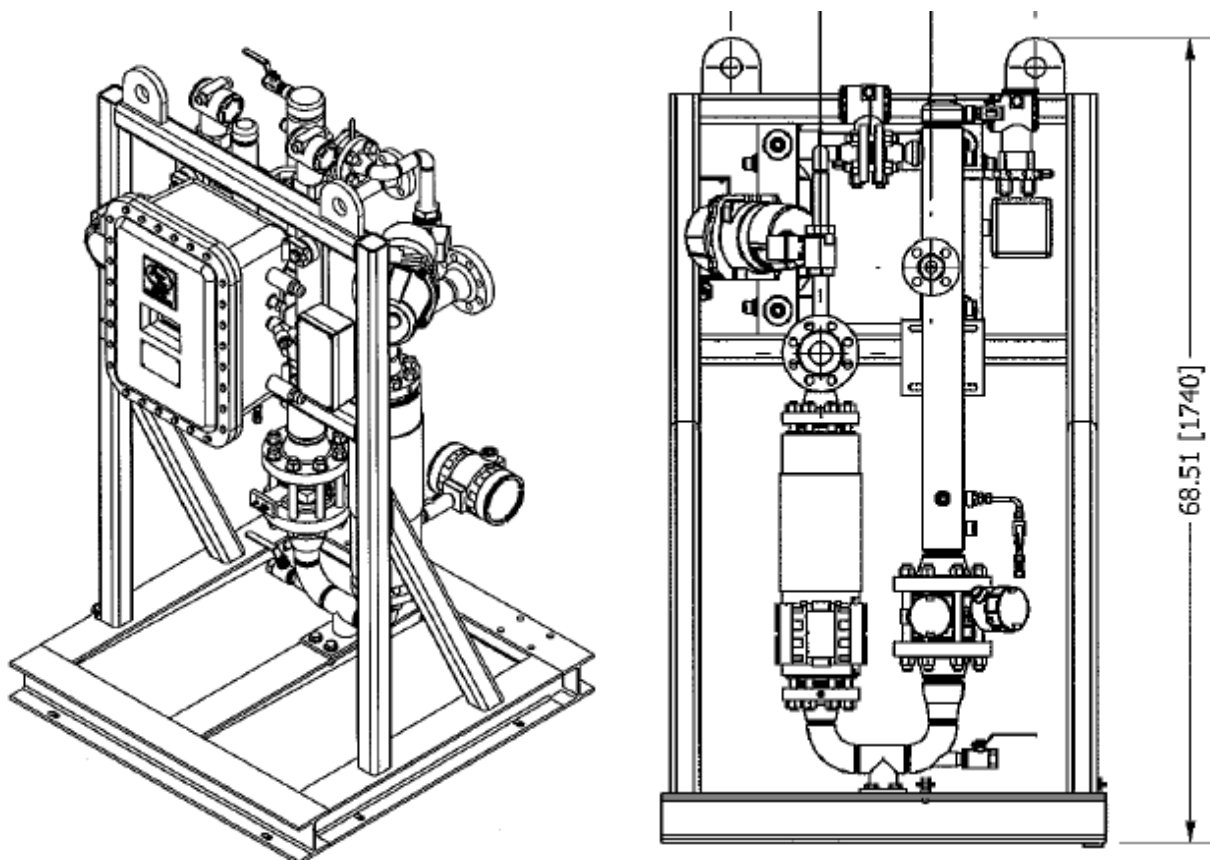


Figure 2-11 MPFM-50 with High GVF OW option

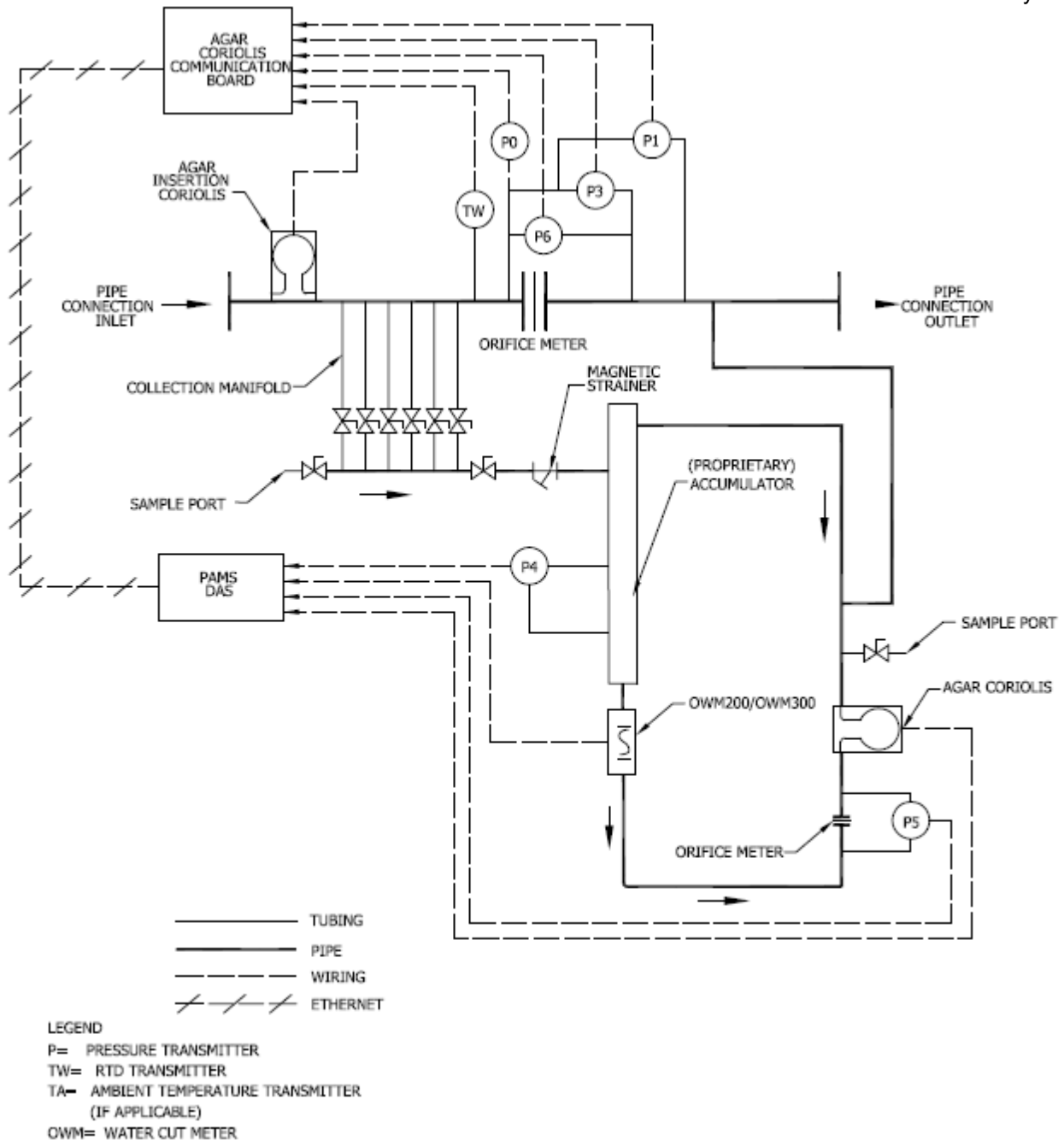


Figure 2-12 Piping & Installation Diagram (P&ID) of MPFM-50 with High GVF OW option

Note in the above two figures that for the High GVF MPFM-50 arrangement, an orifice plate is used instead of the dual venturi for the mass flow calculations corresponding to the fluids passing through it. Also, in order to insure accurate measurement of the water cut, part of the liquid in the main stream is directed towards the OW201 water cut meter by using a combination of Agar patented Multi-Split Flow Diverter and Free Gas Diverting chamber (or multi stream splitting manifold and a 1" FFD gas diverter).

The following equation formulates the explanation for MPFM-50 with High GVF OW option.

$$\alpha_{MAIN} = \frac{\rho_{MAIN} - \rho_o - wC_{HGOW}(\rho_w - \rho_o)(1 - \alpha_{MAIN})}{\rho_g - \rho_o}$$

$$M_{t_MAIN} = \sqrt{pd_{MAIN}\rho_{MAIN}}$$

$$Q_{t_MAIN} = \frac{M_{t_MAIN}}{\rho_{MAIN}}$$

$$Q_{l_MAIN} = (1 - \alpha_{MAIN})Q_{t_MAIN}$$

$$Q_{g_MAIN} = \alpha_{MAIN}Q_{t_MAIN}$$

$$Q_{w_MAIN} = wC_{HGOW}Q_{l_MAIN}$$

$$Q_{o_MAIN} = (1 - wC_{HGOW})Q_{l_MAIN}$$

$$Q_{g_T} = Q_{g_MAIN} + Q_{g_HGOW}$$

$$Q_{w_T} = Q_{w_MAIN} + Q_{w_HGOW}$$

$$Q_{o_T} = Q_{o_MAIN} + Q_{o_HGOW}$$

Where:

α — Calculated gas void fraction

ρ_m — Fluid density measured by the coriolis meter

M_t — Fluid mass flow rate measured by the coriolis meter

C_w — Water concentration in the fluid measured by the OW200

p_d — Pressure differential between the orifice inlet and the orifice outlet.

wC — Calculated water cut

ρ_w, ρ_o, ρ_g — Water, oil and gas densities at the meter condition

Q_l, Q_g, Q_o, Q_w — Calculated liquid, gas, oil and water volumetric flowrates

$MAIN$ — Quantities measured by the main stream section of the MPFM

$HGOW$ — Quantities measured at the High GVF OW skid

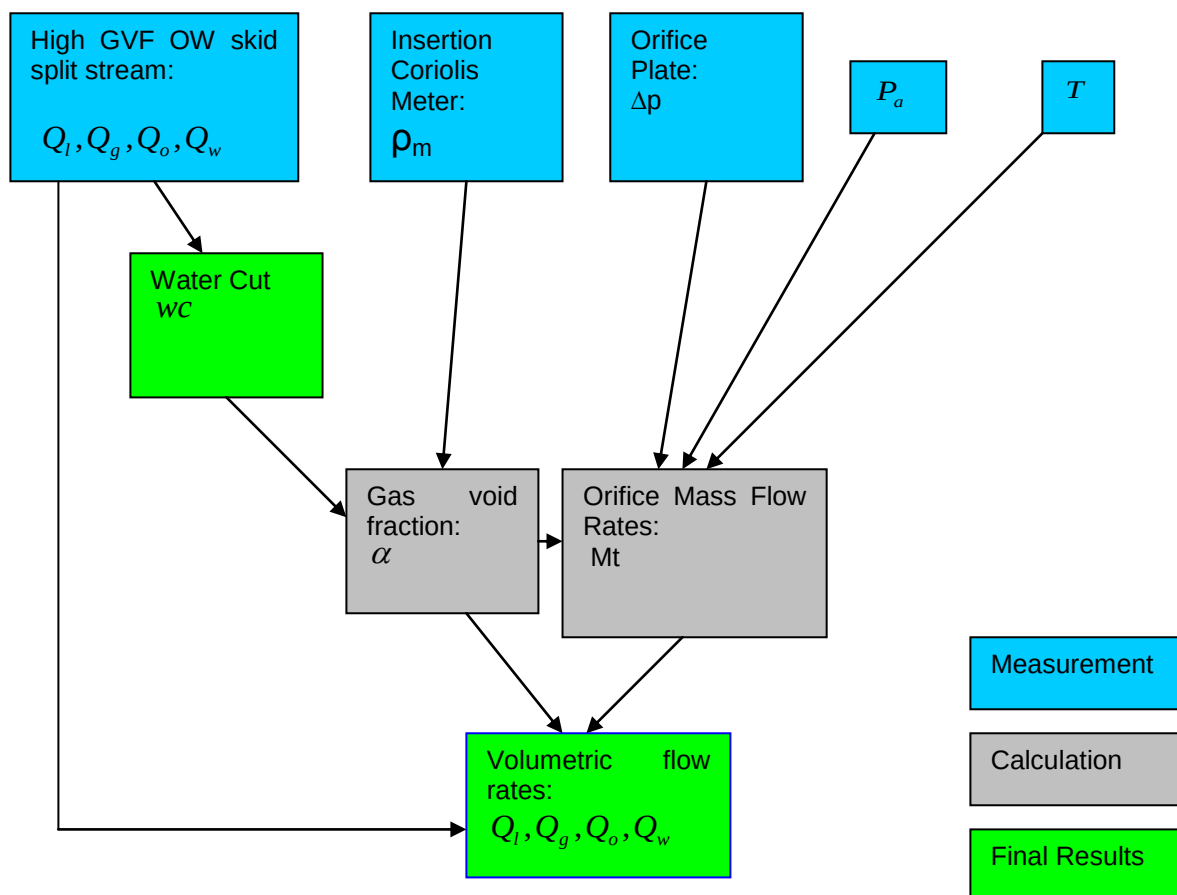


Figure 2-13 MPFM-50 with High GVF OW Calculations

2.10 Low Flow MPFM-50 (FFD) option

For wells that feature instantaneous flow rates that fall below the minimum nominal MPFM-50 measurable flow rates, Agar offers the Low Flow option which allows effective measurement of extremely low instantaneous flow rates without diminishing the measurement accuracy. This is achieved by adding an accumulator skid at the MPFM-50 inlet. The MPFM flow computer will detect if instantaneous flow rates are lower than the nominal minimum rate and send an electronic signal to close the accumulator's outlet valve forcing the incoming liquid to accumulate inside the tank. Once the level of liquid reaches a preconfigured maximum level in the tank, the DAS computer will open the accumulator's outlet valve to temporarily discharge the accumulated liquid at velocities that are higher than the nominal minimum flow rate. Once the liquid is completely discharged to a minimum level, or the instantaneous flow rates fall again below the nominal minimum liquid flow rate, the accumulation cycle is repeated. This option measures the produced fluids in batches; in order to ensure that the minimum measured instantaneous rates are met ensuring that the accuracy of the MPFM measurement is maintained. Depending of the amount of associated gas, a controlled gas discharge leg might be added to the top of the accumulator for optimal batch operation of the low flow accumulator.

Partially separating the gas also reduces the GVF in the MPFM-50 side which makes the liquid and water cut measurement more accurate. As mentioned in section 2.8 Agar also uses Low Flow MPFM-50 (FFD) option in applications of high gas and small pipe diameters.

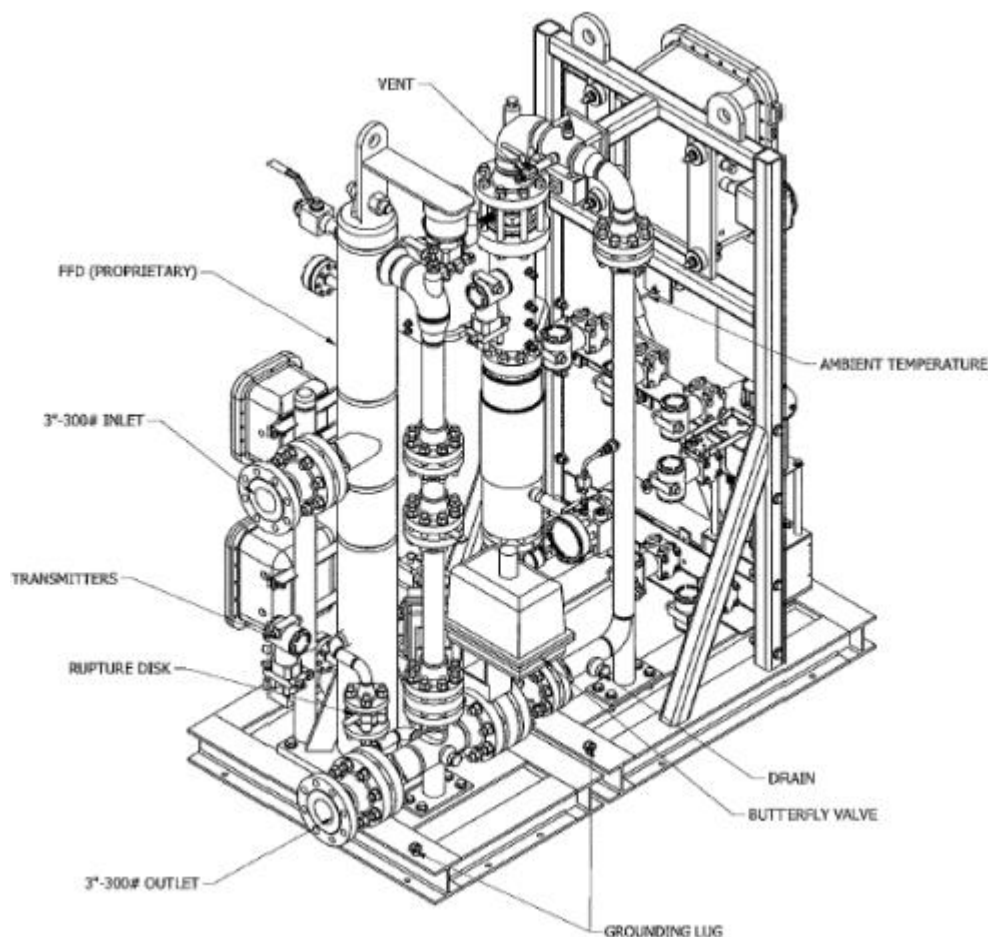


Figure 2-14 Agar MPFM with Low Flow Option

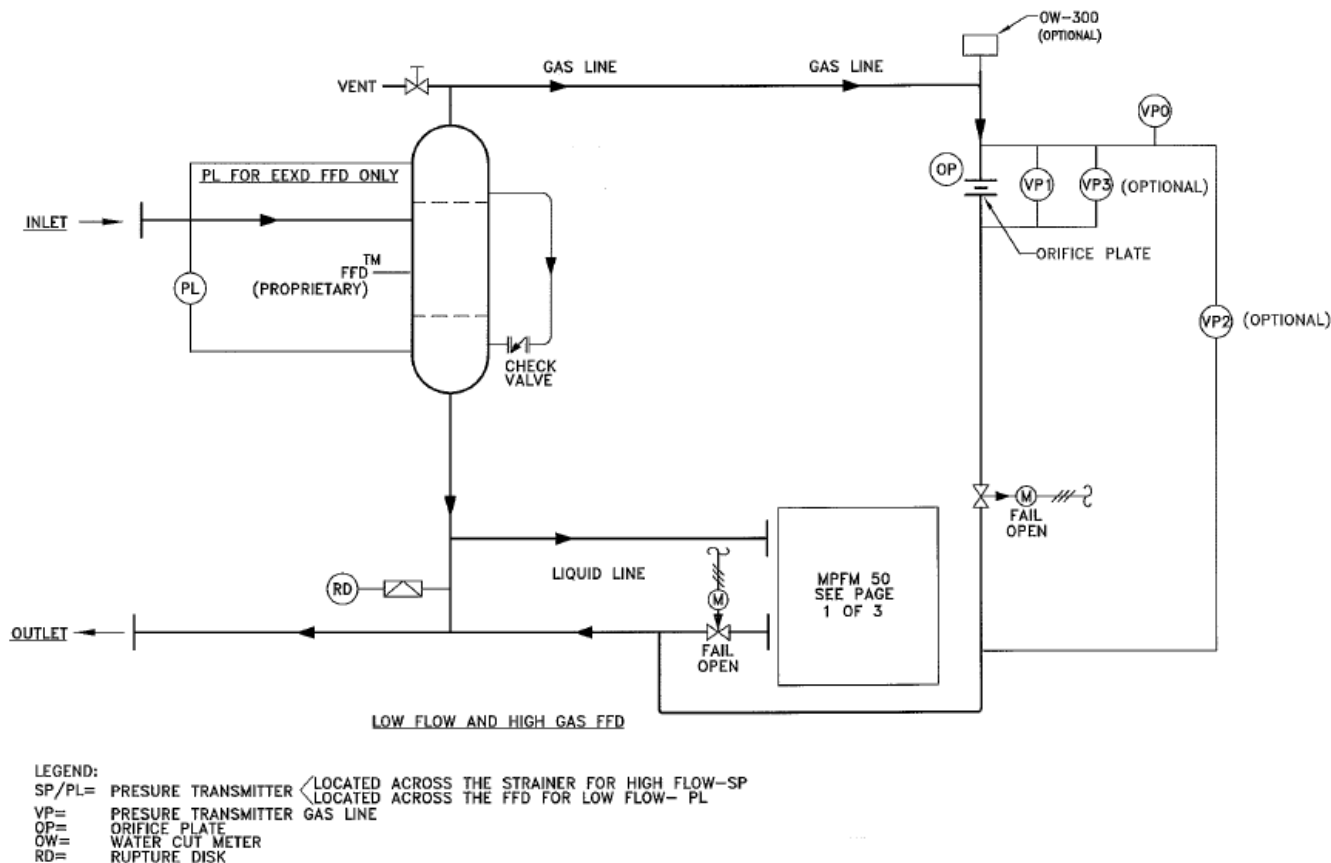


Figure 2-15 Piping & Installation Diagram (P&ID) of MPFM-50 with Low Flow Option

2.11 MPFM Operating Envelope

The flow rates covered by the Agar MPFM-50 sizes 2" and 4" can be seen in the envelope below. Different sizes of MFPM units will have a similar operating envelope covering different flow rates. The envelope is presented in standard conditions and the red and blue solid lines, for the 2" and 4" respectively, show the minimum and the maximum capacity of the meter for different combination of gas and liquid flow rates. The dotted lines show the maximum flow rates for each size at slugging conditions, taking into account that the liquid slug velocity is four times higher than the average velocity (superficial velocity).

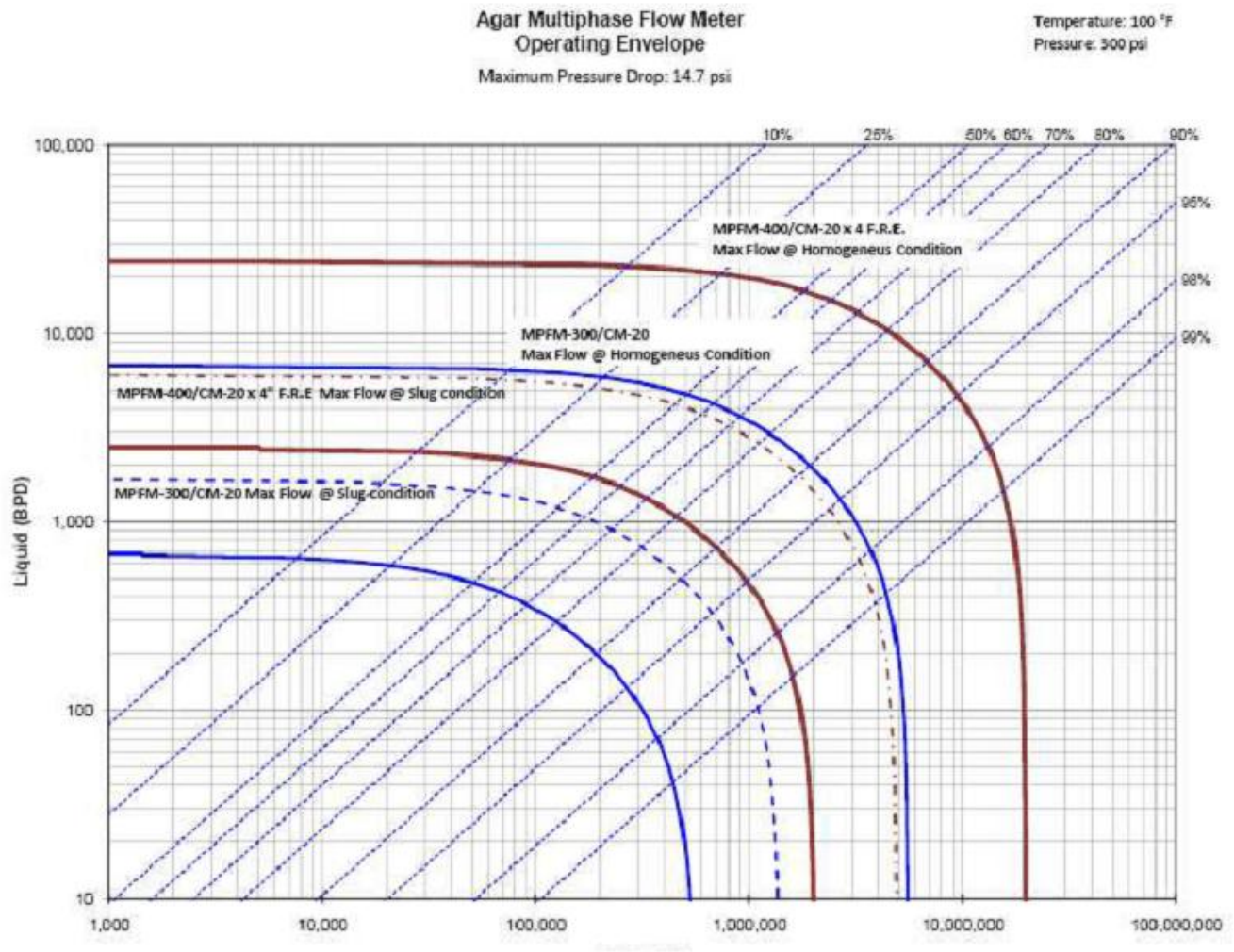


Figure 2-16 MPFM Operating Envelope

2.12 Automatic Purge Pump

2.12.1 Description

The Automatic Purge Pump feature consists of the standard MPFM purge pump assembly with the addition of an actuator to operate the pump and an ID to indicate when the purge fluid in the reservoir is low. The pump can be manually operated if the coupling between the actuator and the pump is removed.

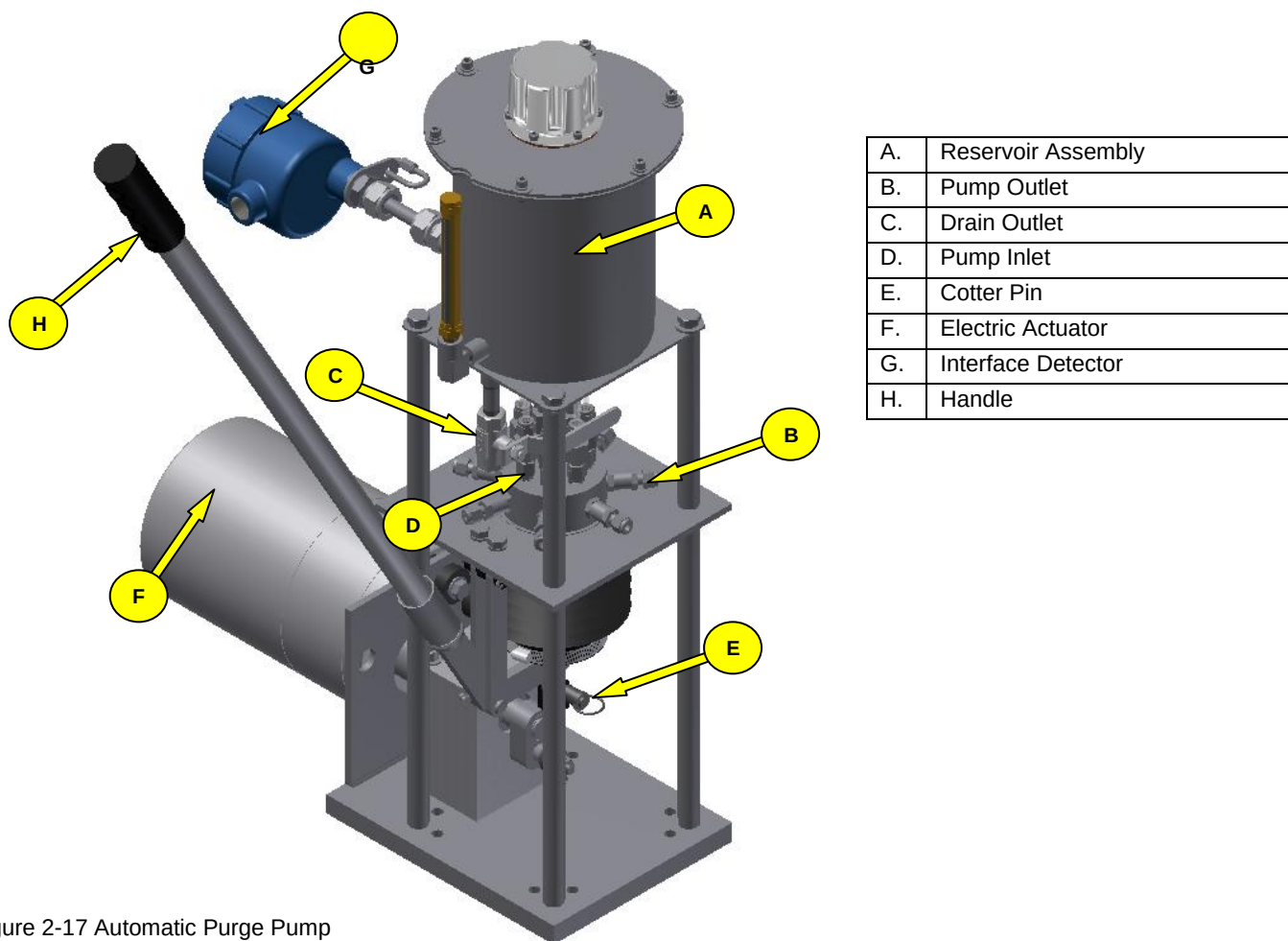


Figure 2-17 Automatic Purge Pump

2.12.2 Theory of Operation

The MPFM DAS will periodically activate the purge pump actuator to purge the pressure transducer capillaries with a known fluid. Activation of the pump will complete a configurable number of strokes; the configurable strokes are available with each activation. Once the configured number of strokes is complete, the unit will wait a configured period of time before activating the purge sequence again.

When the ID indicates that the level of the purge fluid in the reservoir is low, a warning is generated. Normal purging operation continues but the number of actuator strokes after the low fluid warning are counted. Once a configured maximum strokes have occurred, the warning is cleared and an alarm is generated indicating that the reservoir is empty. Purging operation is suspended until the ID indicates that the reservoir has been filled.

The DAS has a provision for making up for missed purge activations. Suppose that the reservoir is empty for some time or the DAS is not running but the meter is still in the process and one or more purge activations are missed. When the DAS is able (reservoir filled or DAS powered) it will attempt to make up for missed purge activations. For example if the DAS is configured to make 2 strokes every 6 hours and the reservoir was empty for 24 hours, then the DAS will attempt to make 8 strokes. But what if the reservoir was empty for 2 weeks? The DAS would attempt to make 112 strokes. This is obviously more than necessary. There is a configurable maximum strokes per activation that can be used to limit this behavior. Example: A maximum of 50 strokes to purge the capillaries.

2.13 MPFM Electrical

The MPFM is adapted to meet the requirements for use in hazardous areas. The applicable design is determined by the customer's request. See APPENDIX A for customer drawings and see APPENDIX C for the electrical drawings and specifications of your MPFM unit.