MULTIPHASE FLOW METERING APPROACHES:
PHYSICS, FIELD PERFORMANCE AND TEST-SEPARATOR COMPARISONS

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ABSTRACT

Multiphase flow meters (MPFMs) are transforming well surveillance by enabling continuous, real-time measurement of oil, water, and gas flow without the need for large test separators. This work reviews the physics and field performance of dominant MPFM's, particularly the Venturi differential-pressure and dual-energy gamma densitometry combination, and compares their validated operating envelopes, accuracy, and limitations with those of conventional test separators.

INTRODUCTION

Multiphase flow metering has become increasingly important as operators seek faster, more reliable ways to monitor well performance. In most production systems, three-phase production (oil, water, and gas) requires accurate phase measurement, which is essential for well testing, reservoir management, production allocation, and optimization. Conventional test separators have long been used for this purpose, but they come with clear limitations. These vessels are large, costly, and operationally demanding. Their large vessel volumes often require several hours of stabilization after a well change, meaning that what operators often receive is not a real-time, continuous picture of well performance, but an averaged snapshot collected over a limited test window.

Multiphase flow meters (MPFMs) represent a major shift from this intermittent style of testing to continuous, real-time well surveillance. The most established and field-proven configuration for MPFMs is the Venturi and dual-energy gamma meter. This workhorse architecture combines a Venturi differential-pressure device for total-mixture mass flow estimation with dual-energy gamma-ray densitometry for phase-fraction determination in three-phase oil, water, and gas flow. Its widespread use comes from its robust performance across a broad range of field conditions and its ability to provide continuous inline measurements without full phase separation. At the same time, no single MPFM is ideal for every application, and the meter’s performance still depends strongly on factors such as flow regime, gas volume fraction, water cut, fluid properties and the operating environment. Therefore, understanding both the physics behind these meters and the conditions under which they perform best is necessary before their use and comparison to conventional separator systems. This paper therefore reviews the role of MPFMs in production metering, compares their performance with conventional test separators, and explains the operating physics of the Venturi dual-energy gamma meter to show why inline metering has become such an important step toward continuous well surveillance and improved production management (Nasri et al., 2014; Theuveny,2001).

COMPARATIVE OVERVIEW OF MULTIPHASE FLOW METERING TECHNOLOGIES

Table 1.1 below provides a comparison between conventional test separators and MPFMs across the main operational criteria relevant to field use. The comparison highlights why MPFMs have become increasingly attractive for continuous, frequent well surveillance.

Table 1.1: MPFM comparison to Test Separators

Attribute	**Test Separator**	**Multiphase Flow Meter (MPFM)**
Measurement Principle	Separate phases; single-phase metering	Inline: velocity + phase fractions
Stabilization Time	4-6h after well switch (large fluid volume)	30-60 min; enables rapid multi-rate tests
Data Type & Frequency	Periodic average (12-24 h snapshot)	Continuous real-time; captures transients
Footprint & CAPEX	Large/heavy; high CAPEX (HP/subsea)	Compact; lower CAPEX; low power
Typical Accuracy (in envelope)	Gas ±2-6%; liquids ±2-10%	Phases ±10% (rel); WC ±2% (abs); wet-gas gas <±2%
GVF/WC Suitability	All GVF; quality depends on residence time; wet gas/emulsions hurt	Inline best ≤~85-90% GVF; partial-sep and wetgas models cover >90-100% GVF
Dominant Uncertainty Drivers	Wet-gas carryover; emulsions/salinity; level control; meter-factor drift	High GVF liquid error; WC driven oil error; property inputs (PVT/attenuation)

Sampling & PVT	Direct samples post-separation; strong for PVT/custody	No samples; needs property inputs; periodic validation (tracer/mass checks)
Operational Use	Often over-subscribed ,fewer routine tests	Offloads routine tests; remote/SCADA; higher cadence
Deployment / Mobilization	Heavy/slow mobilization	Rig-up <2 h; battery/low power options

Table 1.2 provides an overview of the main MPFM types reviewed, along with the physics behind each, their operating ranges and typical accuracy. This helps show that different meter designs are suited to different flow conditions, and that performance depends heavily on the application rather than on the meter alone.

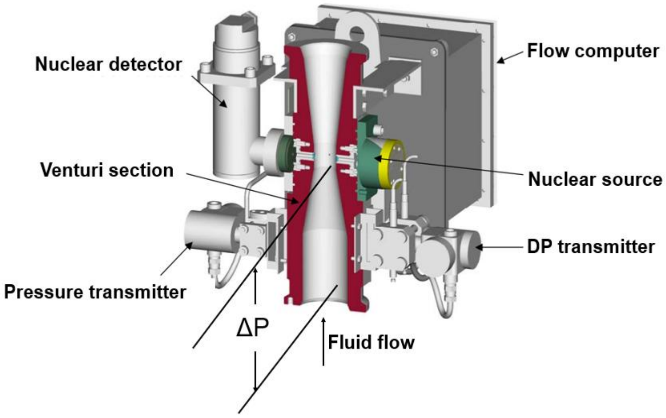
Table 1.2: MPFM's Physics and Key Operating Ranges

Meter / Type	**Sensors & Physics**	**Validated Envelope & Typical Accuracy**
Haimo (partial-sep hybrid)	Venturi (∆P); dual-energy gamma (fractions); gamma cross-correlation (velocities); cyclone + vortex gas leg	GVF 0-99%; phases ±10% (rel); WC ±2% (abs)
Schlumberger Vx (inline)	Venturi (∆P) at throat; dual-energy gamma	GVF ~20-85% (phases ±10%, WC ±2%); liquid ±3%
Dual-Coriolis (partial-sep spool)	Compact separator; Coriolis gas + liquid (mass & density →WC)	±10% vs test separator up to GVF ~88%
Framo (inline, conditioned)	Static mixer; Venturi; dual-energy gamma	Among best performers in field trials
Fluenta 1900VI (inline)	Electrical impedance; gamma density; (Venturi extension)	Acceptable ≤~90% GVF; poor >90% GVF
Dual-mode wet-gas MPFM	Venturi (∆P); dual-energy gamma	GVF 90-100%; gas ≤±2% (reading); liquid $<\pm 2\ m^3/h$ (loop)

Wet-gas Venturi + tracer (system)	Venturi + wet-gas model; periodic tracer dilution	Gas ~±5%; condensate ~±10%; tracer liquids ~±15% vs trap
Microwave WC module	High-frequency permittivity (εr) sensing	WC 0-100%; strong at high WC
Ultrasonic module	Transit-time / attenuation + cross-correlation arrays	Pattern + velocity; fraction trending with calibration

WORKING PRINCIPLE OF THE VENTURI AND DUAL-ENERGY GAMMA METER

The Venturi and dual-energy gamma configuration is one of the most established and field-proven workhorses for inline three-phase measurement. The total mass flow rate is obtained by combining the differential pressure measured across the Venturi with the mixture density determined by the dual-energy gamma meter. This pairing is effective because the Venturi provides a robust total flow measurement, while the gamma system provides the phase and holdup fractions needed to interpret that flow in terms of oil, water, and gas.



Cutaway schematic of Phasewatcher MPFM (Moksnes, 2003)

The meter is based on five transmitter readings: pressure, temperature, differential pressure, low-energy count rate, and high-energy count rate. These measured signals are processed together to determine the mixture density, total flow rate, phase fractions, and finally the individual oil, water, and gas flow rates. The following key equations describes the working principle of the meter.

Key Equations:

$$Q_w = h_w Q_t \qquad \ldots \text{ (Eqn. 1)}$$

$$Q_o = h_o Q_t \qquad \ldots \text{ (Eqn. 2)}$$

$$Q_g = f_{z(\ldots),} h_g Q_t \qquad \ldots \text{ (Eqn. 3)}$$

$$Q_t = A_1 v_1 = A_2 v_2 \qquad \ldots \text{ (Eqn. 4)}$$

Bernoulli’s (neglecting elevation change):

$$P1 + \frac{1}{2}\rho_{mix} {v_1}^2 = P2 + \frac{1}{2}\rho_{mix} {v_2}^2 \qquad \ldots \text{ (Eqn. 5)}$$

$$\Rightarrow \Delta P = \frac{1}{2}\rho_{mix}({v_1}^2 - {v_2}^2) \qquad \ldots \text{ (Eqn. 6)}$$

Solve to get a Venturi flow equation:

$$Q_t = C_d A_2 \sqrt{\frac{(2\,\Delta P)}{(\,\rho_{mix}(1-\beta^4))}} \;\; with\,\beta = \frac{d_2}{d_1} \qquad \ldots \text{ (Eqn. 7)}$$

Dual Energy Gamma (Beer-Lambert law):

$$N_E = N_{0E}\exp\big(-\big(\rho_o \mu_{oE} h_o + \rho_w \mu_{wE} h_w + \rho_g \mu_{gE} h_g\big) D\,\big) \qquad \ldots \text{ (Eqn. 8)}$$

$$h_o + h_w + h_g = 1 \qquad \ldots \text{ (Eqn. 9)}$$

$$\rho_{mix} = h_o \rho_o + h_w \rho_w + h_g \rho_g \qquad \ldots \text{ (Eqn. 10)}$$

**These are the 3 phase densities/holdups that feed the Venturi equations*

The dual-energy gamma section is first used to determine the phase holdups from the measured attenuation of low- and high-energy gamma rays. Eqn. (8) applies the Beer-Lambert law to relate the measured count rates to the attenuation caused by oil, water, and gas across the flow path, while Eqn. (9) provides the closure condition that the three holdups must sum to unity.

The resulting mixture density is fed into the Venturi equations, where Eqns. (4) to (7) combine continuity, Bernoulli’s principle, and the measured differential pressure to determine the total mixture flow rate through the meter. Finally, Eqns. (1) to (3) are used to split this total mixture flow into the individual oil, water, and gas flow rates.

OPERATION OF THE VENTURI DUAL-ENERGY GAMMA METER

Fluid enters the meter and passes through the Venturi tube, where the pressure drop between the upstream section and the throat is measured. At the same time, the dual-energy gamma system is positioned across the Venturi body with a radioactive source on one side of the pipe and a nuclear detector on the other. As the multiphase stream flows through the meter, both low and high-energy gamma rays pass through the fluid and are attenuated differently by the oil, water, and gas present in the pipe. These measured attenuations are then used to determine the phase holdups and mixture density, allowing the meter to calculate the total mixture flow rate and then resolve it into the individual oil, water, and gas flow rates. In this setup, the Venturi provides the total flow measurement, while the dual-energy gamma system provides the phase fractions needed to interpret the flow correctly.

The Venturi dual-energy gamma meter requires regular calibration for accurate use and measurement. In practice, this is done by filling the meter with reference samples of pure oil and pure water, and performing a representative gas analysis before returning the system to normal three-phase operation. This reflects an important point about MPFMs generally: even though the meter provides continuous inline measurements, its accuracy still depends on proper calibration, reliable fluid-property inputs, and periodic end-point checks.

CONCLUSION

Overall, MPFMs have improved well surveillance by providing continuous measurements that go beyond the limited snapshot offered by conventional test separators. Their effectiveness, however, depends on selecting the right meter for the right application, since no single MPFM is suitable for all flow regimes and fluid systems. The Venturi and dual-energy gamma meter remains the most established field-proven architecture, while newer specialized technologies have expanded measurement capabilities in high-GVF environments and high-water-cut conditions. In practice, MPFMs and test separators are best treated as complementary rather than competing systems. When they are used together, they provide a more complete understanding of well performance.

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