

DEP SPECIFICATION

FLOW RATE MEASUREMENT IN WET GAS ENVIRONMENTS BY MEANS OF VENTURI TUBES AND TRACER DILUTION TECHNOLOGY

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DESIGN AND ENGINEERING PRACTICE



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1. INTRODUCTION

1.1 SCOPE

This DEP specifies requirements and gives recommendations for flow rate measurement in wet gas environments by means of Venturi tubes and tracer dilution technology.

The application of Venturis in wet-gas flows requires stricter guidelines than for single-phase (gas or liquid) flows. These guidelines are described and discussed in this DEP in order to achieve the best possible wet-gas measurements by means of Venturis.

The tracer dilution technique is used for the determination of the liquid flow rates in pipelines. It can be used as a part of the wet-gas measurement technique when combined with the over-reading algorithm for the Venturi flow meter. The tracer dilution technique can also be used for the calibration of the liquid readings of a multi-phase flow meter or a direct oil measurement in a high water-cut well stream, provided the liquid flow rate is sufficiently stable. The technique has specific requirements for its correct and optimized implementation. This DEP describes the current best practices for the implementation of the tracer dilution technique. It includes selection of solvents for the tracers, injection of the tracer solutions, mixing, sampling, determination of the shrinkages and laboratory practices.

This is a revision of the DEP of the same number dated July 2008; see (1.5) regarding the changes.

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When DEPs are applied, a Management of Change (MOC) process shall be implemented; this is of particular importance when existing facilities are to be modified.

If national and/or local regulations exist in which some of the requirements could be more stringent than in this DEP, the Contractor shall determine by careful scrutiny which of the requirements are the more stringent and which combination of requirements will be acceptable with regards to the safety, environmental, economic and legal aspects. In all cases, the Contractor shall inform the Principal of any deviation from the requirements of this DEP which is considered to be necessary in order to comply with national and/or local regulations. The Principal may then negotiate with the Authorities concerned, the objective being to obtain agreement to follow this DEP as closely as possible.

1.3 DEFINITIONS

1.3.1 General definitions

The **Contractor** is the party that carries out all or part of the design, engineering, procurement, construction, commissioning or management of a project or operation of a facility. The Principal may undertake all or part of the duties of the Contractor.

The **Manufacturer/Supplier** is the party that manufactures or supplies equipment and services to perform the duties specified by the Contractor.

The **Principal** is the party that initiates the project and ultimately pays for it. The Principal may also include an agent or consultant authorised to act for, and on behalf of, the Principal.

The word **shall** indicates a requirement.

The word **should** indicates a recommendation.

1.3.2 Specific definitions

Term	Definition
Adjustment	Operation of bringing a measuring instrument into a state of performance suitable for its use.
Background Fluorescence	The fluorescence at a specified (optical) wavelength of the target fluid without contamination by fluorescent tracer.
Calibration	Set of operations that establish, under specified conditions, the relationship between values of quantities indicated by a measuring instrument or measuring system, or values represented by a material measure or certified reference material, and the corresponding values realised by standards.
Diameter Ratio (β)	The ratio of the throat diameter and the diameter of the cylindrical entrance section of the Venturi at the plane of the upstream pressure tapplings (provided that the pipe and the cylindrical entrance section are identical in diameter).
Differential Pressure (Inlet Throat) dP	Difference between the (static) pressures measured at the wall pressure tapplings, one of which is on the upstream side and the other of which is in the throat of the Venturi tube, inserted in a straight pipe through which flow occurs, when any difference in height between the upstream and downstream tapplings has been taken into account. (DP in some figures)
Discharge Coefficient	The coefficient, defined for an incompressible fluid flow, which relates the actual flow rate to the theoretical flow rate through a device, and is given by the formula for incompressible fluids.
Flow Conditioners	A device that creates a fully developed turbulent flow profile that would have developed otherwise over a straight pipe length of minimal 50 internal diameters.
Froude Number	The ratio of inertial force and gravitational force for a particular phase. NOTE: This is the ratio of kinetic to potential energy of the gas or the liquid.
Gas Volume Fraction (GVF)	The gas volume flow rate, relative to the multiphase volume flow rate, at the pressure and temperature prevailing in that section. The GVF is normally expressed as a fraction or percentage.
Liquid Hold-Up	The ratio of the cross-sectional area in a conduit occupied by the liquid phase and the cross-sectional area of the conduit.
Lockhart-Martinelli Parameter (LM)	The ratio of the liquid Froude number and the gas Froude number.
Mixing Distance	The length of piping over which, by the virtue of flow turbulence, fluids of different constituents upon their delivery are sufficiently mixed for the purpose of measurement. NOTE: Sufficient mixing in the context of this DEP is achieved if the concentration variation is less than 1 %. The minimum mixing distance under optimal conditions is estimated to be minimal 150 internal pipe diameters, which should not be confused with equivalent pipe lengths that are used for friction calculations. Certain piping designs may efficiently achieve adequate mixing with a relatively short mixing distance.
Multi Phase	Fluids which are present in different states of aggregation.
Multi Phase Flow	Two or more phases flowing simultaneously in a closed conduit. NOTE: This DEP deals in particular with multiphase flows of oil, water and gas in a specific region of > 90 % GVF.

Term	Definition
(Pressure Differential) Primary Device	A device introduced into a pipe (that creates pressure differential) in order to facilitate (flow) measurement.
Pressure Tapping	Annular slot or circular hole drilled in the wall of a conduit in such a way that the edge of the hole is flush with the internal surface of the conduit.
Shrinkage	The reduction of volume of a fluid that results from thermodynamical effects. NOTE: The thermodynamic effects that play a role in the context of this DEP are thermal expansion, phase exchange and molecular packing.
Target Fluid	The fluid phase to which a specified tracer will adhere.
Total Fluorescence	The fluorescence at a specified wavelength of the target fluid upon complete mixing with the fluorescent tracer.
Total Pressure Loss	Difference between the (static) pressures measured at the wall pressure tapplings, one of which is at the upstream side and the other of which is 5 internal pipe diameters downstream of the divergent section of the Venturi tube, inserted in a straight pipe through which flow occurs, after any difference in height between the upstream and downstream tapplings has been taken into account.
Tracer Dilution	The reduction of tracer concentration due to mixing with one of the phases in the flow line.
Tracer Induced Fluorescence	The fluorescence at a specified wavelength of the target fluid upon complete mixing with the fluorescent tracer minus the background fluorescence.
Venturi	Device which consists of a convergent inlet, which is conical, connected to a cylindrical part called the "throat" and an expanding section called the "divergent" which is conical.
Water Cut (WC)	The water volume flow rate, relative to the total liquid volume flow rate (oil and water), both converted to volumes at standard pressure and temperature. The WC is normally expressed as a percentage.
Wedge Meter	A (pressure differential) primary device which consists of a wedge type obstruction that is placed in a circular pipe, all to specified dimensions and geometry.
Wet Gas	A flowing multiphase fluid that contains gas to an amount equivalent to GVF > 90 % and that satisfies the criterion of a Lockhart-Martinelli (LM) parameter < 0.35.

1.4 CROSS-REFERENCES

Where cross-references to other parts of this DEP are made, the referenced section number is shown in brackets (). Other documents referenced by this DEP are listed in (5).

1.5 SUMMARY OF MAIN CHANGES

This DEP is a revision of the DEP of the same number dated July 2008. The following are the main, non-editorial changes.

Section	Change
2.	Added schematic and description to show wet gas measurement technique.
3.3	Added new paragraph describing requirements for horizontally installed wet gas flow meters
3.4	Added new section on wet gas flow meter calibration
3.5	Added new section on design and installation considerations
3.6	Added new section on practical considerations

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1.7 DUAL UNITS

This DEP contains both the International System (SI) units, as well as the corresponding US Customary (USC) units, which are given following the SI units in brackets. When agreed by the Principal, the indicated USC values/units may be used.

2. PHILOSOPHY AND BACKGROUND

Wet-gas well flows can be measured by means of Venturis but only if corrected for additional differential pressure, which is caused by the presence of liquids (ref. 1 to 4).

NOTE: In general, condensed water and condensate (heavier hydrocarbons) are present in such flows. Also, formation water can be produced.

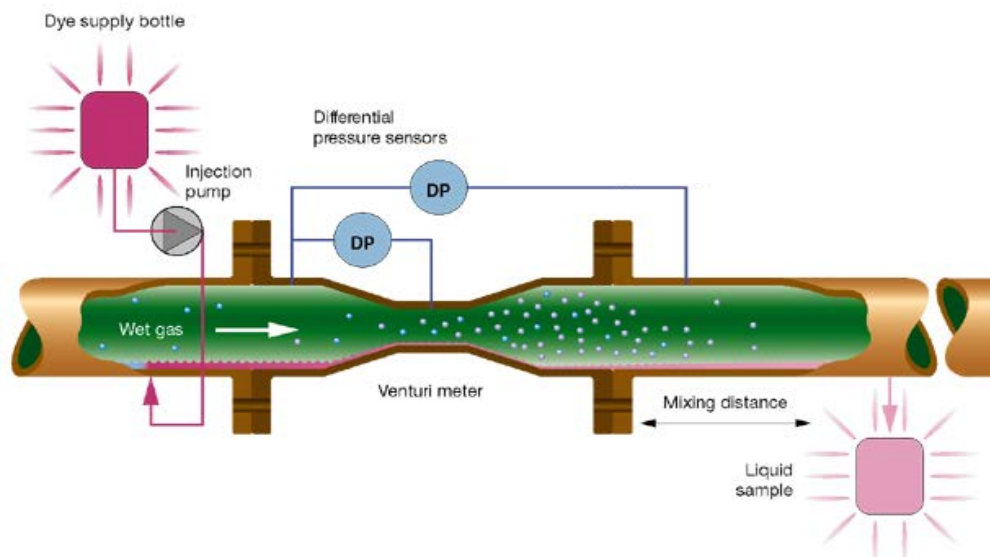
NOTE: Orifice plates and cone meters are also used in wet gas flow measurements. However, their use is for various reasons not recommended.

The application of a Venturi as a wet-gas flow meter requires additional information, which is complicated to obtain (ref. 5). Instead, in-line calibration of the Venturi should be performed by means of the tracer dilution technique (ref. 6 to 12).

The tracer dilution technique can also be applied as a direct oil measurement in a high water-cut well stream (ref. 9).

A schematic overview of the wet gas measurement technique described in this DEP is shown below.

NOTE: The figure is for schematic information only. For example, the liquid sample point is preferably not positioned on the bottom of the pipe, (4.4.1).



As wet gas metering and its applications are relatively new, it is recommended that additional advice is sought from the Principal.

The objectives for measuring the wet gas flow rates should be found in the project metering and allocation philosophy.

3. FLOW METER DESIGN REQUIREMENTS

A wet gas flow meter designed in accordance with this DEP shall consist of a Venturi flow meter with an optional wedge flow meter downstream of it. The wedge flow meter can provide necessary isolation of dP_2 measurements from downstream effects. Moreover, this two-meter configuration provides redundant information, which in theory allows liquid load monitoring.

The unit should be periodically calibrated by means of the tracer dilution technique.

3.1 VENTURI FLOW METER

The Venturi shall be constructed according to ISO 5167 with the divergent section declining at an angle of 7° (ref. 4 and 15).

NOTE: The differential pressure inlet-throat, often referred to as dP_1 , is insufficient to determine both gas and liquid flow rates. To obtain two unknowns, at least two equations are required. To that end, it is possible to use the total pressure loss (inlet-outlet) differential pressure, often referred to as dP_2 , as the liquid loading of the flow also influences this differential pressure. In order to achieve this, it is essential that both dP_1 and dP_2 can be predicted accurately as a function of the flow rates and the physical properties of the fluids. This has been achieved for dP_1 (ref. 3), but only to a lesser extent for dP_2 (ref. 14). Because the geometry of the Venturi plays a role as well, the design of the Venturi should follow rules stricter than those described in ISO 5167.

Fluid properties play a likely role in Δp_2 . Due to the incompleteness of the current theoretical model for the total pressure loss, experimental data is still to be relied on, which dictates the angle of the divergent section. Larger angles result also in larger fluctuations of dP_2 , probably because of boundary layer separation. This has been shown in the divergent section of a Venturi with a 15° angle (ref. 4, 15, 16 and 17). Venturis with a 7° angle of the divergent section have shown smaller variances in the dP_2 readings (ref. 18 and 19).

The downstream pressure tap that facilitates the total differential pressure measurement dP_2 shall be mounted 5 internal pipe diameters (5D) downstream of the end of the divergent section of the Venturi. The dP_2 pressure tap shall have the same properties (internal diameter, angle to pipe surface, surface finishing, etc.) as the pressure tap at the inlet of the Venturi as described in ISO 5167. The internal diameter of the pipe section on which the dP_2 tap is mounted shall have the same internal diameter as the inlet of the Venturi (ref. 18).

The upstream length of the Venturi shall comply with ISO 5167.

The Venturi and its upstream and downstream lengths shall be mounted horizontally (4.3.2).

NOTE: In order to reduce uncertainty, the upstream length should be maximised.

The Venturi shall be installed at the highest part of the installation and be self-draining.

"Flow conditioners" shall not be used.

NOTE: The Δp_2 is in most cases smaller than dP_1 and it is sensitive to the installation. Important aspects are:

- The internal diameter of the pipe to which the dP_2 tapping is mounted.
- The hold-up of liquid near the dP_2 pressure tap.

The first aspect can easily be understood: if the internal diameter of the pipe is different, the fluid velocity will be different and because of Bernoulli's law, the pressure will be different. This was reported during the K-lab tests in 2004 (ref. 18).

The second effect leads to two contributions: the liquid hold-up will change the gas velocity (ref. 15) and thus to a different pressure, similar to the first item, but it will also create a different gas-liquid interface, which will lead to a different pressure gradient. As the Δp_2 tap is mounted 5 D downstream of the end of the divergent section, there is a noticeable pressure drop between the end of the divergent section and the dP_2 pressure tap.

Under laboratory conditions, the outflow of the fluids is well defined, steady and stable. This is not necessarily the case in practical implementations, which may affect dP_2 especially.

3.2 WEDGE FLOW METER

Optionally, a wedge flow meter can be installed 12 D downstream of the end of the divergent section of the Venturi (and thus 7 D downstream of the dP_2 pressure tap) so as to isolate the dP_2 measurement from the influences of disturbances downstream of the meter run.

The wedge flow meter shall be installed in the horizontal metering section.

The wedge shall be placed at the top of the pipe, pointing downwards as is shown in (Appendix 2).

The differential pressure across the wedge flow meter should be minimal 10 kPa (2 psi) at the lowest specified flow rate and should be estimated from the "homogeneous model", which assumes the fluid in the flow line to be a homogeneous mixture, with the liquids distributed as small droplets in the gas with a flow rate weighted density.

NOTE: In this configuration, the liquids, which flow mainly at the bottom of the pipe, will tend to acquire their natural hold-up level, thus minimising effects on the dP_2 measurement. It is possible to measure the differential pressure across the wedge meter as well for the purpose of monitoring. The β -ratio of the wedge meter has to be chosen so that the wedge meter can act as isolator. There is a trade-off: the smaller the β -ratio, the better it acts as isolator, but the higher the permanent pressure loss over the meter.

$$Q_t = Q_g + Q_c + Q_w \quad (1)$$

$$\rho_t = \frac{Q_g \rho_g + Q_c \rho_c + Q_w \rho_w}{Q_t} \quad (2)$$

in which:

Q_t	=	Total volumetric flow rate under line conditions	m^3/s
Q_g	=	Volumetric flow rate of gas under line conditions	m^3/s
Q_c	=	Volumetric flow rate of condensate under line conditions	m^3/s
Q_w	=	Volumetric flow rate of water under line conditions	m^3/s
ρ_t	=	Weighted average density of fluid in the flow line	kg/m^3
ρ_g	=	Density of gas at line conditions	kg/m^3
ρ_c	=	Density of condensate at line conditions	kg/m^3
ρ_w	=	Density of water at line conditions	kg/m^3

The discharge coefficient of a wedge meter should be taken as approximately 0.65 and

$$\Delta p = \frac{Q_t^2 (1 - \beta^4) \rho_t}{2 C_d^2 \beta^4 A_D^2}$$

ε as 1. From above equation, the β -ratio can be derived:

$$\beta = \left[\frac{Q_t^2 \rho_t}{2 \Delta p C_d^2 A_D^2 + Q_t^2 \rho_t} \right]^{\frac{1}{4}} \quad (3)$$

in which:

Δp	=	Differential pressure	Pa
β	=	Beta-ratio of wedge meter	
C_d	=	Discharge coefficient	
A_D	=	Cross sectional area of pipe	m^2

The β -ratio of a wedge flow meter is given as:

$$\beta = \left[\frac{1}{\pi} \left[\frac{\pi}{2} + (1-g)\sqrt{2g-g^2} + \text{TAN}^{-1} \left(\frac{1-g}{\sqrt{2g-g^2}} \right) \right] \right]^{\frac{1}{2}} \quad (4)$$

from equations (3) and (4) the ratio $g = h / r$, (wedge height over internal pipe radius) can be resolved and is shown in (Appendix 2).

NOTE: For example, in Venturis, the β -ratio is defined as the ratio of the throat diameter and the pipe diameter. In order to get comparable figures for the β -ratio of a $\Delta\rho$ flow meter with a different geometry, the β -ratio is defined as the square root of the ratio of the area, available for the flow at the restriction and the pipe cross sectional area A_D . This definition would result in the same β -ratio for Venturis. By using $g = h / r$, β can be derived in accordance with the above, see (Appendix 2).

Table 1 β -ratio of a wedge meter as a function of the depth of the wedge

g (= h / r)	β-ratio
0.700	0.8295
0.800	0.7915
0.900	0.7507
1.000	0.7071
1.100	0.6606
1.200	0.6112
1.300	0.5585
1.400	0.5023
1.500	0.4422
1.600	0.3773

3.3 PRESSURE TAPPINGS

The diameter of the impulse lines shall be in compliance with ISO 5167 and be limited to 10 mm (3/8 in) maximum.

NOTE: If the (*throat diameter*) d is greater than or equal to 33.3 mm (1.31 in), the diameter of these tappings shall be between 4 mm (0.16 in) and 10 mm (0.40 in) and moreover, shall never be greater than 0.1 (*times the internal pipe diameter*) D for the upstream tappings and 0.13 d for the throat pressure tappings.

The upstream, throat, and downstream recovery pressure tapping diameters shall be equal.

If d is less than 33.3 mm (1.31 in), the diameter of the throat pressure tappings shall be between 0.1 d and 0.13 d and the diameter of the upstream pressure tappings shall be between 0.1 d and 0.1 D .

Pressure tappings should be as small as is compatible with the fluid to be used (for example, with its viscosity and cleanness).

Due to the potential for liquid being trapped in the impulse lines, horizontally installed wet gas flow meters shall have pressure tappings on the top part of the pipe to reduce the likelihood of impulse line flooding and to increase the chances of any trapped liquids draining.

The impulse lines shall be sloping down continuously from the differential pressure transmitter to the process. (Refer to Standard Drawing S37.001-225). To facilitate self

draining the process isolation valves shall be full bore ball valves, and the impulse line internal diameter shall not be smaller than 10 mm (1/2 in).

Where the formation of hydrates are expected, appropriate heat tracing of the impulse lines shall be effected.

3.4 WET GAS FLOW METER CALIBRATION

The meter shall calibrate in the horizontal position over the full flow range.

3.4.1 Dry gas calibration

The Venturi meter shall be calibrated under single phase dry gas conditions to establish the discharge coefficient (C_d) and the dP_2/dP_1 ratio when no liquid is present. This is required as the actual values cannot be accurately predicted.

NOTE: For example, ISO 5167 states that the actual discharge coefficient can vary by $\pm 3\%$ for flows having high Reynolds numbers, which is generally the case in high pressure natural gas flows.

3.4.2 Wet gas calibration

The over-reading can be predicted by published correlations. In this DEP, the correlation of De Leeuw is recommended. However, the prediction of the dP_2 behaviour in the presence of liquid is less well understood. The dP_2 behaviour shall be determined in a wet gas test facility over the full liquid loading range for various gas flow rates and line pressures. As the readings are repeatably between similar sized meters, only 1 meter for a batch of meters with a similar design is required to be tested.

3.4.3 Secondary instrumentation

All pressure, differential pressure, and temperature transmitters used shall be calibrated.

3.5 DESIGN AND INSTALLATION CONSIDERATIONS

The reasons for measuring wet gas is established in the metering and allocation philosophy.

3.5.1 Fluid sampling

The requirement for fluid sampling should be discussed between the design team, the wet gas flow meter data users, and the selected meter Supplier at the start of the design stage.

The meter operator and the design team should understand any specific contractual requirements that would require fluid sampling (and the subsequent frequency of that sampling), government regulators, or internal data requirements used for reservoir surveillance and maintenance activities. Confirmations of these requirements need be identified and documented.

NOTE: Obtaining representative fluid samples from a wet gas flow is significantly more difficult than obtaining representative fluid samples from a single phase flow. As a wet gas flow is a multi-component stream which can contain gas with water and hydrocarbon liquids, there is a significant challenge in assuring that any given sample contains all the components of the multi-component flow. With standard wet gas sampling techniques, the general aim is solely to achieve a sample which contains all the component fractions that are present in the flow.

The term "representative sample" is common throughout industry to describe the desired quality of a wet gas sample. However, this term is not defined and there are two different meanings assigned to the term. Some consider a "representative sample" to be a sample in which all components of the flow are present in the sample. But, the ratio of components in the sample do not have to be 'representative' of the components phase flow rate fraction (i.e., "phase fraction"). The sample allows that components fluid properties to be assessed and accounted for. Others consider a "representative sample" to be a sample in which all components of the flow are present in the sample and that the sample contains representative phase fractions. Such a sample is also called an iso-kinetic sample. Achieving iso-kinetic sampling is a great challenge. There are systems on the market but they are not generally independently tested and reviewed in the public domain. It is advised that operators wishing to employ iso-kinetic wet gas sampling techniques discuss the technology with metering community specialists and possibly access the technology at a wet gas flow test facility.