WET GAS METERING BY ISOKINETIC SAMPLING

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ABSTRACT

In the present paper, a multiphase flow meter based on the isokinetic sampling method is described. This technology already has a number of successful installations worldwide and its design has now been updated in order to reduce its dimensions and to make the meter suitable for subsea applications.The first field application of this meter dates back to 2002 and regards the Allegheny platform in the Gulf of Mexico, where an 8" meter was installed by TEA Sistemi. This has been the first worldwide installation of a Wet Gas Meter (WGM) able to measure the flow rates of two liquid and the gas phases, with an excellent accuracy. Since then, a significant number of isokinetic sampling meters have been installed by this company. Noticeable applications have been a 12" meter able to detect liquid volume fractions less than 2.0 E - 05% and a 16" meter, which is the largest WGM ever built. The main limitation of this meter is related to its size and weight which are larger than other WGMs. In order to overcome this potential limitation of the VEGA meter, a newly designed meter, the VIS meter, has been developed by TEA Sistemi in cooperation with ABB, the provider of the conventional instrumentation adopted in these meters. In the new meter described in the present work, a substantial size and weight reduction has been obtained by increasing the separation efficiency and incorporating the instrumentation and valves into the main body of the meter. The final dimensions of the meter are now comparable or less than those of the other WGMs available on the market.

1. INTRODUCTION

The flow meter presented in this paper is based on the isokinetic sampling of the gas-liquid mixture, followed by separation and metering of the individual phases. When compared with other WGMs available on the market, the main advantages of this meter are its excellent accuracy, also at extremely low liquid volume fractions, the possibility of self-calibration, the exclusive use of conventional field instrumentation, with no radioactive sources, and the very wide range of gas and liquid flow rates that a single meter can handle [1, 2].

The development phase of the meter and the preliminary tests carried out at Trecate field, in Italy, with a 2" prototype are described in [1]. In these experiments the self calibration features of the VEGA were fully tested and appear to be a unique characteristic of this flow meter. On the basis of these results, a full scale MPFM was installed in Allegheny TLP, GOM, in August 2002, for production allocation and monitoring. In this application VEGA measurements have been compared with data obtained with a conventional well testing system, certified for production allocation [2].

Typical applications of the VEGA meter cover the GVF range 85%-100%. At present a R&D project is under way, with the objective of extending the operating range of VEGA to the case of Low GVF. This extension requires the use of a different sampling section, which is under development at TEA Laboratory.

The results obtained at Trecate Field and mostly in the Allegheny installation, indicate that the conventional sampling section used for large GVF is able to detect with an excellent accuracy both the overall liquid flow rate and the water flow rate when the liquid volume fraction is as low as 0.2% and the WVF as low as 0.02%. These values of the LVF and WVF are close to the detection limits of other wet gas meters on the market

The excellent results obtained with the Allegheny installation allowed a more severe application: the measurement of the liquid carry-over from a dehydration column operated by STOGIT, in Ripalta, Italy. In this application the minimum LVF to be detected was set to 2.0 E - 05% and the expected accuracy was 10% of the actual liquid flow rate. The excellent results obtained with this installation are reported in [3].

2. DESCRIPTION OF THE FLOWMETER

A schematic diagram of a conventional VEGA meter is shown in Fig. 1. The main components are

- The sampling section.
- The multiphase orifice.
- The gas-liquid separator.

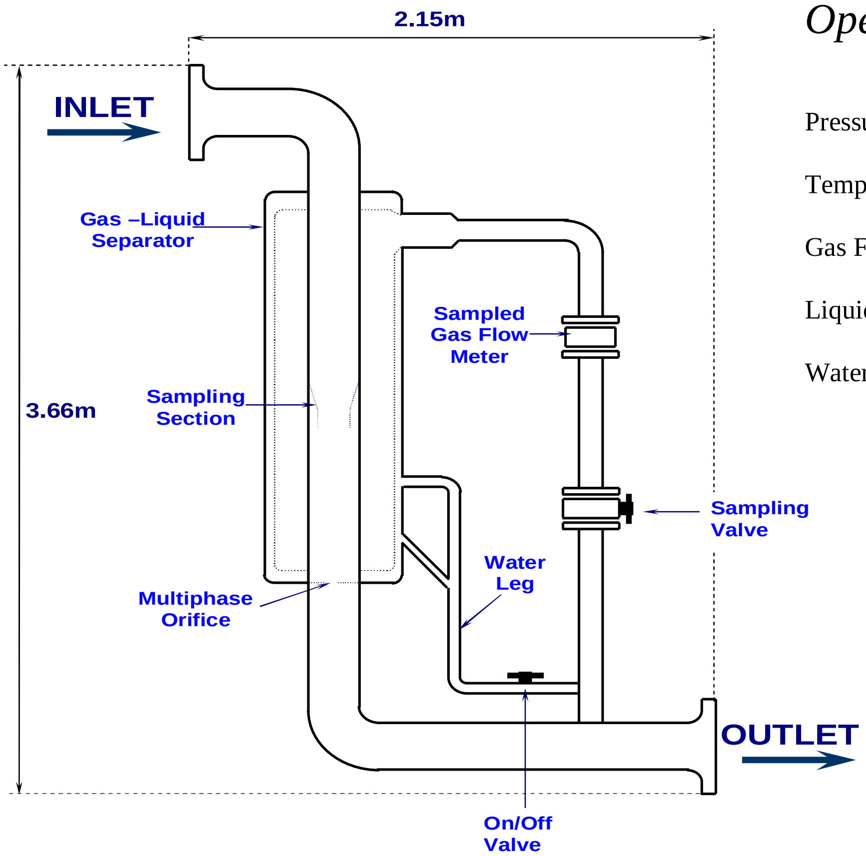
As shown in Fig. 1, the flow in the meter is directed downward and the sampling section precedes the multiphase orifice. Multiphase samples are fed to the separator and then re-injected into the pipe, after the orifice. This means that only part of the total flow passes through the orifice, unless sampling is stopped by closing the flow control valve, also shown in Fig. 1.

Sampling is performed with a multi-port probe in a section of the pipe where the phase velocities are uniform [1]. The fraction of the total flow rate which is sampled is defined as the sampling ratio, r_A. Isokinetic sampling requires that the individual phase velocities at the probe inlet ports be equal to the average phase velocities in the sampling section. In this case the ratio between the sampling probe flow area A_P, and the pipe flow area at the sampling section, A_S, is equal to the sampling ratio,

$$\frac{A_P}{A_S} = r_A \qquad (1)$$

Typical values of r_A are close to 0.1. The sample flow rate is set with a flow control valve.

The sampled gas flow rate is measured with a conventional gas flow meter. For instance in Allegheny, a Vortex meter was used, while in Ripalta an orifice meter . The sampled liquid flow rate is computed from the time required to fill a given volume of the gas-liquid separator. In Allegheny installation, this volume included the Water Leg, a short pipe 6” in diameter located at the outlet of the main vessel where the aqueous phase (water-methanol) was collected. In this application, three differential pressure transmitters were used to determine the fill-up time of different parts of the separator. The same transmitters allowed the densities of the two liquid phases and of the liquid mixture to be determined from the measurement of the static head at different positions in the water leg and in the main vessel. The direct measurement of the density of the aqueous phase allows both the water and the methanol flow rates to be determined with a very good accuracy.



Operating Data

Pressure 150 bar	
Temperature	(-)10 ÷ 90 C
Gas Flow	70 ÷ 500 KSm3/d
Liquid Flow	0 ÷ 470 m3/d
Water Cut	0 ÷ 100 %

Figure 1. Schematic diagram of Allegheny VEGA.

When measuring extremely low liquid volume fractions, like in Allegheny and Ripalta installations, the accuracy of liquid flow rate measurements largely relies upon a complete separation of fine droplets entrained by the gas. In order to achieve complete separation of the entrained liquid, a set of swirl separators was used. The geometry of this separator was optimized with a 3-D simulation of the flow field and the final geometry was tested in a set of laboratory experiments which indicated that the separation efficiency of droplets with diameter $\leq 5\ \mu m$ was better than 99%.

2.1 Multiphase orifice

Single phase flow through an orifice can be described by the equation

$$Q = a\,A\sqrt{\frac{2\,\Delta p/\rho}{1-\eta^4}} \quad , \tag{2}$$

where Q is the volumetric flow rate, a is the discharge coefficient (constant for large Reynolds numbers), ρ is the fluid density, A is the restricted flow area and η is the orifice to pipe diameter ratio.

Gas-Liquid flow through a flow restriction can be modelled using the equation proposed by Murdoch [4]

$$\frac{\Delta p_{TP}}{\Delta p_G} = 1 + c\,\chi + \chi^2 \quad , \tag{3}$$

where ΔP_{TP} represents the pressure drop through the orifice, χ is the Martinelli parameter defined as

$$\chi = \frac{\Delta p_L}{\Delta p_G} \quad , \tag{4}$$

and Δp_L, Δp_G are the pressure drops when the same mass flow rate of liquid or gas flows alone through the orifice. For conditions typical of wet gas flow in pipes, the simplified equation

$$\left(\frac{\Delta p_{TP}}{\Delta p_G}\right)^{1/2} = 1 + m\left(\frac{\rho_L}{\rho_G}\right)^n H_L \tag{5}$$

can be adopted, where $H_L = Q_L/Q_G$ is the non-slip liquid volume fraction. In Eq. (5) the two constants m and n can be tuned on the basis of the results of a set of tests carried out at conditions similar to those encountered in specific applications. It is also possible to derive these constants on the basis of a set of tests performed with a meter operating at actual field conditions according to the self-calibration procedure described in Section 2.2.

It should be noticed that at very low LVFs, as it is the case in Allegheny and Ripalta installations, the effect of the liquid flow rate on the gas pressure drop through the orifice is negligible. Therefore, the knowledge of the adjustable parameters in Eq. (5) is not required.

2.2 Isokinetic Sampling

Isokinetic sampling is an experimental method adopted for the measurement of the local phase velocities in multiphase flow systems. The method is based on the use of a sampling probe which can simply be a tube of small diameter placed parallel to the main flow direction at a desired radial position. The sampling probe is connected to a gas-liquid separator and the gas-liquid sample is continuously extracted. When sampling is isokinetic the flow field around the probe is not modified by the sampling operation.

The VEGA meter uses isokinetic sampling and phase separation to determine the gas and liquid flow rates. This can be accomplished with an efficient mixing of the two (three) phases at the sampling section and by means of a multi-port probe located at a position of the sampling section where the velocity profiles of the gas and the liquid phases are uniform (note that the mean gas velocity at the sampling section may be different from the mean liquid velocity) [1].

Isokinetic sampling conditions are established in the meter by setting the flow control valve at such a position that the ratio between pressure drops through the multiphase orifice in presence of sampling, $\Delta p_{TP,S}$ and without sampling, Δp_{TP} , be equal to

$$\frac{\Delta p_{TP,S}}{\Delta p_{TP}} = (1 - r_A)^2 \tag{6}$$

To give an example, for $r_A = 0.1$ the ratio between pressure drops must be equal to 0.81. Following this procedure, the actual gas and liquid flow rates can be immediately derived without using the orifice calibration equation, Eq. (5). If different flow conditions are tested with this method in a field installation, it is also possible to derive the constants of Eq. (5) and achieve a reliable self-calibration of the meter.

Eq. (6) can be justified considering that according to Eq. (5), when sampling is performed without altering the density ratio and the liquid volume fraction, it is found that

$$\frac{\Delta p_{TP,S}}{\Delta p_{G,S}} = \frac{\Delta p_{TP}}{\Delta p_G} \quad . \tag{7}$$

From this relation, recalling the single phase orifice equation, Eq. (2), it follows that

$$\frac{\Delta p_{TP,S}}{\Delta p_{TP}} = \frac{\Delta p_{G,S}}{\Delta p_G} = \left(1 - \frac{q_G}{Q_G}\right)^2 \ . \tag{8}$$

A comparison between Eqs. (6) and (8) shows that, when sampling is isokinetic, $q_G / Q_G = r_A$. As discussed above a similar equation, $q_L/Q_L = r_A$, holds for the liquid even when sampling is not exactly isokinetic, if the liquid distribution and velocity in the sampling section are uniform.

As r_A is a fixed geometric parameter, the overall gas and liquid flow rates can be immediately obtained from the sampled gas and liquid flow rates as

$$Q_G = q_G / r_A \tag{9}$$

$$Q_L = q_L / r_A \ , \tag{10}$$

under the condition that sampling is isokinetic, without using any empirical correlations.

3. Results of the Allegheny Installation

In Figs. 2 and 3, daily productions of gas and total liquid measured with VEGA are compared with the measurements of the conventional WTS over a period of 2 months. As can be seen from these figures, the two sets of measurements (VEGA and WTS) almost coincide, with a mean absolute difference between the readings of less than 1% (0.8%) for the gas and less than 2.5% (2.2%) for the total liquid.

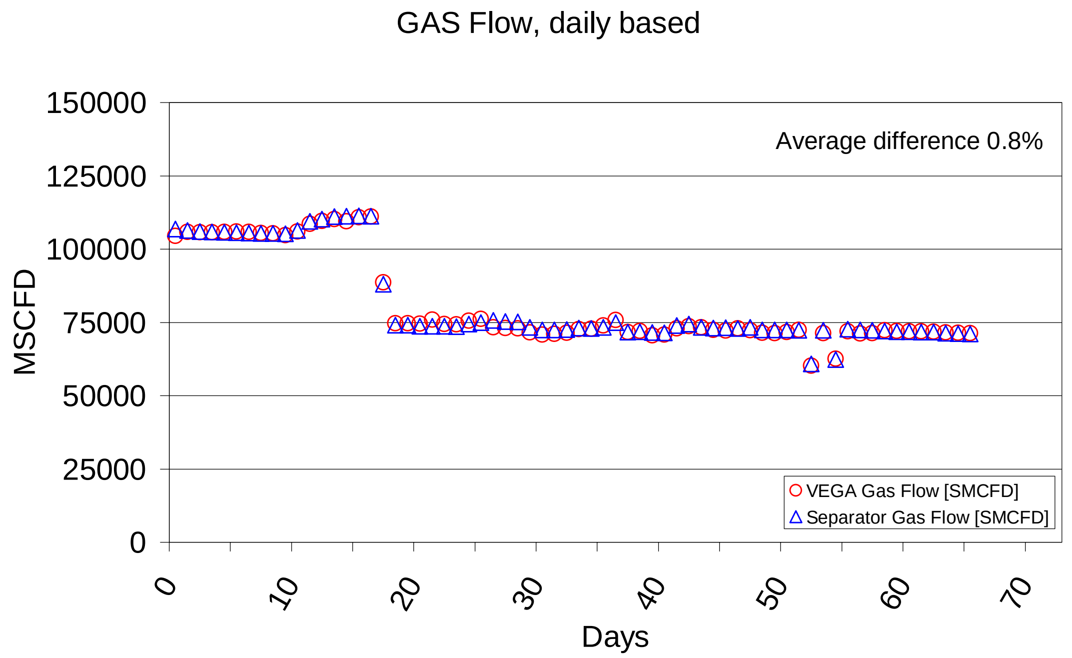


Figure 2. Comparison between gas flow rates.

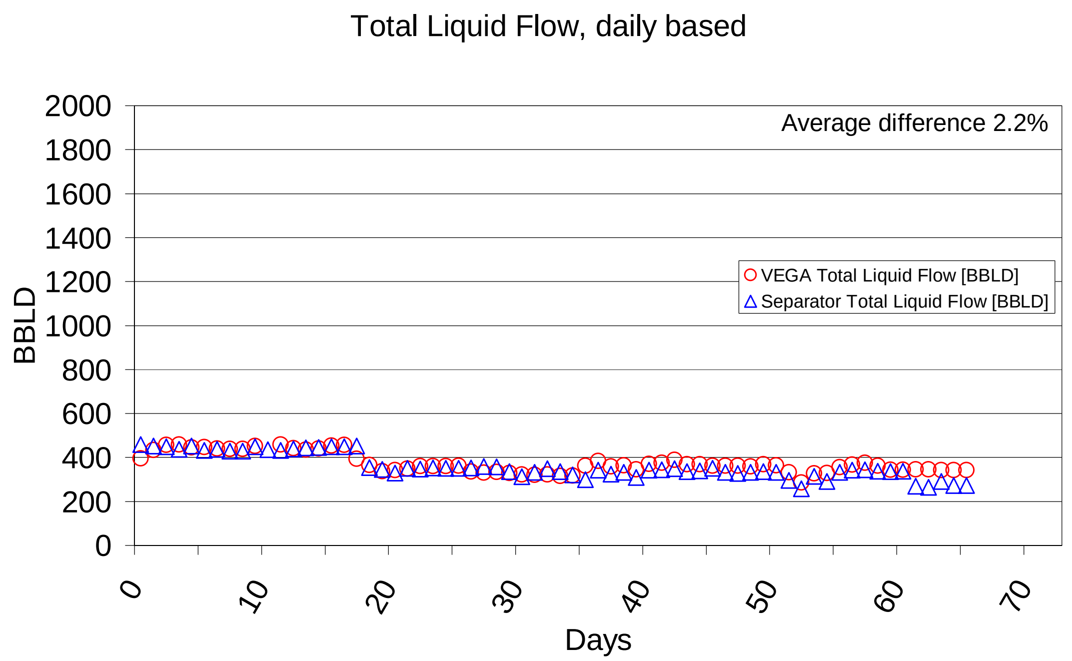


Figure 3. Comparison between total liquid flow rates.

The difference between the measurements of the total liquid seems to depend on two contributions:

- A positive systematic difference of about 1.0% of the VEGA readings with respect to the WTS.
- A random difference slightly above ± 1%.

The systematic difference can easily be removed by introducing a correction factor, but it seems possible that this difference be due to the better efficiency of the gas-liquid separator installed in the VEGA meter. It is then difficult to decide which reading should be corrected. The difference between gas flow rate measurements appears to be completely random.

The flow rate of the water phase has been measured with two different methods using the differential pressure transmitters installed at various positions in the main vessel and in the water leg. The first method implemented was based on the measurement of the density of the liquid mixture, besides to the direct measurement of the densities of the two liquids. This method is not accurate enough, even if the errors in terms of water-cut are acceptable (1-2% absolute error for the water-cut, which becomes 10-20% when the flow rates of the water phase are compared). It was then decided to measure directly the flow rate of the water phase from the fill-up time of the water leg. The condensate flow rate is obtained by subtracting the aqueous phase flow rate from the total liquid flow rate. Using this method, the accuracy of individual condensate and water flow rate measurements is better than 5%. The results obtained along with the mean scatter of these measurements are reported in Fig. 4. From this figure it can be noted that in a few cases the difference between VEGA readings of the water flow rate and the reference values becomes relevant. These discrepancies were due to the occasional malfunctioning of the water flow meter installed in the WTS.

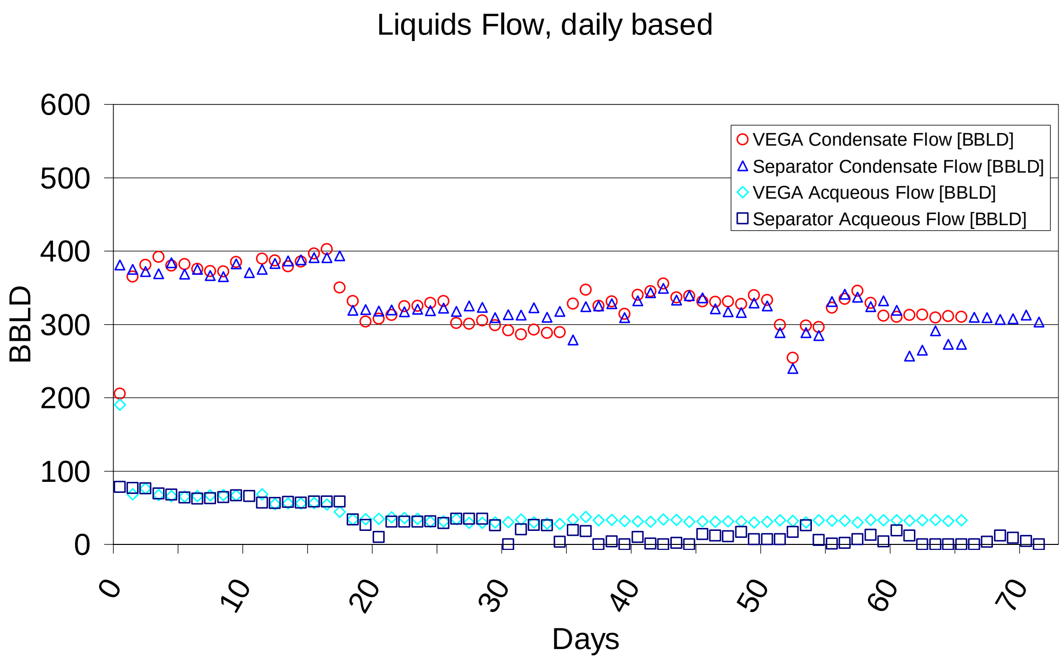


Figure 4. Comparison between condensate and water flow rates.

4. VIS METER

The VIS (VEGA Isokinetic Sampling) meter directly stems from the VEGA meter. The main objectives behind its development have been to realize a consistent reduction in size and adapt VEGA to subsea applications. The VIS meter has been developed by TEA Sistemi, with the support of ABB, the supplier of the meter instrumentation. The reduction in size went through the following steps:

Re-design of the separator. In Fig. 5 a schematic diagram of the new flow meter is shown. As can be seen from this figure, the new system consists of five parts welded together: two clamp-on flanges, A, two short cylinders, B, and a large diameter pipe, C. The cylinders support the main flow pipe, the sampling section, the sample reinjection section, the sampled gas flow meter (typically a Venturi meter) and the two valves required by the measuring system, the liquid discharge valve and the pressure control valve. In the conventional system, the two valves and the sampled gas flow meter are mounted outside of the separator. This increases the overall weight and size of the system.

Reduction of the liquid accumulation volume. In the VEGA meter, in order to avoid any type of liquid level control, the liquid flow rate is measured by determining the time required to fill up a given volume of the gas-liquid separator, which is entirely emptied after the filling-up period. Clearly, the larger is the filling-up time, the more accurate is the measurement of the liquid flow rate. An identical result can be obtained by averaging repeated measurements of the filling-up time. To this purpose, the software governing the system provides both the last reading of this time and a moving average over the last n readings. The user is allowed to fix a different value to n, according to the actual value of the filling-up time.

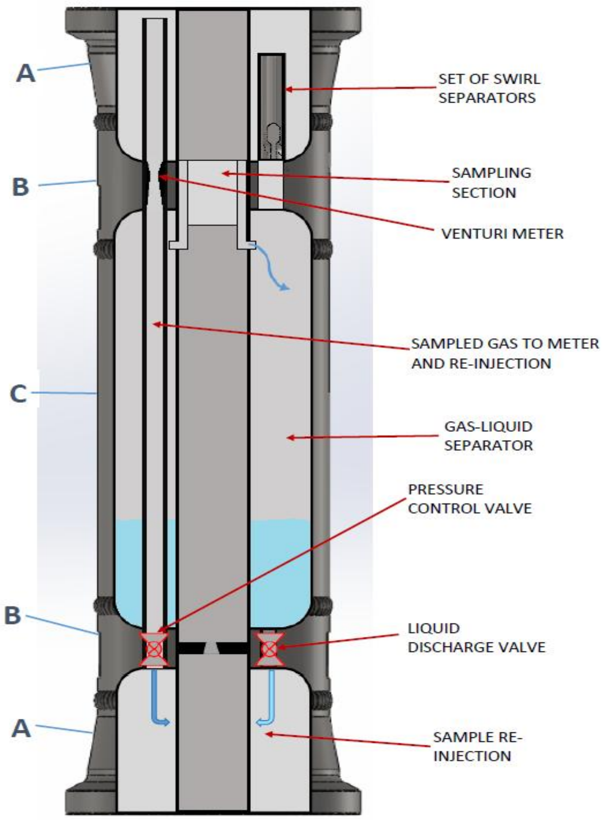


Figure 5. Main features of the VIS meter.

The use of short filling-up times implies that also the gas-liquid and the liquid-liquid separation times are limited. A possible consequence is that the measurement of the densities of the two liquids may be affected by significant errors. In order to face this potential problem, the system has been designed in order to operate even if the separator is flooded with liquid. This allows the sampling time to be increased without limit, up to the time at which the density readings in the separated water and liquid hydrocarbon phases reach constant values. At this time, the separator is emptied and the cycle can be started again.

Compact gas demisters. The reduced dimensions of the separator obliged to a further modification of the system. In VEGA the separation of the liquid entrained by the gas is performed with a set of carefully designed swirl separators. The typical diameter of the swirl separators adopted in the previous VEGA meter was 50 mm. and their length 500 mm. As the separation efficiency depends on the centrifugal force established within the separator and this force is inversely proportional to the diameter, a larger gas velocity can be allowed in a smaller diameter separator. In practice, a reduction of diameter to 30 mm allows the length of the separator to be reduced to 300 mm and causes approximately a 50% reduction of the maximum flow rate through a single separation unit. This flow reduction can be compensated by an increase of the number of units, say from 5 to 10, with the final result that the overall efficiency of the demister is maintained.

The final design of the VIS meter is shown in Fig. 6, where the new and old versions of the meter are compared for the same application.

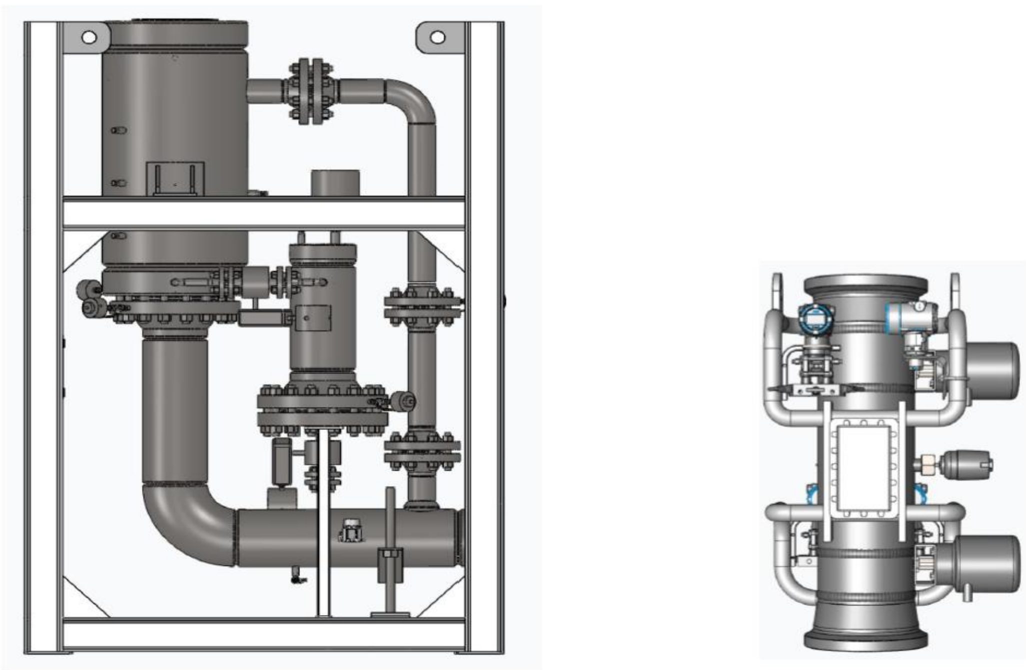


Figure 6. Comparison between the VEGA and VIS meters for the same application.

5. CONCLUSIONS

An extensive set of field tests reported in previous papers [1,2] showed that the VEGA meter is particularly suited for wet gas metering and is characterized by an excellent accuracy. It should also be pointed out that the meter is self-calibrating. Preliminary tests also indicated that the VEGA meter can be safely adopted as an oil production meter.

The Allegheny installation described in the present paper was characterized by very challenging operating conditions: large gas velocities, pressure above 100 Bar and very low condensate and water volume fractions (< 0.2 – 0.3%). In Allegheny, the water flow rate has been determined with an uncertainty of less than 3-4%. If this result is expressed in terms of absolute uncertainty of the water volume fraction, a value of the uncertainty equal to 0.001% is found.

The main limitation of the VEGA meter when compared with other multiphase flow meters available on the market is related to its size and weight. In the present paper, it is shown that this limitation can be removed with a careful design of the meter. In particular, the liquid accumulation volume can be reduced, without losing in accuracy. The valves required for process control and the sampled gas flow meter can be incorporated into the body of the meter. The volume occupied by the gas demister can also be reduced by adopting smaller size swirl separators and finally the meter does not require to be skid-mounted, at least for the smaller sizes, as it happens with other WGMs. The final size of the new VIS meter is now comparable to, or smaller than, the size of the other commercial meters.

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