V-CONE TECHNOLOGY

DP Metering for the New Millennium

Philip A Lawrence
McCrometer, Inc.
Kingwood, TX 77345

Introduction

For many years, differential pressure meters were the only devices available, for measuring volumetric flowrate in a pipe with reasonable accuracy. This family of meters holds the largest share of the market even today.

A more recent addition to this technology is the V-Cone differential pressure meter, which uses a centrally mounted cone to generate a DP. The purpose of this paper is to outline the characteristics of the device, its unique design construction and operation.

History of (ΔP Measurement)

Differential pressure devices have been commercially used with great success for about 85 years. The first experiments being made by Bernoulli during the 1740's from which the Bernoulli principle was derived, this lead to the concept of a flow nozzle by Venturi and subsequently the orifice plate, which is used today worldwide.

Development of these devices has continued with refinements in size, body geometry, inlet /outlet parameters, removable plates and edge profiles. It was only recently that the concept of compressing the fluid to the center of the pipe was radically changed to compression at the pipe wall using a cone, (circa 1986).

Further development of this idea with removable (insertion top plate) cones was designed a few years later. The latest device being a wafer meter with field removable cones.

Basic Principles

In general, differential pressure meters rely on the fact that if a fluid flows through a constriction it must accelerate. This causes its kinetic energy to increase and therefore its pressure to fall by a corresponding amount in accordance with the principle of the conservation of energy. (Total energy in a closed system being a constant).
See Fig 1:

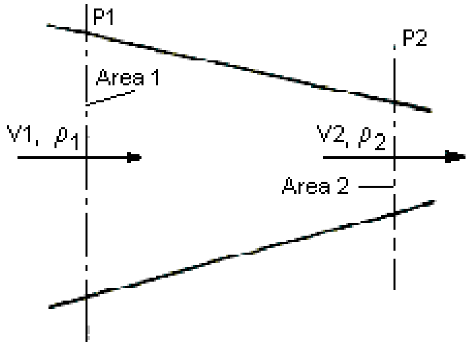


Fig 1

A fluid at mean velocity v_1, and density, ρ_1, passes a X-sectional area of A_1, it then also passes the smaller X-sectional area A_2, at v2, and ρ_2.

By application of Bernoulli's equation and the principle of continuity between these two sections then it can be shown that for an ideal and incompressible fluid:

$$Q_V = \frac{A_2}{(1 - m^2)^{½}} \left(\frac{2\delta P}{\rho_1}\right)^{½}$$

m = ratio A_1 / A_2 & $\delta P = P_1 - P_2$

If the fluid concerned is compressible, (example a gas) then, a second empirical coefficient, or “Expansion Factor” must be introduced, this depends on the physical characteristics of the gas being measured as well as the geometry of the flowmeter. For practical use the equation would then become:

$$Q_V = \frac{C\epsilon A_2}{(1 - m^2)^{1/2}} \left(\frac{2\delta P}{\rho_1} \right)^{1/2}$$

ε = adiabatic expansion factor   C = coefficient of discharge

When high accuracy is required circa +/0.5% of rate, the coefficient, C, must be found by calibration of the meter over a range of flowrates and corresponding Reynolds numbers.

If an accuracy of between +/-1~2% is acceptable then the value of C, can be obtained from national and international standards, (Orifice & Venturi Meters).

V-Cone devices are always calibrated when good accuracy is needed (circa +/- 0.5% of flowrate) this is generally carried out at the manufacturer or at an independent laboratory traceable to NIST or National Standard.
A repeatability of +/- 0.1% the norm for this type of unit at 8000 Re and above.

Venturi & Orifice General Concepts

The Venturi meter or tube is the original form of the ΔP meter. (Strictly speaking the “Venturi-Tube is the primary device and the name ‘Venturi-meter’ refers to the combination of primary and secondary) *see fig 2*

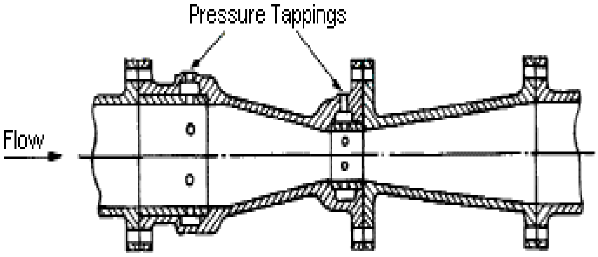


Fig 2

Generally, Venturi meter discharge coefficients are near to unity however, this may change due to wear and usage.

The Orifice Plate is simply a plate with a concentric hole (or not so concentric) forming a partial obstruction to the flow, large amplitude eddies are formed downstream which can reduce the turndown and accuracy of the device.
See fig 3 :

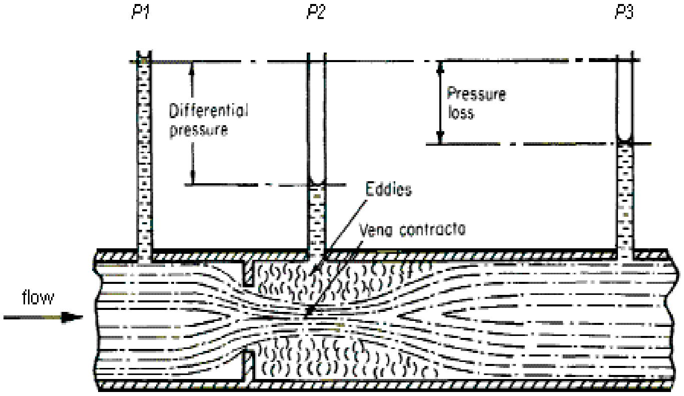


Fig3

V-Cone Meter General Concepts

The V-Cone meter comprises of a centrally mounted cone with the major apex facing the flow, a cone with a more acute angle is fixed to the trailing edges of this cone to allow a smooth transition of the flow into the low pressure zone, downstream. Upstream pressure tapings (pipe wall) and downstream (cone center) are used to obtain the DP across the cone. *See fig 4*

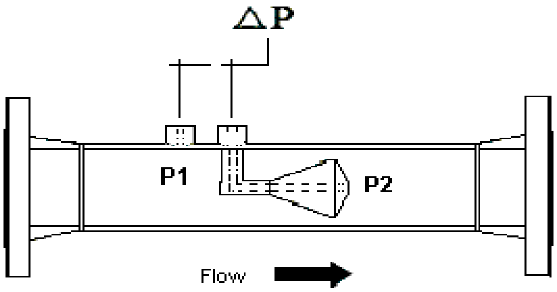


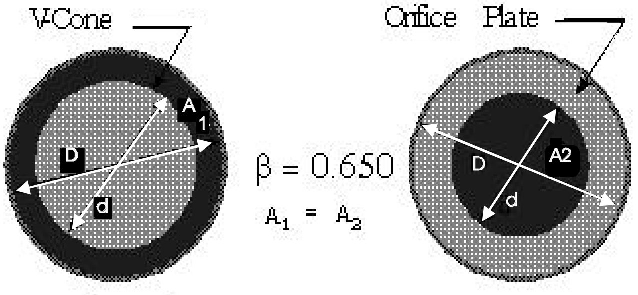
Fig4

Unique advantages derive from this construction since the flow is not compressed to the center or abruptly changed by the blockage. The meter generates high frequency low amplitude downstream turbulence (eddies) which allow a low noise signal to be generated at the pressure transducer. The resolution available at the low-pressure port is better than 1/10” Wg which allows large turndown and repeatability using only one pressure transmitter.

V-Cone Technical Attributes

All DP meters use the same type of mathematical equations with some slight differences, for sizing and for implementation
The following are examples of algorithms for the V-Cone device. *(Other meter data being available from ISO 5167, ANSI 2530(AGA 3)*

Beta Ratio



$$\beta=\sqrt{1-\frac{d^2}{D^2}} \qquad \beta=\frac{d}{D}$$

ß = Beta Ratio D = I.D.of Pipe d = O.D.of Cone / Orifice void space

Cone Diameter $d_{in} = D_{in}\sqrt{1-b^2}$

Flow rate calculation for the V-Cone

For liquids the following equation can be used:

$$k=\frac{\pi}{4}\sqrt{2G_c}\,\frac{D^2\beta^2}{\sqrt{1-\beta^4}}C_d$$

k = the V-Cone meter constant, $\frac{ft^{2.5}}{sec}$
G_c = the gravitational constant, $\frac{ft}{sec^2}$
D = the inside diameter of the pipe, *ft*.
β= Beta ratio of the V-Cone, *dimensionless*.
C_d = coefficient of discharge, *dimensionless*.

If a gas is to be measured, it is necessary to apply a correction factor (Adiabatic Expansion Factor) to correct Bernoulli's Theorem since density changes due to pressure change across the constriction does not apply to liquids. It is necessary to multiply the Y factor by the C*d* or *Cf* .

This coefficient is called the Adiabatic Expansion Factor (or Y factor), for the V-Cone :-

$$Y=\sqrt{\frac{\left[\left(1-\beta^4\right)\times\frac{k}{k-1}\times R^{\frac{2}{k}}\times\left(1-R^{\frac{k-1}{k}}\right)\right]}{\left[\left(1-\left(\beta^4\times R^{\frac{2}{k}}\right)\right)\times(1-R)\right]}}$$

R = 1 - [DP/ PL] (Term used to simplify the equation above)

Velocity Profile & Flow Conditioning

Most DP meters require flow conditioning to obtain a good velocity profile and removal of swirl from the fluid to be measured.

Recent work performed at GRI indicated even with long lengths of smooth upstream piping (100 D's) errors where noticed, the situation being worse when short lengths, or incorrect installation practices were used. From this work certain types of new flow conditioners have been produced to assist in maintaining a good velocity profile, however the V-Cone meter does not generally require this type of conditioning. The meter itself re–profiles the flow due to the way in which the cone interacts with the fluid being measured: *shown in fig 5*

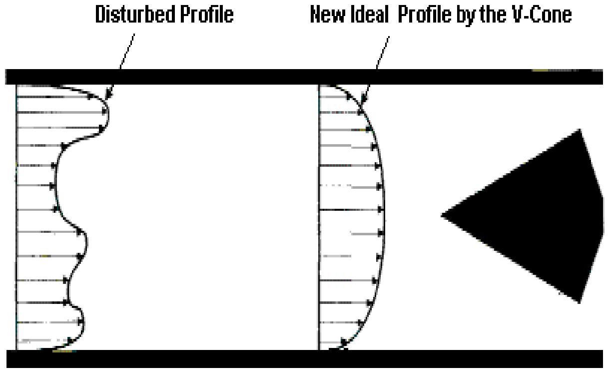


Fig 5

Since the V-Cone is not affected by velocity profile it is possible to install the units in a smaller area (envelope) than conventional DP Devices.
The cost of ownership is enhanced by the reduction of flow conditioning elements needed.

A typical V-Cone installation is shown below, note the short upstream runs (0-3D's) and short downstream runs at (0–1D's).

see Fig 6

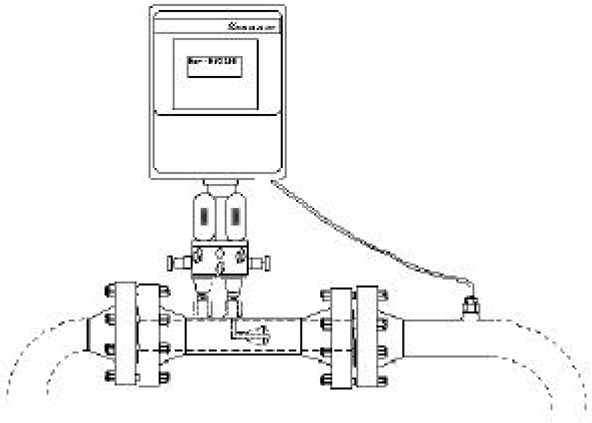


Fig 6

Total Cost of Ownership and Reliability

Most DP meters have no moving parts and thus can be considered to be mechanically stable, however, it can be seen that if beta geometries change, (as with conventional units) the impact on the measurement accuracy may be a problem.

V-Cone units are manufactured so that the beta edge is not worn by contact with the fluid .

The high velocity core flow is forced in a streamlined way to interact with the boundary layer near to the pipe wall, a secondary boundary layer is distributed over the cone area, the net result is a near complete mixing of the pipe velocities and this enables the meter to perform in a predictable manner.

If there is any long term erosion this occurs at the front of the cone where there is no impact on performance and also where there is a strong material content / support structure.

See fig 7:

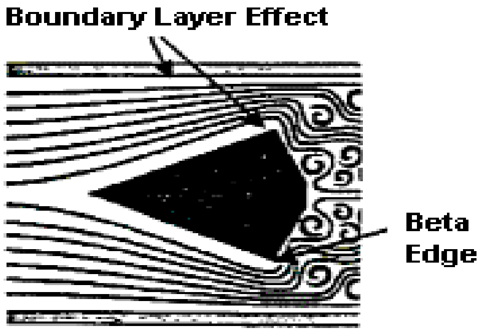


Fig 7

Signal stability can be a major issue with most DP meter types, they can produce signal bounce. V-Cone meters produce high frequency low amplitude vortices down stream of the cone. This type of signal enhances the performance obtainable from a pressure transducer and allows large turndowns to be obtained, since the signal is not being swamped with erroneous noise . Applications in compressor control being ideal in this area.

See fig 8 a& b ;

Fig 8a

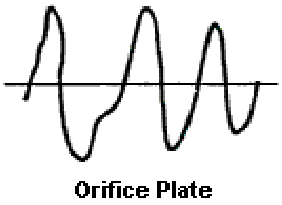


Fig 8b

New areas of use for the V-Cone

BLM (Bureau of Land Management)

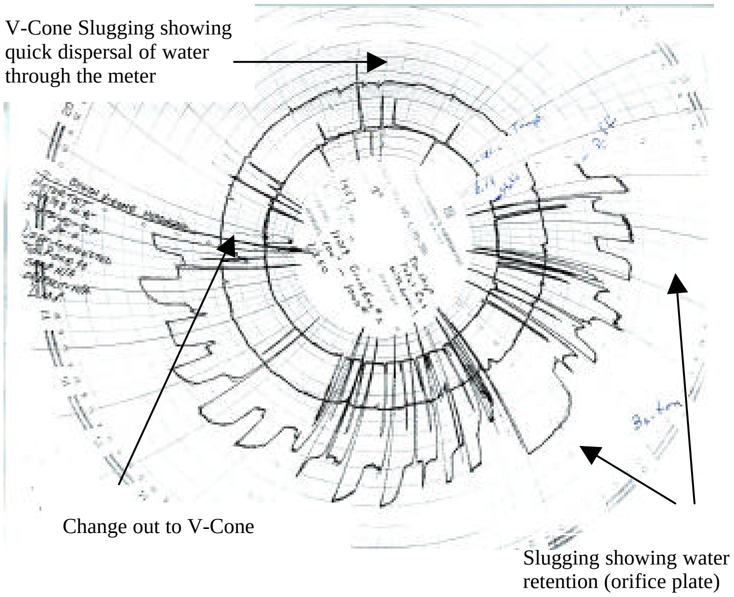
Wet gas measurement to custody transfer standards, using conventional means can show errors due to response time of a transmitter when saturated with liquid, together with the problem of water retention, say up/downstream of an orifice plate.

This problem was recognized by the BLM and remedial use of the V-Cone meter was put into place late last year (98) at a BLM controlled site.

The result being that a tighter uncertainty was obtained and a dispensation to allow the V-Cone meter to be used to current CTM guidelines granted per location basis.

Testing and acceptance was implemented over the latter part of last year (1998) and further usage is planned for 1999.

Wet Gas’ Chart Recorder Results (BLM Site)



V-Cone Slugging showing quick dispersal of water through the meter

Change out to V-Cone

Slugging showing water retention (orifice plate)

Fig 9

Figure 9, shows water being retained at the up/downstream sides of the orifice plate, and then moving into a slug flow condition.

The resulting situation being an overall widening in the uncertainty of the measurement station.

The V-Cone showed a quick response time when the slugging occurred which is shown in the chart results Fig 9. The V-Cone DP tracking the changes in static pressure instantaneously.

Wet Gas Testing

Recently the GRI (Gas Research Institute) performed some wet gas testing, (report number 04-8639-02) with the V-Cone in conjunction with orifice plates to see what effect a two phase mixture would have on these types of devices.

The testing was independently performed by GRI staff and evidence produced that the V-Cone could handle wet gas to the concentrations tested with good accuracy.

Tests were conducted on 4-inch diameter meters installed in a horizontal orientation. Beta ratios of 0.67, 0.59, and 0.45 were tested at three different gas flow rates for each meter. At each gas flow rate, the liquid mass fraction was varied from 0-5%. The tests were conducted using nitrogen and water at pressures of 30 and 110 psia.

The experimental results showed:

An increase in the gas flow reading was recorded when liquid was entrained in the gas. Standard meter calculations would, therefore, overpredict the amount of gas passing through the meter when liquids are entrained.

The amount of increase depended upon the meter beta ratio, the liquid massfraction, the operating pressure, and the gas flow rate.

The beta 0.67 meter had the highest gas measurement error, with a maximum error of 1.5%. The beta 0.45 meter showed the lowest gas measurement error for the meters tested at 30 psia. At 110 psia, the beta 0.59 meter had the lowest gas measurement error for the range of conditions tested.

The two smaller beta ratio meters provided gas measurement accuracy better than 1% with liquid mass fractions up to 5%. V-Cone meters, therefore, can be used in wet gas applications when measurement accuracy of this magnitude is acceptable.

Further data is expected to be obtained from the Joint Industry project (JIP) currently being set up to examine wet gas measurement in further detail.

Installation and Usage

V-Cone meters can be used for any liquid or gas measurement application where robustness and longevity is required; the meter is virtually maintenance free and does not require periodic calibration.

Inspection is required only if the meter is in extreme process conditions.

As with any primary instrument it is necessary to use good secondary instrumentation, which should be re-calibrated according to the manufacturer instructions.

Canadian Custody Transfer

Industry Canada granted certification for the V-Cone last April, this allows usage for CTM service for meters from 1/2inch to 36 inches.
The test results superceded the standard requirements and showed the normal performance of the V-Cone family at +/-0.5 % well inside the Government guidelines.

Conclusions

Differential Pressure meters are here to stay despite advances in vibrating tube meters, vortex meters, and a whole complexity of new units out there.

The technology is easy to work with, to understand, and works well.

V–Cone units operate with mature principles but packaged a little differently, the increasing use of the device is solving many flow-related problems in the real world today and for the next millennium.

Reference Documents

Hayward	A Basic Guide and Source Book for Users	1973.
Szabo / Winarski Hypnar	V-Cone Meter for Natural Gas Flows	1992.
Ifft / Mikkelsen	Pipe Elbow Effects on the V-Cone Flowmeter	1993.
Miller	Flow Measurement Handbook (Latest Edition)	
GRI	Wet Gas Research V-Cone 4 inch Diameter	1997
Lawrence	V-Cone Technology (Old Wine in a new Bottle)	1998