ISA – The Instrumentation, Systems, and Automation Society
Brazos Section

Technical Presentation
9 September 2004

Differential Pressure Producing Flow Elements

WYATT engineering

Intelligent Flow Measurement™

"I need someone well versed in the art of torture—do you know PowerPoint?"

Review of Test Data Indicates Conservatism for Tile Penetration

- **The existing SOFI on tile test data used to create Crater was reviewed along with STS-87 Southwest Research data**
  - **Crater overpredicted penetration of tile coating significantly**
    - **Initial penetration to described by normal velocity**
      - Varies with volume/mass of projectile (e.g., 200ft/sec for 3cu. In)
    - **Significant energy is required for the softer SOFI particle to penetrate the relatively hard tile coating**
      - Test results do show that it is possible at sufficient mass and velocity
    - **Conversely, once tile is penetrated SOFI can cause significant damage**
      - Minor variations in total energy (above penetration level) can cause significant damage
  - **Flight condition is significantly outside of database**
    - **Volume of ramp is 1920cu in vs 3 cu in for test**

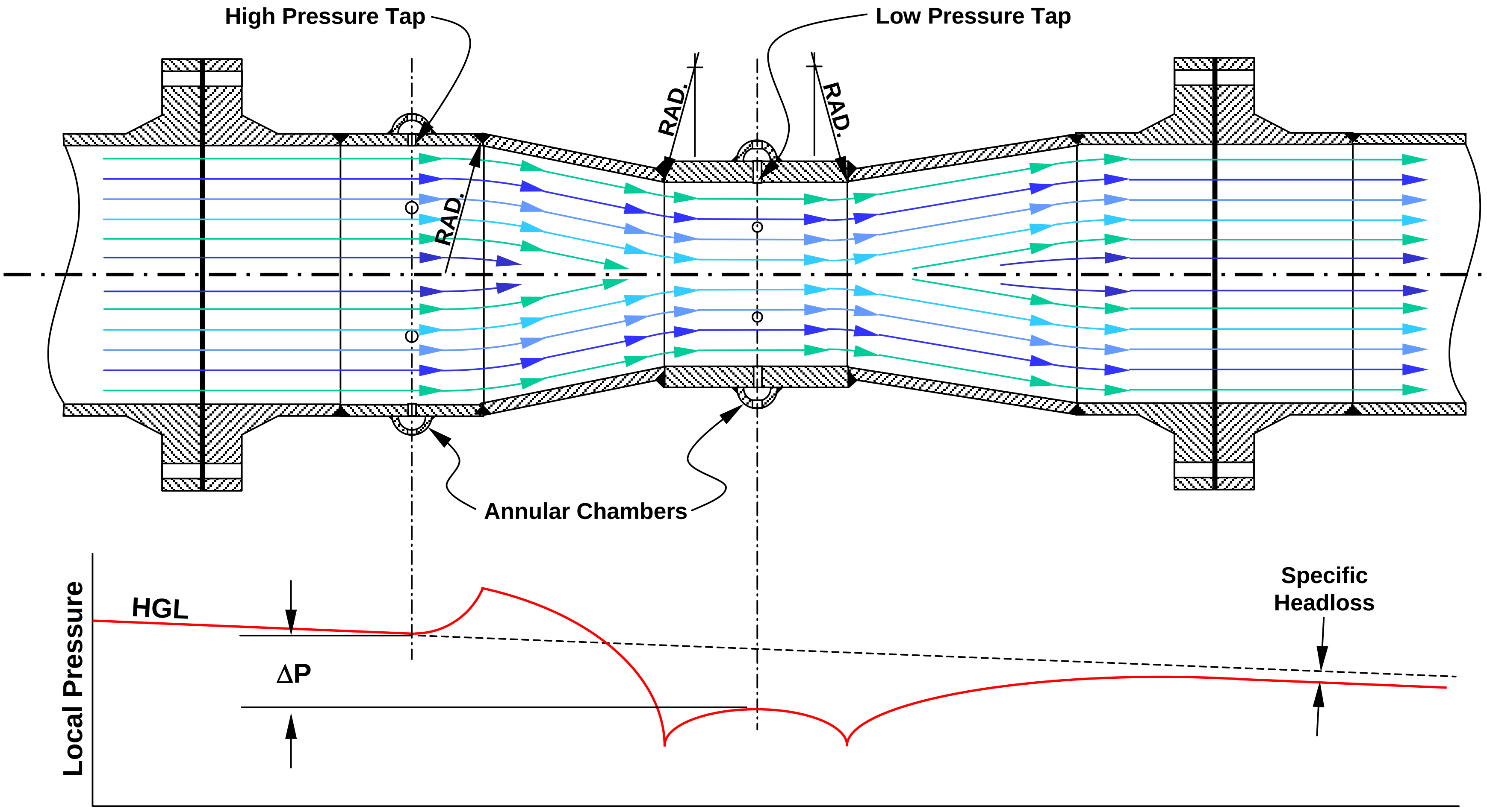
Important information was squeezed in at the bottom of this slide. It indicates that the piece of foam that broke off and struck the shuttle's wing on takeoff was **640 times larger** than anything that had ever been tested.

Product Types

Differential Pressure Devices for Liquid and Gas Flow Measurement

- Venturi Meters
- Flow Tubes
- Orifice Plates
- Flow Nozzles
- Meter Runs
- Performance Test Sections
- Averaging Pitot Tubes

Theory of Operation, Venturi Meters



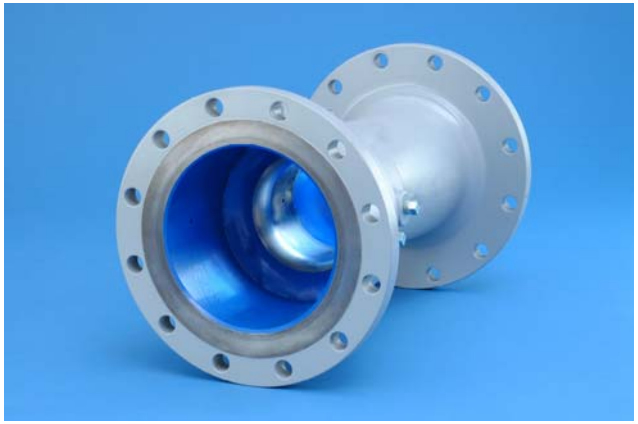
The Basics of Differential Pressure Measurement as Applied to the Classical Venturi Tube

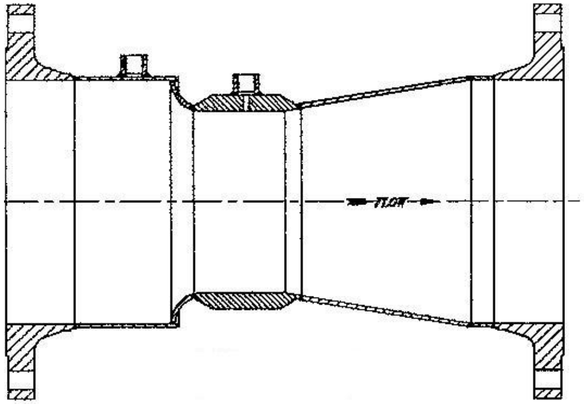
Product Overview

BVT (Badger Venturi Tube) U Series

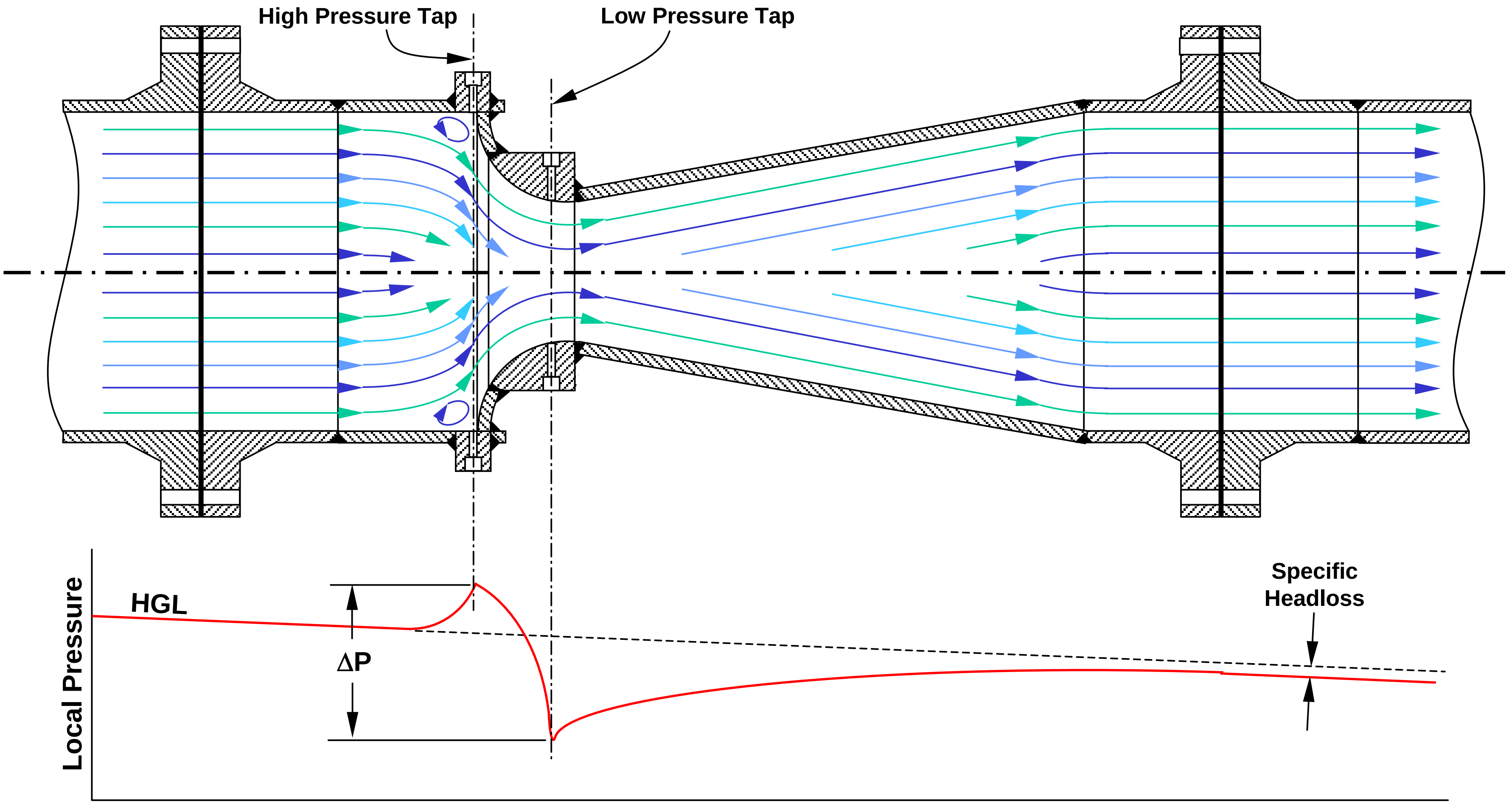
Full Body – Fabricated

- **B** - Machined from Forged Bar Stock
- **F** - Pipe Shell Design
- **W** - Weld-In Design





Theory of Operation, Flow Tubes



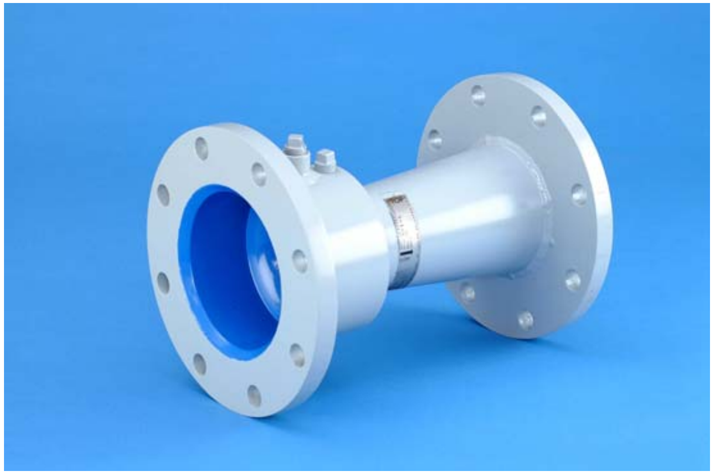
The Basics of Differential Pressure Measurement as Applied to the Lo-Loss® Flow Tube

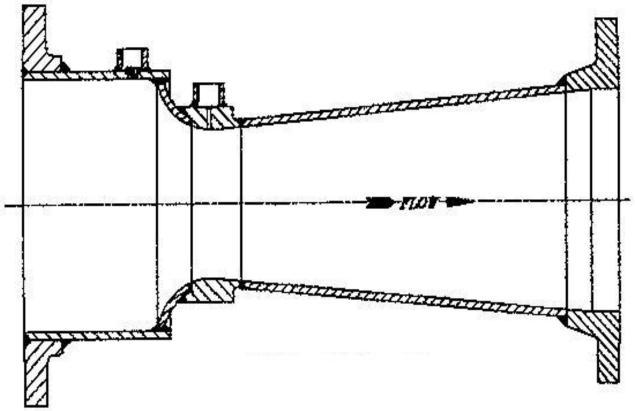
Product Overview

PMT Lo-Loss® U Series

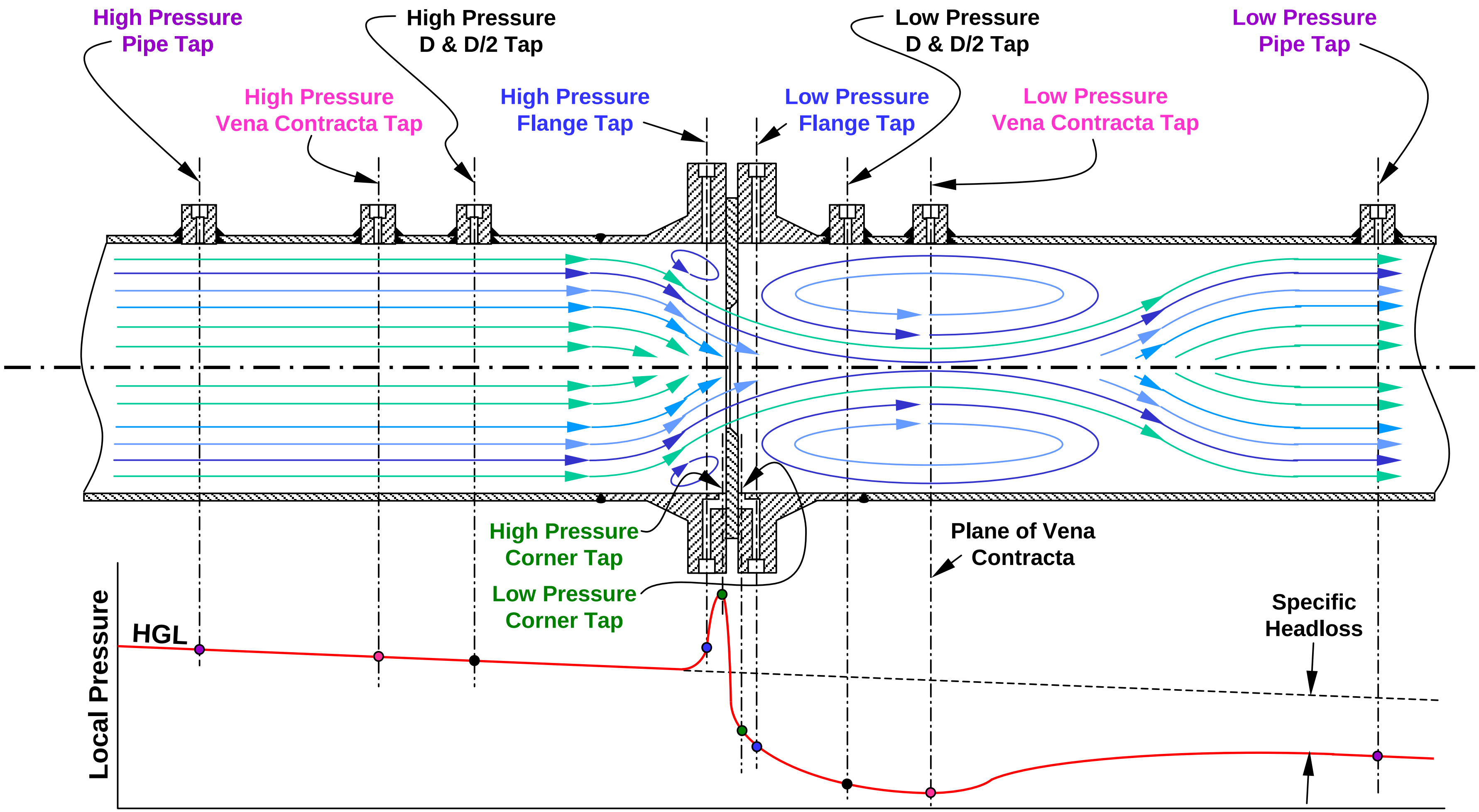
Full Body – Fabricated

- **B** - Machined from Forged Bar
- **F** - Pipe Shell Design
- **W** - Weld-In Design





Theory of Operation, Orifice Plates



The Basics of Differential Pressure Measurement as Applied to the Orifice Plate

Product Overview

Orifice Plates & Meter Runs

- Paddle Type
  - Sharp Edge Concentric
  - Square Edge Eccentric
  - Segmented
  - Quadrant
  - Conical Inlet
- Universal Type
- In accordance with ASME, AGA, or ISO

Why “Specific” Headloss?

- While permanent pressure loss appears to be simply a static pressure drop, it is really a dynamic value.
- Headloss is typically expressed in terms of PSI, inches of water column, kilopascals, etc., but the real unit description in the US Customary System is:

BTU PER POUND OF FLOWING LINE FLUID

- Consequently, headloss represents an ongoing energy expense, “the cost of doing business.”
- Your duty is to minimize that cost.

The Cost of Doing Business: A Comparison, Steam

200 000 lb_m/hr Steam Flow,	200 000 lb_m/hr Steam Flow,
P = 299.696 PSIA, T = 440 °F	P = 299.696 PSIA, T = 440 °F
ρ_1 = 0.621 234 lb_m/ft^3	ρ_1 = 0.621 234 lb_m/ft^3
η= 100%, Energy($) = 7¢/kWh	η= 100%, Energy($) = 7¢/kWh
Operating 24 h/d, 365 d/yr	Operating 24 h/d, 365 d/yr
11.938" x 8.481" **Orifice Plate**	11.938" x 6.921" **Venturi Meter**
ΔP = 200" wc, ΔH = 95.9" wc	ΔP = 200" wc, ΔH = 11.5" wc
$\text{Annual Cost} = \frac{0.0172\,\Delta H\,Q\,\$}{\eta\,\rho} = \frac{0.0172\,(95.9)\,(200\,000)\,(0.07)}{(100\%)\,(0.621234)} =$	$\text{Annual Cost} = \frac{0.0172\,\Delta H\,Q\,\$}{\eta\,\rho} = \frac{0.0172\,(11.5)\,(200\,000)\,(0.07)}{(100\%)\,(0.621234)} =$
$ 37,172 per year	**$ 4,458 per year**

Using the Venturi instead of the Orifice Plate saves $ 32,714 annually.

Theory of Operation

FLOW EQUATION FOR DIFFERENTIAL-PRODUCING FLOW METERS

The flow equation for differential-producing flow meters is as follows:

$$Q\,(lb_m/hr) = \frac{358.92684\, d^2\, F_a C Y \sqrt{\Delta P}\sqrt{\rho_L}\sqrt{g/g_0}}{\sqrt{1-\beta^4}}$$

where:

- Q is the flow rate expressed in Pounds (mass) per Hour;
- d is the Diameter of the meter's throat or bore (inches);
- C is the meter Discharge Coefficient (dimensionless);
- Y is the Expansibility Factor (dimensionless);
- F_a is the Thermal Expansion Correction Factor (dimensionless);
- ΔP is the observed Differential Pressure expressed in Inches of Water (14.7 PSIA, 68 °F);
- ρ_L is the Density of the line fluid at line conditions (lb/ft^3);
- g is the Local Acceleration due to Gravity (ft/s^2);
- g_o is the Standard Acceleration due to Gravity (32.174 05 ft/s^2)
  Note that for most applications, $g/g_0 = 1$;
- β is the Ratio of the Throat Diameter (or Bore) to the Inlet (or Pipe) Diameter.

Theory of Operation (continued)

Once the flow equation is understood, the underlying concepts reveal that the discharge coefficient, C, is actually a ratio:

$$C = \frac{\text{Actual Rate of Flow}}{\text{Theoretical Rate of Flow } (C = 1, Y = 1)}$$

The discharge coefficient simply relates an idealized flow rate to the real flow rate.

When buying a flow meter, therefore, the client is essentially purchasing the manufacturer’s knowledge regarding the value and the uncertainty of C (the discharge coefficient) and, if the line fluid is compressible, Y (the adiabatic expansion factor).

Definitions, Flow

- **Discharge Coefficient, C:** Coefficient defined for an incompressible fluid flow that relates the actual flow rate to the theoretical flow rate through a primary device. It is a dimensionless value given by the formulae:

[SI]

$$C = \frac{q_{m\,actual}}{q_{m\,theoretical}} = \frac{q_m\sqrt{1-\beta^4}}{\frac{\pi}{4}d^2\sqrt{2\Delta p\rho_1}}$$

[USCS]

$$C = \frac{q_{m\,actual}}{q_{m\,theoretical}} = \frac{q_m}{0.09970190d^2\sqrt{\frac{h_w\rho_1}{1-\beta^4}}}$$

The numerical value of C is based on experimental data. Flow calibrations of venturi meters have shown that the value of the discharge coefficient is dependent only on the Reynolds number for a given meter design in a given installation. The uncertainty of C may be reduced by flow calibration in an appropriate flow calibration facility.

Definitions, Compressible Flow

- **Expansibility Factor, ε [Y]:** Coefficient used to take into account the compressibility of the fluid. It is a dimensionless value given by the formulae:

[SI]

$$\varepsilon = \frac{q_m \sqrt{1-\beta^4}}{\frac{\pi}{4} d^2 C \sqrt{2 \Delta p \rho_1}}$$

[USCS]

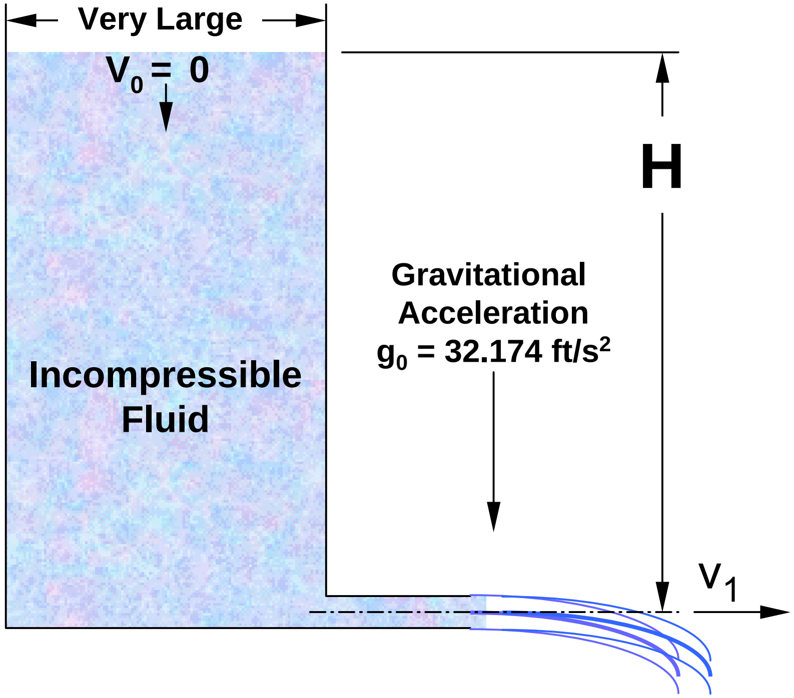
$$Y = \frac{q_m}{0.09970190 d^2 C \sqrt{\frac{h_w \rho_1}{1-\beta^4}}}$$

ε [Y] = 1 when the fluid is incompressible and ε [Y] < 1 when the fluid is compressible. Flow calibrations using a compressible fluid (gas) show that the expansibility factor is dependent on the pressure ratio, beta ratio, and the isentropic exponent of the gas. Expansibility characteristics are essentially independent of the Reynolds number.

Definitions, Compressible Flow (continued)

- **Isentropic Exponent, κ:** Ratio of the relative variation in pressure to the corresponding relative variation in mass density under reversible and adiabatic transformation conditions.
  - Note: The isentropic exponent appears in the different formulae for the expansibility factor and varies with the nature of the gas and with its temperature and pressure.
  - There are many gases and vapors for which values of κ have not been published, particularly over a wide range of pressure and temperature. In such a case, the ratio of the specific heat capacities of ideal gases may be used in place of the isentropic exponent.
- **Pressure Ratio, τ:** The absolute static pressure at the low pressure metering tap divided by the absolute static pressure at the high pressure metering tap.

Potential & Kinetic Energies of Flowing Fluids, Ideal



At the top of the tank, the potential energy of a reference mass of fluid is calculated:

$$PE = mgH.$$

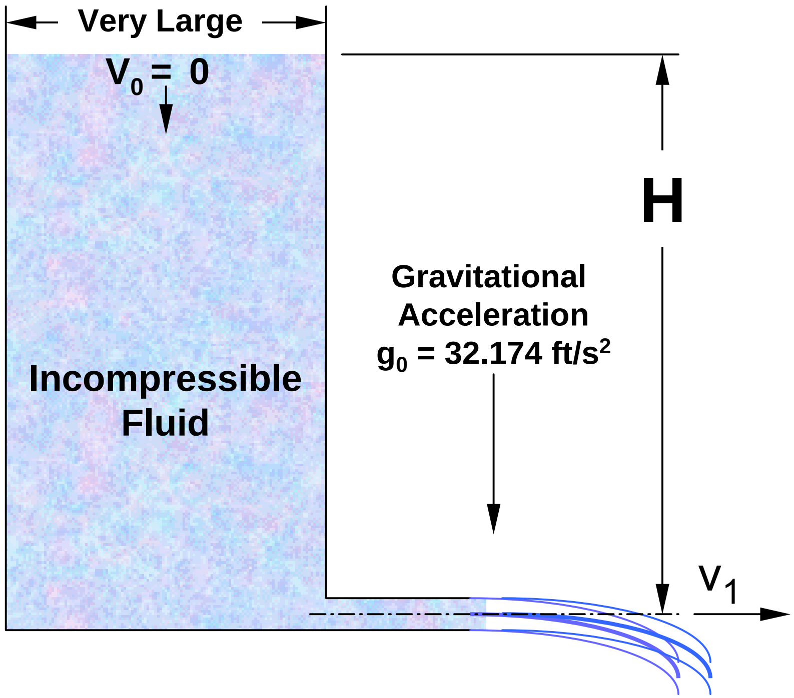
At the discharge pipe on the datum line at the bottom of the tank, the kinetic energy of a reference mass is calculated:

$$KE = \frac{mv_1^2}{2}$$

To determine the Kinetic Energy content of the discharge jet, v_1 must be determined. With no frictional or other losses to the system, the discharge velocity is equal to the free fall velocity:

$$v_1 = gt = g\sqrt{\frac{2H}{g}} = \sqrt{2gH}$$

Potential & Kinetic Energies of Flowing Fluids, Ideal



Since $KE = \frac{mv_1^2}{2}$ and $v_1 = \sqrt{2gH}$,

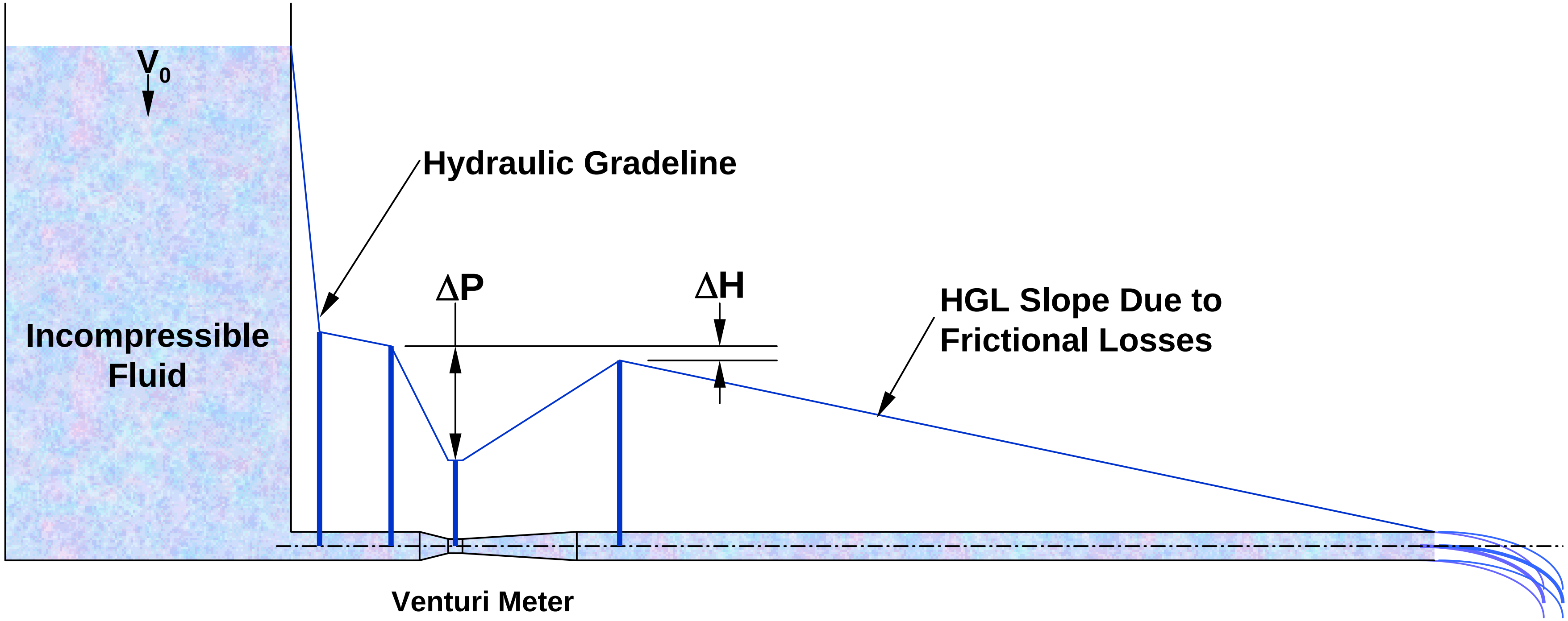
then $KE = \frac{m(2gH)}{2} = mgH$

which is equal to the potential energy of the liquid at the top of the tank:

PE = KE

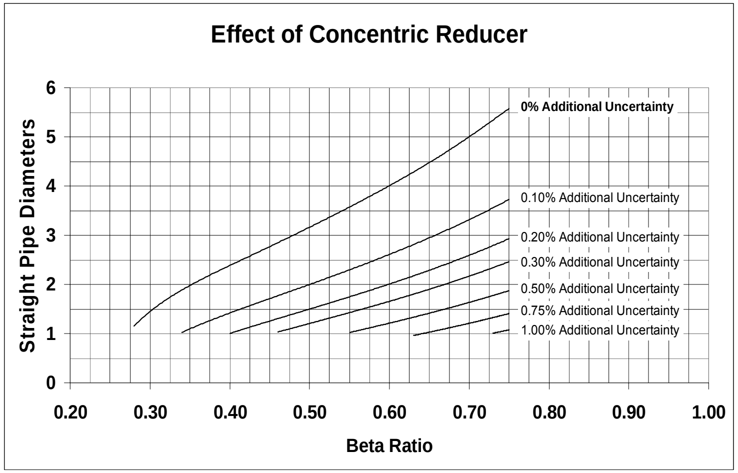
All the Potential Energy was converted to Kinetic Energy.

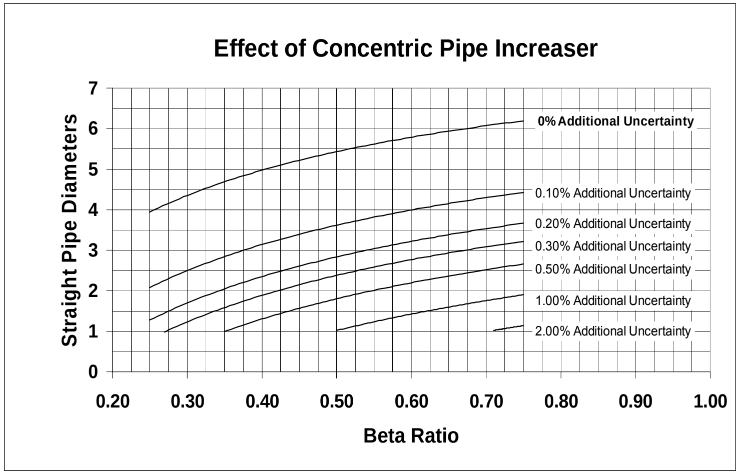
Potential & Kinetic Energies of Flowing Fluids, Real

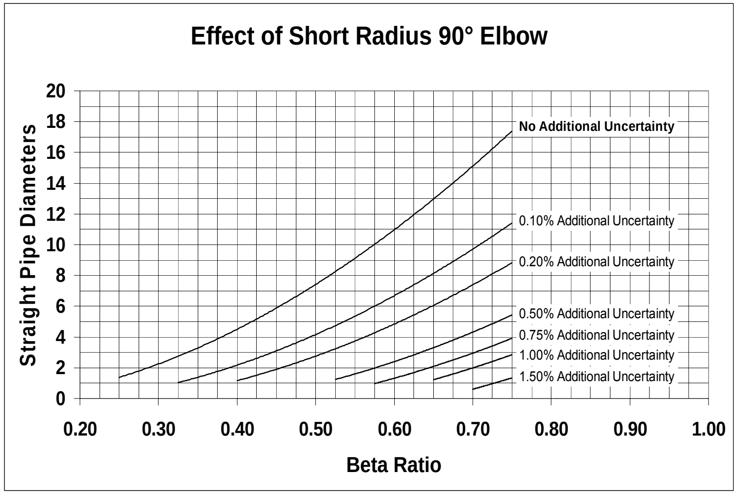


The pressure produced by the line fluid at a given cross section of pipe is an indirect indication of the potential energy present at that cross section. The differential pressure produced by the venturi meter is caused by the conversion of potential energy at the inlet tap cross section to kinetic energy at the throat tap cross section.

Installation Effects, Nonimpact BVTs

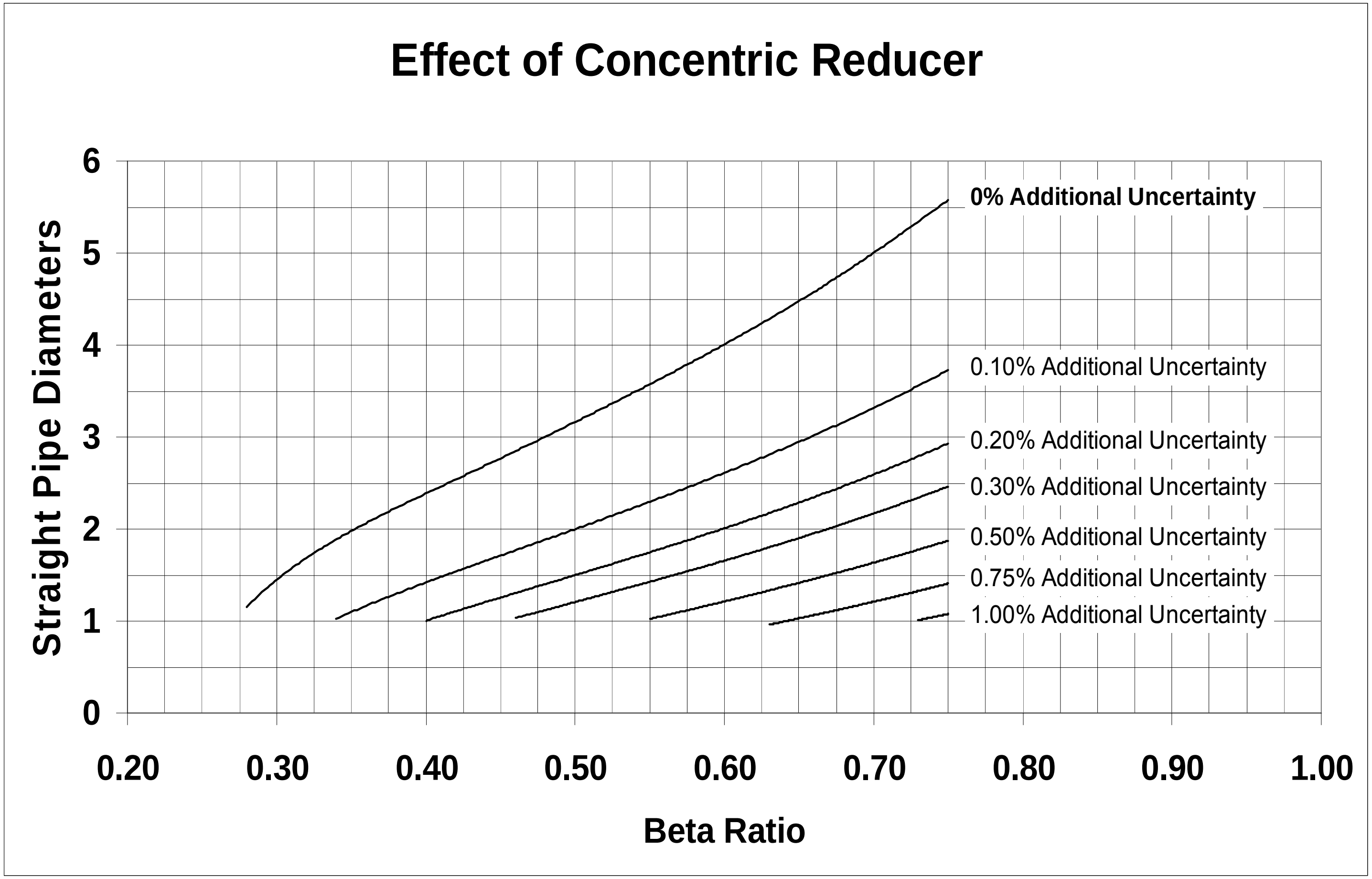




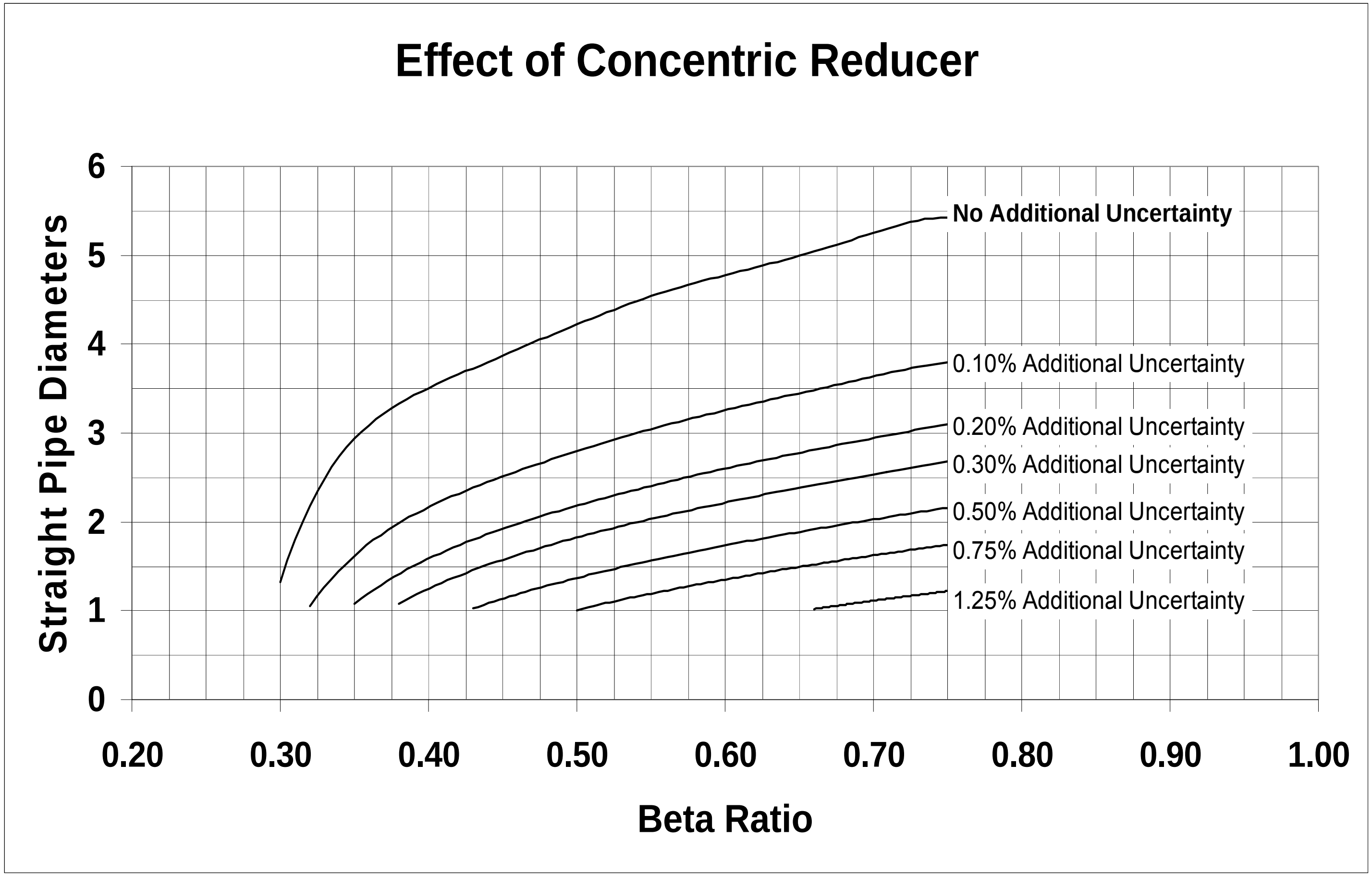


In order to address concerns regarding a given metering design's uncertainty after installation, sensitivity tests must be run to determine its susceptibility to errors caused by common pipe fittings. Only flow test data can answer this question, the opinion of the seller does not matter.

Concentric Reducer Installation Effects, Nonimpact BVTs, Detail



Concentric Reducer Installation Effects, Impact-Type BVTs, Detail

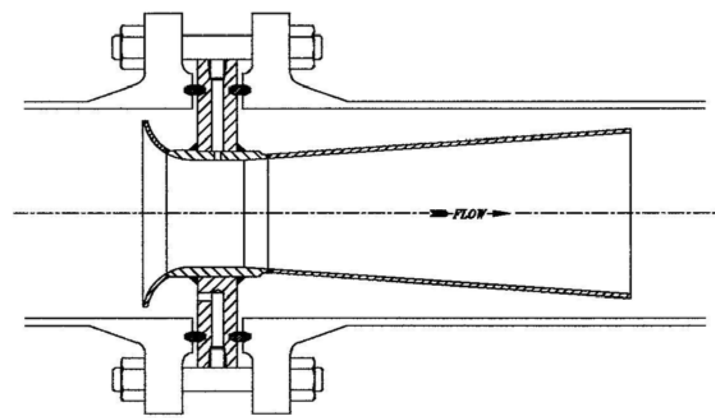


Product Overview

- **BVT-IF Series**

  Insert – Fabricated

  – Constructed from Practically Any Metal
    - 300-Series and 400-Series Stainless Steels
    - Hastalloy® B & C
    - Monel, Inconel, etc.



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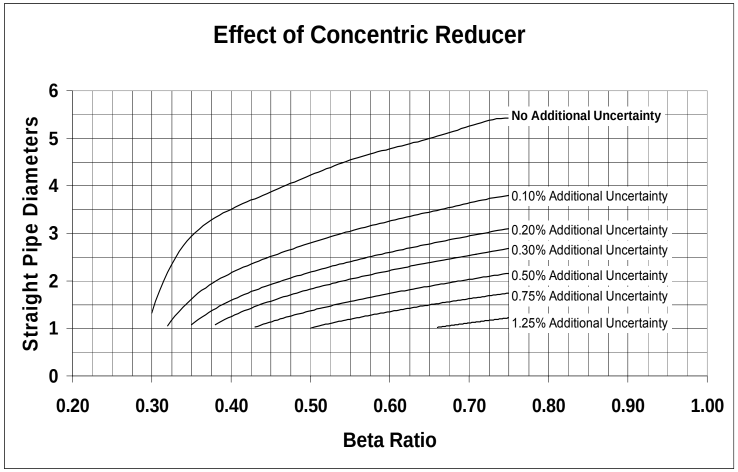
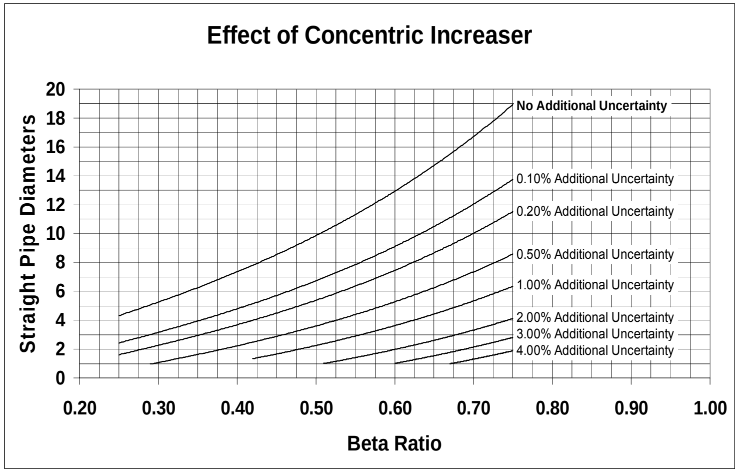
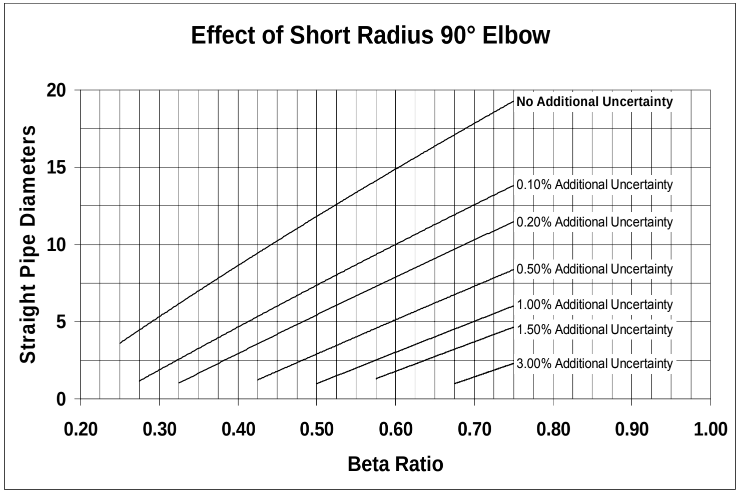
Intelligent Flow Measurement™

Installation Effects, Impact-Type BVTs

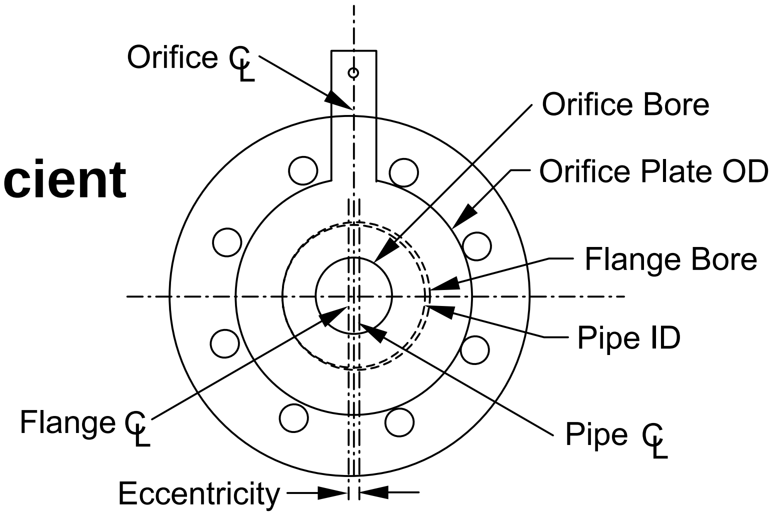




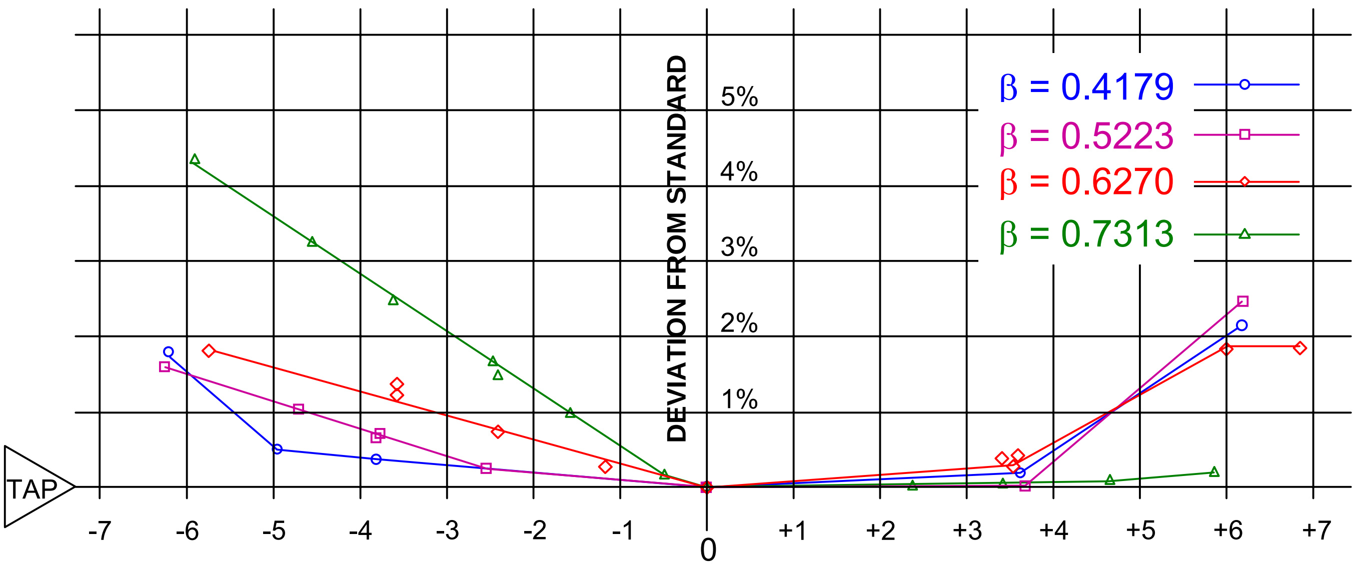


The differential pressure produced by the BVT product line is an indication of the difference in the kinetic energy contents of the line fluid between the high and low pressure tap cross sections. Due to differing velocity profiles, a given flow rate can possess different kinetic energies, and thereby introduce errors in the indicated flow rate. This is the essence of the study of installation effects and installed accuracy.

Effect of Eccentricity on the Discharge Coefficient of Orifice Plates

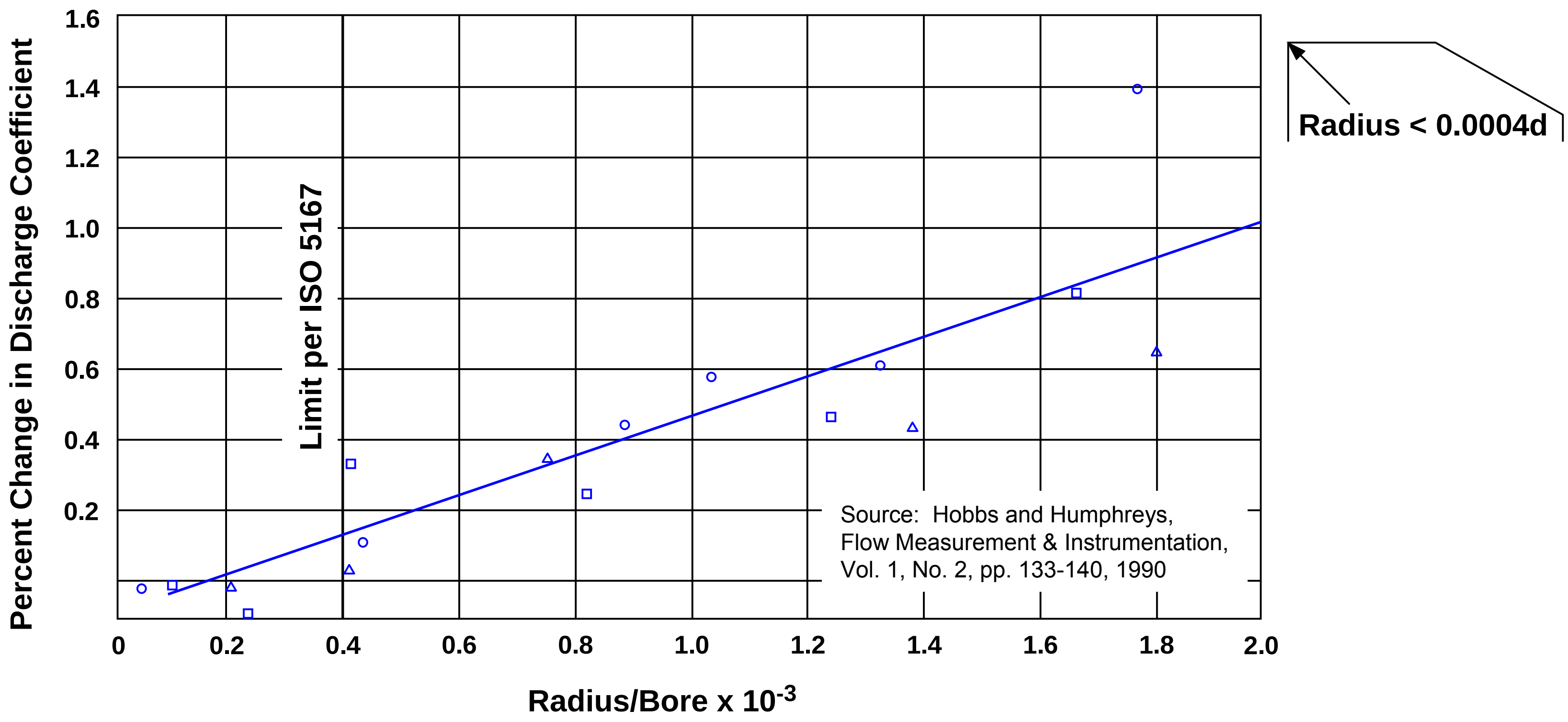


Source: Hobbs and Humphreys, Flow Measurement & Instrumentation, Vol. 1, No. 2, pp. 133-140, 1990

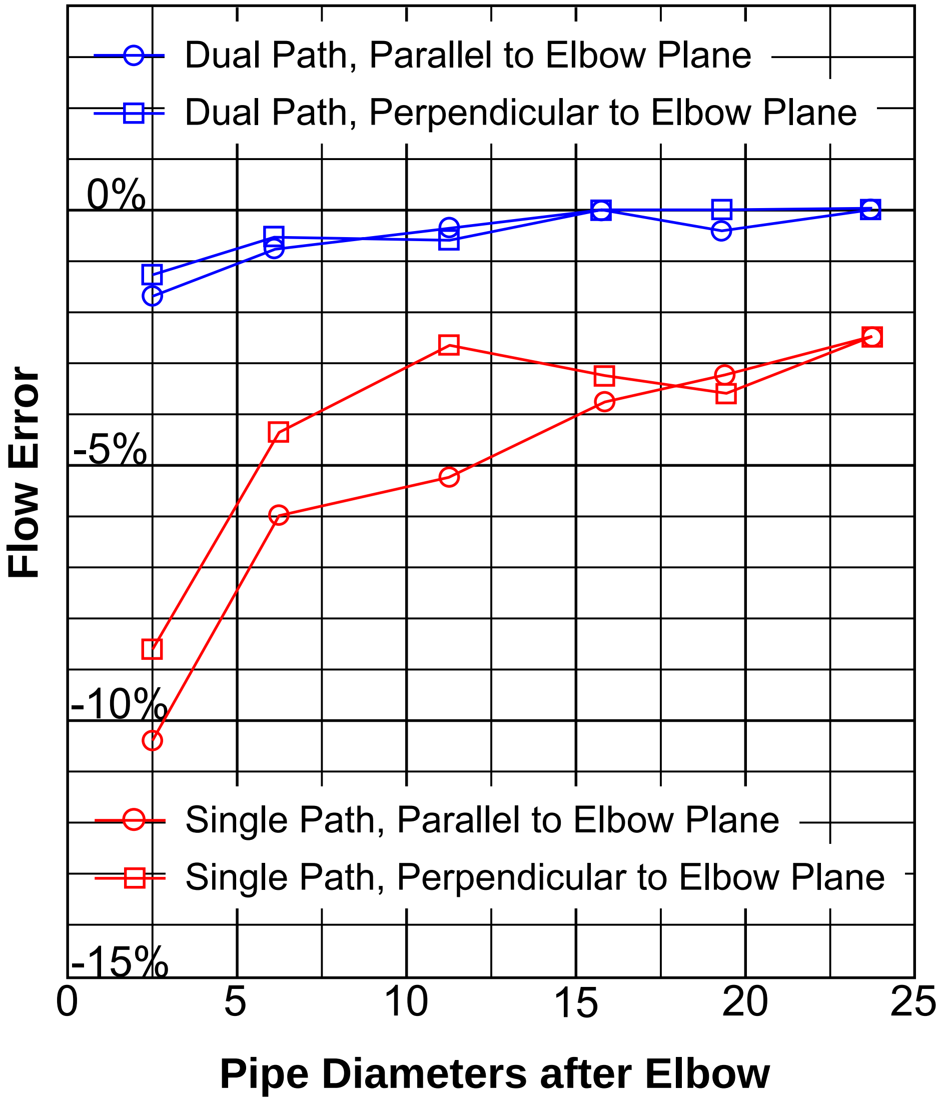


ECCENTRICITY EXPRESSED AS A PERCENTAGE OF PIPE INSIDE DIAMETER

Effect of Edge Sharpness on the Discharge Coefficient of Orifice Plates

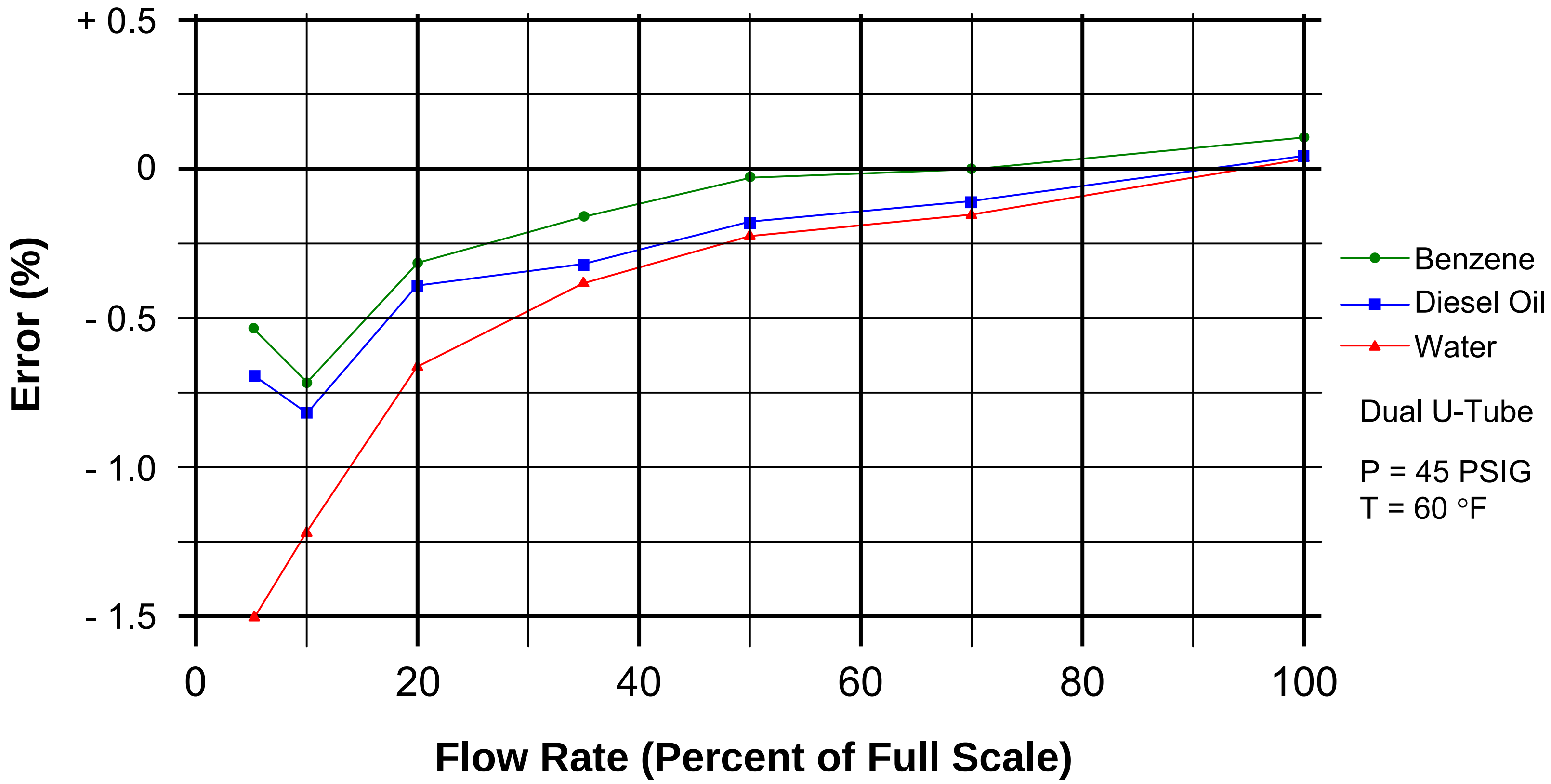


Effects of a Single Elbow on Single Path and Dual Path Ultrasonic Flow Meters

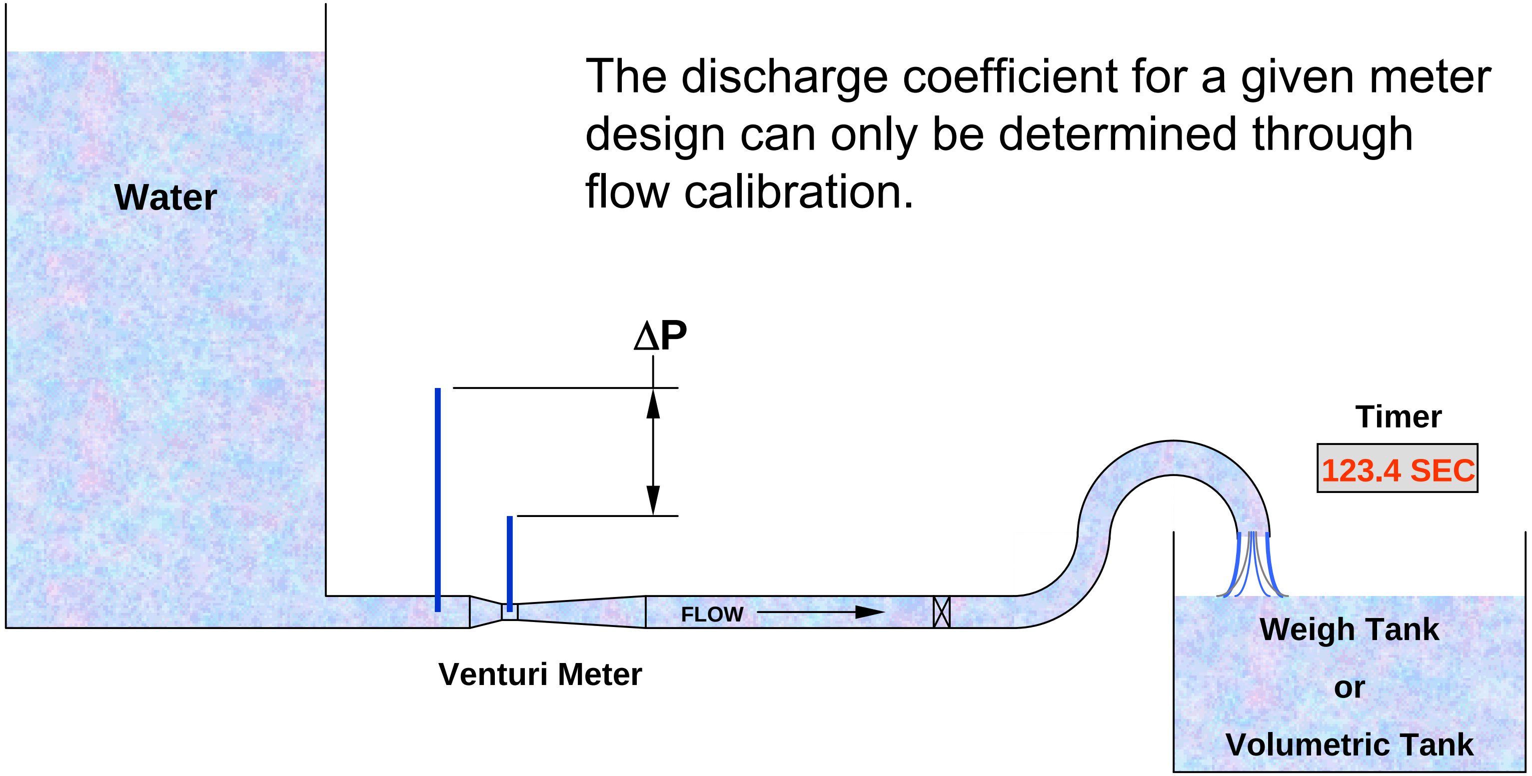


Source: Heritage, J.E.,
Flow Measurement & Instrumentation,
Vol. 1, No. 1, pp. 24 - 30, 1989

Effects of Density and Viscosity on Coriolis Meters



Flow Calibration



The discharge coefficient for a given meter design can only be determined through flow calibration.

$$C = \frac{\text{Collected Volume/Time}}{0.0997019 d^2 F_a \sqrt{\Delta P} \sqrt{1/\rho_L} \sqrt{1/(1-\beta^4)}} = \frac{\text{Actual Rate of Flow (ft}^3\text{/s)}}{\text{Theoretical Rate of Flow (C = 1, Y = 1)}}$$

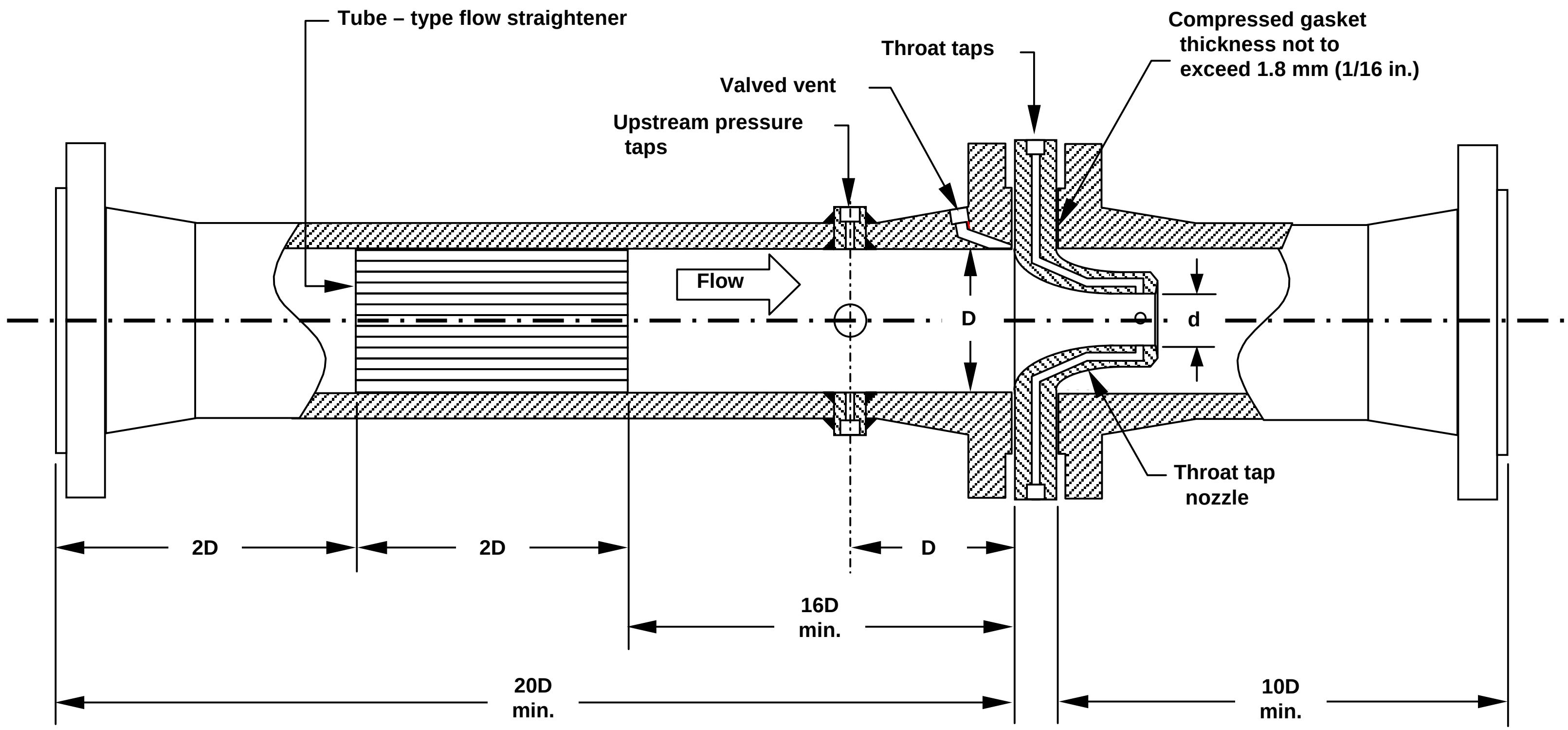
Flow Calibration (continued)

- Flow Calibration
  - May lessen the effect of “unseen” manufacturing tolerances on flow measurement
  - Can establish a background data base for a given meter design
  - May lessen the probability of litigation relating to the flow measurement

- A Meter Can Be Flow Calibrated
  - Using an incompressible fluid (typically water) as the calibration medium
  - Using a compressible fluid (typically air) as the calibration medium
  - Directly against primary standards (gravimetric or volumetric)
  - Indirectly against secondary standards (transfer masters)

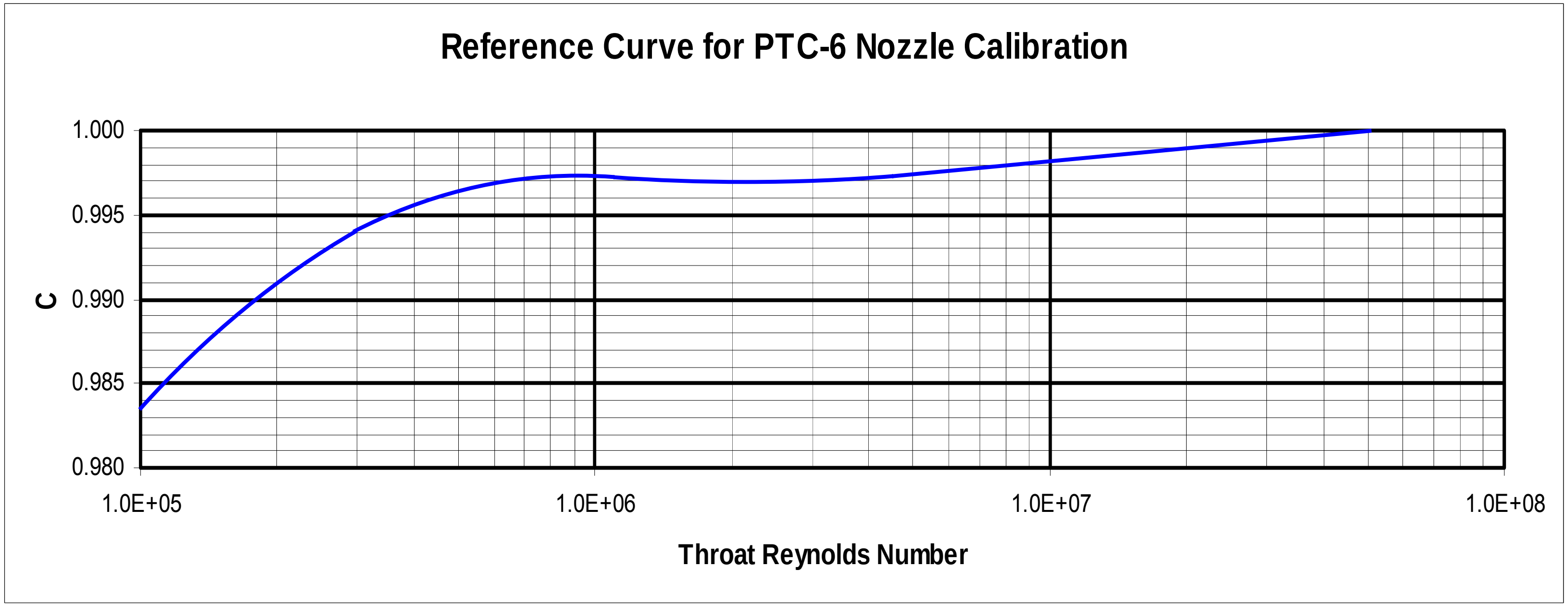
Flow Calibration (continued)

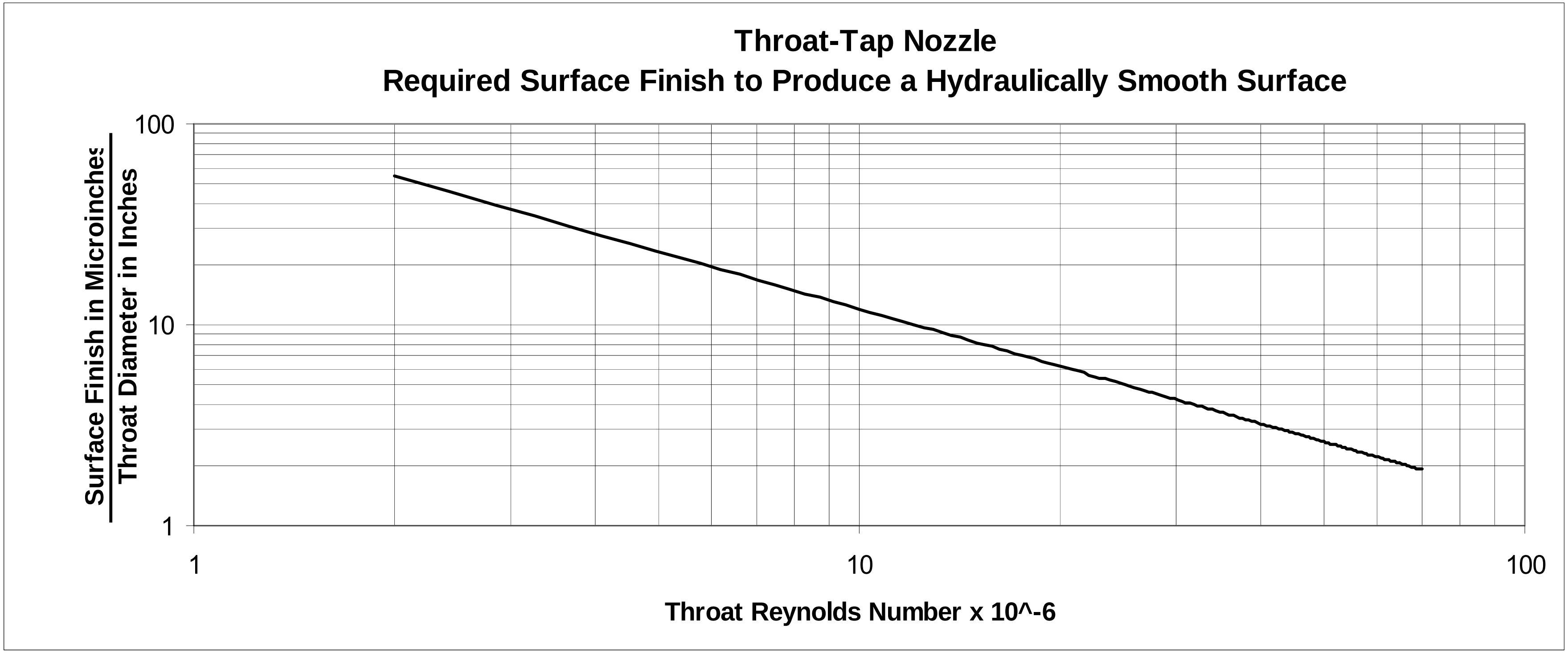
- If the purpose of flow calibration is to lessen flow measurement uncertainty, then the number of unknowns must be limited.
- If all dimensional values and the elapsed time are known without error, then the only remaining error sources are those associated with
  - C, the discharge coefficient
  - Y, the expansibility factor.
- Flow calibration using a compressible fluid as the calibration medium allows for two sources of error, C and Y.
- Flow calibration using an incompressible fluid as the calibration medium eliminates the uncertainty associated with expansibility.
- Model Testing
  - Large meters
  - Unique designs
  - Complicated installations for which data is not available



ASME PTC-6 TEST SECTION

PTC-6 Test Sections were designed primarily for power plant and turbine efficiency testing. The design is thought to trigger a boundary layer effect in the $2(10^6) < R_d < 4\ (10^6)$ range, thus allowing for accurate and reliable data extrapolation for $R_d > 8\ (10^6)$, and typically for throat Reynolds numbers greater than $20\ (10^6)$.


Reference Curve for PTC-6 Nozzle Calibration
1.000
0.995
0.990
0.985
0.980
C
1.0E+05
1.0E+06
1.0E+07
1.0E+08
Throat Reynolds Number


Throat-Tap Nozzle
Required Surface Finish to Produce a Hydraulically Smooth Surface
100
10
1
1
10
100
Surface Finish in Microinches
Throat Diameter in Inches
Throat Reynolds Number x 10^-6

Uncertainty of C

- Calibrated Uncertainty reflects the uncertainty of the flow calibration
  - Uncertainty of volume and/or mass determination
  - Uncertainty of elapsed time determination
  - Errors associated with installation
  - Calibrated Uncertainty: Typically ± 0.2% to ± 0.5%

- Uncalibrated Uncertainty is determined as follows:
  - Geometrically similar meters are built and flow calibrated
  - The mean discharge coefficient is calculated
  - The standard deviation is calculated
  - The precision is determined
  - Uncalibrated Uncertainty: Typically ???

Only with test data can uncalibrated uncertainties be determined.

Uncalibrated Uncertainty: Example

10 Flow Calibrated Meters

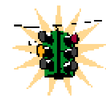
N	Flow Calibrated C	Calculated Values	
1	0.9926	Mean Discharge Coefficient, $\overline{C}$	0.9920
2	0.9931	Standard Deviation, σ	± 0.16%
3	0.9915	2σ (95% Confidence Level)	± 0.32%
4	0.9901	Precision (95% Confidence Level)	± 0.11%
5	0.9919		
6	0.9935	**UNCALIBRATED UNCERTAINTY** (95% Confidence Level)	**± 0.34%**
7	0.9894		
8	0.9922		
9	0.9907		
10	0.9946		

$$\sigma = \sqrt{\frac{\Sigma(\Delta C)^2}{N-1}}$$

$$\text{Precision} = \frac{(\text{Student's t})\,\sigma}{\sqrt{N}}$$

$$U_{95} = \sqrt{(2\sigma)^2 + (P)^2}$$

Probability



TULSA OK, 2ND ST AT DETROIT AV, 15MAR03, 1142PM.

Hit-and-Run involving taxicab and parked vehicle. Pedestrian eye witness states a red-colored taxicab hit a parked delivery truck and sped away. Creek Cab is the only taxi company in greater Tulsa using red vehicles.

FACTS:

1. Of the taxis in greater Tulsa, only 15% are red and are all owned by Creek Cab, Inc. The balance (85%) are green and belong to Tulsa Taxi, LLC.
2. Eye witness was tested under similar atmospheric and lighting conditions and was found to correctly differentiate between Tulsa Taxi and Creek Cab 80% of the time.

Due to the overwhelming probability of successful prosecution, the State of Oklahoma recommends indictment under all applicable criminal statutes.

What is the probability that Creek Cab is liable for damages?

Probability

Assume there are 100 taxicabs servicing Tulsa.

Based on the stated facts, 15 belong to Creek Cab and 85 are owned by Tulsa Taxi. Given the accuracy of the witness's observations (80%), 17 green vehicles are incorrectly identified as being red, and 3 red cabs are misidentified as green. The witness, therefore, would observe 17 + (15 - 3) = 29 red cabs in greater Tulsa: 12 correctly and 17 incorrectly.

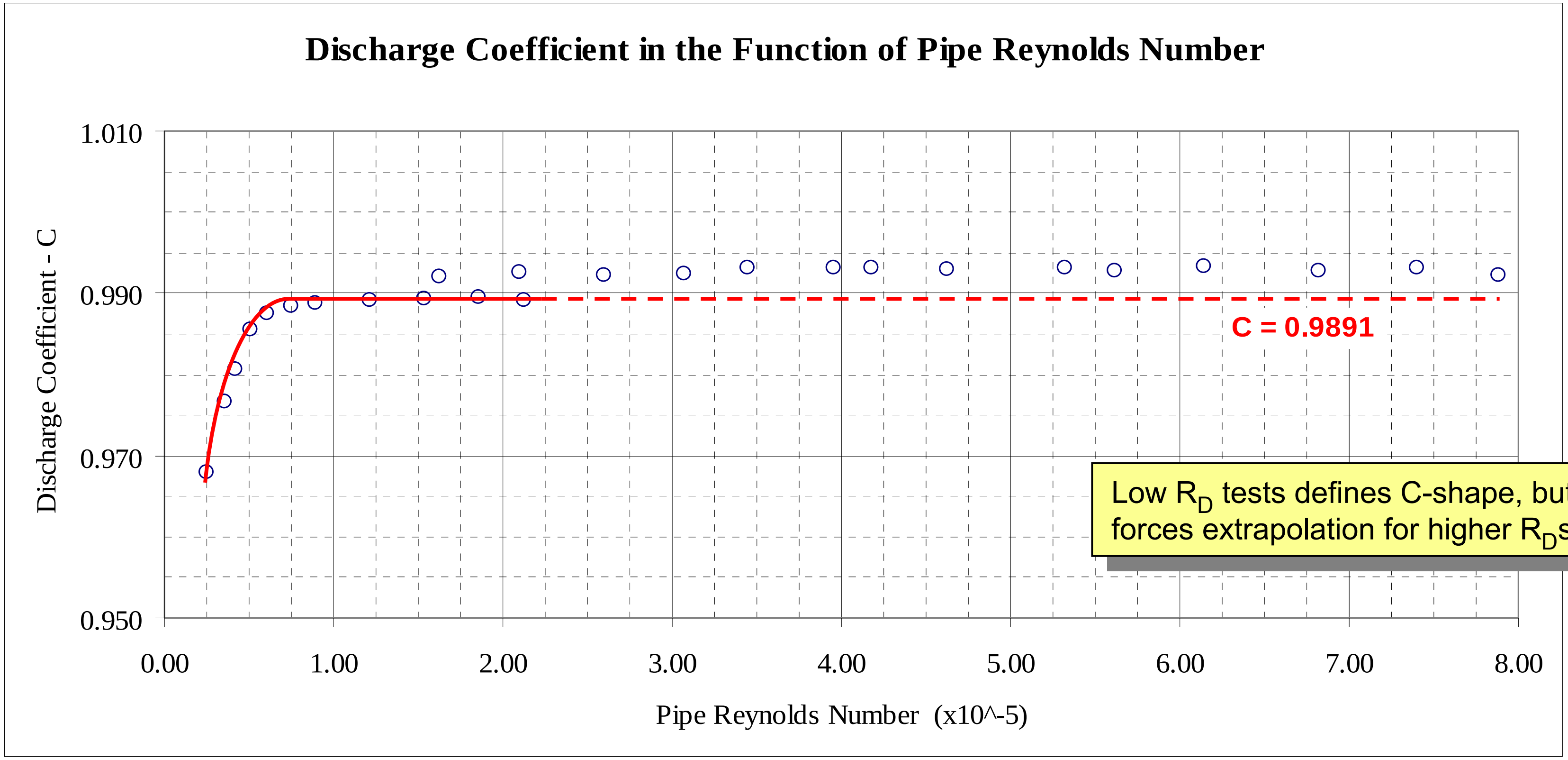
The probability of the Creek Cab being correctly observed at the scene of the accident is:

$$\frac{12\ \text{Correct Observations}}{29\ \text{Total Observations}} = 0.4138,\ \text{or}\ 41.38\%$$

The errors associated with incorrect observations of green cabs in fact exceed the total number of red cabs.

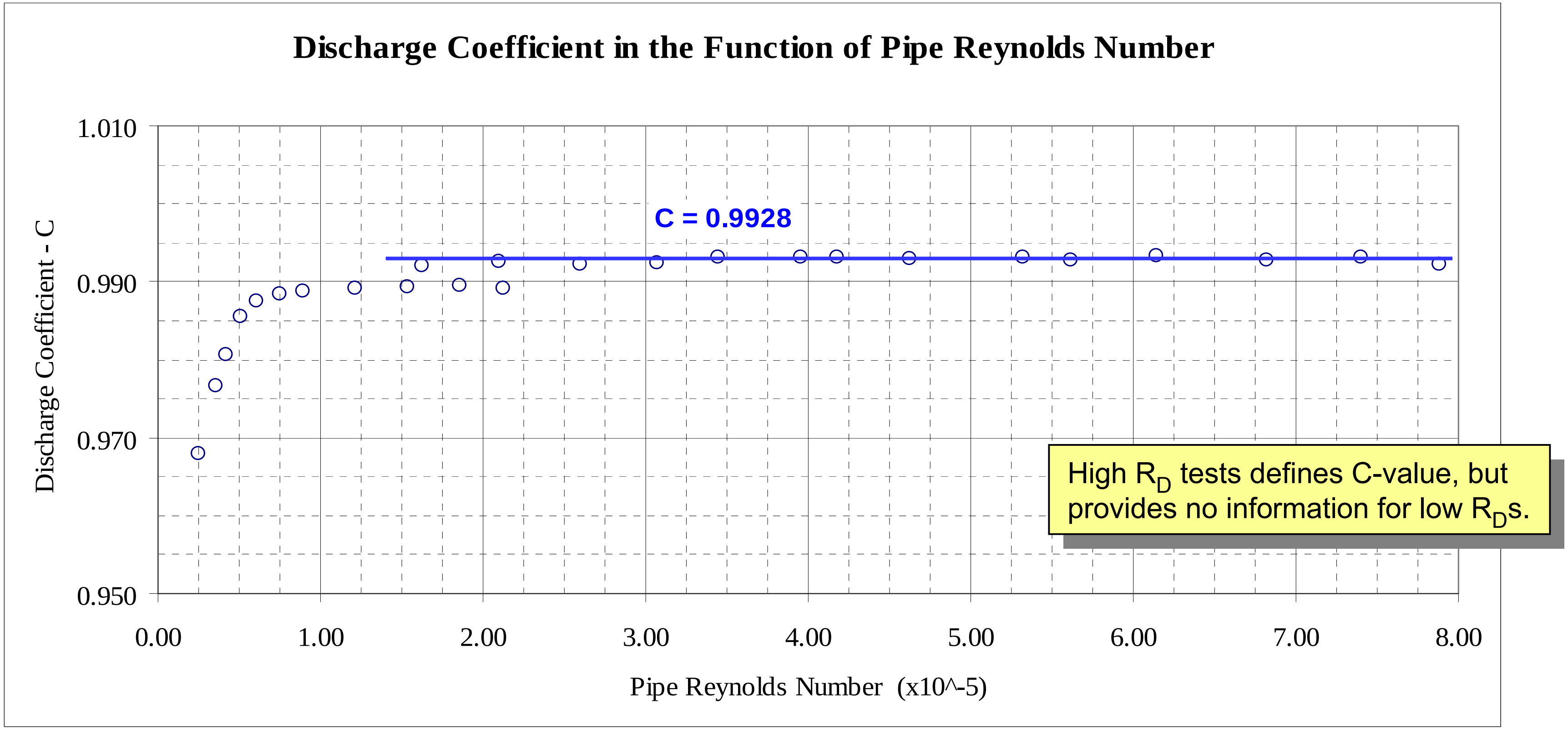
Even with a witness, it is more probable that
Tulsa Taxi is liable for damages than Creek Cab.

Discharge Coefficient in the Function of Pipe Reynolds Number



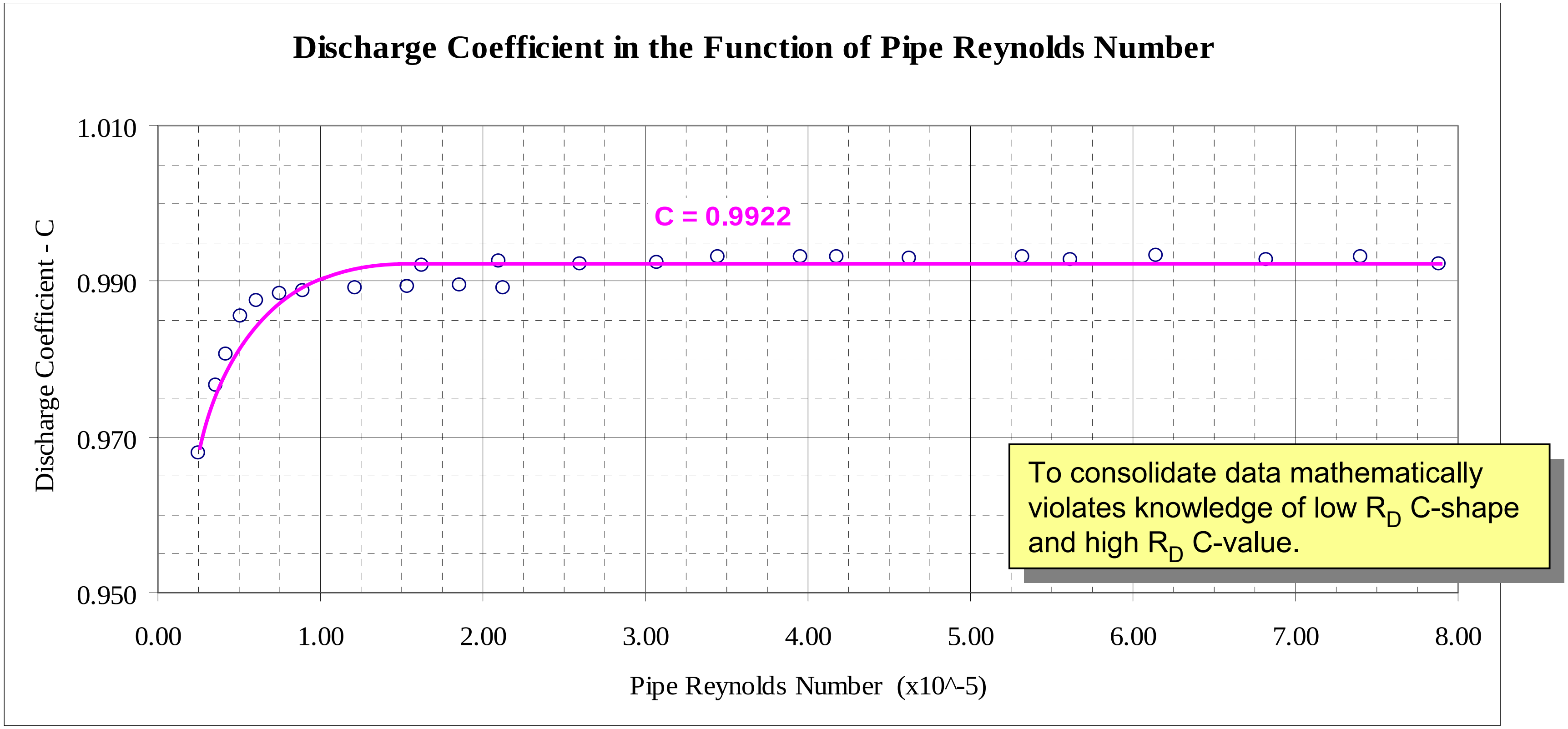
Inlet Diameter (inches):	3.381
Throat Diameter (inches):	1.3770
Beta Ratio (dimensionless):	0.4073
For Pipe Reynolds Numbers > 0.74 x 10^5, Mean Discharge Coefficient:	0.9891

WYATT ENGINEERING, LLC
4" LVM-B METER RUN
Serial Number: 4294
Bettis Atomic Research Laboratory
March 25, 2002



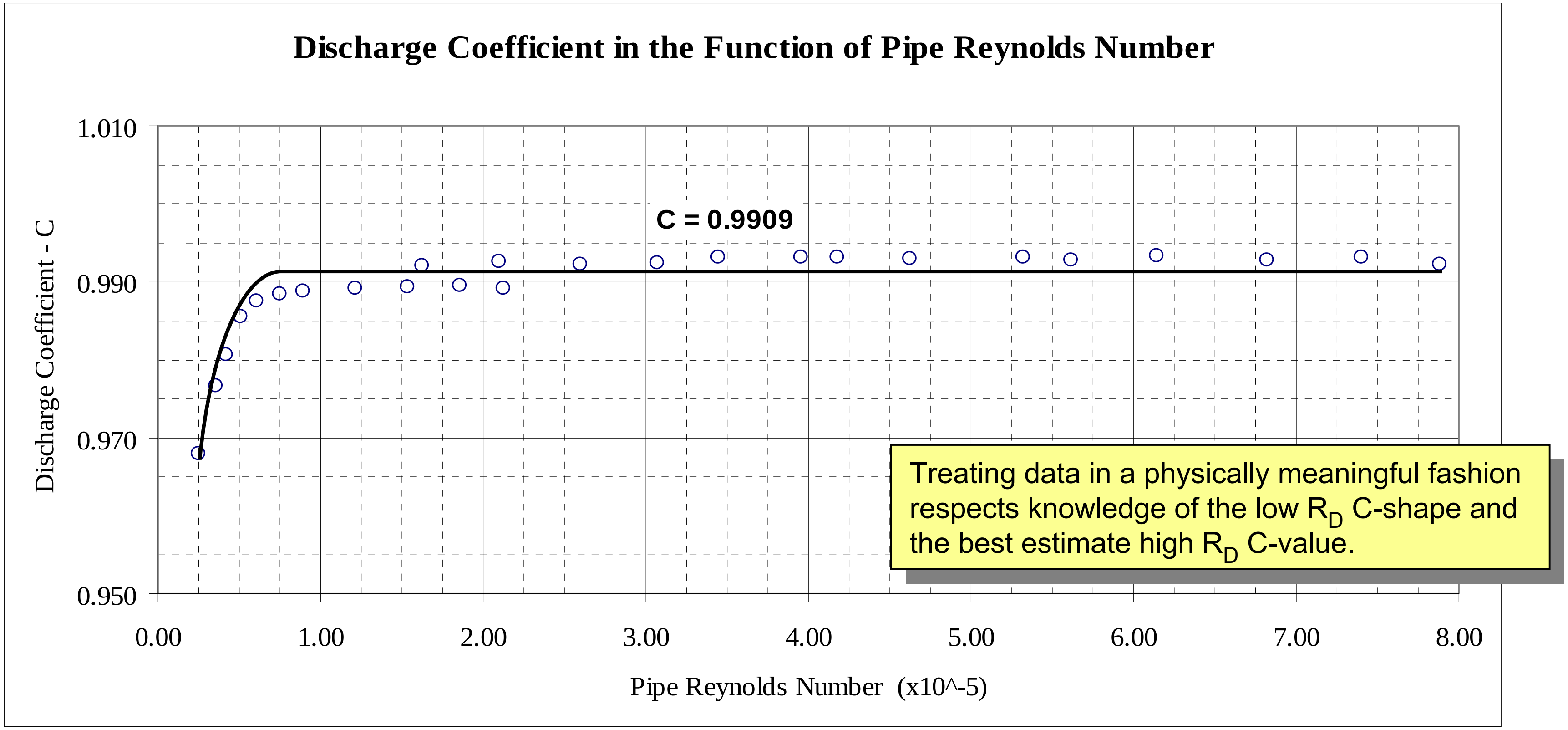
Inlet Diameter (inches):	3.381
Throat Diameter (inches):	1.3770
Beta Ratio (dimensionless):	0.4073
For Pipe Reynolds Numbers > 1.62 x 10^5,	
Mean Discharge Coefficient:	0.9928

WYATT ENGINEERING, LLC
4" LVM-B METER RUN
Serial Number: 4294
Bettis Atomic Research Laboratory
March 25, 2002



Inlet Diameter (inches):	3.381
Throat Diameter (inches):	1.3770
Beta Ratio (dimensionless):	0.4073
For Pipe Reynolds Numbers > 1.49 x 10^5, Mean Discharge Coefficient:	0.9922

WYATT ENGINEERING, LLC
4" LVM-B METER RUN
Serial Number: 4294
Bettis Atomic Research Laboratory
March 25, 2002



Inlet Diameter (inches):	3.381
Throat Diameter (inches):	1.3770
Beta Ratio (dimensionless):	0.4073
For Pipe Reynolds Numbers > 0.74 x 10^5, Mean Discharge Coefficient:	0.9909

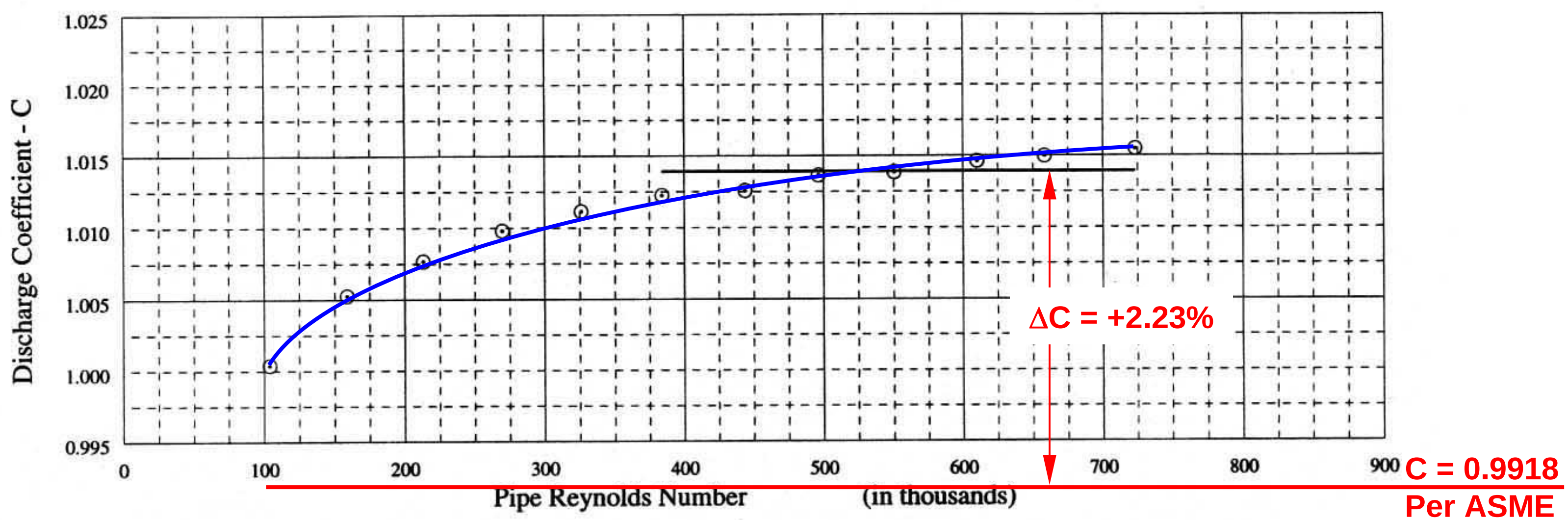
WYATT ENGINEERING, LLC
4" LVM-B METER RUN
Serial Number: 4294
Bettis Atomic Research Laboratory
March 25, 2002

The meter was calibrated so it must be good...

- The following three slides were taken from different manufacturers' web sites and promotional literature.
- Had they understood the data, they wouldn't be bragging about the results.
- Interpret the data for yourself.

WYATT engineering
Intelligent Flow Measurement

Some Manufacturers Do Not Realize How Poorly Their Devices Perform:



$$q_a = C\,F_a\,K_M\,\sqrt{\Delta h}$$

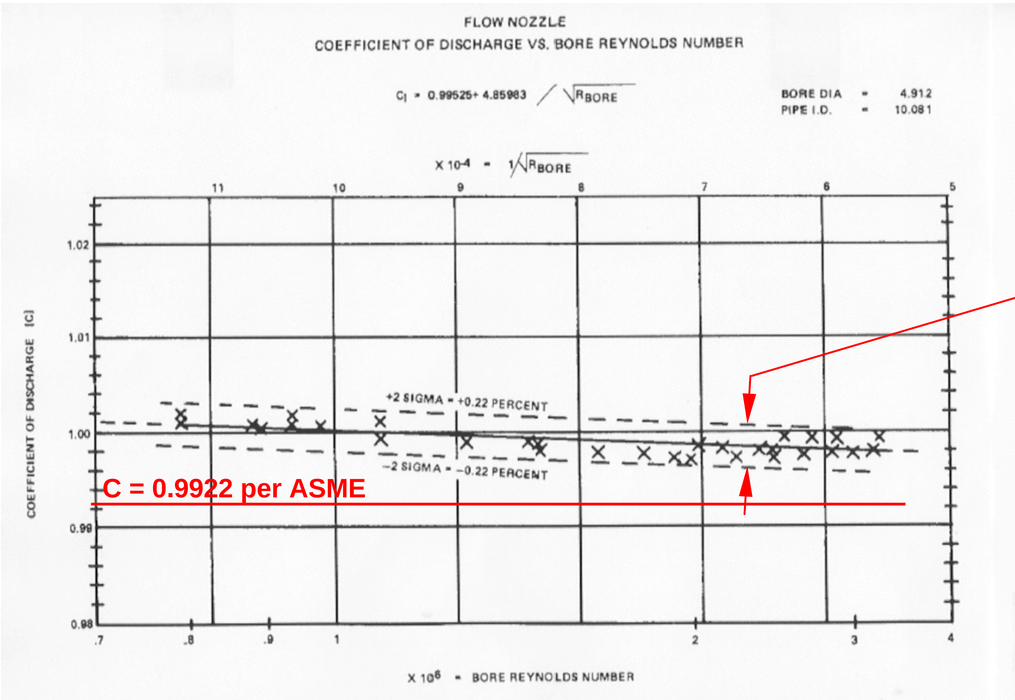
q_a = Actual Flow (ft^3/sec)		
C = Discharge Coefficient (Dimensionless)		
Δh = Pressure Differential (Feet of Water at Run Temperature)		
K_M = Meter Constant = $\frac{a\sqrt{2g}}{\sqrt{1-\beta^4}}$	=	0.3350
F_a = Average Thermal Expansion Factor	=	0.9996
a = Throat Area (ft^2)	=	0.0409
g = Local Acceleration of Gravity (ft/sec^2)	=	32.1625
β = Ratio of Throat to Pipe Diameter (Dimensionless)	=	0.4514
Pipe Diameter (Inches)	=	6.0650
Throat Diameter (Inches)	=	2.7380
For Pipe Reynolds Number > 380.00 x 10^3 avg coefficient	=	1.0139

Purchase Order Number: 26841-ALS
6" FLOW NOZZLE CS SCH STD
Serial Number: P & ID: M-10301
Tag Number: FE-B0302
October 23, 2002

Brand X Website,
23 September 2003

Certified By:

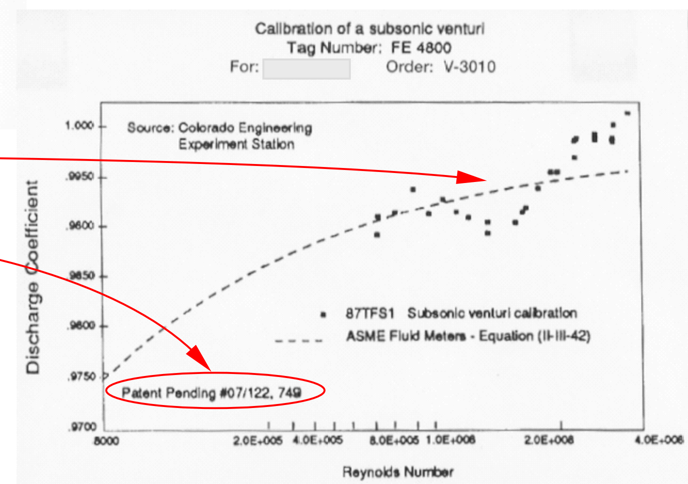
ARL



Some Manufacturers Do Not Know the Difference between Data Scatter and Accuracy

For Some, the Irony is Totally Lost

Impressive, but the Patent Office Has No Record of Such an Application



Brand Y Promotional Literature, Received June 2003

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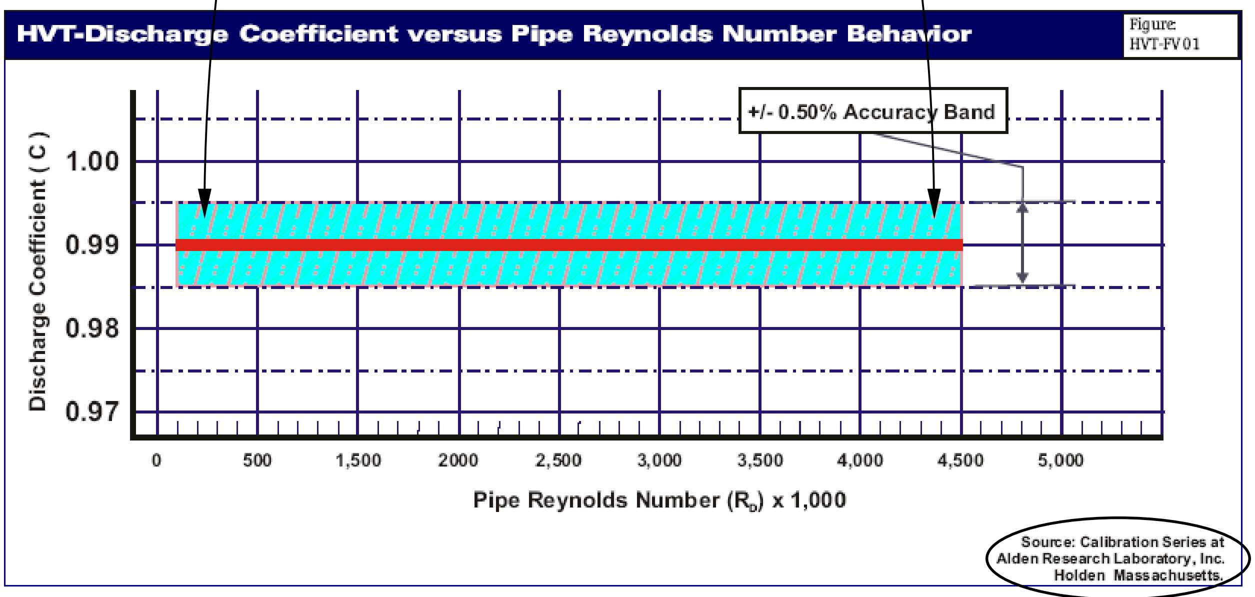
Intelligent Flow Measurement™

Some Feel Safer Providing No Data at All…

The HVT-FV Features and Benefits (continued)

Discharge Coefficient (C) is Stable above pipe Reynolds number of 75,000 R_D. (Continued)

The HVT-FV Coefficient of Discharge is **stable above the threshold R_D value of 75,000.** Additionally, the meter performance below 75,000 R_D is well known and predictable.



…but Do Not Hesitate Using the "Seal of Approval" of a Recognized Test Facility.

Brand Z Website, 9 October 2003

Design Flexibility and Custom Engineering

- Eccentric (Flat Invert) Design for Two-Phase Fluids
- Diaphragm Seals to Minimize Tap Plugging and Fugitive Emissions
- Wafer Style and Insert Meters Lower Cost
- Special Materials for Demanding Applications
  - Titanium
  - Teflon
  - Kynar

Product Overview

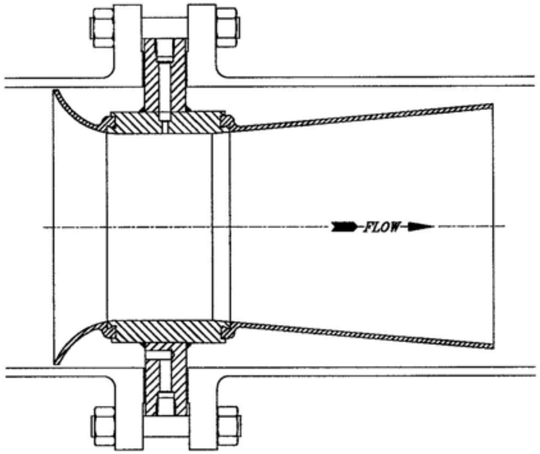
- **BVT-IP Series**

  Insert – Fabricated from Composite Materials

  - Vinyl ester or polyester resin with fiberglass reinforcement

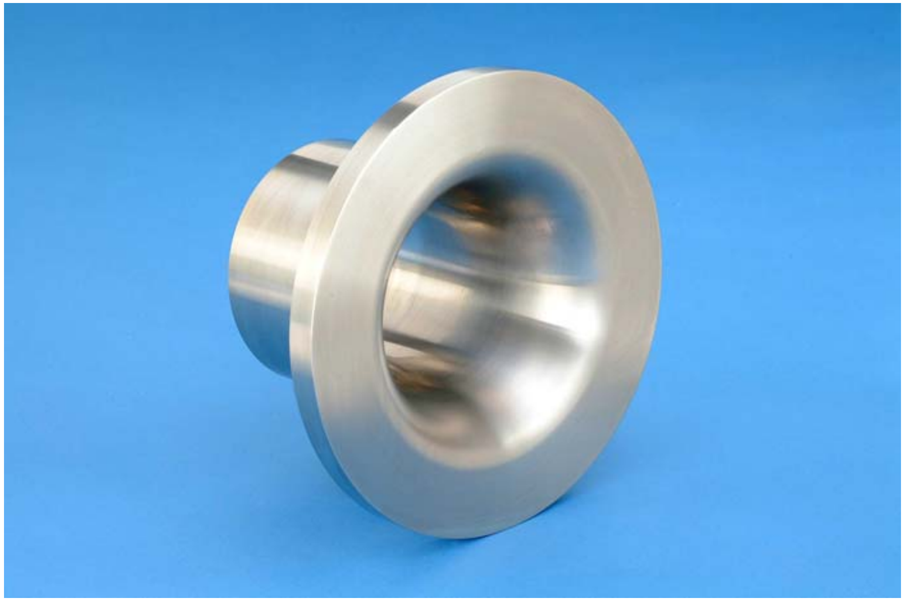
  IL version has a metallic throat and flange

  - Typically Bronze, 316SS, or 304SS

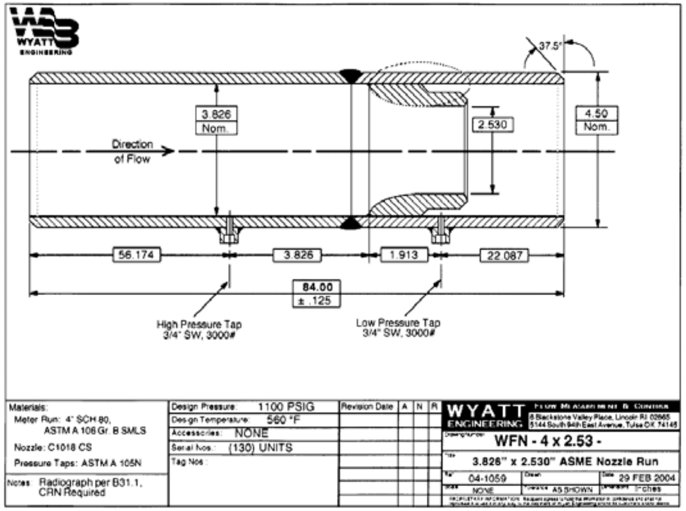


Product Overview

- **Flow Nozzles**
  - In accordance with ASME, AGA, ISO, or ASHRAE
  - Subcritical
  - Critical
  - Meter Runs
  - Test Sections



SAGD Application: Flow Nozzle vs. Venturi Meter

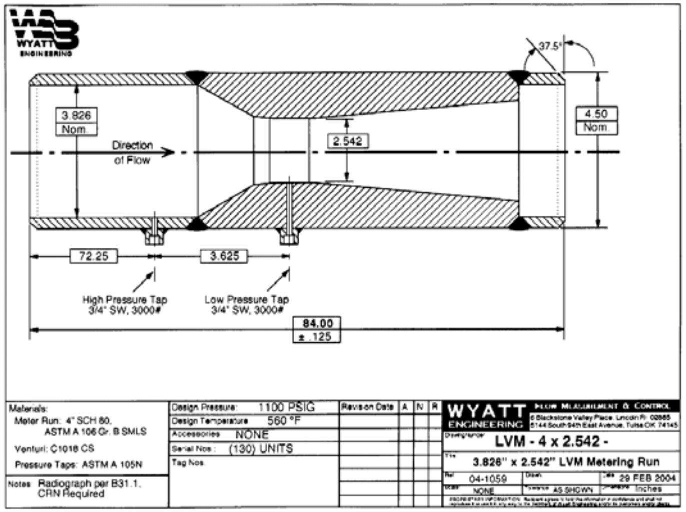


3.826” x 2.530” Flow Nozzle

ΔP = 205” wc, ΔH = 92.1” wc

$$\text{Annual Cost} = \frac{0.0172\,\Delta H\,Q\,\$}{\eta\,\rho} = \frac{0.0172(92.1)(52910.88)(0.07)}{(100\%)(2.115684)} =$$

<u>**$ 2,773 per unit per year**</u>



3.826” x 2.542” Venturi Meter

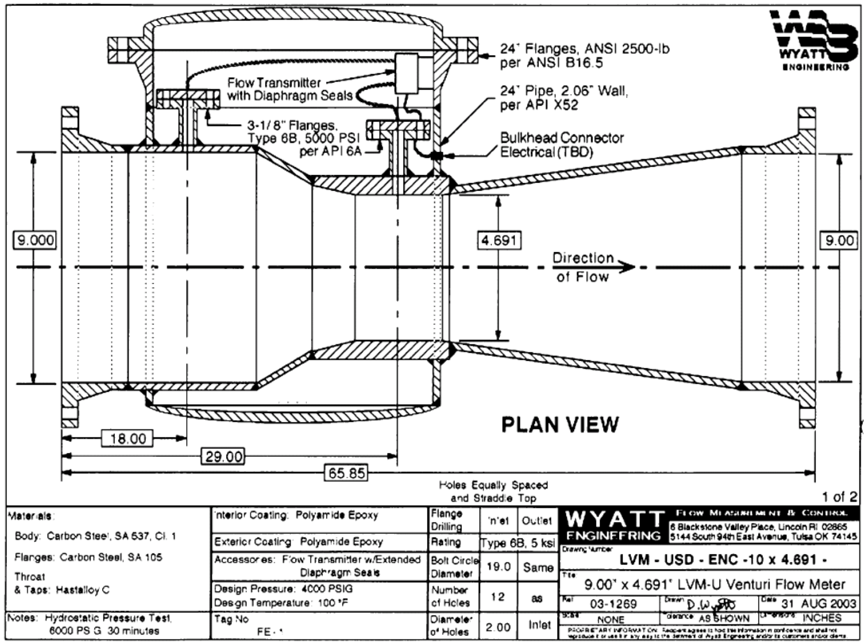
ΔP = 201” wc, ΔH = 10.5” wc

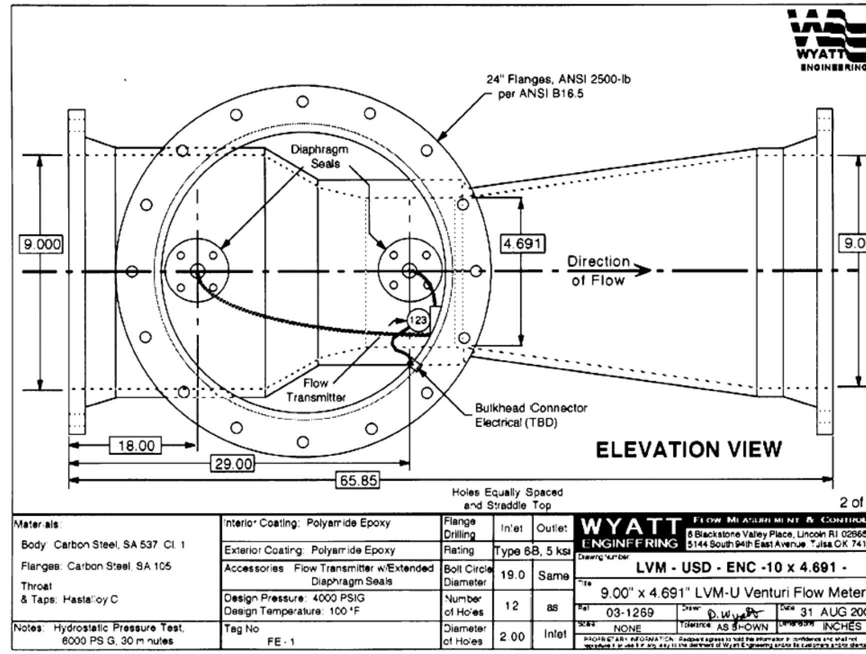
$$\text{Annual Cost} = \frac{0.0172\,\Delta H\,Q\,\$}{\eta\,\rho} = \frac{0.0172(10.5)(52910.88)(0.07)}{(100\%)(2.115684)} =$$

<u>**$ 316 per unit per year**</u>

Savings: $2,457 per unit per year x 130 units = $319,410 per year!

(A similarly sized vortex shedder has even greater losses than the flow nozzle)





North Sea Venturi Meter with Diaphragm Seals and Integral Electronics Module

- Subsea Water Injection to Maintain Reservoir Pressure
- Placed 400 meters below North Sea Surface
- 3-1/8" 5000 PSI API Pressure Connections to Accommodate Diaphragm Seals, Eliminating Tap Plugging
- Fieldbus or 4 – 20 mA DC Output Signal

Miscible Vapor / Water Venturi System

- Single Meter to Measure Both Fluids
- Improves Efficiency and Output of Existing Wells

Miscible Vapor

- Max. Flow Rate: 700 000 Nm^3/d
- Min. Flow Rate: 28 000 Nm^3/d
- Turndown: 25 to 1
- Pressure: 25 MPa
- Temperature: 50 °C

Water

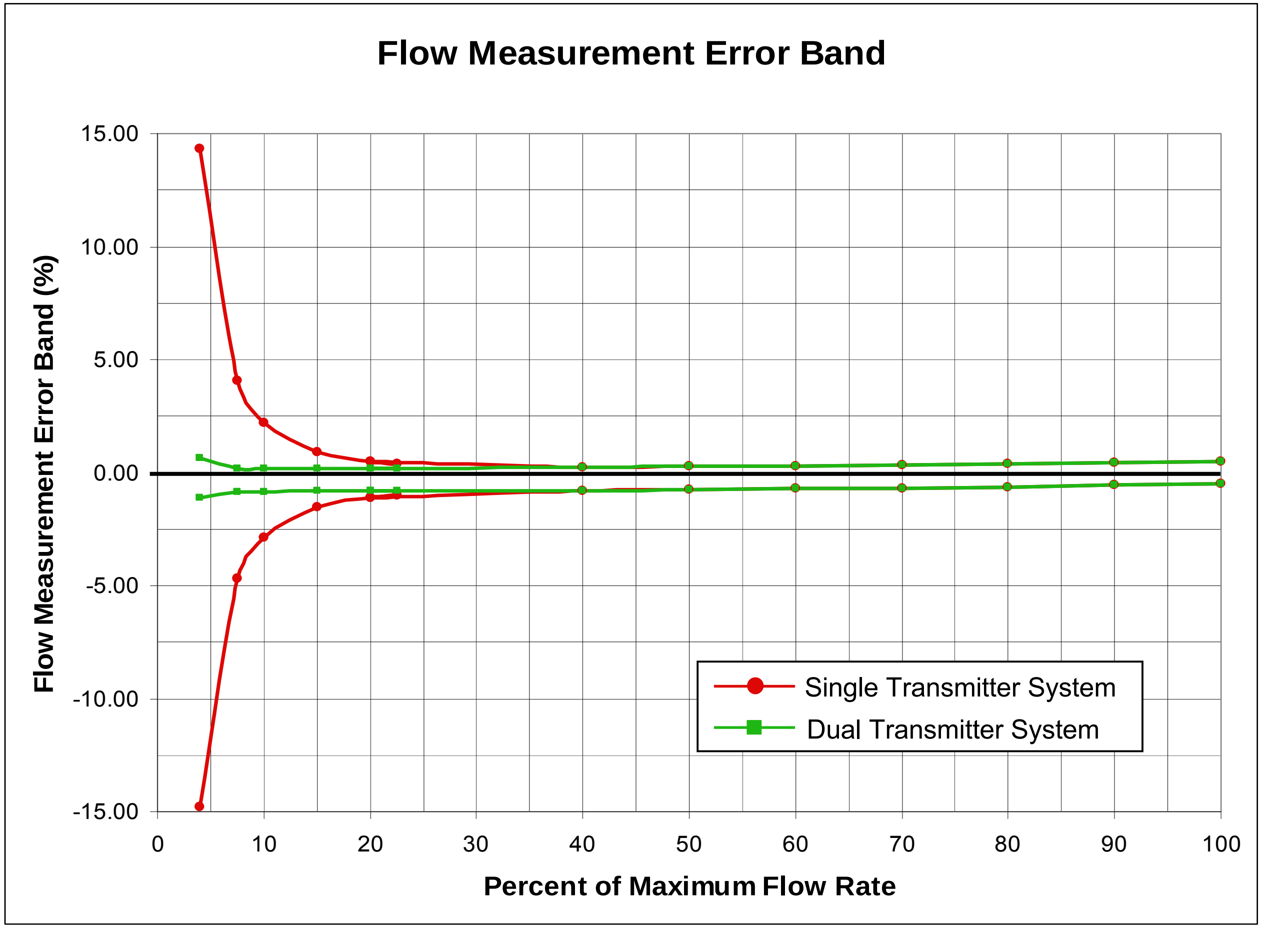
- Max. Flow Rate: 15 000 BPD
- Min. Flow Rate: 250 BPD
- Turndown: 60 to 1
- Pressure: 21 MPa
- Temperature: 27 °C

Solution: <u>ONE</u> 50mm, 75mm, or 100mm Venturi Metering System

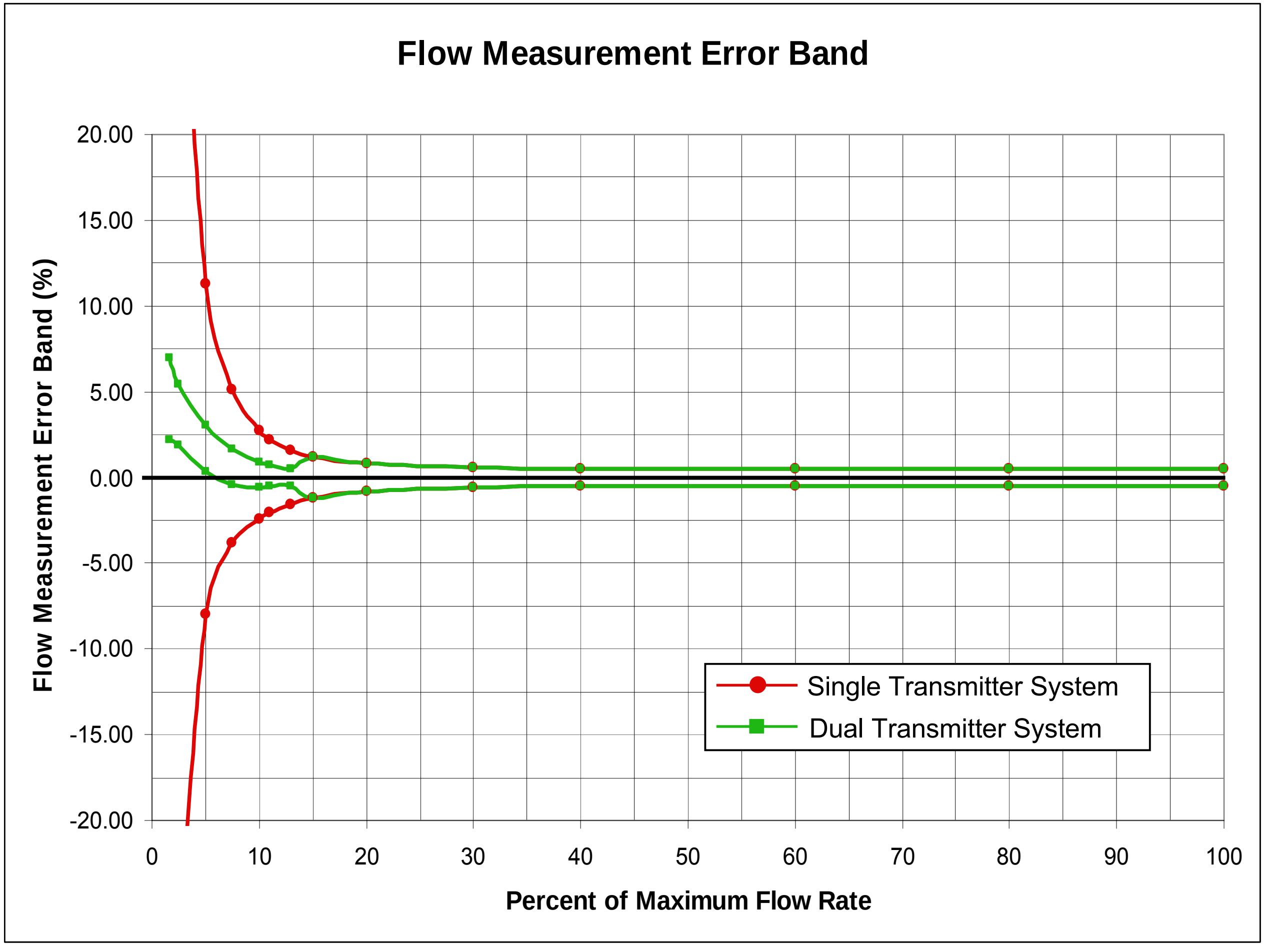
- Differential Pressure: 125.0 kPaD
- Pressure Loss: 8.7 kPa

- Differential Pressure: 272.5 kPaD
- Pressure Loss: 17 kPa

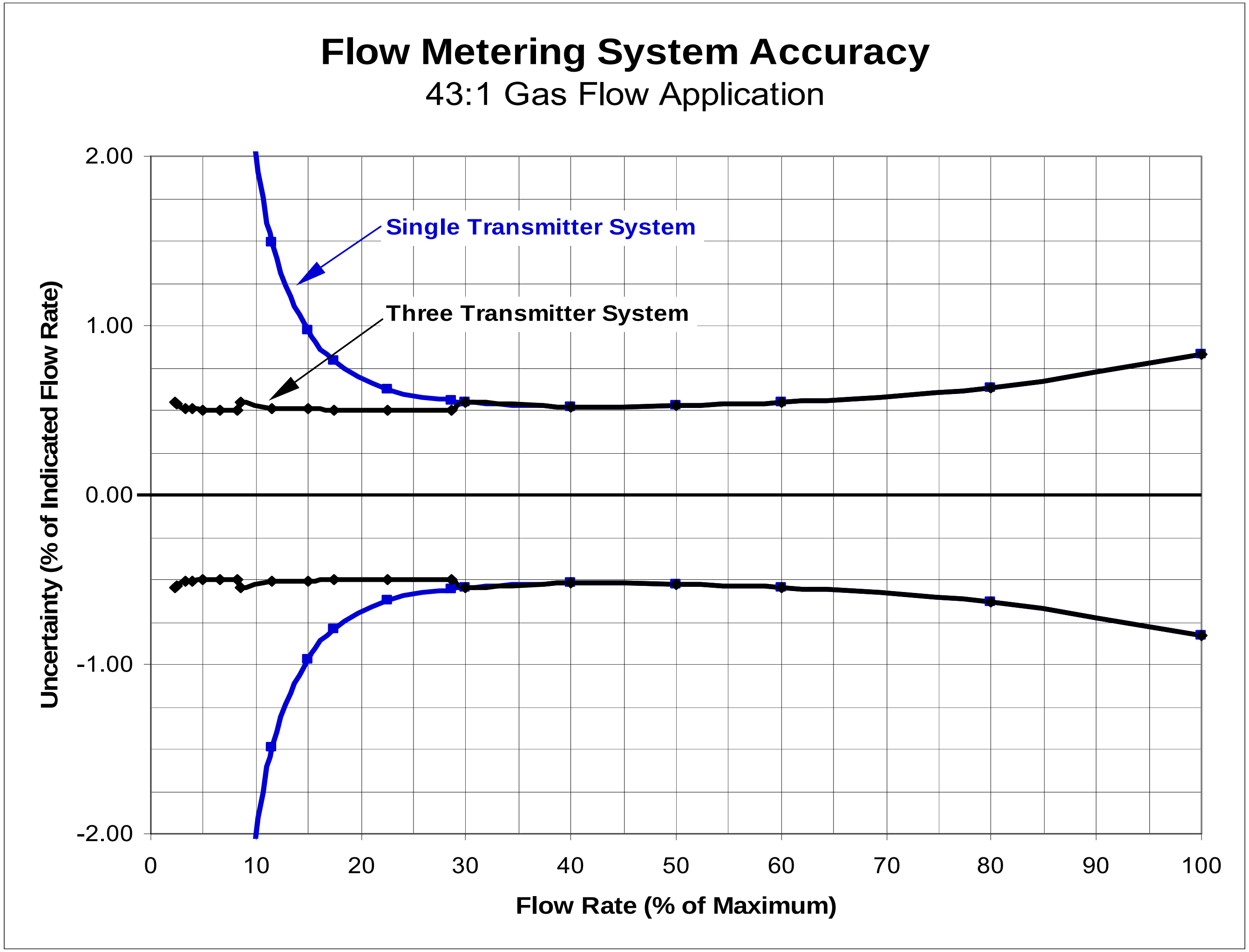
Miscible Vapor Measurement Uncertainty Band



Water Measurement Uncertainty Band



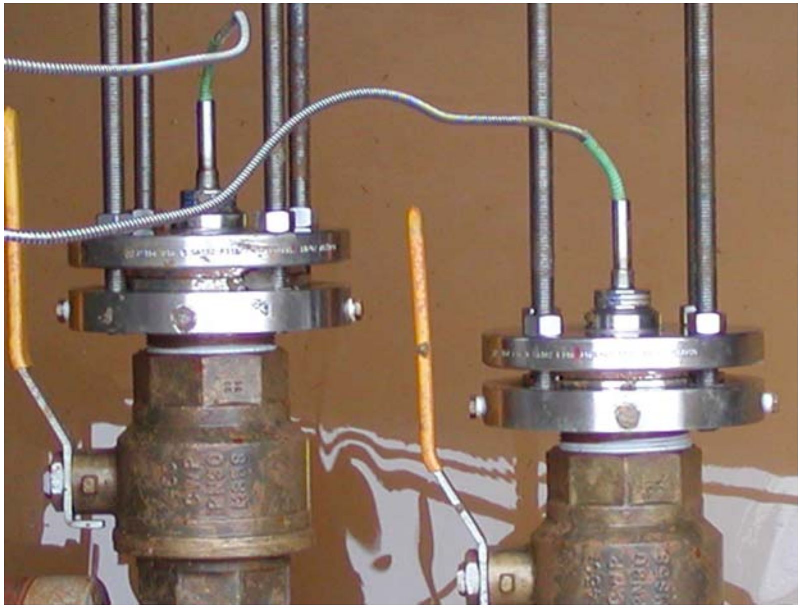
Multiple Flow Transmitters Can Extend the Range of Accurate Flow Measurement



Custom Engineering

Hot Tap Process Seals

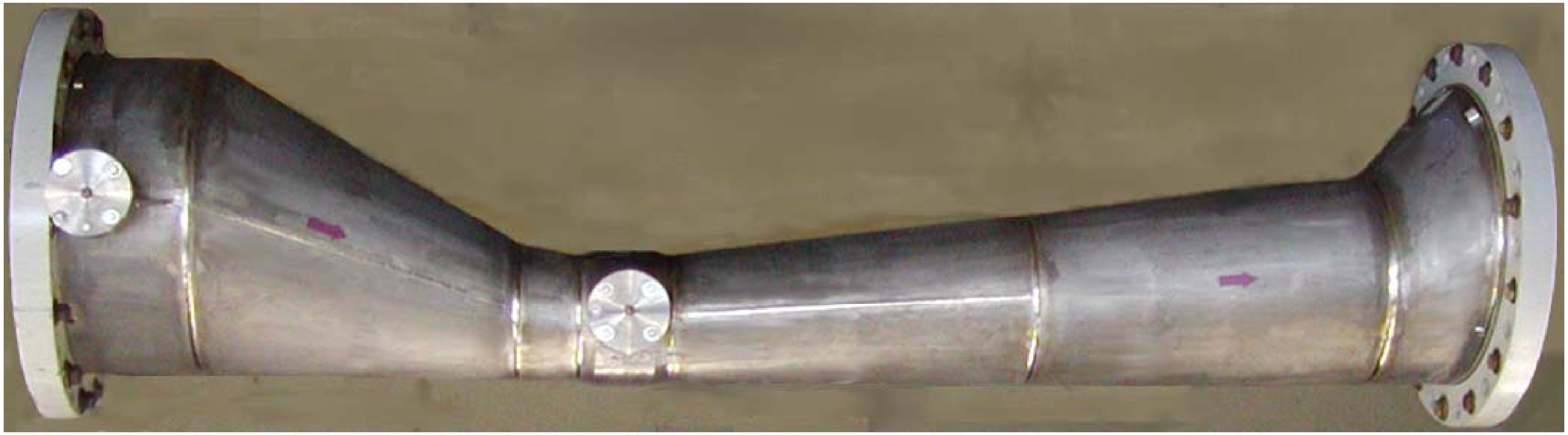
- Allows Use of Venturis for Coke Fines, Slurries, and Viscous Fluids
- Prevents Plugging and Contamination of Secondary Instrumentation
- Minimizes / Eliminates Fugitive Emissions
- Allows for Removal & Calibration under Pressure



Custom Engineering

Eccentric Venturi Meters

- Allows for the Passage of Solids in Liquid Flows, and
- Allows for the Passage of Liquids in Gas Flows
- Minimizes / Eliminates Build-Up
- Low Permanent Pressure Loss
- Flow Calibrated to ±0.25%



WYATT engineering
Intelligent Flow Measurement™

Third Party Certifications - PED

Conformance to the Pressure Equipment Directive (PED) is a legal requirement covering most pressure vessels used in the European Union. Use of nonconforming products can result in civil and criminal penalties.

Wyatt Engineering can provide

- Venturi Meters
  - BVT
  - Lo-Loss®
  - Liberty Venturi Meters
  - ASME, ISO, DIN Venturi Meters
- Flow Nozzles
- Orifice Plates and Orifice Metering Runs

for use in Europe.

Wyatt Engineering has also provided products in conformance with the Japanese High Pressure Gas Safety Law, as well as vessels with Canadian Registration Numbers (CRN).

DNV

DET NORSKE VERITAS

QS CERTIFICATE OF ASSESSMENT-EC

Application of the Council Directive 97/23/EC of 29 May 1997 on Pressure Equipment (AFS 1999:4), as amended.

CERTIFICATE NO. 03-SKM-PED-H-297775-00

Manufacturer

Wyatt Engineering, LLC
6 Blackstone Valley Place
Lincoln, RI, 02865 USA

The manufacturer's Quality System has been assessed with respect to the conformity assessment procedure as described in Module **H** *, and is found to comply with the requirements applicable to it.*

Applications/Limitations:

The certificate is valid for equipment listed in enclosure 1 and based on Quality system documentation according to enclosure 2.

The Manufacturer must inform Det Norske Veritas of any plan for substantial changes to the Quality System in order to examine whether this certificate remains valid. Periodical audits as required will be held to verify the validity of this certificate.

Place and date
Stockholm 2003-08-05

This Certificate is valid until
2006-08-05

DET NORSKE VERITAS INSPECTION AB

Edward Wander

Notified Body No.:
0409

Notice: The certificate is subject to terms and conditions, if any, overleaf. Any significant changes in design or construction of the product, the quality system or amendments to the Directive 97/23/EC (AFS 1999:4) or Standards referenced above may render this certificate invalid. The product liability rests with the manufacturer or his representative in accordance with the Directive 97/23/EC (AFS 1999:4), as amended.

If any person suffers loss or damage which is proved to have been caused by any negligent act or omission of Det Norske Veritas, then Det Norske Veritas shall pay compensation to such person for his proved direct loss or damage. However, the compensation shall not exceed an amount equal to ten times the fee charged for the service in question, provided that the maximum compensation shall never exceed USD 2 million. In this provision "Det Norske Veritas" shall mean the Foundation Det Norske Veritas as well as all its subsidiaries, directors, officers, employees, agents and any other acting on behalf of Det Norske Veritas.

DET NORSKE VERITAS INSPECTION AB Box 30234, 104 25 STOCKHOLM, Sweden
TEL (+46) 8 587 940 00 FAX (+46) 8 651 70 43 Vat. No. SE 556190593501 Registered office. STOCKHOLM

WYATT engineering

Intelligent Flow Measurement™

Third Party Certifications – ISO 9001:2000

DNV

DET NORSKE VERITAS
MANAGEMENT SYSTEM CERTIFICATE

Certificate No. CERT-03848-2002-AQ-HOU-RAB Rev.1

This is to certify that the Quality System
of

WYATT ENGINEERING, LLC

at

2010 Corporate Ridge, #700, McLean, VA 22102 USA
5144 S. 94th East Av., Tulsa, OK 74145 USA
6 Blackstone Valley Pl., Suite 401, Lincoln, RI 02865 USA

Has been found to conform to Quality Management Standard:

ISO 9001:2000

This Certificate is valid for the following products/service ranges:

WYATT ENGINEERING DESIGNS, ENGINEERS, MARKETS, AND MANAGES THE PRODUCTION, INSPECTION, AND TESTING OF FLOW MEASUREMENT AND CONTROL PRODUCTS. WYATT ENGINEERING PROVIDES A COMPLETE LINE OF DIFFERENTIAL PRESSURE PRIMARY ELEMENTS INCLUDING: ASME VENTURIS, WYATT-BADGER LO-LOSS(R) TUBES, VENTURI TUBES, AND ORIFICE PLATES.

Place and date:
Houston, Texas; 21 February 2003

This certificate is valid until:
05 June 2005

Initial Certification Date:
05 June 2002

for the Accredited Unit:
DET NORSKE VERITAS CERTIFICATION, INC.
Houston, TX USA

ANSI•RAB QMS ACCREDITED

Rudy Frueboes
Management Representative
Det Norske Veritas Certification, Inc.

Terry Heaps
Lead Auditor

Further clarifications regarding the scope of this certificate and the applicability of ISO 9001:2000 requirements may be obtained by consulting the organization.
Lack of fulfillment of conditions as set out in the Appendix may render this certificate invalid.

DET NORSKE VERITAS CERTIFICATION, INC., 16340 Park Ten Place, Suite 100, Houston, TX 77084 USA TEL: (281) 721-6600 FAX: (281) 721-6903

WYATT
engineering

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DNV Certification, Inc.
ISO 9001 REGISTERED FIRM