Kuwait 4th Flow Measurement Technology Conference

3-5 December 2019

Hilton Kuwait Resort

OFFICIAL SPONSOR

الراعــي الرسمــي

Flow measurement Selection

YASSER MAHMOUD

Prof. Engineer Instrumentation, Automation & Control
TÜV Functional Instrumented Safety Engineer

Biography - Yasser Mahmoud

- ✓ Certified **"Professional Engineer - P.Eng."** in 'Automation and Control' - Skill Level # 1 (ID 5131886) by Engineers Australia .
- ✓ Certified **"TÜV Functional Instrumented Safety Engineer – TÜVFSEng'** in Process "Safety Instrumented Systems - SIS' according to "IEC-61511 & IEC-61508" by (ID TÜVFSEng - 2557/10) by TÜV Rheinland Germany
- ✓ Credentialed **'Electronics & Control Engineer'** by 'World Educational Services – WES' Reference # 2969235) Canada.
- ✓ B.Sc of **Electronics & Control Engineering**, Mansoura University, Egypt 1999.

Twenty years of practical experience in "Instrumentation, Automation, Control and Process Functional Safety Engineering" in Oil & Gas Industries (Onshore, Offshore and Subsea). First eight years in leading EPC Egyptian Company (ENPPI) and currently honorably representing the Kuwaiti giant Oil Company KOC for almost 12 years till present.

Outlines

A. Selection Challenges

Objectives:

In this paper, an overview is given of the Flow measurement selection and of the most widely used flow sensors. In addition, emphasis is given to some techniques that are extremely useful, yet not being employed.

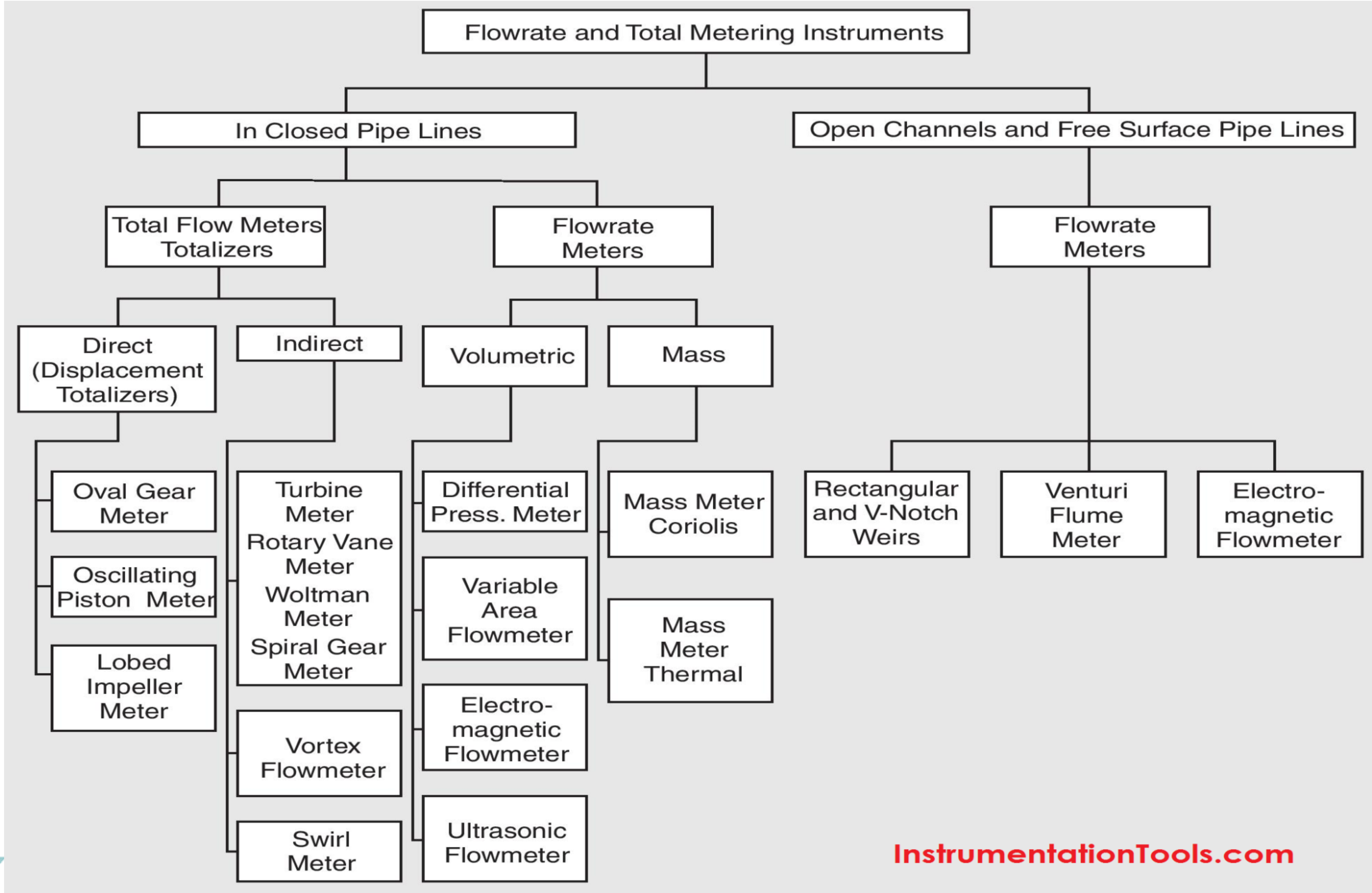
Selection gets more challenging with **Wider Varieties** of **Critical Choices**

This is exactly the case when it comes to **Flow measurement selection**

1. Wide Variety

Nearly every flowmeter category can be further subdivided into a variety of distinctly different subcategories. For example, the positive-displacement type of flow sensors include rotary piston, oval gear, sliding vane, and reciprocating piston designs. If these sub variants are also counted, the number of flow sensors available for consideration is even higher.

A. Selection Challenges



A. Selection Challenges

2. Criticality

No industrial measurement is more important than accurate measurement of flow rates of gases, liquids, and solids. (Consequences of wrong selection vary from inaccurate monitoring to catastrophic money, asset and production losses and even fatal accidents)

- The risk of wrong selection varies from **minor inaccurate flow monitoring** to **catastrophic money, asset and production losses and even fatal accidents**.

A. Selection Challenges

Example-1

It could be easily imagined if you know that inaccurate Flowmeter with 5% FS inaccuracy in crude export of a plant of capacity 300 MBOPD means a daily loss of 15,000 barrel oil, i.e. 15,000 X $70 (Avg.)= **$1,050,000 ~(1 Million USD daily)**.

Note: Even if the selected meter is **very accurate** (based on manufacturer data), wrong selection and employment would result in **massive reading errors**

A. Selection Challenges

Example-2

- **Energy Costs of Head-Type (D/P) Flow measurement:**

One can calculate the yearly operating cost of any flow measurement installation by using the following formula:

$$\$/\mathrm{yr} = C(\$/\mathrm{KWH})(OT)(dP)(F)(SpG)/(\%)$$

Where:

- **C** = a correction factor for the units used (C = 1.65 if the flow is in GPM and the pressure loss is in feet)
- **$/KWH** = unit cost of electricity in the area
- **OT** = operating time of the meter (1.0 if operated continuously)
- **dP** = pressure loss in velocity heads in the particular meter (units are feet or meters)
- **F** = flow rate (units are in GPM or m^3/sec)
- **SpG** = specific gravity of the flowing fluid (water = 1.0)
- **% =** Pump Efficiency (or compressor) expressed as a fraction (70% = 0.7)

A. Selection Challenges

- Orifice sized for 100-in (3.6 psi, 250 mbar) H_2O Pressure Drop, 16-in, schedule 40 steel pipe, flow of 5000 GPM of Water flow, continuously operating meter (*OT* = 1.0), the **cost of electricity is** $0.1/kWh and pump efficiency is 60% (% = 0.6).
  - **$/yr = 1.65(0.1) (1.0) (8.333) (5000) (1.0)/0.6 = <u>$11,457 per year</u>**
- If the cost of electricity is $0.1/kWh and the pumping efficiency is 60%, the operating cost of any continuous pressure drop in any water pumping system can be calculated as **$/yr = 0.635 (GPM) (PSID)**

Therefore, when selecting a flowmeter, we should consider not only the purchase and installation costs but also the operating cost during the life of the flowmeter.

A major component of Head-type flowmeters operating cost is the pumping (or compressor) energy costs.

B. Traditional Selection Procedures

Traditionally, shall comprise **three main steps**:

- **Step-1:** Suitability:

1. **Technically Capable & Available – (Application Based)**
   - **Instrumentation signaling** and **functional requirements**
   - **Process**, **Mechanical**, **Electrical** conditional requirements

   All normally gathered in a datasheet

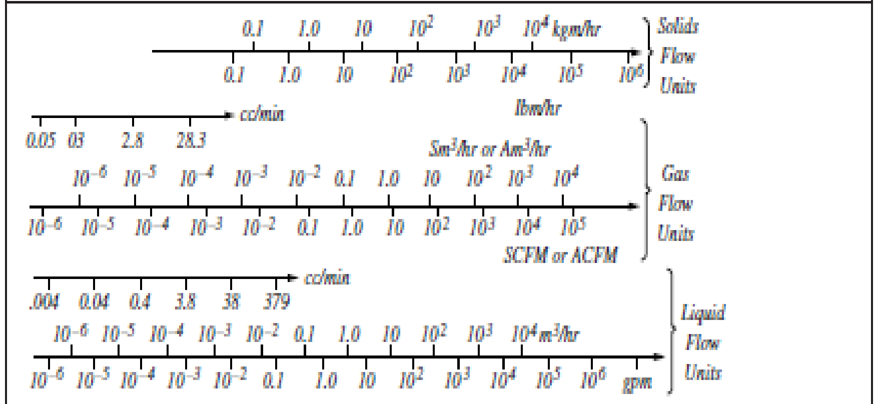
2. **Selection tables** *Samples*

By this process, we are likely to eliminate from consideration about half of the flow sensors listed in the table.

H. Samples of 'Selection Tables‘

Orientation Table for Selecting the Right Flow Sensors

Type of Design	Applicable to Detect the Flow of: Clean Liquids	Viscous Liquids	Slurry	Gas	Solids	Direct Mass—Flow Sensor	Volumetric Flow Detector	Flow Rate Sensor	Inherent Totalizer	Direct Indicator	Transmitter Available	Linear Output	Rangeability	Pressure Loss Thru Sensor	Approx. Straight Pipe-Run requirement (Upstream Diam./Downstream Diam.)	Accuracy * ± % Full Scale ** ± % Rate *** ± % Registration	FLOW RANGE
Elbow Taps	✓	L	L	✓			✓	✓			✓	SR	3:1[8]	N	[7]25/10	5–10*	gpm—m³/hr SCFM—Sm³/hr
Jet Deflection				✓			✓	✓			✓	✓	25:1	N	[7]20/5	2*	SCFM—Sm³/hr
Laminar Flowmeters	✓	✓		✓			✓	✓			✓	✓	10:1	H	15/5	½–5*[8]	gpm—m³/hr SCFM—Sm³/hr
Magnetic Flowmeters	✓[5]	✓[5]	✓[5]				✓	✓			✓	✓	10:1[8]	H	5/3	½**–2*	gpm—m³/hr
Mass Flowmeters, Misc. Coriolis	✓ ✓	✓ ✓	✓ L	✓ ✓	 SD	✓ ✓	✓ ✓	✓ ✓	SD SD	SD SD	✓ ✓	✓ ✓	100:1 20:1	A H	N N	½** 0.15–½**	lbm/hr–kgm/hr SCFM—Sm³/hr
Metering Pumps	✓	✓	✓				✓		✓		SD	✓	20:1	–	N	$^1/_{10}$–1*	gpm—m³/hr
Orifice (Plate or Integral Cell)	✓	L	L	✓			✓	✓			✓	SR	3:1[8]	H	[7]20/5	½**–2*	gpm—m³/hr SCFM—Sm³/hr
Pitot Tubes	✓		L	✓			✓	✓			✓	SR	3:1[8]	M	[7]30/5	0.5–5*	gpm—m³/hr SCFM—Sm³/hr
Positive Displacement Gas Meters				✓			✓		✓	✓	SD	✓	10:1 to 200:1	M	N	½–1***	SCFM—Sm³/hr



Positive Displacement Liquid Meters	✓	✓					✓		✓	✓	SD	✓	10:1⑧	H	N	0.1–2**	gpm—m³/hr
Segmental Wedge	✓	✓	✓				✓	✓			✓	SR	3:1	M	15/5	3**	gpm—m³/hr
Solids Flowmeters		SD	SD		✓	SD	SD	✓	✓	SD	✓	✓	20:1	—	5/3	½**–4*	lbm/hr-kgm/hr
Target Meters	✓	✓	L	✓			✓	✓		SD	✓	SR	4:1	H	20/5	0.5*–5*	---- gpm—m³/hr ---- SCFM—Sm³/hr
Thermal Meters (Mass Flow)	✓	L	L	✓		✓		✓			✓	L	20:1③	A	5/3	1–2*	gpm—m³/hr SCFM—Sm³/hr
Turbine Flowmeters (Dual Turbine)	✓	L		SD			✓	✓			✓	✓	10:1 (>100:1)	H	15/5⑦	¼**	gpm—m³/hr SCFM—Sm³/hr
V-Cone Flowmeter	✓	L	L	✓			✓	✓			✓	SR	3:1②	M	2/5	½–2**	gpm—m³/hr ACFM—Sm³/hr
Ultrasonic Flowmeters Transit		L					✓	✓			✓	✓	20:1	N	⑦15/5	1**–2*	gpm—m³/hr② SCFM—Sm³/hr
Doppler	✓	L	✓	L	L		✓	✓			✓	✓	10:1	N	⑦15/5	2–3*	
Variable-Area Flowmeters (Dual float)	✓	L	L	✓			✓	✓		✓	✓	✓	5:1 (to 20:1)	A	N	½*–10**	gpm—m³/hr SCFM—Sm³/hr
Venturi Tubes	✓	L	L	✓			✓	✓			✓	SR	3:1②	M	⑦15/5	½**–1*	gpm—m³/hr② SCFM—Sm³/hr
Flow Nozzles			L	✓			✓	✓			✓	SR	3:1②	H	⑦20/5	1**–2*	
Vortex Shedding	✓			✓			✓	✓			✓	✓	10:1⑧	H	20/5	0.5–1.5**	gpm—m³/hr ACFM—Sm³/hr
Fluidic	✓						✓	✓			✓	✓	20:1⑧	H	20/5	1–2**	
Oscillating	✓						✓	✓			✓	✓	10:1⑧	H	20/5	0–5*	
Weirs, Flumes	✓	L	L				✓	✓			✓	SD	100:1	M	See Text	2–5*	gpm—m³/hr②

---- = Non-standard Range
L = Limited
SD = Some Designs
H = High
A = Average
M = Minimal
N = None
SR = Square Root

Flowmeter Selection for Metering a Variety of Fluids

	Fluid Details \ Meter Type	Correlation	Elbow Taps	Laminar	Electro-Magnetic	Angular Momentum	Metering Pumps	Orifice	Pitot	Gas Displacement	Liquid Displacement	Solids Flowmeter	Target	Thermal	Liquid Turbine	Gas Turbine	Doppler U-Sonic	Transit U-Sonic	V.A.	Venturi	Vortex Shedding	Vortex Precession	Fluidic Oscillation
Liquid	Clean	X	✓	✓	*✓	✓	✓	✓	✓	X	✓	X	✓	✓	✓	X	X	✓	✓	✓	✓	X	✓
Liquid	Dirty	✓	?	✓	*✓	✓	✓	?	?	X	X	?	✓	✓	?	X	✓	?	✓	✓	?	X	?
Liquid	Slurries	✓	X	?	*✓	?	✓	X	X	X	X	SD	?	?	X	X	?	X	X	?	X	X	X
Liquid	Low Viscosity	✓	✓	✓	*✓	✓	✓	✓	✓	X	?	X	✓	✓	✓	X	✓	✓	✓	✓	✓	X	✓
Liquid	High Viscosity	✓	?	?	*✓	?	✓	?	X	X	✓	SD	?	?	X	X	?	?	?	?	X	X	X
Liquid	Corrosive	✓	✓	?	*✓	✓	?	✓	✓	X	?	X	?	?	?	X	✓	✓	✓	?	?	X	?
Liquid	Very Corrosive	✓	?	X	*✓	X	X	?	?	X	X	X	X	?	X	X	✓	✓	✓	X	X	X	X
Gas	Low Pressure	X	✓	✓	X	✓	X	✓	✓	✓	X	X	✓	✓	X	✓	X	X	✓	✓	✓	✓	X
Gas	High Pressure	X	✓	✓	X	✓	X	✓	✓	✓	X	X	✓	✓	X	✓	X	X	X	✓	✓	✓	X
	Steam	X	X	?	X	X	X	✓	X	X	X	X	✓	X	X	SD	X	X	✓	✓	SD	X	X
	Reverse Flow	X	✓	X	✓	X	X	SD	X	X	X	X	X	X	SD	SD	✓	✓	X	X	X	X	X
	Pulsating Flow	?	X	✓	✓	X	X	?	X	X	X	X	X	X	X	X	✓	✓	?	?	X	X	X

* = Must be electrically conductive

✓ = Generally suitable

? = Worth consideration

X = Not suitable

SD = Some design

*Flowmeter Selection Table**

	Clean Liquids	*Dirty Liquids*	*Corrosive Liquids*	*Viscous Liquids*	*Abrasive Slurries*	*Fibrous Slurries*	*Low Velocity Flows*	*Vapor or Gas*	*Hi Temp. Service*	*Cryogenic Service*	*Semi-Filled Pipes*	*Non-Newtonians*	*Open Channel*
Differential Pressure													
Orifice	✓	??	?	?	X	X	✓	✓	✓	✓	X	??	X
Venturi	✓	?	??	??	??	??	??	✓	??	??	X	??	X
Flow Nozzles and Tubes	✓	??	??	??	??	??	??	✓	??	??	X	??	X
Pitot Tubes	✓	??	?	??	X	X	??	✓	??	??	X	X	X
Elbow	✓	?	?	??	?	??	X	✓	??	??	X	??	X
Magnetic	✓	✓	✓	?	✓	✓	?	X	??	X	??	?	??
Mass													
Coriolis	✓	✓	?	✓	✓	?	?	??	??	??	X	✓	X
Thermal	??	??	??	??	??	??	?	✓	??	X	X	??	X
Oscillatory													
Vortex Shedding	✓	?	?	??	X	X	X	✓	??	??	X	X	X
Fluidic	✓	??	?	??	X	X	X	X	??	??	X	X	X
Vortex Precession	✓	X	??	??	X	X	X	✓	??	X	X	X	X
Positive Displacement	✓	X	??	✓	X	X	✓	✓	??	??	X	X	X
Target	✓	?	?	?	??	X	??	✓	??	??	X	??	X
Turbine	✓	??	??	?	X	X	??	✓	??	??	X	X	?
Ultrasonic													
Transit Time	✓	??	??	??	X	X	??	??	X	??	X	X	?
Doppler	X	✓	??	??	??	??	??	X	X	X	X	??	X
Variable Area	✓	?	?	?	X	X	??	✓	?	X	X	X	X
Weirs and Flumes	✓	?	??	X	??	??	?	X	X	X	✓	X	✓

✓Designed for this service
?? Applicable for the service under certain conditions, consult manufacture
? Normally applicable for this service
X Not applicable for this service
*Courtesy of Fischer & Porter, which today is new ABB Process Automation.

*Flowmeter Selection Table**

Flowmeter	Pipe size, in (mm)	Gases (vapors)		Liquids						Temperature, °F (°C)	Pressure, PSIG (kPa)	Accuracy, uncalibrated (including transmitter)	Reynolds number† or Viscosity
								Slurries					
		Clean	Dirty	Clean	Viscous	Dirty	Corrosive	Fibrous	Abrasive				
SQUARE ROOT SCALE. MAXIMUM SINGLE RANGE 4:1													
Orifice										Process temperature to 1000°F (540°C); transmitter limited to −30–250°F(−30–120°C)	To 4000 PSIG (41,000 kPa)		
Square-edged	>1.5 (40)	✓	X	✓	X	?	?	X	X			±1–2% URV	R_D > 2000
Honed meter run	0.5–1.5 (12–40)	✓	X	✓	?	X	?	X	X			±1% URV	R_D > 1000
Integral	<0.5(12)	✓	X	✓	✓	X	?	X	X			±2–5% URV	R_D > 100
Quadrant/conic edge	>1.5(40)	X	X	✓	✓	?	?	X	X			±2% URV	R_D > 200
Eccentric	>2(50)	?	✓	?	X	✓	?	X	X			±2% URV	R_D > 10,000
Segmental	>4(100)	?	✓	?	X	✓	?	X	X			±2% URV	R_D > 10,000
Annular	>4(100)	?	✓	?	X	✓	?	X	X			±2% URV	R_D > 10,000
Target	0.5–4 (12–100)	✓	✓	✓	✓	✓	?	X	X			±1.5–5% URV	R_D > 100
Venturi	>2(50)	✓	?	✓	?	?	?	?	?			±1–±2% URV	R_D > 75,000
Flow nozzle	>2(50)	✓	?	✓	?	?	?	X	X			±1–±2% URV	R_D > 10,000
Low loss	>3(75)	✓	X	✓	X	X	✓	X	X			±1.25% URV	R_D > 12,800
Pitot	>3(75)	✓	X	✓	?	X	?	X	X			±5% URV	No limit
Annubar	>1(25)	✓	X	✓	X	X	?	X	X			±1.25% URV	R_D > 10,000†
Elbow	>2(50)	✓	?	✓	X	?	?	?	?			±4.25% URV	R_D > 10,000†

LINEAR SCALE TYPICAL RANGE 10:1

Magnetic	0.1–72 (2.5–1800)	X	X	✓	✓	✓	✓	✓	✓	360 (180)	≤1500 (10,800)	±0.5% of rate to ±1% URV	No limit
Positive-displacement	<12 (300)	✓	X	✓	X	X	?	X	X	Gases: 250 (120) Liquids: 600 (315)	≤1400 (10,000)	Gases: ±1% URV Liquids: ±0.5% of rate	≤8000 cS
Turbine (Dual turbine)	0.25–24 (6–600)	✓	X	✓	X	X	?	X	X	–450–500 (–268–260)	≤3000 (21,000)	Gases: ±0.5% of rate Liquids ±1% of rate (±0.1% of rate over 100:1 range)	≤2–15 cS
Ultrasonic Time-of-flight	>0.5 (12)	X	X	✓	?	X	✓	X	X	–300–500 (–180–260)	Pipe rating	±1% of rate to ±5% URV	No limit
Doppler	>0.5 (12)	X	X	X	?	✓	✓	✓	✓	–300–250 (–180–120)	Pipe rating	±5% URV	No limit
Variable-area (Dual float)	≤3 (75)	✓	X	✓	✓	X	?	X	X	Glass: ≤400 (200) Metal: ≤1000 (540)	Glass: 350 (2400) Metal: 720 (5000)	±0.5% of rate to ±1% URV (up to 20:1 range)	<100 cS
Vortex	1.5–16 (40–400)	✓	?	✓	X	?	?	X	X	≤400 (200)	≤1500 (10,500)	±0.75–1.5% of rate	R_D >10,000

cS = centiStokes
URV = Upper range value
✓ = Designed for this application
? = Normally applicable
X = Not applicable
*This material is reproduced by permission of McGraw-Hill, Inc., from R. W. Miller's *Flow Measurement Handbook*, 2nd edition, 1989.
†According to other sources, the minimum Reynolds number should be much higher.

Bibliography

Instrument Engineers' Handbook, 4th Edition, "Process Measurement and Analysis" by ***'Bèla G. Liptak'***

B. Traditional Selection Procedures

- **Step-2:** Performance, Installation, Operation & Maintenance

1. **Performance** e.g. maximum tolerable error (% of Actual Reading (AR), Full Scale (FS) or SPAN), Repeatability, sensitivity & response time. **%Error = Fn (Rangeability)**
2. **Metering range = Fn (*Tolerable Error & Rangeability)***

Rangeability: *the ratio of maximum and minimum flow limits within which the specified error limit must not be exceeded)*.

3. **Operation:** Meter functionality as Monitoring, Process Control or Safety Instrumented Systems (SIS's)
4. **Other parameters like** the Cost (Capital, Installation, Maintenance and Operation), Delivery, installation, operation, or maintenance.
5. **Final selection** choosing **least expensive** sensor that **possesses all required features and characteristics.**

End of step-2 should narrow the choice few (two to three) designs.

B. Traditional Selection Procedures

- **Step-3:** (Optional) Special Requirements e.g.

Reverse Flow, Bidirectional, Pulsating flow, Slurries, Viscous, Corrosive, abrasive, Cryogenic, High temperature, etc.

Each of these special conditions requires special selection consideration for the suitable meter design

Is that enough??

NO

C. Significant Selection Principles

1. Experience Matters:

- Although, these selection steps would help eliminating the technically unsuitable meters, it is not necessary that they would lead to the selection of the perfectly suited meter for a given application.

  For example,

- **Electromagnetic flowmeters** are available for operating at pressures as high as 1500 Psig (10.3 × 106 N/m^2). They are also available for flow rates as high as 500,000 GPM (31.5m^3/sec). **However, Electromagnetic flowmeters are not available to detect a flow rate of 500,000 GPM at 1500 PSIG.**

C. Significant Selection Principles

2. **Complexity helps:**

- **Number of Choices is inversely proportional with Complexity**

The more the complexity of application the easier the selection process.

Number of Choices α (1/Complexity)

For example,

- Complex Application: **a highly corrosive, nonconductive sludge.** Selection is a single sensors design **(Cross-correlation type).**
- In contrast, a **straightforward clean-water application**, **most of the flow detectors** could be suitable. (focus on reasons then)

D. Volumetric Flowrate Formula

Applying Bernoulli

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

where,

$\frac{p}{\rho g}$: pressure head

$\frac{V^2}{2g}$: velocity head

z : elevation head

Therefore,

$$\frac{1}{2}\rho v^2 + \rho g z + p = \text{constant}$$

DERIVES

$$Q(\text{flow}) = K(\text{constant})\sqrt{\frac{h(\text{differential head})}{d(\text{fluid density})}}$$

Simplified Volumetric Flow rate Equation for Head Type Flow meters

E. Important Selection Techniques

Two key selection factors for (Head-Type) Flowmeters that are so important yet not being following

Reynolds Number (Re)

Velocity Head

E. Important Selection Techniques

1- <u>Velocity Head:</u>

Permanent pressure loss through a flowmeter is usually expressed in *<u>velocity heads</u>:* $(v^2/2g)$, Where, ***v*** is the flowing velocity and ***g*** is the gravitational acceleration (9.819 m/sec^2 or 32.215 ft/sec^2 at 60° latitude).

Examples

- Therefore, the velocity head at, say, a flowing velocity of **10 ft/sec** is calculated (in the English units) as $\mathbf{10^2/64.4 = 1.55\ ft}$ of the flowing fluid.
- If the flowing velocity is **3 m/sec**, the velocity head is calculated (in the metric units) as $\mathbf{3^2/19.64 = 0.46\ m}$ of the flowing fluid.

****The velocity head is converted into pressure drop by multiplying it with the specific gravity of the flowing fluid.***

E. Important Selection Techniques

1- Velocity Head (Cont'd)

Velocity Head Requirements of the Different Flowmeter Designs

Flowmeter Type	Permanent Pressure Loss (in Velocity Heads)
Orifice plates	Over 4
Vortex shedding	Approximately 2
Positive displacement	1 to 1.5
Turbine flowmeter	0.5 to 1.5
Flow tubes	Under 0.5

As shown in above table, the different flowmeter designs require different pressure drops for their operation.

E. Important Selection Techniques

2- Reynolds number (Re)

In order to understand the influence of Reynolds number (Re) on Head-Type flow measurement selection, let's first brief about their principal of operation.

- The detection of pressure drop across a restriction is undoubtedly the most widely used method of industrial flow measurement.
- The pressure decrease that results from a flowing stream passing through a restriction is proportional to the flow rate and to fluid density. Therefore, if the density is constant (or if it is measured and we correct for its variations), the pressure drop can be interpreted into a reading of flow.

E. Important Selection Techniques

Reynolds number (Re)

Volumetric Flow Rate Formula:

$$Q(\text{flow}) = K(\text{constant})\sqrt{\frac{h(\text{differential head})}{d(\text{fluid density})}}$$

- **Theoretically**: If the Reynolds number (Re) and flow rate are both constant, the output signal of a head-type flowmeter will also be constant. if Re changes, the meter reading also changes due to Flow-Coefficient variation, even at constant flow.

- **Practically: In some Head-Type Flow meters, the K (Discharge Coefficient) is not constant as expected and varies with the change in Re.**

The hidden trick is that changes of (Re) lead to changes in Meter's Discharge Coefficient that in turn changes the meter reading, even at constant flow

E. Important Selection Techniques

Reynolds number (Re)

$$R_e = \frac{VD\rho}{\mu}$$

where

V = velocity

D = diameter

ρ = density

μ = absolute viscosity

Recommendations

1. Calculate the Reynolds numbers at both maximum and minimum flows and check whether the corresponding change in flow coefficients is within the acceptable error.

2. If Re associated % error in K is intolerable, **Either:**

- **Use different type of sensor**

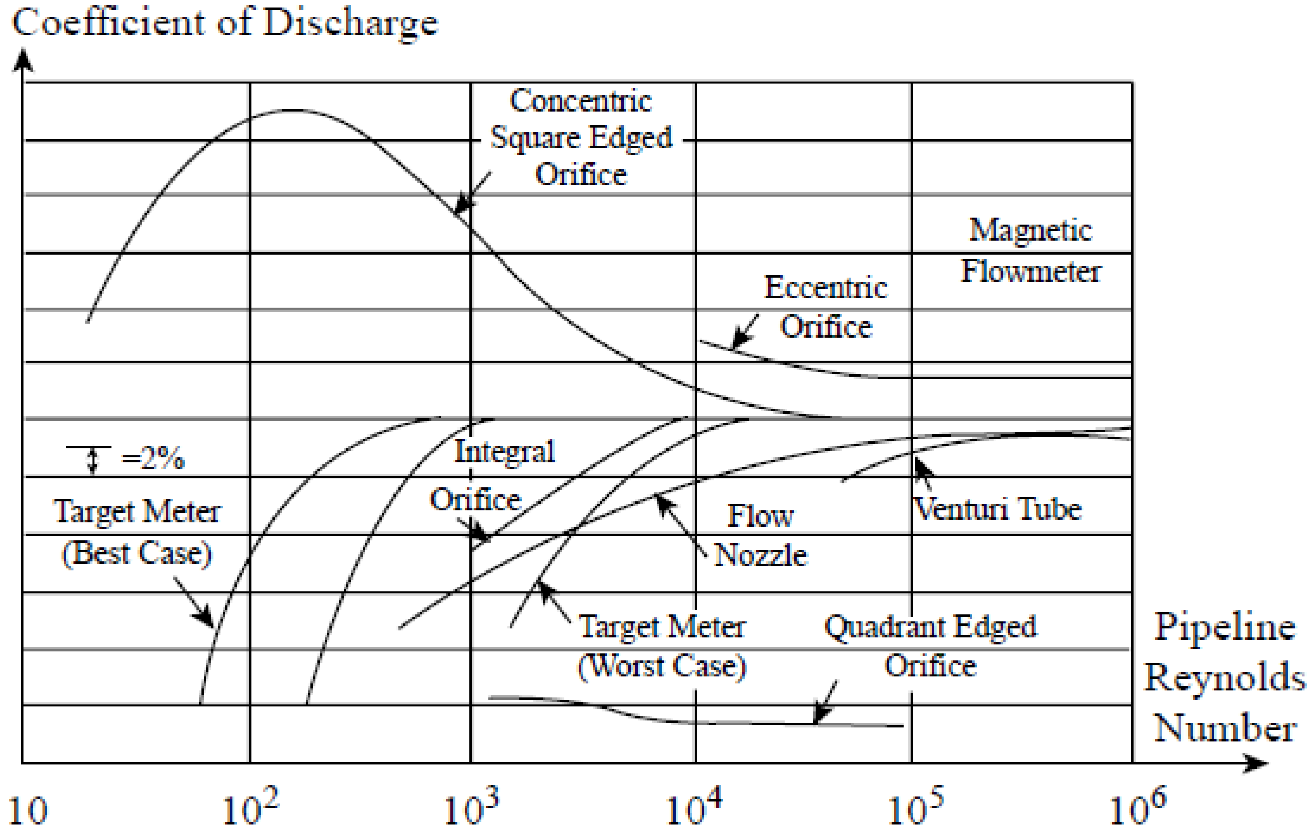
  such as the quadrant-edged orifice for low-Reynolds-number applications

or

- Use Different flowmeter Design that is insensitive to Reynolds variations, such as the magnetic meter.)

E. Important Selection Techniques

Reynolds Number (Re)



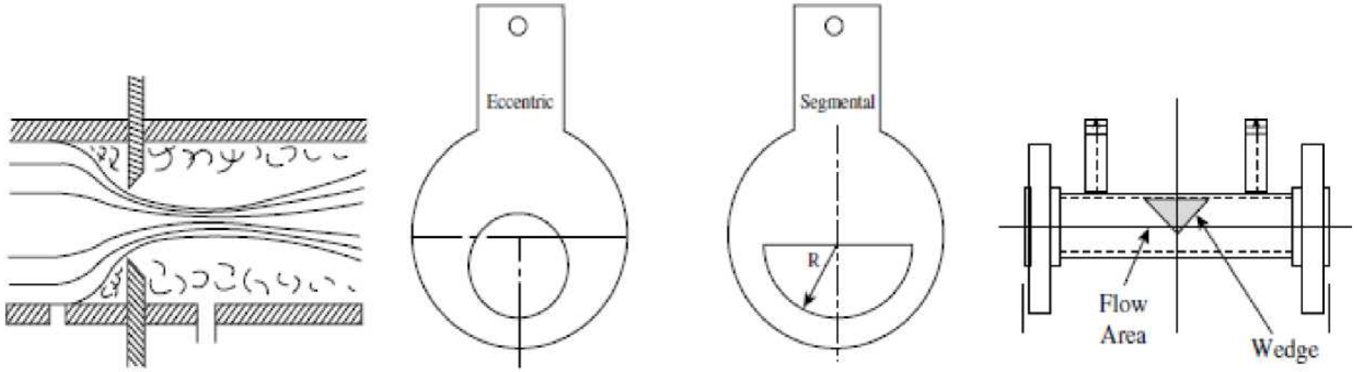
Discharge coefficients as a function of sensor type and Reynolds number (Courtesy of The Foxboro Co.)

Pressure difference producing flowmeter designs,

E. Important Selection Techniques

Reynolds Number (Re)

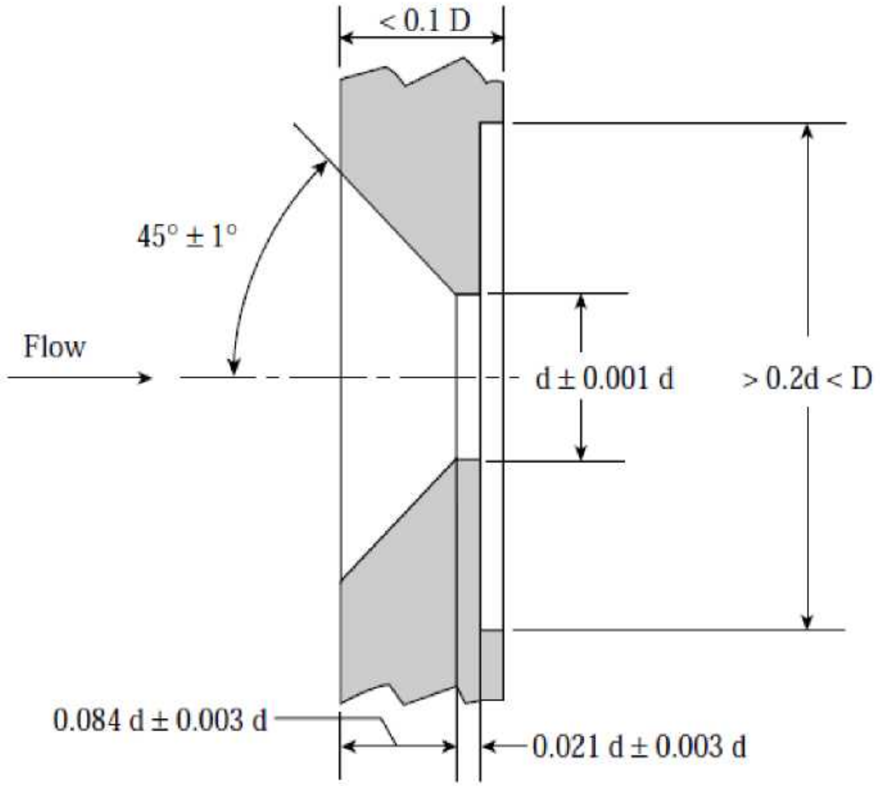
As shown, the orifice plate discharge coefficient is constant within +/- 0.5% over a Reynolds number range of $2x10^4$ to 10^6. The discharge coefficient being constant guarantees that no measurement errors will be caused by Reynolds number variations within this range. On the other hand, if, at minimum flow, the Reynolds number would drop below 20,000, that would cause a substantial increase in the discharge coefficient of the meter and a corresponding error in the measurement. Therefore, it is advisable to limit the use of orifice plates to applications where the Reynolds number stays above 20,000 throughout the flow range.



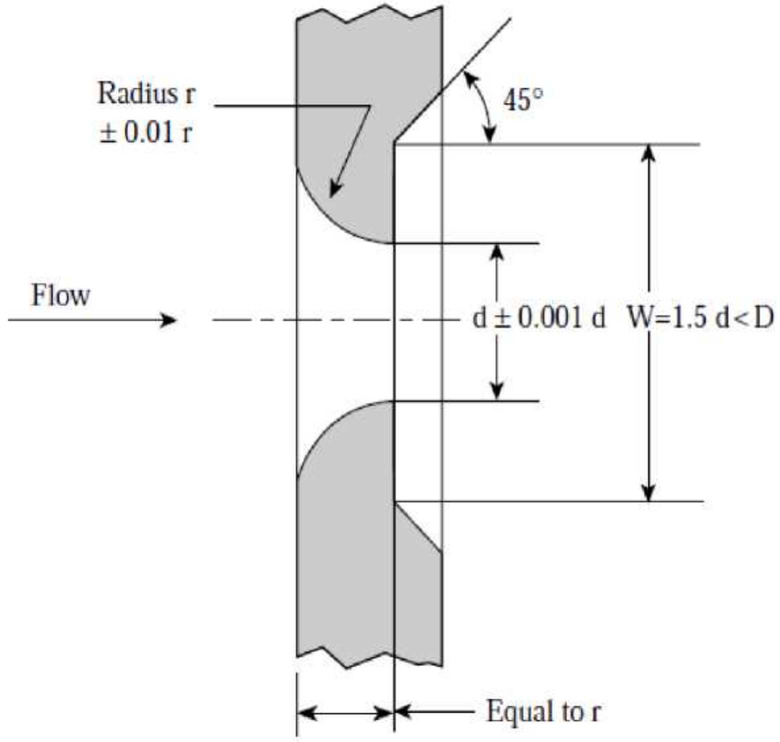
a) Sharp-edged, eccentric, segmental orifice and wedge designs

E. Important Selection Techniques

Reynolds Number (Re)



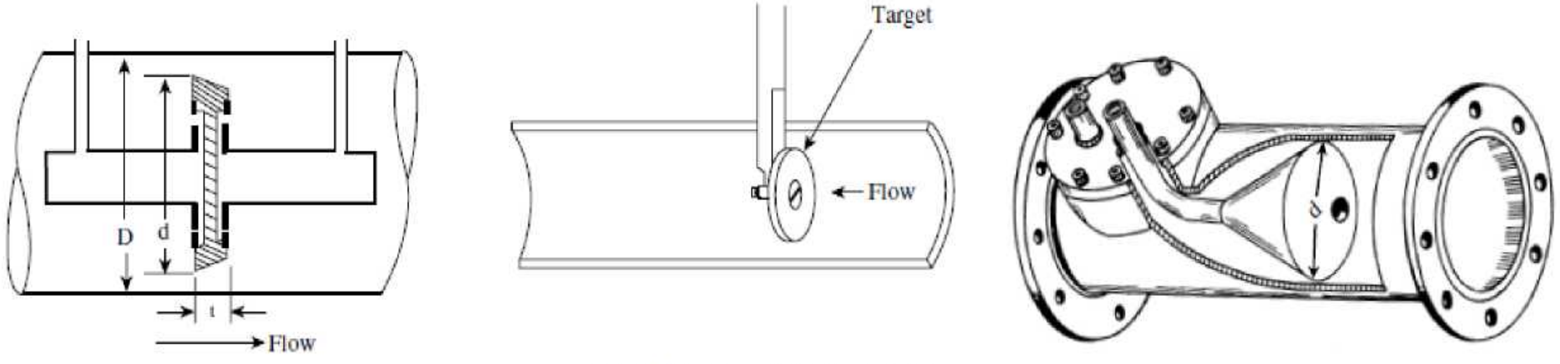
Conical entrance orifice plate.



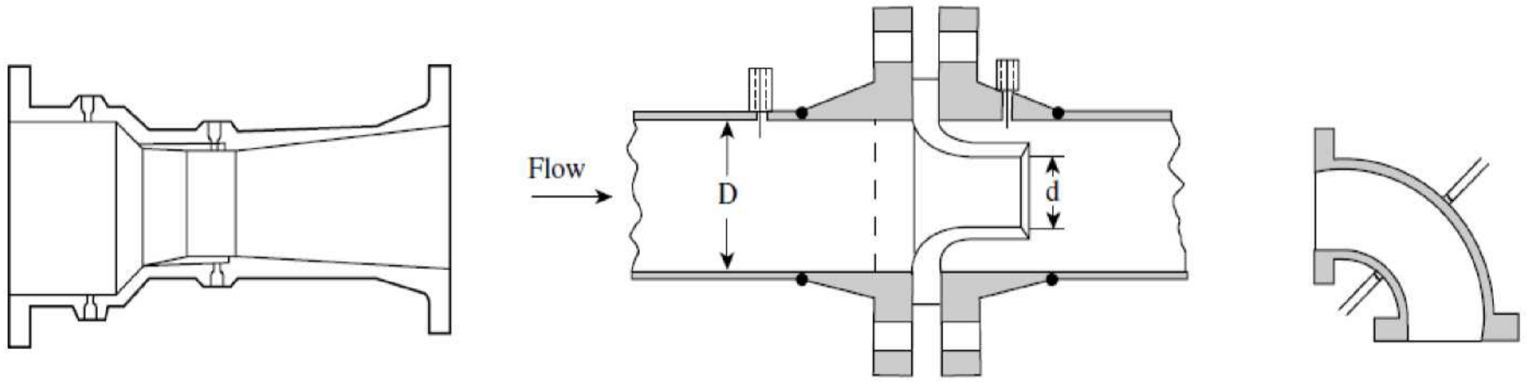
Quadrant edge orifice plate.

E. Important Selection Techniques

Reynolds Number (Re)



b) Annular, target and V-cone designs



c) Venturi tube, flow nozzle and elbow tap designs

E. Important Selection Techniques

Reynolds Number (Re)

Minimum Allowable Reynolds Numbers for Conical and Quadrant Edge Orifices

Type		*Re Limits*										
Conical entrance	β	0.10	0.11	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	
	Re	25	28	30	33	35	38	40	43	45	48	
	β	0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29	0.30
	Re	50	53	55	58	60	63	65	68	70	73	75
Quadrant edge	β	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60			
	Re	250	300	400	500	700	1000	1700	3300			

- **Quadrant Edge** and **Conical Entrance** orifice plates is limited to **lower pipe (Re)** where flow coefficients for sharp-edged orifice plates are highly variable in the range of **500 to 10,000**
- Flow Coefficient stability of 'Quadrant Edge' and 'Conical Entrance' is **10 times** better than 'square-edge'. **Minimum Allowable (Re)** is a function of **β ratio (allowable β ratio ranges are also limited**.) (See above table). **Maximum Allowable (Re)** ranges from **500,000 × (β – 0.1) for Quadrant Edge** to **200,000 × (β) for Conical**.

E. Important Selection Techniques

Reynolds Number (Re)

Selecting the Right Orifice Plate for a Particular Application

Orifice Type	*Appropriate Process Fluid*	*Reynolds Number Range*	*Normal Pipe Sizes, in. (mm)*
Concentric, square edge	Clean gas and liquid	Over 2000	0.5 to 60 (13 to 1500)
Concentric, quadrant, or conical edge	Viscous clean liquid	200 to 10,000	1 to 6 (25 to 150)
Eccentric or segmental square edge	Dirty gas or liquid	Over 10,000	4 to 14 (100 to 350)

F. Common Selection Mistakes & Recommendations

1. Following Clichés like Orifice with facility, turbine for metering, etc. without study.
2. Using Orifice Type Flowmeters below Re 10^4 - leads to inaccurate reading.
3. Using Multi-Phase Flow Meters (MPFM) for metering (Not suitable due to high uncertainty)
4. Using flow meters (Other than MPFM) for measuring multi-phase flows. (Inaccurate)
5. Using Doppler type Ultrasonic flow meters in clean (gas or liquid) services. (Inaccurate)
6. Using Transit-Time Ultrasonic type flow meters in dirty (gas or liquid) services. (Inaccurate)
7. Magnetic Flow meters in non-conductive fluids (e.g. Gas, etc.). (No reading)
8. Using Vortex Flowmeters in velocities less than 1 ft/s (liquids) or less than 20 ft/s (Gas or steam). (No reading)
9. If vortex meters are used below (Minimum Reynolds Numbers of 8000 to 10,000), meters do not function at all; Best performance Re > 20,000 in sizes under 4 in. (100 mm) and Re > 40,000 in sizes above 4 in.
10. Orifice Type Flow meters Installation cost is relatively independent of pipe diameter (unaffected by pipe size), Consequently, the orifice-type installations are relatively expensive in smaller pipe sizes and rather economical in pipe sizes over 6 in. (150 mm).
11. Square-law relationship of Head-type severely limits Rangeability (typically 3:1, Max. 4:1). Flowrates of wider Rangeability should be avoided. ….etc.

G. Recommendations

1. Always check the impact of flow profile on the meter's performance by for instance, calculating Re at max. & min flows to ensure that their influence on flow coefficients is within acceptable error.
2. Regardless of the meter's manufacturer's accuracy, wrong selection could result in a very inaccurate or even not functioning meter.
3. All meters in the market are not designed for multi-phase flow measurement except for Multi-Phase (Poly-phase) meters.
4. Some special designs tolerate some entrainments, not multiple phases.
5. Do not seek perfection; Highest accuracy or most expensive meter might not be really required.
6. Besides capital cost, operating, maintenance, installation costs should also be considered.

QUESTIONS ??

THANK YOU