Theory and Operation of Daniel Orifice Fittings

Differential Pressure Methods for
Flow Measurement

Training Presentation

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Differential Products Agenda

- Fundamentals of Orifice Measurement
- Review of Mechanical Products
- Product Application
- Conclusion

Background

- General concept of orifice metering has been around for centuries.
- Orifice measurement is one of the most widely used forms of measurement today.
- In 1797 Giovanni Venturi performed the first work using orifices in fluid flow measurement.
- This type of device causes a flow restriction in the line

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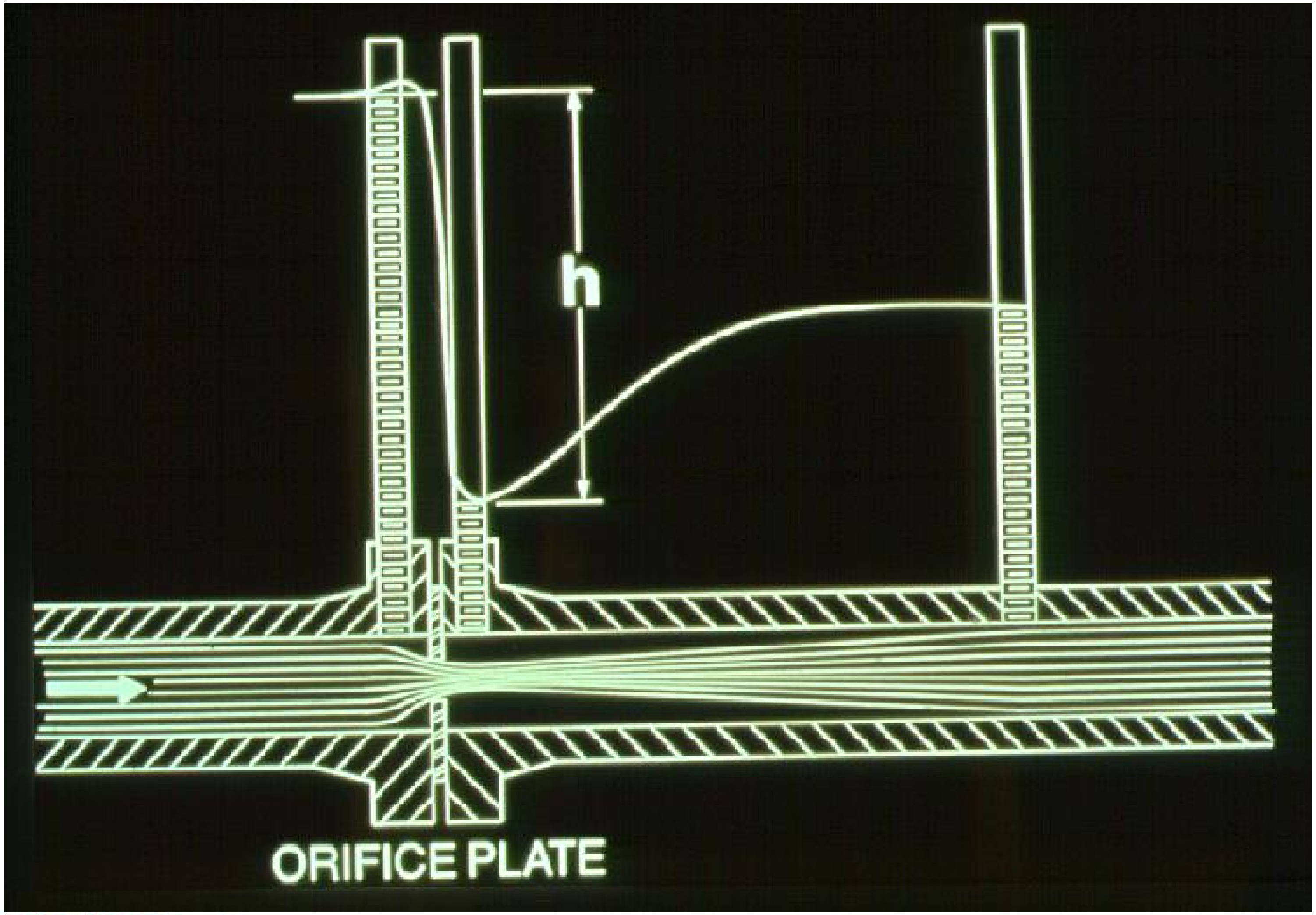
Background

- 1890 Professor Robinson of Ohio State University designed the first orifice meter
- Between 1924 and 1935 research & experimental work was conducted by the American Gas Association (AGA) / American Society of Mechanical Engineers(ASME)

Flow Profile



Definition Of An Orifice Meter

- Primary device that creates a differential pressure
- Secondary element measures the differential
- Many different devices create differential
  - Sharp Square-Edge Orifice Plate
  - Venturi Tube
  - Flow Nozzle
  - Elbow

Orifice Flow Measurement - Advantages

- Flow Can Be Accurately Determined Without Calibration
- Simple To Operate
- Years Of Reliable Operation
- Requires Minimum Service
- Widely Accepted
- Relatively Inexpensive
- No Moving Parts

Orifice Flow Measurement – Meter Accuracy

- Reliability (Uncertainty / Accuracy)
  - Definition of Orifice Bore to Pipe Bore Ratio, Beta (β), where Orifice Bore = (d) and Pipe ID = (D)

$$\text{Beta}(\beta) = \frac{\text{Orifice Bore } (d)}{\text{Pipeline ID } (D)}$$

  - Flange Tap Coefficient @ 0.2 & 0.7 Beta (β) has uncertainty of ± 0.5%
  - Minimum Uncertainty Occurs Between 0.5 & 0.6 β

Orifice Flow Measurement – Meter Accuracy

- Rangeability
  - Often Referred to as “Turn Down” Ratio
- Flow Range of 300,000 SCFH to 100,000 SCFH would be 3 to 1
- ± 0.25% with Flow Calibration
- Typical System Accuracy for Orifice installation is 0.6 to 0.7 %

Orifice Flow Measurement – Meter Accuracy

Repeatability:

Is the ability of a Flow Meter to indicate the same reading each time, under identical flowing conditions

Orifice Flow Measurement – Standards

- AGA Report No.3
- API 14.3
- ISO 5167-1

Importance of Standards

- AGA report #3 provides guidelines for construction and installation of orifice meters.
- Standards must be adhered to completely in order to maintain accuracy.

ISO 5167 – 1

- ISO 5167 specifies the geometry and ‘installation and operating conditions’ for differential flow measurement systems.
- Calculation of Mass or Volume flow rate requires input from a number of physical properties related to the meter dimensions and the flowing medium.
- Ultimately, application of this standard provides concise, regulatory guidelines for accurate measurement of sub-sonic, single phase flow.

→ Mass Flow Rate derivation from 1st principles.

Bernoulli's Theorem states that,

"In a level pipe, running full, the Kinetic Energy plus Pressure Energy is the same at any point".

For a pipe with a constriction in line, such as an **'Orifice Plate'**, this may be expressed as:

Pipe | Orifice

$$\boxed{\tfrac{1}{2} \cdot m \cdot v^2_{\ p} + P_p \cdot Vol.} = \boxed{\tfrac{1}{2} \cdot m \cdot v^2_{\ o} + P_o \cdot Vol.}$$

Density relates to mass and volume by:

$$Density(\rho) = \frac{mass(m)}{volume(v)}$$

ISO 5167 – 1

Therefore, dividing through the pipe and orifice equations by volume:

$$\tfrac{1}{2}\cdot\rho\cdot v_p^2 + P_p = \tfrac{1}{2}\cdot\rho\cdot v_o^2 + P_o$$

Therefore,

$$P_p - P_o = \tfrac{1}{2}\cdot\rho\cdot v_o^2 - \tfrac{1}{2}\cdot\rho\cdot v_p^2$$

So,

$$\Delta P = \tfrac{1}{2}\cdot\rho\cdot\left(v_o^2 - v_p^2\right) \text{ ------------ } *$$

Where,

P = Pressure	ρ = Density
M = Mass	**v** = Flow Velocity
Vol. = Volume	

ISO 5167 – 1

Consider two cross sections in the pipeline:
The first through the full internal bore of the pipeline (A_p)
The second through the full internal bore of the orifice plate (A_o)

Assuming constant volumetric flow of an incompressible fluid, the 'Volumetric Flowrate' can be described by the following equation:

$$Q_v = A_p \cdot v_p = A_o \cdot v_o$$

Therefore,

$$v_p = \left[A_o / A_p \right] \cdot v_o \quad \text{--------------------------- \#}$$

Where,

Q_v	= Volume Flowrate
A	= Cross Sectional Area (c.s.a)
v	= Flow Velocity

ISO 5167 – 1

Combining Equations marked * and #

$$\Delta P = \tfrac{1}{2} \cdot \rho \cdot \left(v_o^2 - \left[\left[\frac{A_o}{A_p} \right] \cdot v_o \right]^2 \right)$$

$$\frac{2\Delta P}{\rho} = v_o^2 - \left[\left[\frac{A_o}{A_p} \right] \cdot v_o \right]^2$$

$$\frac{2\Delta P}{\rho} = v_o^2 - \left[v_o^2 \cdot \left[\frac{A_o}{A_p} \right]^2 \right]$$

ISO 5167 – 1

$$2\Delta P/\rho = v_o^2 \cdot \left[1 - \left[A_o/A_p\right]^2\right]$$

$$v_o^2 = \left[2\Delta P/\rho\right] \cdot \frac{1}{\left[1 - \left[A_o/A_p\right]^2\right]}$$ ---------------- **

Derivation of Beta Ratio (β):

Ratio:

$$A_o / A_p = \frac{\left(\pi/4 \cdot d_o^2\right)}{\left(\pi/4 \cdot d_p^2\right)} = \frac{\left(d_o^2\right)}{\left(d_p^2\right)}$$

From ** :

$$\left[A_o / A_p\right]^2 = \left[\frac{\left(d_o^2\right)}{\left(d_p^2\right)}\right]^2 = \beta^4 \text{ ---------------- ##}$$

Where,

d_o	= Orifice Internal Diameter
d_p	= Pipe Internal Diameter
β	= Orifice to Pipe Diameter Ratio

ISO 5167 – 1

Combining Equations ** and ## ,

$$v_o^2 = \left[2\Delta P / \rho\right] \cdot \frac{1}{(1-\beta^4)}$$

$$v_o = \left[(2\Delta P)^{1/2} / (\rho)^{1/2}\right] \cdot \frac{1}{(1-\beta^4)^{1/2}}$$

$$v_o = \left[(2\Delta P)^{1/2} / (\rho)^{1/2}\right] \cdot (1-\beta^4)^{-1/2}$$ ------------- !!

Note:

$$(1-\beta^4)^{-1/2} = E$$,and is known as the '**Velocity of Approach Factor**'

Volumetric Flow Rate (Q_v):

This is the flow velocity multiplied by the c.s.a., at the point where it is measured.

Equation !! states the 'Flow Velocity' in the orifice (V_o).

The Volumetric Flow Rate is given by:

$$Q_v = \left[\frac{(2\Delta P)^{1/2}}{(\rho)^{1/2}} \right] \cdot E \cdot \left(\frac{\pi}{4} \cdot d_o^2 \right)$$

Multiply by Density(ρ) to get the 'Mass Flow Rate' (Q_m):

$$Q_m = (2\Delta P \rho)^{1/2} \cdot E \cdot \left(\frac{\pi}{4} \cdot d_o^2 \right)$$

$$Q_m = E \cdot \left(\frac{\pi}{4} \cdot d_o^2 \right) \cdot (2\Delta P \rho)^{1/2}$$ ------------------- !!!

ISO 5167 – 1

From ISO 5167:

$$Q_m = C \cdot E \cdot \varepsilon \cdot \left(\pi/4 \cdot d_o^2\right) \cdot (2\Delta P \rho)^{1/2} \cdot 10^{-5} \cdot 3.6$$

Compare !!!

$$Q_m = E \cdot \left(\pi/4 \cdot d_o^2\right) \cdot (2\Delta P \rho)^{1/2}$$

Where,

C	= Discharge Coefficient
ε	= Expansibility Factor

Discharge Coefficient (C):

Discharge Coefficient (C) depends on β, the position of the pressure tappings, and for devices likely to introduce turbulence, such as orifice plates, the Reynolds Number.

Expansibility Factor (ε):

A fluids volume changes at different pressures. At lower pressure the density is not the same at both pressure tappings. The Expansibility Factor corrects for this. It depends on the Isentropic Exponent of the fluid, the ratio of the differential pressure to the line pressure, and the orifice / pipe diameter ratio (β).

ISO 5167

ISO 5167 operates with fundamental S.I. units. The fundamental linear unit is the metre. With orifice and pipe diameter sizes in millimetres, and squared to get the c.s.a. the result would be 10^6 times *too* large.

The fundamental unit for differential pressure (D.P.) is the pascal. D.P is usually entered in millibar (mBar) where, (1 mBar = 100 Pascal). When considering the square root of the D.P. this would make the result ten times *too* small.

Considering both sets of units above, for orifice/pipe dimensions in millimetres, and D.P. in mBar, we must multiply by 10^{-6} to correct to metres, and multiplying by 10 to correct to Pascals. Therefore, (10^{-6} * 10 = 10^{-5}). Multiplying by 10^{-5} converts to the correct S.I. units.

The fundamental units for Mass Flow Rate are kg / sec. Multiply by 3.6 for answer in Tonnes per Hour.

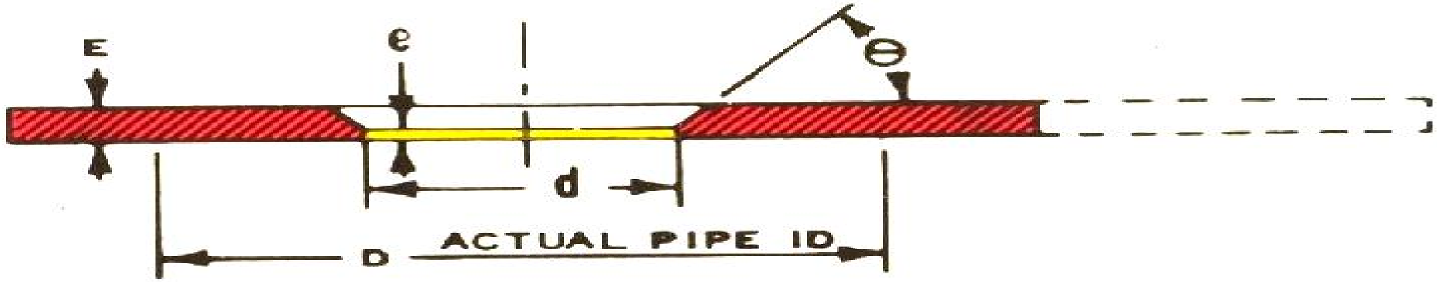
Orifice Plates

- The most fundamental component for orifice flow measurement.
- Flat, circular, and held in line by a fitting or flanges.
- Universal (fitting) or Paddle type (flanges).

Orifice Plates

- AGA Report No. 3 Requirements:
  - Concentricity of the orifice bore
  - Edge Thickness
  - Plate Flatness
  - Plate Finish
  - Edge must be square and sharp, and '***will not***' reflect a beam of light

Orifice Plate Dimensions



e = Edge thickness

E = Plate thickness

Θ = Bevel requirements

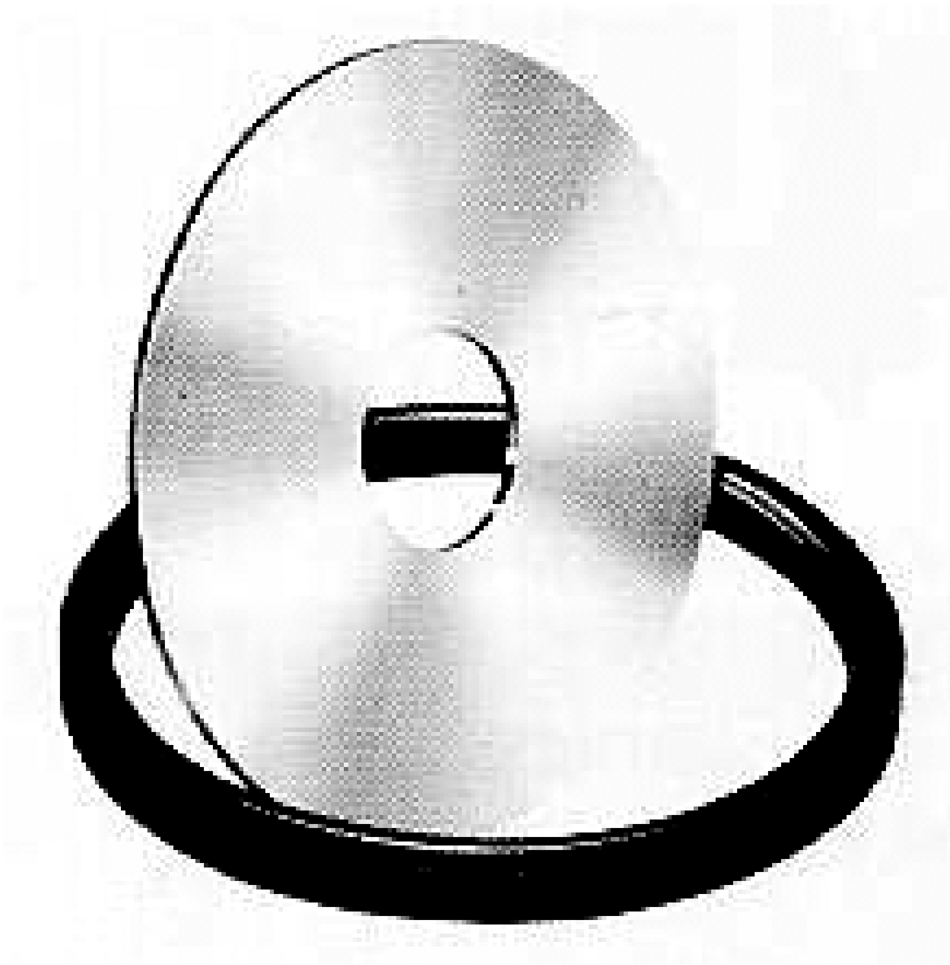
d = Bore

D = Pipe I.D.

Orifice Plates

Orifice Plates – Universal Plate

Orifice Plates – DS (Dual Seal)



Orifice Containment Methods

Three Types:

1. Orifice Flange Union
   – Dead Line Device
2. Single Chamber Fitting
   – Dead Line Device
3. Dual Chamber Fitting
   – Allows Plate Change Out Under Line Pressure

1. Orifice Flange Union

→ Advantages

- Most Economical Means Of Measuring Flow
- Line Sizes 1/2” - 60”
- 150 - 2500 # ANSI
- Standard 1/2” Flange Pressure Taps
- Equipped with Jack Screw
- Styles- Weldnek- Threaded- Slip-On
- Bi-Directional Flow

Orifice Flange Union

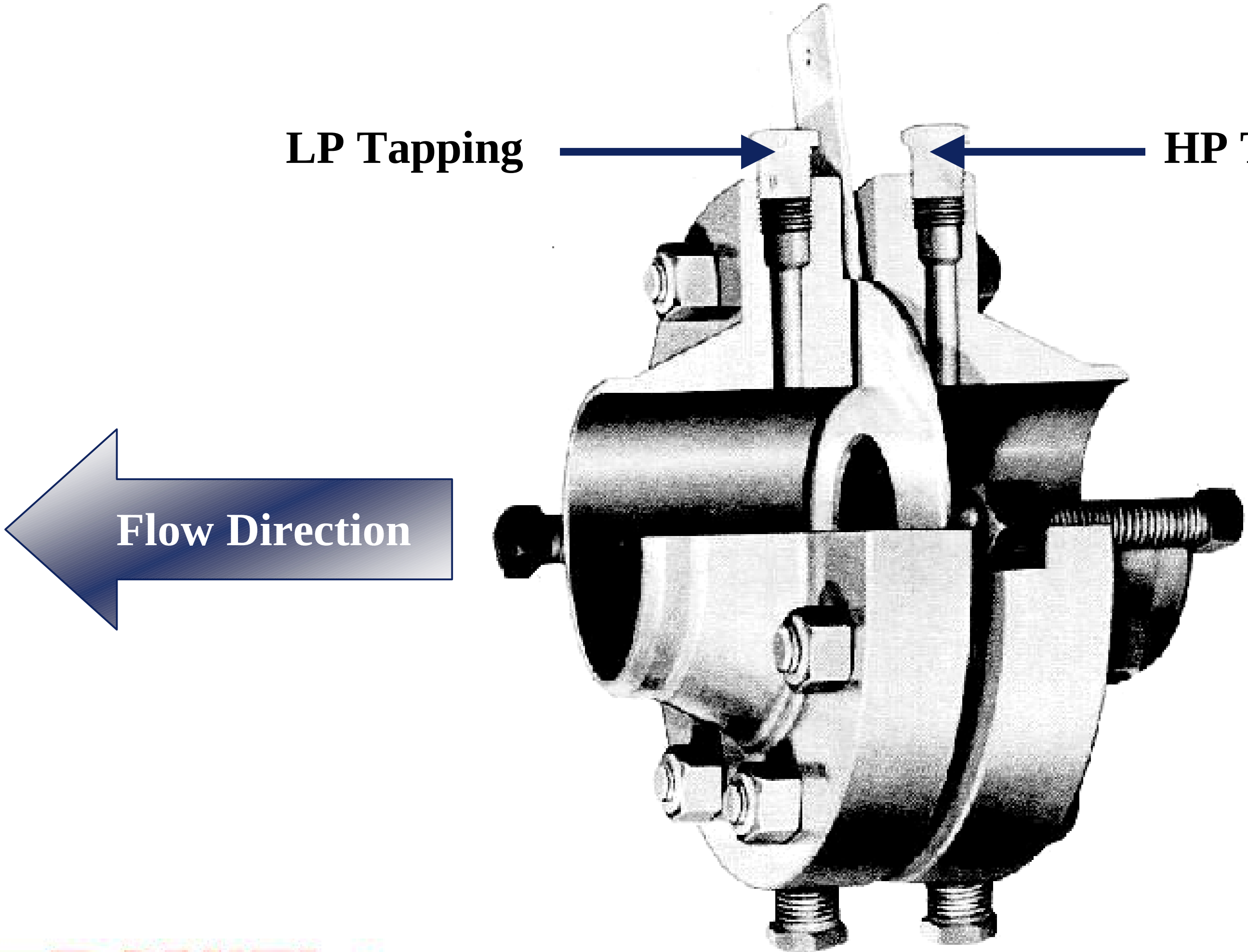
- Disadvantages
  - Plate Change Requires Line Depressurizing
  - Plate Removal Requires Flange Spreading
  - Product Spillage Occurs In Liquid Service

Pressure Tap Location

Flange Taps

- → Most Widely Used
- → Most Accurate
- → 1” Upstream and 1” Downstream From Face Of Plate

Orifice Flange Union – Pressure Taps



2. Single Chamber Fittings

- Two Main Types
  - Simplex Orifice Fitting
  - Junior Orifice Fitting

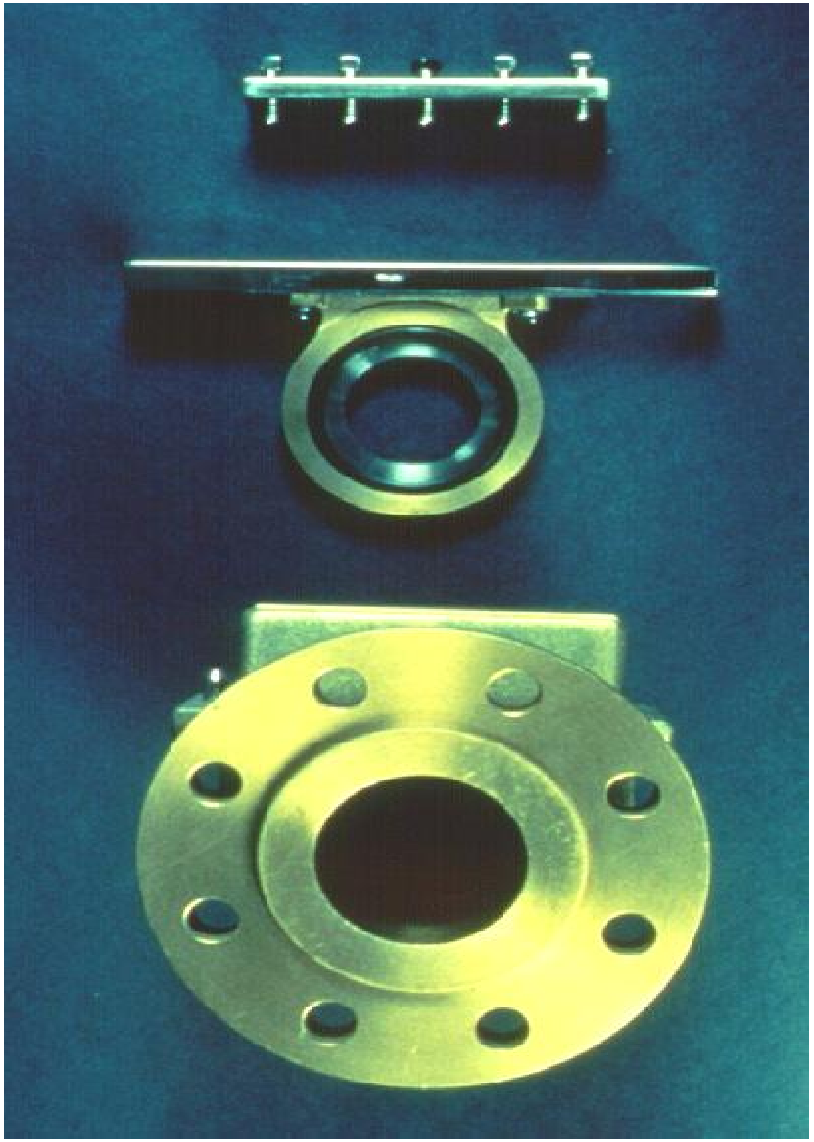
Simplex Orifice Fittings (1.5" – 8")

- Advantages
  - Economical Measuring Device
  - Simple To Operate
  - ANSI 150 #- 2500 #
  - No Flanges To Spread Apart
  - Plate Removal without Spillage
  - Meets AGA 3, API 14.3, ISO 5167
  - Bi Directional Flow

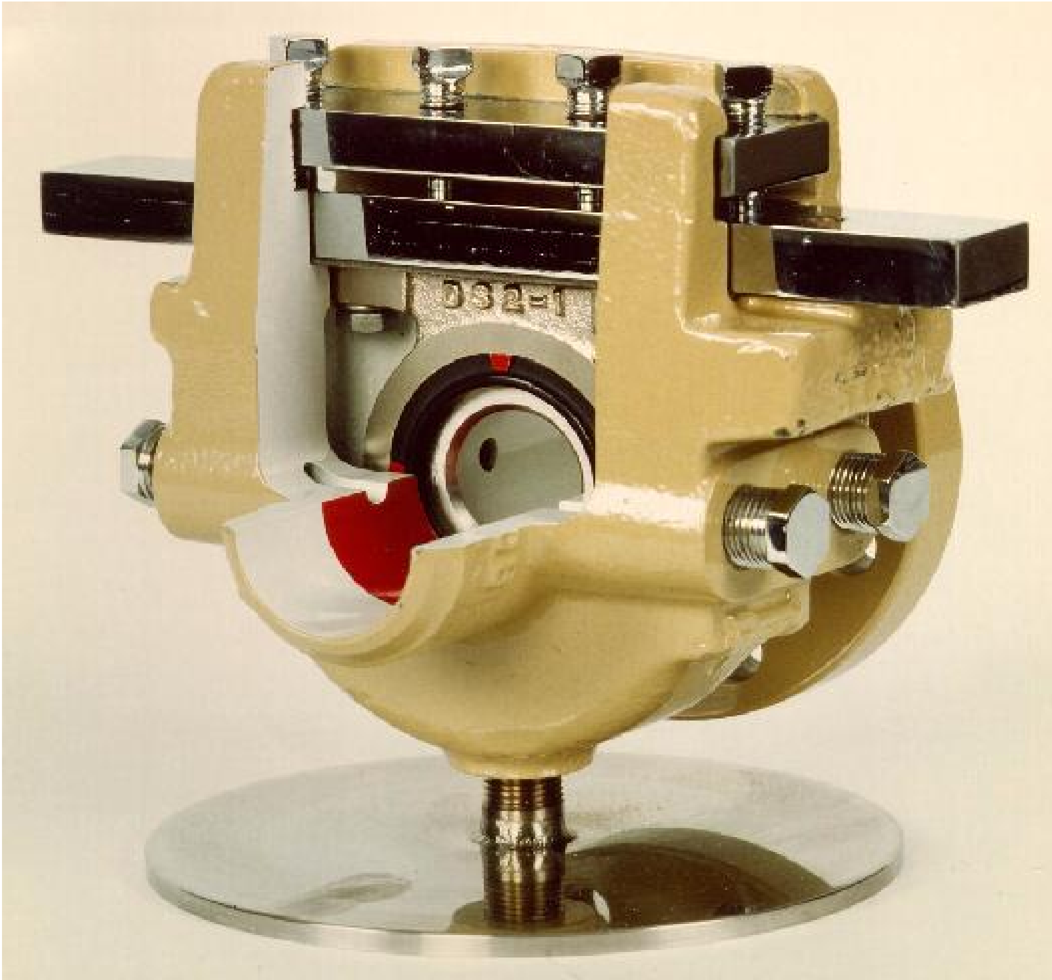
Simplex Orifice Fittings

- Disadvantage
  - Plate Change Requires Line Depressurizing

Simplex Orifice Fittings



Simplex Orifice Fittings



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Junior Orifice Fittings (10” – 42”)

- Advantages
  - Rack and Pinion is added to assist in lifting the plate carrier for larger line sizes
  - 10” to 42” in 150-600# ANSI and up to 2500# in certain sizes
  - Designed For Large Volume Applications: Gathering System, Compressor Stations, City Gates and Power Plants
  - No Spillage In Liquid Service
  - Bi-Directional Flow

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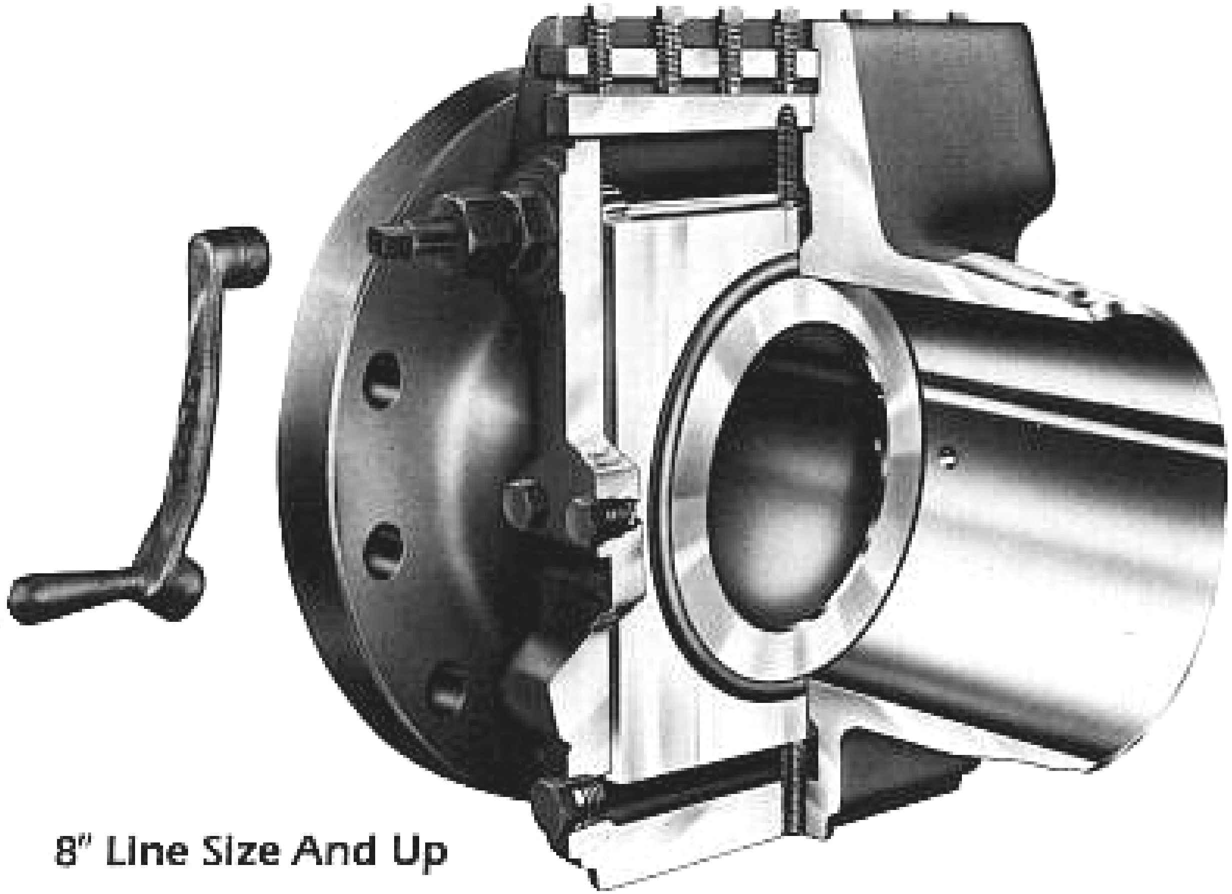
Junior Orifice Fittings



8" Line Size And Up

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Junior Orifice Fittings

- Disadvantage
  - Plate Change Requires Line Depressurizing

3. Dual Chamber Fittings

→ Advantages

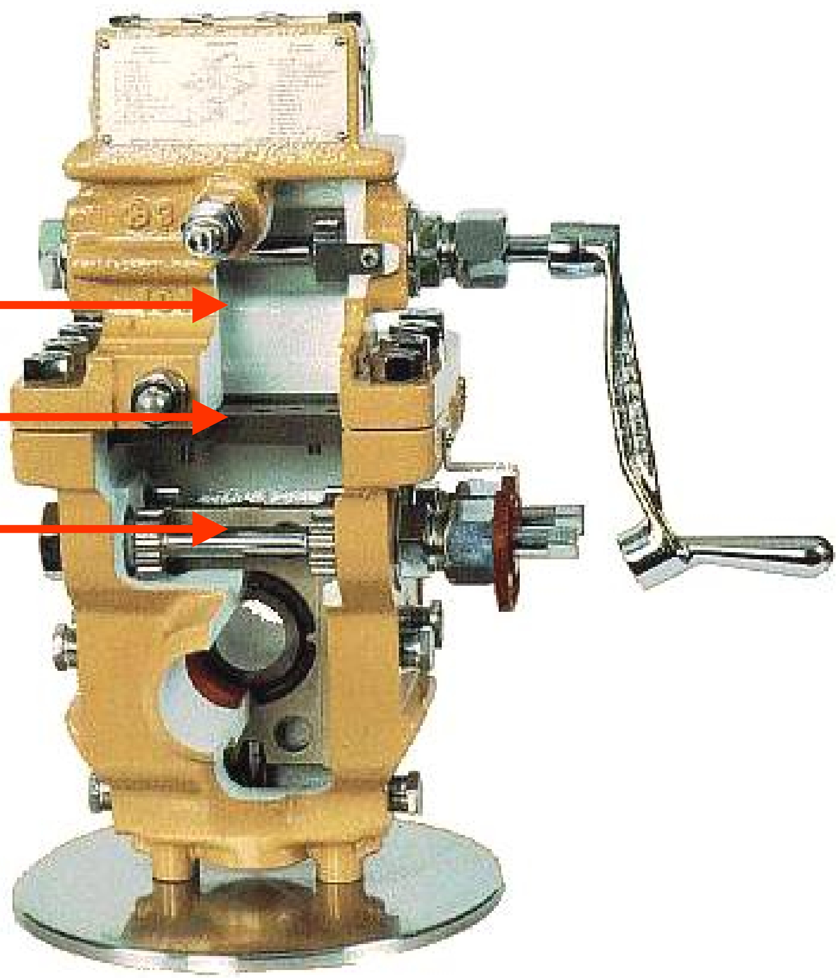
- Proven Technology
- Simple To Operate
- Field Repairable
- NACE Trim Available
- Plate Removal Without De-Pressurizing the line
- Extensive Product Range
- Bi-Directional Flow

Senior Orifice Fitting

Upper Chamber

Slide Valve

Lower Chamber



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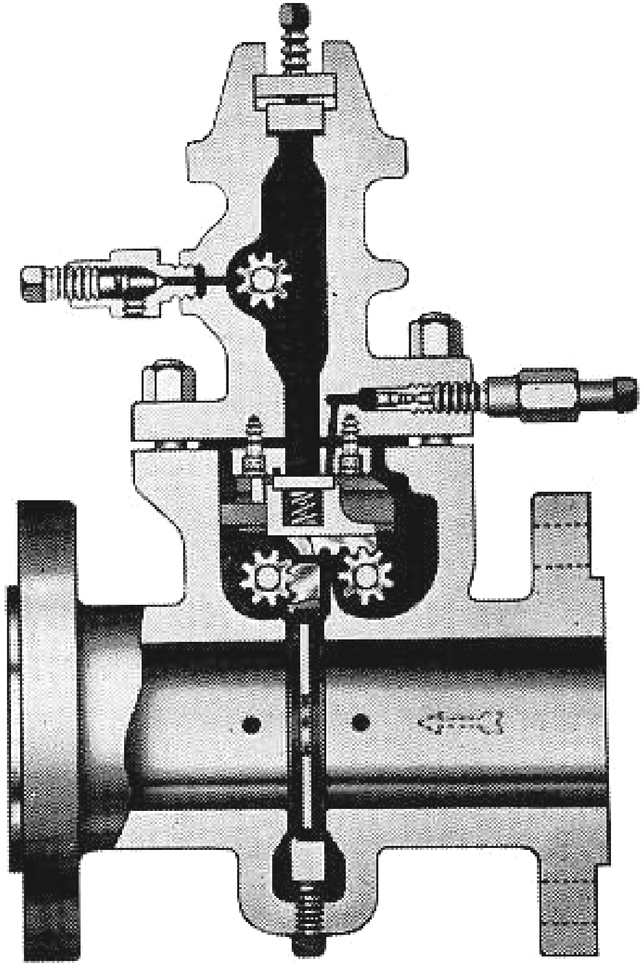
Senior Orifice Fitting



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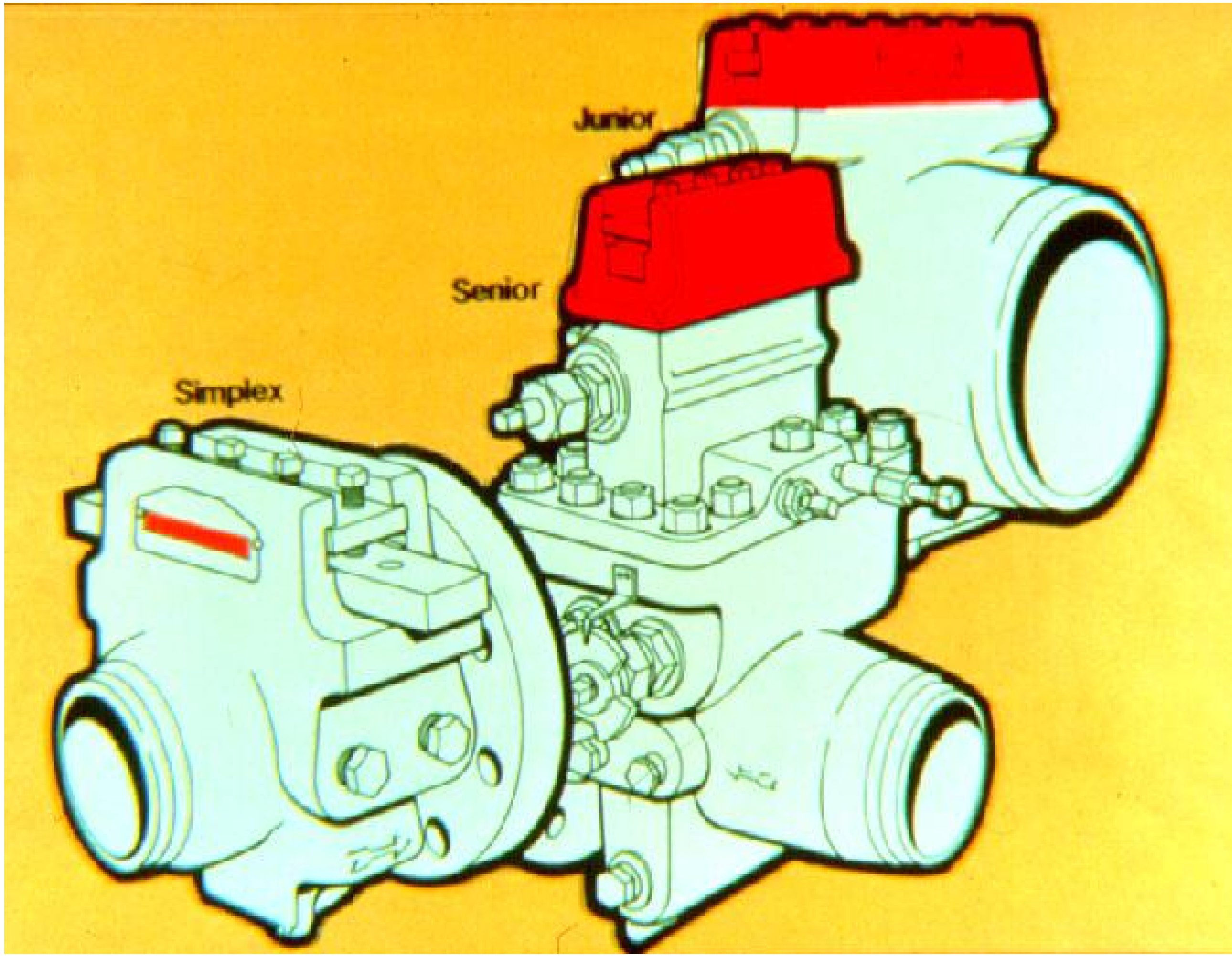
Daniel Orifice Fitting Family



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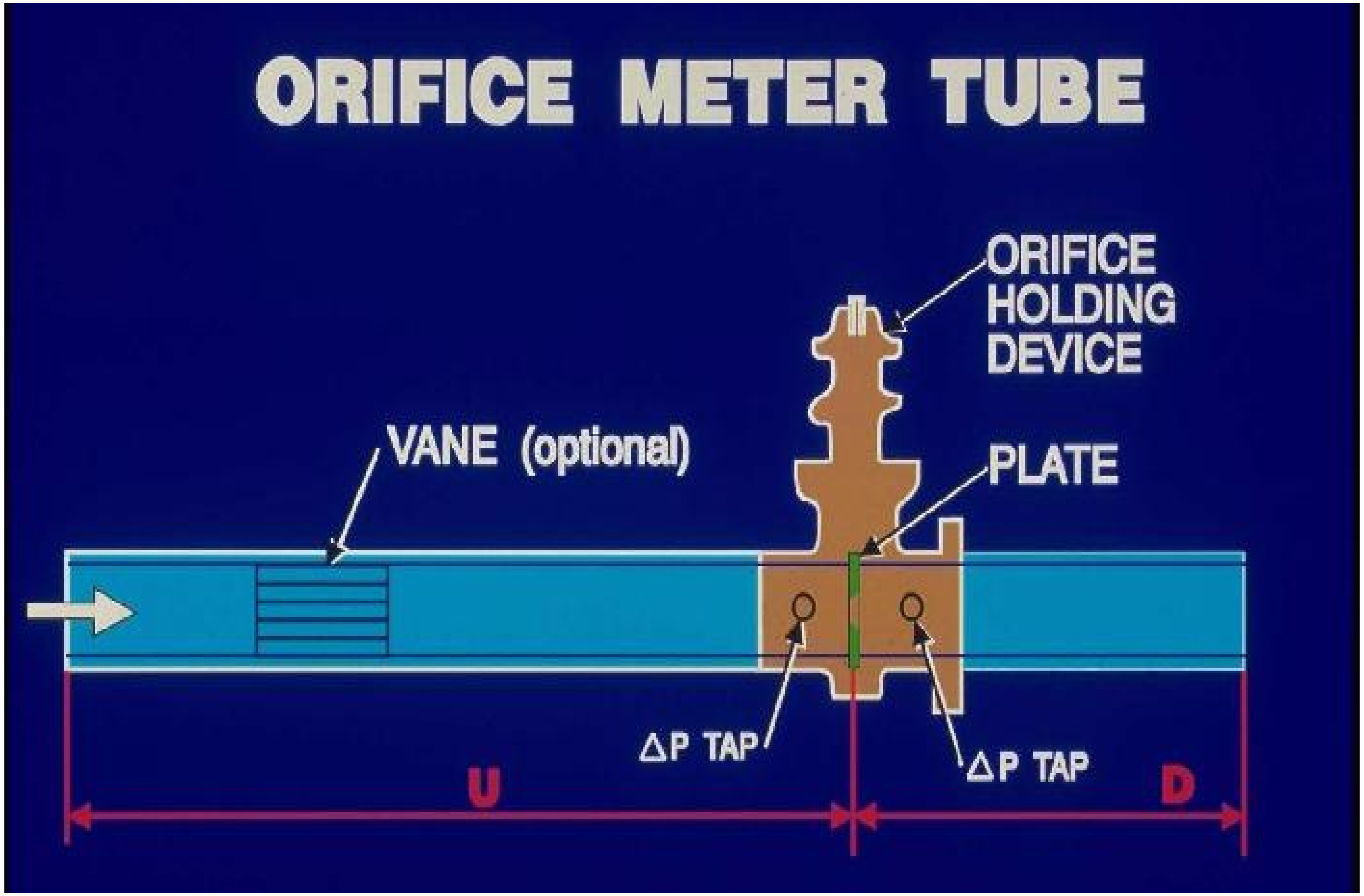
Meter Tubes

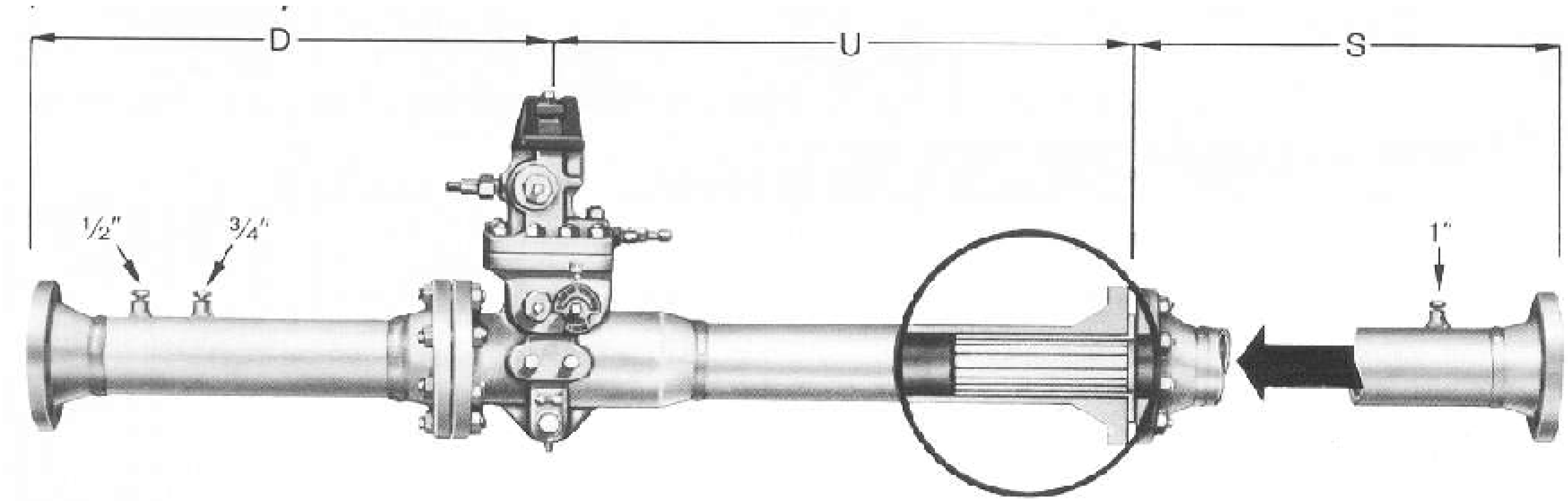
- Consists of Upstream and Downstream Pipe and a fitting or Orifice Flange Union
- AGA Report # 3 Requirements Include:
  - Minimum Upstream and Downstream Lengths
  - Wall I.D. Smoothness, Roundness

Meter Tubes



ORIFICE METER TUBE
ORIFICE HOLDING DEVICE
VANE (optional)
PLATE
ΔP TAP
ΔP TAP
U
D

Meter Tubes and Senior Fitting



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Straightening Vanes

- Bundle of Small Tubes Placed Inside Upstream Section
- Flanged or Line Type
- Purpose
  - Remove Swirls from Flow
  - Shorten the Upstream Section

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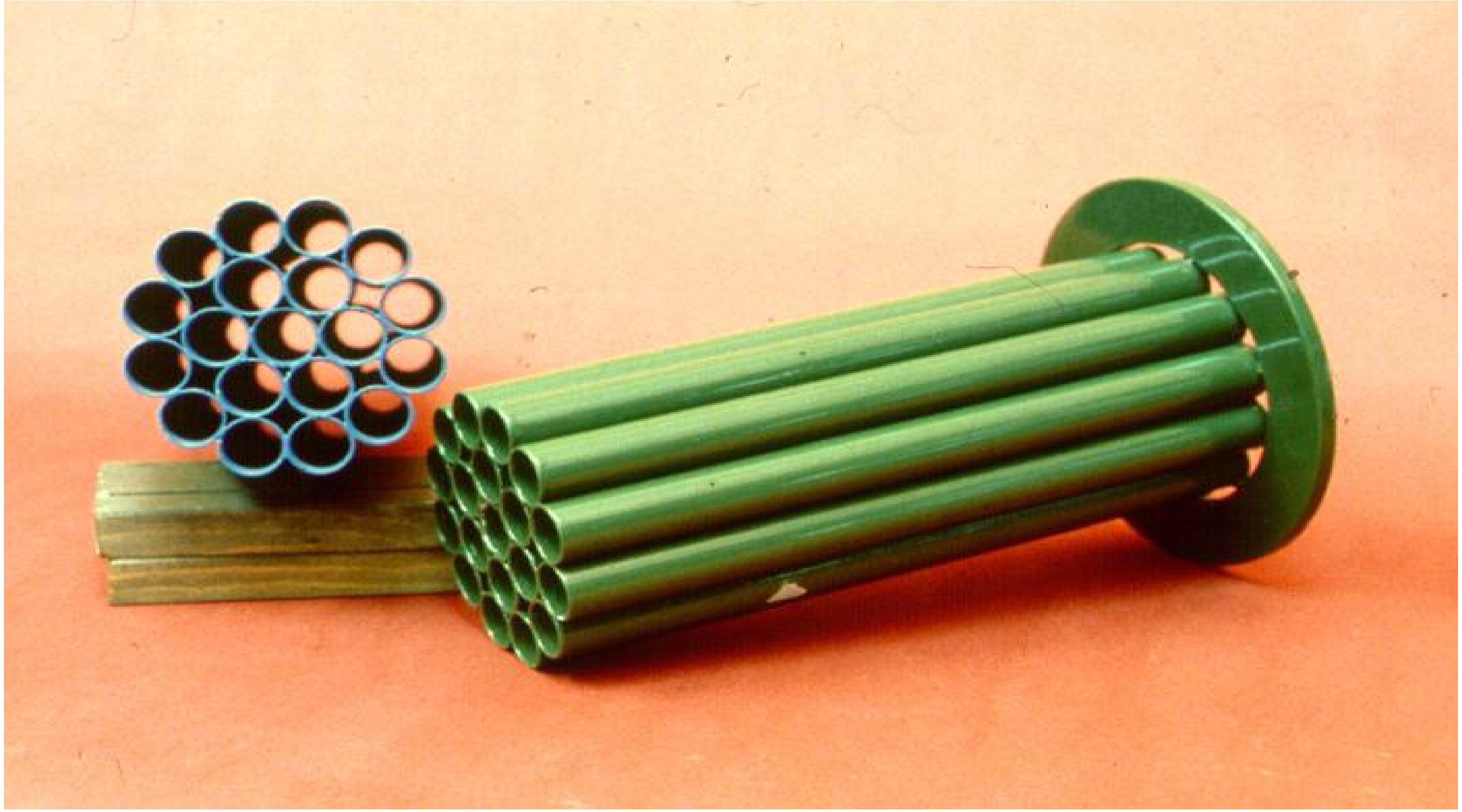
Straightening Vanes



Secondary Devices

- Orifice fitting / plate is known as the ‘Primary Device’
- Secondary devices receive the raw information
- Then it's converted to a proportional signal
  - Electrical or pneumatic
- Corrected volumes are then calculated

Secondary Devices

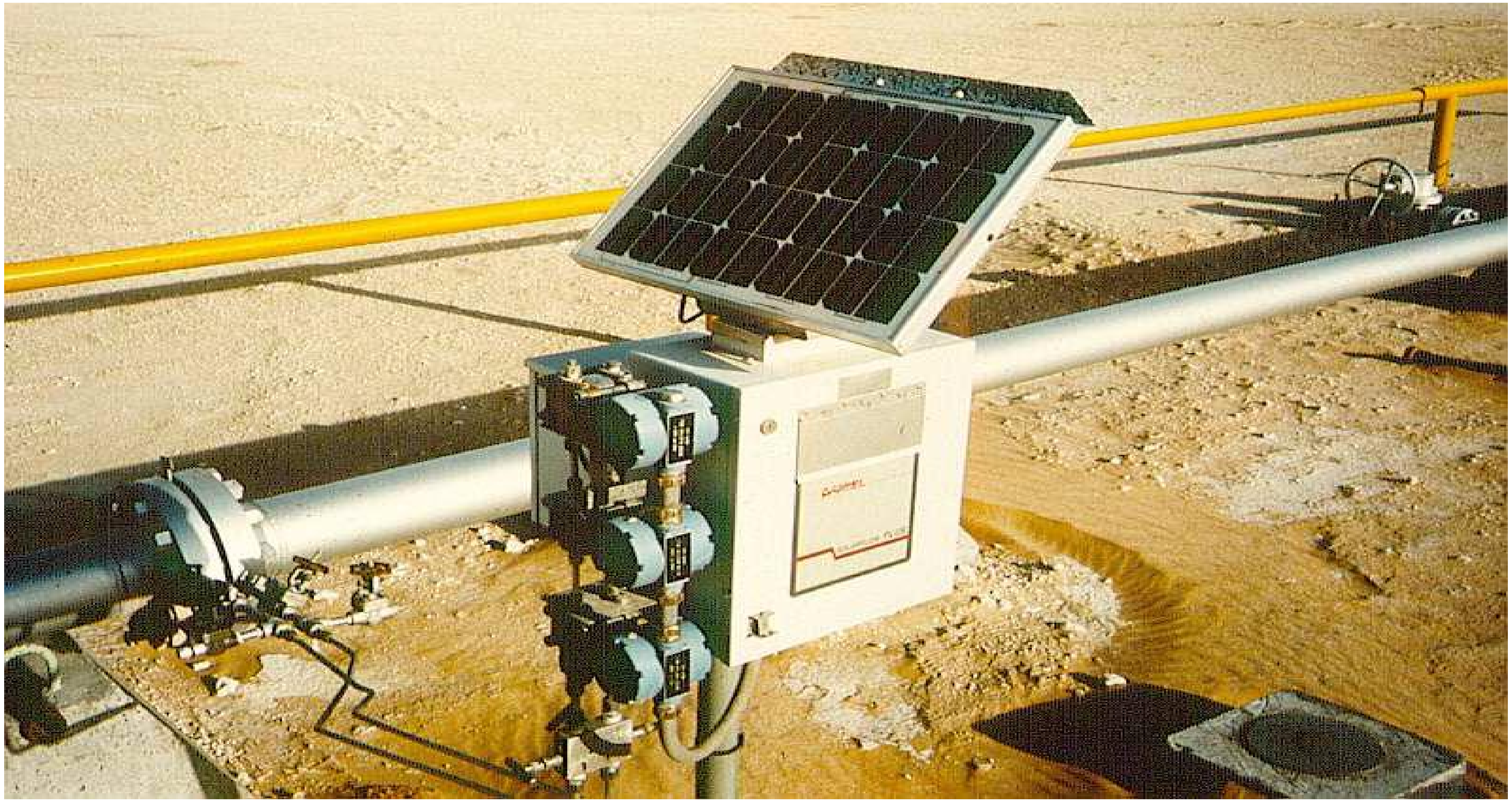
Types:

- Transmitters
  - Differential Pressure
  - Pressure
  - Temperature
- Flow Computers
- Chart Recorders

Flow Computers / Chart Recorders

- Flow computers employing high speed, real time processors are now the most popular devices
- Requirements for real time measurement
- Input signals from DP, P, T
- Calculate corrected flow volumes
- Chart Recorders have to be changed frequently and must be integrated

Orifice Flange Union & Flow Computer



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Senior Orifice Fitting & Flow Computer

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Conclusion

- The new AGA #3 / API 14.3 measurement standard has greatly tightened the tolerances for the manufacture of orifice devices and meter tubes
- To ensure the best possible accuracy of the metering installation, it is imperative that regular scheduled maintenance be performed.
- The primary device, be it a fitting or flange, cannot be expected to provide accurate, reliable flow information if the orifice plate is bowed or otherwise degraded in some way

Conclusion

- The vast body of data supporting Orifice measurement over the years becomes meaningless if the guidelines for the design, manufacture, installation, and maintenance of these devices are not followed

Summary

- Daniel Provide Full Flow Measurement Solutions
  - Measurement Expertise is key
  - Proven Technology
  - High Reliability
  - World wide responsive Service
  - Offer Superior Value through High System Availability
  - World Leading Orifice Fitting Manufacturer

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END OF PRESENTATION

Thank you for your attention

Any Questions?

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