Flow Measurement Options for Pipeline and Open Channel Flow

Presented by Molly Skorpik - 2013 Montana Association of Dam and Canal Systems Conference
Irrigation Training and Research Center

- California Polytechnic State University and USBR
- Short courses for irrigation managers and designers
- www.itrc.org
Overview

- Pipeline Flow Measurement Basics
- Pipeline Flow Measurement Devices
- Open Channel Flow Measurement Devices
Pipeline Flow Measurement

Basics

Continuity equation: flow rate remains constant between locations

flow = velocity x area  or
Q (cfs) = V (fs) x A (sf)

Diagram:

\[ Q = A_1 \times V_1 \]
\[ A_1 = 2 \text{ Sq. Ft.} \]
\[ V_1 = 1 \text{ FPS} \]

\[ Q = A_2 \times V_2 \]
\[ A_2 = 1 \text{ Sq. Ft.} \]
\[ V_2 = 2 \text{ FPS} \]
Pipeline Flow Measurement Basics

Miner’s Inches

- Flow through an orifice with an area of one square inch under a head of six inches
- Uncommon measurement except in ag
- Varies state to state
- 1 cfs = 40 miner’s inch
- 1 miner’s inch = 11 ¼ gallons per minute

Example = District measures 5 cfs
Then 5 cfs * 40 miner’s inches/cfs = 200 miner’s inches
Pipeline Flow Measurement Devices

- Open Pipe Discharge
- Collins Flow Gage
- Propeller Flow Meter
- Venturi Meters
- Ultrasonic Pipe Meters
- Electro-magnetic Meters
Flow measurement based on measuring the velocity of water by turning a propeller in the water. A readout of a flow meter gives both instantaneous flow rate (needle gage) and volume (totalizer).
Pipeline Flow Measurement – Propeller Flow Meter

Installation

• Sizing – Propellers are calibrated to exact inner pipe diameter.
• Full pipe – Pipe must be full.
• Obstructions in pipe – Install on straight sections, consider straightening vanes.
• Turbulence – Avoid elbows, valves, air entrainment.
• Needle movement – Use lowest reading
• Center the meter

Assumptions on pipe ID can introduce error!

<table>
<thead>
<tr>
<th>Pipe Type</th>
<th>Actual ID (in)</th>
<th>% Error if 12&quot; Assumed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel, Standard</td>
<td>12.00&quot;</td>
<td>0.0%</td>
</tr>
<tr>
<td>Steel, Sched 20</td>
<td>12.25&quot;</td>
<td>-4.2%</td>
</tr>
<tr>
<td>Steel, Sched 40</td>
<td>11.94&quot;</td>
<td>1.0%</td>
</tr>
<tr>
<td>PVC, 100 ft PIP</td>
<td>11.96&quot;</td>
<td>0.7%</td>
</tr>
<tr>
<td>PVC, 100 psi PIP</td>
<td>11.61&quot;</td>
<td>6.4%</td>
</tr>
<tr>
<td>PVC, 100 psi IPS</td>
<td>12.09&quot;</td>
<td>-1.5%</td>
</tr>
<tr>
<td>PVC, Sched 40</td>
<td>11.89&quot;</td>
<td>1.8%</td>
</tr>
<tr>
<td>PVC, 160 psi IPS</td>
<td>11.71&quot;</td>
<td>4.8%</td>
</tr>
<tr>
<td>Non-reinforced concrete</td>
<td>12.00&quot;</td>
<td>0.0%</td>
</tr>
</tbody>
</table>
Pipeline Flow Measurement – Propeller Flow Meter

**Operation**

- **Accuracy** – 2% with proper flow rates. Accuracy very poor at velocities less than 1.0 fps for 12” and smaller.
- **Portable propeller meters**
  - Flow will vary when removed
  - Measuring while making adjustments can take hours to stabilize
- **Horizontal vs. vertical placement**
- **Daily and annual maintenance**
  - Remove debris before it gets to the meter, OR
  - Clean the propeller frequently
Pipeline Flow Measurement – Propeller Flow Meter

Advantages
• Easy to use for pipe (pressurized) flow.
• Can have a low relative installation cost.

Disadvantages
• Turbulence in the water makes accurate measurements difficult.
• Material can easily plug the propeller.
Pipeline Flow Measurement – Open Pipe Discharge

Flow measurement is based on measuring the trajectory (path) of the water as it discharges from a pipe and into the air.

**Installation**

- Pipe Horizontal – Must be level to use standard tables and equations.
- Straight Section – Need six pipe diameters prior to discharge.
Pipeline Flow Measurement – Open Pipe Discharge

Example:
Measure 12” horizontal and 2” vertical = 2.19 cfs

![Diagram of pipeline flow measurement method](image)
Pipeline Flow Measurement – Open Pipe Discharge

Operation

- Pipe Flowing Full
- Excess Turbulence
- Pipe Flowing Partially Full
Pipeline Flow Measurement – Open Pipe Discharge

Advantages
• Simple to use, resulting in lower costs.
• Typically the pipe is in-place, no construction required.

Disadvantages
• Velocity and turbulence in the water make accurate measurements difficult.
• Wind can affect readings.
• Messy business (can get wet)
Flow measurement is based on obtaining a pitot tube measurement of the velocity head ($H=\frac{V^2}{2g}$) in pipeline. The Collins Flow gage consists of two mains parts: a hollow impact tube (inserted in pipe) and a water-air manometer connected to the two ends of the tube by hoses.
Pipeline Flow Measurement – Pitot Tube Meters (Collins Flow Gage)

**Installation**

- Tube requires that two holes be drilled and tapped in the pipe.
- Requires specialized tapping equipment.
- Holes must be 180 degrees.
- Once set, multiple use.
Pipeline Flow Measurement – Pitot Tube Meters (Collins Flow Gage)

Operation
• 2 Point Method
• 6 Point Method
• 10 Point Method
• 20 Point Method
Pipeline Flow Measurement – Pitot Tube Meters (Collins Flow Gage)

Advantages
• Quick and simple, once taps are installed.
• Used as standard by some electric utilities.
• Can be used in short sections of pipe with multiple readings.

Disadvantages
• Time required to set up initial taps and threaded fittings.
• Material readings must be taken in large pipes.
Flow measurement is used to measure the flow of water in pipes under pressure. It utilizes the Venturi principle: flow passing through a constricted section of pipe is accelerated and the head is lowered. With cross sectional areas of pipe known, the flow can be determined.
The Bernoulli Equation
Assuming a horizontal flow (neglecting minor elevation differences between measuring points), the Bernoulli Equation can be modified to:

\[ p_1 + \frac{1}{2} \rho v_1^2 = p_2 + \frac{1}{2} \rho v_2^2 \]  \hspace{0.5cm} (1)

where
\[ p = \text{pressure} \]
\[ \rho = \text{density} \]
\[ v = \text{flow velocity} \]

The equation can be adapted to vertical flow by adding elevation heights \( h_1 \) and \( h_2 \).

Assuming uniform velocity profiles in the upstream and downstream flow, the Continuity Equation can be expressed as:

\[ q = v_1 A_1 = v_2 A_2 \]  \hspace{0.5cm} (2)

where
\[ q = \text{flow rate} \]
\[ A = \text{flow area} \]

Combining (1) and (2), assuming \( A_2 < A_1 \), gives the “ideal” equation:

\[ q = A_2 \left[ \frac{2(p_1 - p_2)}{\rho (1 - (A_2/A_1)^2)} \right]^{1/2} \]  \hspace{0.5cm} (3)

For a given geometry \( A_2 \), the flow rate can be determined by measuring the pressure difference \( p_1 - p_2 \).

The theoretical flow rate \( q \) will in practice be smaller (2-40%) due to geometrical conditions.

The ideal equation (3) can be modified with a discharge coefficient:

\[ q = c_d A_2 \left[ \frac{2(p_1 - p_2)}{\rho (1 - (A_2/A_1)^2)} \right]^{1/2} \]  \hspace{0.5cm} (3b)

where
\[ c_d = \text{discharge coefficient} \]

The discharge coefficient \( c_d \) is a function of the jet size - orifice opening - the area ratio \( A_{jc} / A_2 \)

where
\[ A_{jc} = \text{area in "vena contracta"} \]

"Vena Contracta" is the minimum jet area that appears just downstream of the restriction. The viscous effect is usually expressed in terms of the nondimensional parameter \( \text{Reynolds Number - } Re \).

Due to the Bernoulli and Continuity Equation the velocity of the fluid will be at its highest and the pressure at the lowest in "Vena Contracta". After the metering device the velocity will decrease to the same level as before the obstruction. The pressure recover to a pressure level lower than the pressure before the obstruction and adds a head loss to the flow.

Equation (3) can be modified with diameters to:

\[ q = c_d n^2 D_2^2 \left[ \frac{2(p_1 - p_2)}{\rho (1 - c^2)} \right]^{1/2} \]  \hspace{0.5cm} (4)

where
\[ D_2 = \text{orifice, venturi or nozzle inside diameter} \]
\[ D_1 = \text{upstream and downstream pipe diameter} \]
\[ c = D_2 / D_1 = \text{diameter ratio} \]
\[ \pi = 3.14 \]

Equation (4) can be modified to mass flow for fluids by simply multiplying with the density:

\[ m = c_d \pi^2 D_2^2 \left[ \frac{2(p_1 - p_2)}{\rho (1 - c^2)} \right]^{1/2} \]  \hspace{0.5cm} (5)
Pipeline Flow Measurement – Venturi Meters

Installation
- Usually inserted between two flanges.
- Short-upstream end must be the same diameter as pipeline.
- Connect holes in meter to piezometer.

Operation
- Measurement of head – measurements are made at the entrance section and throat sections and used in equation.
- Head loss – Often, a measurement is taken immediately below constriction to document overall loss through meter. Expect 10 to 20 percent loss.
- Table Values of C and K – Need coefficient tables to calculate flow.
Pipeline Flow Measurement – Venturi Meters

Advantages
- Does not obstruct the flow.
- Simple operation. No moving parts.

Disadvantages
- Tubes used to measure pressure can become plugged easily.
- Can be expensive in large installations.
Pipeline Flow Measurement – V-Cone Meter

V-Cone uses pressure differential, similar to the traditional venturi meter.

Same principle as traditional venturi meter
Ultrasonic pulses are transmitted through a moving liquid. The pulses that travel in the same direction as the fluid flow (downstream) travel faster than the pulses that travel against the flow (upstream).
Pipeline Flow Measurement – Portable Ultrasonic Pipe Meters

Installation

- Avoid installation on the same pipe with another ultrasonic flow meter.
- Manufacturer likely requires undisturbed pipe up and downstream of device.
- Weather pipe is running vertical or horizontal, mount transducer on a horizontal plan.
- Chose location of full pipe flow.
- Prepare contact surfaces.

Operation

- Ensure proper signal strength.
- Need accurate measurement of water temperature.
Pipeline Flow Measurement – Portable Ultrasonic Pipe Meters

Advantages
• Non-mechanical.
• Portable, small and lightweight unit.
• If properly installed can be used for flow velocities as low as 0.2 ft sec with reasonable accuracy.
• Various transducer sizes are available for different pipe sizes.
• Can be used for various fluids at various temperatures.
• Accuracy of 2%.
• Easy to program.
• For use on horizontal and vertical pipes.
• Easily checked for signal strength.

Disadvantages
• Limited pipe material types. Yes – metal and most plastics. Linings might interfere.
• Care must be taken with all connections and wires.
• Good working battery should be used.
• May not work just “down stream” of a pump.
• Diagnostic Signal Strengths must be monitored.
• Correct transducer size and location are critical.
Fluid passes through pipe and a voltage proportional to flow rate is generated. The voltage is measured by electrodes. The reading is converted to give a rate of flow.
Pipeline Flow Measurement –
Electromagnetic Flow Meters

Advantages
• Non-mechanical.
• Avoid debris clogging
• Highly accurate up to 0.5%
• No detectable pressure drop
• Insensitive to temperature and pressure
• Various sizes are available for different pipe sizes.

Disadvantages
• Care must be taken with all connections and wires.
• Good working battery should be used.
• Cost may be significant in large pipe diameters.
• Diagnostic Signal Strengths must be monitored.
• Correct size and location are critical.
Reading flow rates

- There will be slight variability with flow readouts.
- Take multiple readings.
- Create form to use for readings.
- Suggest a reading every 5 seconds over a minute period.
- Average the readings and convert to desired output (IE gpm or cfs)
Acknowledgements

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