Utility Flow Metering for Steam and Heated/Chilled Water: A Tutorial

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Review Flow Metering Principles: Flow Meters and Flow Computers

Utility Distribution & Customer Metering Concerns

- Service pressure, temperature, energy
- Expected customer load (flow rates)
- Service Reliability & Service Interruptions
- Billing Accuracy
- Scheduled Maintenance
- Information and Expertise Sharing
- Proposed installation location
- Steam Quality

Basic Input Measurements of Flowing Process Conditions

- Differential Pressure
- Static Pressure
- Temperature
- Volume Flow Rate
- Velocity
- Fluid properties are computed by temperature and/or pressure

Fluid Properties

- Density of Water or Saturated and Superheated Steam can be implied from measured (absolute) pressure and/or temperature and internally stored fluid properties
- Other properties: energy/unit mass, isentropic exponent, and viscosity are also computed
- Unfortunately steam quality is not implied and removing steam condensate prior to metering is a installation requirement

Attributes of Flow Meters

- Accurate Flow Rate Range at fluid density
- Mandatory Installation Piping Requirements
- Available output signal type(s)
- Uncertainty (or accuracy)
- Basis of Calibration (water or air)
- Application of required Correction Factors
- Maintenance required
- Flow profile and flow swirl effects
- Inline vs insertion vs clamp-on types

Attributes of Installation Site

- Fluid state and available inlet and outlet pipe runs
- Elevation above sea level (barometric pressure)
- Process noise in the differential pressure sensing lines at the steam/water interface
- Wet leg compensation of static pressure xmtrs
- Winter demand/Summer demand flow rates
- Vibration in piping systems
- Electrical Interference & Electrical Grounding alternatives
- Interconnections to Building Controls
- Condensate recovery from customer site

Estimating Overall Metering Uncertainty

- Define the intended operating region of flow rate, temperature, and pressure at the site
- Identify the uncertainty in the volume flow rate measurement
- Identify the uncertainty in the inferred steam density as a result of uncertainty in the steam temperature and/or pressure
- RMS the individual error components to arrive at the estimated uncertainty of steam mass flow
- Similar process is used in liquid BTU systems

Commercial Flow Meter Types

- Vortex Flow Meters
- Orifice Plate Square Law Meters
- Contoured Inlet Square Law Meters Nozzles, V-Cone, Accelabar)
- Averaging Pitot Square Law Flow Meters
- Gilflo and ILVA Type Meters
- Target Flow Meters
- Insertion Turbine/Vortex Flow Meters
- Shunt Flow Meters (Bypass or Compound Flow)
- Ultrasonic Flow Meters
- Condensate Flow Meters
- Electromagnetic Flowmeters

Survey of Steam and Condensate Flow Meter Techniques



Basic Techniques

Measure steam into facility

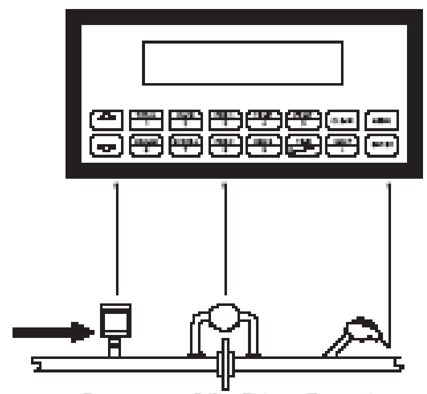
- Measure the volume flow rate in steam line
- Compute the fluid properties of steam from T & P
- Compute (and sum) mass flow rate as:
  - Mass flow = Density * Volume flow
  - Energy flow = Enthalpy * Mass flow

Measure only condensate out from facility

- Requires collection and metering of ALL condensate
- Assumes no unintentional entry of process water into condensate collection

Steam Metering

Steam Mass & Steam Heat Illustration



Calculations

Mass Flow

Mass Flow = volume flow • density (T, p)

Heat Flow

Heat Flow = Volume flow • density (T, p) • Sp. Enthalpy of steam (T, p)

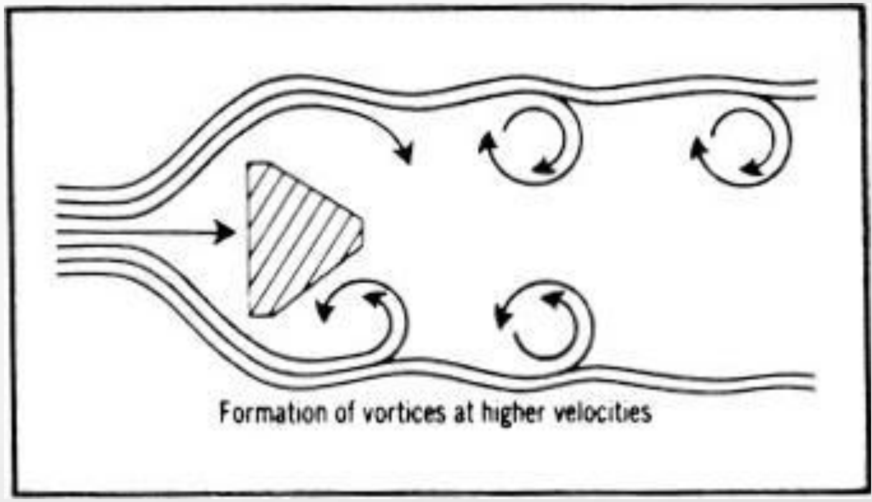
Vortex Flow Meter Principles

Flow around non-streamlined shape produces alternating vortices at higher velocities whose shedding frequency is essentially linear with volume flow through the meter run.

- Calibrated by manufacturer on water.
- Corrections can be applied for effects of flowing temperature on the meter run (K drops with Tf).
- Mass flow can be computed from volume flow and flowing density.
- Full bore and reduced bore models available as well as insertion styles

Some Important Observations

- Grounding of piping and signal common to earth.
- Mounting shedder bar horizontal reduces adverse impact of condensate hitting bar.
- Use adjustable trigger sensitivity if false output @ no flow (this reduces range of the meter).
- Avoid accidental, duplicate corrections.



Vortex Advantages

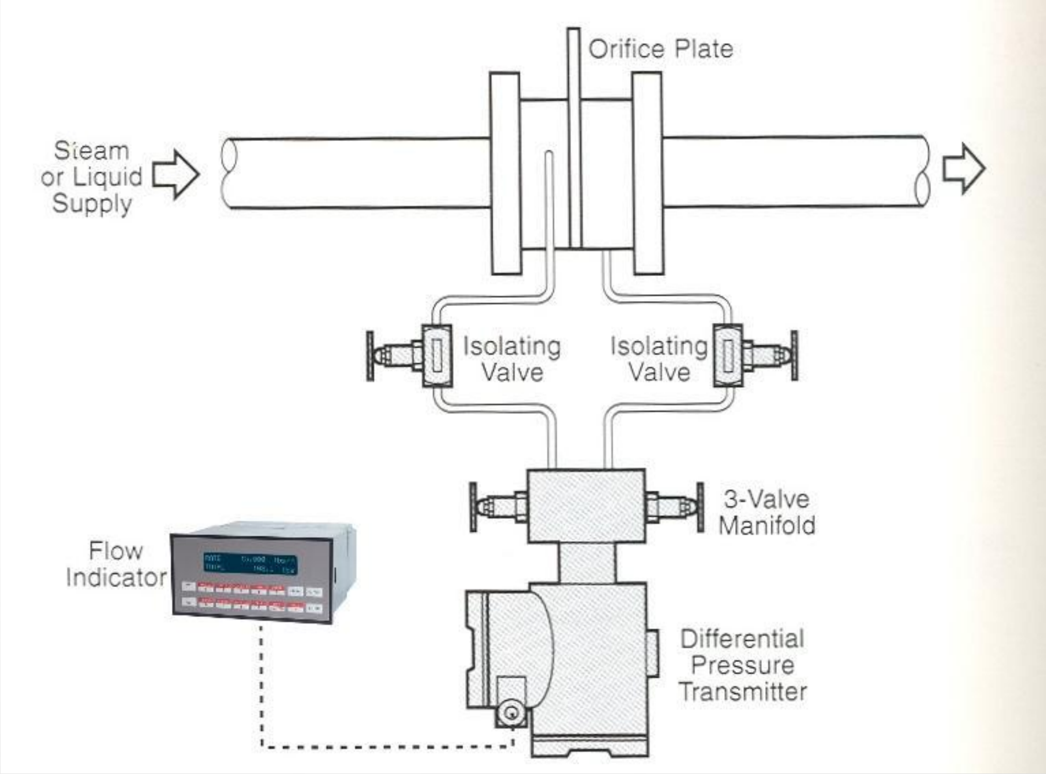
- Most popular steam flow meter.
- Accuracy of +/- 1% of volume flow rate.
- Wide flow turn-down range 15:1 type.
- Pulse and analog output signals available.
- Swirlmeter for short runs.
- Reduced bore meters for existing meter runs and resizing.

Orifice Flow Meter Principles

- Orifice Meters are the historic bench mark "Square-law" flow meter others are compared against.
- Includes various orifice styles and pressure tap locations.
- Intended for limited accurate flow range of 4:1 but can be increased to a usable 20:1 range if stacked (high and low range). DP transmitters are used on primary element.
- Generally not calibrated but rather "sized" with standardized methods and so fabricated and installed.
- Corrections required include: correction for density, dimensional changes with temperature Fa, Y1 correction for velocity of approach, and sometimes Cd verses Rn.

Typical Installation

- Orifice Beta Ratio typically chosen to provide 100“ H_2O at Maximum Flow and nominal line pressure.
- Normal Flow is typically 70% of Maximum Flow.



Considerations for Installation

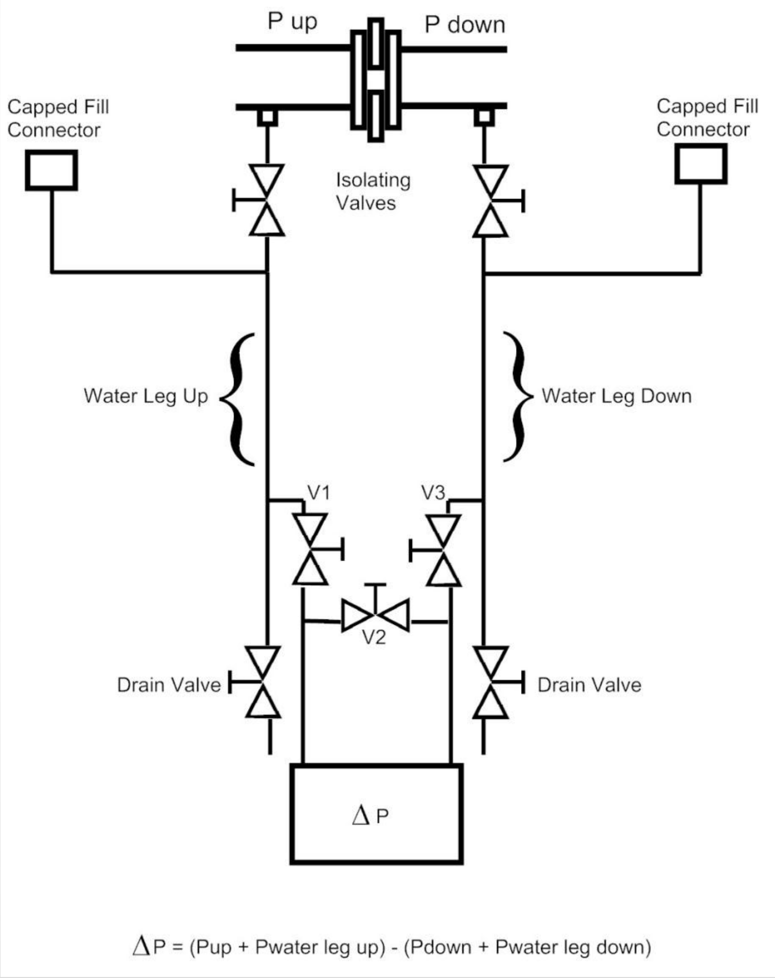
- The Uncertainty of an orifice meter run is approximately +/- 0.5% to +/- 1%.
- The metering code for orifice plates dictate the straight inlet and outlet pipe run requirements for the installation (40 pipe diameters are now called out).
- Also restrictions on weld and gasket protrusion and positioning of the orifice plate.

Using 3-Valve Manifold for Differential Pressure Transmitters in Steam

- Differential pressure transmitters are not intended to see high steam temperatures.
- The differential pressure transmitter is located below the orifice plate and connected to orifice taps by inclined sense lines that should be filled equally with water.
- Sense lines should initially be equally filled to keep equal water legs to leveled delta P transmitter ports.
- To check for proper transmitter output at no flow: Close inlet valve, open bypass valve to produce 0.0” delta P. Close bypass and open inlet to return to normal service.
- Valve sequencing is important to avoid imbalance in legs.

Draining Sense Lines

- If legs are drained to purge contaminates then water legs take time to refill and stabilize. Meter errors can occur in the interim. Manually refill at fill points with V2 closed.
- Do not simultaneously open all 3 valves in manifold. Water legs can be imbalanced and water flushed downstream.



Sizing differential pressure meters for steam service

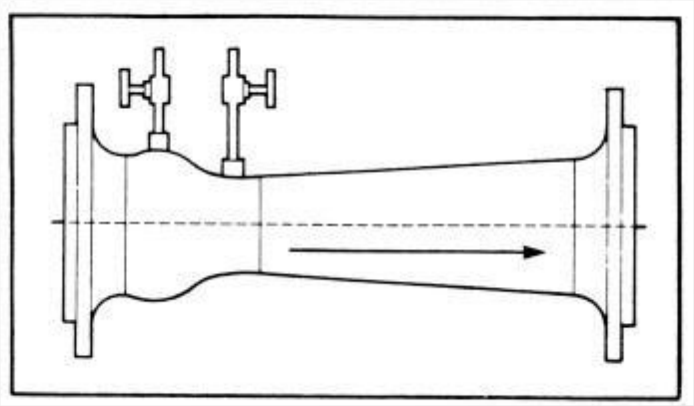
- Steam process noise may limit useful differential pressure to above 0.25” (Is 1” more practical?)
- Note that orifice sizing sheets only compute many key values at the “Normal” flow rate.
- Sizing sheets often compute inaccurate values for saturated steam density and isentropic exponent. ASME Steam Tables should be selected.
- Expected test results should include Y1 at each flow rate. (Need to re-run at other flow rates.)

Contoured Inlet, Square Law Flow Meter Principles

- Class includes Nozzle, Venturi, Wedge
- Industry-standard sizing equations.
- That standard also means long installation straight pipe run requirements.
- Low maintenance .
- Better accuracy than orifice type.
- V-Cone and Accelabar are proprietary types intended for improved performance .

Venturi and Nozzle and Wedge

- Shape of nozzle or venturi is intended to create a predictable flow pattern
- Follows many other characteristics of orifice flow meters
- Unique equation for Y1



Special case of a V-Cone

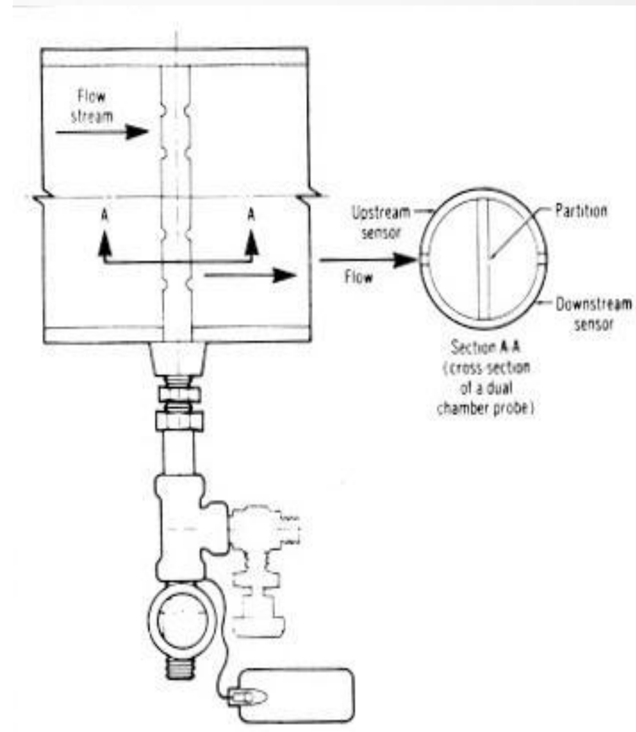
- Calibrated on water
- Condensate can pass easily through meter Shorter inlet/outlet pipe runs required
- Performance is very independent of Rn
- Unique, proprietary equation for Y1

Averaging Pitot Tube Flow Meter Principles

- Class includes averaging pitot tube, annubar, verabar insertion type flow meter types.
- Computation of implied fluid density and diff. pressure are used to compute velocity.
- Velocity and pipe area to compute volume flow.
- Density and volume flow to compute mass flow.
- Low cost in large lines (can be hot tapped).
- Lower differential pressure produced by device.
- Lower pressure loss through meter run.

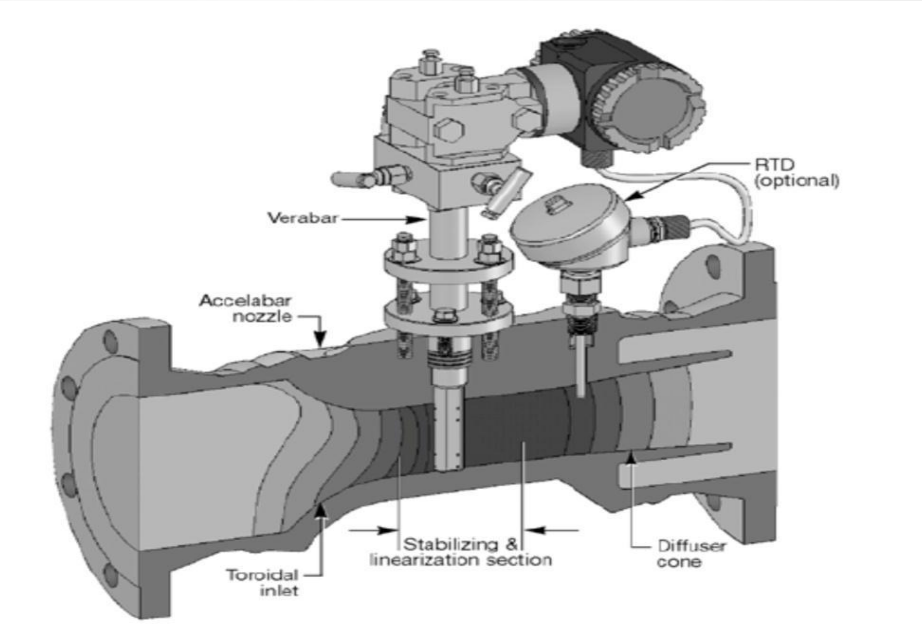
Averaging Pitot Tube Class

- Summary
  - square law
- Advantages
  - inexpensive to install on larger lines
- Disadvantages
  - lower delta P developed
- Remember 0.25” useful limit?



Accelabar-A Novel Configuration

- Toroidal inlet increases velocity at point of measurement.
- Averaging pitot tube provides flow measurement.
- Performance improved - similar to other contoured input devices.

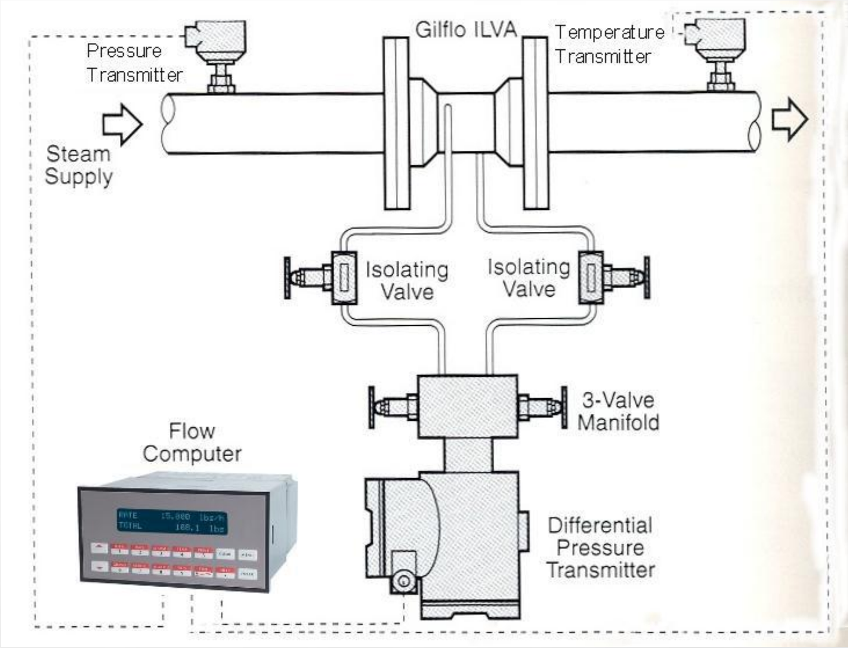


Gilflo and ILVA Flow Meter Principles

- Produces a differential pressure approximately linear with flow rate - movable cone pushes against spring with larger area at higher flows.
- Much wider turn down range than other differential producers .
- Linearization by table (or equation) and with temperature corrections for spring constant .
- Factory calibrated on water with results extrapolated for flowing density and temp.

Gilflo and ILVA

- Wide flow turn-down range w/differential pressure output
- Output DP nearly linear with flow
- Calibrated on water



Target (or Obstruction) Style Flow Meter Principles

- Essentially a square law flow meter with integral, direct strain gauge electrical output.
  (No differential pressure to deal with).
- Insertion and In-Line type available.
- Size of target can be selected to create desired measurement range.
- 15:1 flow range.

Target Meter Equation

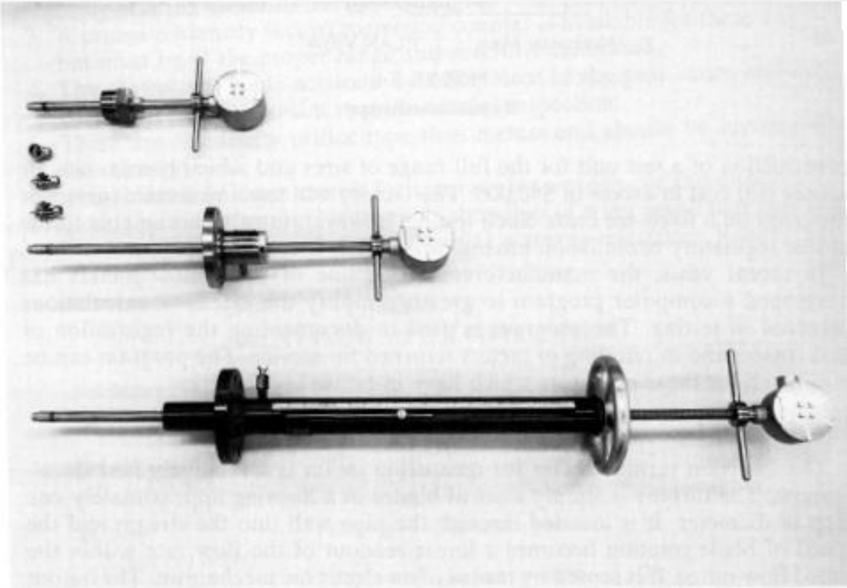
Analog Output = Cd * Density * V^2 * AT/2
where:

- Cd is empirical
- Density is at flowing
- V^2 is velocity squared
- AT is area of target

Linear Insertion-type Flow Meter Principles and Techniques

- Types included - Insertion Turbine and Insertion Vortex devices with pulse output linear with point velocity at the insertion depth and/or over its sensitive area.
- Seeks to apply a mathematical corrections arrive at the average velocity in the line from that measured a known insertion depth from assumed flow profile.
- Also applies mathematical corrections for its blockage effects and operating temperature on the meter run.
- Pressure and/or temperature are used to imply steam density.

Representative Insertion Turbine Flow Meters



Intended for mounting on full port isolation valve

- Can be fully retracted into housing
- Close isolation valve
- Service meter head

Pro's and Con's of Insertion Types

Pro's

- 10:1 - 20:1 Turndown.
- Measures velocity to +/- 1%.
- Can be hot tapped into existing lines.
- Access for maintenance.
- Low pressure drop.
- Inexpensive initial cost in large line sizes.

Con's

- Not as accurate as in-line techniques.
- Dependent on flow profile & swirl & empirical data fit.
- Turbine type needs regular, seasonal maintenance.
- External leakage around seals is potential area of concern.

Additional Steam Metering Techniques

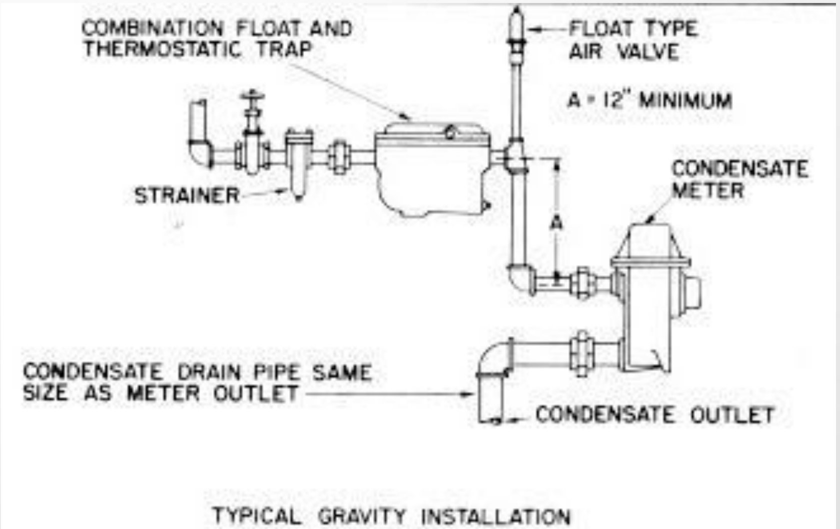
- Shunt Flow Meter
- Flow Meter Manifold -applications where two or more flow meters are used to achieve the required turndown range.
  - Series connection involves 2 meters plus one control valve and manifold controller unit.
  - Parallel connection involves base meter system that brings one or more larger meter on line as the flow rate increases.

Condensate Flow Meter Principles and Techniques

- Suitable for totalization of condensate (which is assumed to follow inlet steam usage).
- The condensate flow pattern may be irregular, particularly in pumped condensate systems.
- Output linear with volume flow.
- May include an electronic pulser on shaft
- Calibrated on water for equivalent. pounds of water at 140 F reference temperature.
- Mathematical corrections can be applied for other condensate temperatures.
- Steam line can be sensed for energy calculations .

Condensate Meter

- Pro's
  - Wide measurement range.
- Con's
  - 2-3 year maintenance.
  - Requires all but only condensate be metered.



Ultrasonic type Flow Meter Principles and Techniques

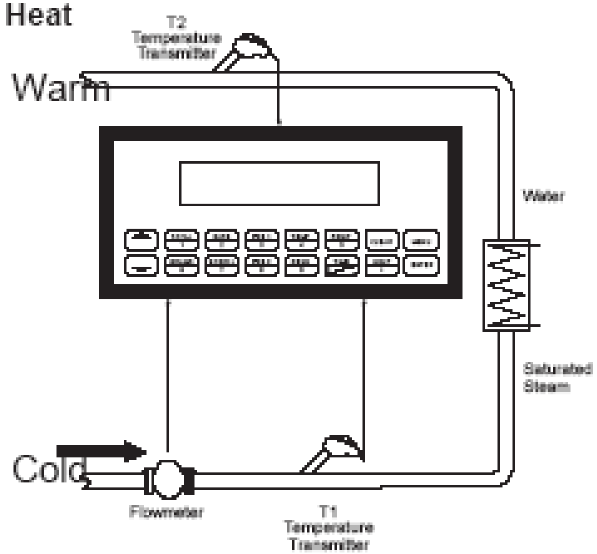
- Measures average velocity of material passing through a narrow ultrasonic beam in the flow meter run by measuring the transit time in two directions using two oriented sensors a known distance apart.
- Assumes uniform velocity profile outside of the beam.
- Computes volume flow rate from pipe area and velocity and density from temperature/pressure.
- Applies mathematical corrections for operating temperature induced changes in the meter run.

Ultrasonic Steam Flow Meter

- 2”-48”
- 20 pipe diameters upstream/10 pipe diameters downstream.
- +/- 1% to 2% accuracy of velocity.
- 0.1 to 150 fps.
- Low pressure drop.
- Tolerant of dirty systems.
- Single or multiple path.
- Possible to mount on existing piping with care.

Chilled/Heater Water BTU Metering

Liquid Delta Heat Illustration



Calculations

Water

Heat = Volume Flow • $\rho(T1)$ • $[h(T_2) - h(T_1)]$

Other heat carrying liquids

Heat = C • volume flow • $(1-\alpha \cdot (T_1 - T_{ref}))^2 \cdot \rho_{ref} \cdot (T_2 - T_1)$

α = Thermal expansion coefficient • 10^{-6}
C = Mean specific heat
$\rho(T1)$ = Density of water at temperature T_1
$h(T1)$ = Specific enthalpy of water at temperature T_1
$h(T2)$ = Specific enthalpy of water at temperature T_2
ρ_{ref} = Reference density
T_{ref} = Reference temperature

More Liquid Meter Types

- Electromagnetic
  - +/- 0.25% to 1%
  - Useful over 100:1
  - Low maintenance
- Positive Displacement
  - +/- 0.25% to 0.5%
  - 10:1 or wider range
  - Requires maintenance
- In-Line Turbine
  - +/- 0.25% to 1%
  - 10:1 or wider range
  - Requires maintenance

News: EPA/ASTM Energy Meter Standard draft for USA coming soon for heating and cooling

EPA tasking ASTM to prepare a USA Heat Meter Standard

Working group drawing on existing OIML Standards but adapting the "essential" requirements for USA

Heat Metering system composed of:

- **Flow Sensor (Various Classes of accuracy and flow range)**
- **Temperature Sensor Pair (Accuracy suitable for delta T)**
- **Calculator (i.e.- Flow Computer)**

Complete Instrument does not have separable subassemblies

Combined Meter does have separable subassemblies

Consider having your technical staff participate in drafting the standard

Traditional and New Roles for Flow Computers

Flow Computer features, functions, and roles

- Uniform instrument functionality at customer sites
- Flexibility of getting all the Heat (Energy) and Mass computations for Steam or Chilled Water in one unit.
- Support for all flow meter types and signal types
- User selectable units of measure (lbs, hlbs, klbs, ...).
- Stored fluid properties for steam and water.
- Variety of conventional outputs.
- Internal interval data-logging for later retrieval.
  - Scaled pulse, analog output, relay alarms.
- Communication options for remote metering.
  - Modbus RTU RS485, Modem, Modbus TCP Ethernet, BACNET.
- Built in test and documentation aids.

Overview of the Flow Computer for steam applications

- Steam Monitoring
  - Mass Flow Monitoring
    - Lbs/Hr, with totalization in lbs.
  - Heat (Energy) Flow Monitoring
    - BTU’s available relative to water at 32 degrees F.
      - ♦ **Total** Heat of Steam
    - BTU’s used relative to condensate temperature (at saturated pressure).
      - ♦ **Net** Heat of Steam
    - BTU’s used relative to condensate return temperature.
      - ♦ **Delta** Heat of Steam

Overview of the Flow Computer in chilled/heated water calculations

Heated and Chilled Water Monitoring

- Volume and Liquid Mass Flow Monitoring
  - Gallons per Minute
  - Lbs/Hr ***(Density Compensation)***
- Heat Flow Monitoring
  - BTU's stored in condensate (relative to water at 32 F).
    - ♦ Liquid **sensible** heat
  - BTU's extracted from heat carrying liquid by monitoring temperature change across process (i.e., heat exchanger).
    - ♦ Liquid **delta** heat

Some Goals for Remote Metering

- Remote meter reading of totalizer(s)
- Data-logging of customer interval usage.
- Easy and flexible access to other site information (beyond basic metering needs)
- Use available communication infrastructure.
- Low installation and monthly operating costs.
- Use a shared communication channel for all metering devices at the customer site.
- Verification of proper operation and/or problem notification and/or remote problem solving.
- Feed data into existing database and billing program.
- Security and access.

Communication Alternatives

Public Channels.

- Dial up modem: periodic polling every hour.
  - Landlines (with or without caller ID).
  - Cellular telephones
- Internet: real time metering every minute.
  - Local provider options: DSL, T1,cable, wireless.
  - Modbus TCP information exchange.
  - Firewalls and IT Managers.

Private channels

- Company fiber-optic network buried along with piping.

Tough Customer Questions and Customer Owned Checking Meters

- My bill can't be that high! Is this thing working?
- Why are these utility guys in here working all the time?
- Customer scrutiny and engineering review of utility meters, calculations, procedures, test methods and maintenance.
- Checking Meter: A customer owned steam metering system installed in series with utility owned steam meter for verification of billing and connection to HVAC system.
- Sub-Metering: Multiple customer owned steam meters intended for customers internal use in allocating costs between various departments or tenants within a facility.

Information Gathering from Customer Sites: Increased Focus on Steam Safety

- Auxiliary Measurements from customer site using the existing communication channel.
- Examples of polling for expanded information:
  - Supply and return line pressures.
  - Readings from existing condensate meter.
  - Monitoring of proper steam trap operation.
  - Room temperatures in man-hole or customer site.
  - Potential flooding of manholes.
  - Remote customer shut-off by motorized valve.
  - Condensate lift pump operation.
- User defined alarm notification.

Questions?

Thank You!

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Versatile and Economical Instrumentation for Utility Metering Applications