Gas Flow Measurement

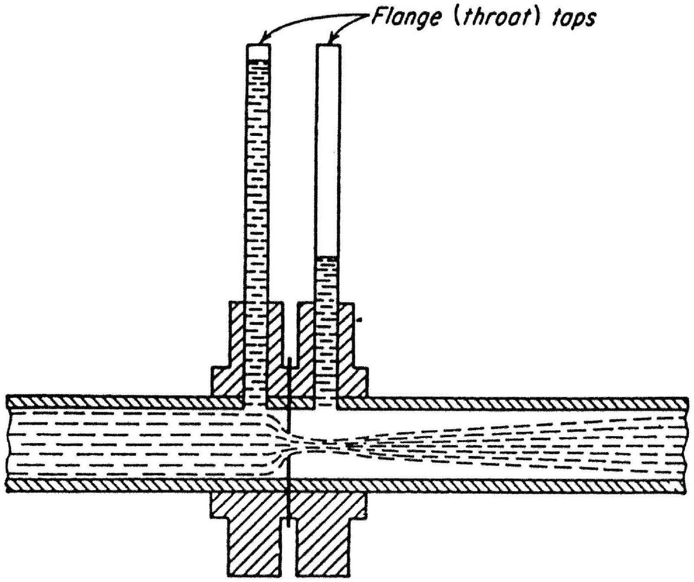
At the end of this module, you will:

- Be familiar with different types of gas meters:
  - Orifice Meters.
  - Critical Flow Prover.
  - Choke Nipples.
  - Pitot Tube.
- Orifice Meters:
  - Be familiar with and be able to derive Eq. 3.8.
  - Be able to explain the basis and terms in Eq. 3.9 (and 3.10).
  - Be able to compute the C' factor (i.e., the orifice flow constant).
  - Be able to reproduce Example 3.1 in complete detail.
- Critical Flow Prover:
  - Be able to explain the "critical flow prover."
  - Be able to use Eq. 3.13 to compute the gas flowrate for a "critical flow prover."
- Choke Nipples:
  - Be familiar with and able to explain the "choke nipple."
  - Be able to use Eq. 3.13 to compute the gas flowrate for a "choke nipple."
- Pitot Tube:
  - Be able to explain the estimation of the gas flowrate using a "pitot tube."

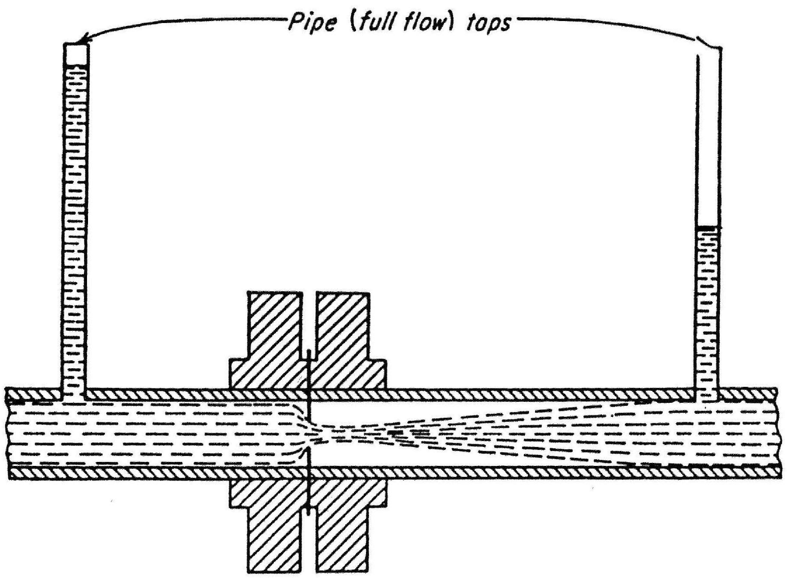
From: Lee, W.J. and Wattenbarger, R.A.: *Gas Reservoir Engineering*, SPE (1996).

Orifice Meter

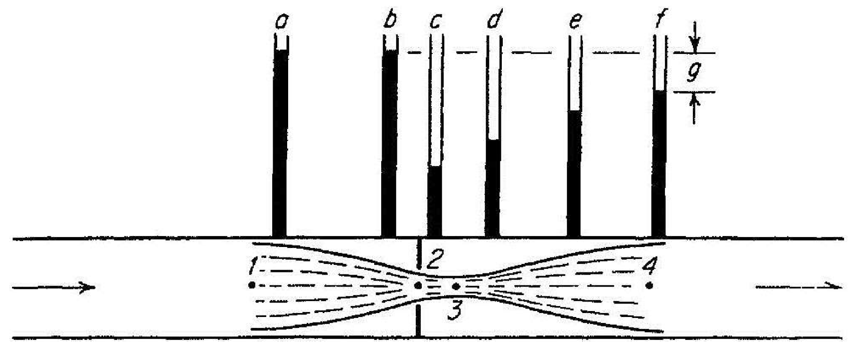
From: Katz, D. L., Cornell, R., Kobayashi, R., Poettmann, F. H., Vary, J. A., Elenblass, J. R., & Weinaug, C. G.: *Handbook of Natural Gas Engineering* (McGraw–Hill, New York) (1959).
Lee, W.J. and Wattenbarger, R.A.: *Gas Reservoir Engineering*, SPE (1996).



a. Orifice installation with "flange taps."



b. Orifice installation with "pipe taps."



c. Pressure recovery after the orifice plate (the quantity "g" is the "permanent pressure loss" due to the orifice plate obstruction.

$$q_{gh} = 218.44 \frac{d_o^2}{\sqrt{1-\beta^4}} \frac{p_f T_{sc}}{p_{sc} z_f T_f} \sqrt{\frac{z_f T_f}{p_f \gamma_g} h_w}$$

Assuming $p_{sc} = 14.73$ psia, $T_{sc} = T_f = 520$ Deg R, $z_f = 1$, and $\gamma_g = 1$ (air)

$$q_{gh} = 338.17 \frac{d_o^2}{\sqrt{1-\beta^4}} \sqrt{h_w p_f}$$

Writing in a general form, we have the "basic orifice equation"

$$q_{gh} = C' \sqrt{h_w p_f}$$

$$C' = F_b \, F_{pb} \, F_{Tb} \, F_g \, F_{Tf} \, F_{pv} \, F_{\mathrm{Re}} \, Y \, F_m \, F_l \, F_a$$

Orifice Meter

The general form of the "basic orifice equation" is

$$q_{gh} = C'\sqrt{h_w p_f}$$

$$C' = F_b\, F_{pb}\, F_{Tb}\, F_g\, F_{Tf}\, F_{pv}\, F_{\mathrm{Re}}\, Y\, F_m\, F_l\, F_a$$

Where:

- h_w = ***Pressure differential across orifice***, **in. of water**
- p_f = ***Flowing pressure*** **(upstream), psia.**
- F_b = ***Basic orifice factor*** **(see LW Tables 3.1 and 3.2)**
- F_{pb} = ***Pressure base factor*** **($14.73/p_{sc}$)**
- F_{Tb} = ***Temperature base factor*** **($T_{sc}/520$)**
- F_g = ***Specific gravity factor*** **($(1/\gamma_g)^{1/2}$)**
- F_{Tf} = ***Flowing temperature factor*** **($(520/T_f)^{1/2}$)**
- F_{pv} = ***Gas deviation factor*** **($(1/z_f)^{1/2}$)**
- F_{Re} = ***Reynolds number factor*** **$[1+b/(h_w p_f)^{1/2}]$ (see LW Tables 3.3 and 3.4 for b)**
- Y = ***Expansion factor*** **(see LW Tables 3.5-3.9 for Y)**
- F_m = ***Manometer factor*** **(manometer correction term — for sales)**
- F_l = ***Gauge location factor*** **(sea level and latitude corrections — for sales)**
- F_a = ***Thermal expansion factor*** **(T_f > 120 Deg F or T_f < 0 Deg F — for sales)**

Note that F_m, F_l, and F_a are usually assumed to be 1.

From: Lee, W.J. and Wattenbarger, R.A.: *Gas Reservoir Engineering*, SPE (1996).

Orifice Meter

Example 3.1—Orifice Meter Calculation. Calculate the gas flow rate through an orifice meter for the following conditions.

h_w = 40 in. of water.
p_f = 143 psig (measured upstream).
T_f = 84°F.
p_{sc} = 14.4 psia.
T_{sc} = 60°F.
d = 4.026 in.
d_o = 1.50 in.
γ_g = 0.7.
Taps = flange type.

Solution.

1. Determine the factors for the orifice constant. We use the abbreviated form here, ignoring the last three factors.

$$C' = F_b F_{pb} F_{Tb} F_g F_{Tf} F_{pv} F_{Re} Y,$$

where $F_b = 460.79$ (from Table 3.1),

$F_{pb} = 14.73/14.4 = 1.0229$,

$F_{Tb} = 1.0$ (because $T_{sc} = 520°R$),

$F_g = (1/0.7)^{0.5} = 1.1952$,

$F_{Tf} = [520/(84+460)]^{0.5} = 0.9777$,

$F_{pv} = (1/0.98)^{0.5} = 1.010$ ($z = 0.98$ from graphical estimates of Chap. 1),

$F_{Re} = 1 + b/[(40)(143+14.4)]^{0.5} = 1.0004$ ($b = 0.0350$ from Table 3.3),

and $Y = 0.9971$ (interpolated from Table 3.5).

2. Calculate C'.

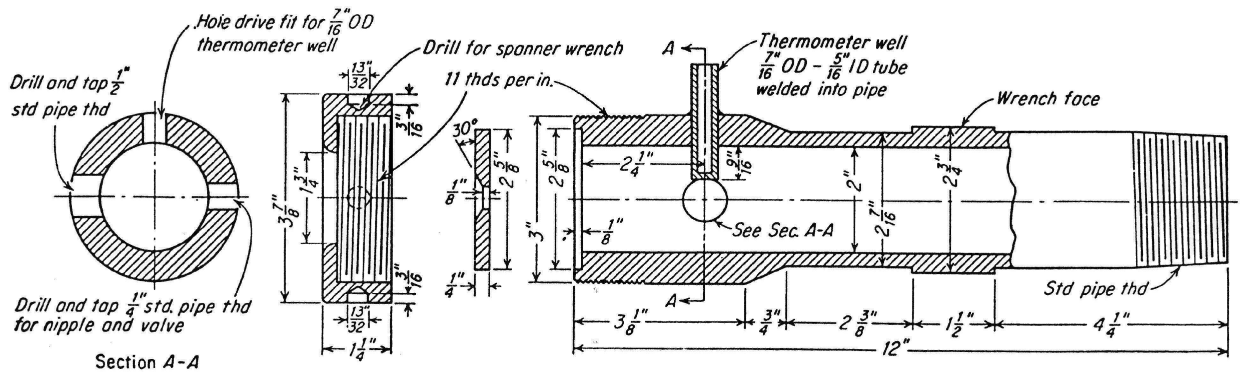
$$C' = F_b F_{pb} F_{Tb} F_g F_{Tf} F_{pv} F_{Re} Y = (460.79)(1.0229)(1.0)(1.1952) \times (0.9777)(1.010)(1.0004)(0.9971) = 554.90.$$

3. Calculate q_{gh}.

$$q_{gh} = C'(h_w p_f)^{0.5} = 554.90[(40)(143+14.4)]^{0.5} = 44{,}030 \text{ scf/hr}.$$

From: Lee, W.J. and Wattenbarger, R.A.: *Gas Reservoir Engineering*, SPE (1996).

Critical Flow Prover



<u>Critical Flow Prover</u>:

The critical flow prover is based on the assumption that critical flow velocity **(*i.e., the velocity of sound at the existing conditions*)**, ***exists*****.**

- **Used if the gas is vented to the atmosphere. (*i.e.*, testing conditions)**
- **Not as accurate as an orifice meter.**
- **Gas flowrate is directly proportional to the absolute upstream pressure.**
- **Flowrate depends only on:**
  - **Upstream pressure,**
  - **Upstream temperature,**
  - **Gas gravity, and**
  - **Orifice diameter.**

From: Lee, W.J. and Wattenbarger, R.A.: *Gas Reservoir Engineering*, SPE (1996).

Critical Flow Prover

$$q_{gh} = C\, p_f \,/\, \sqrt{\gamma_g T_f}$$

Where:

- C = Coefficient (LW Table 3.10 (flow prover)).
- p_f = Flowing pressure (upstream), psia.
- γ_g = Gas specific gravity (air = 1.0)
- T_f = Flowing Temperature, Deg R.
- q_{gh} = Gas Rate (14.4 psia and 60 Deg F), scf/hr.

Example 3.3—Critical Flow Prover Calculation. Calculate the gas flow rate through a critical flow prover.

d = 2 in.
d_o = 0.875 in.
p_f = 150 psia.
T_f = 70°F.
γ_g = 0.7.

Solution.

1. Determine the factors to calculate q_{gh}.

C = 309.3 (from Table 3.10).

2. Calculate q_{gh}.

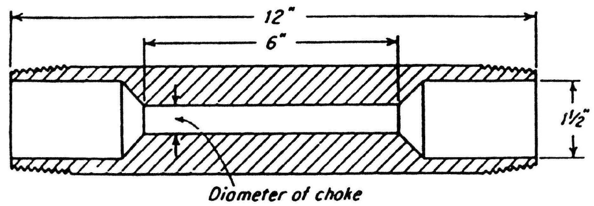
$$q_{gh} = \frac{(309.3)(150)}{\sqrt{(0.7)(70+460)}} = 2{,}408.7 \text{ scf/hr.}$$

TABLE 3.10—COEFFICIENTS FOR CRITICAL FLOW PROVER AND CHOKE NIPPLE (AFTER REF. 1)

Orifice size (in.)		Value of C: Critical Flow Prover, 2-in. pipe	Critical Flow Prover, 4-in. pipe	Choke Nipple
1/16	0.063	1.524		
3/32	0.094	3.355		
1/8	0.125	6.301	—	6.25
3/16	0.188	14.47	—	14.44
7/32	0.218	19.97		
1/4	0.250	25.86	24.92	26.51
5/16	0.313	39.77	—	43.64
3/8	0.375	56.58	56.01	61.21
7/16	0.438	81.09	—	85.13
1/2	0.500	101.8	100.2	112.72
5/8	0.625	154.0	156.1	179.74
3/4	0.750	224.9	223.7	260.99
7/8	0.875	309.3	304.2	
1	1.000	406.7	396.3	
1 1/8	1.125	520.8	499.2	
1 1/4	1.250	657.5	616.4	
1 3/8	1.375	807.8	742.1	
1 1/2	1.500	1,002.0	884.3	
1 3/4	1.750	—	1,208	
2	2.000	—	1,596	
2 1/4	2.250	—	2,046	
2 1/2	2.500	—	2,566	
2 3/4	2.750	—	3,177	
3	3.000	—	3,904	

From: Lee, W.J. and Wattenbarger, R.A.: *Gas Reservoir Engineering*, SPE (1996).

Choke Nipples



Choke Nipple:

- **Can be used to control gas flowrates.**
- **Also requires critical flow criteria to be met.**
- **Same flowrate relation as Critical Flow Prover, just different coefficients.**

$$q_{gh} = C\, p_f \,/\, \sqrt{\gamma_g T_f}$$

Where:

- C = Coefficient (LW Table 3.10 (choke nipple)).
- p_f = Flowing pressure (upstream), psia.
- γ_g = Gas specific gravity (air = 1.0)
- T_f = Flowing Temperature, Deg R.
- q_{gh} = Gas Rate (14.4 psia and 60 Deg F), scf/hr.

TABLE 3.10—COEFFICIENTS FOR CRITICAL FLOW PROVER AND CHOKE NIPPLE (AFTER REF. 1)

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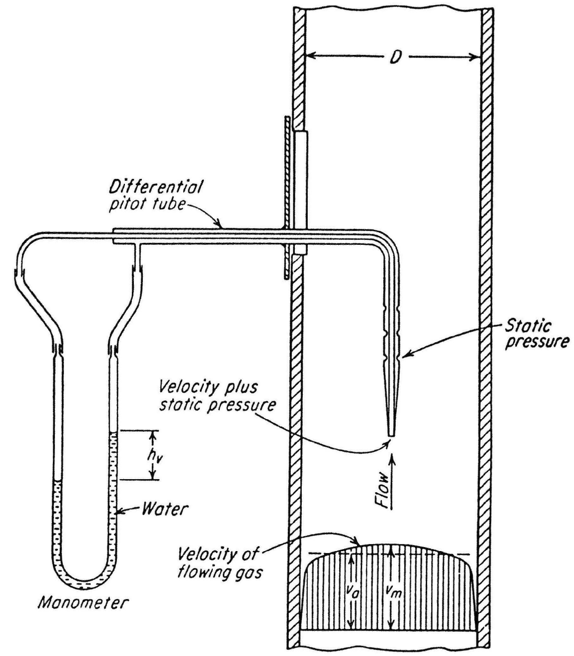
Pitot Tube

Pitot Tube:

- Estimates gas flowrate from velocity.
- Not commonly used in industry.
- Primarily used in the laboratory.
- Pressure at tip of tube is the "impact pressure."



$$q_{gh} = 291.67\, d^2\, F_g F_{Tf} \sqrt{h_w p_{imp}}$$

Where:

d = Diameter of external housing of pitot tube.
F_g = Specific gravity factor $(1/\gamma_g)^{1/2}$
F_{Tf} = Flowing temperature factor $(520/T_f)^{1/2}$
q_{gh} = Gas Rate (14.4 psia and 60 Deg F), scf/hr.
h_w = Pressure differential across orifice, in. of water
p_{imp} = Impact pressure on pitot tube, psia.

From: Lee, W.J. and Wattenbarger, R.A.: *Gas Reservoir Engineering*, SPE (1996).