3.0 The V-Cone Flow Measurement System

3.1 Application Data

The customer must provide application parameters so that the appropriate V-Cone flowmeter may be selected. McCrometer has an extensive meter performance database of fluid properties which can be utilized for sizing purposes.

3.2 Flow Calculations

Nomenclature

Symbol	Description	English Units	Metric Units
α	Material Thermal Expansion α or α_{cone}, α_{pipe} (alpha)	$^{\circ}R^{-1}$	$^{\circ}R^{-1}$
β	Beta Ratio	-	-
C_D	Flowmeter Coefficient	-	-
d	Cone Outside Diameter	in	mm
D	Pipe Inside Diameter	in	mm
ΔP	Differential Pressure (DP)	inWC	mbar
ΔP_{max}	Maximum Differential Pressure on Sizing	See note 4	See note 4
F_a	Material Thermal Expansion Factor	-	-
k	Gas Isentropic Exponent	-	-
k_1	Flow Constant	$\sqrt{\frac{lbm \cdot ft^3}{s^2 \cdot inWC}}$	$\sqrt{\frac{kg \cdot m^3}{s^2 \cdot mbar}}$
k_2	Simplified Liquid Flow Constant	See note 4	See note 4
μ	Viscosity	cP	cP
P	Operating Pressure	psiA	barA
P_b	Base Pressure	psiA	barA
Q	Actual Volume Flow	ACFS	m^3/s
Q_{max}	Maximum Flowrate on Sizing	See note 4	See note 4
Q_{STD}	Standard Gas Volume Flow	SCFS	Nm^3/s
Re	Reynolds Number	-	-
ρ	Flowing Density (rho)	lbm/ft^3	kg/m^3
ρ_{water}	Water Density	62.3663 lbm/ft^3	999.012 kg/m^3
S_g	Specific Gravity of the Gas	-	-
S_L	Specific Gravity of the Liquid	-	-
T	Operating Temperature	°R	K
T_b	Base Temperature	°R	K
T_d	Deviation from Standard Temperature (°R)	$T_d = T - 527.67$	$T_d = T - 527.67$
U_1	Unit Conversion	0.0360912 psiA/inWC	0.001 barA/mbar
U_2	Unit Conversion	144 in^2/ft^2	1,000,000 mm^2/m^2
U_3	Unit Conversion	167.213 lbm /s^2 ft inWC	100 kg/m s^2 mbar
U_4	Unit Conversion	124.0137 cP ft s / lbm	1
U_5	Unit Conversion	2.6988 °R lbm / ft^3 psiA	348.338 K kg / m^3 barA
v	Velocity	ft/s	m/s
Y	Gas Expansion Factor	-	-
Z	Gas Compressibility	-	-
Z_b	Base Gas Compressibility	-	-

General Flow Calculations (continued)

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3.2.1	V-Cone Beta Ratio	$\beta = \sqrt{1 - \frac{d^2}{D^2}}$	β from sizing report
3.2.2	Flow Constant	$k_1 = \frac{\pi \cdot \sqrt{2 \cdot U_3}}{4 \cdot U_2} \cdot \frac{D^2 \cdot \beta^2}{\sqrt{1-\beta^4}}$	
3.2.3	Material Thermal Expansion Factor	$F_a = 1 + 2 \cdot \alpha \cdot T_d$	See note 1
3.2.4	Material Thermal Expansion Factor if cone and main pipe are made of different materials	$F_a = \frac{D^2 - d^2}{[(1-\alpha_{pipe} \cdot T_d) \cdot D]^2 - [(1-\alpha_{cone} \cdot T_d) \cdot d]^2}$	See note 1
3.2.5	Pipeline Velocity	$v = \frac{4 \cdot U_2 \cdot Q}{\pi \cdot D^2}$	
3.2.6	Reynolds Number	$\mathrm{Re} = U_4 \frac{v \cdot D \cdot \rho}{\mu}$	Dimensionless number which can be used to correlate meter calibration in different fluids
3.2.7	V-Cone Gas Expansion Factor	$Y = 1 - (0.649 + 0.696 \cdot \beta^4) \frac{U_1 \cdot \Delta P}{k \cdot P}$	For Liquids Y = 1
3.2.8	Wafer Gas Expansion Factor	$Y = 1 - (0.755 + 6.78 \cdot \beta^8) \frac{U_1 \cdot \Delta P}{k \cdot P}$	For Liquids Y = 1
3.2.9	Liquid Density	$\rho = \rho_{água} \cdot S_L$	
3.2.10	Gas Density	$\rho = U_5 \frac{S_g \cdot P}{Z \cdot T}$	
3.2.11	Actual Volume Flowrate	$Q = F_a \cdot C_D \cdot Y \cdot k_1 \cdot \sqrt{\frac{\Delta P}{\rho}}$	See notes 2, 3 & 5
3.2.12	Standard Gas Volume Flowrate	$Q_{STD} = Q \cdot \left(\frac{P \cdot T_b \cdot Z_b}{P_b \cdot T \cdot Z} \right)$	Converts actual flow to standard flow at base conditions

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3.3 Simplified Liquid Calculation

3.3.1	Simplified Liquid Flow Constant	$k_2 = \frac{Q_{\max}}{\sqrt{\Delta P_{\max}}}$	See note 4
3.3.2	Simplified Liquid Flowrate	$Q = k_2 \sqrt{\Delta P}$	See note 4

Notes:

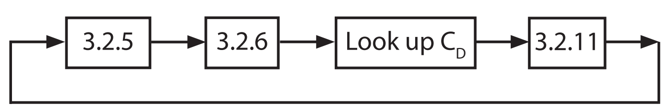
1. Material Thermal Expansion – The thermal expansion equations correct for dimensional changes which occur as the operating temperature deviates from the base temperature of 68° F (see 3.2.3 and 3.2.4) The F_a factor can be excluded from the flow equation if the operating temperature is:

   < 100° Fahrenheit , < 559.67° Rankine , < 37.78° Celsius, < 310.93 K.

   If the F_a factor is significant and the operating temperature is stable then a constant F_a value can be used. If the F_a factor is significant and the temperature varies then an F_a factor should be calculated prior to every flow calculation.

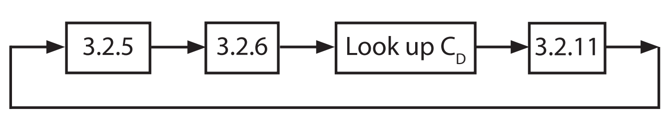
2. Discharge Coefficient – Discharge coefficients can be implemented in the flow equations via several different methods. Typical methods are average C_D , C_D look up table, or C_D fitted data. If a C_D look up table or fitted data is utilized additional calculations must be made based on the Reynolds number (see example process 3d and 5b).

3. Liquid – Typical Calculation Process
   a. Given: D, β, ρ, C_D, and input of ΔP
      Calculate: 3.2.2, 3.2.11
   b. Given: D, β, ρ, C_D, and input of ΔP, T
      Calculate: 3.2.2, 3.2.3 or 3.2.4 if req., 3.2.11
   c. Given: D, β, S_l, C_D, and input of ΔP, T
      Calculate: 3.2.2, 3.2.3 or 3.2.4 if req., 3.2.9, 3.2.11
   d. Given: D, β, μ, ρ, C_D look up, and input of ΔP
      Calculate: initially set C_D = 0.8, 3.2.2, 3.2.3 or 3.2.4 if req., 3.2.11



Iterate until flowrate is <0.01% different from last calculation

4. Simplified Liquid Calculation – The simplified liquid calculation can be used if the operating temperature is stable and the C_D is constant. The simplified flow constant (k_2) can be calculated from equation 3.3.1 using the V-Cone Application Sizing sheet. The flowrate can then be calculated using equation 3.3.2. Units of measure will be the same as those listed on the V-Cone Application Sizing sheet.
5. Gases and steam – Typical Calculation Process:
   a. Given: D, β, μ, S_g, Z, k, C_D, and inputs of ΔP, P, T
      Calculate: 3.2.2, 3.2.3 or 3.2.4 if req., 3.2.7 or 3.2.8, 3.2.10, 3.2.11
   b. Given: D, β, μ, S_g, Z, k, C_D look up, and inputs of ΔP, P, T
      Calculate: initially set C_D=0.8, 3.2.2, 3.2.3 or 3.2.4 if req., 3.2.7 or 3.2.8, 3.2.10, 3.2.11



Iterate until flowrate is <0.01% different from last calculation

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