CRANE

FLOW OF FLUIDS
AN ENGINEERED SOFTWARE BUSINESS

ERRATA
CRANE FLOW OF FLUIDS
THROUGH VALVES, FITTINGS AND PIPE
TECHNICAL PAPER NO. 410
METRIC VERSION

CONTACT

Please address questions and possible errata to solutions@flowoffluids.com

FRONT MATTER	CORRECTION PRINTED
PAGE VI F_k should be F_γ "...individual gas constant...(J/kg·k)" should be "...(J/kg·K)" "...universal gas constant...(J/kg·k)" should be "...(J/k mol·K)"	 08/2011 10/2010 10/2010
TEXT	
PAGE 1-7 Fig. 1-7 key should be: "5% Reduction of Pipe ID (ε=0.046mm, ID=97.2mm)	11/2012
PAGE 1-8 k is used in 6 places on this page for the specific heat ratio, k should be replace with γ Eq. 1-25 $c = \sqrt{kRT}$ should be $c = \sqrt{\gamma RT}$	11/2012
PAGE 2-5 Steam Flow Tests - Curves 19 to 31, Key – Curve No. 26 is repeated, the first should be 25	11/2012
PAGE 2-7 "...sum of the inverses of the individual resistance of each component:" should be "...sum of the square roots of the inverse of the individual..." Eq. 2-6 $\frac{1}{K_{Total}} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + \cdots \frac{1}{K_n}$ should be $\frac{1}{\sqrt{K_{Total}}} = \frac{1}{\sqrt{K_1}} + \frac{1}{\sqrt{K_2}} + \frac{1}{\sqrt{K_3}} + \cdots \frac{1}{\sqrt{K_n}}$	08/2011 08/2011

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PAGE 2-8

Fig. 2-9, left side Scale - Valve or fitting size in millimetres:
Should have the labels "Schedule 80" on the left and "Schedule 40" on the right.
"Schedule 40" at the extreme right hand side of the figure should be removed

11/2012

PAGE 2-11

Eq. 2-16 $K_1 = 0.5\left(1 - \frac{d_1^2}{d_2^2}\right)^2$ should be $K_1 = 0.5\left(1 - \frac{d_1^2}{d_2^2}\right)$ — 10/2010

Eq. 2-18 $K_1 = 0.5(1 - \beta^2)^2$ should be $K_1 = 0.5(1 - \beta^2)$ — 10/2010

Eq. 2-27 $K_2 = \frac{0.5\sqrt{\sin\frac{\theta}{2}}(1-\beta^2)^2}{\beta^4}$ should be $K_2 = \frac{0.5\sqrt{\sin\frac{\theta}{2}}(1-\beta^2)}{\beta^4}$ — 10/2010

PAGE 2-13

"...expansion bend up of continuous 90 degree..." should be "...bend made up of..."

10/2010

PAGE 2-15

Column for values of G added to table 2-3:

10/2010

Table 2-3: Constants for K_{branch} in Equation 2-37

Angle (α)	G	H	J
0-60°	Table 2-4	1	2
$\alpha = 90° \text{ at } \beta_{branch} \le \frac{2}{3}$	1	1	2
$\alpha = 90° \text{ at } \beta_{branch} = 1$ *	$G = 1 + 0.3\left(\frac{Q_{branch}}{Q_{comb}}\right)^2$	0.3	0

Replace Tables 2-2 and 2-4:

08/2011

Table 2-2: Values of C for Equation 2-35

		Q_{branch} / Q_{comb} ≤ 0.4	Q_{branch} / Q_{comb} > 0.4
β^2_{branch}	≤ 0.35	$C = 1$	
β^2_{branch}	> 0.35	$C = 0.9\left(1 - \frac{Q_{branch}}{Q_{comb}}\right)$	$C = 0.55$

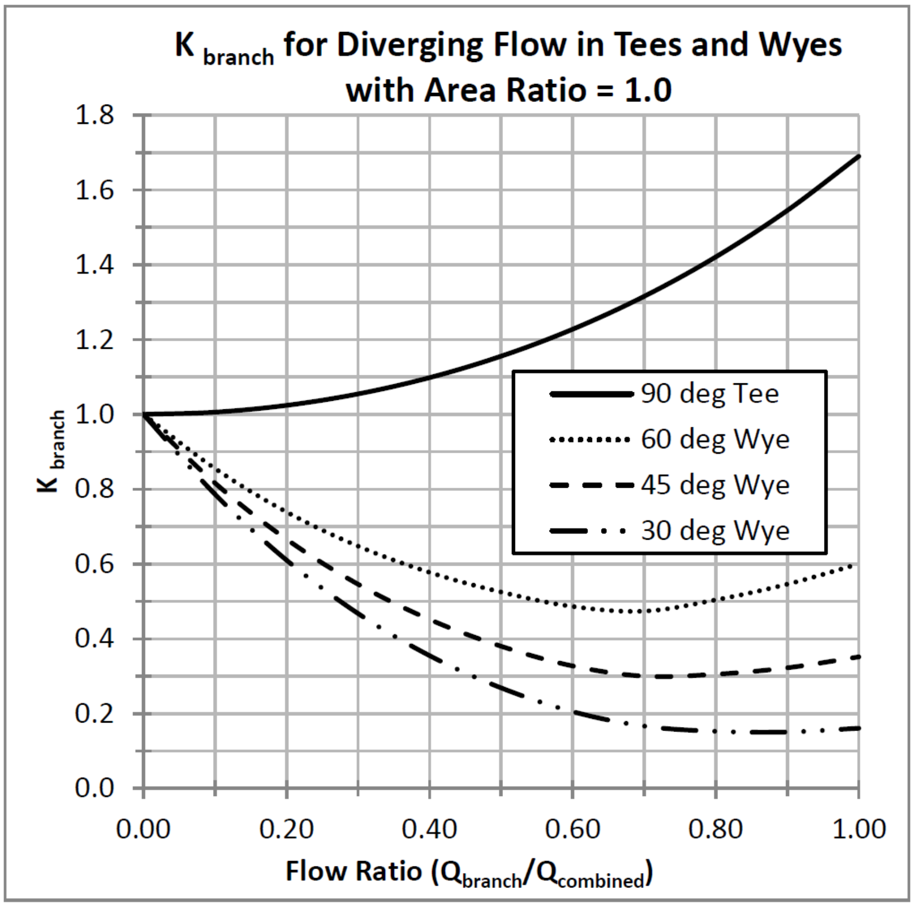
Table 2-4: Values of G for Equation 2-37

β^2_{branch}	Q_{branch}/Q_{comb}	G	Q_{branch}/Q_{comb}	G
≤ 0.35	≤ 0.4	$G = 1.1 - 0.7\frac{Q_{branch}}{Q_{comb}}$	> 0.4	$G = 0.85$
> 0.35	≤ 0.6	$G = 1.0 - 0.6\frac{Q_{branch}}{Q_{comb}}$	> 0.6	$G = 0.6$

08/2011

PAGE 2-16

New Figure 2-16:



08/2011

PAGE 3-4

Eq. 3-4 should be: $F_P = \frac{1}{\sqrt{1+\frac{\sum K}{0.0016}\left(\frac{K_V}{d^2_{nom,v}}\right)^2}}$

11/2012

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The definition should be: $K_{B1} = 1 - \left(\frac{d_{nom,v}}{d_{nom1}}\right)^4$	11/2012
The definition should be: $K_{B2} = 1 - \left(\frac{d_{nom,v}}{d_{nom2}}\right)^4$	11/2012
The definition should be: "$d_{nom,v}$ = nominal valve size (mm)"	11/2012
The definition should be: "d_{nom} = nominal pipe size (mm) (1=upstream, 2=downstream)"	11/2012
Eq. 3-5 should be: $K_{reducer}^{inlet} = 0.5\left[1 - \left(\frac{d_{nom,v}}{d_{nom1}}\right)^2\right]^2$	11/2012
Eq. 3-6 should be: $K_{reducer}^{outlet} = 1.0\left[1 - \left(\frac{d_{nom,v}}{d_{nom2}}\right)^2\right]^2$	11/2012
Eq. 3-7 should be: $\sum K = 1.5\left[1 - \left(\frac{d_{nom,v}}{d_{nom}}\right)^2\right]^2$	11/2012
Eq. 3-10 should be: $F_{LP} = \frac{F_L}{\sqrt{1 + F_L^2 \frac{\sum K_i}{0.0016}\left(\frac{K_V}{d_{nom,v}^2}\right)^2}}$	11/2012
Footnote added: "*For use only with control valves per ANSI/ISA 75.01.01, for reducers in pipelines see page 2-11"	10/2010
PAGE 3-5	
Eq. 3-13 should be $Y = 1 - \frac{x}{3F_\gamma x_T}$	08/2011
Definition of x should read: "x = pressure drop ratio = $\Delta P/P'_1$"	04/2010
F_k should be F_γ	08/2011
Eq. 3-14 should be $x_{TP} = \frac{x_T/F_P^2}{1 + x_T \frac{\sum K_i}{0.0018}\left(\frac{K_V}{d_{nom,v}^2}\right)^2}$	11/2012
The definition should be: "$d_{nom,v}$ = assumed nominal valve size (mm)"	11/2012
PAGE 4-5	
Eq. 4-7b $J = \left(\frac{19000\beta}{Re}\right)$ should read: $J = \left(\frac{19000\beta}{Re}\right)^{0.8}$	08/2011
PAGE 4-6	
"The data is also plotted on page A-21 of this reference" should be "…page A-22"	04/2010
"Equation 4-16 may be used for orifices…" should be "…Equation 4-14"	04/2010
"1. The specific heat ratio, k." should be "1. The specific heat ratio, γ."	08/2011

Eq. 4-15 should be: — 08/2011

$$Y = 1 - (0.351 + 0.256\beta^4 + 0.93\beta^8)\left[1 - \left(\frac{P'_2}{P'_1}\right)^{\frac{1}{\gamma}}\right]$$

Eq. 4-16 should be: — 08/2011

$$Y = \left\{\left[\frac{\gamma\left(\frac{P'_2}{P'_1}\right)^{\frac{2}{\gamma}}}{\gamma - 1}\right]\left[\frac{1-\beta^4}{1-\beta^4\left(\frac{P'_2}{P'_1}\right)^{\frac{2}{\gamma}}}\right]\left[\frac{1-\left(\frac{P'_2}{P'_1}\right)^{\frac{\gamma-1}{\gamma}}}{1-\left(\frac{P'_2}{P'_1}\right)}\right]\right\}^{0.5}$$

The paragraph beginning "The expansibility factor has been experimentally determined…" should have the following added at the end: "For the purposes of accurate metering, the expansibility factor equations should be limited to conditions when the pressure ratio is greater than 0.80 ($P'_2/P'_1 \geq 0.80$) per the ASME standard. There are some critical flow applications discussed in the next section where stringent metering accuracy is not a requirement, and therefore the charts on page A-22 reflect a greater range of pressure ratios." — 08/2011

The paragraph beginning "Values of k for some …" shall have the terms "k" replaced with the terms "γ". — 08/2011

The paragraph beginning "The critical pressure ratio is the largest ratio…" shall be rewritten as follows: "The critical pressure ratio r_c is the largest ratio of downstream pressure to upstream pressure capable of producing sonic velocity. Values of critical pressure ratio which are a function of the ratio of nozzle diameter to upstream diameter as well as the specific heat ratio γ are plotted on page A-22, and are derived from the following relationship[46]:" — 08/2011

Add Eq. 4-17: — 08/2011

$$r_c^{\frac{1-\gamma}{\gamma}} + \left(\frac{\gamma - 1}{2}\right)\beta^4 r_c^{\frac{2}{\gamma}} = \frac{\gamma + 1}{2}$$

The paragraph beginning "Flow through nozzles and venturi meters…" shall be rewritten as follows: "Flow through nozzles and venturi meters is limited by the critical pressure ratio. Other applications which require the determination of a mass flow rate under critical conditions include equipment ruptures and pressure relief valves. In these cases, the stringent accuracy of metering applications is not required, and therefore the expansibility factors can be taken at pressure ratios below 0.80. Minimum values of Y to be used in Equation 4-14 for this condition, are indicated on the plots on page A-22 by the termination of the curves at $P'_2/P'_1 = r_c$." — 08/2011

PAGE 6-2

Viscosity Conversion should be $\nu = \dfrac{\mu}{\rho'} = \dfrac{\mu}{S_{4°C}} = \dfrac{1000\mu}{\rho}$ — 08/2011

PAGE 6-3 Eq. 6-9 should be: $\Delta P_{per\ metre} = 6.05 \times 10^{10} \frac{Q^{1.85}}{C^{1.85} d^{4.87}}$ $\Delta P = 6.05 \times 10^{10} \frac{LQ^{1.85}}{C^{1.85} d^{4.87}}$ $h_L = \frac{\Delta P}{\rho g} = 6.177 \times 10^{6} \frac{LQ^{1.85}}{C^{1.85} d^{4.87}}$	08/2011 08/2011 08/2011
PAGE 6-4 Eq. 6-17 $v_S = c = \sqrt{kRT}$ should be $v_S = c = \sqrt{\gamma RT}$ $v_S = c = \sqrt{kP'\bar{V}}$ should be $v_S = c = \sqrt{\gamma P'\bar{V}}$	11/2012 11/2012
PAGE 6-5 Eq. 6-25 $\frac{1}{K_{Total}} = \frac{1}{K_1} + \frac{1}{K_2} + \frac{1}{K_3} + \cdots \frac{1}{K_n}$ should be $\frac{1}{\sqrt{K_{Total}}} = \frac{1}{\sqrt{K_1}} + \frac{1}{\sqrt{K_2}} + \frac{1}{\sqrt{K_3}} + \cdots \frac{1}{\sqrt{K_n}}$ Eq. 6-32 $q = YCA\sqrt{2gh_L} = YCA\sqrt{\frac{2g\Delta P}{\rho}}$ should be $q = YCA\sqrt{2gh_L} = YCA\sqrt{\frac{2\Delta P}{\rho}}$	08/2011 08/2011
PAGE 6-6 Eq. 6-34 should be: $F_P = \frac{1}{\sqrt{1+\frac{\sum K}{0.0016}\left(\frac{K_V}{d^2_{nom,v}}\right)^2}}$ $K_B = 1 - \left(\frac{d_{nom,v}}{d_{nom}}\right)^4$ Eq. 6-35 should be: $K^{inlet}_{reducer} = 0.5\left[1 - \left(\frac{d_{nom,v}}{d_{nom1}}\right)^2\right]^2$ $K^{outlet}_{reducer} = 1.0\left[1 - \left(\frac{d_{nom,v}}{d_{nom2}}\right)^2\right]^2$ Eq. 6-36 should be: $\sum K = 1.5\left[1 - \left(\frac{d_{nom,v}}{d_{nom}}\right)^2\right]^2$ Eq. 6-37 should be: $F_{LP} = \frac{F_L}{\sqrt{1+F_L^2\frac{\sum K_i}{0.0016}\left(\frac{K_V}{d^2_{nom,v}}\right)^2}}$ Eq. 6-38 should be corrected as follows: $Y = 1 - \frac{x}{3F_\gamma x_T}$ *without fittings*	11/2012 11/2012 11/2012 11/2012 11/2012 11/2012 08/2011

$Y = 1 - \frac{x}{3F_\gamma x_{TP}}$ *with fittings*	08/2011
$x_{TP} = \frac{x_T/F_p^2}{\sqrt{1+x_T\frac{\sum K_i}{0.0018}\left(\frac{K_V}{d_{nom,v}^2}\right)^2}}$	11/2012
$F_\gamma = \frac{\gamma}{1.4} = \frac{c_p/c_v}{1.4}$	08/2011
Eq. 6-39 should be corrected as follows:	
$x \geq F_\gamma x_T$ *without fittings*	08/2011
$x \geq F_\gamma x_{TP}$ *with fittings*	08/2011
PAGE 7-2 Ex. 7-3 "for graphical solutions of steps 5 through 7, use pages A-31 & A-32" should be removed Ex. 7-3 5. Should be $C_V = 29.84 \frac{3.826^2}{\sqrt{2.475}} = 277.7$	08/2011
PAGE 7-6 Ex. 7-10 "…as described in Example 6-4…" should be "…Example 7-4…"	10/2010
PAGE 7-7 Ex. 7-12 7. $K_{orifice} = \left[\frac{\sqrt{1-\beta^4(1-C_d^2)}}{C_d\beta^4} - 1\right]^2$ should be $K_{orifice} = \left[\frac{\sqrt{1-\beta^4(1-C_d^2)}}{C_d\beta^2} - 1\right]^2$	10/2010
PAGE 7-8 Ex. 7-14 Should be: "Find: The velocity in both the 100 and 125 mm pipe sizes…"	11/2012
PAGE 7-9 Ex. 7-15, Schematic - Should be: "65mm Globe Lift Check Valve with…" 7. Should be: "For 150 metres of 80 mm Schedule 40 pipe,"	11/2012 11/2012
PAGE 7-10 Ex. 7-17 1. should be: $t = {}^9/_5\, t_c + 32$ 2. should be: $t = \left({}^9/_5 \times 15.6\right) + 32 = 60°\text{F}$	08/2011 08/2011

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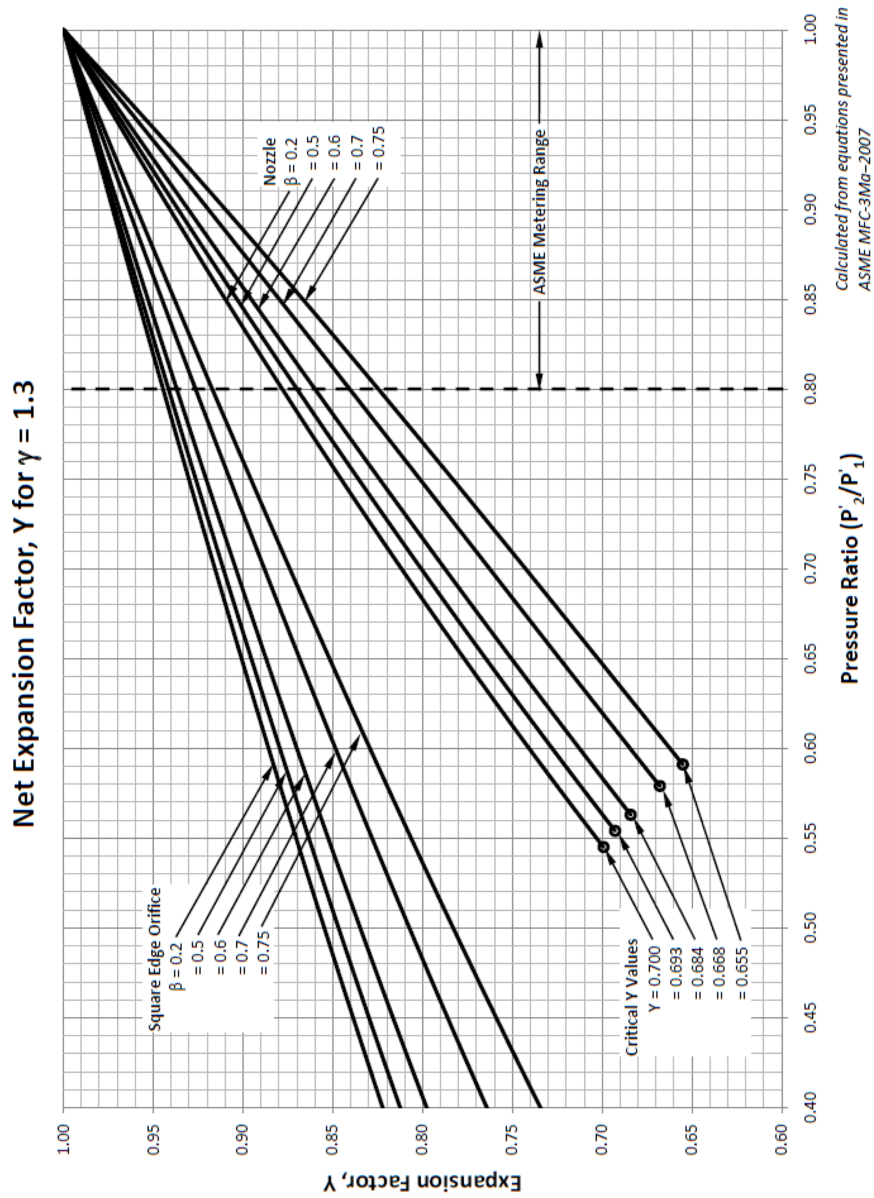
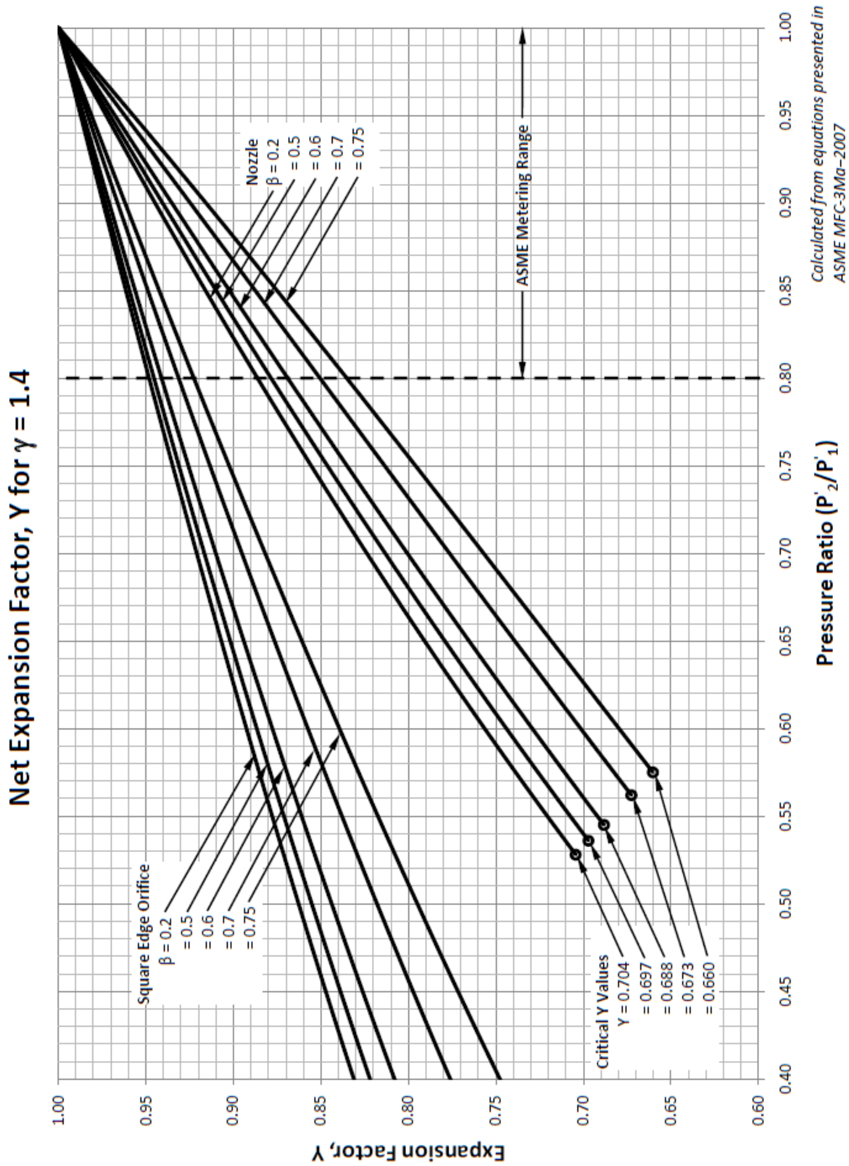
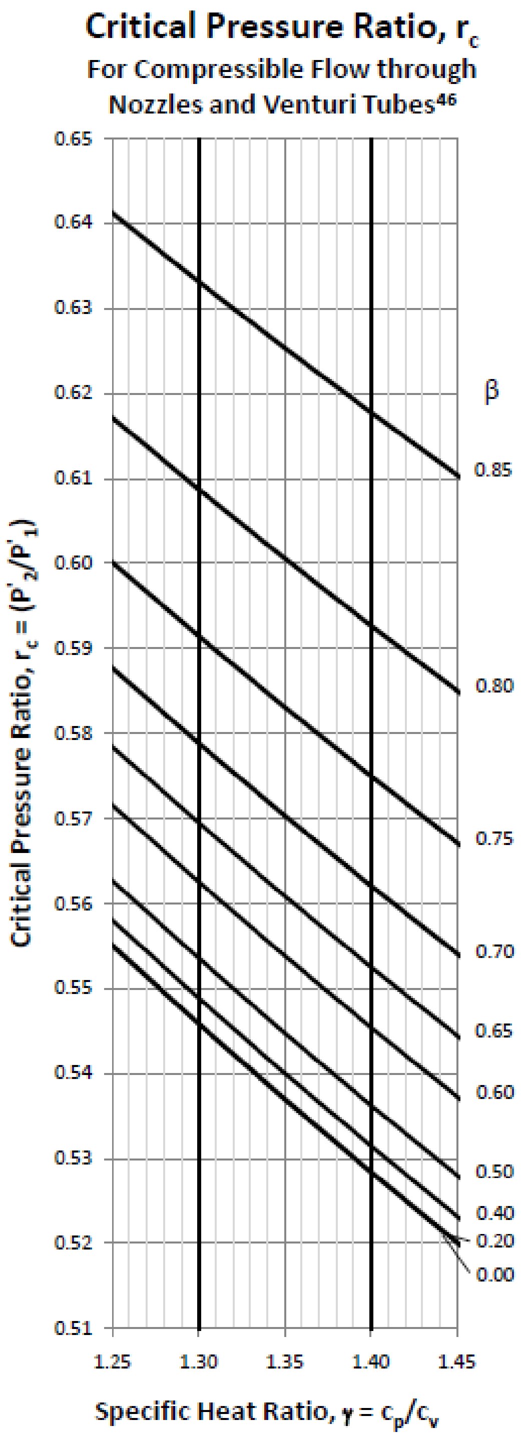
PAGE 7-16 Ex. 7-25 Should be: "Find: The discharge rate in cubic metres per second…"	11/2012
PAGE 7-17 Ex. 7-26 23. "f = 0.0155" should reference page A-25 rather than A-24 24. Should be "…flow rate will be 89400 litres/min."	10/2010 11/2012
PAGE 7-18 Ex. 7-27 5. should be: $\sum K = 1.5\left[1-\left(\frac{d_{nom,v}}{d_{nom}}\right)^2\right]^2 = 1.5\left[1-\left(\frac{80}{100}\right)^2\right]^2 = 0.194$ $F_P = \frac{1}{\sqrt{1+\frac{\sum K}{0.0016}\left(\frac{K_V}{d_{nom,v}^2}\right)^2}} = \frac{1}{\sqrt{1+\frac{0.194}{0.0016}\left(\frac{98}{80^2}\right)^2}} = 0.986$ …effective Kv of (98)(0.986)=96.6	11/2012
6. should be: $F_P = \frac{1}{\sqrt{1+\frac{0.194}{0.0016}\left(\frac{72.8}{80^2}\right)^2}} = 0.992$	11/2012
7. should be: $K_V = \frac{q_h}{F_P\sqrt{\frac{p_1'-p_2'}{S}}} = \frac{57}{0.992\sqrt{\frac{5.54-4.94}{0.979}}} = 73.40$	11/2012
8. "will be throttled to a Kv = 73.47" should be "C_v =73.40"	11/2012
PAGE 7-19 Ex. 7-28 2. Should be: $\sum K_i = 0.5\left[1-\left(\frac{d_{nom,v}}{d_{nom1}}\right)^2\right]^2 + \left[1-\left(\frac{d_{nom,v}}{d_{nom1}}\right)^4\right]$ $\sum K_i = 0.5\left[1-\left(\frac{80}{100}\right)^2\right]^2 + \left[1-\left(\frac{80}{100}\right)^4\right]$ $\sum K_i = 0.0648 + 0.5904 = 0.6552$	11/2012
3. Should be: $F_{LP} = \frac{F_L}{\sqrt{1+F_L^2\frac{\sum K_i}{0.0016}\left(\frac{K_V}{d_{nom,v}^2}\right)^2}}$ $F_{LP} = \frac{0.9}{\sqrt{1+0.9^2\left(\frac{0.6552}{0.0016}\right)\left(\frac{73.40}{80^2}\right)^2}} = 0.8810$	11/2012
4. Should be: $q_{h\,max} = \left(\frac{0.8810}{0.992}\right)(73.40)\sqrt{\frac{5.54-(0.9495\times0.312)}{0.979}}$ $q_{h\,max} = 150.9\ m^3/hr$	11/2012
5. should be: $\Delta p_{max} = \left(\frac{0.8810}{0.992}\right)[5.54-(0.9495\times0.312)]$	11/2012

$\Delta p_{max} = 4.14\ bar$	
PAGE 7-20 Ex. 7-29 Should be: "Find: The flow rate in litres per minute"	11/2012
PAGE 7-21 Ex. 7-31 1. Should be $NRPD = \Delta P \left[\frac{\sqrt{1-\beta^4(1-C_d{}^2)}-C_d\beta^2}{\sqrt{1-\beta^4(1-C_d{}^2)}+C_d\beta^2} \right]$ 5. Should be $NRPD = 1.732 \left[\frac{\sqrt{1-0.395^4(1-0.982^2)}-0.982\times0.395^2}{\sqrt{1-0.395^4(1-0.982^2)}+0.982\times0.395^2} \right] = 1.272\ psi$	08/2011 08/2011
PAGE 7-23 Ex. 7-34 Should be: "Find: The...and average power cost of €0.08/kWh"	11/2012
APPENDICES	
PAGE A-19 Total Temp headings: 160, 180, 200, 220, 250, 300, 350, 400, 450, 550, 650 Should be: 340, 360, 380, 400, 420, 440, 460, 500, 550, 600, 650	04/10
PAGE A-21 Flow Coefficient C for Venturi Nozzles : Should be: "...equations presented in ASME MFC-3Ma-2007"	11/2012

PAGE A-22	
Page title should cite reference 27 and also 46	04/2010
Graphs should change to the following: 	10/2010


Net Expansion Factor, Y for γ = 1.4
Nozzle
β = 0.2
= 0.5
= 0.6
= 0.7
= 0.75
ASME Metering Range
Square Edge Orifice
β = 0.2
= 0.5
= 0.6
= 0.7
= 0.75
Critical Y Values
Y = 0.704
= 0.697
= 0.688
= 0.673
= 0.660
Expansion Factor, Y
Pressure Ratio (P'2/P'1)
Calculated from equations presented in ASME MFC-3Ma–2007
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40

10/2010

	08/2011
PAGE A-30 Under STANDARD TEES AND WYES delete "For Converging or Diverging Flow:"	04/2010

PAGE B-4 Equivalents of Kinematic and Saybolt Universal Viscosity Should be: "Note: To obtain the Saybolt Universal Viscosity equivalent…"	11/2012