

A large, white, cylindrical industrial storage tank is the central focus of the image. It is surrounded by a dense network of pipes, ladders, and walkways. The tank has several vertical pipes extending from its base. The background shows a clear blue sky with some light clouds. The overall scene is an industrial facility, likely a refinery or chemical plant.

**CHEMCAD 6.0 SIZING TOOLS
PIPES, PUMPS, METERS AND VALVES**

By John E. Edwards

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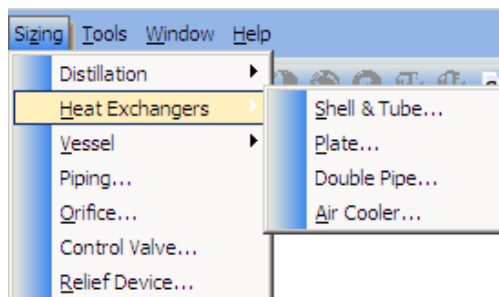
APPENDICES

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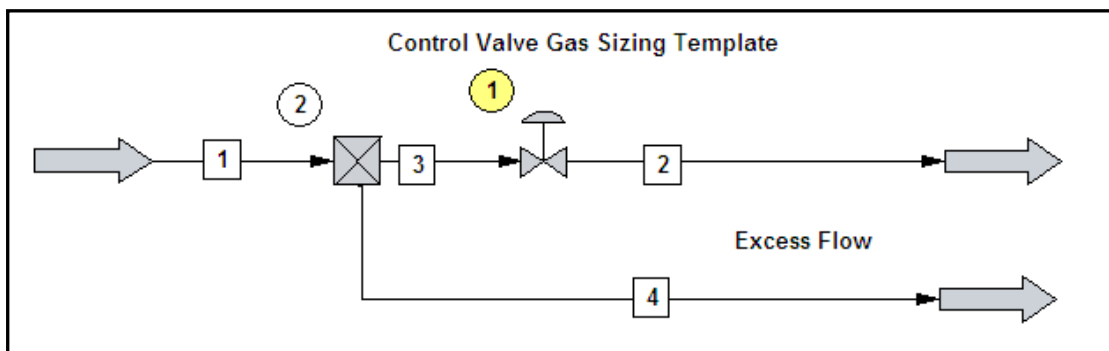
CHEMCAD 6.0 SIZING TOOLS - PIPES, PUMPS, METERS AND VALVES – INTRODUCTION

CHEMCAD simulation software provides tools for the sizing of most types of process plant and equipment. This training note reviews the shortcut and rigorous sizing facilities available for pipes, pumps, control valves, relief valves and orifice plates. Actual design cases are presented to demonstrate the power and flexibility of the software, which when used in conjunction with the Excel mapping tool, provides the designer with powerful facilities.

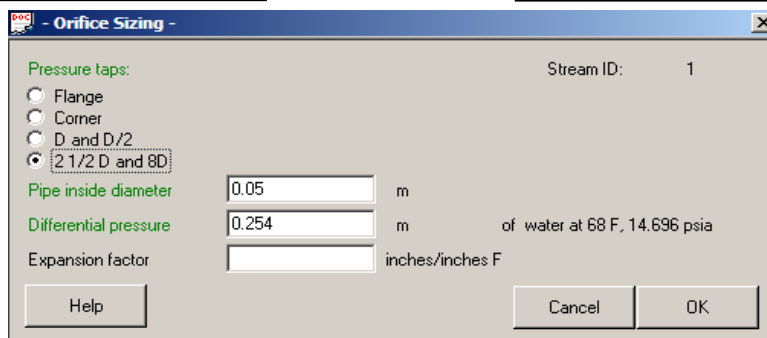
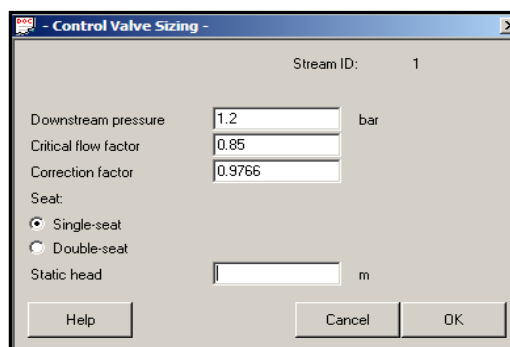
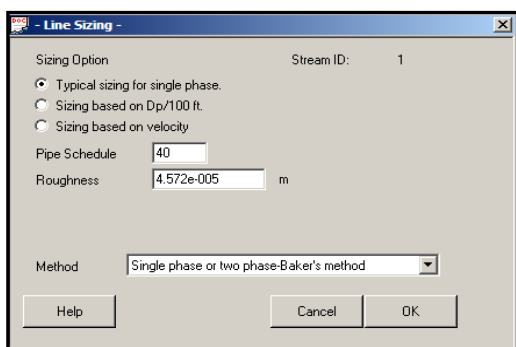
Short cut methods for Pipes, Control Valves and Orifice Plates are accessed from the main toolbar Sizing command as shown below:



The stream properties to be used for sizing are selected by a single mouse click on the stream in the model to be studied. In the example shown below Stream 1, as indicated by the black square markers, has been selected.



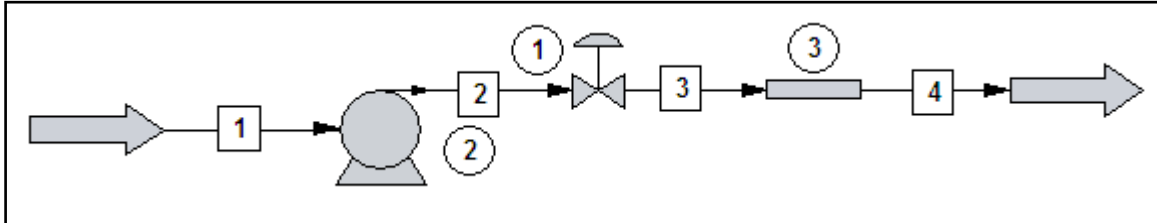
Selecting the sizing tool required will make available the relevant data input Window, as shown below, for Pipes, Control Valves and Orifice Plates:



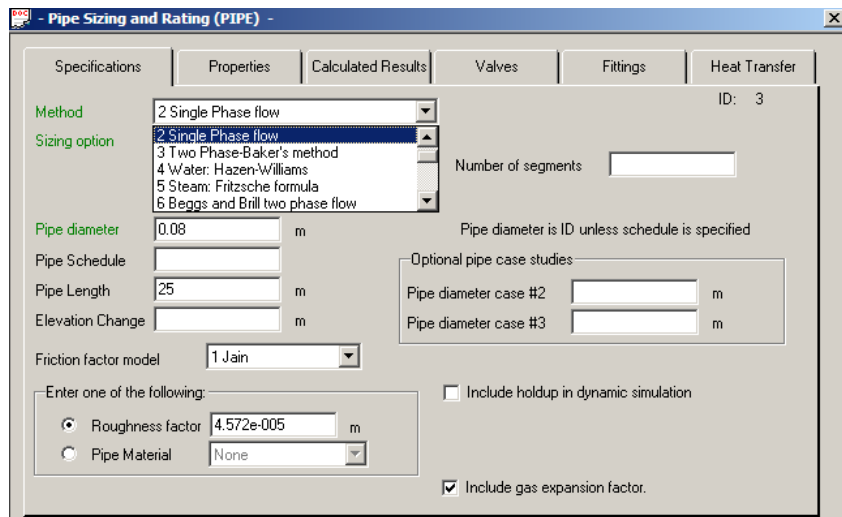
INTRODUCTION

After data entry, selecting the OK command will provide the calculation results in WordPad or Excel format. When this report is combined with the Stream properties WordPad report, obtained from “Results - Stream Properties - Select Streams”, a comprehensive report can be created by editing in Word. The shortcut methods are suitable for use in conceptual design to establish initial plant sizing and costing. For example, the short cut method for control valves only considers globe valves and the critical flow and reducer correction factors need to be calculated or determined from specific manufacturers’ data.

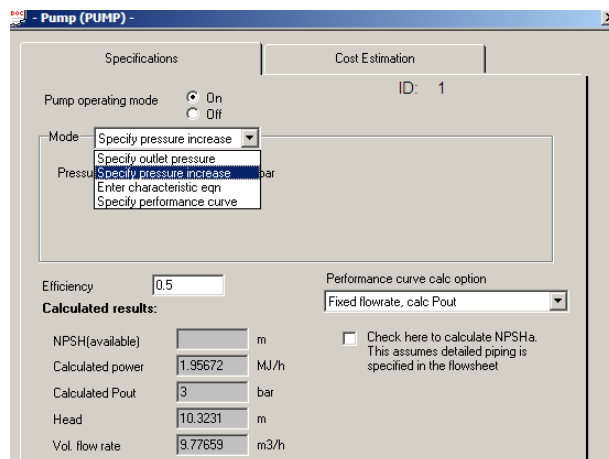
For detailed design and specification a more rigorous approach is required involving the use of additional CHEMCAD UnitOps and manufacturers’ sizing data. The flowsheet below shows the UnitOps for Pipes, Pumps and Control Valves which allow for a more thorough analysis.



The main Pipe UnitOp data entry Window is shown and allows for the selection of a comprehensive range of sizing methods, options and friction factors. The Churchill friction factor correlation is valid for the laminar, transition and turbulent flow regimes whereas Jain is suitable for Reynolds Numbers in the range 4.0 E03 to 1.0 E08. The static head is entered using the elevation change, where negative values are used for pipes going downwards in the direction of flow.



The Pump UnitOp data entry Window is shown and allows for the selection of a comprehensive range of operating modes, including multiple speed line performance curves allowing for the study of variable speed applications.



CHEMCAD 6.0 SIZING TOOLS – PIPE UNITOP VALIDATION CASE

PROCESS DESCRIPTION

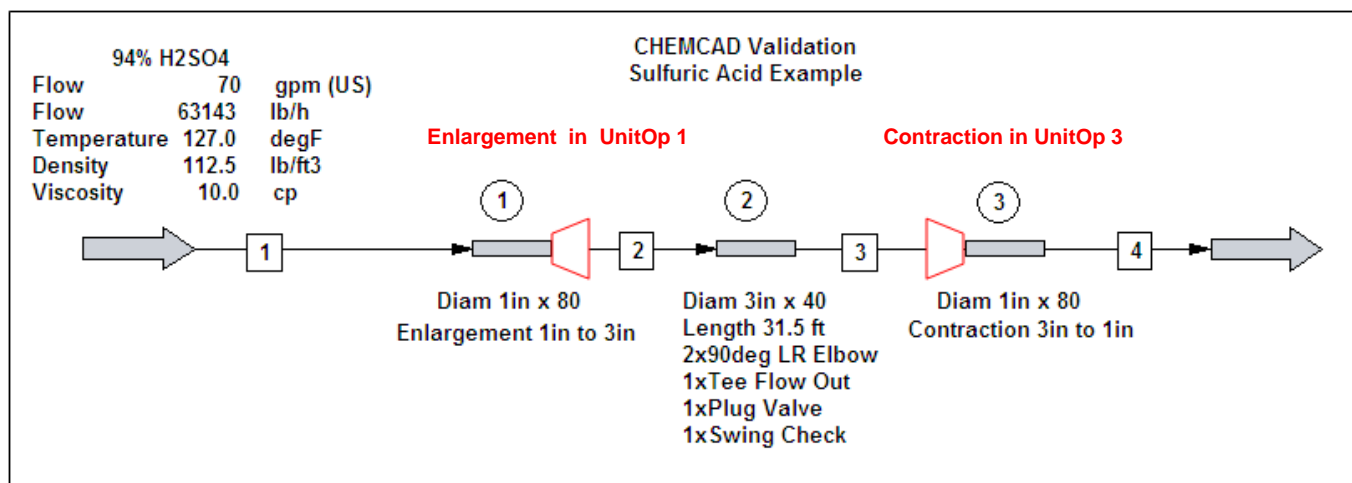
This validation case study has been based on the flow of 94% Sulphuric Acid through a 3 in x Schedule 40 carbon steel pipe. CHEMCAD results are validated against an example given in www.cheresources.com/eqlength.shtml . The process conditions are shown below:

Process Data	Units	Example Data	CHEMCAD
Mass Flow Rate	lb/h	63143	
Volumetric Flow rate	gpm (US)	70	70
Density	lb / ft ³	112.47	112.47 (Pipe Props)
Specific Gravity	dimensionless	1.802	
Viscosity	cps	10	10 (Pipe Props)
Temperature	°F	127	127
Pipe ID	in	3.068	3.068
Velocity	ft / s	3.04	3.036
Reynold's Number	dimensionless	12998	12998.9
Darcy Friction Factor	f (pipe)	0.02985	0.03000
Friction Factor at Turbulence	f _t	0.018	Not declared
Straight Pipe	ft	31.5	31.5

The pipe section has 2 x 90° elbows, 1 x flow-out branch Tee, 1 x swing check valve, 1 x plug valve, and 1 x 3 in to 1 in expansion. The contraction has been added to the model for testing purposes.

CHEMCAD MODEL

For practice you can build the model or use the model called "Sulfuric Acid" in the electronic media supplied. It is strongly recommended that you work with a copy of this job. The model flowsheet is shown that represents the piping layout .



MODEL CONFIGURATION

The key aspect of this problem is the handling of the enlargement and contraction. The fitting must be located in the 1 in pipe section with separate Pipe UnitOps 1 and 3 included to allow for this. Locating the enlargement and contraction in Pipe UnitOp 3 gives incorrect results. Refer to Appendix I for a detailed assessment of this theory.

The plug valve L/D has been entered as a user value as the CHEMCAD library value did not match the example data.

The Pipe Section data entry for the 3 in pipe is shown following.

The Churchill friction factor has been selected due to the application being in the transition flow region.

CHEMCAD library has been used for pipe roughness factor.

Friction factor model

Enter one of the following:

Roughness factor ft

Pipe Material

RESULTS

The fitting resistance coefficients used are shown in the table together with CHEMCAD derived L_{eq} values.

Fittings	L_{eq}/D	L_{eq}	L_{eq} (CHEMCAD)	$K = f_t (L/D)$	Quantity	Total L_{eq}
90° Long Radius Elbow	20	5.1	5.1	0.36	2	10.23
Tee Flow-out branch	60	15.3	14.8	1.08	1	15.34
Swing Check Valve	50	12.8	12.9	0.9	1	12.78
Plug Valve	18	4.6	4.6 ⁽¹⁾	0.324	1	4.6
3in x 1in Reducer	None	822.7	492.6 ⁽²⁾	57.92	1	822.7
Total						865.6

Notes

- (1) User value fitting coefficient entered into CHEMCAD
- (2) The value quoted is calculated using f_{pipe} , if f_t is used value is 821.6. Refer to control Excel worksheet for further details.

The spreadsheet studies the handling of the enlargement fitting by different methods. It can be seen that there is agreement between the different methods with the main issue being whether to use f_t or f_{pipe} to calculate L_{eq} .

Validation of CHEMCAD in handling pipe diameter changes.									
Example 96% Sulfuric Acid		CHEMCAD		Fittings 1 in x 80 by 3 in x 40 Enlargement				CHEMCAD	
Data		Results		Calculations using pipe conditions f				Results	
				Inlet Pipe				Inlet Pipe	
D1	0.0798 ft			K1	$2.6 \sin^2(\theta/2)(1-\beta^2)^2$	0.549			
L1	0.5 ft			Friction Loss (hf)1	$K1(v1^2/2g)$	8.30	ft fluid		
v1	31.21 ft/s	31.20	v1^2/2g	(hf)1(p/144)		6.48	psi		
f1		0.0270		Equivalent Length Method Inlet Pipe				Example Calculations using ft	
D2	0.2557 ft		D1/D2	L1/D1	K1/f1	20.304		K1/f1	30.48
L2	31.5 ft			(Leq)1	(L/D)1D1	1.62	ft	(L/D)1D1	2.43
v2	3.04 ft/s	3.038	v2^2/2g	Friction Loss (hf)1	(fLv^2/2gD)1	8.300	ft fluid	(fLv^2/2gD)1	12.32
Re No	12998	12998.9		(hf)1(p/144)		6.48	psi	(hf)1(p/144)	9.62
f2	0.02985	0.0300		Outlet Pipe					
ft	0.018			K2	$K1\beta^4$	57.84			
$\Delta P/100ft$	1.308 psi	1.32		Friction Loss (hf)2	$K2(v2^2/2g)$	8.28	ft fluid		
ρ	112.47 lb/ft3			(hf)2(p/144)		6.47	psi		
psi/100ft	1.307			Equivalent Length Method Outlet Pipe				Example Calculations using ft	
θ	30 deg			L2/D2	K2/f2	1926.29	K2/f2	3213.12	
d	3.0684 in			(Leq)2	(L/D)2D2	492.55	ft	(L/D)2D2	821.60
W	63143 lb/h			Friction Loss (hf)2	(fLv^2/2gD)2	8.25	ft fluid	(fLv^2/2gD)2	13.76
				(hf)2(p/144)		6.44	psi	(hf)2(p/144)	10.75
g	32.2 ft/s^2			Pressure Loss				Enlargement located in larger diameter pipe	
Formulae used for K1 and K2				Basis 1.32 psi/100ft		6.48	psi	Total Leq	38.4 ft
$h_L = \frac{v_1^2}{2g} (1 - \beta^4) - K_1 \frac{v_1^2}{2g}$				K value method		6.82	psi	Leq($\Delta p/100ft$)	0.505 psi
$h_L = \frac{K_1 v_1^2}{\beta^4 2g} - K_2 \frac{v_1^2}{2g}$								Calculated From psi/100ft	0.505 psi
Formula used for calculating $\Delta P/100ft$				Note consistency of results throughout on inlet and outlet using the Crane method with pipe f				Calculated (fLv^2/2gD)2	0.642 ft fluid
Set L=100				Also consistent results using $\Delta P/100ft$ method				Friction Loss (hf)2	0.501 psi
$\Delta P = 0.00000336 \frac{f L W^2}{\rho d^5}$				CHEMCAD calculates correctly only when enlargement or contraction is placed in smaller diameter pipe UnitOp					
				CHEMCAD calculates equivalent length of fittings using prevailing pipe friction factor and not ft					
Fittings 1 in x 80 by 3 in x 40 Contraction									
				K1	$0.5(1-\beta^2)^2$	0.451			
				Friction Loss (hf)1	$K1(v1^2/2g)$	6.827	ft fluid		
				(hf)1(p/144)		5.332	psi		5.34 psi
				L1/D1	K1/f1	16.702			
				(Leq)1	(L/D)1D1	1.33	ft		1.33 ft
Entrance to Pipe									
				K1	0.5	0.5			
				Friction Loss (hf)1	$K1(v1^2/2g)$	7.564	ft fluid		
				(hf)1(p/144)		5.91	psi		5.91 psi
				L1/D1	K1/f1	18.50			
				(Leq)1	(L/D)1D1	1.48	ft		1.47 ft
Exit from Pipe									
				K1	1	1			
				Friction Loss (hf)1	$K1(v1^2/2g)$	15.13	ft fluid		
				(hf)1(p/144)		11.82	psi		11.8 psi
				L1/D1	K1/f1	37.01			
				(Leq)1	(L/D)1D1	2.95	ft		2.95 ft

CHEMCAD predicts a line pressure drop of 12.61 psi as compared to the example line pressure drop of 11.734 using the total equivalent length method.

CHEMCAD physical property predictions for 94% Sulfuric Acid did not agree with the example values. CHEMCAD has a feature in the Pipe UnitOp to allow the user to enter different physical properties to the Stream values and this was used.

CHEMCAD 6.0 SIZING TOOLS – CONTROL VALVE LIQUID SIZING TOOL

TOPIC REVIEW

CHEMCAD provides facilities for the sizing of globe type control valves. The methods are based on “Control Valve Sizing” by Masoneilan Company, 6th Edition, which is entirely compatible with ISA SP39.1, “Control Valve Sizing Equations for Incompressible Fluids”. The fundamental equations are presented as follows:

The valve coefficient (Cv) metric equations for non-viscous liquid flow are given by:

For sub-critical flow where $\Delta P < C_f^2(\Delta P_s)$

$$C_v = 1.16q \sqrt{\frac{G_f}{\Delta P}}$$

Where

q	liquid flow rate (m ³ / h)
C_f	critical flow factor from manufacturers' data
G_f	specific gravity of liquid at flowing temperature, water at 15°C=1.0
ΔP	actual pressure drop (bar)

For critical flow where $\Delta P \geq C_f^2(\Delta P_s)$

$$C_v = \frac{1.16 q}{C_f} \sqrt{\frac{G_f}{\Delta P_s}}$$

$$\Delta P_s = P_1 - \left(0.96 - 0.28 \sqrt{\frac{P_v}{P_c}} \right) P_v$$

Where

P₁	upstream pressure (bar)
P₂	downstream pressure (bar)
P_v	fluid vapour pressure at flowing temperature (bar)
P_c	critical pressure (bar)
μ	fluid viscosity (cps)

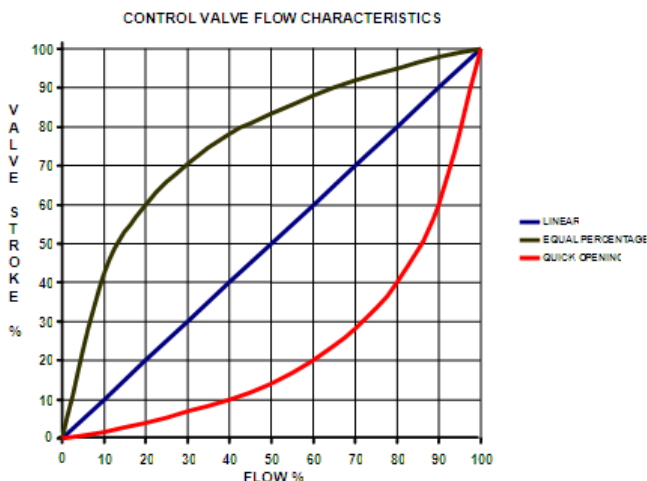
Laminar flow can result at high viscosity or when the valve ΔP or C_v is small.

Calculate turbulent flow C_v and laminar flow C_v and use the larger value as the required C_v.

For laminar flow we have:

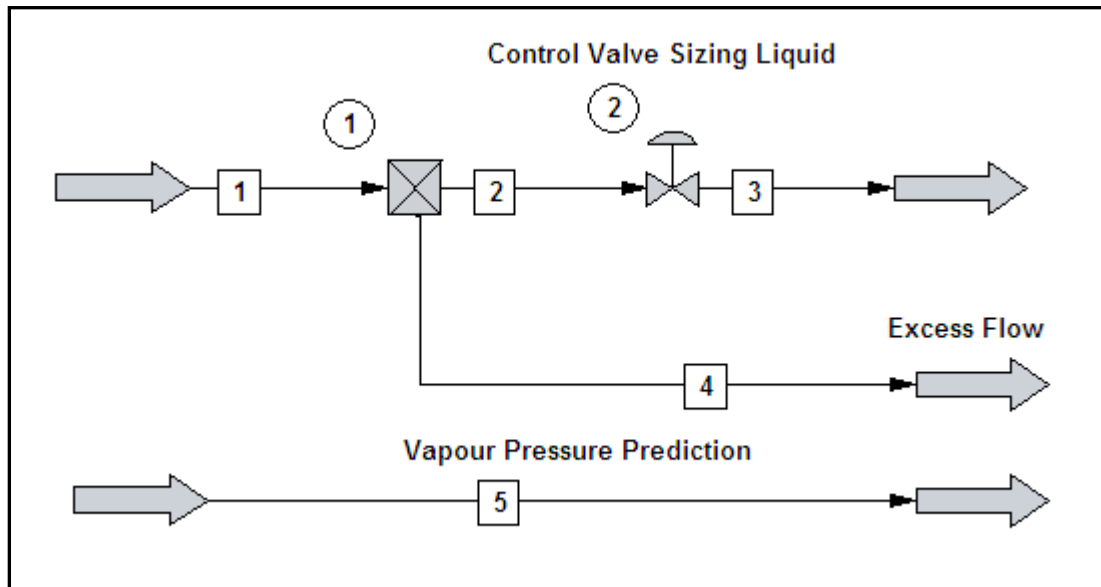
$$C_v = 0.032 \left(\frac{\mu q}{\Delta P} \right)^{0.667}$$

The control valve characteristic curves are shown below. Generally equal % is used for temperature and flow and linear valves are used for pressure and level.



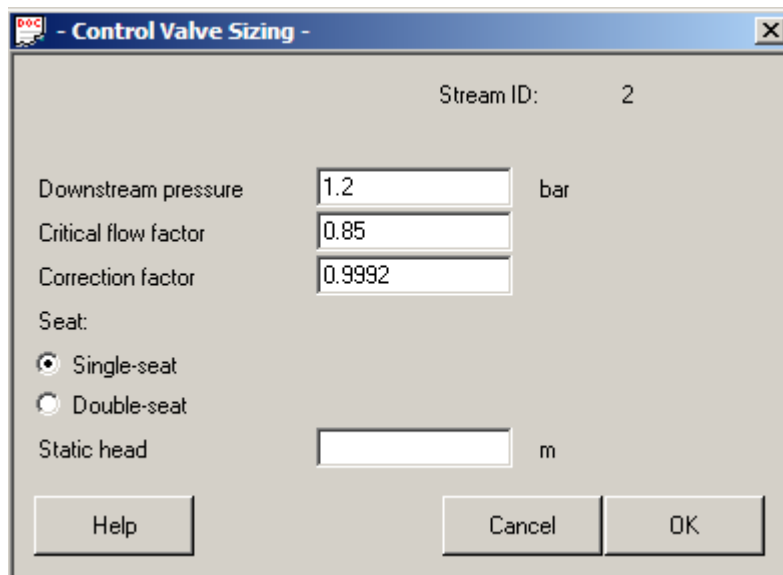
CHEMCAD MODEL

The CHEMCAD Control Valve Sizing Liquid model is set up with streams suitably configured for liquids as shown below. A dummy stream is used to determine liquid vapour pressure. Data Map is defined to interface with the spreadsheet Control Valve Sizing Liquid located in My Simulation folder.



MODEL CONFIGURATION

The Divider UnitOp 1 allows for transfer of Control Valve calculated flow to Stream 2 to maintain the mass balance around the Divider. A globe control valve can be sized by selecting Sizing – Control Valve on the main Toolbar. Sizing is carried out using the stream properties of the selected stream. The data entry Window is as follows:



This facility has limited use as it only applies to globe type control valves of sizes ≥ 1 in and the non-critical flow condition. For a more rigorous design the user should enter manufacturers data into the Control Valve data entry screen.

RESULTS

Sizing spreadsheet Control Valve Liquid Sizing has been created to analyse the CHEMCAD model calculation results and to obtain Physical Property Data to allow for validation of control valve results. Sizing parameters are calculated using the relevant equations.

The sizing spreadsheet for liquid control valve sizing is shown below:

Control Valve Sizing			Liquid Methanol		Sizing Corrections			Critical Flow Factor Cf	
Design Mass Flow	kg/h	600.0	$\Delta P_s = P_1 - \left(0.96 - 0.28 \sqrt{\frac{P_v}{P_c}} \right) P_v$	Critical Flow Factor	C _f	0.85	Rigorous ΔP _s	1.840	
Design Volume Flow	q m ³ /h	0.760		Inlet Pressure Adjusted for Vapor Pressure	ΔP _s	1.832	1.840		
Temperature	deg C	25	$\Delta P_s = P_1 - P_v$	Critical Flow Test Parameter	C _f ² (ΔP _s)	1.323			
Inlet Pressure	P ₁ bar	2	Subcritical	Critical(Flash) Flow Test		Subcritical			
Downstream Pressure	bar	1.2	$C_v = 1.16 q \sqrt{\frac{G_f}{\Delta P}}$	Subcritical Flow Coefficient	C _v	0.876			
Liquid Density	G _f kg/m ³	789.6	Critical	Critical Flow Coefficient	C _v	0.681			
Liquid Viscosity	cp	0.5	$C_v = \frac{1.16 q}{C_f} \sqrt{\frac{G_f}{\Delta P_s}}$				Effect of Pipe Reducers		
Vapor pressure at flowing conditions	P _v bar	0.1684		Valve Size	mm	25			
Pressure at Critical Point	bar	80.97	Data Base Look Up	Line Size	mm	50			
Valve Flow Coefficient Required	C _v	0.876	Laminar	Effect of Reducers Correction Factor		0.9992			
Valve Coefficient at Full Opening	C _v	2					High Viscosity, Laminar Flow		
Valve Characteristic	0 Equal Percentage	0 Equal %, 1 Linear		Laminar Flow Coefficient	C _v	0.020			
Valve Opening Position	%	64	Adjust for design max flow	Laminar Flow Test		Turbulent			
Actual Mass Flow	kg/h	599.3		Selection of Valve Type		Single Seat Globe (Flow to Close)			
Actual Volume Flow	m ³ /h	0.759							
Valve Coefficient Achieved	C _v	0.875							
Downstream Vapor Fraction		0.000							
Flowing Condition		Liquid Only							

The spreadsheet is configured to facilitate the sizing of most types of control valve under non-critical, critical and laminar flow conditions. It also allows for the entry of valve characteristic, critical flow factor F_a from manufacturers' data and for the effect of reducers.

The spreadsheet allows for the position of Control Valve UnitOp 2 to be adjusted to obtain the C_v at the specified flow conditions.

CHEMCAD 6.0 SIZING TOOLS – CONTROL VALVE GAS AND VAPOUR SIZING TOOL

TOPIC REVIEW

The methods are based on “Control Valve Sizing” by Masoneilan Company, 6th Edition, which is entirely compatible with ISA SP39.3, “Control Valve Sizing Equations for Compressible Fluids”. The fundamental equations are presented as follows:

The gas density at flowing conditions is given by the following:

$$\rho_G = \frac{M_w}{22.415} \times \frac{P_f}{Z} \times \frac{273}{T_f} \text{ kg / m}^3$$

Where **M_w** molecular weight of fluid (kg / kmol)
p_f flowing pressure (bar)
T_f absolute flowing temperature (°K)
Z gas compressibility

The valve coefficient (Cv) metric equation for gas and vapour flow at sub-critical and critical conditions is given by:

$$C_v = \frac{Q \sqrt{G T}}{257 C_f P_1 (y - 0.148 y^3)}$$

Where **Q** gas flow rate at 15°C and 1013 mbar (m³ / h)
C_f critical flow factor from manufacturers' data
G specific gravity of gas (air =1.0)
P₁ inlet pressure (bar)
T flowing temperature (°K = 273 + °C)

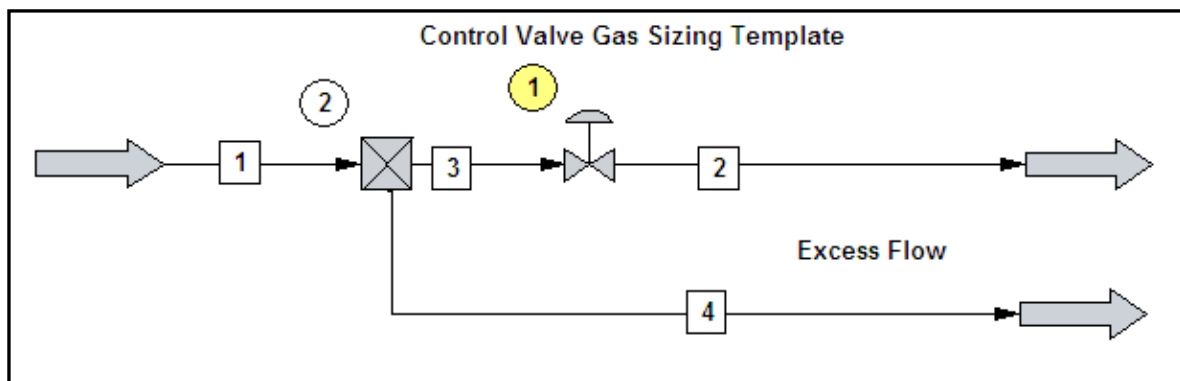
Where y is given by the following:

$$y = \frac{1.63}{C_f} \sqrt{\frac{\Delta P}{P_1}}$$

y has a maximum value of 1.5 when (y - 0.148 y³) becomes 1.0 ie at critical flow condition.

CHEMCAD MODEL

The simple CHEMCAD model Control Valve Gas Sizing is set up with streams suitably configured for steam, vapours and gases as shown below:



RESULTS

Sizing Spreadsheet Control Valve Gas Sizing has been created to analyse the CHEMCAD model calculation results and to obtain Physical Property Data to allow for validation of control valve results. Sizing parameters are calculated using the relevant equations.

The sizing spreadsheet for Gas and Vapour control valve sizing is shown below:

Control Valve Sizing		Gas		Sizing Corrections		
Process Fluid		Nitrogen			Critical Flow Factor Cf	
Molecular Weight		28.01				
Initial Sizing Mass Flow	kg/h	700.0	Sizing Flow Entered	Critical Flow Factor (Full opening)		0.85
Gas Density (1.013 bar, 15 degC)	kg/m ³	1.1847		Note: Onset of critical flow conditions as Cf is lowered.		
Design Volume Flow (1.013 bar, 15 degC)	sm ³ /h	590.87	$\rho_g = \frac{M_w}{22.415} \times \frac{P_f}{Z} \times \frac{273}{T_f} \text{ kg / m}^3$	Critical Pressure Drop		0.759
Temperature	deg C	25		Critical Flow Test		Critical
Inlet Pressure	bar	2.10	$C_v = \frac{Q \sqrt{G T}}{257 C_f P_1 Y + 0.148 Y^2}$	Flow Coefficient (y < 1.5)	Cv	22.712
Downstream Pressure	bar	1.20		Flow Coefficient (y > 1.5)	Cv	21.862
Gas Density at Inlet Conditions	kg/m ³	2.37		When y = 1.5, bracketed "y" function = 1		
Gas Viscosity	cp	0.0178		Effect of Pipe Reducers		
Gas Specific Gravity (air = 1)		0.9668	$F_r = \left[1 + \frac{\Sigma K}{N_2} \left(\frac{C_v}{d^2} \right)^2 \right]^{-0.5}$	Valve Size	mm	50
Valve Flow Coefficient Required	Cv	22.71		Line Size	mm	80
Corrected Valve Flow Coefficient Required	Cv	23.37		Effect of Reducers Correction Factor		0.9718
Valve Coefficient at Full Opening	Cv	36	$\Sigma K = K_1 + K_2 = 1.5 (1 - \beta^2)^2$	Fisher Method Fp		0.9741
Valve Characteristic		0 Equal Percentage		Critical Flow Parameter	y	1.255
C27 = 0, Equal % = 1, Linear			$y = \frac{1.63}{C_f} \sqrt{\frac{\Delta P}{P_1}}$	Selection of Valve Type	Single Seat Globe (Flow to Close)	
Valve Position	%	78	Adjust valve position to give sizing flow D5	1	Cf	
Actual Mass Flow	kg/h	690.5		Single Seat Globe (Flow to Close)		0.85
Standard Volume Flow 0 degC	m ³ /h	552.48		Single Seat Globe (Flow to Open)		0.9
Standard Volume Flow 15 degC	m ³ /h	582.87		Rotating Disc (Flow to Close)		0.68
Actual Volume Flow	m ³ /h	290.91		Rotating Disc (Flow to Open)		0.85
Case Valve Coefficient (y < 1.5)	Cv	22.405		Double Seat Globe V Port		0.98
Case Valve Coefficient (y > 1.5)	Cv	21.566		Butterfly		0.65
CHEMCAD Control Valve Sizing Results (Not linked)				Ball Valve (Flow to Open)		0.6
Total flow	690.53 kg/h			Angle Valve (Flow to Close)		0.81
Upstream pressure	2.1 bar			Angle Valve (Flow to Open)		0.9
Downstream pressure	1.2 bar					
Critical flow factor	0.85					
Corr. factor for reducers	0.974					
Static head	0 m					
Seat type	Single-Seat					
Flow type	Critical flow					
Calc. coefficient Cvc	21.69					
Capacity coefficient Cv	36					
Cvc / Cv ratio	0.6026					
Valve size	0.0508 m					

The spreadsheet is configured to facilitate the sizing of most types of control valve under non-critical and critical flow conditions. It also allows for the entry of valve characteristic, critical flow factor F_a from manufacturers' data and for the effect of reducers.

The spreadsheet allows for the position of Control Valve UnitOp 1 to be adjusted to obtain the C_v at the specified flow conditions.

CHEMCAD 6.0 SIZING TOOLS – ORIFICE PLATE SIZING TOOL

TOPIC REVIEW

CHEMCAD provides facilities for the sizing of concentric orifice plates used in the measurement of fluid flow rates. The methods are based on "Principles and Practice of Flow Meter Engineering" by L.K.Spink, Foxboro Company, 1967. The fundamental equations are presented as follows:

The equation for non-viscous liquid flow is given by:

$$S = \frac{W_m}{N D^2 F_a F_m \sqrt{G_f} \sqrt{h_m}}$$

Where	W_m	maximum rate of flow (lb/h)
	D	inside pipe diameter (in)
	F_a	ratio of area of primary device bore at flowing temperature to that at 68°F
	F_m	manometer correction factor (=1 for diaphragm transmitters)
	N	constant for units adjustment (N=2835 for lb/h)
	G_f	specific gravity of liquid at flowing temperature, water at 60°F=1.0
	h_m	maximum differential pressure (in wg)

$$F_a = 1 + 2\alpha (t_f - 68)$$

Where	α	coefficient of thermal expansion for orifice material (in/in °F) see below typical value for 18/8 SS is 9.5E-06 and for Monel is 7.0E-06
	t_f	flowing temperature (°F)

The orifice resistance coefficient is given by:

$$K_r = \frac{1 - \beta^2}{C^2 \beta^4}$$

$$C = \frac{C_d}{(1 - \beta^4)^{0.5}}$$

Where	C	orifice flow coefficient
	d	orifice bore
	β	d/D (Note: for better measurement try and keep in the range 0.3 to 0.6)

The equation for viscous liquid flow is given by:

$$S = \frac{W_m}{N D^2 F_a F_m F_c \sqrt{G_f} \sqrt{h_m}}$$

The application of the viscosity correction factor F_c for plant operational measurements and control is rarely justified. Viscosity limits for 1% calculation tolerance vary in the range of 1 to 8 cps depending on the β ratio, keeping <0.6, and pipe size. F_c can vary in the range of 1.0 to 1.09. Refer to L.K.Spink Flow Handbook for more information.

TOPIC REVIEW

Universal Equation for steam, vapours or gases is given by:

$$S = \frac{W_m}{359 D^2 F_a F_m F_c Y \sqrt{v_f} \sqrt{h_m}}$$

$$v_f = \frac{m_w P_f}{10.73 T_f Z_f}$$

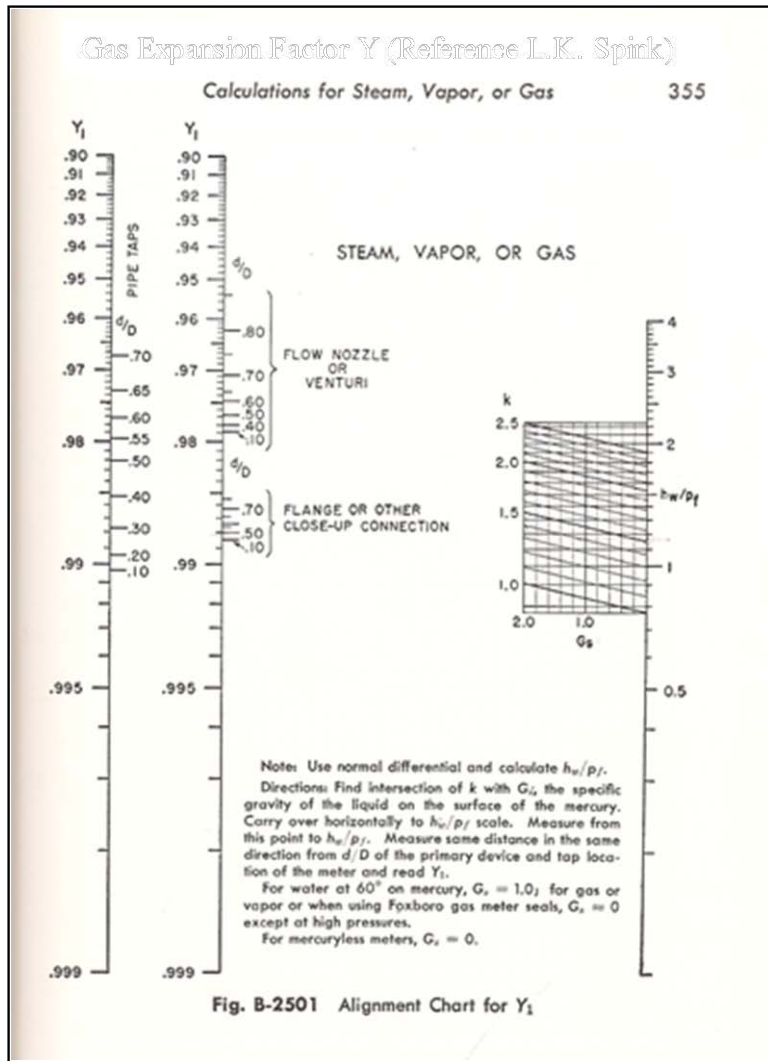
Where F_c viscosity or Reynolds number correction, Re >50000 using $F_c = 1.0$ is acceptable.
 m_w molecular weight of flowing fluid
 P_f flowing pressure (psia)
 T_f flowing absolute temperature ($^{\circ}R = ^{\circ}F + 460$)
 Y gas expansion factor determined from alignment chart shown below

S for Flange, Vena Contracta, Radius or Corner Taps

$$S = 0.598\beta^2 + 0.01\beta^3 + 0.00001947\beta^2(10\beta)^{4.425}$$

S for Full Flow Taps ($2\frac{1}{2}D$ and $8D$)

$$S = 0.58925\beta^2 + 0.2725\beta^3 - 0.825\beta^4 + 1.75\beta^5$$



The sizing procedure is to determine an initial S and then d/D assuming $F_c = 1$ and $Y = 1$. Then use alignment chart to determine Y and obtain new d/D from modified S/Y value.

TOPIC REVIEW

If steam is wet the specific weight is adjusted as follows where q is the steam dryness (vapour) fraction:

$$V_{fw} = \frac{V_f}{q}$$

If a drain or vent hole (d_n) is used to prevent the build up of entrained gas or liquid, the orifice bore is reduced in accordance with the following relationship:

$$d_a = d \left(1 - 0.55 \left(\frac{d_n}{d} \right)^2 \right)$$

The orifice sizing data input requires entry of the orifice plate material thermal expansion factor; typical values are shown in the table below.

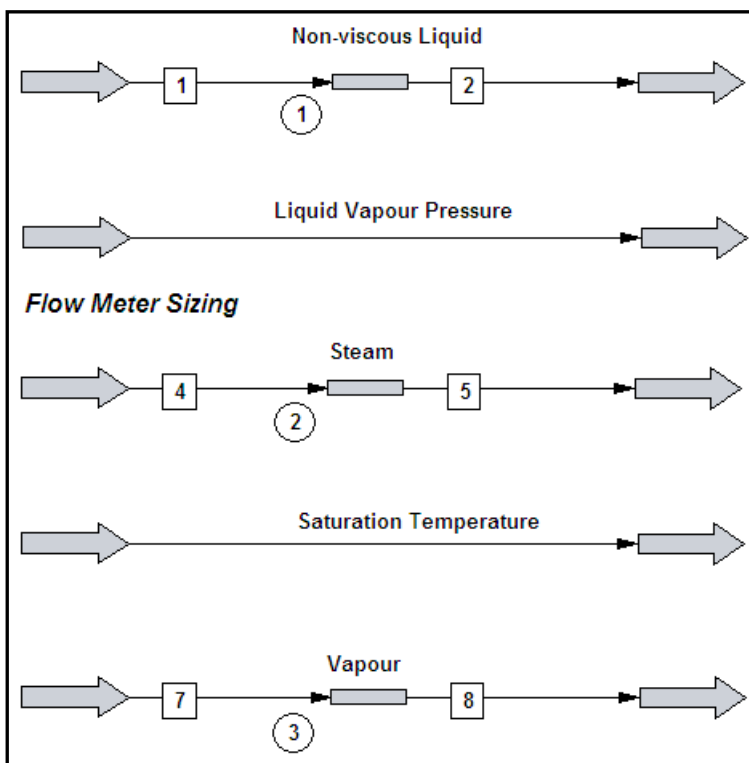
Orifice Plate Thermal Expansion Factor F _a	
Material	Thermal Expansion Factor
	in/in °F
Carbon Steel	6.7 E-06
Stainless Steel ANSI 304	9.6 E-06
Nickel alloy	13.3 E-06

In sizing metering sections, the pipe should be sized to satisfy reasonable pipe line velocities which are summarised in the Appendices.

The flow meter differential, h_m, is typically set in the range 100 to 200 in wc for liquids and in the range 25 to 50 in wc for gases; being adjusted to achieve an acceptable β ratio in the range 0.3 to 0.6.

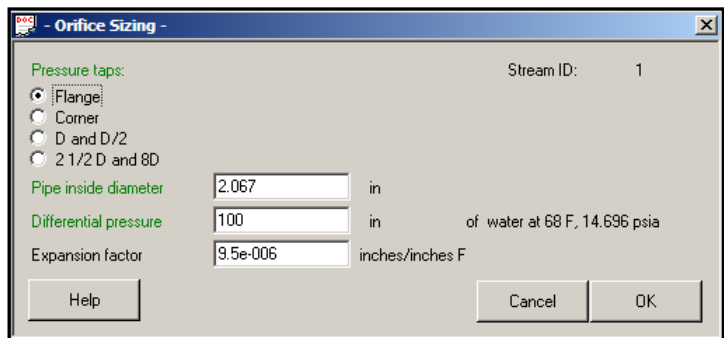
CHEMCAD MODEL

The CHEMCAD model Flow Meter Sizing is set up with streams suitably configured for liquids, steam, vapours and gases as shown below. Dummy streams are used to determine liquid vapour pressure and steam saturation temperature. Data Maps are defined to interface with the relevant Worksheet LIQUID, STEAM or VAPOUR of the Flow Meter Sizing spreadsheet.



MODEL CONFIGURATION

An orifice plate is sized by selecting Sizing – Orifice on the main Toolbar. Sizing is carried using the stream properties of the selected stream. The data entry Window is as follows:



RESULTS

Sizing Spreadsheets have been created to analyse the CHEMCAD model calculation results and to obtain Physical Property Data to allow validation of orifice sizing results. In all cases agreement was found to be within -0.75% accuracy. Sizing parameters and thermal expansion factors are calculated using the relevant equations and values for d/D and Y were determined manually from the appropriate tables in L.K.Spink.

The sizing spreadsheet for Liquid orifice plate sizing is shown below:

Orifice Plate Sizing			Liquid							
Process Fluid			Water		CHEMCAD ORIFICE SIZING TOOL RESULTS					
Design Mass Flow	W_m	lb/h	10000.0		Flowrate	Vapor	0 lb/h	Liquid	10000 lb/h	
Temperature	t_f	deg F	200.00		Flowrate		0 ft ³ /hr		166.4175 ft ³ /hr	
Inlet Pressure	P_f	psia	30		Density		0 lb/ft ³		60.0898 lb/ft ³	
Liquid Density	ρ	lb/ft ³	60.090		Pressure taps	Flange				
Liquid Viscosity	μ	cp	0.303		Differential pressure	100 in of water				
Vapor pressure at flowing conditions		psia	11.531		Reynolds No.	100912.1				
Meter differential pressure	h_m	in wg	100.0		S_m (Sizing parameter)	0.0839				
Liquid specific gravity	G_f		0.9650		C_d (Discharge coefficient)	0.601				
Calculated pipe velocity	v	ft/s	0.90		Beta ratio (d/D)	0.3719				
Pipe internal diameter	D	in	2.067		Pipe inside diameter (D)	2.0669 in				
Material thermal expansion	α	in/in degF	9.50E-06		Bore size (d)	0.7686 in				
Thermal expansion factor	F_a		1.0025E+00		K_r (Flow resistance factor)	122.3639				
Sizing parameter	S		0.0838	0.0839	This data copied and pasted from CHEMCAD orifice sizing tool result					
Goal Seek E30 = E29 changing F33	S_{calc}		0.0841		Select Pressure Taps					
Pressure Taps			Flange, Radius, Corner		Flange, Radius, Corner Taps					
Beta Ratio	d/D		0.3719	0.3719	Use full flow taps for restriction orifice plate					
Bore Size	d	in	0.7686	0.7686	Source for Scaife L.K. Spink Tables 12 and 13					
Discharge Coefficient	C_d		0.6010	0.6068	Flange, Vena Contracta, Radius or Corner Taps					
Flow Resistance Factor	K_r		122.36	122.32	$S = \frac{W_m}{N \cdot D^3 \cdot F_a \cdot F_{sc} \cdot \sqrt{G_f \cdot h_m}}$ $S = 0.598\beta^2 + 0.01\beta^3 + 0.00001947\beta^2 (10\beta)^{4.25}$					
Reynolds Number	Re		1.009E+05		Full Flow Taps (2½D and 8D)					
					$S = 0.58925\beta^2 + 0.2725\beta^3 - 0.825\beta^4 + 1.75\beta^5$					
					Manual CCD Entry					
					Cell Colour Key					
					Calculated Data					
					Data to CCD					
					Data from CCD					

RESULTS

The sizing spreadsheet for Steam orifice plate sizing is shown below:

Orifice Plate Sizing		Steam					
Molecular weight			18.01				
Design Mass Flow	W _m	lb/h	10000.0				
Temperature	t	deg F	450.00	400.002			
Inlet Pressure	P _i	psia	246.92				
Compressibility	Z _i		0.938				
Isentropic Coefficient			1.3236				
Dryness fraction	q		1.000				
Specific weight	v _r	lb/ft ³	0.4857				
Meter differential pressure	h _m	in wg	200.0				
Reynolds number correction	F _r	Re>50000	1.0000				
Expansion Factor	Y		0.9894	0.8100 0.989			
Pipe internal diameter	D	in	3.067				
Pipe velocity	v	ft/s	0.90				
Material thermal expansion	α	in/in degF	9.60E-06				
Thermal expansion factor	F _s		1.007E+00				
Sizing parameter	S		0.3015	0.2983			
Pressure Taps			Flange				
Beta Ratio	d/D	0.3 to 0.6	0.667	0.662			
Bore Size	d	in	2.0456	2.030308	-0.75%		
Discharge Coefficient	C _d		0.6069				
Flow Resistance Factor	K _r		6.1083	6.3694			
Reynolds Number	Re		1.16E+06				

CHEMCAD ORIFICE SIZING TOOL RESULTS

Vapor

Flowrate 10000 lb/h

Flowrate 20582.63 ft³/hr

Density 0.4858 lb/ft³

Gas isentropic exponent 1.3236

Pressure taps Flange

Differential pressure 200 in of water

Reynolds No. 1157226

Sm (Sizing parameter) 0.2983

Gas expansion factor 0.9894

Cd (Discharge coefficient) 0.6069

Beta ratio (d/D) 0.667

Pipe inside diameter (D) 3.067 in

Bore size (d) 2.0456 in

Kr (Flow resistance factor) 6.1083

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$V_f = \frac{m_w P_f}{10.73 T_f Z_f}$

$F_s = 1 + 2\alpha (t_f - 68)$

Initial S for d/D assuming F_c = 1 and Y = 1

$S = \frac{W_m}{359 D^2 F_s F_m F_c Y \sqrt{v_r} \sqrt{h_m}}$

$K_r = \frac{1 - \beta^4}{C^2 \beta^4}$

$C = \frac{C_d}{(1 - \beta^4)^{0.5}}$

Manual CCD Entry

Cell Colour Key

Calculated Data

Data to CCD

Data from CCD

The sizing spreadsheet for Vapour or Gas orifice plate sizing is shown below:

Orifice Plate Sizing		Vapour or Gas Nitrogen					
Molecular weight			28.01				
Design Mass Flow	W _m	lb/h	1000.0				
Temperature	t	deg F	100.00				
Inlet Pressure	P _i	psia	30.00				
Compressibility	Z _i		1.000				
Isentropic Coefficient			1.4097				
Specific weight	v _r	lb/ft ³	0.1398	0.1399			
Meter differential pressure	h _m	in wg	50.0	1.6667			
Reynolds number correction	F _r	Re>50000	1.0000				
Expansion Factor	Y		0.9804	0.9800			
Pipe internal diameter	D	in	2.067				
Pipe velocity	v	ft/s	79.91				
Material thermal expansion	α	in/in degF	9.50E-06				
Thermal expansion factor	F _s		1.001E+00				
Sizing parameter	S		0.2513	0.2464			
Pressure Taps			Flange				
Beta Ratio	d/D	0.3 to 0.6	0.6174	0.615			
Bore Size	d	in	1.2762	1.271			
Discharge Coefficient	C _d		0.6095				
Flow Resistance Factor	K _r		9.7969	10.0263			
Reynolds Number	Re		1.67E+05				

CHEMCAD ORIFICE SIZING TOOL RESULTS

Vapor

Flowrate 1000 lb/h

Flowrate 7146.473 ft³/hr

Density 0.1399 lb/ft³

Gas isentropic exponent 1.4097

Pressure taps Flange

Differential pressure 50 in of water

Reynolds No. 166652.7

Sm (Sizing parameter) 0.2464

Gas expansion factor 0.9804

Cd (Discharge coefficient) 0.6095

Beta ratio (d/D) 0.6174

Pipe inside diameter (D) 2.067 in

Bore size (d) 1.2762 in

Kr (Flow resistance factor) 9.7969

This data copied and pasted from CHEMCAD orifice sizing tool result

$V_f = \frac{m_w P_f}{10.73 T_f Z_f}$

$F_s = 1 + 2\alpha (t_f - 68)$

Initial S for d/D assuming F_c = 1 and Y = 1

$S = \frac{W_m}{359 D^2 F_s F_m F_c Y \sqrt{v_r} \sqrt{h_m}}$

$K_r = \frac{1 - \beta^4}{C^2 \beta^4}$

$C = \frac{C_d}{(1 - \beta^4)^{0.5}}$

Manual CCD Entry

Cell Colour Key

Calculated Data

Data to CCD

Data from CCD

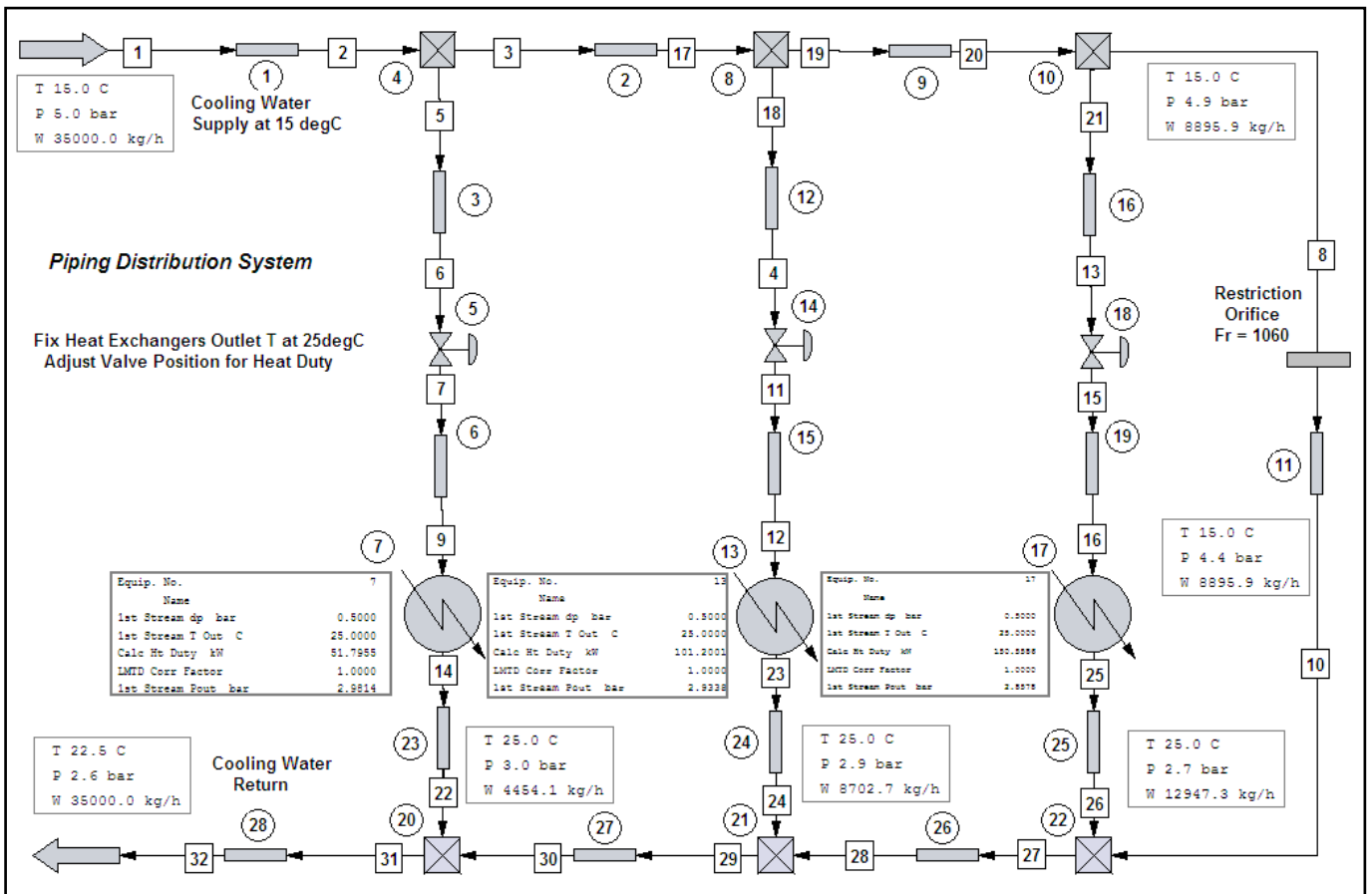
CHEMCAD 6.0 SIZING TOOLS – SERVICES PIPING DISTRIBUTION SYSTEM

PROCESS DESCRIPTION

This case study develops the design of a cooling water distribution system supplying three shell and tube heat exchangers. Cooling Water supply is 35000 kg/h at 25°C and 5 bar pressure. The heat exchanger duties are 50 kW, 100 kW and 150 kW with cooling water return temperatures all set at 25 °C. The piping design is to be based on a 3 m/s velocity allowing for upgrade to 75000 kg/h. A restriction orifice, giving a 0.5 bar pressure drop at the flowing conditions, is to be installed in the spillback line. Control valves are to be sized and used to control heat exchanger cooling water flow to satisfy the design duties.

CHEMCAD MODEL

For practice you can build the model or use the model called “Piping Distribution System” in the electronic media supplied. It is strongly recommended that you work with a copy of this job. The model flowsheet is shown that represents the piping layout .



MODEL CONFIGURATION

The key aspect of this problem is the handling of the enlargement and contraction. The reducer fitting must be located in the smaller pipe ie the supply and return equipment headers. The Tees also need careful consideration with the main header UnitOps specified as Flow Through Run, the equipment supply headers as Flow-out Branch and the return equipment headers as Flow-in Branch.

The restriction orifice plate is sized to achieve a 0.5 bar pressure drop at prevailing conditions.

RESULTS

The control valves are sized initially to achieve a 150 kW maximum duty requiring a Cv of 34. Once sized the control valve is positioned manually to adjust the flow to achieve the specified duty whilst maintaining a 25°C outlet temperature. It should be noted that the model as configured is not achieving a pressure balance at the mixers. This could be achieved by the use of the Node UnitOp or replacing the Restriction Orifice with a Control Valve to adjust the return pressure.

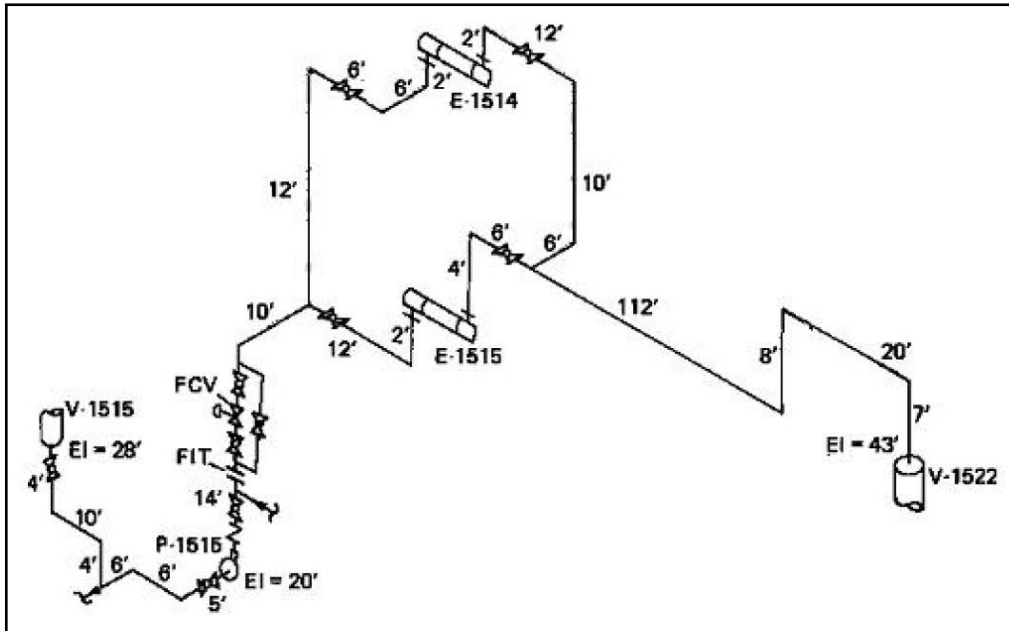
CHEMCAD 6.0 SIZING TOOLS – PIPE NETWORK WITH PUMP CURVE

PROCESS DESCRIPTION (Chemstations Piping Seminar Example 3)

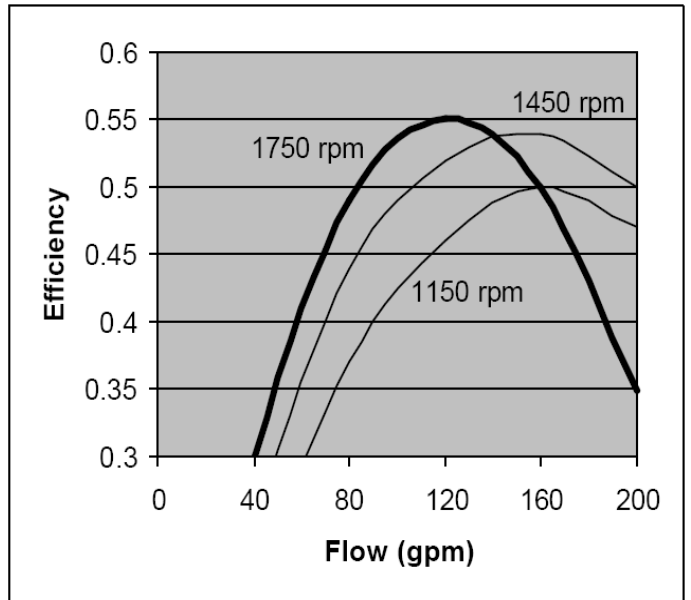
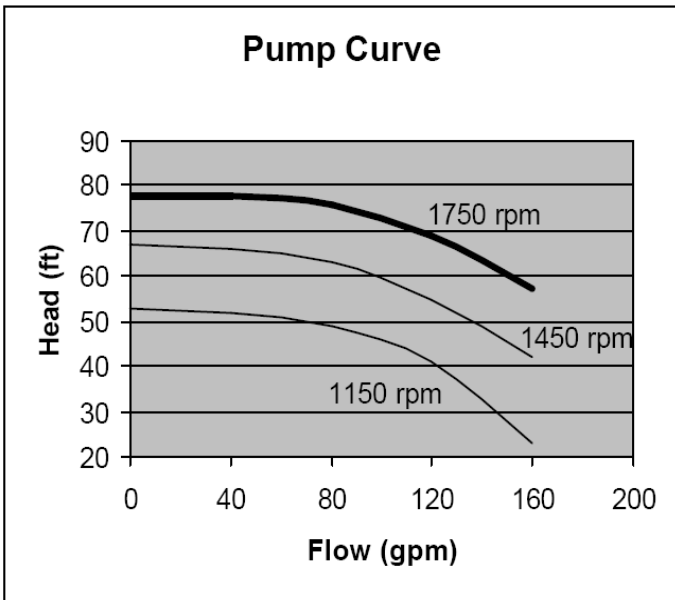
The piping system is to be designed to transport 120 gpm of glacial acetic acid at an inlet temperature of 70°F which is then heated through heat exchangers to 140°F. The outlet pressure must be no less than 20 psia. The piping system and its individual elements are to be sized for typical design conditions.

The piping layout, valves and fittings to be used are shown in the isometric. An orifice plate and control valve is to be installed downstream of the pump to measure and control flow manually. It is required to determine the branched flow split flow and pressure drops in the pipe network

Further more the layout is to be tested to ensure an adequate Net Positive Suction Head (NPSH) is available at the pump suction. The NPSHa is defined as the total pressure available at the pump suction minus the vapour pressure of fluid at pump suction conditions. If the NPSHa is less than that required by the pump then cavitation will result.

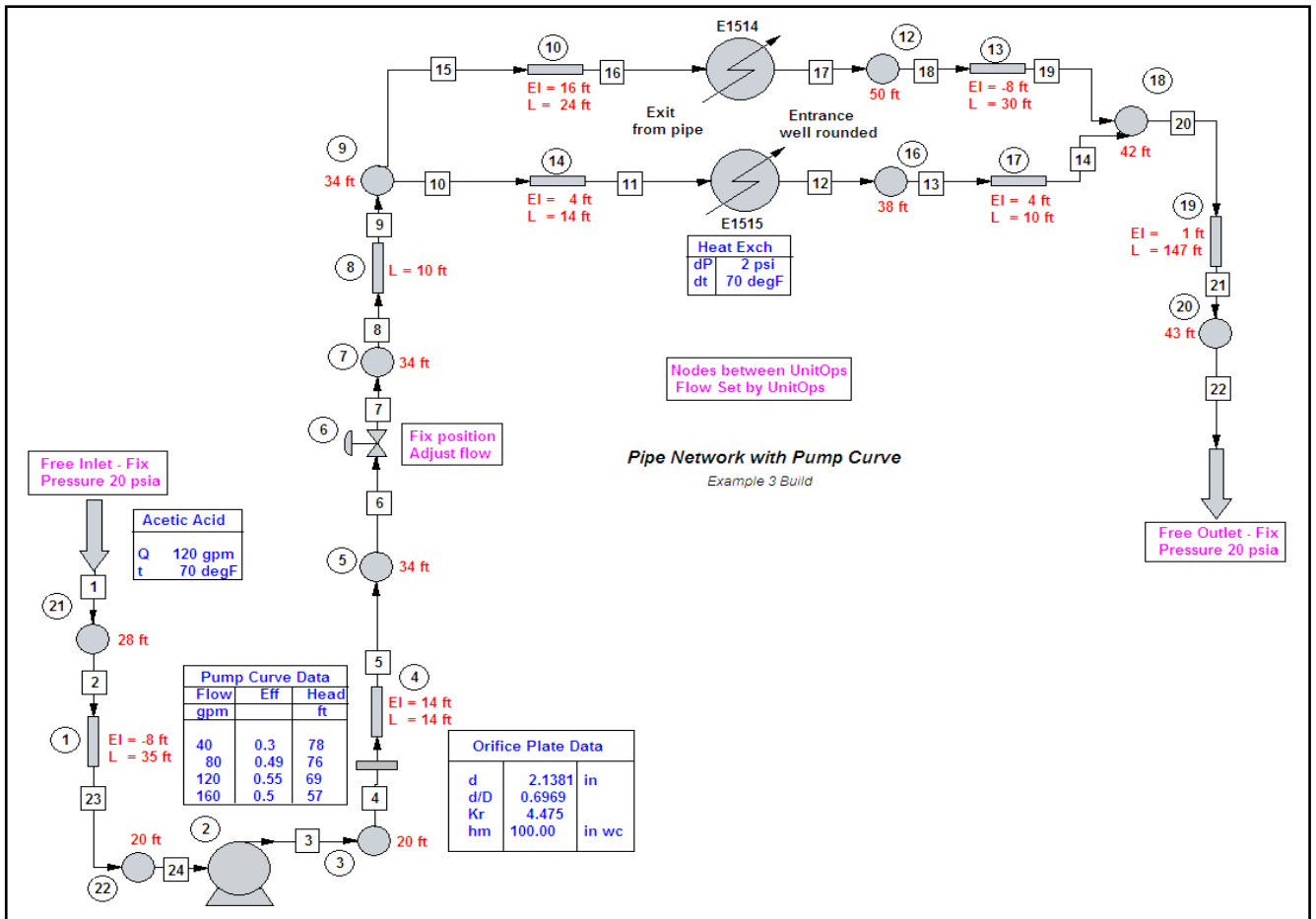


The centrifugal pump to be used has the following performance characteristics:



CHEMCAD MODEL

For practice you can build the model or use the model called “Piping Example 3 Build” in the electronic media supplied. It is strongly recommended that you work with a copy of this job. The model flowsheet is shown that represents the piping layout . This problem is solved in CHEMCAD using the Pressure Node UnitOp.



MODEL CONFIGURATION

The Pressure Node UnitOp can be considered a calculator that adjusts the network pressure at the node based on the flowrate. In the network the Node sets the pressure between UnitOps that calculates flow as a function of pressure.

Pipe UnitOps calculate flows based on the P_{in} and P_{out} , the Pump and Control Valve UnitOps calculate flows based on the downstream pressure in the Node; it follows that Node UnitOps located between UnitOps that calculate the flow are set in the “Flow Set by Upstream and Downstream UnitOps”.

The pressure at the Inlet and Outlet Nodes of this network are fixed at 20 psi and the stream is defined as Free ie not effected by a UnitOp. The inlet flow could also have been fixed by the Inlet Node.

At a UnitOp there are three variables- P_{in} , P_{out} and F ; a single equation constrains the system so specification of any two variables sets the remaining variable.

The Inlet and Outlet Nodes configuration is Fixed Pressure and all other Nodes are Variable Pressure as shown below:

Mode		Fixed pressure		ID:
Pressure at node	20	psia	Minimum pressure	10
Elevation	20	ft	Maximum pressure	30
Flowrate Options				
Inlet Streams			Outlet Streams	
Stream	Mode	Value	Stream	Mode
1	Free inlet stream		2	Flow set by UnitOp

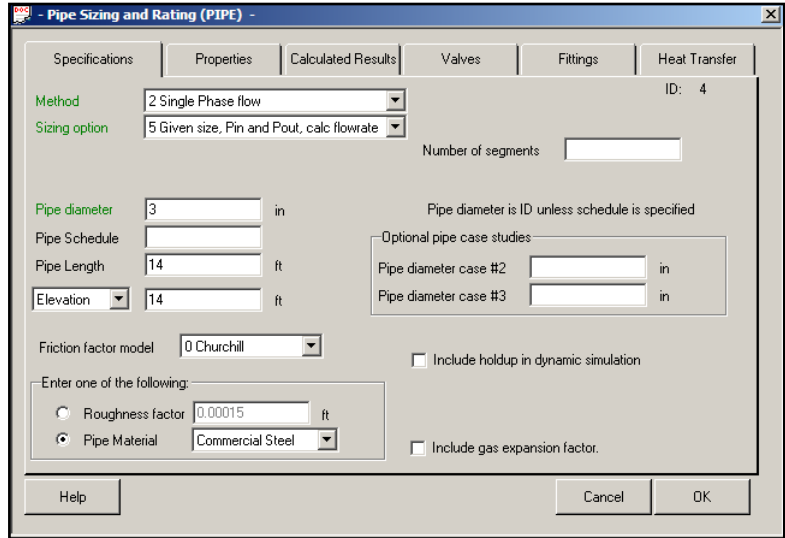
Mode		Variable pressure		ID:
Pressure at node	39.3687	psia	Minimum pressure	30
Elevation	34	ft	Maximum pressure	80
Flowrate Options				
Inlet Streams			Outlet Streams	
Stream	Mode	Value	Stream	Mode
5	Flow set by UnitOp		6	Flow set by UnitOp

MODEL CONFIGURATION

The pump discharge line size is determined using the CHEMCAD Sizing > Piping facility using a design velocity of 3 m/s. A discharge line size of 3 in was selected and for the suction pipe 4 in, a nominal size larger.

The Pipe UnitOps Method, Sizing Option, Friction Factor and Roughness Factor are configured identically.

Stream Properties:			
-- Overall --			
Mass flow lb/h	92575.1563		
Actual dens lb/ft3	65.2869		
-- Liquid only --			
Mass flow lb/h	92575.1563		
Actual dens lb/ft3	65.2869		
Visc cP	1.1811		
Pipe Parameters:			
Schedule	Calculated	Next larger	Next smaller
	40	40	40
Flow Regime	Single phase	Single phase	Single phase
Pipe ID in	3.068	4.0533	2.1316
Nominal Dia. in	3	4	2
-- Overall --			
Press Drop psi/100ft	3.2011	0.7918	20.3878
Velocity ft/sec	7.6679	4.3931	15.8851
-- Liquid only --			
Reynolds Number	161360.8	122136.4	232249.8
Friction Factor	0.0197	0.0196	0.0203
Press Drop psi/100ft	3.2011	0.7918	20.3878



The pump discharge stainless steel orifice plate is calculated using the CHEMCAD Sizing > Orifice tool. It is specified with flange taps, a design differential of 100 in wc and thermal expansion 9.6 E-06 in/in °F. The unrecovered pressure loss is accounted for by adding the calculated K_r in the downstream Pipe UnitOp User specified window.

Loadings and Properties			
	Vapor		Liquid
Flowrate	0 lb/h		92575.1563 lb/h
Flowrate	0 ft3/hr		176.7864 gpm
Density	0 lb/ft3		65.2869 lb/ft3
Pressure taps			
Flange			
Differential pressure	100	in of water	
Reynolds No.	161361.338		
Sm (Sizing parameter)	0.339		
Cd (Discharge coefficient)	0.6102		
Beta ratio (d/D)	0.6969		
Pipe inside diameter (D)	3.068	in	
Bore size (d)	2.1381	in	
K_r (Flow resistance factor)	4.4749		

User specified fittings/valves				
Type	L/D, K_r, K_s	K_i	K_d	Count
K_r	4.475			
L/D				
L/D				

To size the control valve from an initial build, copy the pipe network inlet stream to the control valve inlet stream using Specifications > Copy Stream Data and change the pressure to 45 psig. Specify valve with a 20 psi pressure drop and a correction factor of 0.95.

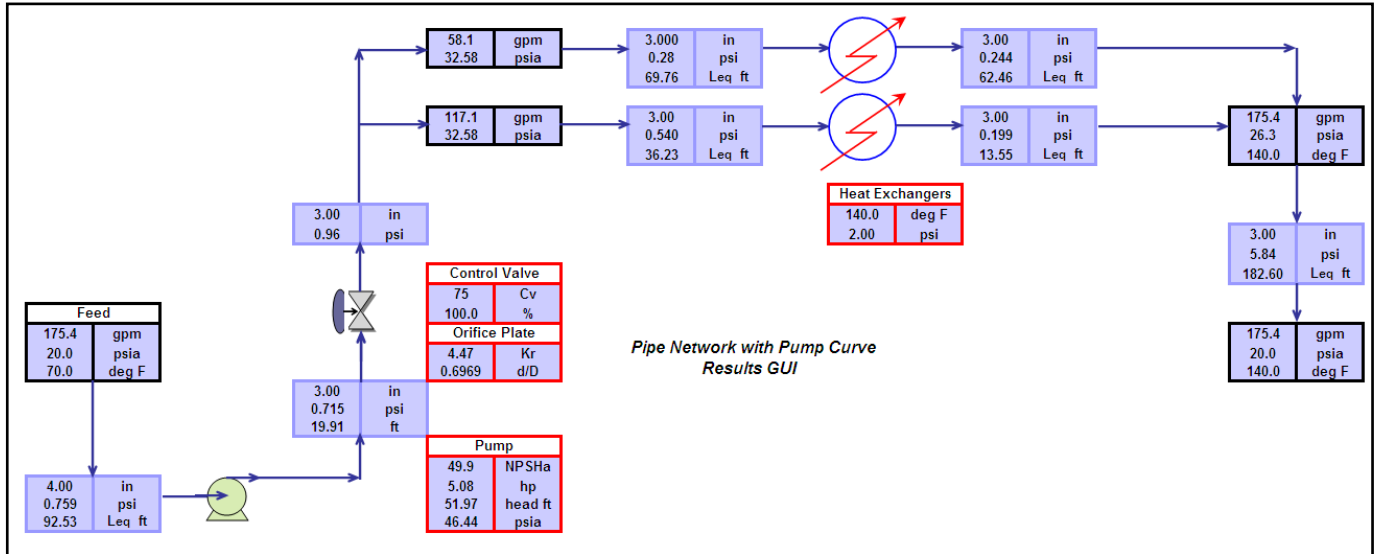
Loadings and Properties			
	Vapor		Liquid
Flowrate	0 lb/h		92575.1719 lb/h
Flowrate	0 ft3/hr		176.7864 gpm
Density	0 lb/ft3		65.2869 lb/ft3
Total flow	92575.1719	lb/h	
Upstream pressure	39.3687	psia	
Downstream pressure	25	psia	
Critical flow factor	0.98		
Corr. factor for reducers	0.95		
Static head	0	ft	
Seat type	Single-Seat		
Flow type	Subcritical flow		
Calc. coefficient Cvc	50.1999		
Capacity coefficient Cv	75		
Cvc / Cv ratio	0.6693		
Valve size	3	in	

In the example shown no allowance has been made for reducers at the pump suction and discharge which are normally required; as discussed earlier these can have a significant effect and would require additional Pipe UnitOps at the pump inlet and discharge.

RESULTS

The results have been presented in a Graphical User Interface (GUI) format to give a clearer representation. It has been generated using the CHEMCAD Data Map facility. The graphics and reporting have been done using Excel.

The results are shown for the control valve fully open. It can be seen there is adequate NPSH and the discharge pressure criteria have been met. The flow split through the heat exchangers, as a result of the piping layout and resistances, is predicted to be 56.1 gpm and 117.1 gpm.



Alternatively a report can be generated using the standard CHEMCAD reporting facilities.

CHEMCAD 6.0 SIZING TOOLS – RELIEF VENT PIPING MANIFOLD RATING

PROCESS DESCRIPTION

This case study investigates the sizing of a relief piping manifold connected to three exothermic reactors; a typical arrangement in a multiple batch reactor facility. Each reactor has been fitted a 4 in graphite bursting(rupture) disc complete with a vacuum support set at 2 barg. are shown below:

The reactor dimensions and contents			
Reactor	Dimensions (m)	Composition	Nozzle (m)
1	D = 2.0, H = 3.0, Head Ellipsoidal R = 0.67	THF wf = 1, Rx volume vf = 0.2	D = 0.1
2	D = 1.5, H = 2.0, Head Ellipsoidal R = 0.67	Toluene wf = 1, Rx volume vf = 0.5	D = 0.1
3	D = 1.8, H = 2.5, Head Ellipsoidal R = 0.67	THF wf = 0.5, Tol wf = 0.5 Rx volume vf = 0.3	D = 0.1

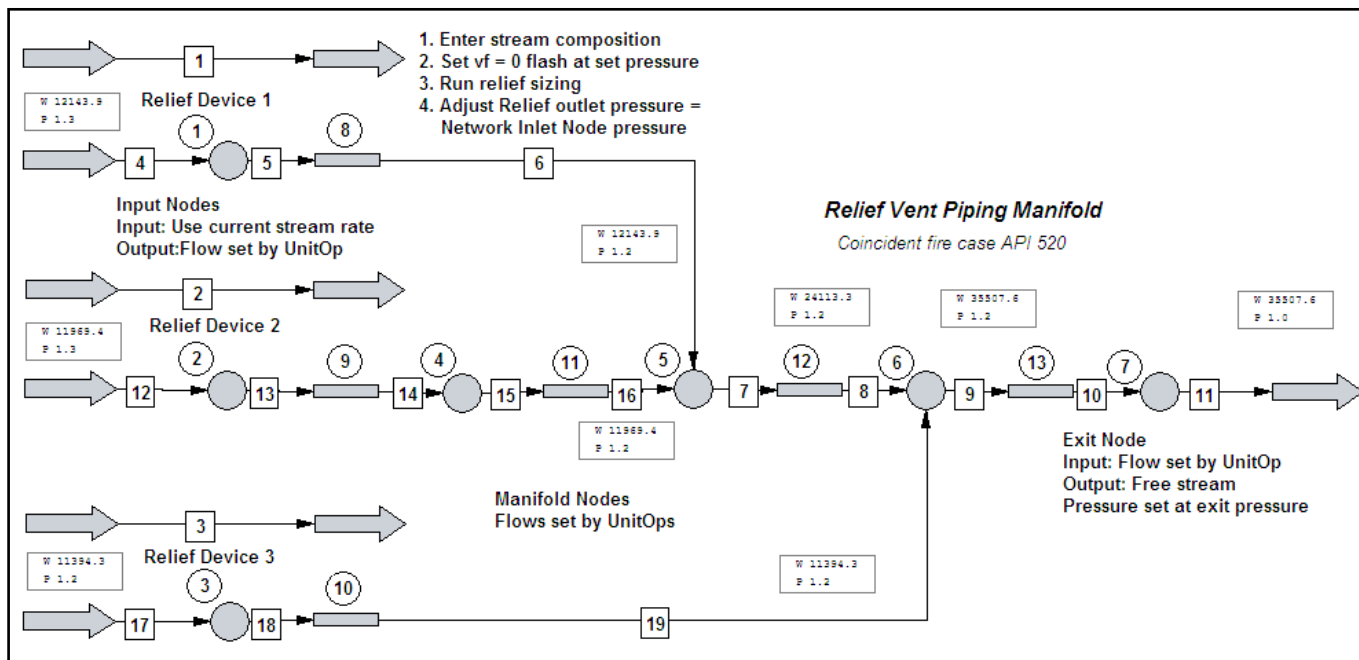
The relief devices are to be sized for external fire to API 520 standard. To provide a margin of safety the reactors are assumed to be uninsulated. Reactor 1 is considered to be carrying out an exothermic reaction with a heat evolution of 500 MJ/h.

Refer to paper “Emergency Relief Systems (ERS) Sizing Software Methods and Practice” (P&I Design MNL043A) to decide suitable Vessel and Vent Flow models, relief device discharge coefficients and F factor for uninsulated vessel.

The key consideration in this application is to ensure that the vent piping manifold does not restrict the vent flow in the event of a coincident relief. As a general rule sonic flow (ie maximum flow) will be achieved in the relief device if $P_{in} > 0.5 \times P_{out}$, where P_{out} is the manifold back pressure.

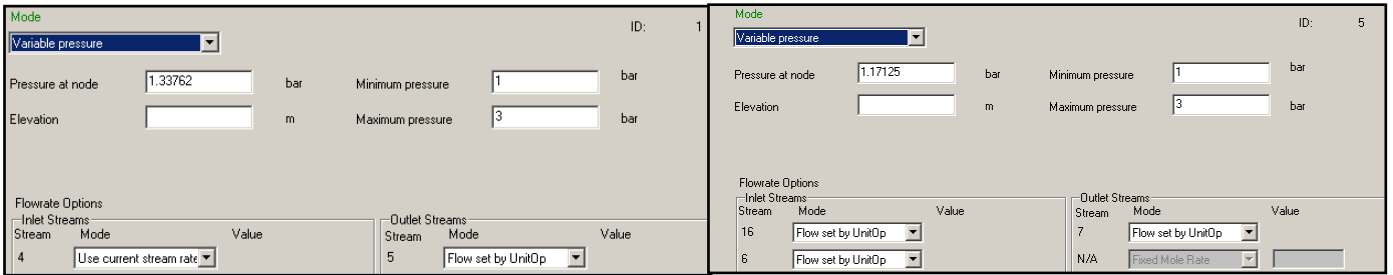
CHEMCAD MODEL

For practice you can build the model or use the model “Relief Vent Piping Manifold” in the electronic media supplied. It is recommended that you work with a copy of this job.

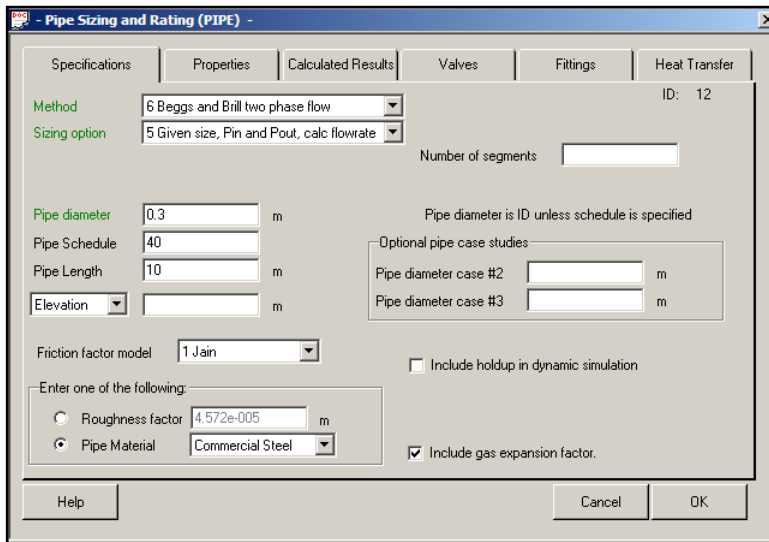


MODEL CONFIGURATION

The Inlet Nodes are specified in Variable Pressure Mode using current stream rate with the outlet flow being constrained by the UnitOp. All Nodes in the network use Variable Pressure mode with all Flows set by UnitOp. The Outlet Node is set at a Fixed Pressure and Free outlet stream. This outlet Node can be used to test the effect of back pressure build up in downstream equipment.

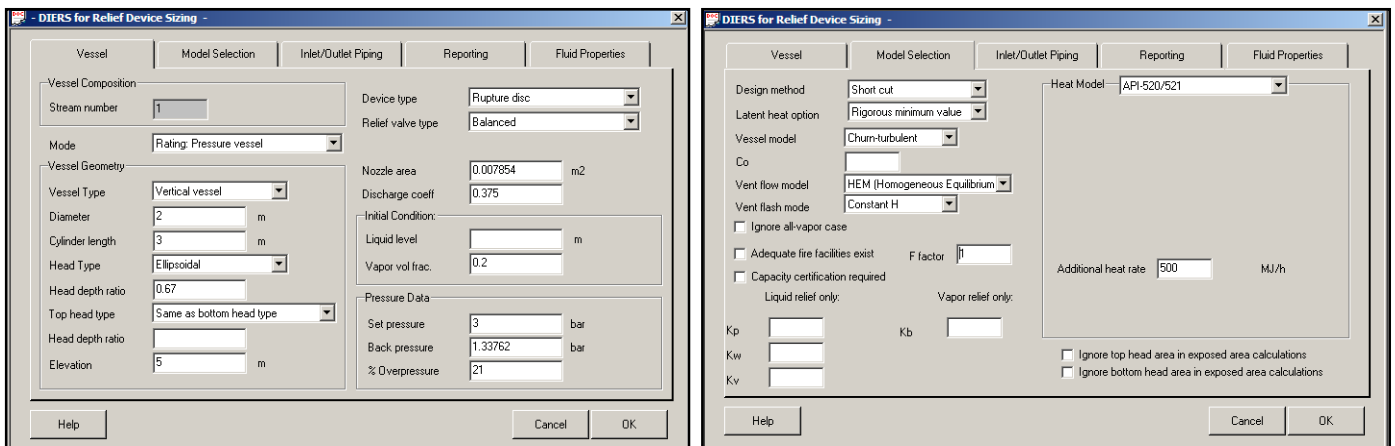


The Pipe UnitOps specifications windows are all specified as shown; note that Beggs and Brill for two phase flow is required and for the Nodes to calculate correctly Sizing Option 5 > Given size, P_{in} and P_{out} , calculate flow. Pipe size and length are entered to suit.



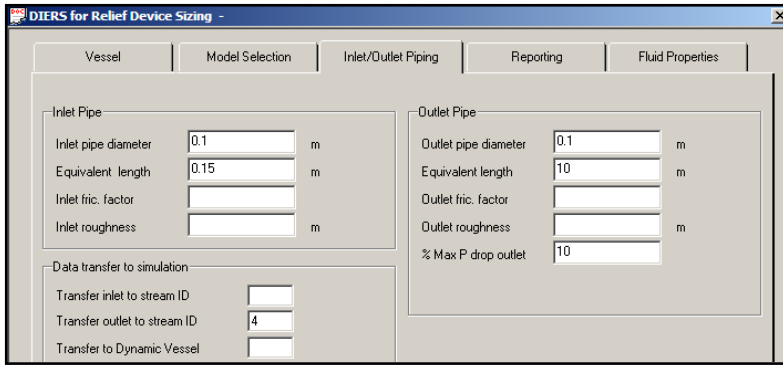
The relief flows from the individual reactor emergency relief devices are determined using Sizing > Relief Device. The relief stream to be studied is selected by single mouse click (note black squares at ends of stream). The stream is specified to represent the relief device inlet at stagnant conditions. The component weight fractions are entered with a nominal flow set at any value, say 1, in units used. The stream pressure is set at the relief pressure and the vapour fraction set at 0 to give the bubble point of the mixture.

The relief device specifications are entered as shown



MODEL CONFIGURATION

The Inlet and Outlet piping details are entered. Note that the outlet stream from the relief device is transferred to Stream 4, the appropriate inlet to the vent piping network.



Device type	Rupture disc	
Vent model	HEM (Homogeneous Equilibrium Model)	
Vessel model	Churn turbulent model	
Design model	API-520/521	
Rating	Pressure vessels.	
API 520-521	Adequate firefighting and drainage facilities do not exist.	
Vertical vessel		
Head type	Ellipsoidal	
Head K factor (dpth / R)		0.67
Vessel dimensions:		
Diameter	m	2
Length (T to T)	m	3
Vessel volume	m ³	12.231
Liquid level	m	3.338
Initial vapor volume fraction		0.2
Height above ground	m	5
Fluid properties:		
Vapor mass	kg	20.346
Liquid mass	kg	7657.3
Vapor density	kg/m ³	8.3173
Liquid density	kg/m ³	782.55
Surface tension	N/m	0.014767
Liquid viscosity	cP	0.23956
Vapor Z factor		0.93221
Cp/Cv		1.1262
Vapor MW		72.107
Liquid heat capacity	kJ/kg-K	2.0635
Latent heat	kJ/kg	381.02
Relief device analysis:		
Set pressure	bar	3
Back pressure	bar	1.3376
% Overpressure		21
Temperature	C	109.14
Discharge coefficient		0.375
C0 radial distribution paramtr		1.5
Kb Backpressure corr. factor		1
Exposed area	m ²	20.822
Environmental factor		1
* Additional heat rate	MJ/h	500
Heat rate	MJ/h	3579.6
Check adequacy of device for rating case.		
Specified nozzle area	m ²	0.007854
Rupture disc diameter	m	0.1
Calculated nozzle area	m ²	0.0065066 (For heat model 1)
The following calculation is base on vent area	0.007854 m ² .	
Calculated vent rate	kg/h	11543
Calc critical rate	kg/h	11543
Calc critical press	bar	2.1171
Nozzle inlet vap. mass fraction		0.8302
Device inlet density	kg/m ³	9.9967
Nozzle inlet vap. vol. fraction		0.99783

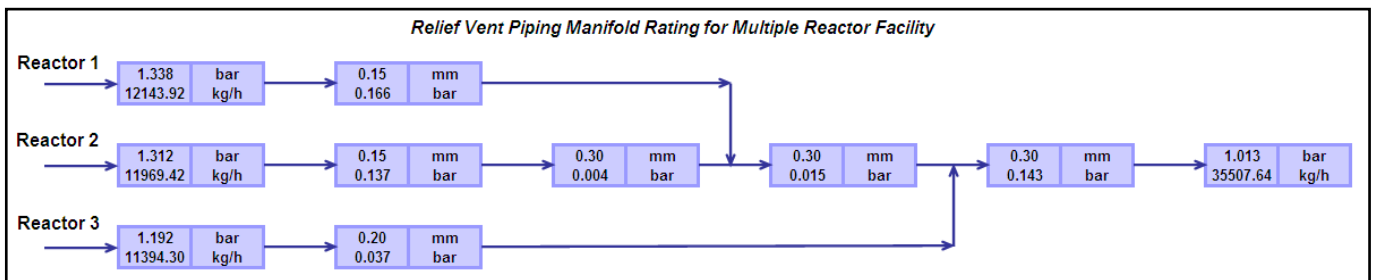
On clicking OK the relief sizing report is generated in Excel as shown.

The relief manifold back pressure is now re-entered as the relief device back pressure and the sizing re-run until the manifold back pressure equals relief device back pressure.

RESULTS

The results have been presented in a Graphical User Interface (GUI) format to give a clearer representation. It has been generated using the CHEMCAD Data Map facility. The graphics and reporting have been done using Excel.

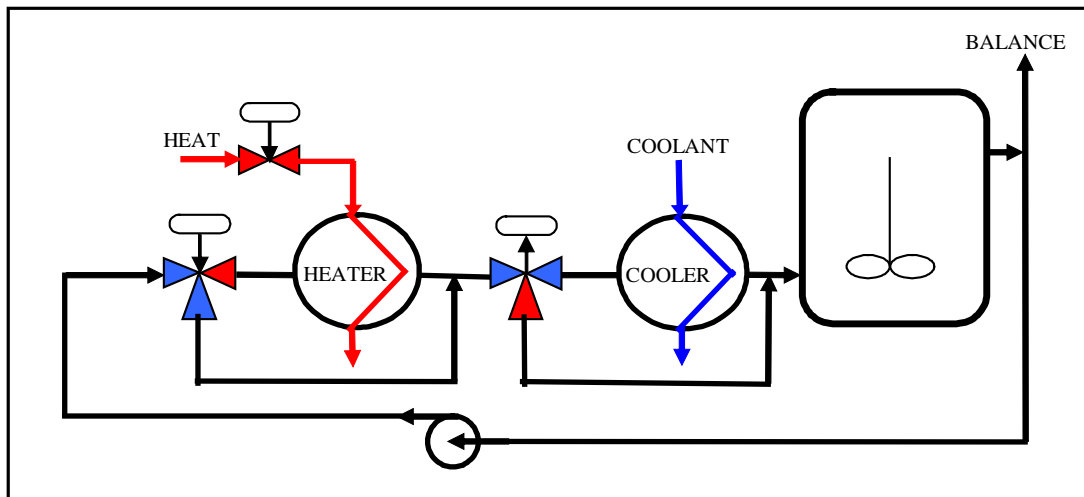
Note that the manifold back pressure is < 0.5 x the set pressures of the relief devices which verifies that the relief venting is not being reduced by the manifold for a coincident relief scenario.



CHEMCAD 6.0 SIZING TOOLS – REACTOR JACKET CIRCULATION STUDY

PROCESS DESCRIPTION

This Case Study investigates a batch reactor temperature control system which uses a jacket recirculation loop as shown in the schematic below. It was required to determine recirculation sytem pressure drops, size the pump and confirm satisfactory jacket side heat transfer film coefficients.



This arrangement requires an adequate recirculation flowrate determined by the reactor size and number of mixing nozzles. The jacket inlets have mixing nozzles fitted to induce a rotational flow in the jacket and enhance heat transfer. Nozzles should be fitted to induce circulation in the same direction of rotation. Inadequate flow and / or high viscosity at low temperatures will result in poor heat transfer and could result in loss of thermal stability when carrying out exothermic reactions.

CHEMCAD does not predict the pressure drop across the mixing nozzles, so the Pfaudler Balfour correlation, shown below, is used. The pressure drop was calculated in Excel and transferred interactively to the model.

$$P = \left(\frac{G}{N} \right)^{1/C} \left(\frac{SG \mu^{0.23}}{0.8A} \right)$$

- Where G circulation flow (US gpm)
- P jacket pressure drop (psi)
- SG specific gravity
- μ viscosity (cps)
- N number of agitating nozzles
- A, C constants depending on nozzle size

Note: Total jacket pressure drop = 1.25 x Nozzle Pressure

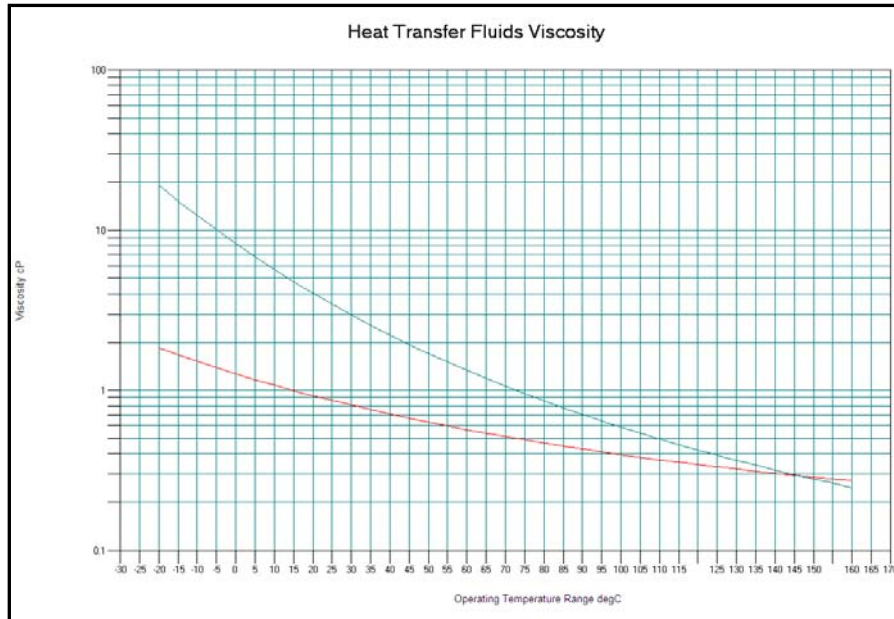
Mixing Nozzle Constants and Maximum Recommended Flow			
Size (ins)	A	C	Maximum Flow (m3/h)
3.0	700.0	0.5	43
2.0	144.0	0.5	17.0
1.5	60.0	0.51	9.0
1.25	36.8	0.48	

The case study is based on a Pfaudler Balfour AH 500-LL glass lined reactor with two 1.5" mixing nozzles fitted and a jacket circulation rate of 16 m³/h using a nominal pipe size of 2 in.

The jacket operating temperature range was -20°C to 160°C and heat transfer fluid Dowtherm J was selected as being suitable. User component 50% Ethylene Glycol / Water mixture at -20°C was the coolant available on plant.

PROCESS DESCRIPTION

The viscosity temperature graph, shown below, has been obtained from the Thermophysical - Data Base - Plot Properties facilities in CHEMCAD.



The jacket side film coefficient is calculated from the following correlations:

$$E = \frac{D_2^2 - D_1^2}{D_1}$$

Where E equivalent diameter of jacket space for heat transfer
 D₂ jacket inside diameter (in)
 D₁ shell outside diameter (in)

The modified Reynolds Number due to inconsistent units is given by:

$$R = \frac{39.75 G SG}{E \mu N^{0.5} DN^2}$$

Where DN mixing nozzle diameter (in) and all other symbols as previously noted

For turbulent flow conditions in the jacket, Re > 60, the jacket film coefficient is calculated from:

$$h = \frac{433 k R^{0.66} \left(\frac{C_p \mu}{k} \right)^{0.333}}{E}$$

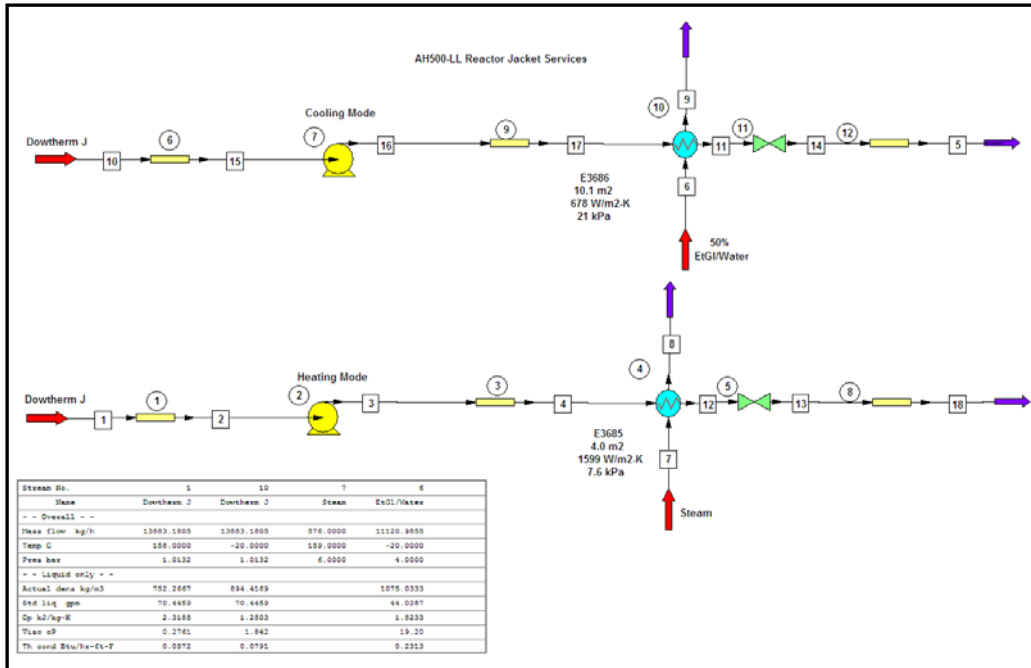
For laminar flow conditions in the jacket, Re ≤ 60, the jacket film coefficient is calculated from:

$$h = \frac{6.14 k R^{1.7} \left(\frac{C_p \mu}{k} \right)^{0.333}}{E}$$

Where k thermal conductivity (Btu / ft² h °F / ft)
 h jacket film coefficient (Btu / ft² h °F)
 C_p specific heat (Btu / lb °F)
 μ viscosity (cps)

CHEMCAD FLOWSHEET

For practice you can build the model or use the model called TCMCIRCOWJ in the electronic media supplied. It is strongly recommended that you work with a copy of this job. The model flowsheet is shown that represents the piping layout .



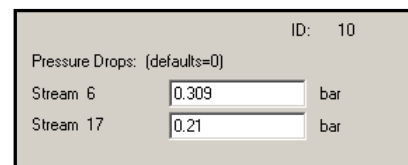
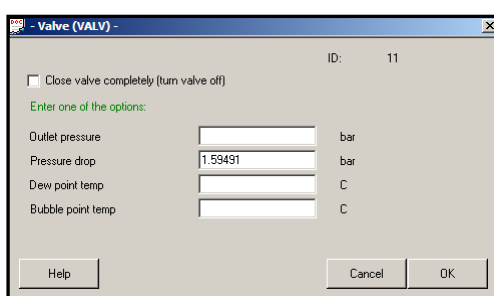
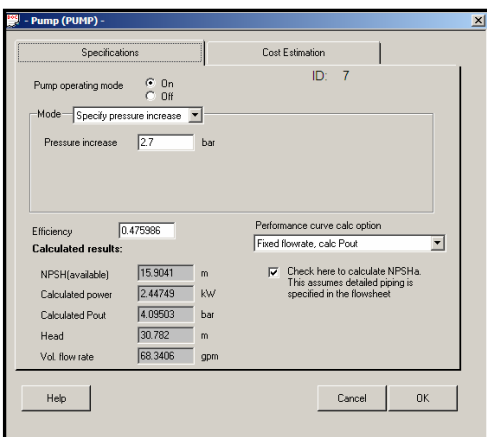
MODEL CONFIGURATION

The Pipes Sizing Tool is suitable for an initial assessment of pipe sizing, say for initial estimating purposes, but when progressing to detailed design the Pipe UnitOp is used. This UnitOp provides extensive sizing methods coupled with the facility to enter elevation changes, pipe fittings and valves. In this case ball valves are being used and their treatment is discussed in Appendix I.

The inlet stream pressure is set to 1.25 bar being equivalent to the pad pressure of the system; two cases are used to study the behaviour at minimum and maximum temperatures.

The pump UnitOp is used in its simplest format, being set for pressure increase, which is then adjusted manually until the outlet stream pressure is equal to 1.25 bar. This mode is acceptable in this configuration but would not be suitable if a recycle was involved as it would add the specified pressure increase on each iteration. Pump curves can be introduced if required.

The jacket pressure drop is catered for by using the Valve UnitOp. The pressure drop is calculated in Excel using the prevailing Stream conditions and then transferred to the model using the Data Mapping feature. The heat exchanger pressure drop is entered into the simplified Heat Exchanger UnitOp.



RESULTS

The control (supervisory) spreadsheet TCMCIRCDOWJ for this job is shown below. The input stream parameter conditions can be defined here and stream physical property data, as required, is mined from the model for calculation purposes.

1	Flow(Std)	Density	Viscosity	Temperature	Jacket DP	Pump	Head	Pump NPSH	Conductivity	Specific Heat	V1553 Reactor AH-500-LL Dimensions			Equivalent	Modified	Jacket Film	Coefficient	
2	G	ρ	μ	t	P	Pout	H	H	k	Cp	D2	D1	Diameter	Reynolds #	h	h	h	
3	gpm(US)	kg/m3	cp	deg C	bar	bar	m fluid	m fluid	Btu/ft h F	Btu/lb F	mm	in	mm	in	E	Re	Btu/ft2hF	W/m2K
4	70.45	751.74	0.28	158.57	0.87	3.27	26.4	10.53	0.057	2.320	1607	63.3	1535	60.43	5.802	337.56	444.62	2524.5
5	kg/h	gpm(US)			psi	m wg	Hx1.2				Reference: K.Thompson 04/09/06							
6	13883.18	81.31			8.84	33.38	31.72											
7	gpm(US)	kg/m3	cp	degC	bar	bar	m fluid	m fluid	Btu/ft h F	Btu/lb F								
8	70.45	894.30	1.84	-19.84	1.59	4.10	30.8	15.90	0.079	1.253								
9	kg/h	gpm(US)			psi	m wg	Hx1.2											
10	13883.18	68.35			16.26	41.76	36.94											
11																		
12	Nozzle D	Nozzle	Coefficients		P = $\left(\frac{G}{N}\right)^{1/2} \left(\frac{SG \cdot \mu^{0.22}}{0.8 \cdot A}\right)$		V1553		Design Case		h = $\frac{6.14 \cdot k \cdot R^{1.7} \cdot (C_p \mu)^{0.333}}{E}$		Re ≤ 60		h = $\frac{433 \cdot k \cdot R^{0.66} \cdot (C_p \mu)^{0.333}}{E}$		Re > 60	
13	in	Number	A	C			500 gal	Fluid	m3/h									
14	1.5	2	60	0.51				Dowtherm J	16.0									
15	Dynamic Friction Loss Summary										Cell Colour Key		Re ≤ 60		Re > 60			
17	Mode	Suction	Discharge	Heat Exch	Jacket	Return	Total Discharge Friction Loss			Calculated Data								
18		bar	bar	bar	bar	bar	bar	m wg	m fluid	Data to CCD								
19	Heating	0.185	0.653	0.078	0.866	0.114	1.712	17.460	23.226	Data from CCD								
20	Cooling	0.169	0.592	0.210	1.595	0.103	2.500	25.494	28.507	CCD Validation Data								

This feature provides the designer with very powerful facilities for performing calculations external to the model and testing for their impact on performance. It also allows the model performance to be validated against established engineering correlations, in other words provides an independent check.

The model is set up to determine the pressure drop and pump characteristics at the maximum and minimum operating temperatures.

Initially the design proposed the use of a 50% Ethylene Glycol / Water mixture directly on the jacket. However it was established that laminar conditions were prevalent on the jacket, resulting in unacceptable nozzle pressure drops and heat removal capabilities. The use of Dowtherm J provided satisfactory thermal and hydraulic conditions.

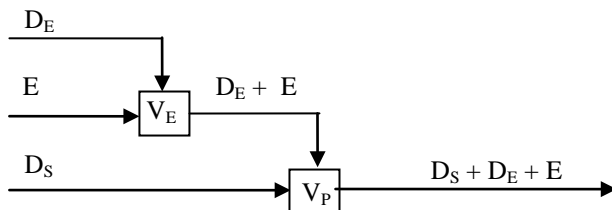
The design case for the pump head was at the minimum operating temperature requiring a head of 30.8 m of fluid at a discharge pressure of 41.8 m wg. The jacket pressure drop was calculated, at minimum temperature, as 1.59 bar; this value was transferred to the model UnitOp Valve. The design case for NPSH occurred at the maximum operating temperature with 10.53 m fluid being available.

This model can be used for studying similar systems using any selected heat transfer fluid.

CHEMCAD 6.0 SIZING TOOLS – STREAM BLENDING SYSTEM STUDY

PROCESS DESCRIPTION

This Case Study investigates a flow blending application in which a “wild” flow from a ship offloading facility is blended with an additive stream of varying composition to achieve a preset blend specification. The basic flow diagram and nomenclature used are shown below:



- Where D_E Diesel in Methyl Ester Flow (m³/h)
- E Methyl Ester Flow (m³/h)
- V_E Methyl Ester Volume Fraction
- D_S Diesel Flow from Ship (m³/h)
- D_P Bio-diesel Blend Flow (m³/h)
- V_P Bio-diesel Product Volume Fraction

$$V_E = \frac{E}{E + D_E} \text{ rearranging gives } D_E = \frac{E(1 - V_E)}{V_E}$$

Substituting for D_E $V_P = \frac{E}{E + D_E + D_S}$ gives $E = \frac{V_P D_S}{(1 - V_P/V_E)}$ and $\frac{D_E + E}{D_S} = \frac{1}{(V_E/V_P - 1)}$

We can now determine the Methyl Ester flow required to achieve a specified product blend volume fraction knowing Ship Diesel Flow and Methyl Ester volume fraction in the Methyl Ester / Diesel mixture. This relationship is used to derive the control system set point.

The process flow ratio is calculated from the equation

$$\frac{D_E + E}{D_S} = \frac{1}{(V_E/V_P - 1)}$$

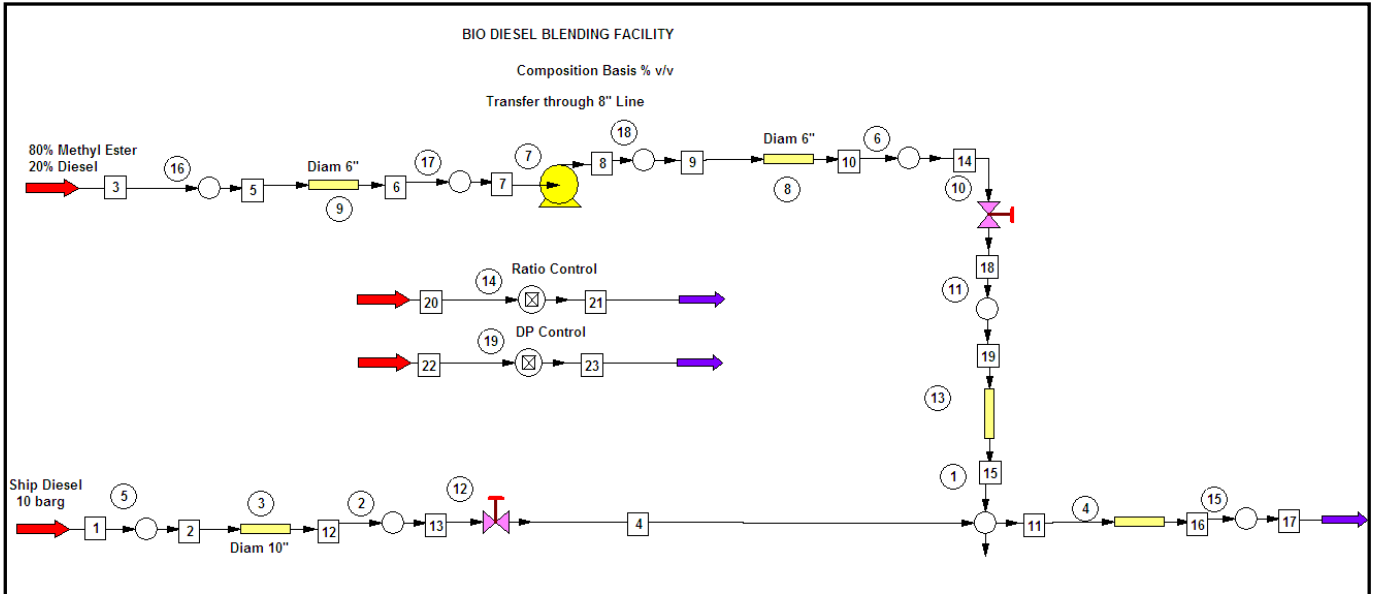
which gives the following results

Ester Blend to Ship Flow Ratios			
Methyl Ester %	Product Blend %	V_E / V_P	Ship to Ester Blend Flow Ratio
100	15	6.667	0.176
	10	10.0	0.111
	5	20.0	0.053
80	15	5.33	0.231
	10	8.0	0.143
	5	16.0	0.067

The above relationship allows the process operator to set the final Product blend volume fraction by simply entering the Methyl Ester blend and final Product blend volume fractions. The control system flow ratio will be derived automatically.

CHEMCAD FLOWSHEET

For practice you can build the model or use the model called BLENDCONTROL in the electronic media supplied. It is strongly recommended that you work with a copy of this job. The model flowsheet is shown that represents the piping layout .



CONFIGURATION

This model is operated in full dynamic mode. To provide the required operational flexibility the blend pump is provided with a variable speed motor to control the pressure drop across the blend flow ratio control valve.

The Pump UnitOp 7 is specified by using the manufacturer’s pump curve data using two speed lines as shown below:

- Pump (PUMP) -

Specifications | Cost Estimation

Pump operating mode: On, Off ID: 7

Mode: Specify performance curve

Number of speed lines: 2

Pump speed: 2536.2 RPM

Scale factor: []

Efficiency: 0.677409

Performance curve calc option: Fixed flowrate, calc Pout

Calculated results:

NPSH(available): [] m

Calculated power: 84.9961 kW

Calculated Pout: 14.568 bar

Head: 154.184 m

Vol. flow rate: 158.297 m3/h

Check here to calculate NPSHa. This assumes detailed piping is specified in the flowsheet

Buttons: Help, Cancel, OK

- Pump Performance Curve -

RPM: 1500

Vol. flowrate m3/h	Efficiency fractional (0 - 1)	Head m
1e-006	1e-006	42.84
40	0.43	40.2
80	0.64	39.78
120	0.7	35.7
160	0.68	26.52
200	0.25	15
240	0.15	10

- Pump Performance Curve -

RPM: 2960

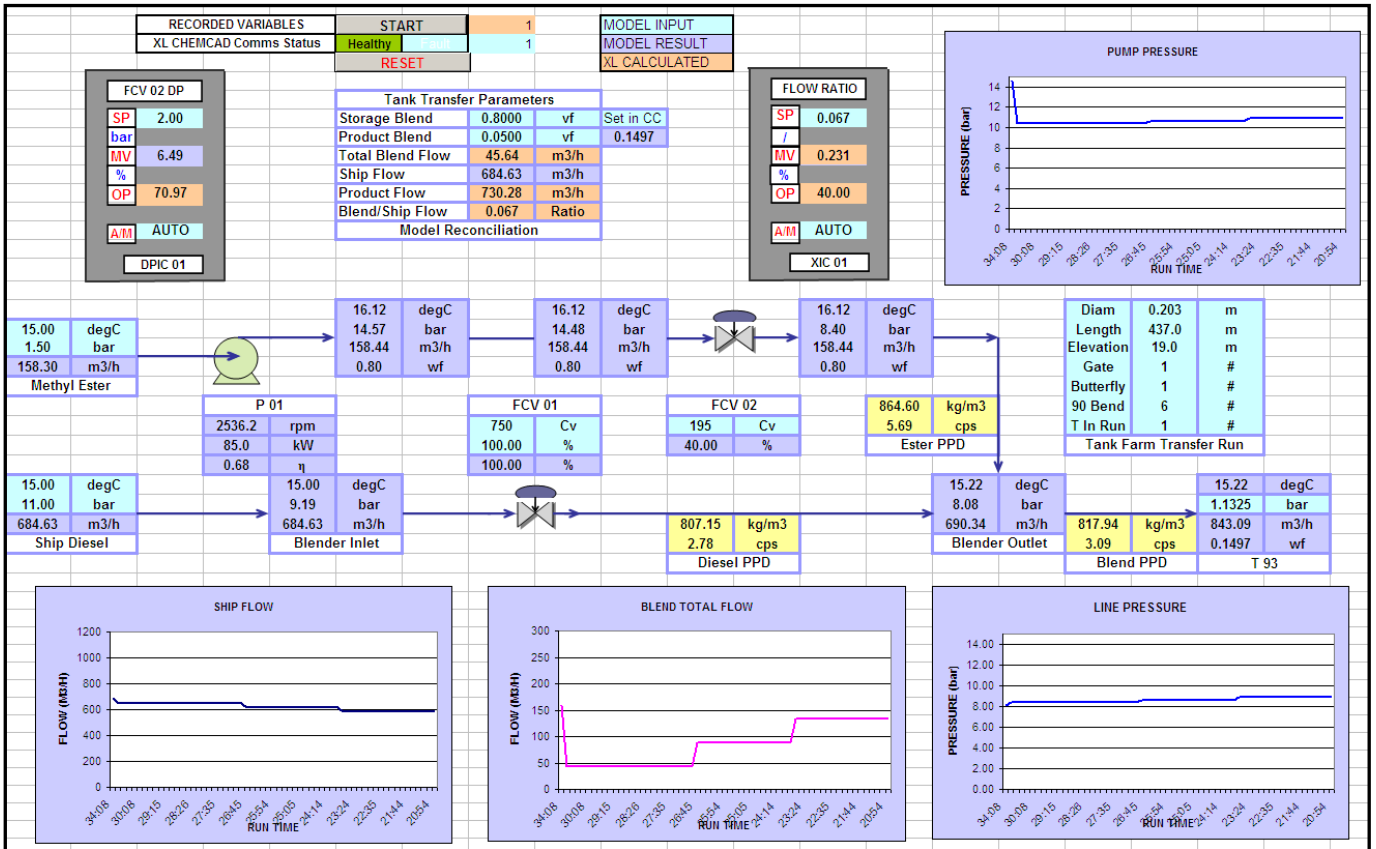
Vol. flowrate m3/h	Efficiency fractional (0 - 1)	Head m
1e-006	1e-006	163.2
40	0.26	161.16
80	0.46	160.14
120	0.59	159.12
160	0.68	155.04
200	0.72	147.9
240	0.74	138.72

The blend ratio between Streams 14 and 15 is controlled at a preset value using Controller UnitOp 14 to adjust Control Valve UnitOp 10 position. The pressure drop across this valve is controlled using Controller UnitOp 19 to adjust Pump UnitOp 7 speed.

RESULTS

The plots in the Excel control sheet calculates the results for 80% and 100% Methyl Ester transfer to T 93 for product blends of 5%, 10% and 15%. The Excel spreadsheet is provided with a “Row Insert” macro which allows CHEMCAD model results, after each iteration, to be transferred to a new blank row which, in turn, results in a column of data to provide the plots as shown. The CHEMCAD model is controlled from an Add In function available from CC5 and the macro is controlled from the Start / Reset Control buttons.

For convenience a Dynamic Model is used to allow for Methyl Ester blend changes to be entered during the run. The spreadsheet enables the CHEMCAD model results to be validated by independent calculation and helped in the development of a suitable control strategy.



The control strategy developed is summarised below:

This flow ratio will be entered into the flow ratio control system which will manipulate the Methyl Ester blend flow control valve to achieve the desired ratio. In the event that the Methyl Ester blend flow cannot achieve the required ratio the control system will cut back the Ship Discharge flow control valve. This cut back feature will be achieved by split range valve operation.

The pressure drop across the Methyl Ester flow control valve will be controlled at an operator preset value by manipulating the duty Methyl Ester blend pump speed. It is anticipated that the optimum pressure drop setting will vary depending on the back pressure resulting from the transfer line to tank farm storage.

The CHEMCAD process model predicted Ship Discharge flows in the range 685 to 758 m³/h for transfers to T93 and 580 to 653 m³/h for transfers to T37 indicating that pipe line pressure drops are controlling.

APPENDICES

- Appendix I Fluid Flow in Pipes Fundamentals**
- Appendix II Flow Meter Considerations**
- Appendix III Control Valve Logic in CHEMCAD**
- Appendix IV General Information**

Appendix I

Fluid Flow in Pipes Fundamentals (Reference Crane 410M)

Pressure at the base of a vertical column of fluid

$$p = H \rho$$

- p** pressure (lb/ft²)
- H** height of column of fluid (ft)
- ρ** specific weight of fluid (lb/ft³)

Continuity Equation for incompressible fluid flow:

$$Q = a_1 v_1 = a_2 v_2 \quad \longrightarrow \quad D_1^2 v_1 = D_2^2 v_2 \quad \longrightarrow \quad \frac{D_1^2}{D_2^2} = \frac{v_2}{v_1} = \beta$$

Bernoulli's Equation in consistent units (ft lb/lb = ft or m)

$$\frac{p_1}{w} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{w} + \frac{v_2^2}{2g} + z_2 + \sum h_L$$

- a** area of flow section (ft², m²)
- D** circular pipe diameter (ft, m)
- v** velocity of fluid (ft/s, m/s)
- g** gravitational constant (32.2 ft/s² or 9.81 m/s²)
- z** potential energy or static head (ft, m)
- h_L** losses due to friction or work done
- 1, 2** state 1 to state 2, below 1 refers to smaller diameter and 2 to larger diameter

Apply Bernoulli's equation for loss at sudden enlargement from small diameter 1 to large diameter 2

$$\frac{v_1^2}{2g} = \frac{v_2^2}{2g} + h_L \quad \longrightarrow \quad h_L = \frac{(v_1 - v_2)^2}{2g} \quad \longrightarrow \quad h_L = \frac{v_1^2}{2g} (1 - \beta^2)^2 = K_1 \frac{v_1^2}{2g}$$

The final form is equivalent to Crane equation 3.17.1, to express loss in terms of larger diameter:

$$h_L = \frac{K_1}{\beta^4} \frac{v_2^2}{2g} = K_2 \frac{v_2^2}{2g}$$

For loss due to sudden contraction

For loss at entry to pipe

For loss at exit from pipe

Refer to Crane 410M A-26 for gradual contractions and enlargements.

$$h_L = 0.5 (1 - \beta^2) \frac{v_1^2}{2g}$$

$$h_L = 0.5 \frac{v_1^2}{2g}$$

$$h_L = \frac{v_1^2}{2g}$$

Appendix I

General Equations for Fluid Flow

The Darcy equation is used to calculate the friction head loss h_L (m or ft) of fluid:

$$h_L = \frac{f L}{D} \frac{v^2}{2g}$$

f Darcy friction factor, also known as the Darcy-Weisbach or Moody or Blasius friction factor

L equivalent length of pipe (m or ft)

Note that friction factor f is dimensionless:

$$f = \frac{\text{m}}{\text{m}} \frac{\text{s}^2}{\text{s}^2} = 1$$

In using reference data care should be taken to ensure the correct friction factor data is being used. Unfortunately friction factors are sometimes quoted without definition and incorrect use can lead to significant errors. CHEMCAD Pipe UnitOp uses the Darcy form throughout.

The Fanning friction factor f_F is commonly used in Chemical Engineering and is related to the Darcy friction factor f as follows:

$$f = 4f_F$$

The form of the Darcy equation using the Fanning friction factor becomes

$$h_L = \frac{2f_F L}{D} \frac{v^2}{g}$$

or in the more common form

$$h_L = \frac{4f_F L}{D} \frac{v^2}{2g}$$

For laminar flow conditions (Reynolds Number $Re < 2300$). The

Darcy friction factor is given by

$$f = \frac{64}{Re} \quad \text{and the Fanning is given by } f_F = \frac{16}{Re} \quad \text{where}$$

$$Re = \frac{v D \rho}{\mu}$$

The Jain equation is used to solve directly for the Darcy Weisbach friction factor f for a full-flowing circular pipe. It is an approximation of the implicit Colebrook-White equation.

$$f = \frac{0.25}{\left[\log_{10} \left(\frac{\epsilon}{3.7D} + \frac{5.74}{Re^{0.9}} \right) \right]^2}$$

The equation was found to match the Colebrook-White equation within 1.0% for $10^{-6} < \epsilon/D < 10^{-2}$ and $5000 < Re < 10^8$. However the Churchill method is applicable for all values of ϵ/D and Re .

For an independent check of the friction factor the Moody diagram is used. Knowing the pipe flow Re and the pipe roughness coefficient ϵ (units of m or ft), giving the relative roughness ϵ/D (consistent units), the friction factor can be determined. The laminar flow line formula will allow verification of the diagram friction factor being used. Check friction factor at $Re=1000$; if Darcy $f=0.064$ and if Fanning $f_F=0.016$.

Appendix I

General Equations for Fluid Flow

A common form of the Darcy equation is the Darcy Weisbach equation which gives pressure drop in lb/in².

$$\Delta P = 0.00000336 \frac{f L W^2}{\rho d^5}$$

ΔP Pressure drop lb/in²

W Flow Rate lb/h

ρ Fluid Density lb/ft³

d Inside Diameter in

In a complex pipe system of pipes and fittings the total head loss is computed from each part using:

$$h_L = \sum \frac{f L}{D} \frac{v^2}{2g} + \sum K \frac{v^2}{2g}$$

It should be noted that f is the friction factor of the flowing fluid in the pipe section of diameter D whereas the equivalent lengths of valves and fittings are related to the fully turbulent friction factor f_t giving:

For the pipe $K = f \frac{L}{D}$ For the fittings $K = f_t \frac{L_{eq}}{D}$

An alternative approach is to determine the K values of the straight lengths of pipe, individual valves and fittings and substitute in the following:

$$\Delta P = 0.00000028 \frac{K W^2}{\rho d^4}$$

CHEMCAD calculates the equivalent length of fittings using the pipe friction factor and not the friction factor at fully turbulent conditions. This procedure is acceptable at fully turbulent conditions. However under laminar and transitional flow conditions the user should check, using the relationships presented here, to ensure acceptable design conditions.

If it is found that the pressure loss is significantly increased through the use of the prevailing friction factor the user can modify the equivalent length by adding an additional L/D correction in User Specified Fittings and Valve section on the Valve entry screen.

To overcome these problems CHEMCAD includes the facility to use the Darby 3K Method (Chemical Engineer July 1999, April 2001) which is valid over a wide range of Re and fitting size, can be used. Where we have:

$$K_f = \frac{K_m}{Re} + K_i \left(1 + \frac{K_d}{D_{in,nom}^{0.3}} \right)$$

3K values for common fittings are presented later.

Appendix I

Losses due to Valves, Pipe Fittings and Special Components

CHEMCAD library resistance coefficients are derived from the Crane 410M reference.

In CHEMCAD, when handling enlargements and contractions the reducer fitting should be located in the smaller diameter Pipe UnitOp.

Orifice Plates Crane (410M A-20)

Orifice Plate Resistance K_r value is declared in CHEMCAD result report.

$$C = \frac{C_d}{(1 - \beta^4)^{0.5}}$$

$$K_r \approx \frac{(1 - \beta^2)}{C^2 \beta^4}$$

In CHEMCAD pressure loss due to orifice plates is entered as a User fitting on the valve screen.

Control Valves

For a detailed review of valve sizing issues refer to Emerson Process Management, Fisher Control Valve Handbook, 4th Edition. However piping installation factors influencing the valve performance are reviewed here.

As a general “rule of thumb” control valves, fitted with full size trims, are usually sized to be less than the line size, typically $\frac{1}{2}D$. This results in valves being fitted between pipe reducers. Line size valves, fitted with reduced trims, simplify installation but with a potential increase in cost.

The valve sizing is adjusted by the Piping Geometry Factor, F_p , which for a valve installed between identical reducers, is given by:

$$F_p = \left(1 + \frac{\sum K}{N_2} \left(\frac{C_v}{d^2} \right)^2 \right)^{-0.5}$$

$$\sum K = K_1 + K_2 = 1.5 (1 - \beta^2)^2$$

d = nominal valve size (in or mm)

$\beta = d/D$

$N_2 = 0.00214$ (mm) and 890 (in) and C_v is valve sizing coefficient at 100% opening.

For liquid sizing we have a modified coefficient:

$$C_v = \frac{q}{N_1 F_p} \sqrt{\frac{G_f}{P_1 - P_2}}$$

$N_1 = 0.0865$ (m^3/h , kPa), 0.865 (m^3/h , bar), 1.00 (gpm, psia)

G_f = specific gravity referenced to water at 60°F

CHEMCAD allows for entry of F_p correction factor in the control valve sizing calculation procedure.

Appendix I

Losses due to Valves, Pipe Fittings and Special Components

It should be noted that for ball valves Crane quotes a standard L/D of 3. Manufacturers' data should be checked to see if this is valid for size and type of valves being used.

The Resistance Coefficients and L/D can be determined from manufacturers' C_v data as follows:

Crane 410M, Equation 3-16, page 3-4 gives:

$$C_v = \frac{29.9 D^2}{K^{0.5}} \quad \text{where} \quad K = \frac{h_L}{v^2/2g}$$

- D = Inside Pipe Diameter (in)
- C_v = Flow Coefficient (US gpm / psi)
- K = Resistance Coefficient (velocity head loss)

We also have the relationship:

$$K = f \frac{L}{D} \quad \text{for full turbulence} \quad \frac{L}{D} = \frac{K}{f_T}$$

- f = Darcy (Moody) friction factor
- f_T = Darcy (Moody) friction factor at full turbulence

Tables of equivalent lengths for reduced bore and full bore ball valves

Worcester Type 44/459 Reduced Bore Ball Valve						
Nominal Bore	C _v	L	L/D	K	Ft	D
mm	US gpm/psi	ft				in
15	8.3	1.9	36.7	1.942	0.053	0.622
20	13.6	5.5	80.1	2.228	0.028	0.824
25	37.5	3.0	34.3	0.770	0.022	1.049
40	79.7	3.9	29.1	0.946	0.033	1.610
50	106	7.5	43.5	1.452	0.033	2.067
80	435	7.0	27.4	0.419	0.015	3.068
100	638	27.0	80.5	0.577	0.007	4.026
150	675	41.0	81.1	2.655	0.033	6.065

Worcester Series 5 Flanged Ball Valve						
NB Sch 40	C _v	K	Ft 410M A23	L/D	L	D
mm	US gpm/psi		ε 0.05 mm		ft	in
15	32	0.131	0.0250	5.2	0.27	0.622
20	54	0.141	0.0240	5.9	0.40	0.824
25	94	0.123	0.0230	5.3	0.47	1.049
40	254	0.093	0.0200	4.7	0.63	1.610
50	130	0.966	0.0187	51.6	8.9	2.067
80	350	0.647	0.0175	36.9	9.4	3.068
100	720	0.453	0.0165	27.5	9.2	4.026
150	1020	1.163	0.0145	80.2	40.5	6.065
200	1800	1.120	0.0140	80.0	53.2	7.981
250	2970	1.034	0.0135	76.6	64.1	10.05

Appendix I

Piping Design Considerations

Industry practice for initial design of piping systems is based on economic velocity or allowable pressure drop $\Delta P/100\text{ft}$. Once detailed isometrics are available the design will be adjusted to satisfy local site conditions.

Reasonable Velocities for Flow of Fluids through Pipes (Reference Crane 410M)				
Service Conditions	Fluid	Reasonable Velocities		Pressure Drop
		m/s	ft/s	kPa / m
Boiler Feed	Water	2.4 to 4.6	8 to 15	
Pump Suction and Drain	Water	1.2 to 2.1	4 to 7	
General Service	Liquids pumped, non viscous	1.0 to 3.0	3.2 to 10	0.05
Heating Short Lines	Saturated Steam 0 to 1.7 bar	20 to 30	65 to 100	
Process piping	Saturated Steam 1.7 and up	30 to 60	100 to 200	
Boiler and turbine leads	Superheated Steam 14 and up	30 to 100	100 to 325	
Process piping	Gases and Vapours	15 to 30	50 to 100	0.02% line pressure
Process piping	Liquids gravity flow			0.05

Reasonable velocities based on pipe diameter (Process Plant Design, Backhurst Harker p235)

Pump suction line for d in $(d/6 + 1.3)$ ft/s and d mm $(d/500 + 0.4)$ m/s
 Pump discharge line for d in $(d/3 + 5)$ ft/s and d mm $(d/250 + 1.5)$ m/s
 Steam or gas d in $20d$ ft/s and d mm $0.24d$ m/s

Heuristics for process design (Reference W.D.Seader, J.D.Seider and D.R.Lewin, "Process Design Principles") are also given:

Liquid Pump suction $(1.3 + d/6)$ ft/s 0.4 psi /100 ft
 Liquid Pump discharge $(5.0 + d/3)$ ft/s 2.0 psi / 100 ft
 Steam or gas $(20d)$ ft/s 0.5 psi / 100 ft

Control valve pressure drop needs to be at a reasonable % of total system pressure drop to provide good control. If too low, ie valve oversized, the control valve opening will be small leading to unstable control; if too high flow could be limited leading to throughput concerns. A general "Rule of Thumb" is for a full sized trim control valve to be half the line size.

Appendix II

Flow Meter Considerations

To model piping systems, involving special items such as flow meters, CHEMCAD provides a facility under the Valve Data entry Window in the Pipe UnitOp for resistance parameters to be entered in various formats. The following guidelines should be considered when selecting flow meter sizes.

Magnetic Flow Meter

Velocity Limits for Flow of Fluids through Magnetic Flow Meters (Foxboro Bulletin)				
Service Conditions	Fluid	Reasonable Velocities		Pressure Drop
		m/s	ft/s	kPa / m
General Service and Process Piping	Liquids pumped, non viscous	0.9 to 4.6	3.0 to 15	Line size meter Same ΔP as pipe
	Erosive Slurries	0.9 to 4.6	3 to 6	
	Coating forming liquids	1.8 to 4.6	6 to 16	

Mass Flow Meter

Because of the wide turndown capability of Coriolis flowmeters (30:1 to as high as 200:1), the same flow can be measured by two or three different sized flow tubes subject to accuracy requirements. Using the smallest possible meter lowers the initial cost and reduces coating build-up, but increases erosion/corrosion rates and head loss.

Using a meter that is smaller than line size is acceptable if the process fluid is clean with a low viscosity. However on corrosive, viscous, or abrasive slurry services, this practice may cause reduced operational life. Flow tube sizes and corresponding pressure drops, inaccuracies, and flow velocities can be obtained from software provided by the manufacturer.

Different Coriolis meter principles incur different pressure drops, but in general they require more than traditional volumetric meters, which usually operate at less than 10 psi. This higher head loss is due to the reduced tubing diameter and the circuitous path of flow. Head loss can be of concern if the meter is installed in a low-pressure system, or if there is a potential for cavitation or flashing, or if the fluid viscosity is very high.

Vortex Shedding Meter

Measurable flow velocities on liquids are in the general range of 0.5 to 9.0 m/s (1.5 to 32 ft/s).

On gas or steam the flow velocities are in the range $\sqrt{\frac{74}{\rho}}$ to 79 m/s ($\sqrt{\frac{50}{\rho}}$ to 260 ft/s)

Where ρ fluid density (kg/m³ or lb/ft³)

Process fluid viscosity requires the Reynolds Number to be greater than 20000

Linear performance is achieved for Reynolds Number in the range 20000 to 7.0 E06

Appendix II

Flow Meter Considerations

Differential Head Flowmeters

The differential pressure measured and unrecovered pressure loss across a square edge concentric orifice plate is dependent on the pressure tap location; as shown in the diagrams below. It can be seen that full flow taps (2½D and 8D) measures the permanent pressure loss and should be used for restriction orifice calculations.

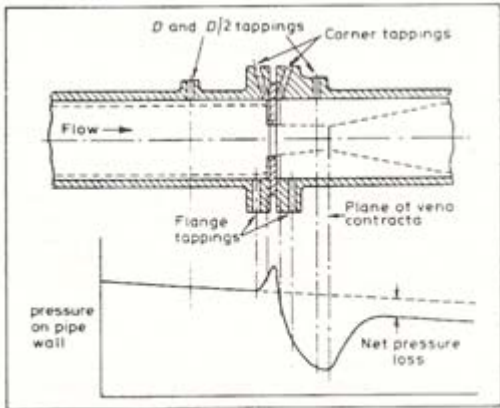
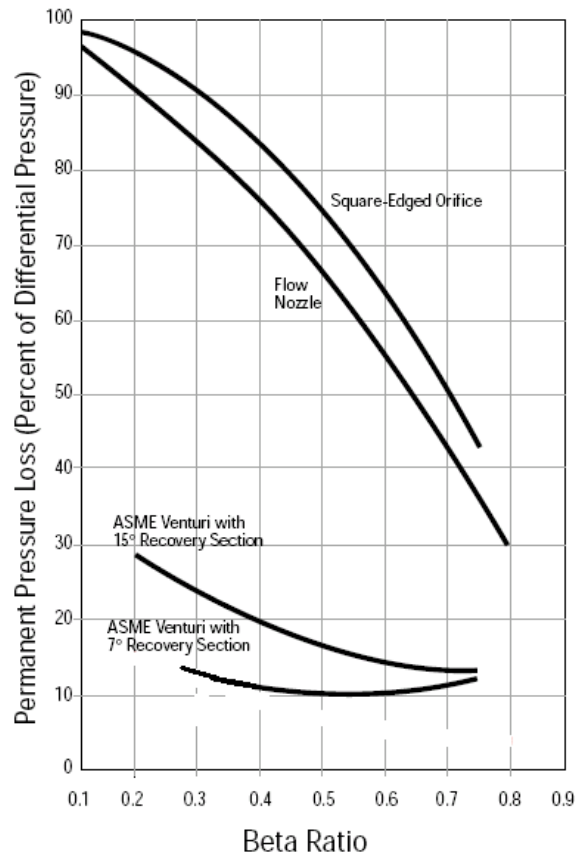


Figure 1—Section of square-edged orifice plate showing variation of pressure along the pipe wall (by courtesy of BSI)



For liquids

$$Q = K d^2 C \sqrt{\frac{h}{\rho_f}}$$

$$W = K d^2 C \sqrt{h \rho}$$

For gases

$$W = K d^2 C \sqrt{\frac{h \rho_f M}{T_f}}$$

The diagram below shows the dependency of flow coefficient C on Re and d/D (β). d/D (β) ratios ≤ 0.6 are preferred. For β > 0.6 viscosity effects are magnified combined with increased sensitivity to upstream piping configurations.

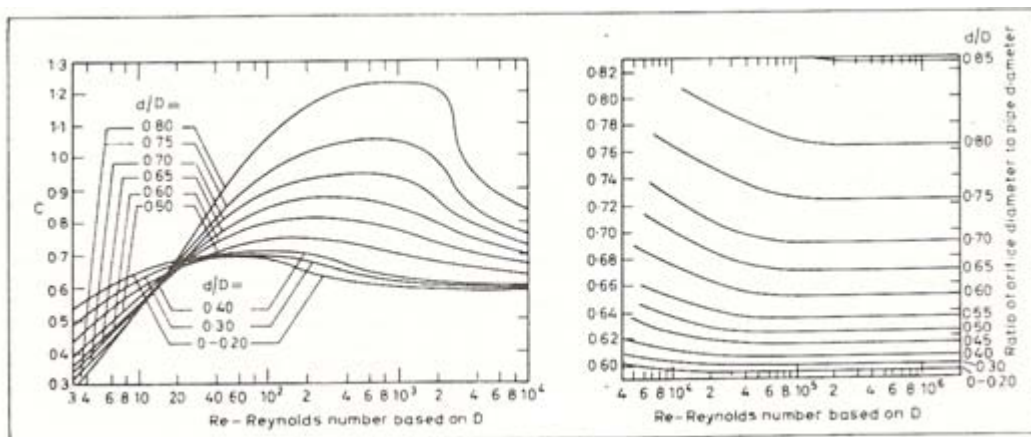


Figure 2—Flow coefficient C for square edged orifices (by courtesy of Crane Co)

Appendix III

Control Valve Logic in CHEMCAD

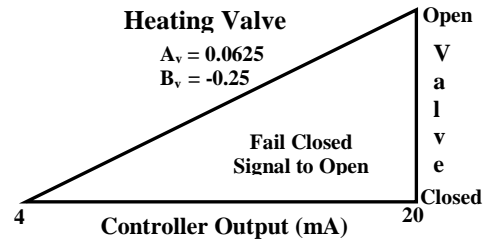
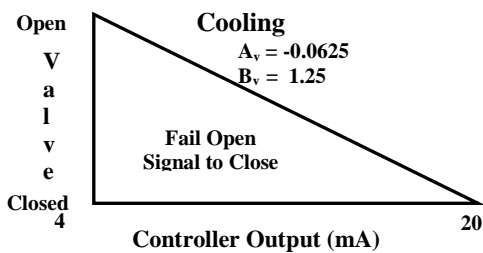
The controller output is used by the control valve to determine the valve position. The control valve algorithm is as follows:

$$T_v \left(\frac{du}{dt} \right) + u = A_v * P + B_v$$

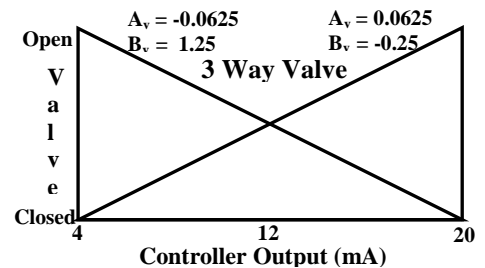
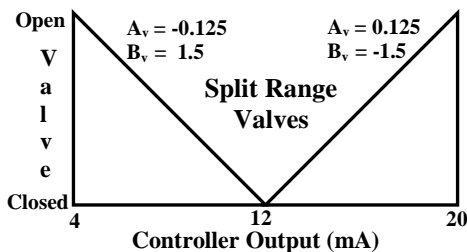
Where: T_v = valve time constant
 u = valve position logic 0(closed) or 1(open)
 P = input signal mA for logic 0 or 1

In the default condition, the time dependent term is equal zero. Time valve constant T_v must be either 0 or positive. The larger this value is the slower is the valve response to the signal change.

SINGLE CONTROL VALVE OPERATIONS							
ACTION	CONTROL OUTPUT		POSITION	STATE	LOGIC EQUATION	COEFFICIENTS	
	mA	%				A_v	B_v
FAIL CLOSED	4	0	Closed	0	$0 = 4A_v + B_v$	0.0625	-0.25
	20	100	Open	1	$1 = 20A_v + B_v$		
FAIL OPEN	4	0	Open	1	$1 = 4A_v + B_v$	-0.0625	1.25
	20	100	Closed	0	$0 = 20A_v + B_v$		



DUAL CONTROL VALVE OPERATIONS IN SPLIT RANGE							
ACTION	CONTROL OUTPUT		POSITION	STATE	LOGIC EQUATION	COEFFICIENTS	
	mA	%				A_v	B_v
FAIL CLOSED	12	50	Closed	0	$0 = 12A_v + B_v$	0.125	-1.5
	20	100	Open	1	$1 = 20A_v + B_v$		
FAIL OPEN	4	0	Open	1	$1 = 4A_v + B_v$	-0.125	1.5
	12	50	Closed	0	$0 = 12A_v + B_v$		



**Appendix IV
General Information**

**Pipe dimensions to ASME B36.1 /API 5L
Plastic Lined Pipe Dimensions**

Imperial

NB	DN	OD (inches)	Wall Thickness (inches)										
			SCH 5	SCH 10	SCH 20	SCH 30	SCH 40	SCH 60	SCH 80	SCH 100	SCH 120	SCH 140	SCH 160
3/4"	20	1.05	0.065	0.083	x	0.095	0.113	x	0.154	x	0.17	x	0.219
1	25	1.315	0.065	0.109	x	0.114	0.133	x	0.179	x	0.2	x	0.25
1.1/2	40	1.9	0.065	0.109	x	0.125	0.145	x	0.2	x	0.225	x	0.281
2	50	2.375	0.065	0.109	x	x	0.154	x	0.218	x	0.25	x	0.344
2.1/2	65	2.875	0.083	0.12	x	x	0.203	x	0.276	x	0.3	x	0.375
3	80	3.5	0.083	0.12	x	x	0.216	x	0.3	x	0.35	x	0.438
4	100	4.5	0.083	0.12	x	x	0.237	x	0.337	x	0.437	x	0.531
5	125	5.563	0.109	0.134	x	x	0.258	x	0.375	x	0.5	x	0.625
6	150	6.625	0.109	0.134	x	x	0.28	x	0.432	x	0.562	x	0.719
8	200	8.625	0.109	0.148	0.25	0.277	0.322	0.406	0.5	0.593	0.718	0.812	0.906
10	250	10.75	0.134	0.165	0.25	0.307	0.365	0.5	0.593	0.718	0.843	1	1.125
12	300	12.75	0.165	0.18	0.25	0.33	0.406	0.5	0.687	0.843	1	1.125	1.312

Metric

NB	DN	OD (mm)	Wall Thickness (mm)										
			SCH 5	SCH 10	SCH 20	SCH 30	SCH 40	SCH 60	SCH 80	SCH 100	SCH 120	SCH 140	SCH 160
3/4"	20	26.67	1.65	2.11	x	2.41	2.87	x	3.91	x	4.32	x	5.56
1	25	33.401	1.65	2.77	x	2.90	3.38	x	4.55	x	5.08	x	6.35
1.1/2	40	48.26	1.65	2.77	x	3.18	3.68	x	5.08	x	5.72	x	7.14
2	50	60.325	1.65	2.77	x	x	3.91	x	5.54	x	6.35	x	8.74
2.1/2	65	73.025	2.11	3.05	x	x	5.16	x	7.01	x	7.62	x	9.53
3	80	88.9	2.11	3.05	x	x	5.49	x	7.62	x	8.89	x	11.13
4	100	114.3	2.11	3.05	x	x	6.02	x	8.56	x	11.10	x	13.49
5	125	141.3002	2.77	3.40	x	x	6.55	x	9.53	x	12.70	x	15.88
6	150	168.275	2.77	3.40	x	x	7.11	x	10.97	x	14.27	x	18.26
8	200	219.075	2.77	3.76	6.35	7.04	8.18	10.31	12.70	15.06	18.24	20.62	23.01
10	250	273.05	3.40	4.19	6.35	7.80	9.27	12.70	15.06	18.24	21.41	25.40	28.58
12	300	323.85	4.19	4.57	6.35	8.38	10.31	12.70	17.45	21.41	25.40	28.58	33.32

CRP Flex-Rite Ltd Lined Pipe Dimensions www.crp.co.uk		
Spool NB in	PTFE Thickness mm	Pipe Wall Thickness mm
1/2	2.0	2.9
3/4	2.0	2.9
1	3.2	3.4
1 1/2	3.2	3.7
2	3.3	3.9
3	3.3	5.5
4	4.5	6.0
6	5.5	7.1
8 Standard	5.0	7.0
8 Heavy	8.0	7.0
10 Standard	5.0	7.8
10 Heavy	9.0	7.8
12 Standard	6.0	8.4
12 Heavy	9.5	8.4

Appendix IV General Information

Table of Roughness Coefficients

For turbulent flow the friction coefficient depends on the Reynolds Number and the roughness of the duct or pipe wall. Relative roughness for materials are determined by experiments.

Surface	Roughness Coefficients ϵ	
	Roughness Coefficient ϵ	
	0.001 m	ft
Copper, Lead, Brass, Aluminium	0.001 – 0.002	$3.33 - 6.7 \cdot 10^{-6}$
PVC and Plastic Pipes	0.0015 – 0.007	$0.5 - 2.33 \cdot 10^{-5}$
Stainless Steel	0.015	$5 \cdot 10^{-5}$
Commercial Steel Pipe	0.045 – 0.09	$1.5 - 3 \cdot 10^{-4}$
Drawn Steel	0.015	$5 \cdot 10^{-5}$
Weld Steel	0.045	$1.5 \cdot 10^{-4}$
Galvanized Steel	0.15	$5 \cdot 10^{-4}$
Rusted Steel(corrosion)	0.15 – 4	$5 - 133 \cdot 10^{-4}$
New Cast Iron	0.25 – 0.8	$8 - 27 \cdot 10^{-4}$
Worn Cast Iron	0.8 – 1.5	$2.7 - 5 \cdot 10^{-3}$
Rusty Cast Iron	1.5 – 2.5	$5 - 8.3 \cdot 10^{-3}$
Asphalted Cast Iron	0.01 – 0.015	$3.33 - 5 \cdot 10^{-5}$
Smoothed Cement	0.3	$1 \cdot 10^{-3}$
Ordinary Concrete	0.3 - 1	$1 - 3.33 \cdot 10^{-3}$
Coarse Concrete	0.3 - 5	$1 - 16.7 \cdot 10^{-3}$
Well Planed Wood	0.18 – 0.9	$6 - 30 \cdot 10^{-4}$
Ordinary Wood	5	$16.7 \cdot 10^{-3}$

Darby 3K Coefficient Values (Reference Darby Chemical Engineering April 2001)

Fitting		r/D	(L/D) _{eq}	K _m	K _i	K _d
Tees, Flow Through Branch (as elbow)	Threaded	1.0	60	500	0.274	4.0
	Threaded	1.5	None	800	0.14	4.0
	Flanged	1.0	20	800	0.28	4.0
	Stub-in branch		None	1000	0.34	4.0
Tees, Flow Through Run	Threaded	1.0	20	200	0.091	4.0
	Flanged	1.0	None	150	0.017	4.0
	Stub-in branch		None	100	0	0
Valves (ρ in lb/ft ³)	Diaphragm	Dam Type	None	1000	0.69	4.9
	Plug 3 way	Branch	90	500	0.41	4.0
	Plug 3 way	Through	30	300	0.14	4.0
	Plug	Straight	18	300	0.084	3.9
	Gate	$\beta = 1$	8	300	0.037	3.9
	Globe	$\beta = 1$	340	1500	1.70	3.6
	Swing Check	$v_{\min} = 35 \rho^{-0.5}$	100	1500	0.46	4.0
	Lift Check	$v_{\min} = 40 \rho^{-0.5}$	600	2000	2.85	3.8

Appendix IV
General Information

Control Valve Sizing Coefficients (Reference Fisher Handbook 4th Edition)

Single Ported Globe Style Valve Bodies					
Size (in)	Plug Type	Characteristic	Port ϕ (in)	Travel (in)	C_v
½	Stem Guided	Equal %	0.38	0.5	2.41
¾	Stem Guided	Equal %	0.56	0.5	5.92
1	Microform	Equal %	$\frac{3}{8}$ - $\frac{3}{4}$	$\frac{3}{4}$	3.07-8.84
1	Cage Guided	Linear / Equal %	15/16	$\frac{3}{4}$	20.6/17.2
1½	Microform	Equal %	$\frac{3}{8}$ - $\frac{3}{4}$	$\frac{3}{4}$	3.2- 10.2
1½	Cage Guided	Linear / Equal %	1 $\frac{7}{8}$	$\frac{3}{4}$	39.2/35.8
2	Cage Guided	Linear / Equal %	25/16	1 $\frac{1}{8}$	72.9/59.7
3	Cage Guided	Linear / Equal %	37/16	1½	148/136
4	Cage Guided	Linear / Equal %	4 $\frac{3}{8}$	2	236/224
6	Cage Guided	Linear / Equal %	7	2	433/394
8	Cage Guided	Linear / Equal %	8	3	846/818

Size (in)	Valve Style	Degrees Opening	C_v
1	V-Notch Ball Valve	60 / 90	15.6 / 34.0
1½	V-Notch Ball Valve	60 / 90	28.5 / 77.3
2	V-Notch Ball Valve	60 / 90	59.2 / 132
2	Butterfly Valve	60 / 90	58.9 / 80.2
3	V-Notch Ball Valve	60 / 90	120 / 321
3	Butterfly Valve	60 / 90	115 / 237
4	V-Notch Ball Valve	60 / 90	195 / 596
4	Butterfly Valve	60 / 90	270 / 499
6	V-Notch Ball Valve	60 / 90	340 / 1100
6	Butterfly Valve	60 / 90	664 / 1260
8	V-Notch Ball Valve	60 / 90	518 / 1820
8	Butterfly Valve	60 / 90	1160 / 2180
10	V-Notch Ball Valve	60 / 90	1000 / 3000
10	Butterfly Valve	60 / 90	1670 / 3600

**Appendix IV
General Information**

Worcestor Series 5 Flanged Ball Valve

Flow Coefficients

Valve Size		Model	Flow Coefficients	
mm	in		Cv	Kv
15	½	519/529	32	27
20	¾	519/529	54	46
25	1	519/529	94	80
40	1½	519/529	254	219
50	2	51/52	130	112.5
80	3	51/52	350	303
100	4	51/52	720	623
150	6	51/52	1020	882
200	8	51/52	1800	1557
250	10	51/52	2970	2560
See Note 3			Cv – Flow in US GPM Pressure – psi Kv – Flow in M³/hr Pressure – bar	

Worcestor Series 44/459 Reduced Bore Ball Valves

Flow Coefficients

Valve Size		Flow Coefficients		Equivalent Length of Pipe	
mm	in	Cv	Kv	Feet	Metres
15	½	8.3	7.2	1.9	0.58
20	¾	13.6	11.8	5.5	1.67
25	1	37.5	32.6	3	0.91
32	1¼	57	49.3	3.1	0.94
40	1½	79.7	69.1	3.9	1.19
50	2	106	91.8	7.5	2.28
65	2½	188	163	150	1.52
80	3	435	377	7	2.13
100	4	638	553	27	8.21
150	6	675	585	41	12.47
Cv – Flow in US GPM Pressure – psi Kv – Flow in M³/hr Pressure – bar					

Note that the equivalent length of pipe has been declared which requires a friction coefficient at turbulence to be determined to allow a K value to be calculated; see later.

**Appendix IV
General Information**

Atomac AKH3 Lined Ball Valves

**Maximum C_v (K_v) Values
for V-Port AKH3 Valves**

in (mm)	C_v	K_v
1 (25)	6/14	5/12
1½ (40)	15	13
2 (50)	40	36
3 (80)	65	56
4 (100)	141	122
6 (150)	189	163

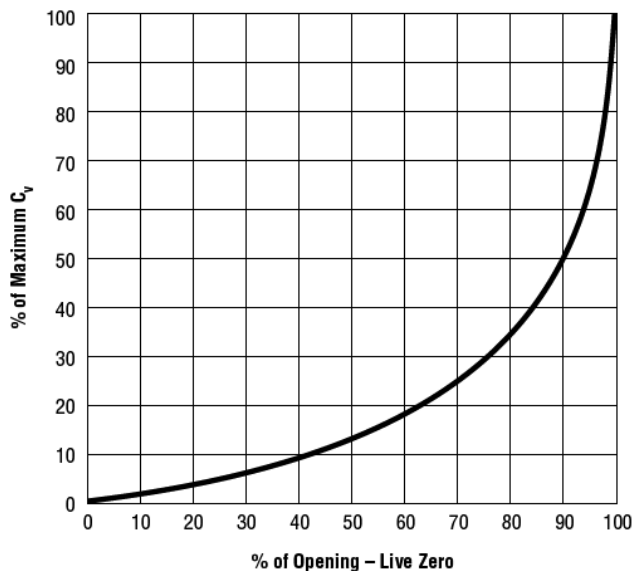
C_v = US gal/min at 1 psi Δp (K_v = m³/hr at 1 bar Δp)

Refer to Sections II and IV of the Durco Technical Manual for valve and actuator sizing.

Consult factory for AKH2A data.

ISO 5211 mounting pad facilitates actuation.

**A Typical Characteristic Curve
for V-Port AKH3 Valves**



Flowserve Corporation ASF Inline Strainers

Flow Rates

Size in (mm)	Filter in μm C_v (K_v) 100	Filter in μm C_v (K_v) 300	Filter in μm C_v (K_v) 500	Filter in μm C_v (K_v) 1000
1 (25)	8.1 (7.0)	8.3 (7.1)	8.4 (7.2)	9.2 (7.9)
1½ (40)	21.9 (18.8)	24.8 (21.3)	27.4 (23.6)	28.0 (24.1)
2 (50)	34.4 (29.6)	36.1 (31.1)	37.5 (32.3)	41.4 (35.4)
3 (80)	91.1 (78.4)	97.4 (83.8)	105.1 (90.4)	109.4 (94.1)
4 (100)	152.7 (131.4)	163.0 (140.2)	172.8 (148.7)	178.2 (153.3)
6 (150)	333.7 (287.1)	356.0 (306.3)	389.6 (335.2)	405.5 (348.9)
8 (200)	544.0 (468.0)	556.7 (479.0)	576* (495*)	596.3 (513.0)

*Estimated Value

C_v = US gal/min at 1 psi Δp (K_v = m³/hr at 1 bar Δp). Flow rates for other mesh sizes available upon request.