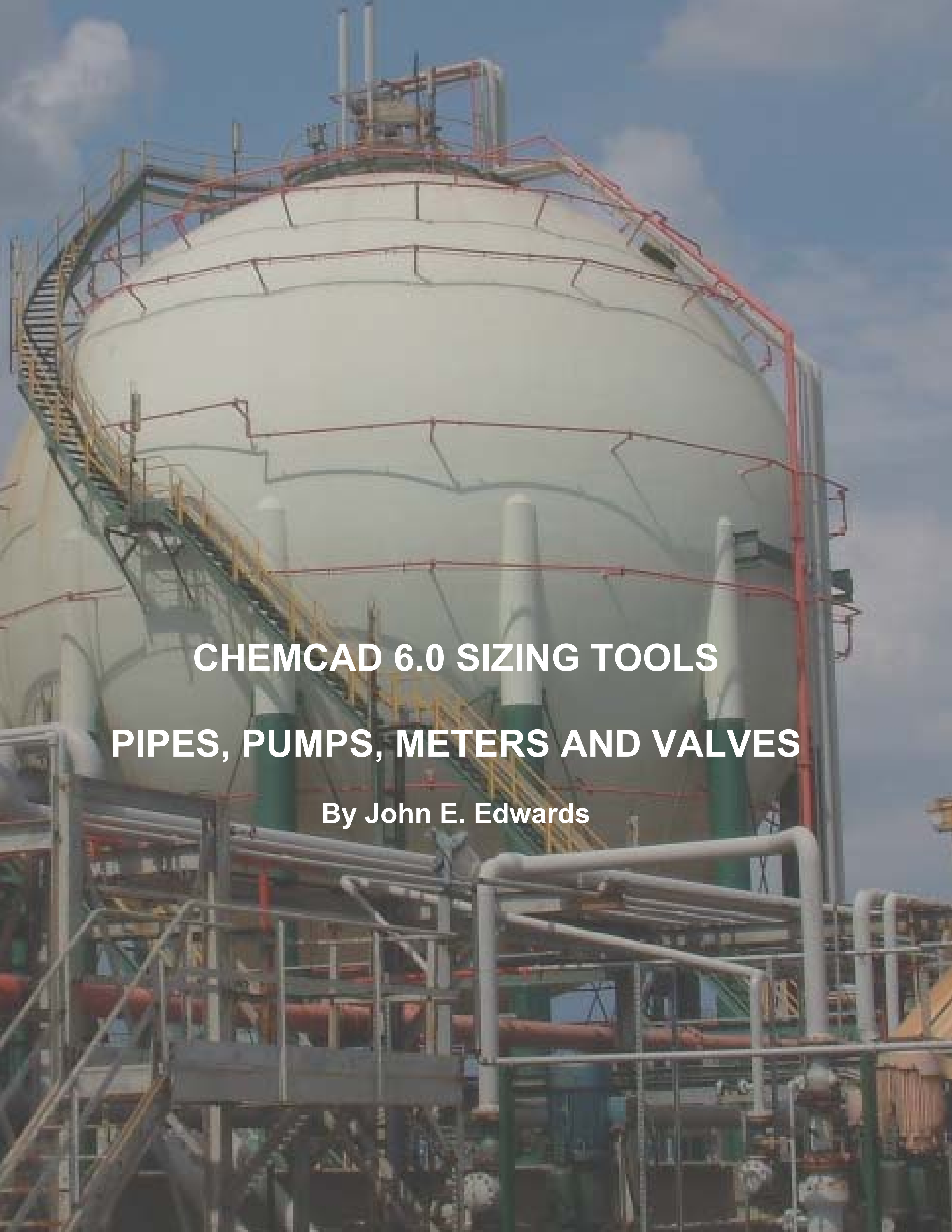


CHEMCAD 6.0 SIZING TOOLS

PIPES, PUMPS, METERS AND VALVES

By John E. Edwards

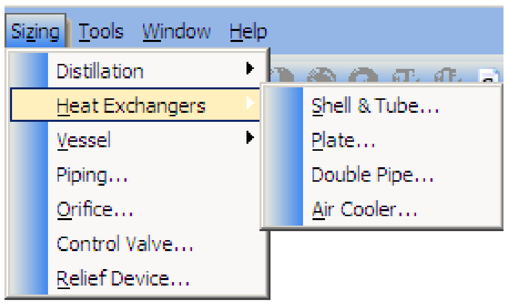
CONTENTS

APPENDICES

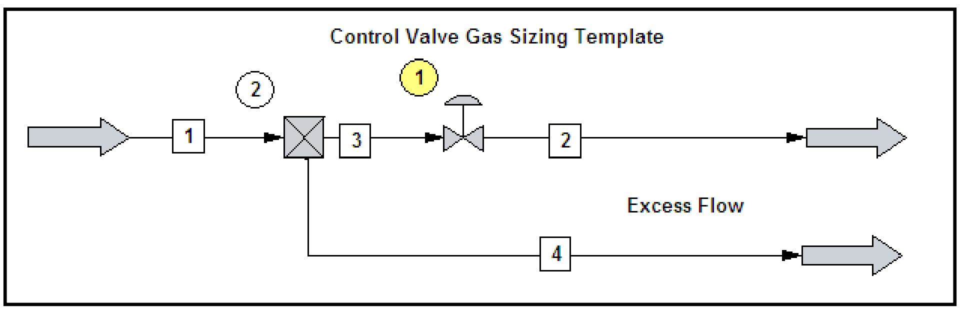
CHEMCAD 6.0 SIZING TOOLS - PIPES, PUMPS, METERS AND VALVES – INTRODUCTION

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.

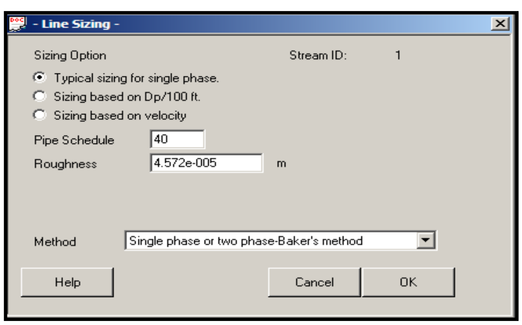
Short cut methods for Pipes, Control Valves and Orifice Plates are accessed from the main toolbar Sizing command as shown below:

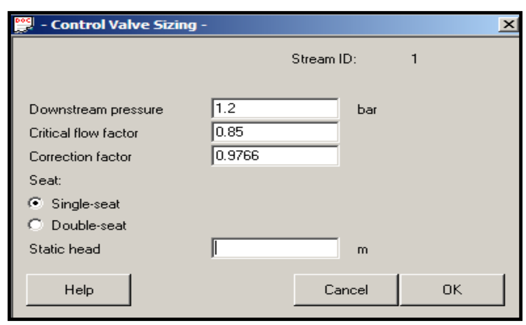


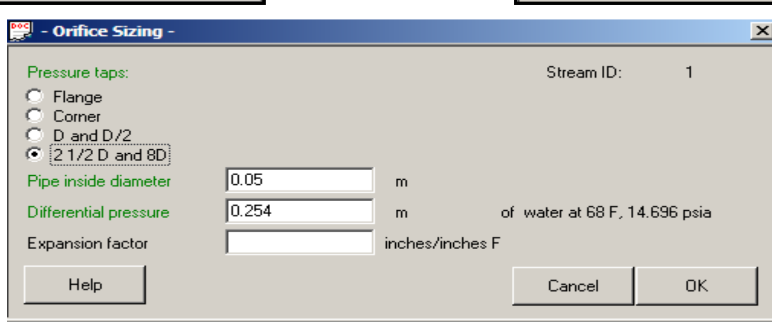
The stream properties to be used for sizing are selected by a single mouse click on the stream in the model to be studied. In the example shown below Stream 1, as indicated by the black square markers, has been selected.



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



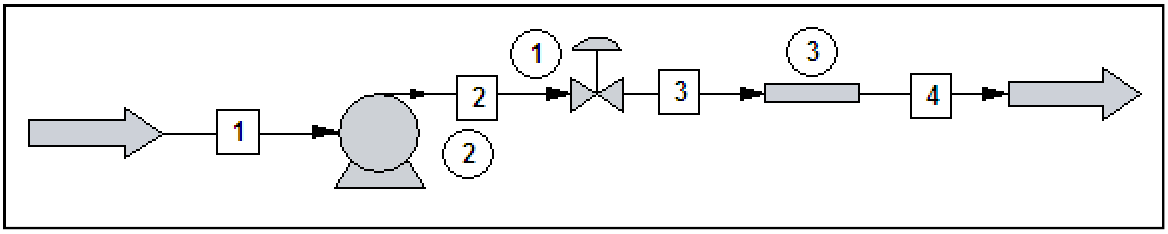




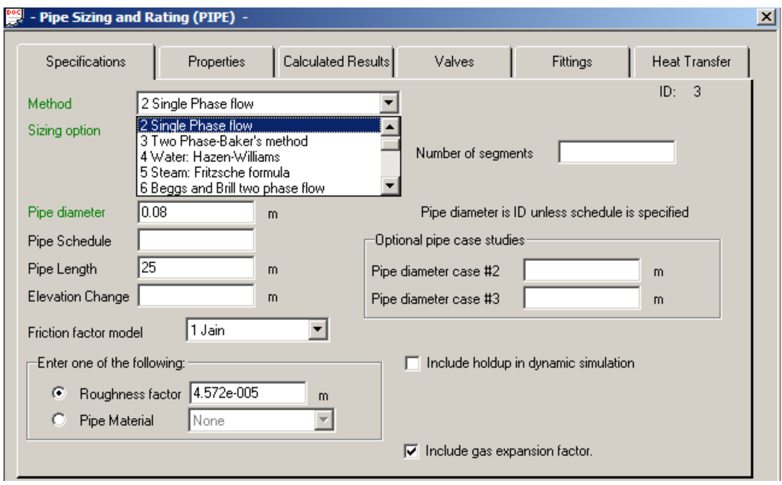
INTRODUCTION

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.

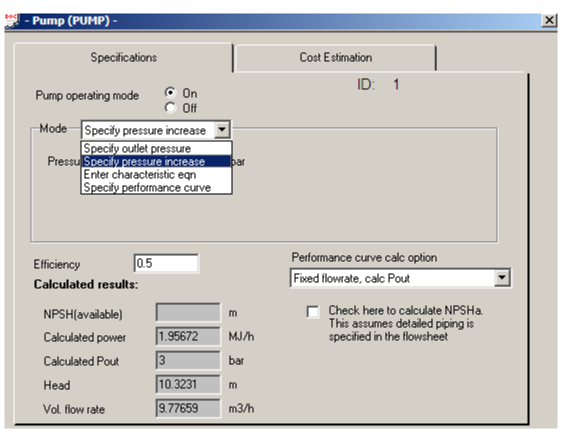
For detailed design and specification a more rigorous approach is required involving the use of additional CHEMCAD UnitOps and manufacturers' sizing data. The flowsheet below shows the UnitOps for Pipes, Pumps and Control Valves which allow for a more thorough analysis.



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

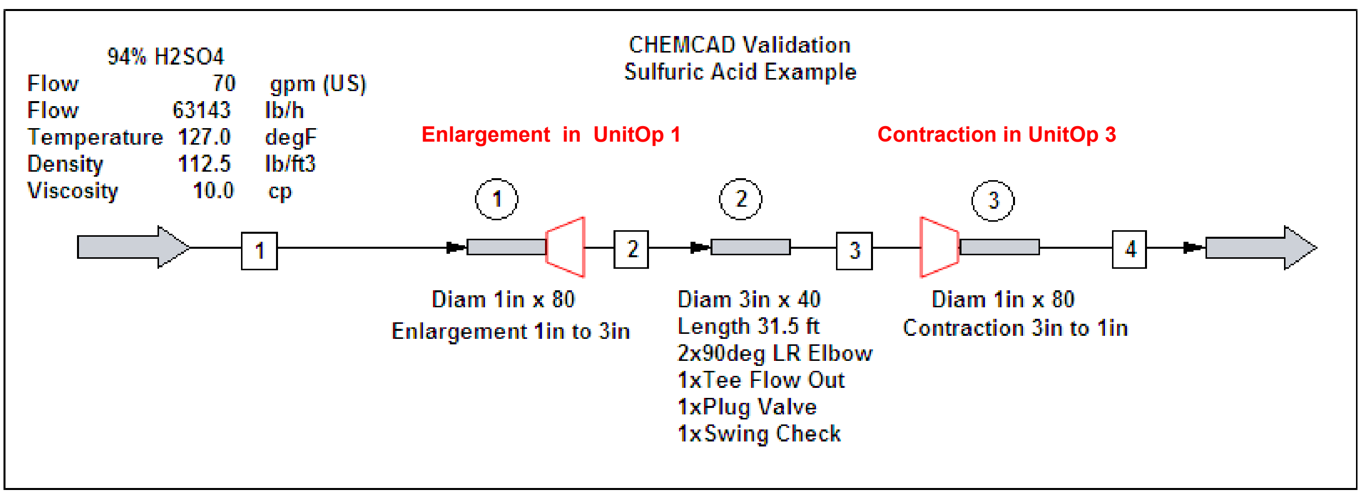
This validation case study has been based on the flow of 94% Sulphuric Acid through a 3 in x Schedule 40 carbon steel pipe. CHEMCAD results are validated against an example given in www.cheresources.com/eqlength.shtml . The process conditions are shown below:

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	ºF	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 90º 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

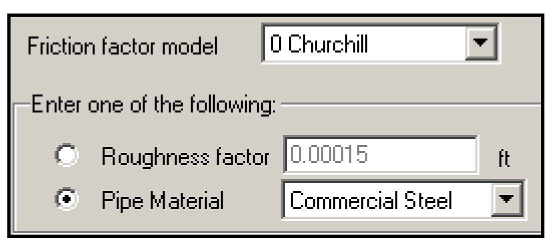
The key aspect of this problem is the handling of the enlargement and contraction. The fitting must be located in the 1 in pipe section with separate Pipe UnitOps 1 and 3 included to allow for this. Locating the enlargement and contraction in Pipe UnitOp 3 gives incorrect results. Refer to Appendix I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

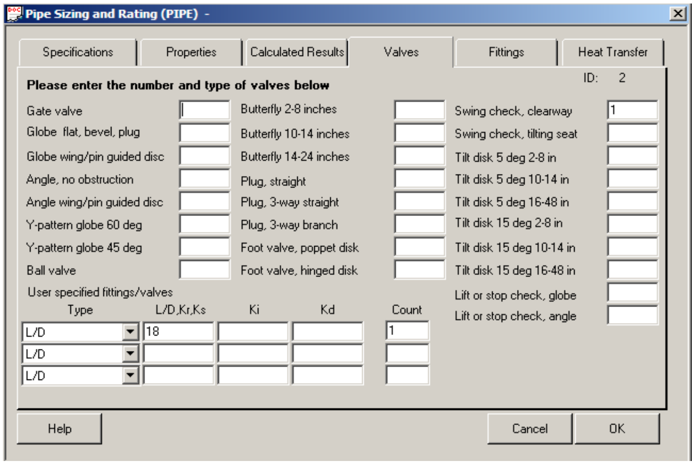
The Pipe Section data entry for the 3 in pipe is shown following.

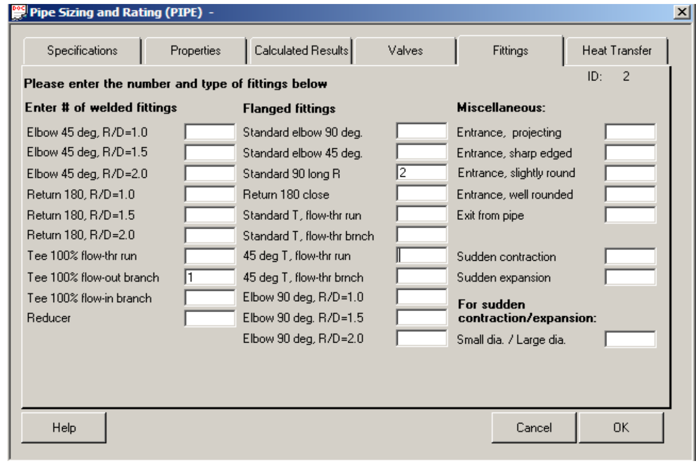
The Curchill friction factor has been selected due to the application being in the transition flow region.

CHEMCAD library has been used for pipe roughness factor.



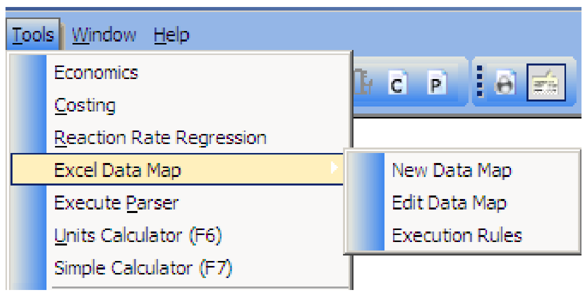
MODEL CONFIGURATION





DATA MAPPING

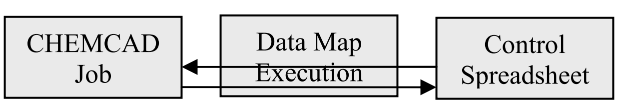
The model is controlled directly from an Excel spreadsheet Sulfuric Acid. This is linked to the model using the CHEMCAD Data Mapping Tool which is accessed from the main Toolbar. The Data Map operation is controlled by the Execution Rules.

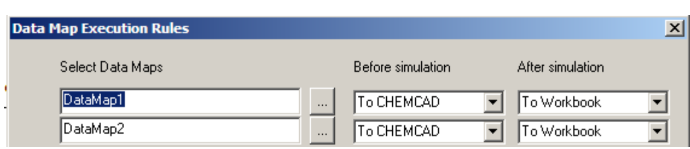


The control spreadsheet, located in the My Simulation folder, is selected with Browse. The Data Map is shown in which the desired Stream or UnitOp is selected, with the required parameter, and assigned an Excel cell in the control spreadsheet.

					New	Embed
	Excel Workbook Path:		C:\DOCUMENTS AND SETTI...		Browse	Open
	Excel Worksheet Name:		Validation			
Map Rule	CC Obj Type	CC Obj ID	Par ID	Component	WrkSht Cel...	Weight
To Workshe...	UnitOp	1	Calc. Velocity	<None>	F9	1.00000
To Workshe...	UnitOp	1	Fric factr liq	<None>	F10	1.00000
To Workshe...	UnitOp	2	Calc. Velocity	<None>	F13	1.00000
To Workshe...	UnitOp	2	Reynolds # liq	<None>	F14	1.00000
To Workshe...	UnitOp	2	Fric factr liq	<None>	F15	1.00000

The execution rules, as set below, transfers input data to CHEMCAD at the start of the simulation and returns results at the end of the simulation.





The Excel program has a control macro, located and activated from Add Ins, installed which enables the CHEMCAD model to be linked and controlled from the tool bar using the features shown.

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}
90º 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 Data			CHEMCAD Results		
D1	0.0798	ft			
L1	0.5	ft			
v1	31.21	ft/s	31.20	v1^2/2g	15.13
f1			0.0270		
D2	0.2557	ft		D1/D2	0.312
L2	31.5	ft			
v2	3.04	ft/s	3.036	v2^2/2g	0.143
Re No	12998		12998.9		
f2	0.02985		0.0300		
ft	0.018				
ΔP/100ft	1.308	psi	1.32		
ρ	112.47	lb/ft3			
psi/100ft	1.307				
θ	30	deg			
d	3.0684	in			
W	63143	lb/h			
g	32.2	ft/s^2			

Formulae used for K1 and K2

$$h_L = \frac{v_1^2}{2g}\left(1-\beta^2\right) = K_1\frac{v_1^2}{2g}$$

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

Formula used for calculating ΔP/100ft
Set L=100

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

Fittings 1 in x 80 by 3 in x 40 Enlargement						CHEMCAD Results Inlet Pipe	
Calculations using pipe conditions f							
Inlet Pipe							
K1	2.6sin(θ/2)(1-β^2)^2	0.549					
Friction Loss (hf)1	K1 (v1^2/2g)	**8.30**	ft fluid				
	(hf)1(ρ/144)	6.48	psi				
Equivalent Length Method Inlet Pipe				Example Calculations using ft			
L1/D1	K1/f1	20.304		K1/ft	30.48		
(Leq)1	(L/D)1D1	1.62	ft	(L/D)1D1	2.43	2.405	ft
Friction Loss (hf)1	(fLv^2/2gD)1	**8.300**	ft fluid	(fLv^2/2gD)1	12.32		
	(hf)1(ρ/144)	6.48	psi	(hf)1(ρ/144)	9.62	9.64	psi
Outlet Pipe							
K2	K1/β^4	57.84					
Friction Loss (hf)2	K2 (v2^2/2g)	**8.28**	ft fluid				
	(hf)2(ρ/144)	6.47	psi				
Equivalent Length Method Outlet Pipe				Example Calculations using ft			
L2/D2	K2/f2	1926.29	K2/ft	K2/ft	3213.12		
(Leq)2	(L/D)2D2	492.55	ft	(L/D)2D2	821.60		
Friction Loss (hf)2	(fLv^2/2gD)2	**8.25**	ft fluid	(ftLv^2/2gD)2	13.76		
	(hf)2(ρ/144)	6.44	psi	(hf)2(ρ/144)	10.75		

Pressure Loss			
Pressure Loss	Basis 1.32 psi/100ft	6.48	psi
	K value method	6.82	psi

Enlargement located in larger diameter pipe			
	Total Leq	38.4	ft
	Leq(Δp/100ft)	0.505	psi
Calculated	From psi/100ft	0.505	psi
Calculated	(fLv^2/2gD)2	0.642	ft fluid
Friction Loss (hf)2	(hf)2(ρ/144)	0.501	psi

Note consistency of results throughout on inlet and outlet using the Crane method with pipe f
Also consistent results using ΔP/100ft method
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				CHEMCAD	
K1	0.5(1-β^2)	0.451			
Friction Loss (hf)1	K1 (v1^2/2g)	6.827	ft fluid		
	(hf)1(ρ/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(ρ/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	11.8	psi
	(hf)1(ρ/144)	11.82	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 $\Delta P < C_f^2 (\Delta P_s)$

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

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 15ºC=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	**P_1**	upstream pressure (bar)
	P_2	downstream pressure (bar)
	P_v	fluid vapour pressure at flowing temperature (bar)
	P_c	critical pressure (bar)
	μ	fluid viscosity (cps)

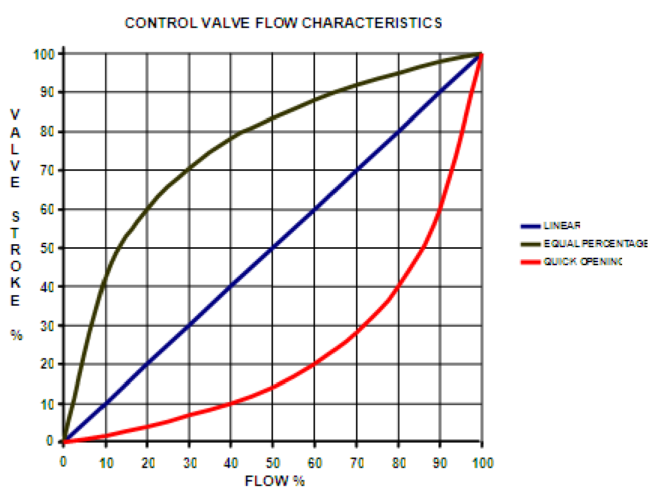
Laminar flow can result at high viscosity or when the valve ΔP or C_v is small.

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:

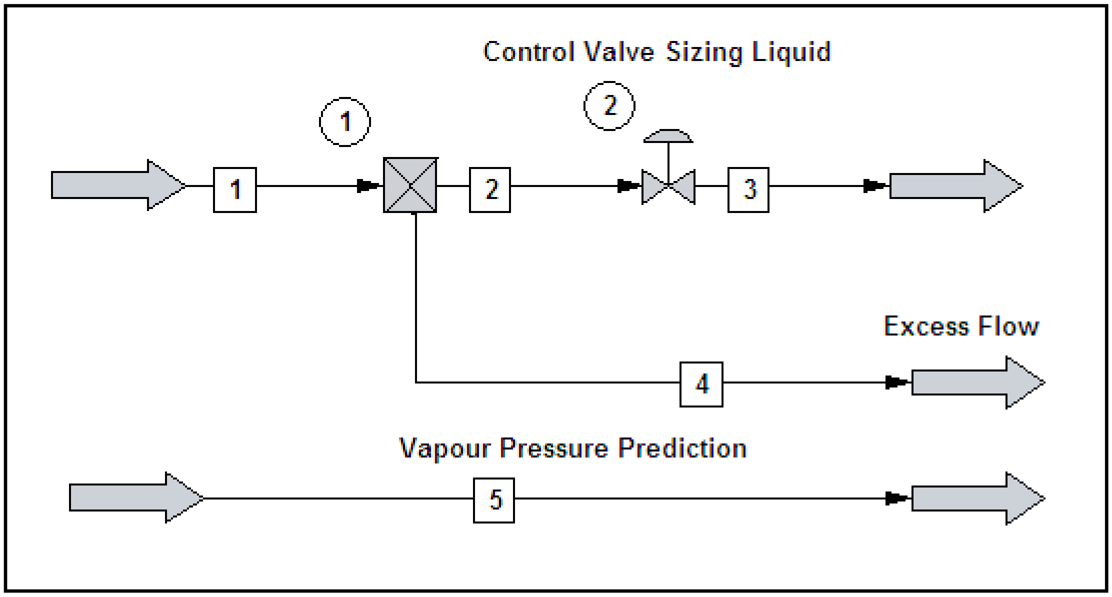
$$C_v = 0.032 \left(\frac{\mu\, q}{\Delta P}\right)^{0.667}$$

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.



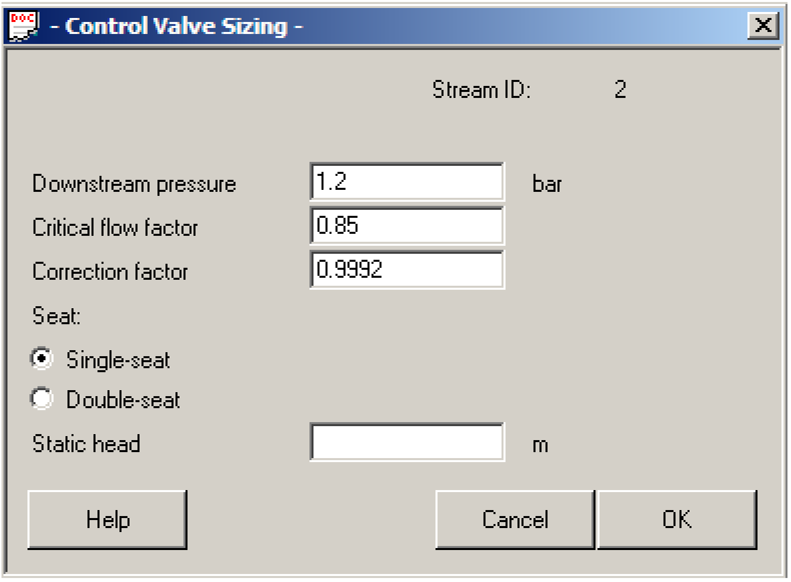
CHEMCAD MODEL

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 to be 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 manufacturer’s 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			Sizing Corrections			
Process Fluid		Methanol				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
					Inlet Pressure Adjusted for Vapor Pressure	ΔP_s	1.832	1.840
Design Volume Flow	q m3/h	0.760			Critical Flow Test Parameter	$C_f^2(\Delta P_s)$	1.323	
Temperature	deg C	25	$\Delta P_s = P_1 - P_v$		Critical(Flashing) Flow Test		Subcritical	
				Subcritical				
Inlet Pressure	P1 bar	2		$C_v = 1.16\,q\sqrt{\frac{G_f}{\Delta P}}$	Subcritical Flow Coefficient	C_v	0.876	
					Critical Flow Coefficient	C_v	0.681	
Downstream Pressure	bar	1.2						
				Critical				
Liquid Density	Gf kg/m3	789.6		$C_v = \frac{1.16\,q}{C_f}\sqrt{\frac{G_f}{\Delta P_s}}$		Effect of Pipe Reducers		
Liquid Viscosity	cp	0.5						
					Valve Size	mm	25	
Vapor pressure at flowing conditions	Pv bar	0.1684			Line Size	mm	50	
					Effect of Reducers Correction Factor		0.9992	
Pressure at Critical Point	bar	80.97	Data Base Look Up					
				Laminar		High Viscosity, Laminar Flow		
Valve Flow Coefficient Required	C_v	0.876						
					Laminar Flow Coefficient	C_v	0.020	
Valve Coefficient at Full Opening	C_v	2			Laminar Flow Test		Turbulent	
Valve Characteristic	0	Equal Percentage	0 Equal %, 1 Linear		Selection of Valve Type	Single Seat Globe (Flow to Close)		
Valve Opening Position	%	64	Adjust for design max flow					
Actual Mass Flow	kg/h	599.3						
Actual Volume Flow	m3/h	0.759						
Valve Coefficient Achieved	C_v	0.875						
					Cell Colour Key			
Downstream Vapor Fraction		0.000			Calculated Data			
					Data to CCD			
Flowing Condition		Liquid Only			Data from CCD			

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:

$$\rho_G = \frac{M_W}{22.415} \times \frac{P_f}{Z} \times \frac{273}{T_f} \, kg \; / \; m^3$$

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

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

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

Where	**Q**	gas flow rate at 15ºC and 1013 mbar (m^3 / h)
	C_f	critical flow factor from manufacturers’ data
	G	specific gravity of gas (air =1.0)
	P_1	inlet pressure (bar)
	T	flowing temperature (ºK = 273 + ºC)

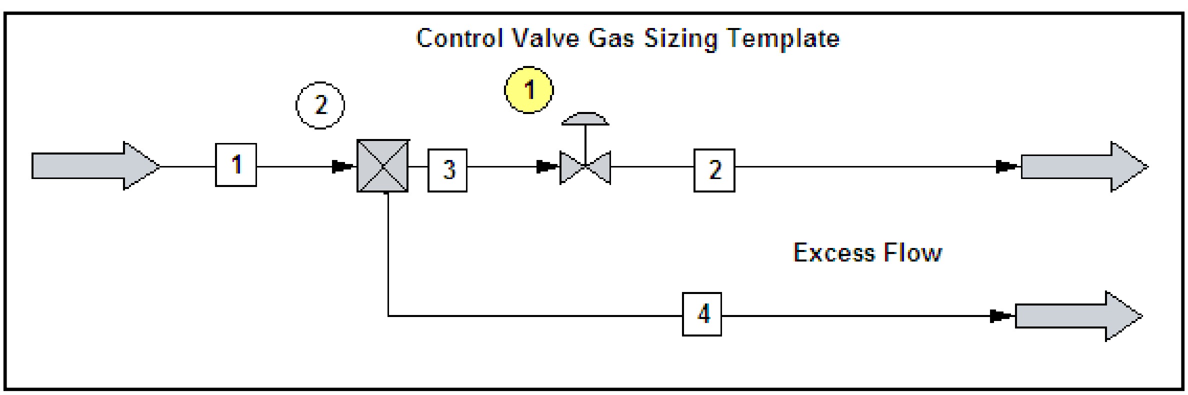
Where y is given by the following:

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

y has a maximum value of 1.5 when $\left(y - 0.148 \; y^3\right)$ 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	
Process Fluid		**Nitrogen**	
Molecular Weight		28.01	
Initial Sizing Mass Flow	kg/h	700.0	Sizing Flow Entered
Gas Density (1.013 bar, 15 degC)	kg/m3	1.1847	
Design Volume Flow (1.013 bar, 15 degC)	sm3/h	590.87	
Temperature	deg C	25	
Inlet Pressure	bar	2.10	
Downstream Pressure	bar	1.20	
Gas Density at Inlet Conditions	kg/m3	2.37	
Gas Viscosity	cp	0.0178	
Gas Specific Gravity (air = 1)		0.9668	
Valve Flow Coefficient Required	Cv	22.71	
Corrected Valve Flow Coefficient Required	Cv	23.37	
Valve Coefficient at Full Opening	Cv	36	
Valve Characteristic	0	Equal Percentage	
C27 = 0, Equal % =1, Linear			
Valve Position	%	78	Adjust valve position to give sizing flow D5
Actual Mass Flow	kg/h	690.5	
Standard Volume Flow 0 degC	m3/h	552.48	
Standard Volume Flow 15 degC	m3/h	582.87	
Actual Volume Flow	m3/h	290.91	
Case Valve Coefficient (y < 1.5)	Cv	22.405	
Case Valve Coefficient (y >= 1.5)	Cv	21.566	
CHEMCAD Control Valve Sizing Results (Not linked)			
Total flow	690.53	kg/h	
Upstream pressure	2.1	bar	
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	

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

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

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

$$\Sigma K = K_1 + K_2 = 1.5\left(1 - \beta^2\right)^2$$

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

Sizing Corrections		
	Critical Flow Factor Cf	
Critical Flow Factor (Full opening)		0.85
Note: Onset of critical flow conditions as Cf is lowered.		
Critical Pressure Drop		0.759
Critical Flow Test		Critical
Flow Coefficient (y < 1.5)	Cv	22.712
Flow Coefficient (y >= 1.5)	Cv	21.862
When y = 1.5, bracketed "y" function =1		
	Effect of Pipe Reducers	
Valve Size	mm	50
Line Size	mm	80
Effect of Reducers Correction Factor		0.9718
Fisher Method Fp		0.9741
Critical Flow Parameter	y	1.255
Selection of Valve Type	Single Seat Globe (Flow to Close)	
1	Cf	
Single Seat Globe (Flow to Close)	0.85	
Single Seat Globe (Flow to Open)	0.9	
Rotating Disc (Flow to Close)	0.68	
Rotating Disc (Flow to Open)	0.85	
Double Seat Globe V Port	0.98	
Butterfly	0.65	
Ball Valve (Flow to Open)	0.6	
Angle Valve (Flow to Close)	0.81	
Angle Valve (Flow to Open)	0.9	
		Data Entry in CC
		Cell Colour Key
		Calculated Data
		Data to CCD
		Data from CCD

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

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

Where
- **α** coefficient of thermal expansion for orifice material (in/in ºF) see below typical value for 18/8 SS is 9.5E-06 and for Monel is 7.0E-06
- $\mathbf{t_f}$ flowing temperature (ºF)

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:

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

$$\nu_f = \frac{m_w\, p_f}{10.73\ T_f\, z_f}$$

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 (ºR=ºF + 460)
Y	gas expansion factor determined from alignment chart shown below

S for Flange, Vena Contracta, Radius or Corner Taps

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

S for Full Flow Taps (2½D and 8D)

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

Gas Expansion Factor Y (Reference L.K. Spink)

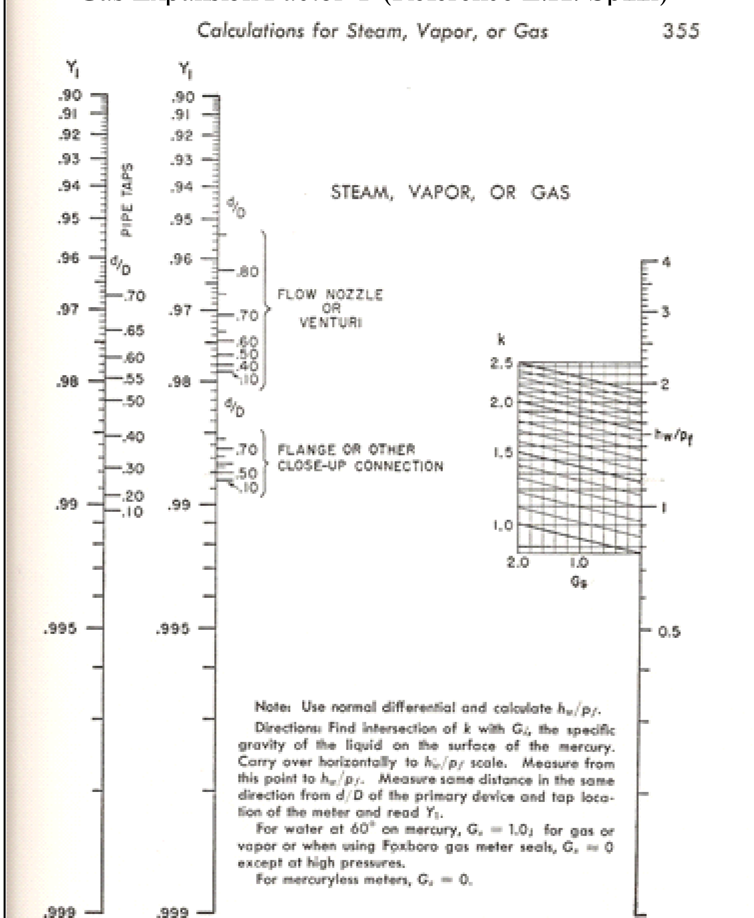


Fig. B-2501 Alignment Chart for Y_1

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:

$$\nu_{fw} = \frac{\nu_f}{q}$$

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

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

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

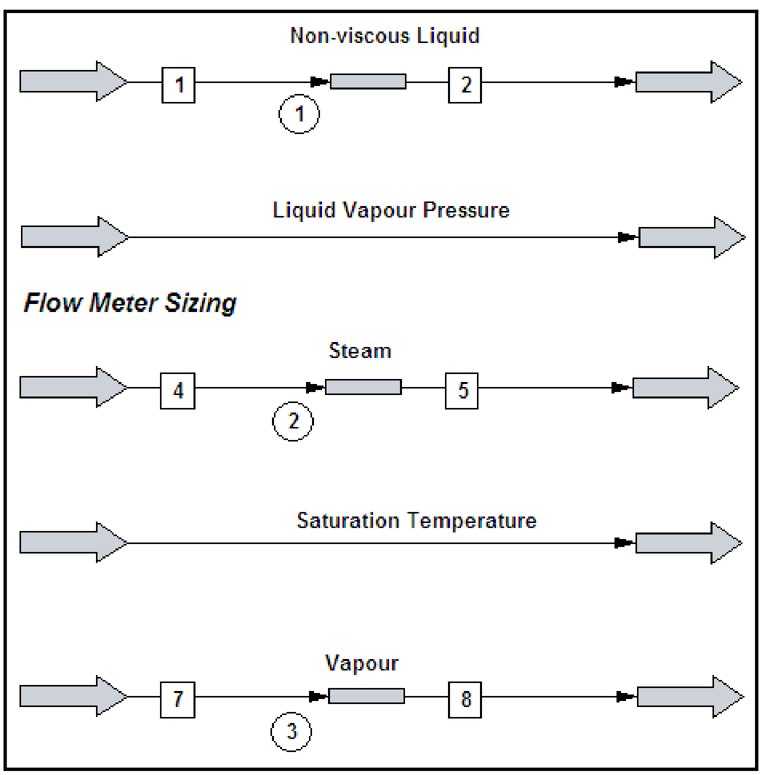
Orifice Plate Thermal Expansion Factor F_a	
Material	Thermal Expansion Factor in/in ºF
Carbon Steel	6.7 E-06
Stainless Steel ANSI 304	9.6 E-06
Nickel alloy	13.3 E-06

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.

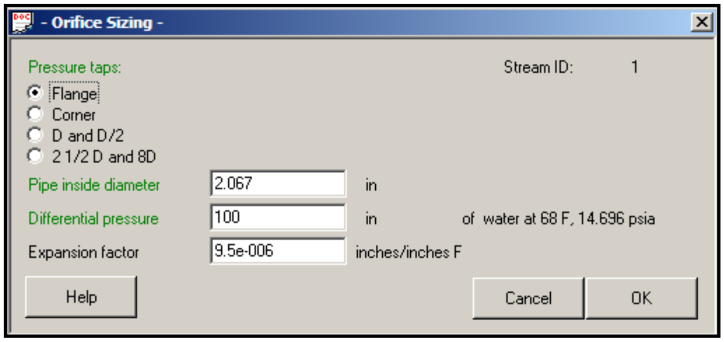
CHEMCAD MODEL

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	
Design Mass Flow	W_m	lb/h	10000.0	
Temperature	t_f	deg F	200.00	
Inlet Pressure	P_f	psia	30	
Liquid Density	ρ	lb/ft3	60.090	
Liquid Viscosity	μ	cp	0.303	
Vapor pressure at flowing conditions		psia	11.531	
Meter differential pressure	h_m	in wg	100.0	
Liquid specific gravity	G_f		0.9650	
Calculated pipe velocity	v	ft/s	0.90	
Pipe internal diameter	D	in	2.067	
Material thermal expansion	α	in/in degF	9.50E-06	
Thermal expansion factor	F_a		1.0025E+00	
Sizing parameter	S		0.0838	0.0839
Goal Seek E30 = E29 changing F33	Scalc		0.0841	
Pressure Taps		Flange,Radius,Corner		
Beta Ratio	d/D		0.3719	0.3719
Bore Size	d	in	0.7686	0.7686
	β			
Discharge Coefficient	C_d		0.6010	
	C			0.6068
Flow Resistance Factor	K_r		122.36	122.32
Reynolds Number	Re		1.009E+05	

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

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

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

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

CHEMCAD ORIFICE SIZING TOOL RESULTS	Vapor		Liquid	
Flowrate	0	lb/h	10000	lb/h
Flowrate	0	ft3/hr	166.4175	ft3/hr
Density	0	lb/ft3	60.0898	lb/ft3
Pressure taps	Flange			
Differential pressure	100	in of water		
Reynolds No.	100912.1			
Sm (Sizing parameter)	0.0839			
Cd (Discharge coefficient)	0.601			
Beta ratio (d/D)	0.3719			
Pipe inside diameter (D)	2.0669	in		
Bore size (d)	0.7686	in		
Kr (Flow resistance factor)	122.3639			

This data copied and pasted from CHEMCAD orifice sizing tool result

Select Pressure Taps: Flange, Radius,Corner Taps

Use full flow taps for restriction orifice plate

Source for Scalc L.K. Spink Tables 12 and 13

Flange, Vena Contracta, Radius or Corner Taps

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

Full Flow Taps (2½D and 8D)

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

Cell Colour Key
Manual CCD Entry
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_f	deg F	450.00	400.002	
Inlet Pressure	P_f	psia	246.92		
Compressibility	Z_f		0.938		
Isentropic Coefficient			1.3236		
Dryness fraction	q		1.000		
Specific weight	v_f	lb/ft3	0.4857		
Meter differential pressure	h_m	in wg	200.0		
Reynolds number correction	F_c	Re>50000	1.0000		
	hm / pf			0.8100	
Expansion Factor	Y		0.9894	0.989	
				Y from alignment chart in Data with initial d/D	
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_a		1.007E+00		
				Initial S for d/D assuming Fc = 1 and Y = 1	
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		
	C			0.6777	
Flow Resistance Factor	K_r		6.1083	6.3694	
Reynolds Number	Re		1.16E+06		

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

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

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

$$K_r = \frac{1-\beta^2}{C^2\beta^4} \qquad C = \frac{C_d}{(1-\beta^4)^{.5}}$$

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	

This data copied and pasted from CHEMCAD orifice sizing tool result

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_f	deg F	100.00	
Inlet Pressure	P_f	psia	30.00	
Compressibility	Z_f		1.000	
Isentropic Coefficient			1.4097	
Specific weight	v_f	lb/ft3	0.1398	0.1399
Meter differential pressure	h_m	in wg	50.0	1.6667
Reynolds number correction	F_c	Re>50000	1.0000	
	hm / pf			1.6667
Expansion Factor	Y		0.9804	0.9800
				Y from alignment chart in Data with initial d/D
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_a		1.001E+00	
				Initial S for d/D assuming Fc = 1 and Y = 1
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	
	C			0.6584
Flow Resistance Factor	K_r		9.7969	10.0263
Reynolds Number	Re		1.67E+05	

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

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

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

$$K_r = \frac{1-\beta^2}{C^2\beta^4} \qquad C = \frac{C_d}{(1-\beta^4)^{.5}}$$

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

Manual CCD Entry

Cell Colour Key: Calculated Data / Data to CCD / Data from CCD

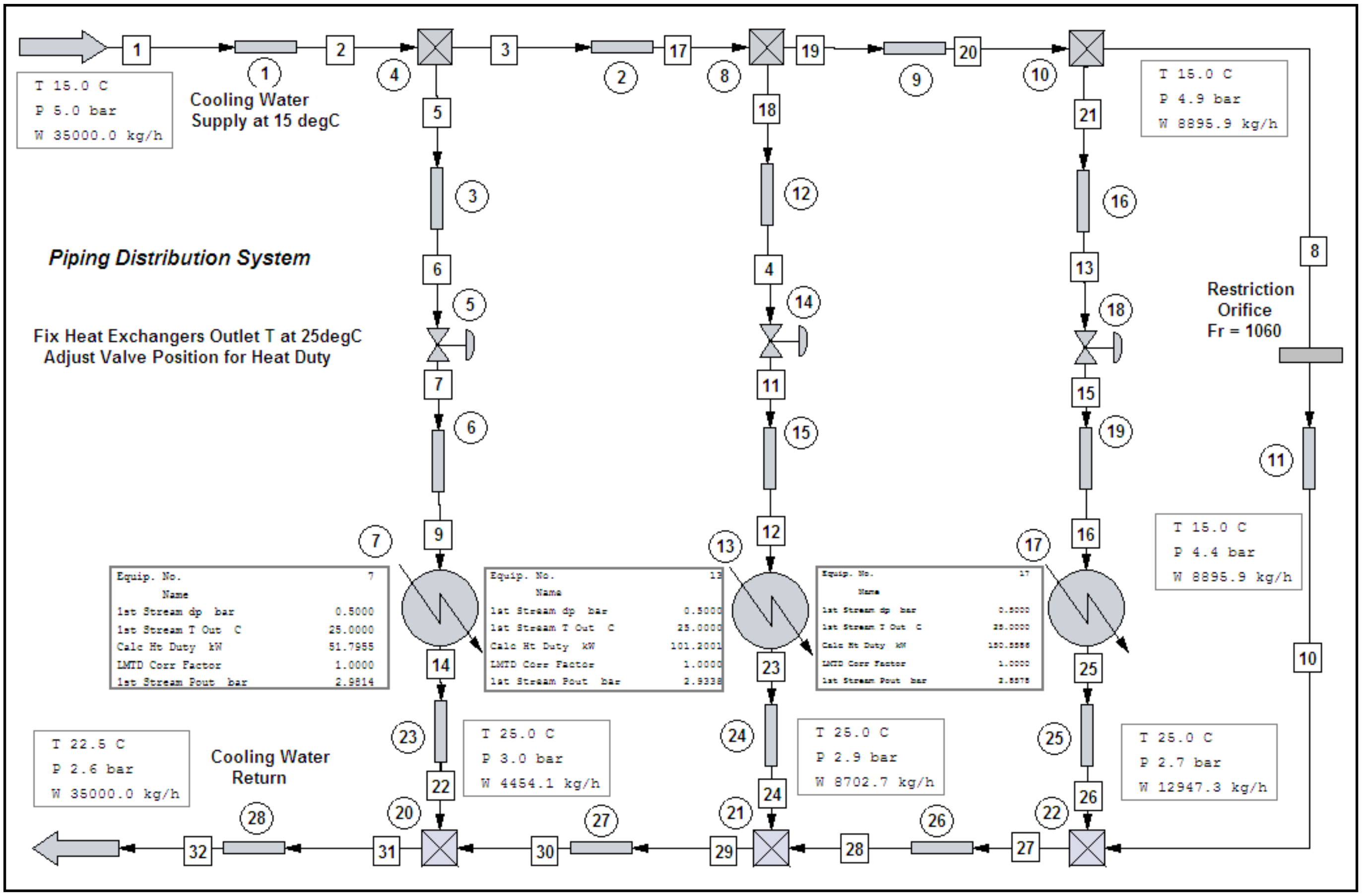
CHEMCAD 6.0 SIZING TOOLS – SERVICES PIPING DISTRIBUTION SYSTEM

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 25ºC 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 ºC. 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 C_v of 34. Once sized the control valve is positioned manually to adjust the flow to achieve the specified duty whilst maintaining a 25ºC 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.

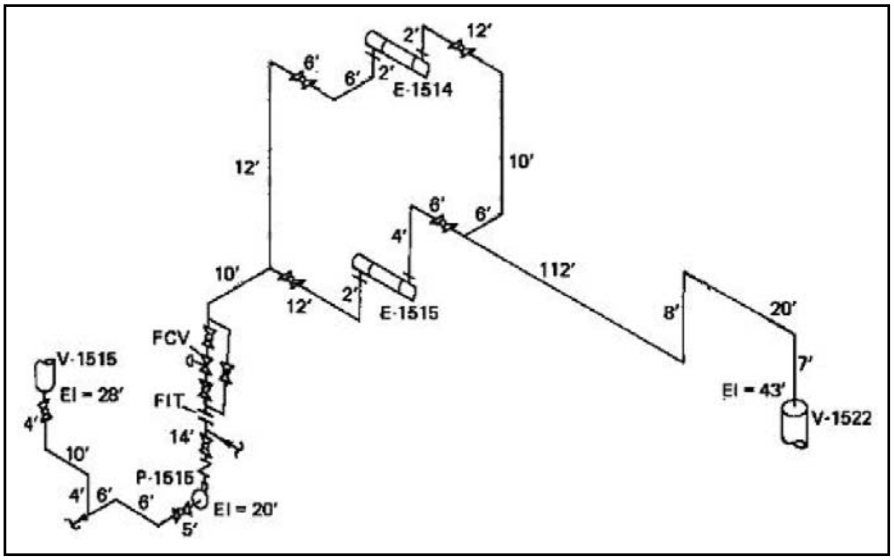
CHEMCAD 6.0 SIZING TOOLS – PIPE NETWORK WITH PUMP CURVE

PROCESS DESCRIPTION (Chemstations Piping Seminar Example 3)

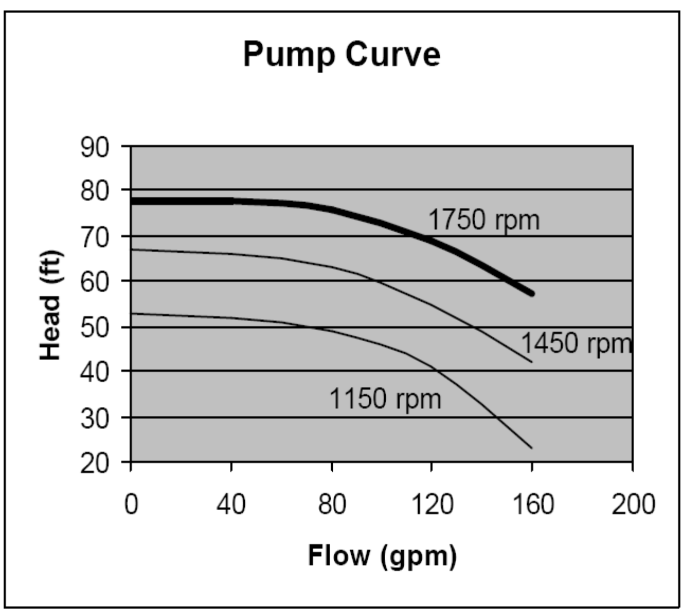
The piping system is to be designed to transport 120 gpm of glacial acetic acid at an inlet temperature of 70ºF which is then heated through heat exchangers to 140ºF. The outlet pressure must be no less than 20 psia. The piping system and its individual elements are to be sized for typical design conditions.

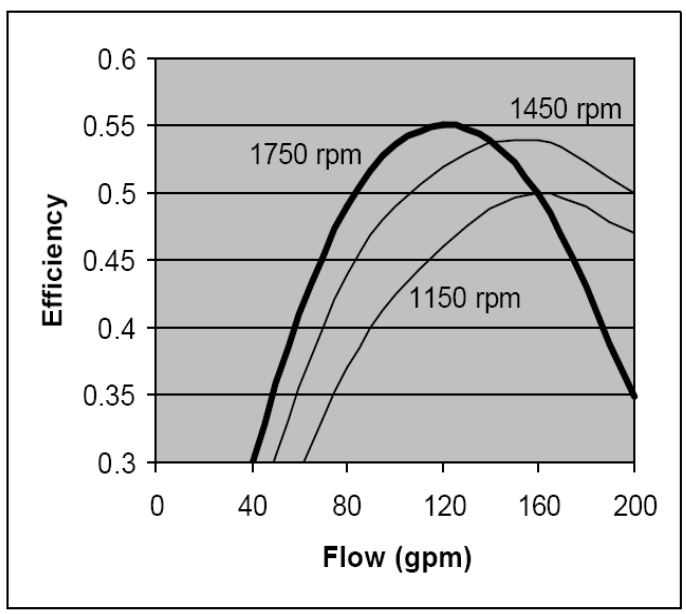
The piping layout, valves and fittings to be used are shown in the isometric. An orifice plate and control valve is to be installed downstream of the pump to measure and control flow manually. It is required to determine the branched flow split flow and pressure drops in the pipe network

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.



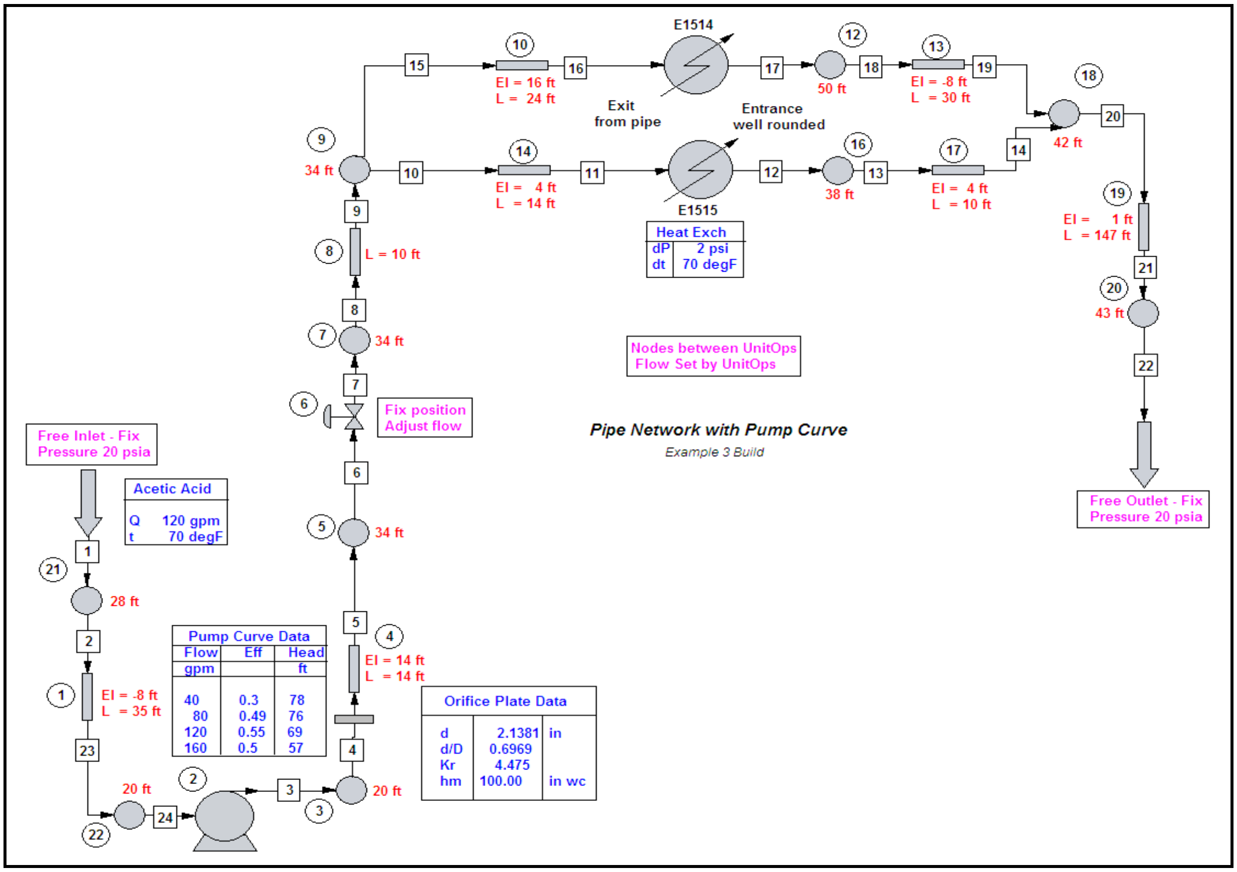
The centrifugal pump to be used has the following performance characteristics:





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

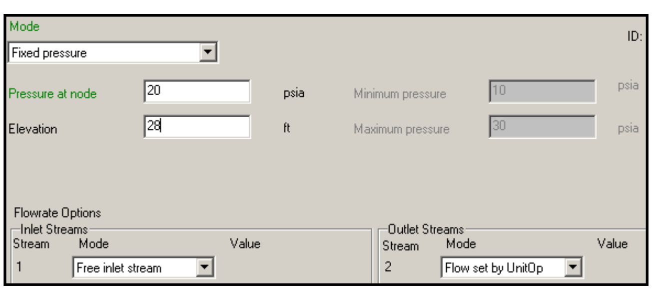
The Pressure Node UnitOp can be considered a calculator that adjusts the network pressure at the node based on the flowrate. In the network the Node sets the pressure between UnitOps that calculates flow as a function of pressure.

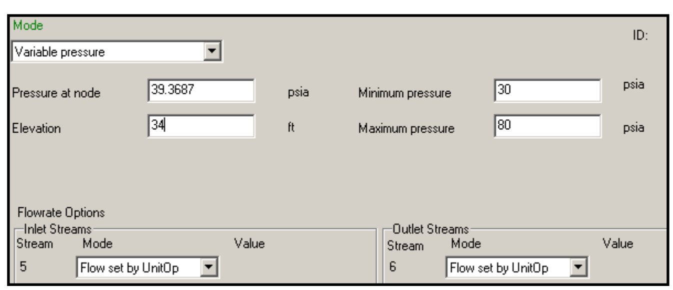
Pipe UnitOps calculate flows based on the P_{in} and P_{out}, the Pump and Control Valve UnitOps calculate flows based on the downstream pressure in the Node; it follows that Node UnitOps located between UnitOps that calculate the flow are set in the "Flow Set by Upstream and Downstream UnitOps".

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:



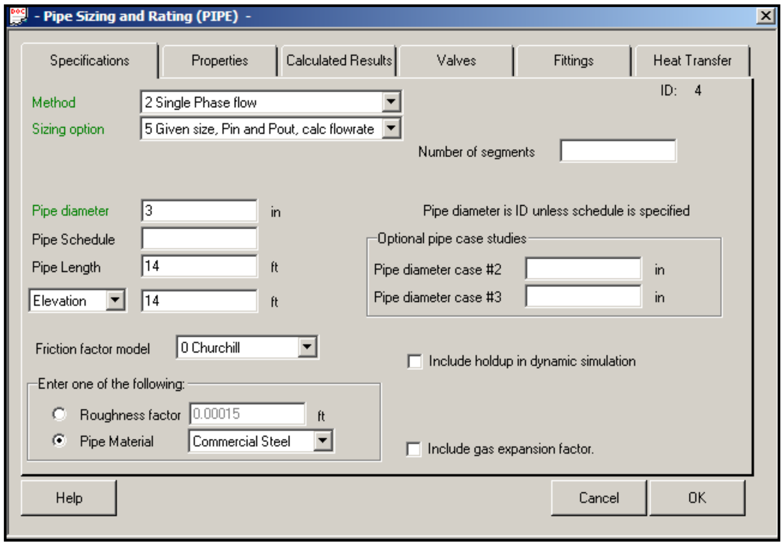


MODEL CONFIGURATION

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 0f 3 in was selected and for the suction pipe 4 in, a nominal size larger.

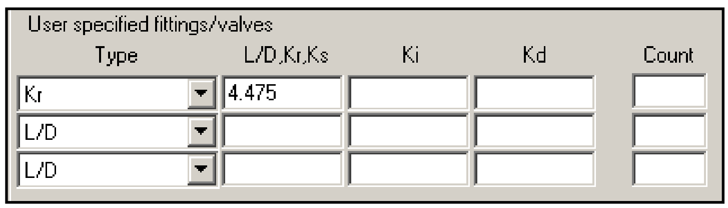
The Pipe UnitOps Method, Sizing Option, Friction Factor and Roughness Factor are configured identically.

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:			
	Calculated	Next larger	Next smaller
Schedule	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 ºF. 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		
Kr (Flow resistance factor)	4.4749			



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.

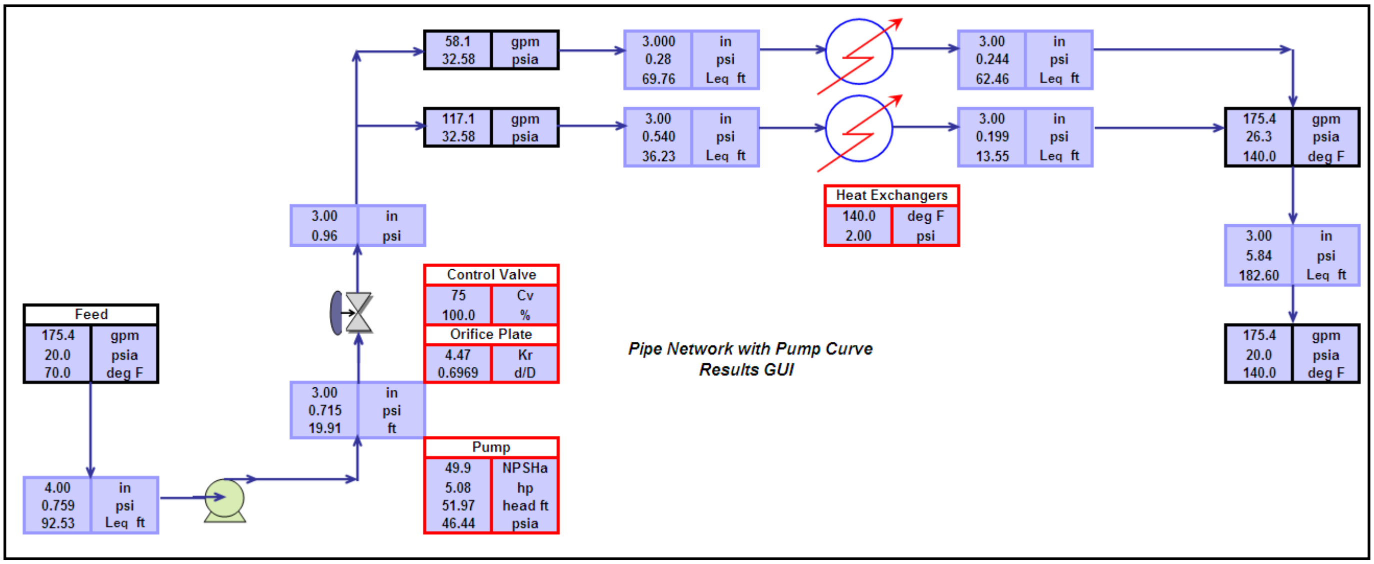
Loadings and Properties				
	Vapor		Liquid	
Flowrate	0	lb/h	92575.1719	lb/h
Flowrate	0	ft3/hr	176.7864	gpm
Density	0	lb/ft3	65.2869	lb/ft3
Total flow	92575.1719	lb/h		
Upstream pressure	39.3687	psia		
Downstream pressure	25	psia		
Critical flow factor	0.98			
Corr. factor for reducers	0.95			
Static 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

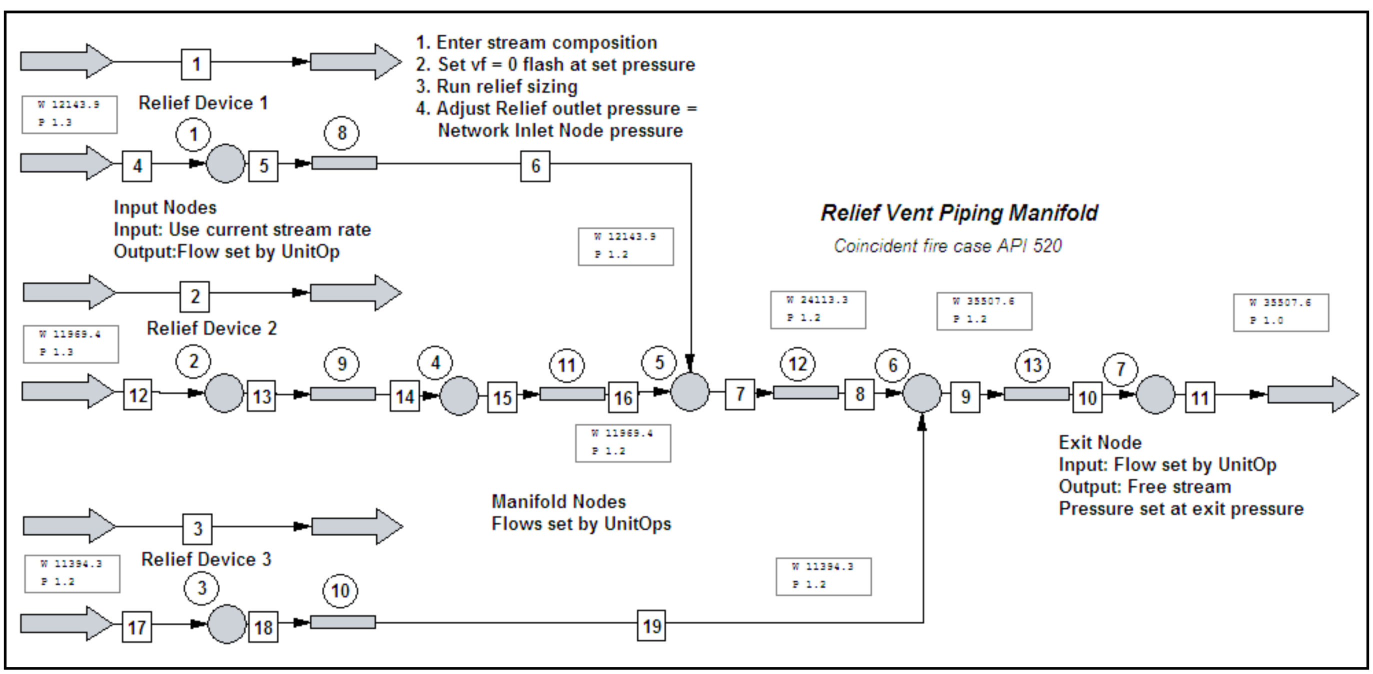
The relief devices are to be sized for external fire to API 520 standard. To provide a margin of safety the reactors are assumed to be uninsulated. Reactor 1 is considered to be carrying out an exothermic reaction with a heat evolution of 500 MJ/h.

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 $P_{in} > 0.5xP_{0ut}$, where P_{out} is the manifold back pressure.

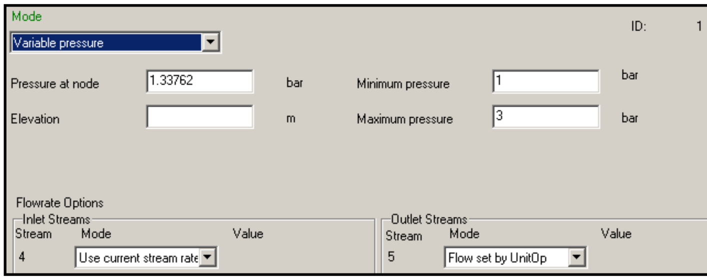
CHEMCAD MODEL

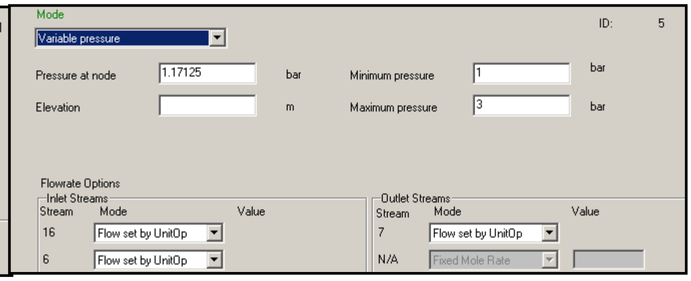
For practice you can build the model or use the model "Relief Vent Piping Manifold" in the electronic media supplied. It is recommended that you work with a copy of this job.



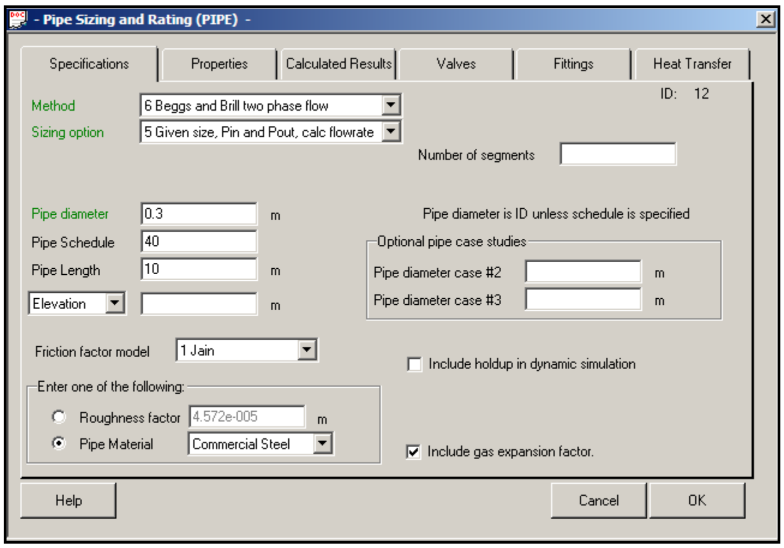
MODEL CONFIGURATION

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.



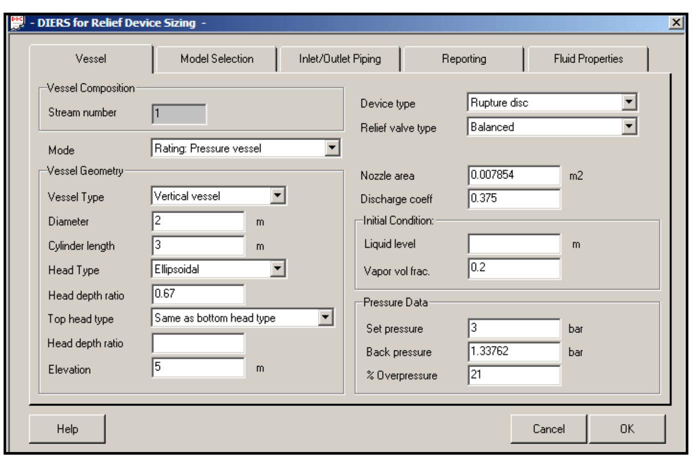


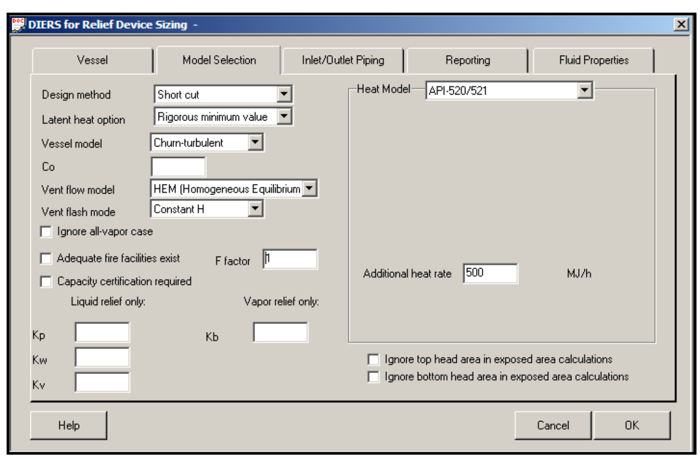
The Pipe UnitOps specifications windows are all specified as shown; note that Beggs and Brill for two phase flow is required and for the Nodes to calculate correctly Sizing Option 5 > Given size, P_{in} and P_{out}, calculate flow. Pipe size and length are entered to suit.



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.

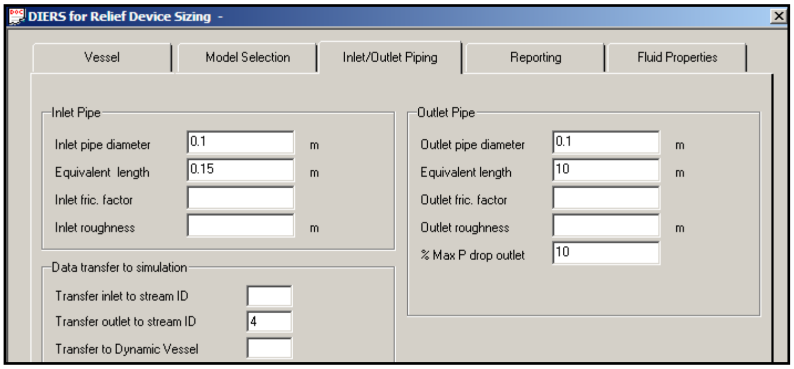
The relief device specifications are entered as shown





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	m3	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/m3	8.3173
Liquid density	kg/m3	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	m2	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	m2	0.007854
Rupture disc diameter	m	0.1
Calculated nozzle area	m2	0.0065066 (For heat model 1)
The following calculation is base on vent area	0.007854	m2.
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/m3	9.9967
Nozzle inlet vap. vol. fraction		0.99783

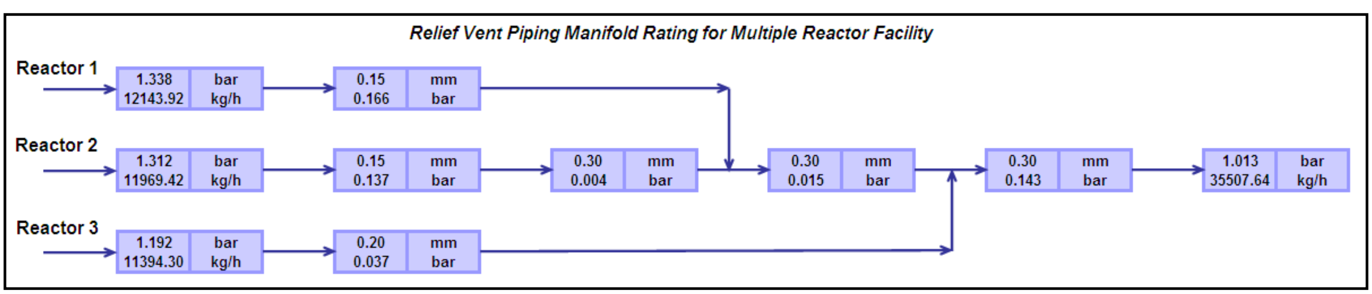
On clicking OK the relief sizing report is generated in Excel as shown.

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.

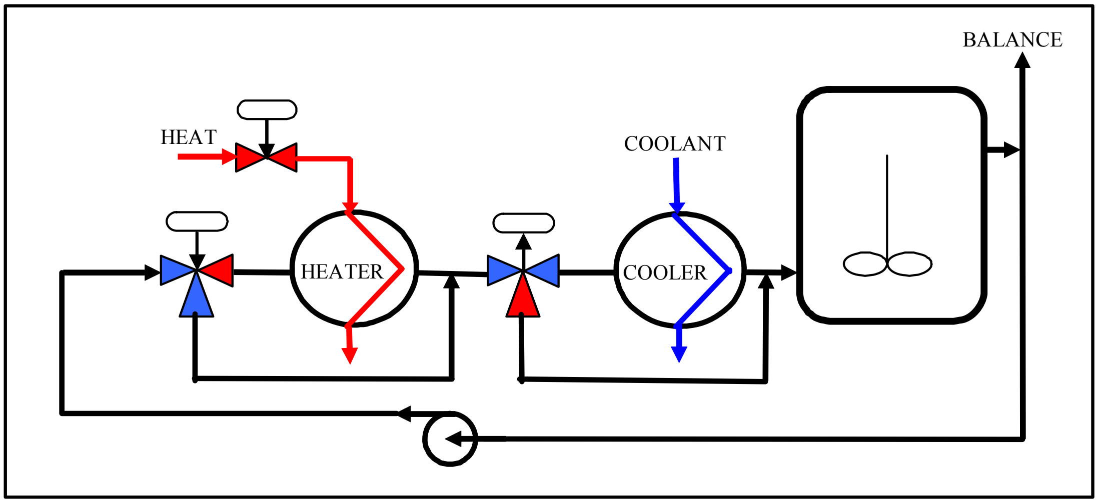
Note that the manifold back pressure is < 0.5 x the set pressures of the relief devices which verifies that the relief venting is not being reduced by the manifold for a coincident relief scenario.



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

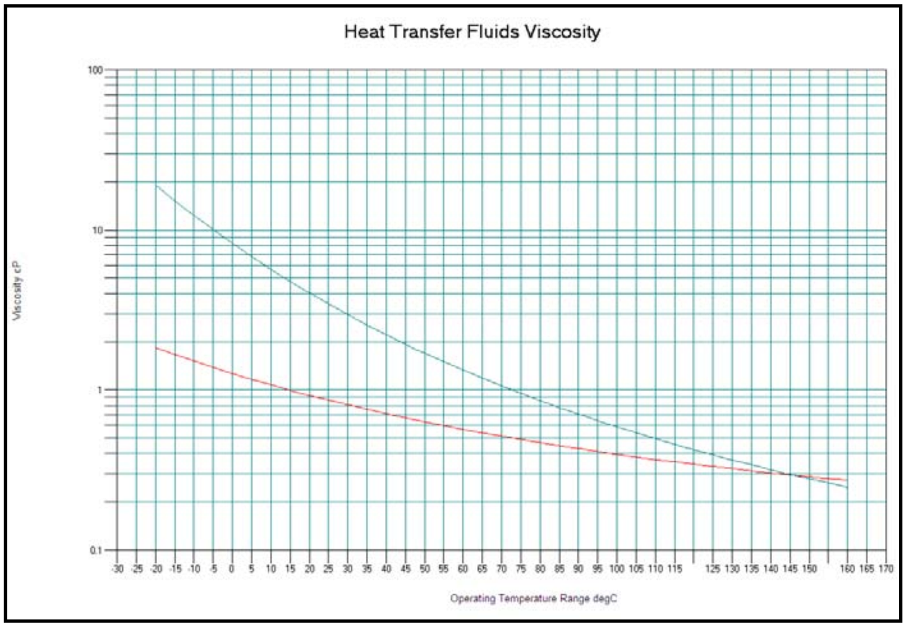
Mixing Nozzle Constants and Maximum Recommended Flow			
Size (ins)	A	C	Maximum Flow (m3/h)
3.0	700.0	0.5	43
2.0	144.0	0.5	17.0
1.5	60.0	0.51	9.0
1.25	36.8	0.48	

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 m^3/h using a nominal pipe size of 2 in.

The jacket operating temperature range was -20ºC to 160ºC and heat transfer fluid Dowtherm J was selected as being suitable. User component 50% Ethylene Glycol / Water mixture at -20ºC 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
	D_2	jacket inside diameter (in)
	D_1	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:

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

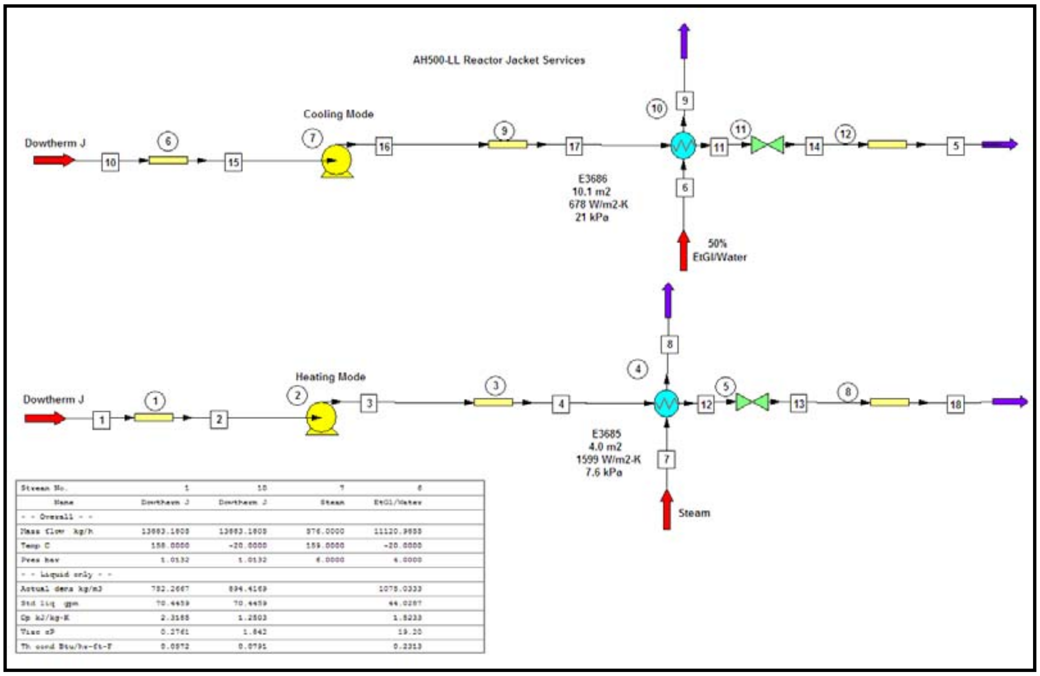
For laminar flow conditions in the jacket, Re ≤ 60, the jacket film coefficient is calculated from:

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

Where	k	thermal conductivity	(Btu / ft^2 h ºF / ft)
	h	jacket film coefficient	(Btu / ft^2 h ºF)
	C_p	specific heat	(Btu / lb ºF)
	μ	viscosity	(cps)

CHEMCAD FLOWSHEET

For practice you can build the model or use the model called TCMCIRCDOWJ 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.



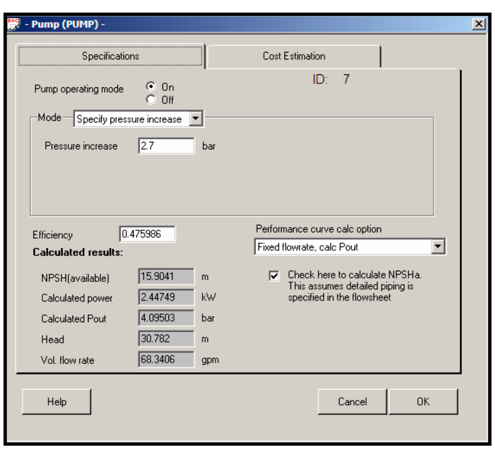
MODEL CONFIGURATION

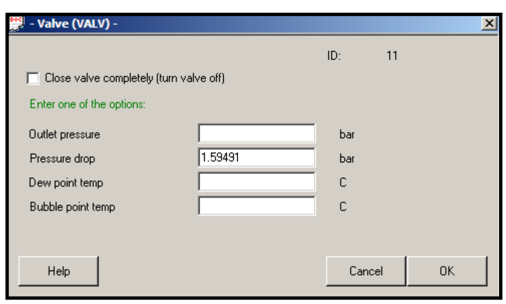
The Pipes Sizing Tool is suitable for an initial assessment of pipe sizing, say for initial estimating purposes, but when progressing to detailed design the Pipe UnitOp is used. This UnitOp provides extensive sizing methods coupled with the facility to enter elevation changes, pipe fittings and valves.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

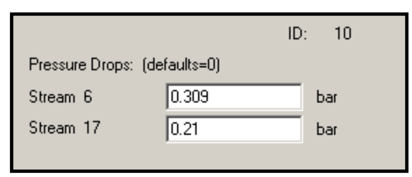
The inlet stream pressure is set to 1.25 bar being equivalent to the pad pressure of the system; two cases are used to study the behaviour at minimum and maximum temperatures.

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	
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	H×1.2				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							Btu/ft2hF	W/m2K
8	70.45	894.30	1.84	**-19.84**	1.59	4.10	30.8	15.90	0.079	1.253						60.20	271.06	1539.1
9	kg/h	gpm(US)			psi	m wg	H×1.2											
10	13883.18	68.35			16.26	**41.76**	**36.94**											
11																		
12	Nozzle D	Nozzle	Coefficients				V1553	**Design Case**										
13	in	Number	A	C			500 gal	**Fluid**	**m3/h**									
14	1.5	2	60	0.51				**Dowtherm J**	**16.0**									
15																		
16	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								

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

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

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

Re ≤ 60:

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

Re > 60:

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

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.

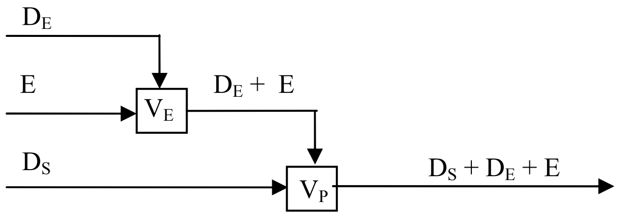
The design case for the pump head was at the minimum operating temperature requiring a head of 30.8 m of fluid at a discharge pressure of 41.8 m wg. The jacket pressure drop was calculated, at minimum temperature, as 1.59 bar; this value was transferred to the model UnitOp Valve. The design case for 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 (m^3/h)
- E Methyl Ester Flow (m^3/h)
- V_E Methyl Ester Volume Fraction
- D_S Diesel Flow from Ship (m^3/h)
- D_P Bio-diesel Blend Flow (m^3/h)
- V_P Bio-diesel Product Volume Fraction

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

Substituting for D_E

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

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

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

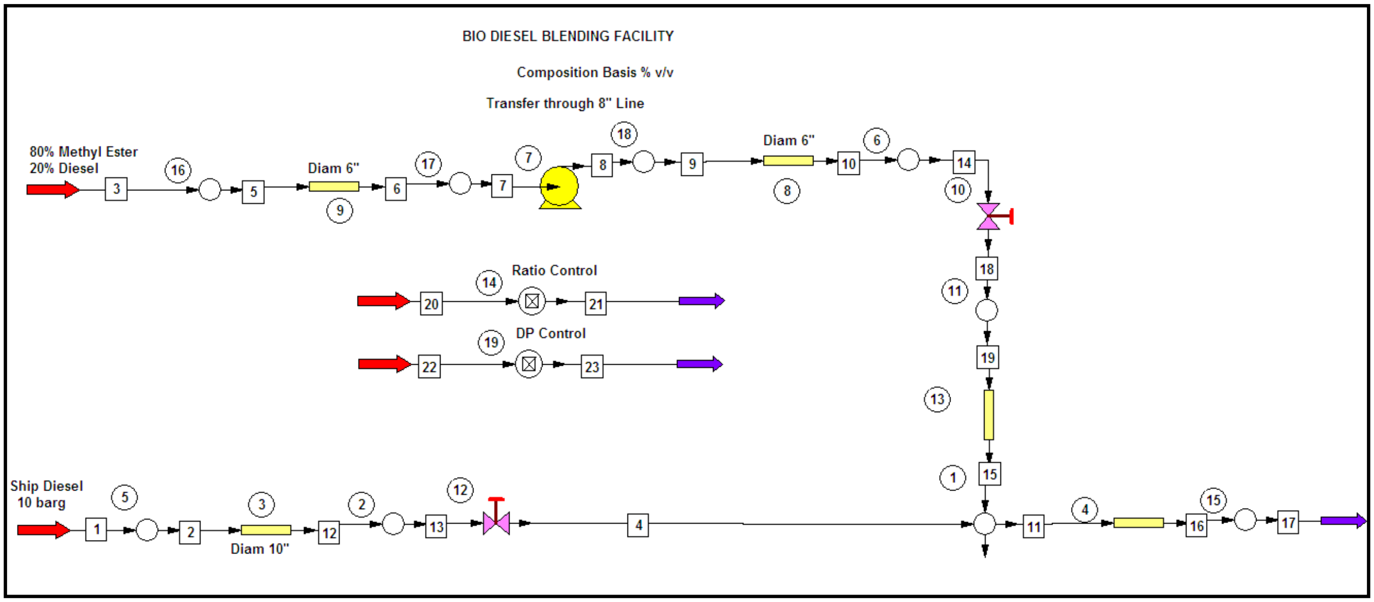
which gives the following results

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

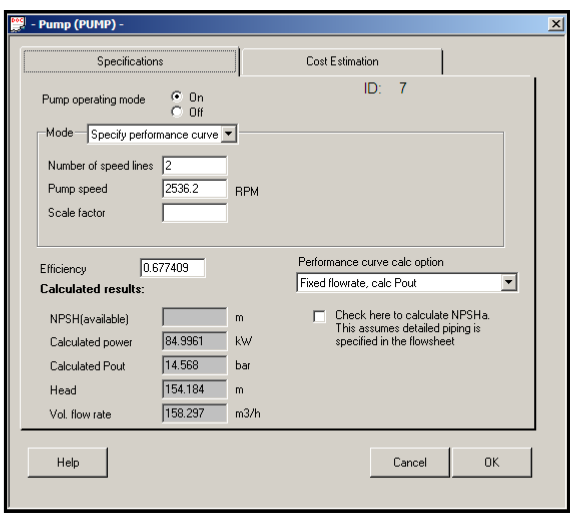
For practice you can build the model or use the model called BLENDCONTROL in the electronic media supplied. It is strongly recommended that you work with a copy of this job. The model flowsheet is shown that represents the piping layout.

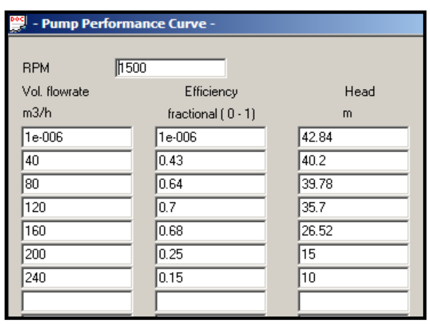


CONFIGURATION

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:

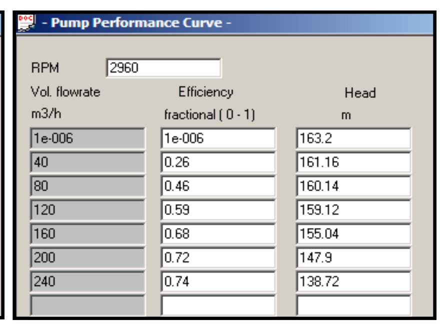




- Pump Performance Curve -

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

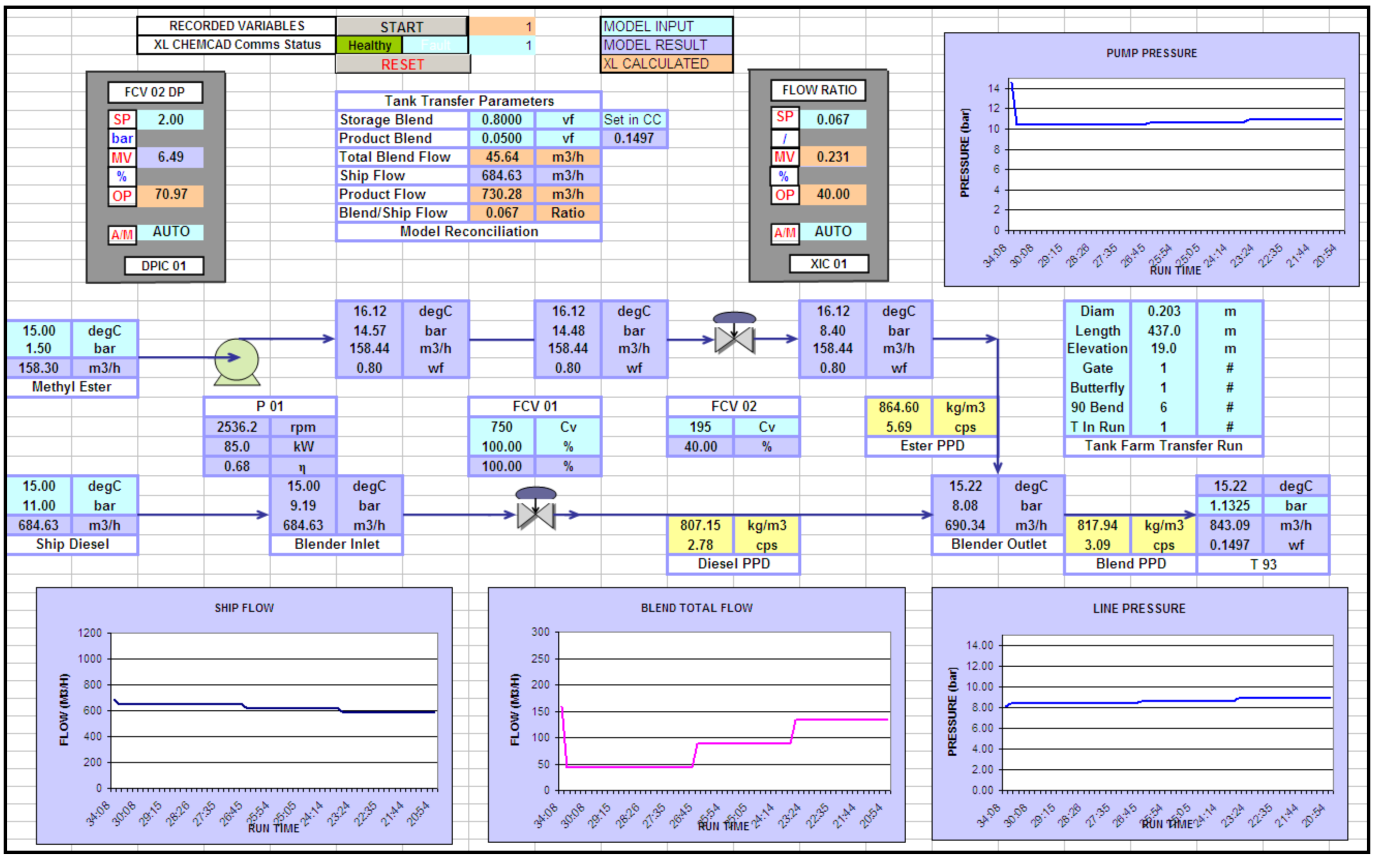
Vol. flowrate m3/h	Efficiency fractional (0 - 1)	Head m
1e-006	1e-006	163.2
40	0.26	161.16
80	0.46	160.14
120	0.59	159.12
160	0.68	155.04
200	0.72	147.9
240	0.74	138.72

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.

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The CHEMCAD process model predicted Ship Discharge flows in the range 685 to 758 m^3/h for transfers to T93 and 580 to 653 m^3/h for transfers to T37 indicating that pipe line pressure drops are controlling.

APPENDICES

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/ft^2)

H height of column of fluid (ft)

ρ specific weight of fluid (lb/ft^3)

Continuity Equation for incompressible fluid flow:

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

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 (ft^2, m^2)

D circular pipe diameter (ft, m)

v velocity of fluid (ft/s, m/s)

g gravitational constant (32.2 ft/s^2 or 9.81 m/s^2)

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

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

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

For loss at entry to pipe $$h_L = 0.5\frac{v_1^2}{2g}$$

For loss at exit from pipe $$h_L = \frac{v_1^2}{2g}$$

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

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:

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

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 from 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 $f = \frac{64}{Re}$ and the Fanning is given by $f_F = \frac{16}{Re}$ 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.

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

The equation was found to match the Colebrook-White equation within 1.0% for $10^{-6} < \varepsilon/D < 10^{-2}$ 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/in^2.

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

ΔP Pressure drop In/in^2
W Flow Rate lb/h
ρ Fluid Density lb/ft^3

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.

$$C = \frac{C_d}{\left(1 - \beta^4\right)^{0.5}} \qquad K_r \approx \frac{\left(1 - \beta^2\right)}{C^2 \beta^4}$$

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 ½D. 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:

$$F_p = \left(1 + \frac{\Sigma K}{N_2}\left(\frac{C_v}{d^2}\right)^2\right)^{-0.5} \qquad \Sigma K = K_1 + K_2 = 1.5\left(1 - \beta^2\right)^2$$

d = nominal valve size (in or mm)
β = 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 60ºF

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)
Cv	=	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 ΔP/100ft. 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

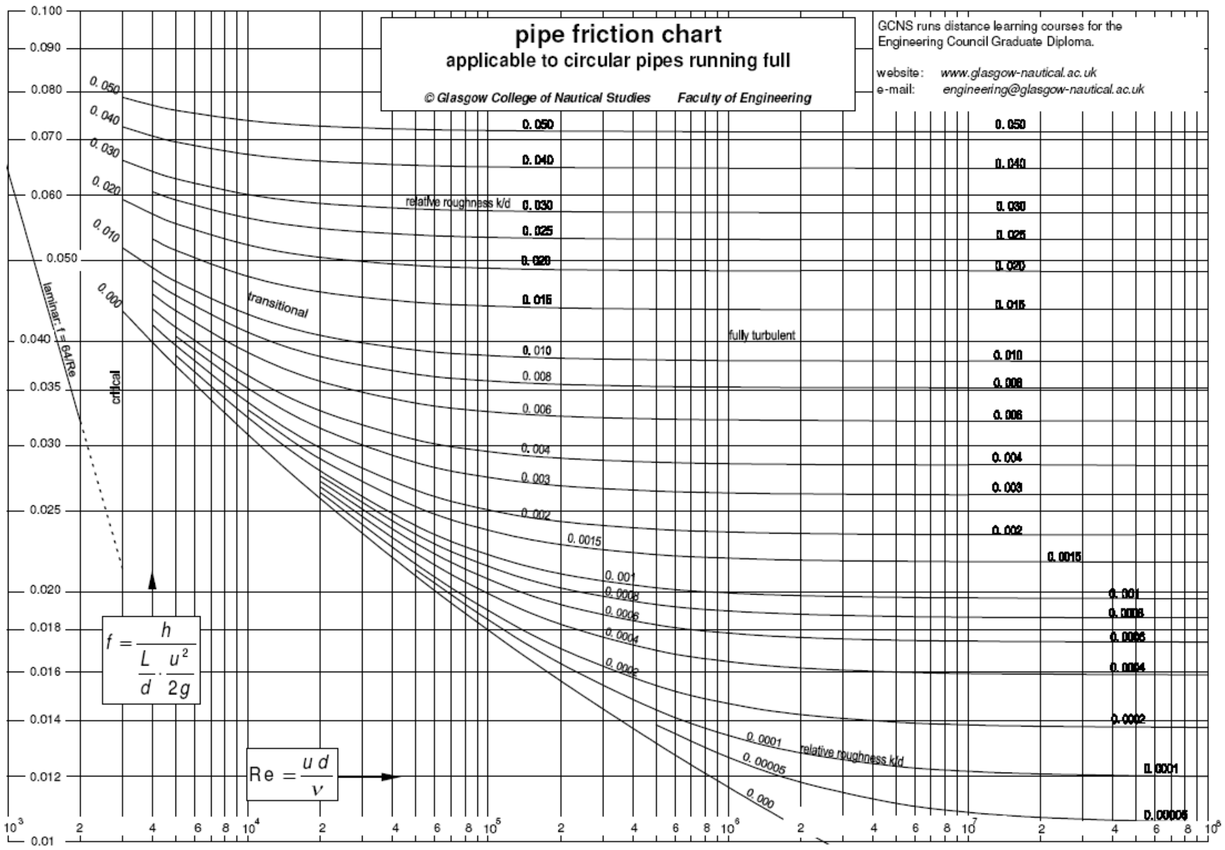
Heuristics for process design (Reference W.D.Seader, J.D.Seider and D.R.Lewin, "Process Design Principles") are also given:

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.

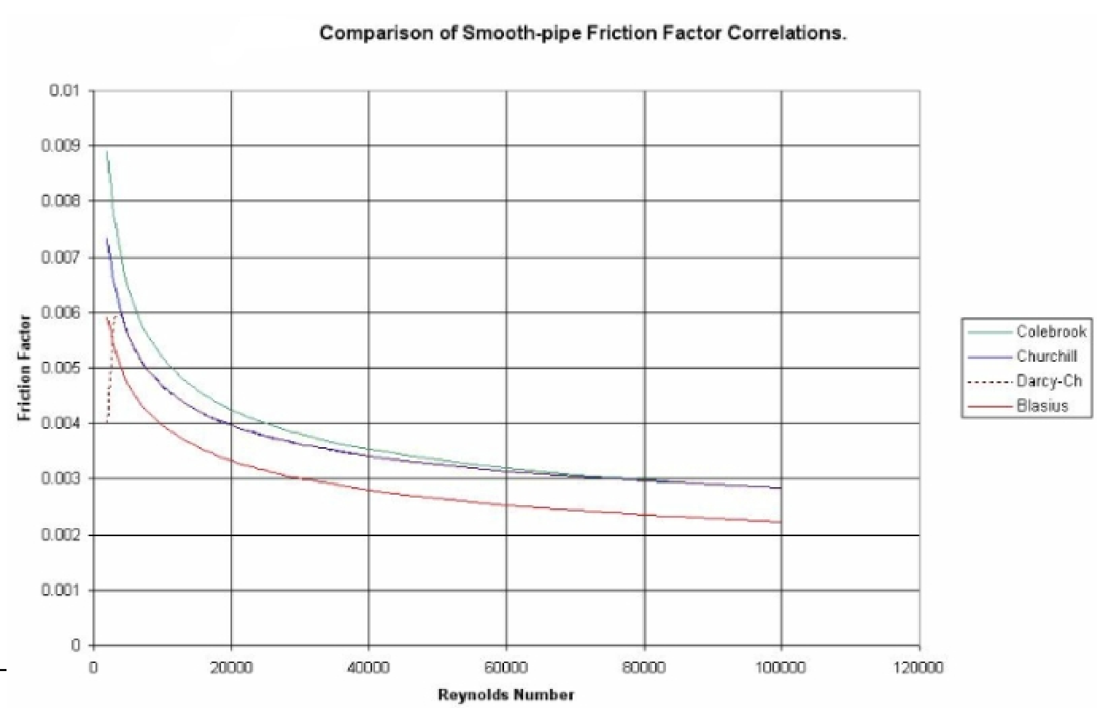
Appendix I

Moody Diagram – Darcy Friction Factor



Example Friction factor for cast iron pipe D = 500mm, ε = 0.5 mm (ε/D = 0.001) with Re of 300000 is 0.026

The diagram below shows Colebrook, Churchill, Darcy-Churchill and Blasius friction factors for smooth pipes. The Blasius Equation being the most accurate for smooth pipes. estimating turbulent pressure drops. Smooth pipe conditions are very well defined.



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/m^3 or lb/ft^3)

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.

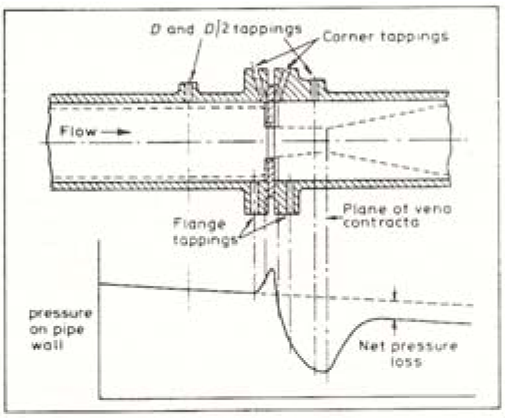
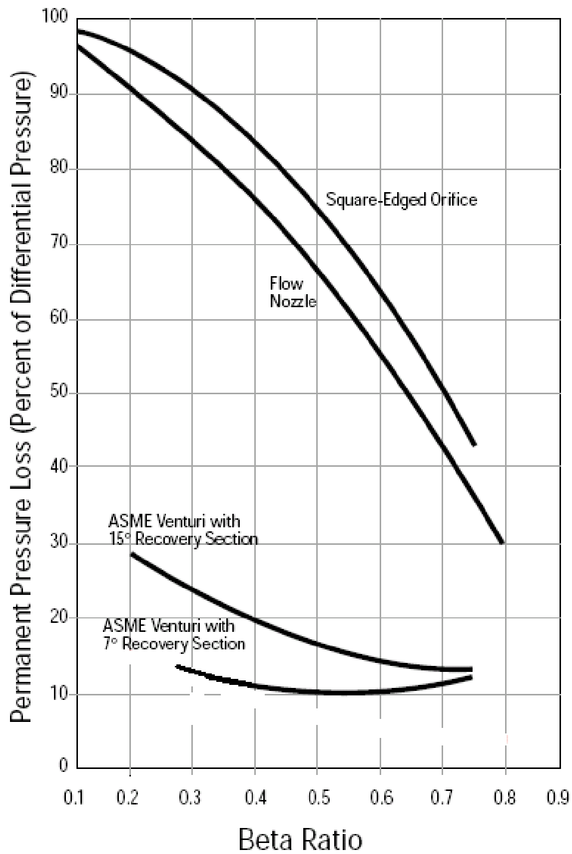


Figure 1—*Section of square-edged orifice plate showing variation of pressure along the pipe wall (by courtesy of BSI)*



For liquids

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

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

For gases

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

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.

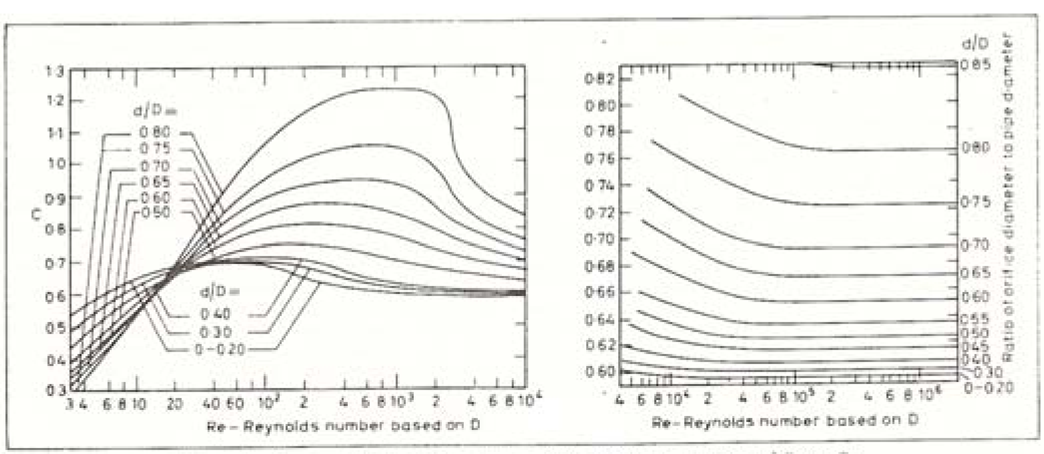


Figure 2—*Flow coefficient C for square edged orifices (by courtesy of Crane Co)*

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:

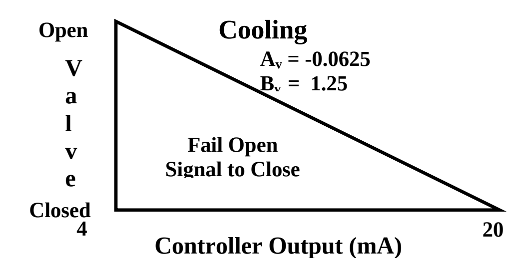
$$T_v\left(\frac{du}{dt}\right) + u = A_v * P + B_v$$

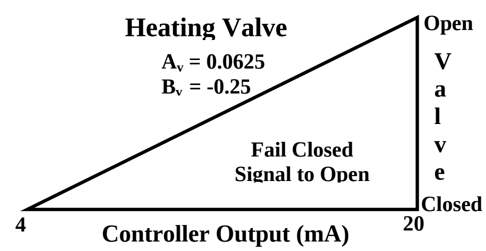
Where: Tv = valve time constant
u = valve position logic 0(closed) or 1(open)
P = input signal mA for logic 0 or 1

In the default condition, the time dependent term is equal zero. Time valve constant Tv 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

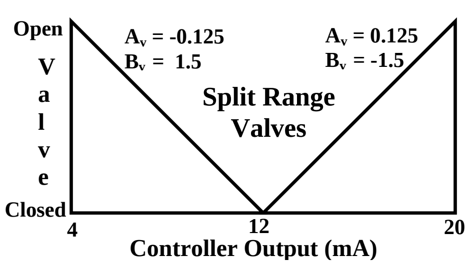
ACTION	CONTROL OUTPUT		POSITION	STATE	LOGIC EQUATION	COEFFICIENTS	
	mA	%				A_v	B_v
FAIL CLOSED	4	0	Closed	0	$0 = 4A_v+B_v$	0.0625	-0.25
	20	100	Open	1	$1 = 20A_v+B_v$		
FAIL OPEN	4	0	Open	1	$1 = 4A_v+B_v$	-0.0625	1.25
	20	100	Closed	0	$0 = 20A_v+B_v$		

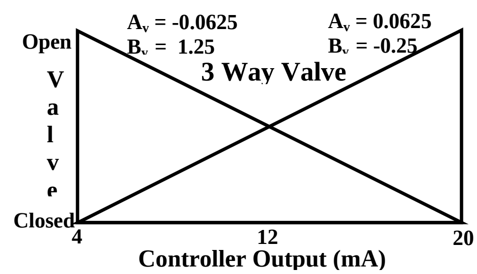




DUAL CONTROL VALVE OPERATIONS IN SPLIT RANGE

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
½	2.0	2.9
¾	2.0	2.9
1	3.2	3.4
1½	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.

Roughness Coefficients ε		
Surface	Roughness Coefficient ε	
	0.001 m	ft
Copper, Lead, Brass, Aluminium	0.001 – 0.002	3.33 – 6.7 10^{-6}
PVC and Plastic Pipes	0.0015 – 0.007	0.5 – 2.33 10^{-5}
Stainless Steel	0.015	5 10^{-5}
Commercial Steel Pipe	0.045 – 0.09	1.5 - 3 10^{-4}
Drawn Steel	0.015	5 10^{-5}
Weld Steel	0.045	1.5 10^{-4}
Galvanized Steel	0.15	5 10^{-4}
Rusted Steel(corrosion)	0.15 – 4	5 - 133 10^{-4}
New Cast Iron	0.25 – 0.8	8 - 27 10^{-4}
Worn Cast Iron	0.8 – 1.5	2.7 - 5 10^{-3}
Rusty Cast Iron	1.5 – 2.5	5 – 8.3 10^{-3}
Asphalted Cast Iron	0.01 – 0.015	3.33 - 5 10^{-5}
Smoothed Cement	0.3	1 10^{-3}
Ordinary Concrete	0.3 - 1	1 – 3.33 10^{-3}
Coarse Concrete	0.3 - 5	1 – 16.7 10^{-3}
Well Planed Wood	0.18 – 0.9	6 - 30 10^{-4}
Ordinary Wood	5	16.7 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	β = 1	8	300	0.037	3.9
	Globe	β = 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 %	⅜ - ¾	¾	3.07-8.84
1	Cage Guided	Linear / Equal %	15/16	¾	20.6/17.2
1½	Microform	Equal %	⅜ - ¾	¾	3.2- 10.2
1½	Cage Guided	Linear / Equal %	1⅞	¾	39.2/35.8
2	Cage Guided	Linear / Equal %	25/16	1⅛	72.9/59.7
3	Cage Guided	Linear / Equal %	37/16	1½	148/136
4	Cage Guided	Linear / Equal %	4⅜	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

Worcester 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		

Worcester 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

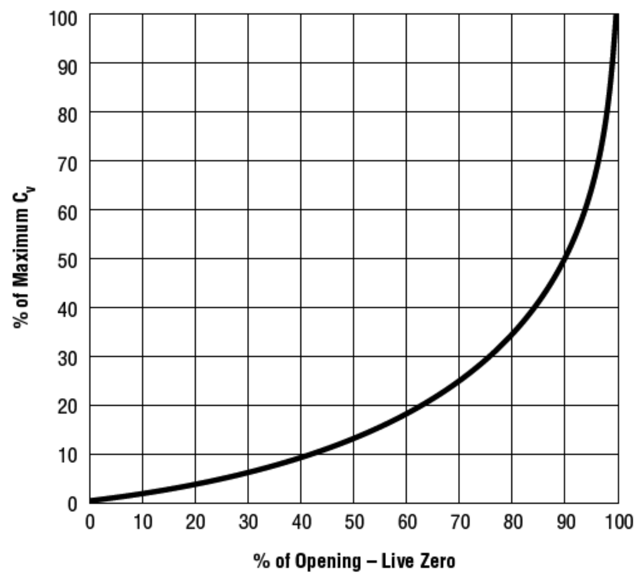
C_v = US gal/min at 1 psi Δ p (K_v = m^3/hr at 1 bar Δ p)

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 Δ p (K_v = m^3/hr at 1 bar Δ p). Flow rates for other mesh sizes available upon request.