P & I Design Ltd
Process Instrumentation Consultancy & Design

2 Reed Street, Gladstone Industrial Estate,
Thornaby, TS17 7AF, United Kingdom.
Tel. +44 (0) 1642 617444 Fax. +44 (0) 1642 616447
Web Site: www.pidesign.co.uk

Batch Reactor Systems Technology Symposium
Teesside, October 2001
(formerly presented at European CHEMCAD Symposium, Berlin, 1999)

RELIEF & BLOWDOWN

IN

MULTIPURPOSE BATCH PLANT

by John E. Edwards & David S. Regan
jee@pidesign.co.uk

Contents

Appendices

References

1. HG Fisher et al, “Emergency Relief Design using DIERS Technology”, Diers/AIChE 1992.
2. J. Wilday and J. Etchells, “Workbook for Chemical Reactor Relief System Sizing”, HSE Contract Research Report 136/1998.
3. S.S. Grossel, “Design and Sizing of Knock-Out Drums/Catchtanks for Reactor Emergency Relief Systems”, Plant Operations Progress (Vol 5, No.3) July 1986.
4. “Sizing Selection and Installation of Pressure Relieving Devices in Refineries”, API 520 6th Edition March 1993.
5. “Guide for Pressure Relieving and Depressuring Systems”, API 521 4th Edition March 1997.
6. “Venting Atmospheric and Low-Pressure Storage Tanks”, API 2000 4th Edition September 1992.
7. “Technical Guidance Note (Dispersion) D1”, HMIP June 1993.
8. “Occupational Exposure Limits 2001, EH40”, HSE 2001.

1.0 Introduction

To achieve safe operation of chemical reactors processing exothermic reactions requires a combination of Preventative and Protective Measures.

Preventative Measures minimise the occurrence of an event and include:-

- Automatic control systems including the use of an independent hardwired alarm and trip system based on Safety Integrity Level (SIL) analysis.
- Provision for appropriate manual intervention.

Protective Measures mitigate the consequences of a runaway reaction and include:-

- Emergency pressure relief.
- Crash cooling.
- Reaction inhibition.
- Drown out.

This paper reviews the techniques associated with the design of emergency pressure relief and blowdown systems. Process simulation software CHEMCAD is used as a design tool for studying this important area of Process Engineering.

The benefits of a pressure relief system are:-

- Different and independent failure modes to the preventative measures.
- Provides relatively passive means of protection.
- Provides adequate protection if all other systems fail.

The emergency pressure relief system is considered the ultimate protection. The primary basis of safety for overpressure protection is based on prevention involving management control procedures and instrument protective systems.

Emergency pressure relief may not be appropriate due to economical, environmental or technical considerations. In such cases, appropriate preventative measures must be relied on.

The design of emergency relief systems for exothermic batch reactors requires a thorough understanding of the reaction conditions including:-

- The credible maloperations and system failures that might occur during reaction.
- The kinetics of the reaction under runaway conditions.
- Whether the reaction pressure is from vapour, gas or both.
- The flow regimes in the vessel and relief system during relief.
- The design and layout of the relief system.

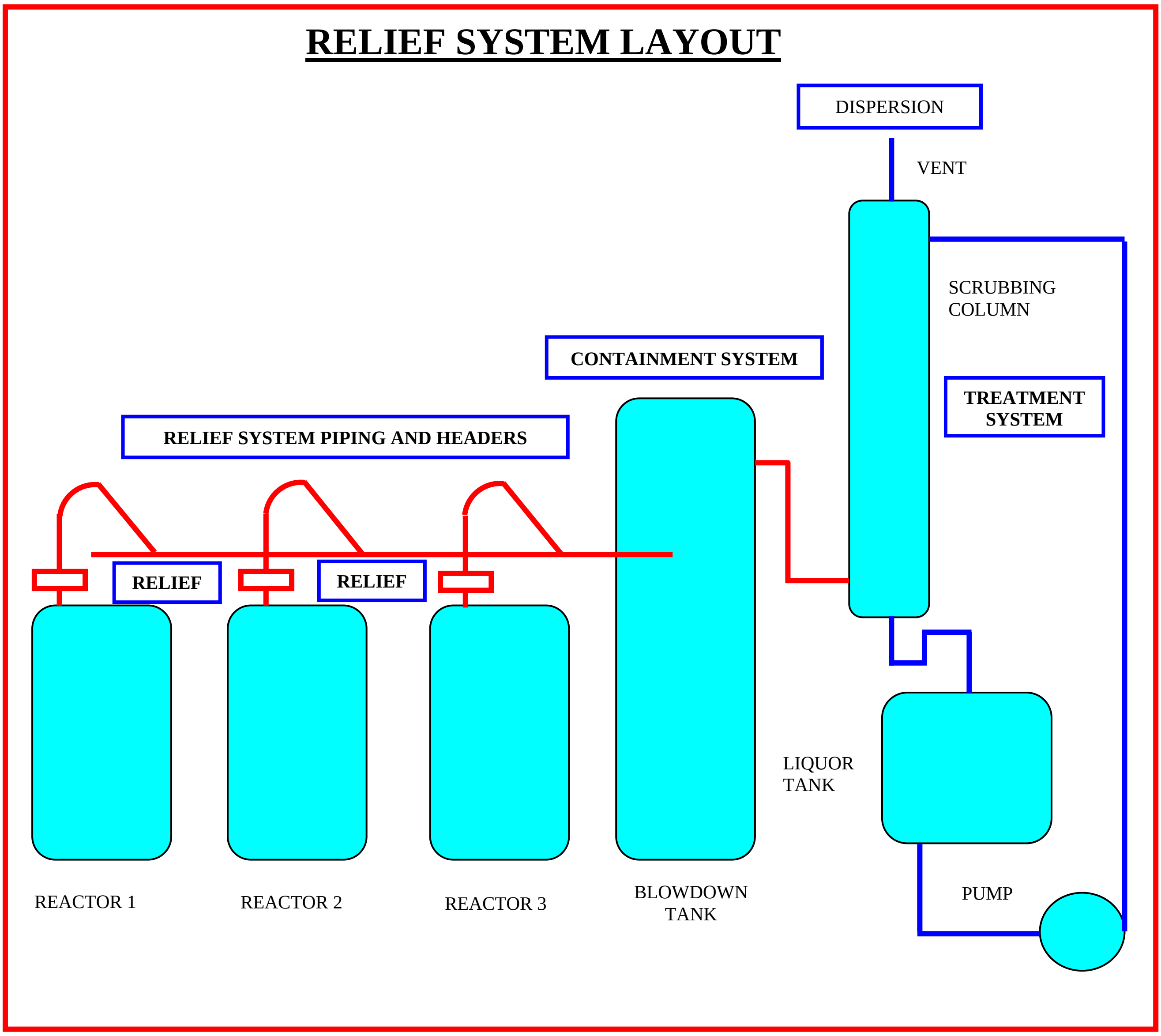
Significant research has been carried out particularly by the Design Institute for Emergency Relief Systems (1) (DIERS) and a recent publication in the UK by the Health and Safety Executive (2) Workbook for Chemical Reactor Relief System Sizing is a useful design tool.

2.0 Relief System Layout

The emergency relief system comprises certain key components:-

- Primary pressure relief device.
- Relief system piping and headers.
- Containment system.
- Treatment system.
- Atmospheric dispersion.

Specific design techniques are required for each component of the system and process modelling of the total integrated system will demonstrate the adequacy of the total design.



2.0 Relief System Layout

2.1 Pressure Relief Devices

The pressure relief device is either a relief valve, a bursting disc or a combination of both. On chemical reactors the bursting (rupture) disc is most favoured due to being able to handle the following conditions:-

- Rapid pressure rise with full relief area available, except when vacuum support used.
- Toxic fluids where no leakage past a safety valve is permitted.
- Corrosive fluids that may cause progressive deterioration of a safety valve.
- Fluids that may deposit solids or gums that interfere with safety valve operation.

The major disadvantages of bursting discs are :-

- Require a larger allowance between the operating pressure and the set pressure.
- If the operating pressure and the set pressures are too close, the disc can fail prematurely due to pressure pulsations.
- Loss of containment of reactor contents on operation i.e. valve does not reseat, unless used in conjunction with a safety valve.

To mitigate against the loss of containment due to operation of a bursting disc sized for the worst case scenario the installation of a smaller bursting disc/relief valve combination in parallel set at a lower relief pressure can be considered. This smaller system operates in the event of nuisance pressure build ups, due to maloperation, without total loss of containment. This technique has the disadvantage, due to the poor set pressure tolerance of bursting discs typically ± 10%, of significantly increasing the set pressure of the main bursting disc to ensure the smaller disc operates first. This may lead to an undesirable situation particularly when protecting for exothermic runaway events.

The relief pressure at which the relief device is fully open should be set at the lowest pressure practicable consistent with preventing nuisance operations for the following reasons :-

- For most exothermic runaway reactions, the reaction rate and heat release rate increases exponentially with temperature. For a vapour pressure system, a low relief pressure means a low relief temperature and hence a relatively low rate of heat release. The relief area required is directly proportional to the rate of heat release by the reaction.

- For a relief system venting a two-phase mixture, pressure relief acts to remove reactants from the reactor. A low relief pressure allows a greater margin between the relief pressure and maximum permitted pressure, and advantage is taken of this by the sizing methods to yield a smaller relief area.

The specified relief pressure for a bursting disc is subject to a tolerance of up to ± 10% of the gauge pressure and reduces with increasing temperature. Bursting disc capacity is reduced significantly by the use of a vacuum support.

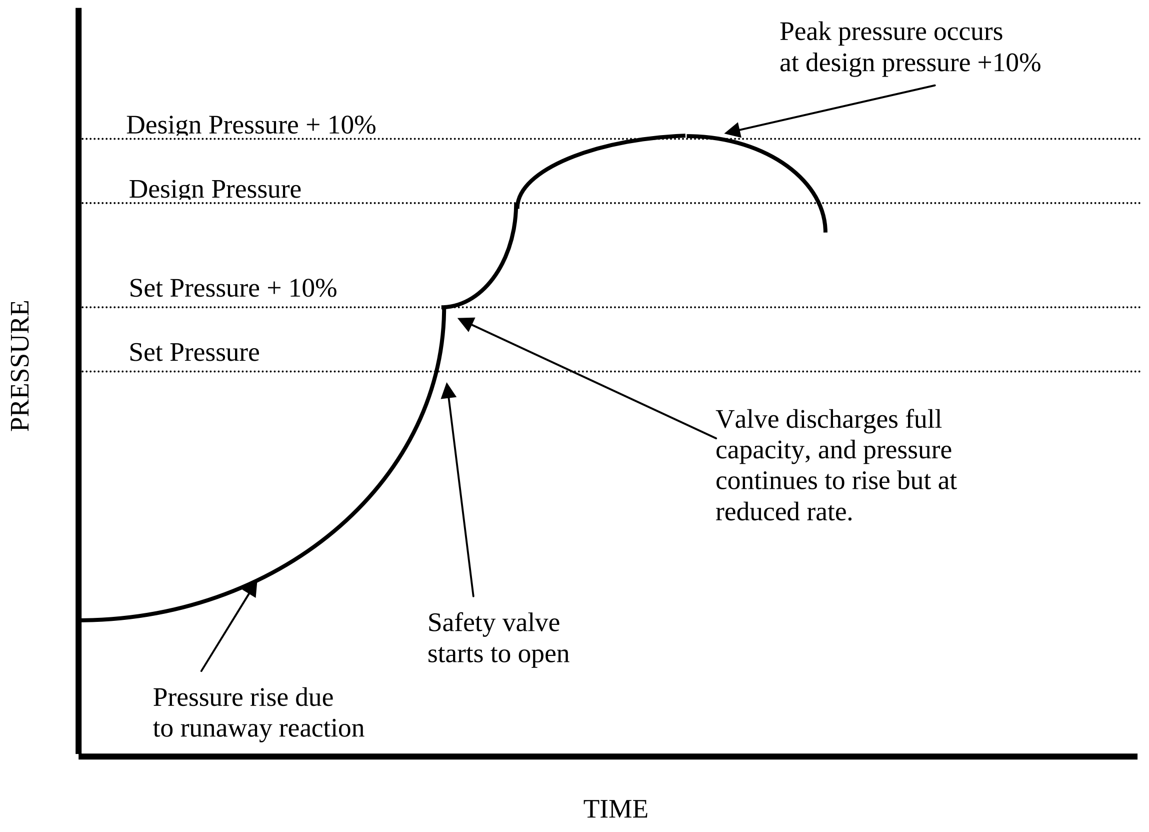
The relief area required for a specified device depends on the discharge coefficient, 0.625 for a bursting disc. The diameter required is calculated on this basis with no allowance for vacuum support. When using vacuum supports the % free area is reduced by 0.6 (size range 100 – 200mm) and the bursting disc diameter to provide the area required is calculated accordingly.

The requirements for the design of the relief system sizing can be summarised:-

- The equipment design pressure plus permitted accumulation is not exceeded.
- The pressure relief system is as small as possible consistent with the above clause. A small relief system minimises cost, disposal requirements and the potential rate at which material could be discharged to the environment.

CHEMCAD facility Relief Device under Equipment Sizing is used for design.

Pressure Versus Time for a Runaway Reaction with an Optimum Size of Relief Valve



2.2 Relief System Piping and Headers

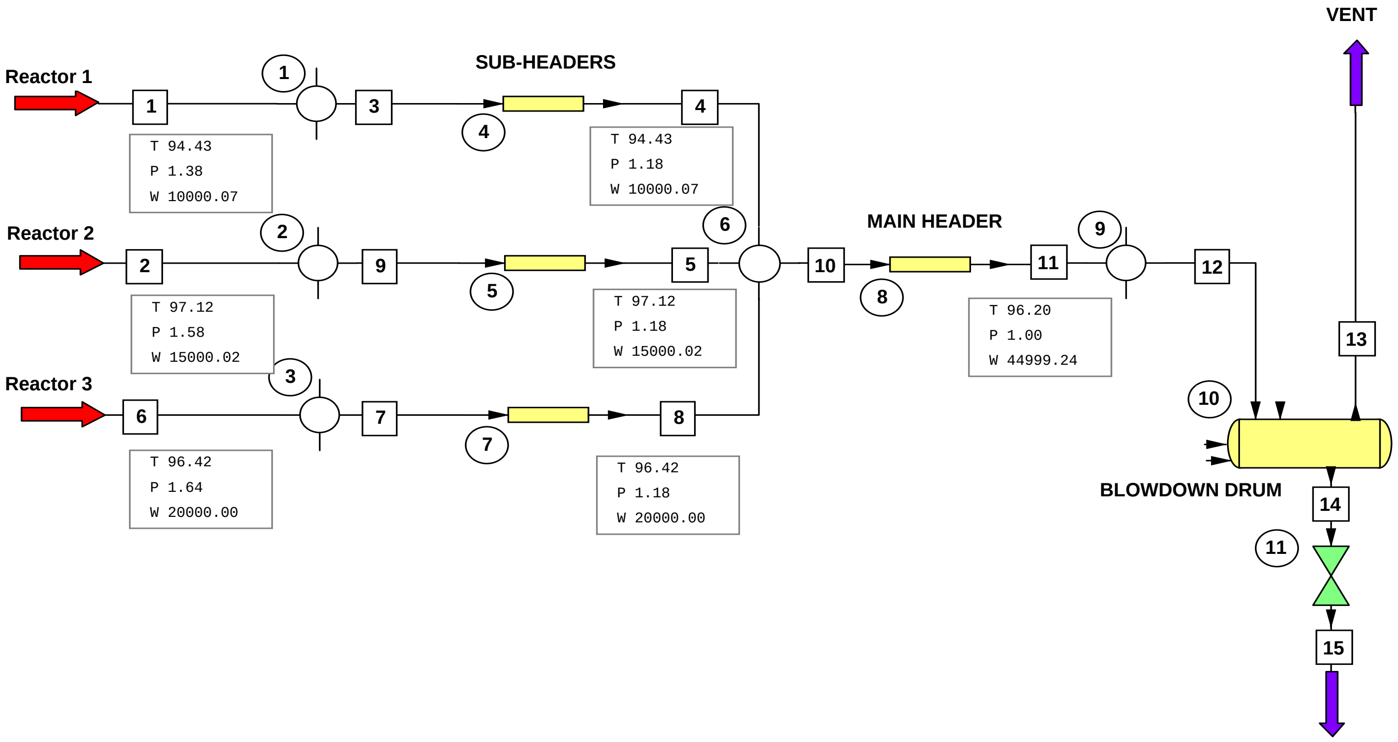
The flow capacity of a bursting disc is determined by the disc diameter and the discharge coefficient. However the system capacity can be limited by the discharge piping system.

Key features of the relief system piping design can be summarised:-

- Branch pipe from reactor to the header to be not less than the outlet diameter of relief device.
- Branch pipe to enter main header as a 45 degree T, flow through branch.
- All 90° bends to have maximum R/D consistent with layout constraints.
- Main header to slope towards the blowdown drum and enter tangentially.
- Consideration to be given to nitrogen inerting to prevent explosive mixtures.
- Provision of adequate inspection and test facilities to ensure headers are clear.

To size the relief device a knowledge of the discharge piping size and layout is required and this is discussed in Section 4.0.

RELIEF SYSTEM HEADER SIMULATION



2.3 Containment System

In many instances the discharge stream from an emergency relief system is a two phase vapour liquid mixture. The stream is routed to a blowdown/knock out drum designed to disentrain the liquid from the vapour to allow discharge to atmosphere or for downstream treatment. The justification for the blowdown drum is:-

- Prevents release of hot, toxic and corrosive liquid resulting in potential safety hazards and environmental damage.
- Prevents release of flammable droplets leading to vapour cloud explosion.
- Allows downstream treatment of toxic vapours for treatment in a wet scrubber, flare or incinerator.

There are many designs of blowdown drum depending upon the circumstances but key features include:-

- Tangential inlet into a vessel of sufficient diameter to effect good vapour – liquid separation.
- Total volume sufficient to hold the estimated carryover, typically two times the volume of the largest reactor connected to the relief system.
- Adequate instrumentation monitoring for level and pressure detection.
- Appropriate facilities for drainage and material handling.
- Appropriate facilities for quenching reaction mixtures.

Depressurisation scenarios and blowdown drum dynamics in relation to rate of pressure rise can be modelled.

Sizing of the blowdown drum is carried out in accordance with API 521. The basic design method(3) involves the calculation of the allowable vapour velocities for the components under consideration which allows the vapour flow area to be set. A drum diameter can then be determined on the basis that the vapour flow area occupies half of the drum area.

The drum volume allowed for the disentrained liquid is based on the following criteria:-

- For non-foaming systems the volume should be equal to the maximum working volume of the largest reactor connected to the system.
- For foaming systems the volume should be a minimum of 1.5 times the maximum working volume of the largest reactor connected to the system.

As a general rule in multi-purpose batch plants the minimum blowdown drum volume should be equal to 2 times the maximum working volume of the largest reactor connected to the system.

P&I Design have developed a spreadsheet XLBLOWDOWN for the sizing of blowdown drums.

2.4 Treatment System

The treatment of vapours arising from the containment system depends on the nature of the release and the potential hazard to health as a result of the emission to atmosphere. The principles of BATNEEC are applied to ensure an appropriate design.

As a minimum, a discharge stack is required designed in accordance with HMIP Technical Guidance Note (Dispersion) D1(7). This guidance note was not intended for short duration emergency releases so the design needs to be validated using appropriate dispersion models such as Phast 6.0 Unified Dispersion Model by DNV or ADMS 3.0 Atmospheric Buoyancy Model.

If a reasonable stack height can achieve, for the components under consideration, maximum ground level concentrations not exceeding the Short-term exposure limit (15-minute reference period)(8) and the annual discharge limit for the site is not exceeded no further treatment facilities are required.

Invariably vapours vented from exothermic reactions under normal processing conditions are treated by contacting with a scrubbing liquor in a random packed tower with suitable hydraulic design parameters and packed height for mass transfer and/or fast chemical reaction.

Column hydraulics design involves ensuring adequate liquor circulation flow to satisfy minimum wetting rate for the packing, and that the packing is adequately loaded (liquid/gas ratio) for mass transfer. Column loading should not exceed 80% flood.

The mass transfer or reactive absorption model used depends on the process. The chemical reaction exotherm requires adequate circulating liquor volume and flow to satisfy stoichiometric requirements and to control system temperature. A heat exchanger may also be required if the heat evoution from the reaction justifies it.

If scrubbing facilities are available a reasonable practice is to back vent the blowdown tank to the site scrubber to mitigate for nuisance releases to atmosphere. In this case the blowdown tank can be fitted with a bursting disc or breather valve discharging to the vent stack and the vapour flow to the scrubber is flow limited to prevent flooding.

The set pressure of the blowdown tank relief device should be set as low as practicable to minimise the back pressure on the relief header system.

P&I Design have proprietary software XLSCUBBER which is based on fast chemical reaction which assumes the concentration of scrubbed gas at the liquid film interface is zero making the mechanism gas film controlled. CHEMCAD with its extensive electrolyte features is used for slow reactions and absorption mechanisms.

3.0 Relief System Sizing

3.1 Design Fundamentals

3.1.1 Vessel and Vent Flow Models(1),(2)

In relief system design there are three main types of system to be considered depending on the nature of the reaction.

- **Vapour pressure systems**

  The pressure generated by a runaway reaction is entirely due to the vapour pressure of the reacting mixture which rises as the temperature of the mixture increases during a thermal runaway.

- **Gassy systems**

  The pressure generated by a runaway reaction is entirely due to a permanent gas which is evolved by the chemical reaction.

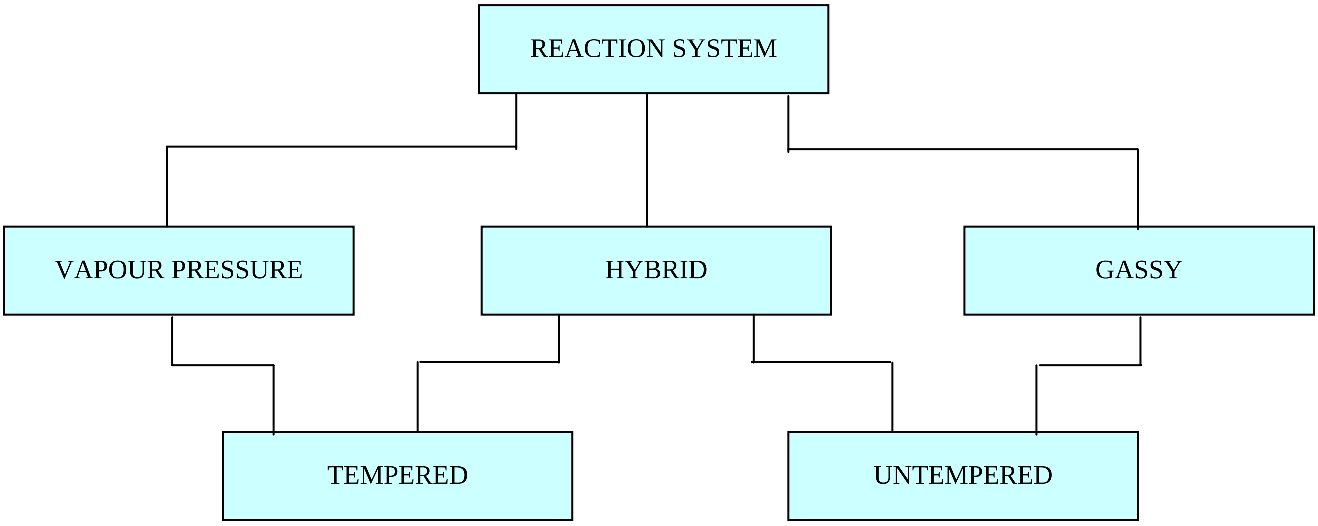
- **Hybrid systems**

  The pressure is due to both the evolution of a permanent gas and increasing vapour pressure with increasing temperature.

Vapour pressure systems are **tempered** in that the temperature and reaction rate is controlled during relief due to latent heat removal.

Gassy systems are **untempered** in that pressure relief does not control the temperature or reaction rate.

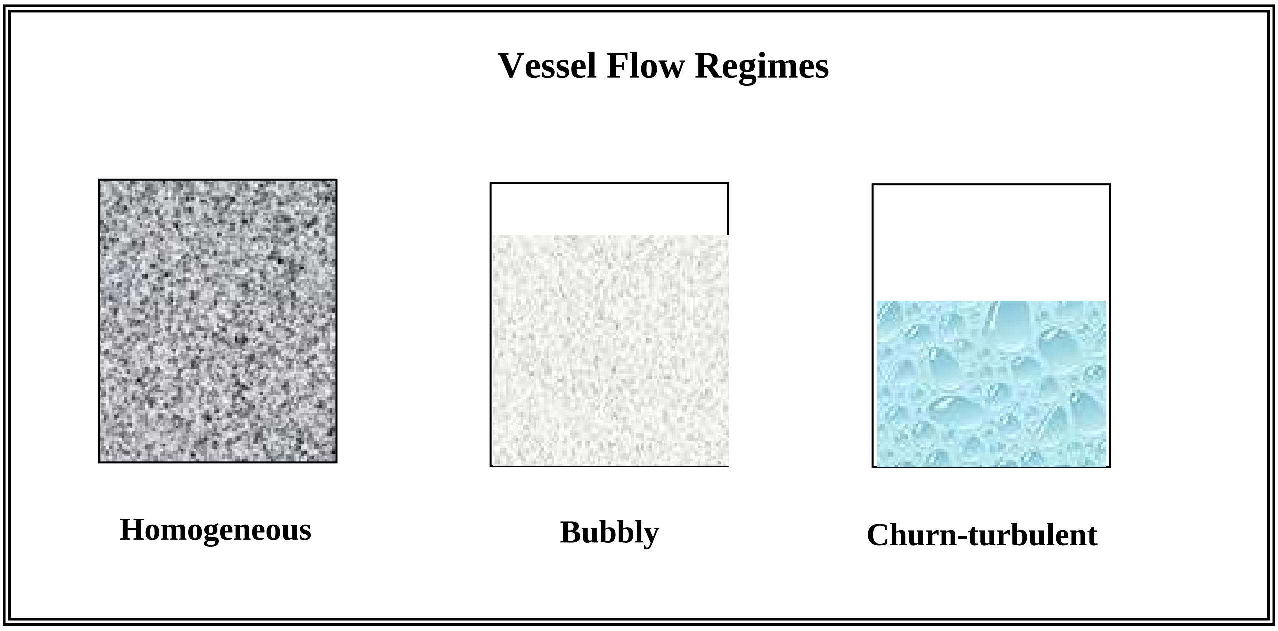
Chemical Reactor System Types



3.1.1 *Vessel and Vent Flow Models (Cont.)*

The two phase flow regime within the venting vessel will influence the fraction of gas or vapour within this two phase mixture. The vessel flow regimes considered are:-

- **Homogeneous**
- **Bubbly**
- **Churn-turbulent**



Level swell, depending on reactor level, results in venting of a two phase mixture typical of gassy and hybrid systems.

Foamy systems invariably will vent a two phase mixture throughout the relief period.

Two phase flow models for Relief Device Sizing to be considered are:-

- **Homogeneous equilibrium model (HEM)**

  Assumes uniform mixing of phases across the pipe section – no phase slip, thermal equilibrium, and vapour/liquid equilibrium. (Recommended by DIERS).

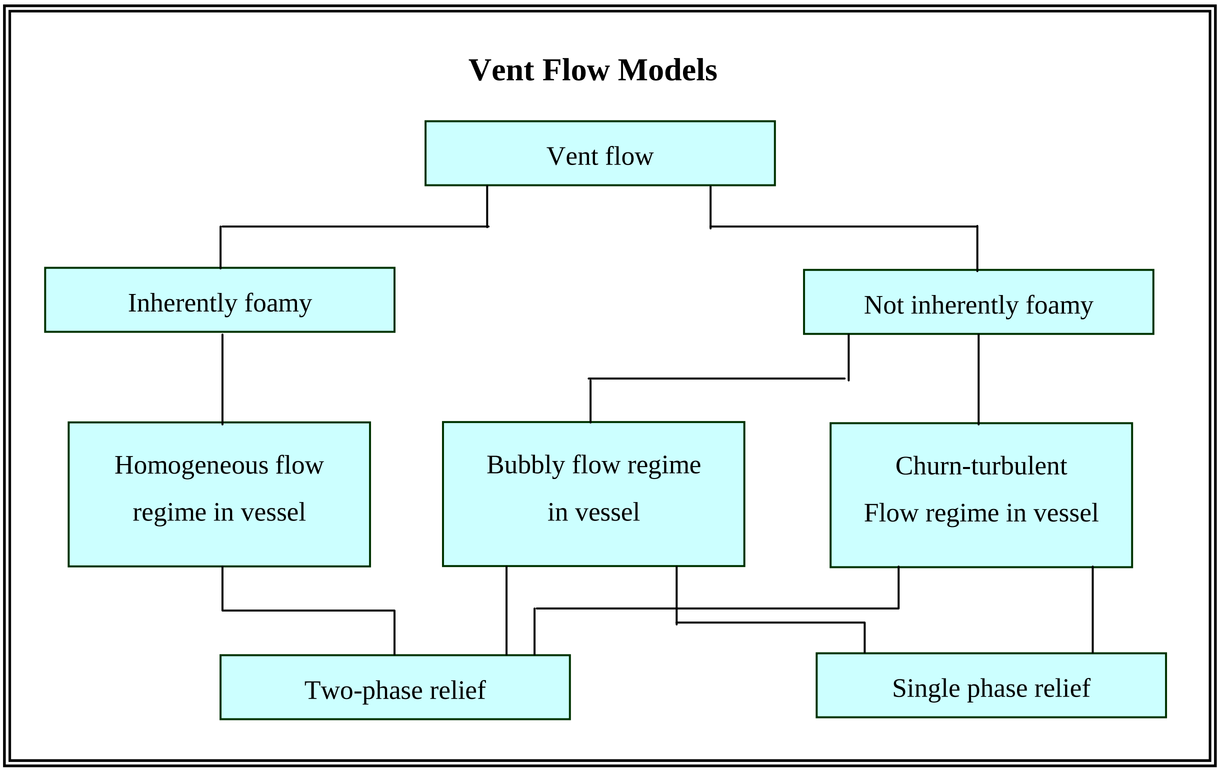
- **Equilibrium rate model (ERM)**

  Assumes no flashing in the relief system until the choke point and then flashing at equilibrium rate at the choke point.

- **Henry Fauske model (HNE)**

  Neglects friction and assumes two-phase relief system flow is not choked which is less conservative.

3.1.1 ***Vessel and Vent Flow Models*** *(Cont.)*



The vessel and vent flow models should be established experimentally. The following assumptions are considered conservative (safe):-

- **For tempered systems**

  Two-phase rather than vapour relief.
  Homogeneous vessel behaviour.
  Homogeneous equilibrium model (HEM) for relief system flow.

- **For untempered systems**

  Two phase relief at the point of maximum gas generation rate.
  Level swell behaviour in the reactor which minimises early loss of reactants by relief e.g. churn turbulent.
  Homogeneous equilibrium model for relief system flow.

3.1.2 Heat Models

For relief device sizing from exothermic reactions experimental data is required from reaction screening techniques (1) (2) to establish the maximum rate of pressure rise and maximum rate of temperature rise.

Heat input rates can be user defined from a knowledge of the thermal characteristics of the reaction system and associated jacket services. This is particularly useful when considering operational and control system failure modes such as maximum heat input from jacket systems.

Heat input rates can also be as a result of external fire. This has received extensive investigation by several organisations including API, NFPA and OSHA.

Refer to Appendix III for establishing heat inputs using the following:-

API 520 (4) / API521 (5) (operating pressure > 15 psig)
API 2000 (6) (operating pressure $\leq$ 15 psig)

Vent flow model single phase vapour is usually appropriate for external fire cases.

Where,		
	Q = total heat absorption	Btu/hr
	A = total wetted surface	ft^2
	F = environmental factor (4, 5)	(API 521 Table 5)

In API 520/API 521 the heat input Q is determined from:-

$Q = 21000\ FA^{0.82}$	with adequate drainage and fire fighting equipment
$Q = 34500\ FA^{0.82}$	without adequate drainage and fire fighting equipment

In API 2000 for low pressure storage tanks the heat input Q is determined from:-

$Q = 20000\ A$	in the range $0.4 \times 10^6 < Q < 4 \times 10^6$ Btu/hr
$Q = 199300\ A^{0.566}$	in the range $4 \times 10^6 < Q < 9.95 \times 10^6$ Btu/hr

Appendix IV summarises the design basis for estimation of the heat transfer areas for the different standards.

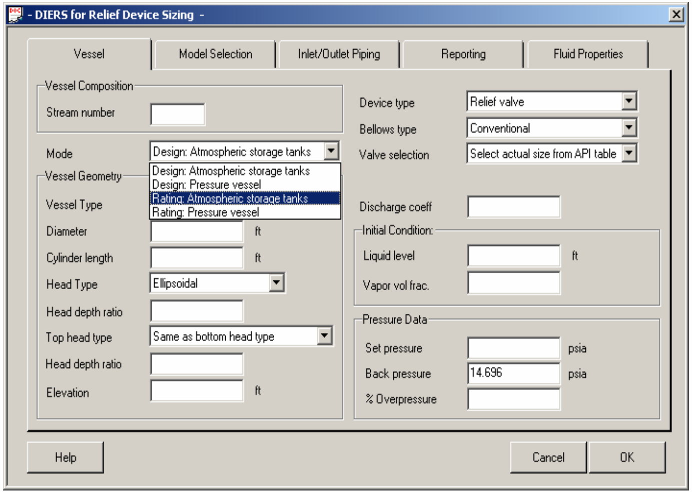
A vent flow rate can be specified which allows for consideration of regulator failure and enables reaction gas evolution rates to be considered.

3.2 CHEMCAD – Relief Device Sizing

Chemstations CHEMCAD relief device sizing software allows data entry of all the relevant design parameters.
The data entry screens for the module are shown below. It can be seen that these are in Windows format making the very efficient and easy to use.
The Vessel screen allows selection for the design or rating of Atmospheric storage tanks or Pressure Vessels using conventional relief valves, bursting discs or both in combination.
The Model screen allows selection for vessel model, vent flow model and heat model:-

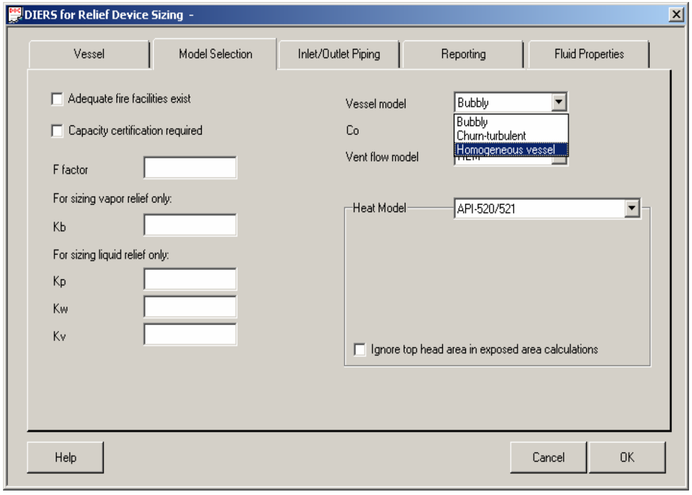
- Vessel model - Bubbly, Churn-turbulent, Homogeneous vessel.
- Vent flow model - HEM, ERM, Henry-Fauske HNE, Non-flashing liquid, Single phase vapour.
- Heat model – API 520/521, API 2000, OSHA 1910.106, NFPA 30, Specify heat rate, Specify vent flow rate, Tempered runaway.

Vessel Screen



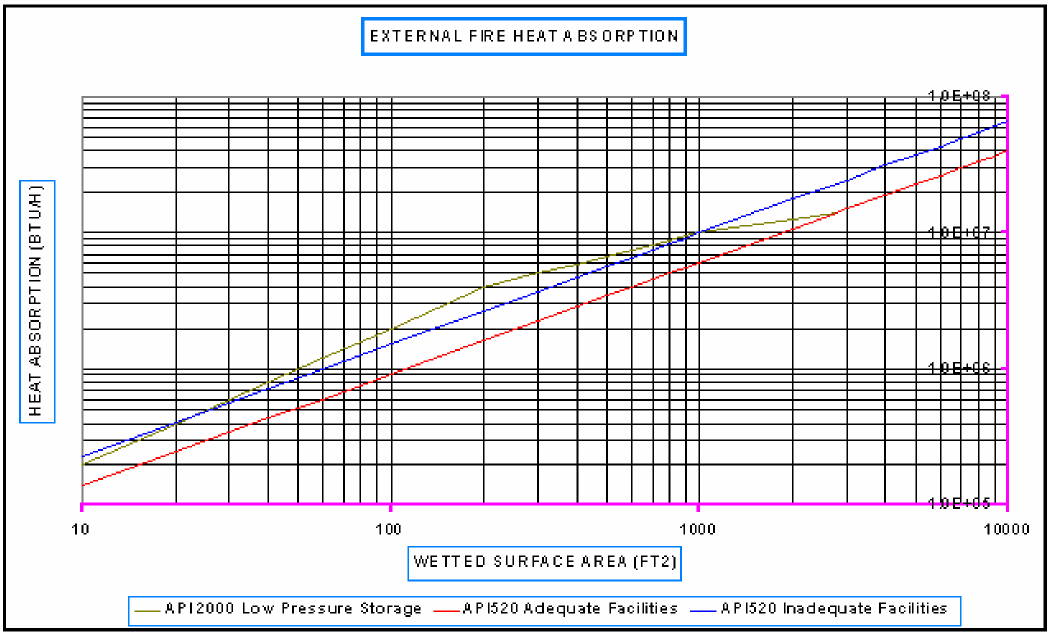
Vessel Composition
Stream number
Mode: Design: Atmospheric storage tanks
Design: Atmospheric storage tanks
Design: Pressure vessel
Rating: Atmospheric storage tanks
Rating: Pressure vessel
Vessel Geometry
Vessel Type
Diameter ft
Cylinder length ft
Head Type: Ellipsoidal
Head depth ratio
Top head type: Same as bottom head type
Head depth ratio
Elevation ft
Device type: Relief valve
Bellows type: Conventional
Valve selection: Select actual size from API table
Discharge coeff
Initial Condition:
Liquid level ft
Vapor vol frac.
Pressure Data
Set pressure psia
Back pressure: 14.696 psia
% Overpressure

Model Screen



☐ Adequate fire facilities exist
☐ Capacity certification required
F factor
For sizing vapor relief only:
Kb
For sizing liquid relief only:
Kp
Kw
Kv
Vessel model: Bubbly
Bubbly
Churn-turbulent
Homogeneous vessel
Co
Vent flow model: HEM
Heat Model: API-520/521
☐ Ignore top head area in exposed area calculations

The Heat model used is decided by the heat input basis due to external fire from the graph below and by reference to Appendix IV or specific process conditions.



3.2 CHEMCAD – Relief Device Sizing

To carry out relief device sizing efficiently the following procedure has been developed for use with CHEMCAD:-

- Prepare the vessel design parameters input data table (Appendix I).
  Diameter, cylinder length, dished end depth ratio (h/R), liquid level.

- Prepare process parameters input data table (Appendix I).
  Components, charge details weight and mole fractions.

- Define the component list and thermodynamics.
  For common organic solvent based systems.
  Equilibrium K Ideal Vapour Pressure.
  Enthalpy H Latent Heat.

- Set up Flow Sheet with Reactor Inputs and Vent Manifold model.

- Define stream compositions.
  Set vapour mole fraction to 1.0 and stream pressure at relief device set pressure and flash to obtain relieving temperature and enthalpy.

- Complete Relief Device Sizing entry data:-
  - Assign relevant Stream Number from Flowsheet.
  - Mode Design for new device.
    Rating for existing device.
  - Device Type including coefficient of discharge from manufacturer's data. Caution with bursting discs with vacuum support.
  - Select Vessel Model and Vent Model based on knowledge of process. Alternatively, use conservative Homogeneous Vessel and HEM Vent Flow model. For external fire single phase vapour is usually appropriate.
  - Specify Heat Model.
    For external fire API 2000 is conservative compared with API 520/521.
    API 520/521 with inadequate drainage/fire fighting facilities and Environmental Factor F = 1.0 is conservative.
  - Valve selection – use calculated size for rating case.
  - Complete inlet/outlet piping details.

- Complete results print out after each device sizing run

4.0 Relief System Header

The CHEMCAD Pipe Simulator and Pressure Node UnitOps are used to Design and Rate the relief manifold.

The vent conditions are available from the relief device sizing runs which are now entered into the relevant streams using the relief temperature and stream pressures set at 1.2 bar initially. The pressure node UnitOp provides a unique and powerful tool to automatically calculate the pressure distribution in the pipe manifold and converges to a pressure balance throughout the network.

Isothermal flow conditions are assumed at the downstream relief discharge temperature.
Actual flow conditions will be between isothermal and adiabatic conditions, but for most cases the more conservative isothermal conditions are recommended.
(Reference API 521(5), p 58, 5.4.1.3.2.)

The model can be run for an individual reactor relief or for coincident reactor relief cases in the event of external fire. The vessel fire zones are established based on plant layout and operations.

The model allows for the prediction of the maximum back pressure on the relief device attributable to the vent manifold pressure drop.

Provided the manifold back pressure (P_B) does not result in $P_B/P < 0.55$, where P is the inlet pressure, flow through the relief device is sonic (choked) providing maximum flow.

If we have a maximum blowdown tank pressure P_T and a minimum equipment design pressure P_D provided

$$P_D \geq \frac{P_T \; + \; \text{Vent} \quad \text{Manifold}\,\Delta P}{0.55}$$

the system will not suffer any reduction in capacity at the maximum blowdown tank pressure. Where the equipment design pressure is such that sonic velocity cannot be maintained the maximum allowable back pressure and the reduction in relief capacity is considered for specific cases. The reduction in relief device capacity can be determined by applying the appropriate back pressure in the Relief Device Sizing module.

Appendix 1

Vessel Design Parameters

Vessel (Device)	**Material**	**Volume l**	**Pressure**		**Physical Parameters**		**Dished End Parameters**				**Liquid Level m**
			Design barg	**Set barg**	**Diameter M**	**Tan-Tan m**	**Top hd/R**	**Base hd/R**	**Base Depth m**	**Base Volume l**	
Reactor 1	SS	4000	2	1.9	1.8	2.286	0.5	0.5	0.46	756	0.949
Reactor 2	GL	7000	6.9	4.0	2.134	1.677	0.453	0.5	0.533	1231	1.168
Reactor 3	GL	7000	6.9	4.0	2.134	1.677	0.453	0.5	0.533	1231	1.532

Process Parameters

Vessel (Device)	**Process Specification**						
	Fluid	**Volume l**	**Liquid ρ kg/m³**	**Weight kg**	**Mol wt kg/kmole**	**Liquid kg/kmole**	**Liquid Mole fraction**
Reactor 1 (BD01)	Toluene	2000	867	1734	92	18.850	1.000
Reactor 2 (BD02)	DCM	3500	1326	4641	85	54.600	1.000
Reactor 3 (BD03)	Toluene	1000	867	867	92	9.424	0.138
	DCM	3500	1326	4641	85	54.600	0.800
	$SOCl_2$	300	1640	492	118	4.169	0.062
		4800		6000		68.190	1.000

Appendix II

Relief Piping Equivalent Length

A specific design was based on the following:-

Relief device inlet and outlet piping diameter = 150mm.
Main header diameter = 250mm.

The total equivalent length of a typical vessel branch was taken as 45.1 m, based on 4 x standard 90° elbows, 1 x 45°T flow through branch, 1 x sudden expansion ($d_a/d_b = 0.6$) and 15 m straight pipe.

The total equivalent length of the main header with proposed 250 mm diameter was taken as 85.2 m based on 6 x 45°T flow through run, 1 x sudden expansion and 22 m straight pipe.

All equivalent lengths can be referred to the same size by the resistance coefficient K relationship (reference Crane Pub 4.10M Equation 2-5 p2 –10).

$$K_a = K_b \left(\frac{d_a}{d_b} \right)^4$$

where 'a' defines K and d with reference to the pipe size to which all resistances are to be expressed, and where (reference Crane Pub 4.10M Equation 2-4 p2 – 8).

$$K = f \left(\frac{L}{D} \right)$$

Assuming the friction factor f is constant in both pipes we have:-

$$\left(\frac{L}{D} \right)_a = \left(\frac{L}{D} \right)_b \left(\frac{d_a}{d_b} \right)^4$$

In our case we will refer to 150 mm diameter,

$$\frac{d_a}{d_b} = \frac{150}{250} = 0.6$$

Main header equivalent length referred to 150mm diameter

$$\left(\frac{L}{D} \right)_{150} = 85.2 \text{ x } (0.6)^4 = 11.1$$

Total equivalent length for relief vent = 45.1 + 11.1 = 56m.

Appendix III

Blowdown Tank Sizing and Dynamics(3)

The method for the sizing of horizontal blowdown tanks presented in API 521 is summarised and provides the design basis for P&I Design module XLBLOWDOWN.

Allowable vapour velocity

$$\mathbf{U_A = 0.27 \left(\frac{\rho_L - \rho_V}{\rho_V}\right)^{0.5}}$$

Where $\mathbf{U_A}$ = allowable vapour velocity ft/sec

ρ_L = liquid density lb/ft^3

ρ_V = vapour density lb/ft^3

The vapour flow area is given by

$$\mathbf{A_V = \frac{Q_V}{U_A}}$$

Where $\mathbf{A_V}$ = vapour flow area ft^2

$\mathbf{Q_V}$ = vapour flow rate ft^3/sec

Assume $\mathbf{A_V}$ occupies half of the drum area so that drum diameter **D**(ft) is given by

$$\mathbf{D = \left(\frac{2\ A_V}{0.785}\right)^{0.5}}$$

The drum volume allowed for the disentrained liquid $\mathbf{V_L}$ (ft$^{3)}$ is based on the following criteria:-

- For non-foaming systems the volume should be equal to the maximum working volume of the largest reactor connected to the system.
- For foaming systems the volume should be a minimum of 1.5 times the maximum working volume of the largest reactor connected to the system.

Ignoring the volume of both heads, the drum length **L** (ft) is given by

$$\mathbf{L = \frac{2\ V_L}{0.785\ D^2}}$$

If the drum length is 2 to 3 times its diameter the design is acceptable. If **L** is greater than **3D** assume a larger diameter and repeat the calculation until a satisfactory **L/D** ratio is achieved.

For futher information on this topic the reader is referred to API 521(5) and the paper by Grossel (3)

Appendix III

Blowdown Tank Sizing and Dynamics$^{(3)}$

Typical design case for blowdown tank sizing on multi-purpose batch process plant using P&I Design Spreadsheet XLBLOWDOWN

Component	MW	BP(1 bara)	BP(3.5 bara)	Density Gas		Density Liquid		Max Vap Vel	Max Allow Vap Flow		Flow Area	Drum Diam	
	kg/kmol	DegC	DegC	kg/m3	lb/ft3	kg/m3	lb/ft3	ft/s	kg/h	ft3/s	ft2	ft	mm
Acetone	58.0	56.25	97.55	1.9076	0.1192	690.0	43.11	5.13	9479.3	48.75	9.51	4.92	1500
DCM	84.9	39.75	80.22	2.9294	0.1830	1200.0	74.98	5.46	15493.6	51.88	9.51	4.92	1500
Ethanol	46.1	78.29	113.57	1.4534	0.0908	700.0	43.74	5.92	8336.7	56.27	9.51	4.92	1500
N Hexane	86.2	68.73	115.25	2.7059	0.1691	570.0	35.61	3.91	10250.9	37.16	9.51	4.92	1500
Methanol	32.0	64.70	99.7	1.0464	0.0654	710.0	44.36	7.03	7126.3	66.81	9.51	4.92	1500
Toluene	92.1	110.60	160.85	2.5872	0.1616	720.0	44.99	4.50	11272.1	42.74	9.51	4.92	1500
DMF	73.1	152.00	180.00	1.9667	0.1229	790.0	49.36	5.40	10300.1	51.38	9.51	4.92	1500
Nitrobenzene	123.1	210.80	180.00	3.3119	0.2069	1020.0	63.73	4.73	15182.2	44.97	9.51	4.92	1500
O Xylene	106.2	144.40	180.00	2.8572	0.1785	730.0	45.61	4.31	11925.7	40.94	9.51	4.92	1500
Ethyl Acetate	88.1	77.06	120.42	2.7292	0.1705	770.0	48.11	4.53	11972.8	43.03	9.51	4.92	1500

BLOWDOWN DESIGN CASE

Component	MW	BP(1 bara)	Pressure	Density Gas		Density Liquid		Max Vap Vel	Max Allow Vap Flow	
	kg/kmol	DegC	bara	kg/m3	lb/ft3	kg/m3	lb/ft3	ft/s	kg/h	ft3/s
Methanol	32.0	64.7	1.0	1.0464	0.0654	710.0	44.36	7.03	7126.3	66.81
		99.7	3.5	3.6625	0.2288			3.75	13300.0	35.62
				2.3544						

Rx Volume	Drum Length	
m3	Ft	m
1.0	3.72	1.13
1.6	5.94	1.81
2.5	9.29	2.83
2.7	9.85	3.00

Drum Design Selected

Diameter = 1500mm
Tan-tan = 3000mm
Volume = 5m3

Appendix III

Blowdown Tank Sizing and Dynamics(3)

The method for studying the dynamic response of blowdown tanks is based on a simple dynamic mass balance without flash and is the basis for P&I Design module XLBLOWDOWN.
The pressure rise is calculated using the ideal gas law and at isothermal conditions temperature **T**
The nomenclature is shown below and equations require consistent units.

V_T = blowdown tank volume
W_I = mass flow rate in
W_O = mass flow rate out
V_I = volumetric flow in
V_O = volumetric flow out
M = instantantaneous vapour mass in blowdown tank
P_O = initial blowdown tank pressure
P = instantaneous blowdown tank pressure

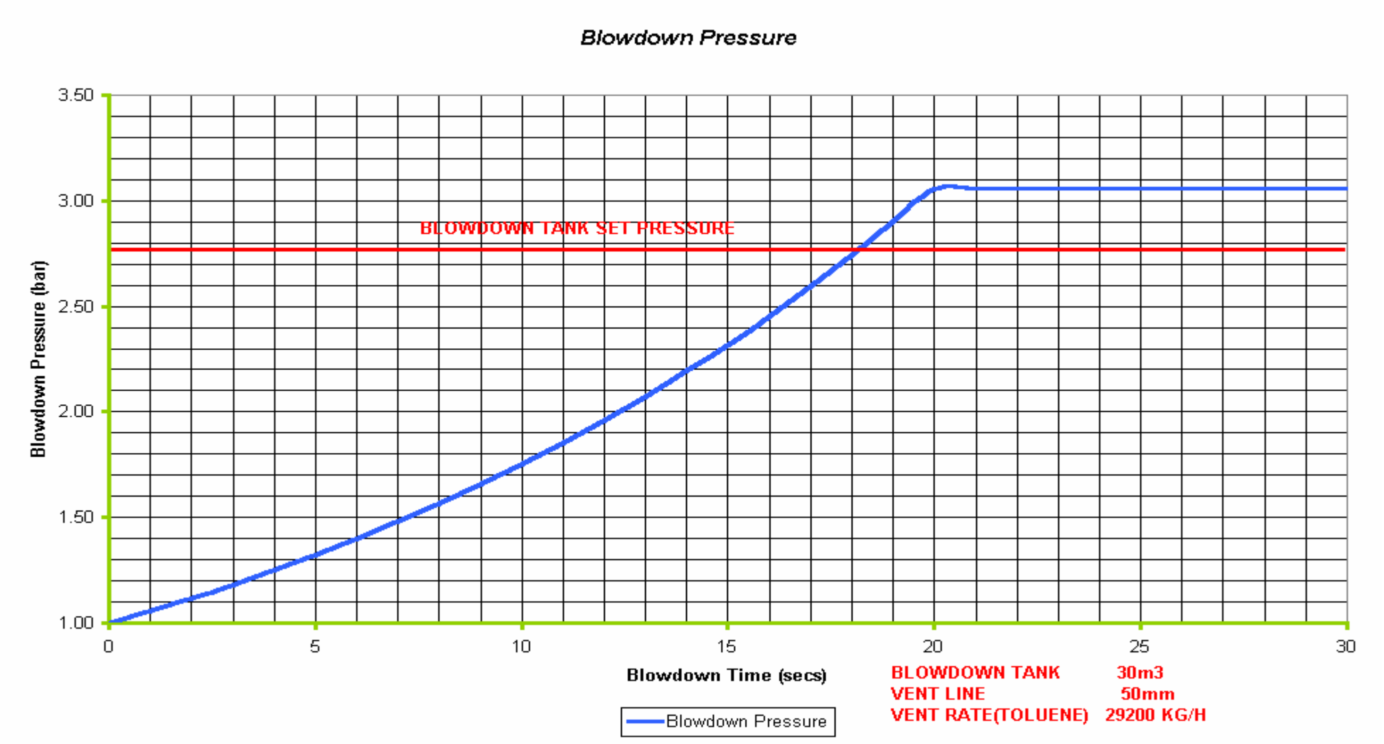
Density of a vapour is of the form $\rho = \frac{M}{22.4}\frac{273}{T}\frac{P}{1} = k\ P$ where **M** is the molecular weight

Accumulation = Rate In – Rate Out

$$\frac{dM}{dt} = k\ V_T \frac{dP}{dt} = W_I - W_O = k\ P\ V_I - k\ P\ V_O$$

Rearranging gives $$\frac{dP}{P} = \left(\frac{V_I - V_O}{V_T}\right) dt$$

Integrating and rearranging gives $P = P_O e^{A\ t}$ where $A = \frac{V_I - V_O}{V_T}$



Appendix IV

Estimation of Heat Transfer Area from Total Area

EQUIPMENT	AGENCY GOVERNING THE EQUIPMENT OPERATION		
	NFPA-30 & OSHA 1919.106	API-520 & API-521 Operating Pressure > 15 psig	API-2000 Operating Pressure ≤ 15 psig
1. Sphere	55% of total exposed area.	Area up to the maximum horizontal diameter or up to the height of 25 ft., whichever is greater.	As in API-520/521.
2. Horizontal Tank	75% of total exposed area. If under 200 ft^2, use 100% of total exposed area.	Area equivalent to the average inventory level up to the height of 25ft.	75% of total exposed area.
3. Vertical Tank	100% of total exposed area for the first 30 ft. Exclude bottom area if the bottom is flat and supported on ground.	Area equivalent to the average inventory level up to the height of 25 ft.	As in OSHA.
4. Process Vessel	-	Area equivalent to the average inventory level up to the height of 25 ft.	-
5. Fractionating Column	-	Area equivalent to liquid level in bottom, and reboiler if part of the column, plus liquid hold up from all trays up to a height of 25 ft.	-

Note: Compressed Gas Association and Chlorine Institute consider total calculated area as the heat transfer area.