Effect of Different Parameters on Depressuring Calculation Results

Saeid Rahimi

01-Nov-2010

Introduction

Emergency depressuring facilities are utilized to accomplish at least one of the following objectives:

- To reduce the risk of catastrophic equipment failure (due to thermal decomposition of unwetted surfaces) and/or BLEVE during fire exposure
- To reduce the risk of equipment failure during an exothermic runway reaction (out of interest of this note)
- To reduce the amount of material released if there is a loss of contaminant
- To rapidly move the system into "safe" state, in the event of other emergency scenarios like power failure, failure of control system etc.

Depressuring valve sized for above cases will be also used to depressurize system for maintence and normal shutdowns. In view of above possibilities and considering different conditions from which depressuring will start, the following categories can be made:

1) Fire depressuring (immediate depressurization of system on fire)
2) Adiabatic depressuring (depressurization of system under emergency scenarios like utility failure or vessel out of fire during fire)
3) Isochoric depressuring (depressurization of system after a prolonged shutdown)

Depressuring parameters

There are some depressuring parameters which are independent of type of depressuring such as:

- **Vessel dimension**

  Refer to technical note "Setting Hysys Depressuring Model Dimensions to Get More Accurate Results" for the effect of vessel dimensions on final results and how to set them to get the volume, surface area, wetted area and metal weight of model same as actual system.

- **Valve specifications**

  Since depressuring system is independently sized by vendor using maximum fire depressuring rate and differential pressure given in process datasheet, then any valve type can be used. The only point is that same valve type and CV shall be used for cases other than fire. Valve type may be important when a supercritical mixture is depressurized. Supercritical depressurization sometimes shows a spike in the profile of depressuring flow rate and vessel gas and liquid contents. This is observed when vessel gas content gets suddenly condensed and vaporized again. This error may be resolved if:

  - Type of valve is changed to "General"
  - "Calculate Pressure" option is used instead of "Calculate CV"

1) Fire Case

This scenario can be called "hot depressuring" which is aiming depressuring rate calculation and consequently size of depressuring system (restriction orifice).

- **Initial pressure**

  Different pressures have been recommended as initial pressure in different standards or practices like design pressure, PSV set pressure, high-high pressure switch. Regardless of this variety, higher pressure is more conservative.

- **Final pressure**

  Final pressure has been sometime specified very generic:

  - 6.9 barg or 50% of design pressure whichever is lower within 15 minutes.
  - 6.9 barg within 15 minutes.
  - 50% of design pressure within 15 minutes.

  Sometimes, it is specified based on type of fire.

  - 6.9 barg within 15 minutes for vessel on jet fire
  - 50% of design pressure within 15 minutes for vessel on pool fire.

  and sometimes according to vessel content and thickness:

  - 6.9 barg within 15 minutes if vessel contains flammable gas (which may fuel the fire) and vessel thickness is more than 25 mm.
  - 50% of design pressure within 15 minutes if vessel does not contain flammable gas and vessel thickness is more than 25mm.
  - 6.9 barg within 15 minutes minus 3 min. for each 5mm reduction in thickness if vessel contains flammable gas (which may fuel the fire) and vessel thickness is less than 25mm.
  - 50% of design pressure within 15 minutes minus 3 min. for each 5mm reduction in thickness if vessel doe not contains flammable gas and vessel thickness is less than 25mm.
  - 6.9 barg within 8 minutes if vessel containing LPG or light condensate regardless of vessel thickness to avoid BELEVE

  Shorter time and lower final pressure generates higher depressuring rate and consequently larger depressuring system. See technical note "How to Set Depressuring Time for Fire".

- **Depressuring time**

  Refer to above section. Depressuring time can be higher or lower than 15 minutes according to client standard especially for huge vessels such as figure type slug catcher where depressuring rate can exceed flare system design limit.

- **Initial temperature**

  Maximum operating temperature is normally used as initial temperature for fire depressuring.

- **Initial liquid level**

  The following criteria have been used:

  - High liquid level
  - Normal liquid level
  - High-high liquid level for vessel with on/off level control and Normal liquid level for continuous control
  - Normal liquid level plus 75 mm per tray for trayed columns
  - Normal liquid level plus 30 mm per each 240 mm of internal packing for packed columns

  Higher level will result in higher depressuring rate.

Table 1 – Environment factor

System Description	F
Bare vessel	1.0
Insulated with fire resistant insulation	
25 mm	0.3
37mm	0.2
50mm	0.15
73mm	0.1
100mm and above	0.075
Mounded	0.03
Underground	0

- **Heat input model**

  - For vessel containing liquid, "API- 521 fire" equation ($q = 43.2\ F\ A_w^{0.82}$) is appropriate. F shall be defined as per Table 1. No credit is taken for normal insulation, fire fighting and depressuring facilities ($F = 1.0$).
  - For totally dry systems, "Fire" equation ($q = C_1 + C_2$ time $+ C_3$ (C_4 – Vessel Temp) +….) is usually used. For this purpose, constant heat input can be defined by setting $C_1 = Q\ A$ and $C_2 = C_3 = C_4 = C_5 = 0$ where Q (fire heat flux) range

as advised by API is 80 to 100kW/m^2. Refer to discussion made on fire heat flux in technical note "Fire Heat Flux to Un-Wetted Vessel", where the adequacy of this equation is discussed.

- **Heat loss model**

  There are three heat loss models: none, simple, detail. Although specifying the system heat loss in "detail" model seems more realistic but "none" model is normally used for fire case. This model assumes that system is totally insulated from surrounding so that total fire heat is absorbed by vessel gas content (not metal) and there is no heat loss to ambient. This is because plate was at fire temperature in API test through which fire heat flux was measured. In other words, fire heat flux given by API (for both wetted and unwetted vessels) is the net heat transmitted to gas which is not taking into account the vessel mass and conductivity.

- **Initial composition**

  It is very hard to generalize the effect of initial composition on depressuring rate and size but it is advised to check high and low molecular weight and density cases. If the system consists of several vessels with different compositions (such as fractionation columns) feed, bottom and top composition can be examined to find the largest required rate.

  Water as one the major components in any hydrocarbon system needs special attention especially if vessel contains separate water phase (three phase separator). In this case, it is recommended to ignore water and consider vessel containing only hydrocarbon because:

  1. Water has very high heat capacity (Cp) and absorbs fire heat input without considerable increase in temperature. Furthermore, system temperature reduction due to joule-Thompson effect during depressuring works in opposite way and water (vessel content) does not usually reach boiling point within depressuring time (15 minutes).

     For example, according to following calculation the temperature raise is only 40°C for 1m^3 of water after 15 minutes exposure to fire where the cool down effect of depressuring can be much more than 40°C.

     $Q = 43.2\ F\ A_w^{0.82} = 43.2 \times 1 \times 6^{0.82} = 187.7$ kJ/sec (Maximum wetted area of 1m3 liquid is 6m^2)

     $\Delta T = Q\ \text{Time} / \rho V C_p = (187.7 \times 15 \times 60) / (1000 \times 1 \times 4.2) = 40.2$ °C

  2. Water latent heat at boiling point is also 5-10 times of hydrocarbons which results in less depressuring rate.

  For system containing gas and water/water solution (ideally no hydrocarbon) such as Amine or TEG, water solution can be considered although it may not have much contribution in vapor generation.

- **PV**

  PV of zero may be appropriate for fire case.

2) Adiabatic/Isochoric Case

This scenario can be called "cold depressuring" which is targeting minimum vessel design temperature using orifice size from hot depressuring.

- **Initial pressure**
  - ➢ Adiabatic blowdown is usually from high-high pressure switch or settle out pressure of compressor loop
  - ➢ isochoric blowdown starts from pressure corresponding to system initial temperature

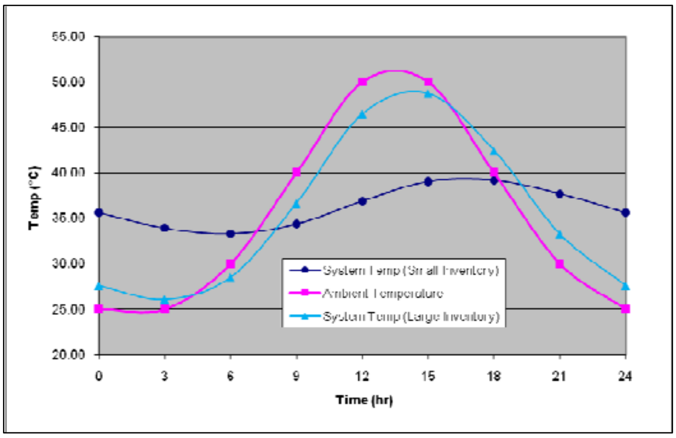

Figure 1- System temperature profile with ambient temp.

- **Initial temperature**
  - ➢ Adiabatic blowdown is usually from normal operating temperature or settle out temperature of compressor loop
  - ➢ Isochoric blowdown starts from temperature of system after being exposed to minimum ambient temperature for a long time. As a conservative assumption, minimum ambient temperature is usually used as system initial temperature. This is quite valid assumption for non-insulated small vessels. For large inventory vessels, system temperature will follow ambient temperature changes with some margin and time lag. The margin depends on system heat content and total heat

transfer rate. A detail calculation is required to specify minimum system temperature during coldest period of year. In some cases, the margin is so high that system temperature actually flocculates within narrow band as shown in figure 1.

Considering the objective of cold depressuring, lower initial temperature is preferred as it will cause lower fluid/metal temperature.

- **Final pressure**

  Final pressure is often atmospheric pressure.

- **Initial liquid level**

  Lower initial liquid level will result in lower fluid/metal temperature therefore LLL of LSLL can be used.

- **PV**

  PV can be specified as per below table. Since higher PV will cause lower fluid/metal temperature, the maximum value of each range is recommended.

System Description	PV Range (%)	Recommended value (%)
Liquid filled systems	40 - 70	70
Initially two phase systems or gas filled with liquid condensation	70 - 87	87
Gas filled systems	87 - 98	98

- **Heat loss model**

  It is obvious that "none" model will result in lower temperature but it is generally preferred to define the model heat loss features similar to the actual system using "detail' model. Proper margin can be considered on final temperature results (if required). Below section reviews the effect of detail model parameters on final results.

  1) **Metal thickness**

     Metal thickness affects heat transfer and heat content. Thicker plate means lower heat transfer and higher mass (heat) content. It seems the effect of metal thickness on heat transfer is negligible because the controlling resistant is not metal conductivity (resistant). Higher mass means that higher amount of heat must be consumed for one degree reduction in system temperature.

  2) **Insulation thickness**

     Adding insulation will increase the adiabatic behavior of system and result in lower temperature. Insulation specifications shall be entered if actual system is insulated.

  3) **Ambient temperature**

     Lower ambient temperature will causes lower system temperature.

  4) **Recycle efficiency**

     Although some people believe that using recycle efficiency of 1% for gas and 100% for liquid as advised by Hysys instruction manual gives different temperature for gas and liquid which is in fundamentally correct but my study shows using recycle efficiency other than 100% will substantially increase the gas temperature. Refer to technical note "Validation of Hysys Depressuring Utility" where hysys results are in good agreement with experimental data using 100% for both gas and liquid.

- **Valve CV**

  If overdesigned CV from fire case is utilized for cold depressuring, fast depressuring won't allow system to gain some heat from ambient. This will cause lower system temperature. Under-designed CV will have reverse impact.

- **Water**

  If three phases (gas, water and oil) are present, no water to be considered as it has very high heat capacity and doesn't allow system temperature to drop. For system containing gas and water/water solution (ideally no hydrocarbon) such as Amine or

TEG, water solution should be considered if ignoring water ends up with exotic material (for very low temperature) which may not be really required for these systems.

Case study

- **Fire**

  A two phase vertical flat end vessel without piping and any insulation, 2m ID, 3.18m T/T at initial pressure and temperature of 20 bara and 40°C respectively containing $3m^3$ (corresponding to HLL) of liquid with below composition is assumed as a base case. This system is going to be depressurized within 15 minutes during fire through a Fisher valve (100% open, C_l= 25) and the effect of different parameters on final depressuring results were examined (Table 1).

  Initial composition: C_1 = 20%mol, C_2 = 20%mol, C_3 = 20%mol, n-C_4 = 20%mol, n-C_5 = 20%mol

- **Adiabatic**

  The same vessel containing $1m^3$ of liquid (corresponding to LLL), adiabatically depressurized from 20 bara and minimum ambient temperature of 5°C is considered as a base case for preparation of Table 2 where the effect of different input parameters on depressuring results have been shown.

Contact

Please feel free to contact S.Rahimi@gmail.com or ContactUs@chemwork.org should you have any comment, question or feedback.

Table 1 – Effect of different parameters on fire depressurization results

Parameter	Input data							Calculation Results	
	Total Volume (m3)	Liquid Volume (m3)	Heat input model	Time (min)	Vessel orientation	PV	Final pressure (bara)	Flow rate (kg/s)	Valve CV (gpm/min)
Base case	10	3	API	15	Vertical	0%	6.9	1.2	16.25
PV	10	3	API	15	Vertical	**50%**	6.9	1.189	16.1
Final pressure	10	3	API	15	Vertical	0%	**10**	0.796	10.8
Liquid volume	10	**1**	API	15	Vertical	0%	6.9	0.648	8.8
Water	10	**2+1(w)**	API	15	Vertical	0%	6.9	1.042	14.1

Table 2 – Effect of different parameters on adiabatic depressurization results

Parameter	Input data										Calculation Results		
	Total Volume (m3)	Liquid Volume (m3)	Heat loss model	Heat loss parameter			Vessel orient.	PV	Final pressure (bara)	Valve CV (gpm/ min)	Time (m':s'')	Flow rate (kg/s)	Min fluid temp (°C)
				Amb temp (°C)	Ins thick (mm)	Metal thick (mm)							
Base case	10	1	detail	5	0	10	Vertical	87%	1.2	16.25	21:40	1.199	-9.78
CV	10	1	detail	5	0	10	Vertical	87%	1.2	**20.00**	17:30	1.476	-10.30
PV	10	1	detail	5	0	10	Vertical	**70%**	1.2	16.25	21:45	1.199	-8.93
Heat loss model	10	1	**none**	-			Vertical	87%	1.2	16.25	20:00	1.199	-16.74
Ambient temp	10	1	detail	**20**	0	10	Vertical	87%	1.2	16.25	21:40	1.199	-9.25
Insulation thickness	10	1	detail	5	**30**	10	Vertical	87%	1.2	16.25	21:40	1.199	-9.49
Metal thickness	10	1	detail	5	0	**30**	Vertical	87%	1.2	16.25	22:50	1.199	-4.61
Final pressure	10	1	detail	5	0	10	Vertical	87%	**2.5**	16.25	14:05	1.199	-0.63
Vessel orientation	10	1	detail	5	0	10	**Horizontal***	87%	1.2	16.25	21:40	1.199	-9.78**
Liquid volume	10	**2**	detail	5	0	10	Vertical	87%	1.2	16.25	33:00	1.199	-7.18
Water	10	**1(w)**	detail	5	0	10	Vertical	87%	1.2	16.25	10:06	1.199	0.01

* System dimension has been defined so that horizontal vessel total volume, liquid volume, wetted area and weight is same as base case (vertical vessel)

** Vessel orientation does not have any effect on temperature because Hysys (till version 2006) uses heat transfer model developed for vertical surface for horizontal vessels also.