Is 600mm Sufficient to Keep BDV Functional?

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20-Nov-2010

Introduction

Figure 1 shows a typical arrangement for blow down valve (BDV) with restriction orifice (RO) which is used to depressurize to the safe pressure within a limited time. You might have noticed that a 600 mm spool piece is kept between BDV and RO.

Orifice plate is the main element to kill the pressure from upstream system pressure to flare system back pressure. Pressure drop will result in temperature drop due to Joule Thomson (JT) effect.

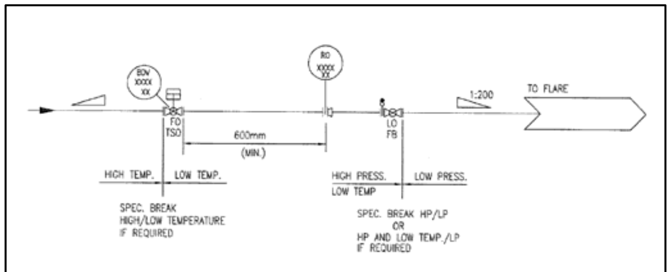

Figure 1– Automatic depressurization valve arrangement

This low temperature will migrate back to the upstream of RO and probably reaches BDV. It can potentially drop BDV body temperature below zero where moisture from atmosphere may form ice and may prevent operator from closing the BDV after accomplishing the depressurization. This may cause re-pressurization of process because of back flow from other BDVs/PSVs. Therefore, 600 mm spool piece is supposed to be adequate length to increase the RO downstream temperature to a temperature above zero.

This note is trying to answer questions like “Why 600 mm not 1000mm?” or “Is 600mm sufficient to keep BDV functional?”

Heat Transfer Modeling

Giving response to this question needs heat transfer modeling. Cold gas downstream of RO has very high velocity which will result in high internal heat transfer coefficient. So pipe wall temperature downstream of RO will reach gas temperature and this temperature will travel back to BDV. Cold temperature will dissipate after travelling some distance towards BDV gaining heat from pipe internal fluid and ambient depends on overall heat transfer features of surrounding. Pipe internal fluid is a high velocity gas which is released from process system so internal heat transfer mechanism is forced convection. Internal fluid is initially at system operating temperature and as depressuring continues its temperature reduces. Ambient temperature and heat transfer condition is independent of depressuring. Depend on weather conditions it can be forced or free convection but the most conservative assumption is free convection. Outside heat transfer coefficient is much lesser than internal one.

The temperature profile of pipe can be predicted by energy balance for differential element shown in figure 2.

$$q_x - q_{x+dx} - dq_{conv,in} - dq_{conv,out} = 0 \qquad (1)$$

Replacing $q_x = -kA\frac{dT}{dx}$ and $q_{x+dx} = -kA\frac{dT}{dx} - kA\frac{d^2T}{dx^2}dx$ in equation (1) gives:

$$kA\frac{d^2T}{dx^2}dx - h_{out}P_{out}\,dx\,(T - t_{out}) - h_{in}P_{in}\,dx\,(T - t_{in}) = 0 \qquad (2)$$

Further modifications will result in equation (3):

$$\frac{d^2T}{dx^2} - \frac{h_{out}P_{out}}{kA}(T - t_{out}) - \frac{h_{in}P_{in}}{kA}(T - t_{in}) = 0 \qquad (3)$$

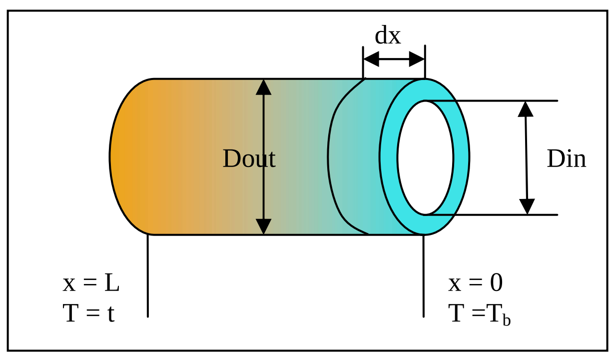

Figure 2 – Equation (4) boundary conditions

This equation can be solved with different assumptions. Most conservative assumption is to ignore internal or external heat transfer then the last term in above equation will be omitted. I prefer to take another approach and assume $t_{in} = t_{out}$. This can be conservative if the minimum of t_{in} or t_{out} is used for calculation. Rearranging equation (3) will result in following equation:

$$\frac{d^2T}{dx^2} - \left(\frac{h_{out}P_{out} + h_{in}P_{in}}{kA}\right)(T - t) = 0 \qquad (4)$$

If $\theta = (T - t)$ then equation (4) will be reduced to $\frac{d^2\theta}{dx^2} - m^2\theta = 0$ (5)

The typical solution to equation (5) would be $\theta = C_1 e^{mx} + C_2 e^{-mx}$ (6)

Where $m = \left(\frac{h_{out}P_{out} + h_{in}P_{in}}{kA}\right)^{0.5}$, $A = \pi\left(D_{out}^2 - D_{in}^2\right)$, $P_{out} = \pi D_{out}$ and $Pin = \pi D_{in}$

Boundary conditions for solving equation (6) are:

1) At RO location (x = 0), T = T_b, so $\theta_b = T_b - t$ then $C_1 + C_2 = \theta_b$
2) At distance where pipe temperature reached process or ambient temperature (x = L), T = t, so $\theta = 0$ then $C_1 e^{mL} + C_2 e^{-mL} = 0$

From 2nd boundary limit, C_1 = 0 then from the 1st one, $C_2 = \theta_b$.

So the final solution will be $\theta = \theta_b e^{-mx}$ (7)

Case study

A 600# system initially at (t_{in}) 50°C is depressurized through 20" (500 mm ID, 525 mm OD) flare line upstream of RO. Depressuring calculation dictates design temperature of -25°C and -100°C for pressure vessel and flare line respectively and you are going to set piping spec break considering below typical criteria for material selection:

CS :	-29°C < design temperature
LTCS :	-46°C < design temperature < -29°C
SS :	-105°C < design temperature < -46°C

According to above criteria, CS and SS can be used for pressure vessel and flare line. Below exercise is going to verify the distance between RO and BDV to ensure that changing material from SS to CS at the edge of BDV is the correct design. Table -1 shows the distance at which -29°C will be obtained based on the result of equation (7) with different assumptions specified in the same table.

Other inputs are:

Depressuring flow rate:	10,000 kg/hr	Pipe thermal conductivity (k):	45 W/m K
Fluid heat capacity :	1 kJ/kg K	Fluid density :	10 kg/m3
Fluid Viscosity :	0.02 Cp	Fluid thermal conductivity :	0.03 W/m K
Ambient Temperature (t_{out}):	5°C	Ambient heat transfer coe. (h_{out}) :	5 W/m2 K

Table 1 – Case study results

Parameter	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Internal heat transfer considered?	Yes	Yes	No	No
External heat transfer considered?	Yes	No	Yes	Yes
Fluid temperature, t (°C)	t_{out}	t_{out}	t_{out}	t_{in}
h_{in} (W/m^2K)	33.57	33.57	NA	NA
m	8.20	7.63	3.01	3.01
x (mm)	137	148	374	212

Based on above results, piping material can be changed from SS to CS at the edge of BDV if 600 mm is provided between RO and BDV. The same arrangement has been shown in Figure-3. It should be note that it is too unrealistic to ignore internal heat transfer which has the major contribution in heating up the pipe (Case 3).

Figure 4 and 5 are graphical representations of equation (8) when desired temperature at the edge of BDV (T) is 0°C and RO temperature (T_b) is -105°C (Figure 4) and -46°C (Figure 5). These figures can be used as reference.

$$x = \frac{1}{m} \ln\left(\frac{T_b - t}{T - t}\right) \quad (8)$$

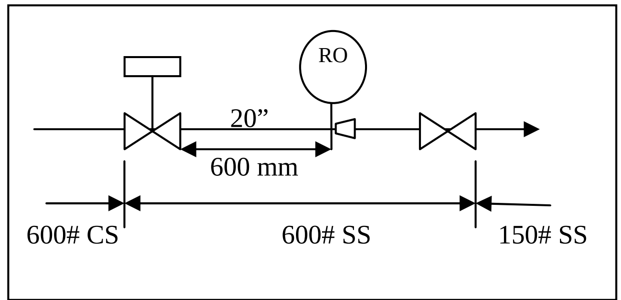

Figure 3 – BDV spec break arrangement

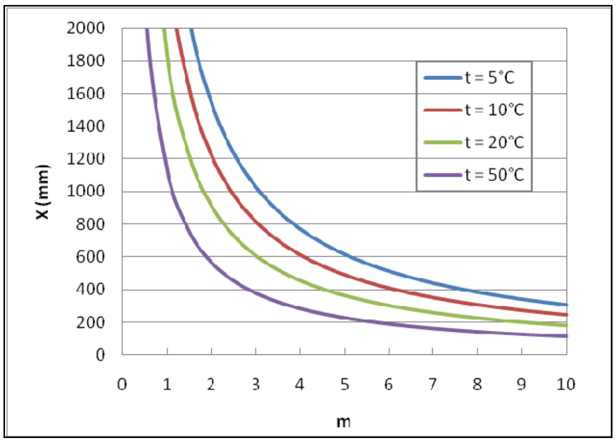

Figure 4 – Piping spool length when T_b is -105°C

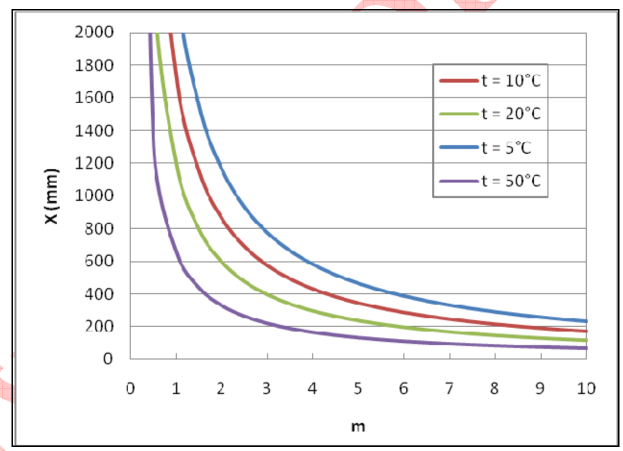

Figure 5 – Piping spool length when T_b is -46°C

Conclusion

1) It can be clearly observed that for such a low temperature application, 600 mm is sufficient to increase the pipe wall temperature from -100°C to 0°C. This basically because the area from which cold temperature back propagation takes place is much smaller that the area from which heat is gained. But it should be noted that there might be some cases where detail calculation of length is required especially if m coefficient is less than 5.

2) The same heat transfer model can be used to specify :

- The location of pipe spec break when two pipes with different design temperatures are connected. The purpose is to calculate the length of pipe which should be made of material suitable for high/low temperature. For example, connecting PSV outlet SS pipe carrying very low temperature fluid to the middle of LTCS flare header (Figure 6). The most conservative approach is to upgrade the flare header material to SS but it is worth to optimize flare header material using the same approach.

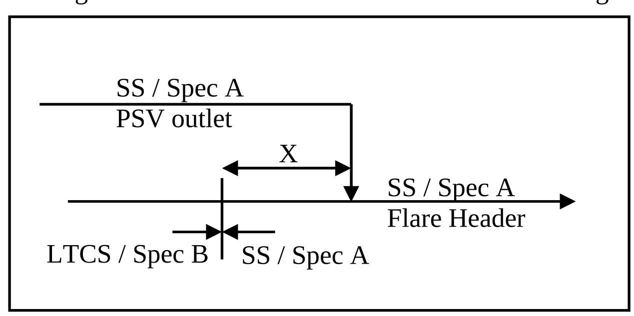

Figure 6 – location of material/piping break

It should be noted that above heat conduction model does not predict the pipe metal temperature because of cold gas infiltration from PSV outlet line into flare header (line packing) which may take place in this particular example.

- The distance between vent (manual depressuring) valves where globe valve is used to throttle the flow (where temperature drop takes pace) and upstream ball valve is used to isolate the process from flare after venting.

- The distance between drain valves where there is a possibility of liquid flashing causing subzero temperatures at throttling valve and upstream valve needs to remain operable.

3) Blow down valve can be subjected to subzero temperature in two scenarios:

- Initial stage of depressuring when system pressure is high and minimum temperature takes place downstream of RO. This temperature travels towards BDV by conduction. 600 mm spool piece can safeguard this scenario.

- Ending stages of depressuring when process gas reaches low temperature. Although gas temperature is usually not as low as first scenario but BDV in contact with cold high velocity gas can easily reach gas temperature. This scenario needs extra precaution as the risk of freezing ambient moisture on valve body persists. Depressuring study results should be reviewed to identify the pressure at which process gas reaches subzero temperature. If this pressure is much lower than process design pressure (say below 70% of design pressure), no extra provision is required. This is because BDV's actuator sized for design differential pressure (process design pressure minus zero) should be able to close the valve at lower differential pressure even in presence of ice. Otherwise, anti-condensation coating and heat tracing may be used for BDV.

Both scenarios can be ignored if the process vessel has been already designed for design pressure and minimum design temperature (coincident) or stress calculation shows that pressurization of pressure vessel at low metal temperature to flare header back pressure is not a concern with respect to brittle fracture.

NOMENCLATURE	
A	Pipe wall cross section area
D	Pipe diameter
h	Heat transfer coefficient
k	Pipe metal conductivity
T	Pipe temperature upstream of RO (function of distance form RO)
T_b	Pipe temperature downstream of RO = Minimum fluid temperature
t	Fluid temperature
m	Heat transfer ratio coefficient
P	Pipe perimeter
q	Heat transfer rate
x	Distance
SUBSCRIPTS	
in	Inside pipe
out	Outside pipe

Contact

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