CHEMICAL ENGINEERING
ESSENTIALS FOR THE CPI PROFESSIONAL

LIQUID FLASHING IN A CONTROL VALVE WITHOUT CHOKED FLOW

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Many engineers may wonder if it is possible to have flashing liquid flow in a control valve even if flow is not choked. The short answer is yes, but it is not very common. This article provides a more detailed answer to this question.

The basic liquid-sizing equation ($Cv = Q \sqrt{G/\Delta P}$) indicates that the liquid flowrate (Q) through a control valve is proportional to the square root of pressure drop (ΔP). However, this linear relationship does not always hold true. When the pressure drop is increased by lowering the downstream pressure, at some point, the flow no longer increases and the flow is considered choked.

This limiting or choking pressure drop is represented by ΔP_{choked}. If flow is choked, the result must be either cavitation or flashing. However, the inverse is not the case. That is, it is possible to have cavitation or flashing without choked flow. Furthermore, cavitation noise and damage often start before ΔP reaches ΔP_{choked}. Most valve manufacturers recognize this fact and use one of several methods to predict when cavitation noise and damage are likely to occur. But engineers may also wonder: is there the possibility of flashing before ΔP reaches ΔP_{choked}?

1	Flow rate	gpm	**80**
2	Upstream temperature	degF	**110**
3	Upstream pressure	psiA	**88.5**
4	Differential pressure	psi	**5**
5	Downstream pressure	psiA	**83.5**
6	Vapor pressure	psiA	**84**
CALCULATED PERFORMANCE			
7	Capacity	Cv	**35.8**
8	Percent of full travel	%	**71.6**
9	% of max capacity	%	**50.4**
10	sound pressure level	dBA	**< 85**
11	Flow velocity (inlet)	ft/s	**8.43**
12	Choked pressure drop	psi	**13.5**
13	Pressure recovery factor (F_L)		**0.91**
Notes			
Note: Valve is in flashing conditions			

Figure 1. This control-valve sizing calculation sheet indicates flashing conditions without choked flow

Figure 1 is an example of a control-valve sizing datasheet that indicates flashing but not choked flow. There is a note stating that the valve will be in flashing conditions. The software that created Figure 1 states that "Valve is in flashing conditions" if the valve outlet pressure (P_2) is less than the liquid's vapor pressure. The fact that the downstream pressure on Line 5 (83.5 psia) is less than the liquid's vapor pressure on Line 6 (84 psia) tells us that the fluid exiting the valve will be flashing. However, on Line 12, the choked pressure drop is

13.5 psi, indicating that the pressure drop across the valve must be at least 13.5 psi for flow to be choked. However, the actual pressure drop across the valve (Line 4) is only 5 psi. This means that flow will not be choked. To summarize, the sizing calculation tells us that we will have flashing, but not choked flow.

To verify these findings, the author developed a series of calculations based on the data in Figure 1 (see Figure 2) and then formulated a graph representing these calculations in graphical form (see Figure 3). Examining Figures 2 and 3, it can be concluded that flow is indeed not choked and any "flashing" (or vaporization) that takes place begins with vaporization of the liquid after it has passed through the vena contracta (the area of the system with the smallest diameter). It is the conditions at the vena contracta that determine the rate of flow through a valve, and if vaporization is to cause flow to choke, it must happen at the vena contracta. Downstream of the vena contracta, a largely vapor fluid would have to reach sonic velocity somewhere downstream before flow would choke.

(1) $$\Delta P_{choked} = F_L^{\,2}(P_1 - F_F P_V)$$ ISA Eq. 3

(2) $$\text{where } F_F = 0.96 - 0.28\sqrt{\frac{P_V}{P_C}}$$ ISA Eq. 4

(2a) $$F_F = 0.96 - 0.28\sqrt{\frac{84}{644}}$$

(2b) $$F_F = 0.86$$

(3) $$F_F P_V = 0.86 \text{ x } 84$$

(3a) $$F_F P_V = 72.2$$

(1a) $$\Delta P_{choked} = 0.91^2(88.5 - 72.2)$$

(1b) $$\Delta P_{choked} = 13.5$$

(4) $$F_L = \sqrt{\frac{\Delta_P}{P_1 - P_{vc}}}$$

(4a) $$P_{vc} = P_1 - \frac{\Delta P}{F_L^2}$$

(4b) $$P_{vc} = 88.5 - (5/0.91^2)$$

(4c) $$P_{vc} = 82.5$$

All pressures in psia

Figure 2. These calculations indicate flashing conditions without choked flow

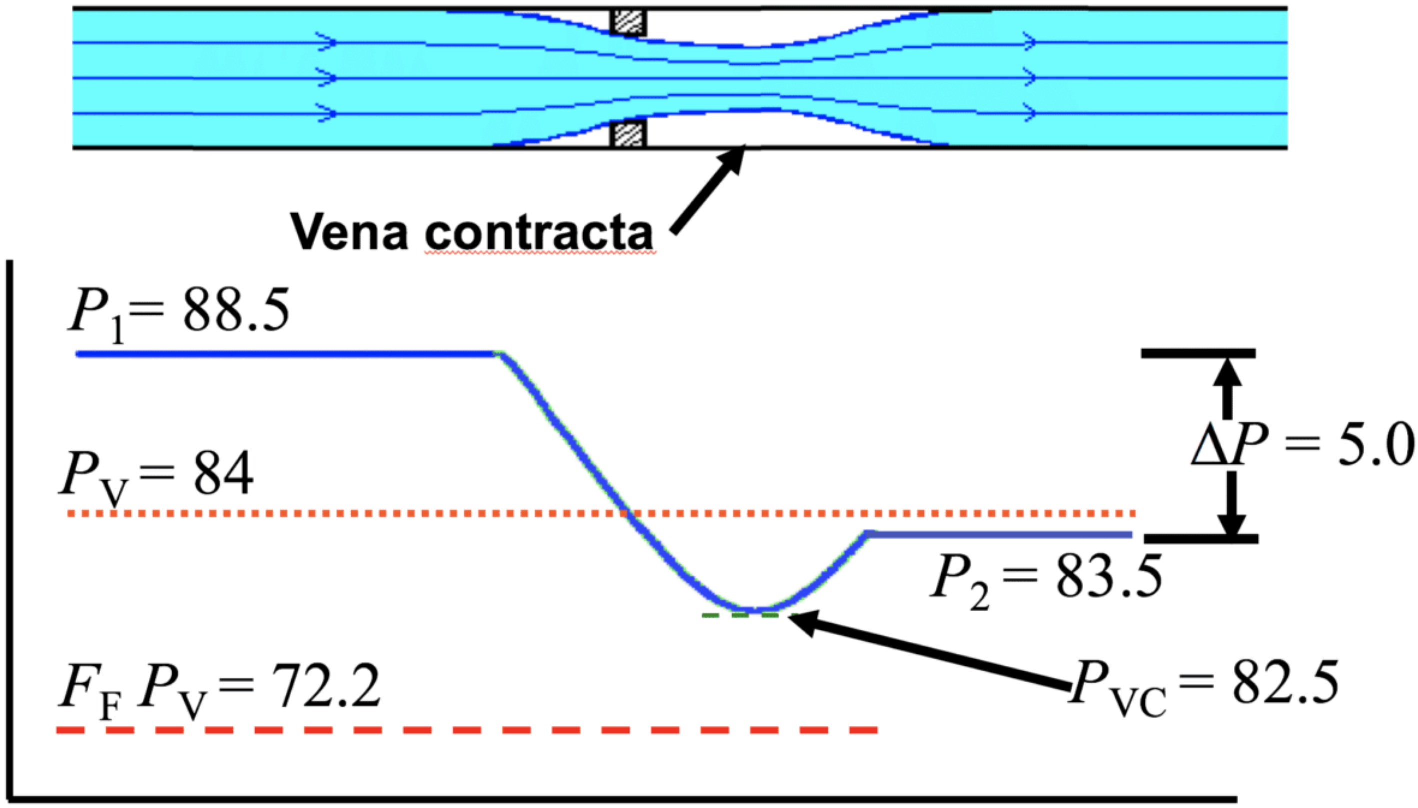

Figure 3. This chart shows the graphical representation of the results of the calculations in Figure 2

In Figure 2, Lines 1 and 2 are Equations 3 and 4 in the Valve Sizing Equation Standard from the International Society of Automation (ISA; Research Triangle Park, N.C.; www.isa.org). Line 1 calculates ΔP_{choked} (the pressure drop at which liquid flow through a control valve will choke). Because any particularly small volume of the liquid is only in the vena contracta for a very short time, experiments have determined that liquid in the vena contracta will not vaporize when its local pressure decreases to the vapor pressure of the liquid. However, for vaporization to occur, the pressure at the vena contracta must drop to slightly below the vapor pressure. An approximation of how much below the vapor pressure the vena contracta pressure must fall for vaporization is included in the ISA standard as the Critical Pressure Ratio Factor (F_F) (ISA Equation 4), and this is repeated on Line 2, where P_C is the thermodynamic critical pressure of the liquid. When the pressure at the vena contracta drops to the vapor pressure, P_v, multiplied by F_F, flow will choke. Calculated values of F_F can range between 0.68 and 0.96, depending on the ratio of vapor pressure to critical pressure.

Lines 2a and 2b show calculation of the value of F_F for this application, which is 0.86.

Lines 3 and 3a calculate the value of $F_F P_V$ to be used in the equation on Line 1.

Lines 1a and 1b, calculate ΔP_{choked} to be 13.5 psia, which agrees exactly with Line 12 of the computerized sizing calculation in Figure 1.

Line 4 is the commonly accepted definition of the Liquid Pressure Recovery Factor (F_L).

Line 4a is the equation on Line 4 rearranged to solve for P_{vc}, the pressure at the vena contracta. Note that this equation is only valid if the fluid at the vena contracta is not vaporizing.

Lines 4b and 4c calculate that the pressure at the vena contracta will be 82.5 psia when the process conditions