

Temperature Increases across JT Valves and Adiabatic Flashes

by

Michael W. Hlavinka, Ph.D., P.E.
Bryan Research & Engineering, Inc.

There have been many questions concerning temperature rises predicted by ProMax across JT valves and other adiabatic flashes. Depending on conditions, ProMax may predict the temperature to rise in an adiabatic flash. This temperature rise is frequently seen in throttling a fluid that produces little or no vapor relative to the liquid. This is common in the rich amine flash of a sweetening plant and the rich glycol flash of a TEG dehydration unit. However, this situation is not restricted to these processes.

From an energy balance, the governing equation for the expansion is that the enthalpy change across the flash is zero, assuming negligible heat transfer to the surroundings and negligible kinetic and potential energy changes. Satisfying this condition may require the temperature to increase rather than decrease. Two energy components that must be considered in the flash calculations are the vaporization of fluid and the dissipation of the pressure energy. Large amounts of energy are required to create vapor produced in expansion, and this energy must be supplied by the system to maintain the energy balance. In order to provide the heat of vaporization, the system temperature will normally decrease to keep the enthalpy constant and balance the energy of the created vapor. The second significant energy component is the dissipation of pressure. As the pressure is lowered through the flash, the energy associated with the pressure must be dissipated. This dissipation usually results in an *increase* in temperature because the system absorbs this energy by increasing the temperature. Therefore, two competing phenomena are usually occurring in the expansion process. The larger component will dictate whether the temperature increases or decreases. When little or no vapor is formed, the pressure dissipation component may be controlling and cause the temperature to rise.

To prove this temperature rise can indeed occur, consider the expansion from P_1, T_1 to P_2, T_2 across a valve. The net ΔH for the process must be zero. Since enthalpy is a state function, this expansion can be split into two parts: an isobaric expansion from P_1, T_1 to P_1, T_2 (state A to B) followed by an isothermal change from P_1, T_2 to P_2, T_2 (state B to C). Since $\Delta H_{AB} + \Delta H_{BC} = 0$,

$$\Delta H_{AB} = -\Delta H_{BC} \quad (1)$$

For simplicity, consider the expansion of a pure compressed liquid (e.g., water) where no vapor occurs during the expansion. In this case, the change from state A to state B is an isobaric temperature change of a liquid given by:



$$\Delta H_{AB} = \int_{T_1}^{T_2} C_p^L dT = \bar{C}_p^L (T_2 - T_1) = \bar{C}_p^L \Delta T \quad (2)$$

where \bar{C}_p^L is an average heat capacity for the liquid over the temperature change. The change from state B to C is an isothermal expansion which can be obtained using the definition $H = U + PV$:

$$\Delta H_{BC} = U|_{P_2, T_2} - U|_{P_1, T_2} + (PV)|_{P_2, T_2} - (PV)|_{P_1, T_2} \quad (3)$$

Substituting equations (2) and (3) into equation (1) yields:

$$\Delta T = \frac{U|_{P_1, T_2} - U|_{P_2, T_2} + (PV)|_{P_1, T_2} - (PV)|_{P_2, T_2}}{\bar{C}_p^L} \quad (4)$$

Since the liquid is incompressible, the isothermal internal energy change is usually small, especially relative to $\Delta(PV)$. Therefore,

$$(PV)|_{P_1, T_2} - (PV)|_{P_2, T_2} \approx (P_1 - P_2)\bar{V} \quad (5)$$

$$U|_{P_1, T_2} - U|_{P_2, T_2} \approx 0 \quad (6)$$

where \bar{V} is an average specific volume of the liquid at temperature T_2 over the pressure range. Substituting equations (5) and (6) into equation (4) gives:

$$\Delta T = \frac{(P_1 - P_2)\bar{V}}{\bar{C}_p^L} \quad (7)$$

Since $P_1 > P_2$, $\Delta T > 0$ and there is a temperature rise with this expansion.

For the case where vaporization does occur, using the same principles outlined above, the following equation can be derived for a pure component expanded from the liquid state to some vapor fraction ψ in the two phase region:

$$\Delta T = \frac{U^L|_{P_1, T_2} - U^L|_{P_2, T_2} + (PV^L)|_{P_1, T_2} - (PV^L)|_{P_2, T_2} - \psi\lambda}{\bar{C}_p^L} \quad (8)$$

where the L superscripts denote liquid properties and λ is the latent heat of vaporization for the component at temperature T_2 . Making the same assumptions as in equations (5) and (6) in equation (8) yields:

$$\Delta T = \frac{(P_1 - P_2)\bar{V}^L - \psi\lambda}{\bar{C}_p^L} \quad (9)$$

Therefore, when $(P_1 - P_2)\bar{V}^L > \psi\lambda$, a temperature increase will be seen in the expansion even though vapor has been produced.