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Preventing Phenolic Resin Reactor Accidents:
"Easy to Use" Procedure for Checking Adequacy of Emergency Relief Vent Sizes

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Based upon large scale experience Monsanto Company used the following simple vent sizing formula for the phenolic resin reactors (Howard, 1973)

$$D = 0.26\,(V)^{1/2} \tag{1}$$

where D is the vent diameter in inches and V is the volume of reactants in gallons. It is noted that formula (1) is only applicable for a relief set pressure $P_s \approx 1.5$ psig (0.103 bar g) and corresponding self heat rate $\dot{T}_s \approx 6.5°C\ min^{-1}$. Formula (1) can be restated as

$$A / V = 9.0 \cdot 10^{-3}\ m^{-1} \tag{2}$$

where A (m^2) is the vent area and V (m^3) is the volume of reactants. Following Fauske methodology (Fauske, 2006) Eq. 2 can be generalized as follows

$$A / V = 1.7 \cdot 10^{-3}\,\frac{\dot{T}_s}{P_s^{1/2}} \tag{3}$$

Setting $\dot{T}_s = 6.5°C\ min^{-1}$ and $P_s = 1.5$ psig Eq. 3 results in $A/V = 9.0 \cdot 10^{-3}\ m^{-1}$.

Vent sizing formula (3) is also consistent with dedicated phenolic runaway reaction tests performed by Fauske & Associates with A/V ≈ 2.8 • 10^{-2} (Leung et al., 1998). Considering the most severe tests with P_s = 13 psig and corresponding $\dot{T}_s$ = 62°C, results in

$$A / V = 1.7 \cdot 10^{-3} \frac{62}{13^{1/2}} \\ = 2.9 \cdot 10^{-2} \text{ m}^{-1} \tag{4}$$

The above observations are consistent with Fauske's generalized vent sizing formula (Fauske, 2006)

$$A / V = \frac{8 \cdot 10^{-4}}{P_s^{1/2}} \frac{\dot{T}_s}{C_D} \tag{5}$$

where C_D is the discharge coefficient determined from $C_D = [1 + 4f\ L/D]^{-0.39}$ where f = 0.005. Setting C_D = 0.5, P_s = 13 psig and $\dot{T}_s$ = 62°C min^{-1} results in A/V = 2.75 • 10^{-2} m^{-1}, and P_s = 1.5 psig and $\dot{T}_s$ = 6.5°C min^{-1} results in A/V = 8.5 • 10^{-3} m^{-1}.

The generalized Monsanto formula (Eq. 3) also clearly explains the 1999 catastrophic vessel failure of a phenol-formaldehyde reactor with A/V = 6.9 • 10^{-3} m^{-1} and a relief set pressure P_s = 4 psig (0.276 bar g). The allowable self heat rate $\dot{T}_s$ for safe relief venting is given by

$$\dot{T}_s = \frac{1}{1.7 \cdot 10^{-3}} (A / V) P_s^{1/2} \\ = \frac{1}{1.7 \cdot 10^{-3}} 6.9 \cdot 10^{-3} \cdot 4^{1/2} \\ = \underline{8.1 °\text{C min}^{-1}} \tag{6}$$

which compares to the actual self heat rate of $\dot{T}_s$ = 50°C min^{-1} at 4 psig obtained by VSP2 calorimetry simulation of the accident.

Using Fauske's generalized formula results in

$$
\begin{aligned}
\dot{T}_s &= \frac{1}{8 \cdot 10^{-4}} (A / V) P_s^{1/2} C_D \\
&= \frac{1}{8 \cdot 10^{-4}} 6.9 \cdot 10^{-3} \cdot 4^{1/2} \cdot 0.5 \qquad (7) \\
&= \underline{8.6°C\ min^{-1}}
\end{aligned}
$$

Therefore, formula (5) is recommended as an "easy to use" procedure to check the adequacy of existing reactor relief systems together with appropriate calorimetry testing of credible worst case scenarios providing the correct values of $\dot{T}_s$ at relief set pressures P_s (as low as practical < 5 psig).

References

Fauske, Hans K., 2006, "Revisiting DIERS' Two-Phase Methodology for Reactive Systems Twenty Years Later," Process Safety Progress, Vol. 25, No. 3, 1998.

Howard, W. B., 1973, "Reactor Relief Systems for Phenolic Resins," Monsanto Company, June, 1973.

Leung, Joseph C. et al., 1998, "Phenolic Runaway Reaction: Pressure Relief and Containment," Int. Symp. on Runaway Reactions, Pressure Relief Design, and Effluent Handling, March 11-13, 1998, New Orleans, Louisiana, U.S.A.