Relief Device Sizing in Ethylene Service

Challenges and Methods

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Agenda

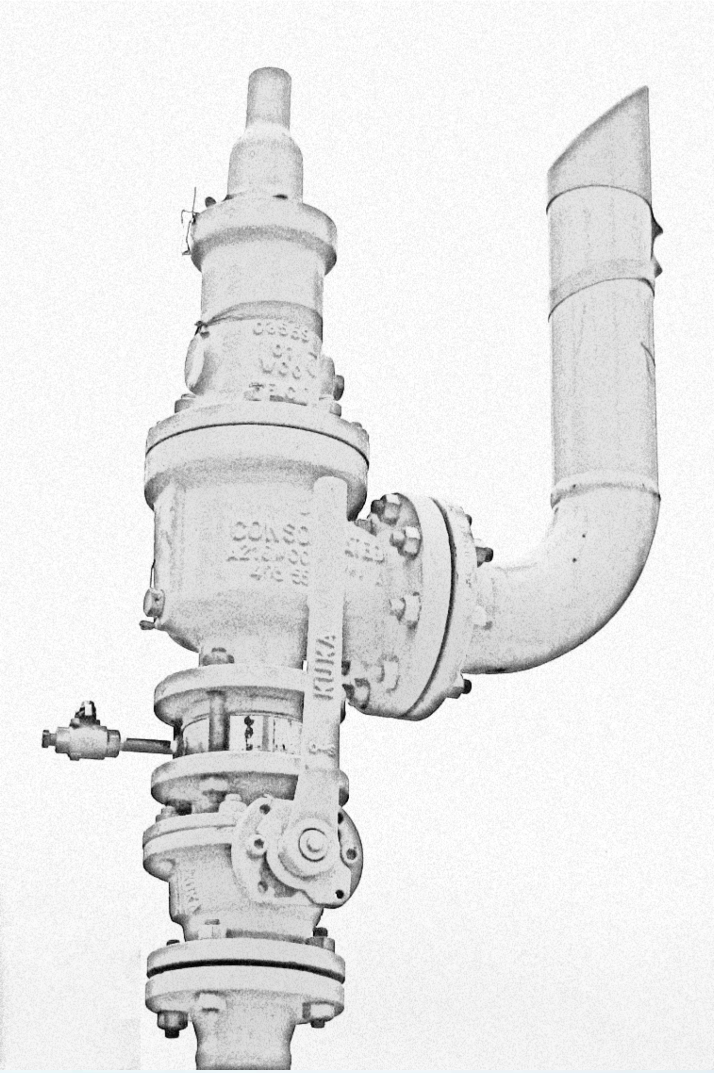
1. Introduction
2. Capacity Estimation
   I. Isentropic Expansion Coefficient
   II. Comparisons
3. High Pressure Operations
   1. ASME Concerns at high pressure
   2. Decomposition
   3. JT Coefficient
4. Questions

Introduction

1. An inherent part of process design is overpressure protection

2. A known issue associated with overpressure protection is the behavior of relieved fluid in the region of the critical point

3. Why?



Sizing Challenges

API Vapor Capacity

$$w = A \times C \times K_d \times K_B \times P \times \sqrt{\frac{M}{TZ}}$$

Where

w = mass flow through the orifice

A = Effective orifice area

C = function of the ratio of specific heats

K_d = Effective coefficient of discharge

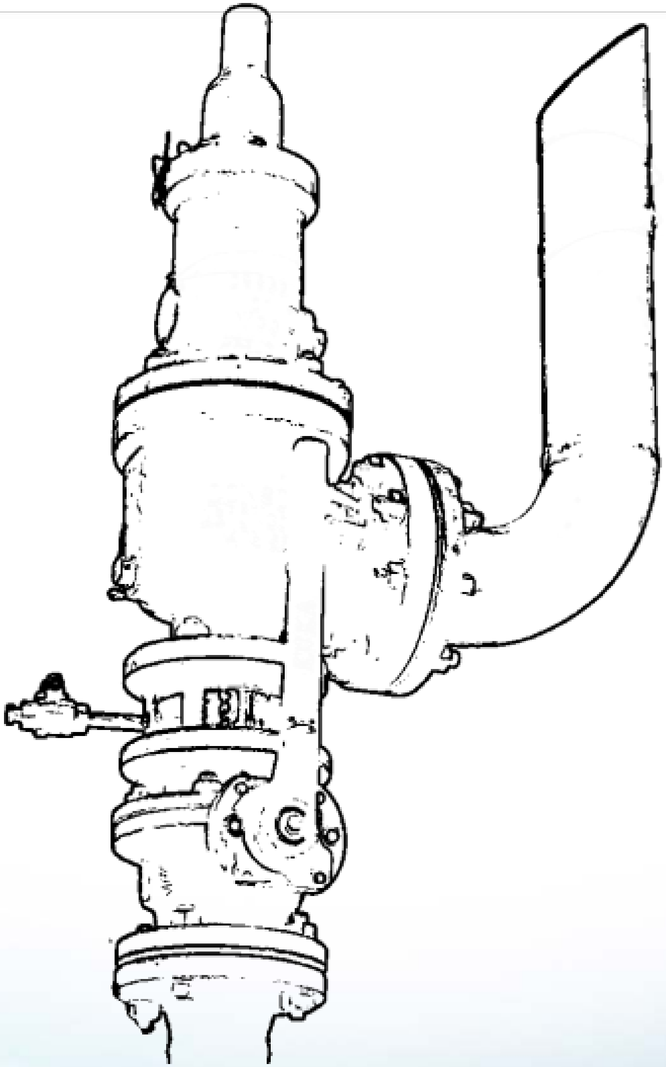
K_B = Backpressure correction factor

P = Relieving pressure

M = Molecular Weight

T = Relieving Temperature

Z = Compressibility Factor



Sizing Challenges

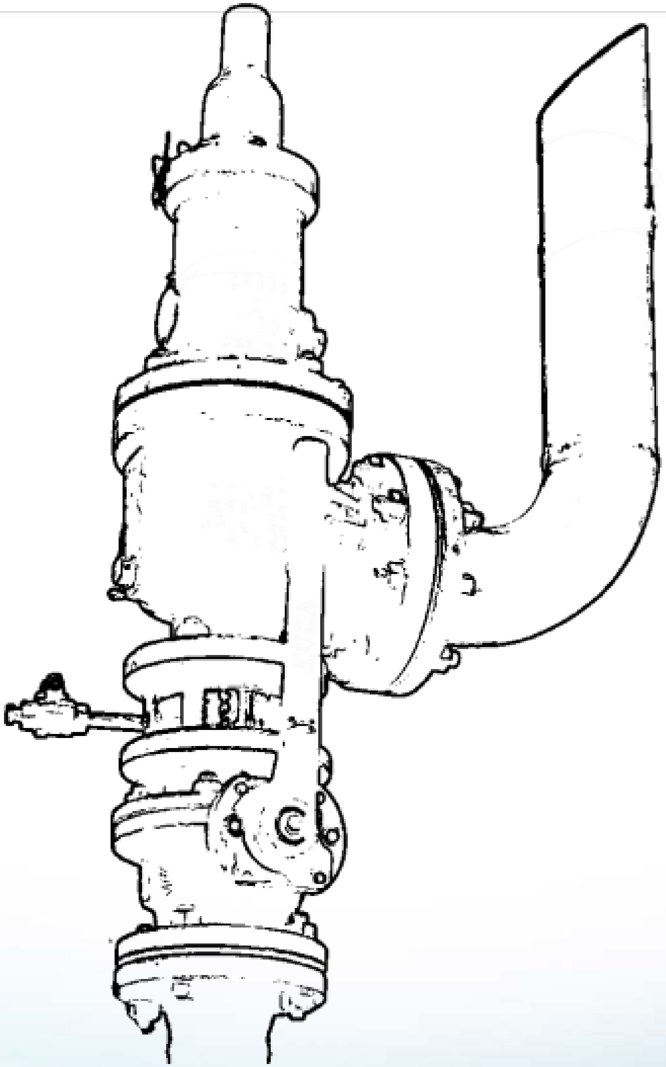
API Vapor Capacity

$$C = \sqrt{k\left(\frac{2}{k+1}\right)^{\frac{(k+1)}{(k-1)}}}$$

Where

k = ratio of ideal heat capacities = Cp/Cv

Used as an approximation of the isentropic expansion coefficient



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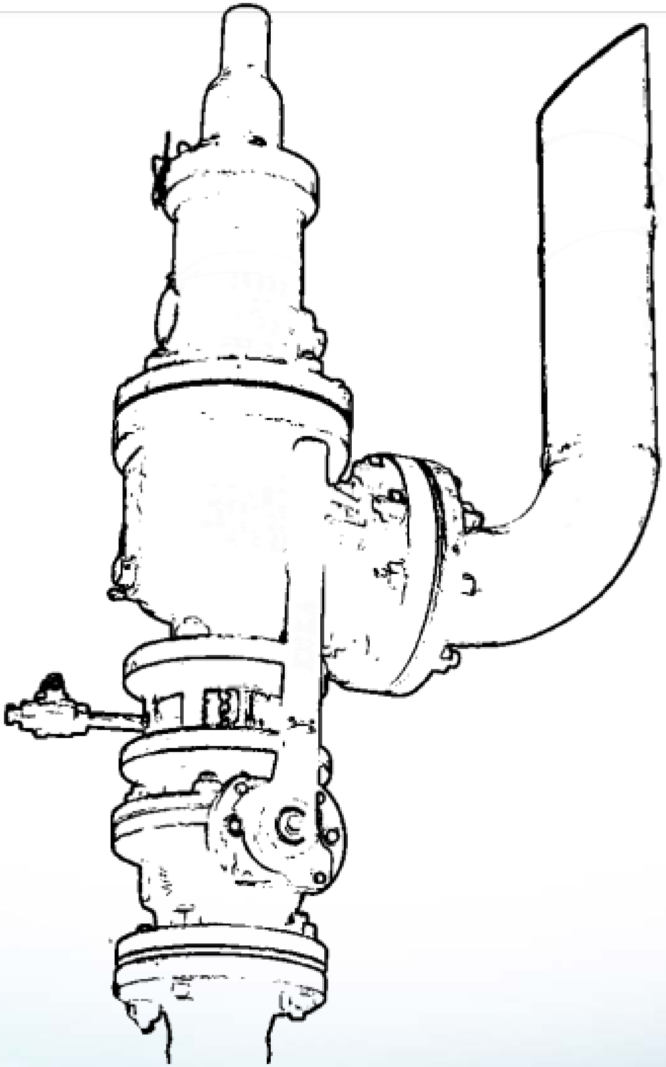


Sizing Challenges

Isentropic Expansion Coefficient

$$n = \frac{v}{P}\left(\frac{\partial P}{\partial v}\right)_T \frac{C_P}{C_V}$$

Where

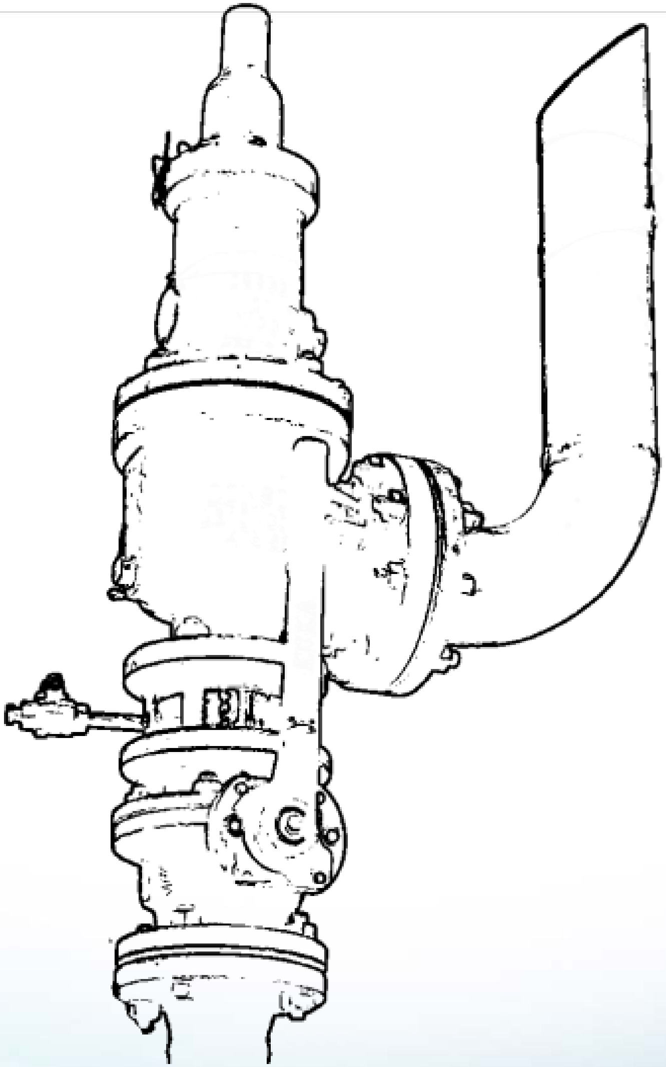
$n =$ Isentropic expansion coefficient

$v =$ volume

$P =$ Pressure

$C_P =$ Constant pressure heat capacity

$C_v =$ Constant volume heat capacity



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5.6.1 Applicability

The sizing equations for pressure relief devices in vapor or gas service provided in this section assume that the pressure-specific volume relationship along an isentropic path is well described by the expansion relation,

$$PV^k = \text{constant}$$

where

k is the ideal gas specific heat ratio at the relieving temperature.

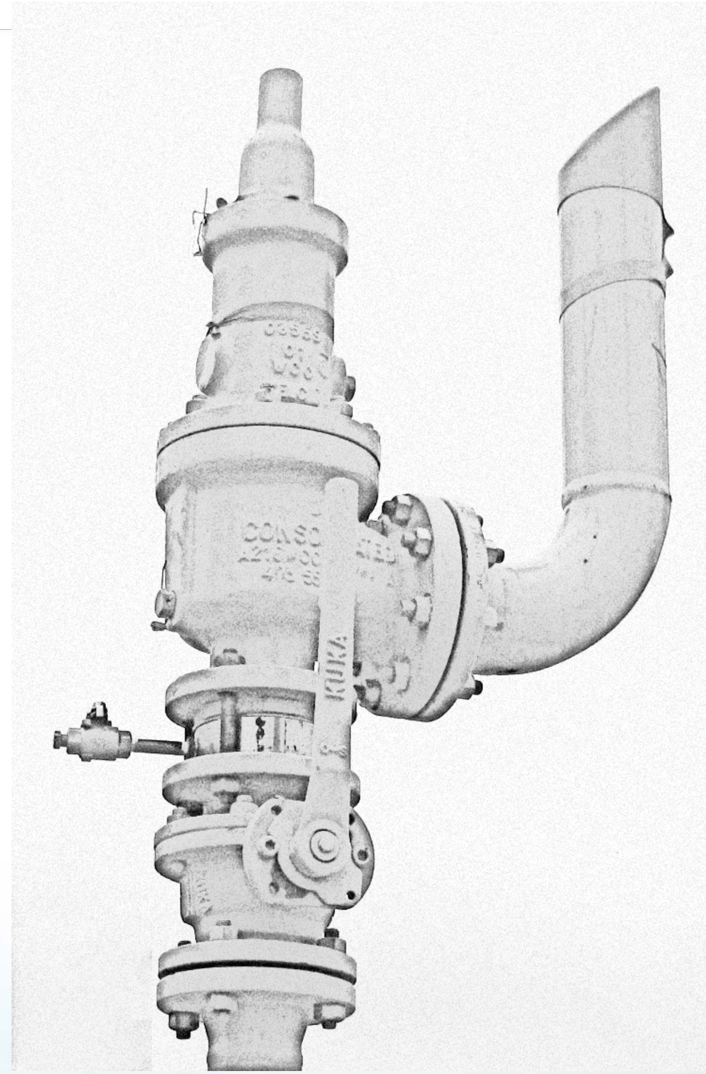
5.6.1 Applicability (continued)

Years of experience with this basis indicates that this approach has provided satisfactory results over a wide range of conditions. **However, the validity of the assumption may diminish at very high pressures or as the vapor or gas approaches the thermodynamic critical locus.** One indicator that the vapor or gas may be in one of these regions is a **compressibility factor, *Z*, less than approximately 0.8, or greater than approximately 1.1.** To ensure the most appropriate sizing results, users should establish the limits of applicability for their own systems.

Physical Property Challenges

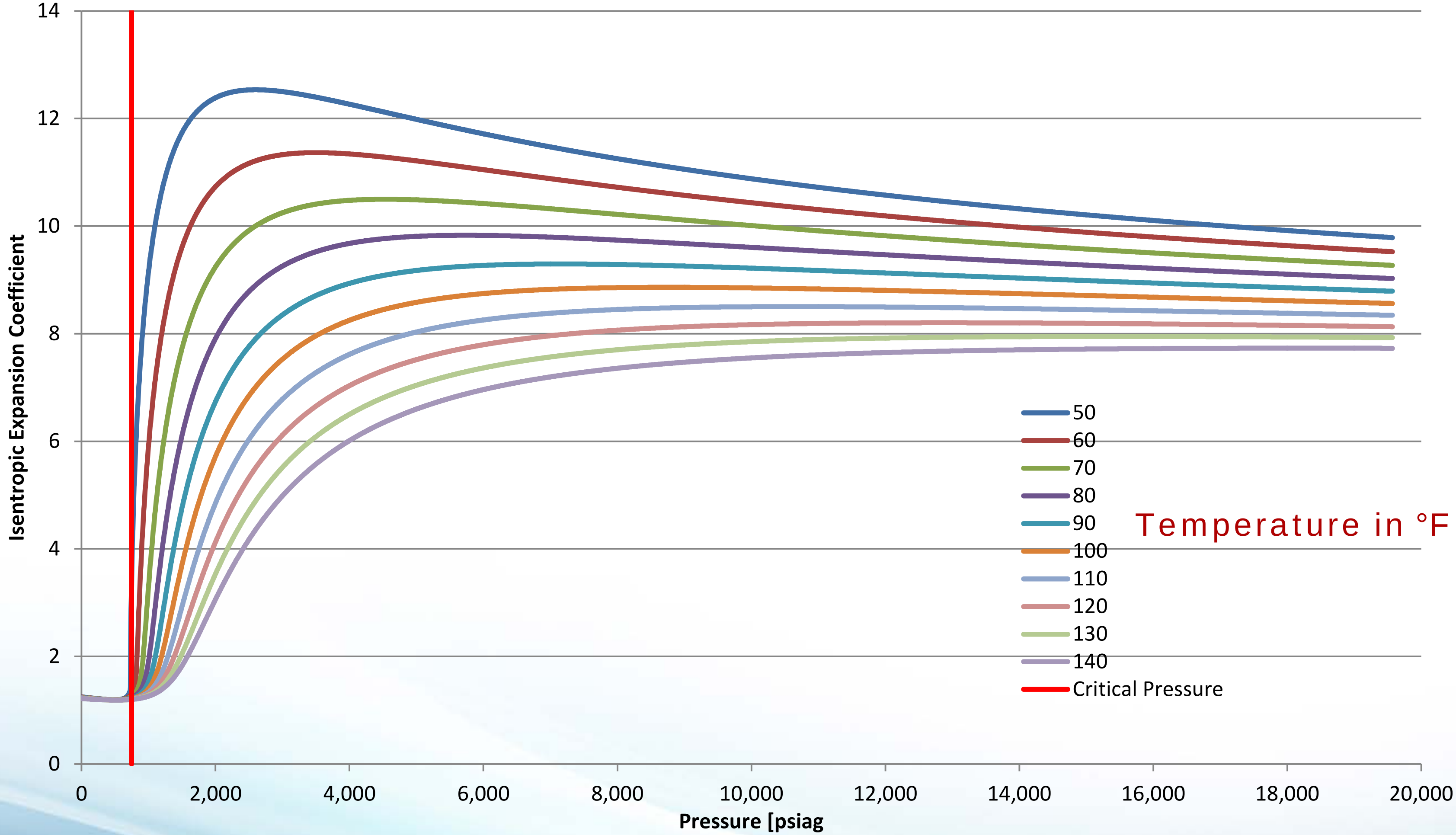
Thermodynamic Properties

Chemical	T_c [°F]	P_c [psig]
Ethane	90	708
Ethylene	48.6	731
Propane	206	616
Propylene	197	667



Physical Property Challenges

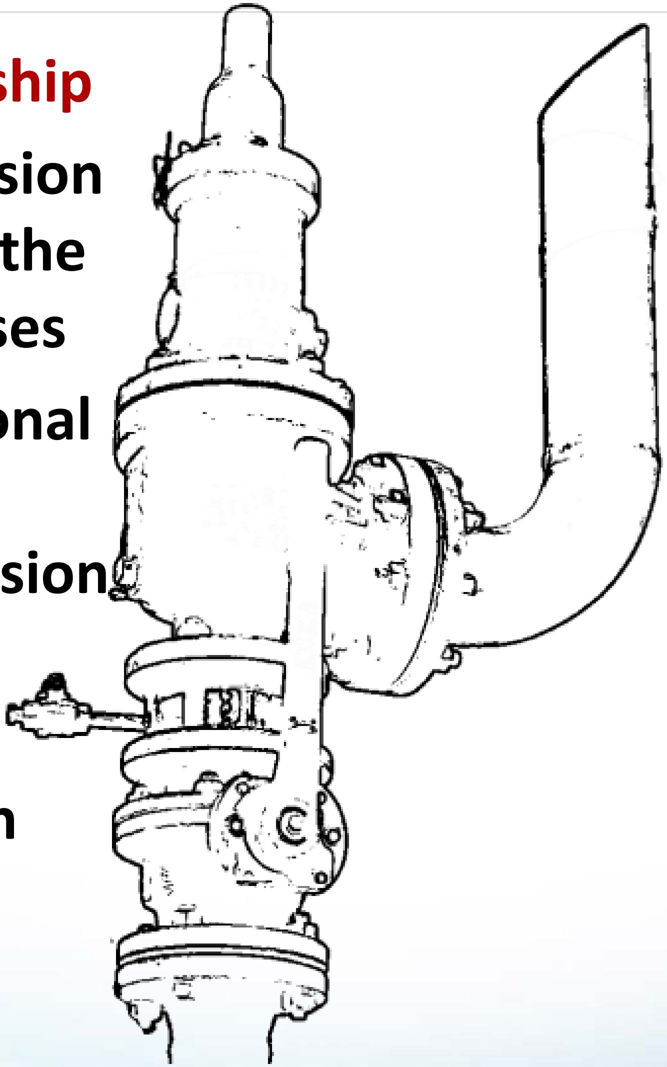
Isentropic Expansion Coefficient of Ethylene at constant temperatures



Sizing Challenges

Modeling the pressure volume relationship

1. As the slope of the isentropic expansion coefficient increases, the validity of the nozzle equation assumption decreases
2. For supercritical fluids the conventional approach is to use API Vapor Sizing equations with the isentropic expansion coefficient.
3. When this method is not sufficient, need to use a sizing method that can account for the pressure-volume relation over the expansion.



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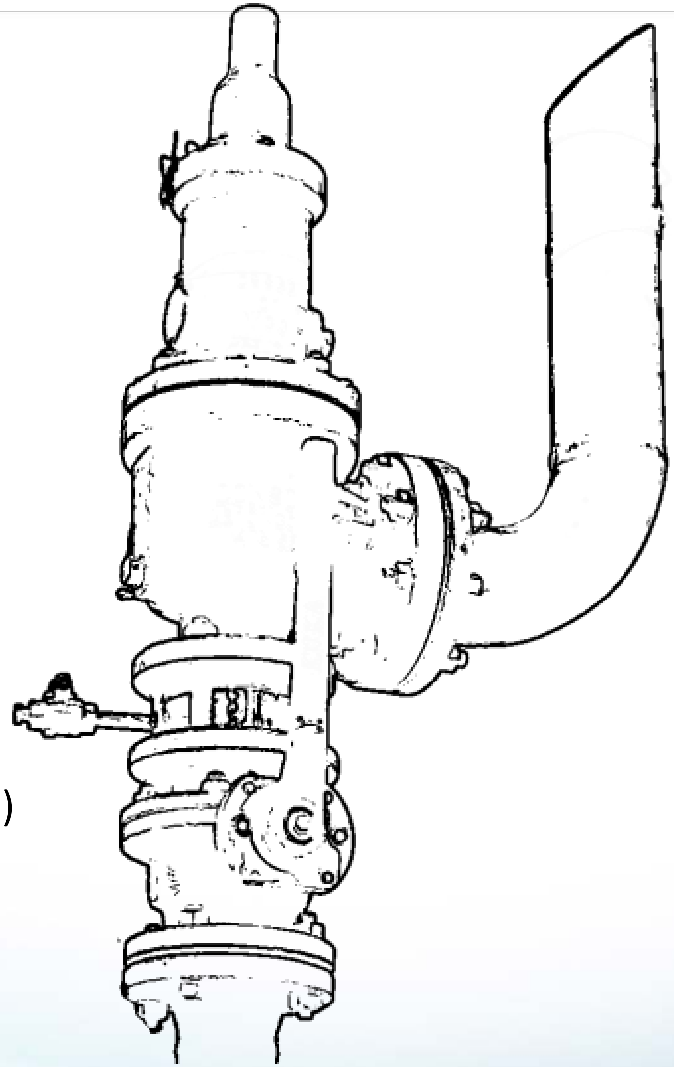
Sizing Challenges

Direct Integration Method

$$G^2 = \left[\frac{-2 \times \int_{P_1}^{P} v \times dP}{v_t^2} \right]_{max} = \left[\rho_t^2 \times \left(-2 \times \int_{P_1}^{P} \frac{dP}{\rho} \right) \right]_{max}$$



Where

$G =$ mass flux through the nozzel

$v =$ specific volume of the fluid

$\rho =$ mass density of the fluid

$P =$ stagnation pressure of the fluid

$1 =$ fluid condition at the inlet to the nozzel

$t =$ fluid condtion at the throat (minimum crossectional area)

Capacity is estimated by:

$$w = G_{max} \times A \times \prod(K)$$

Sizing Challenges

Capacity Estimation Comparison

1. A 2×J×3 relief device used

   A = 1.287 in^2

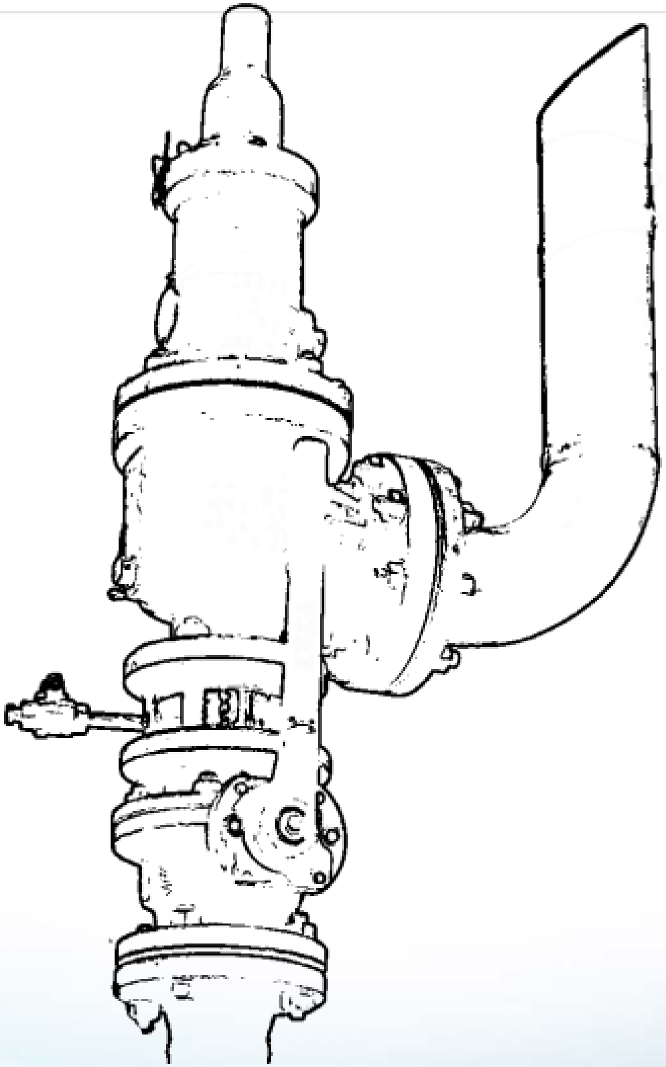
2. Pressures were varied between

   250 to 2500 psig

3. Temperatures were varied between

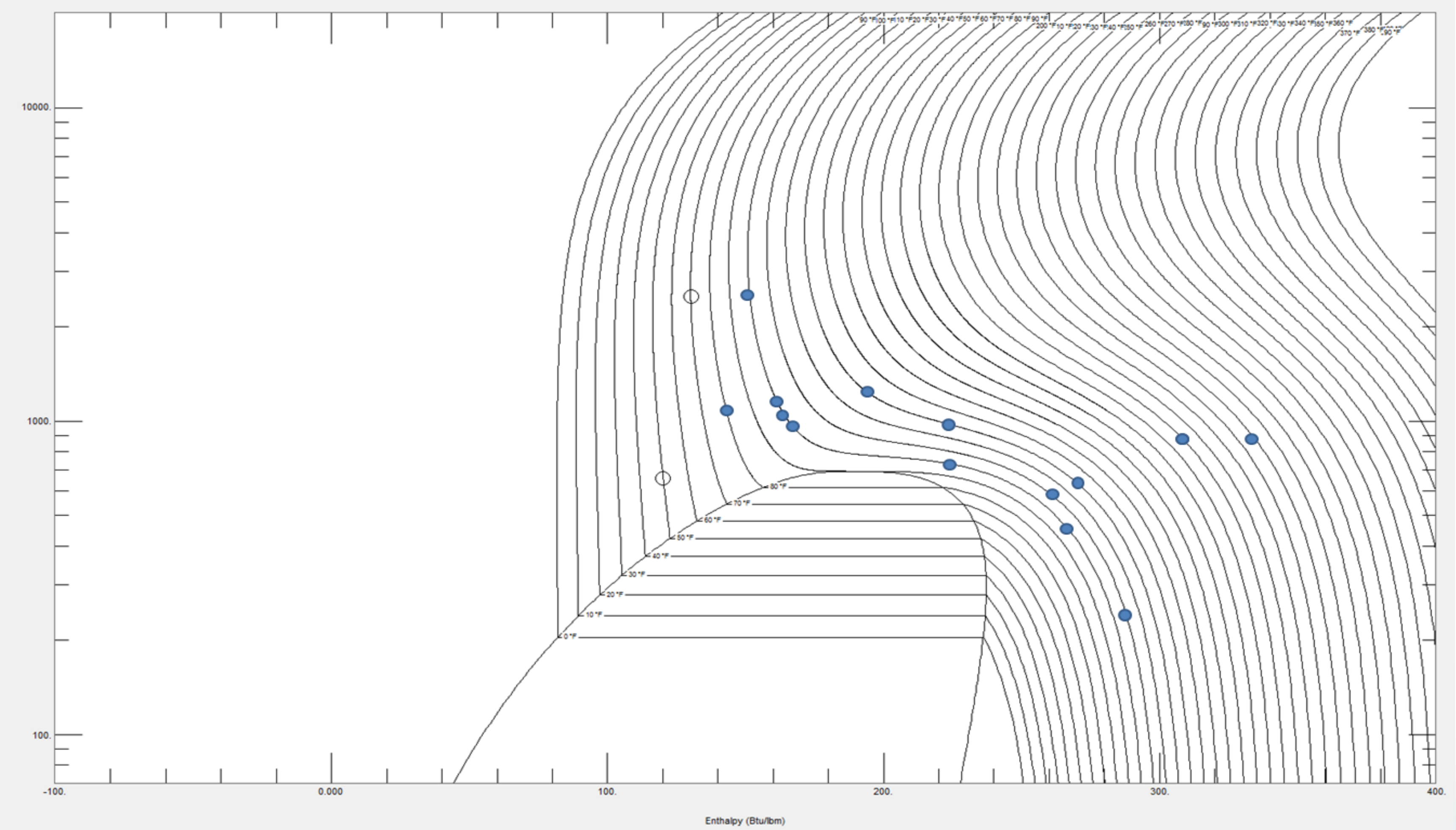
   50 ant 350 °F

4. Calculations peformed on Ethane, Ethylene, Propane and Propene



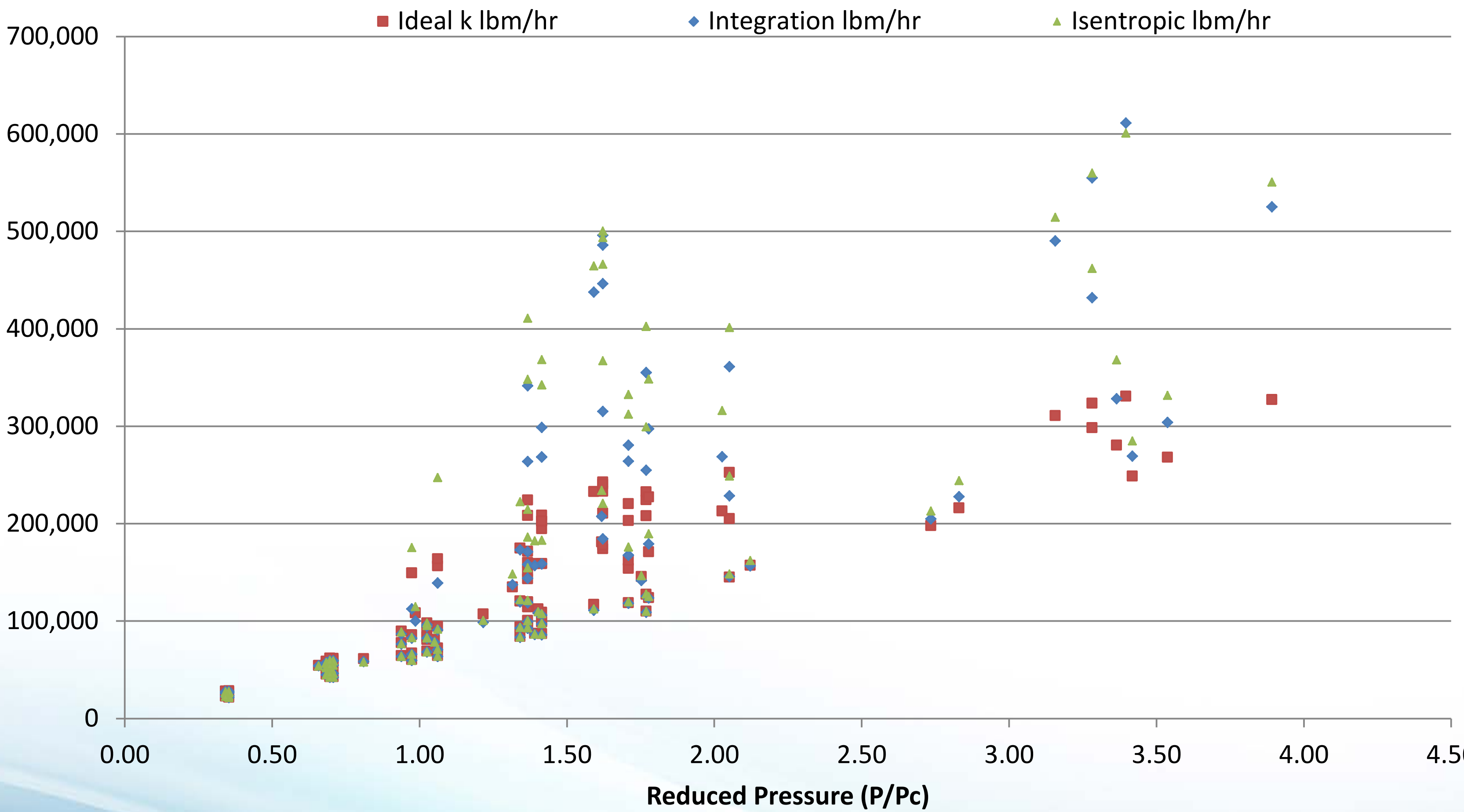
Sizing Comparison

Pressure Ethalpy Diagram of Ethylene with test cases plotted



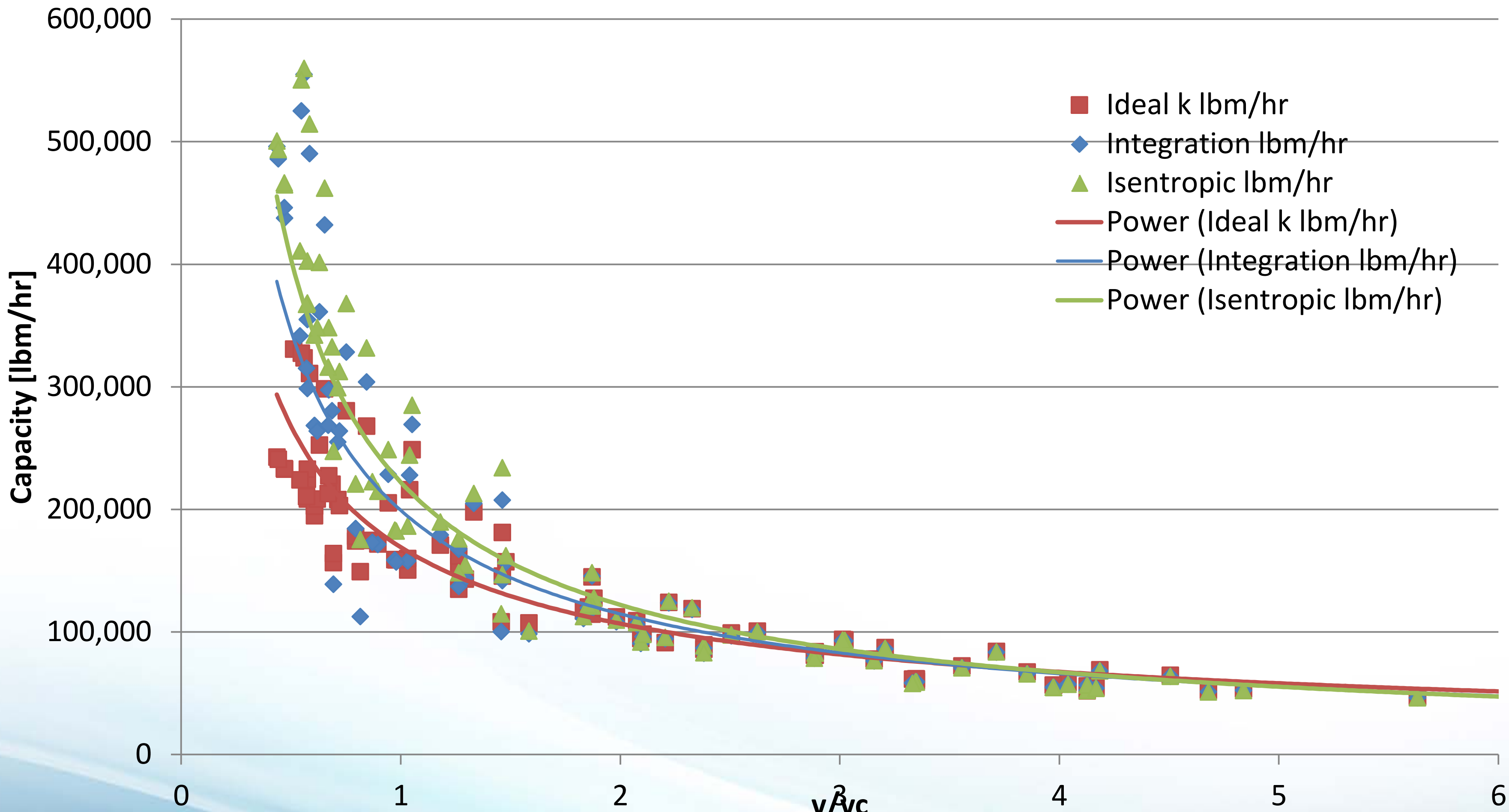
Sizing Comparison

Predicted Capacity verses Reduced Pressure



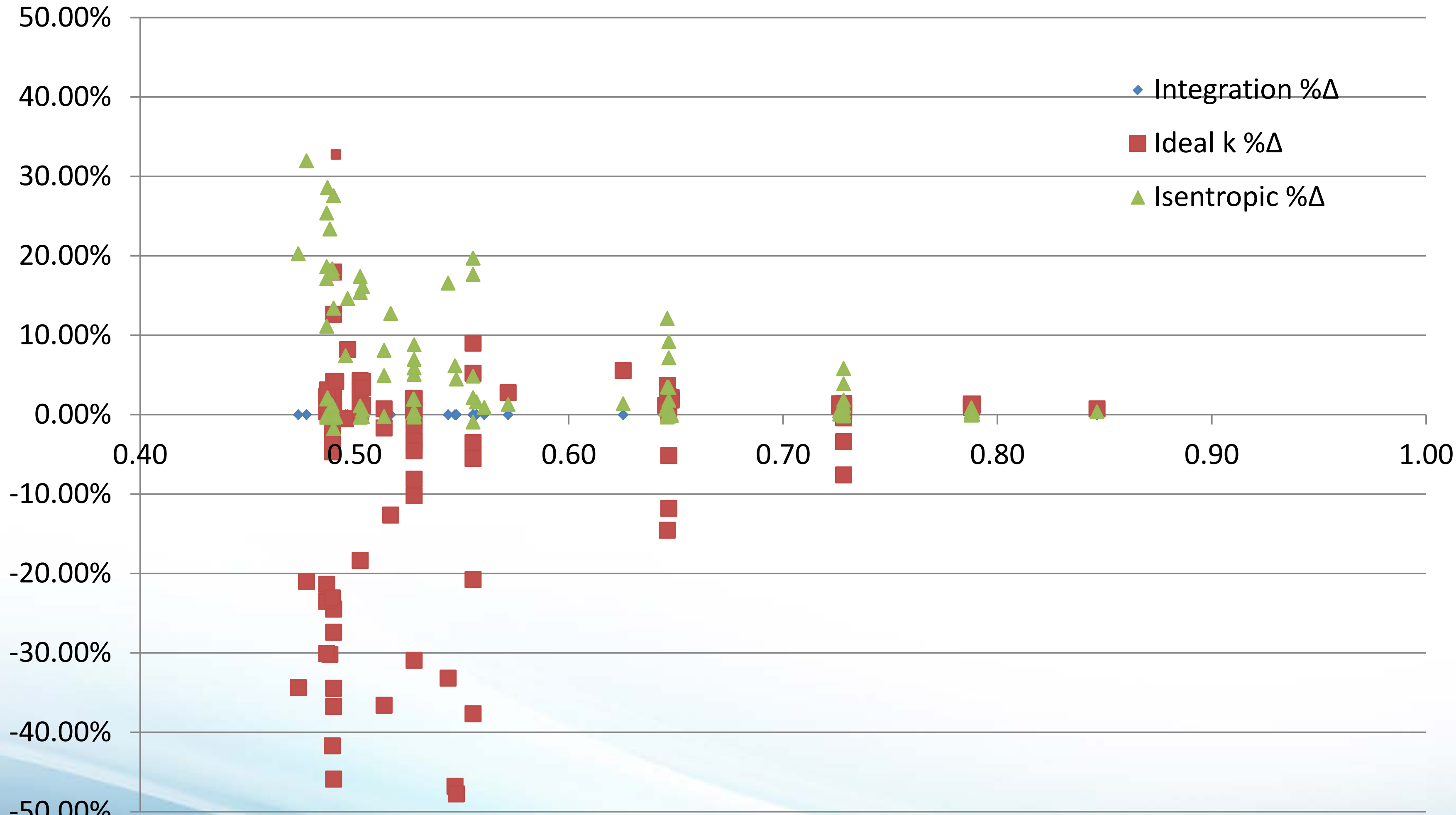
Sizing Comparison

Predicted Capacity verses Reduced Volume



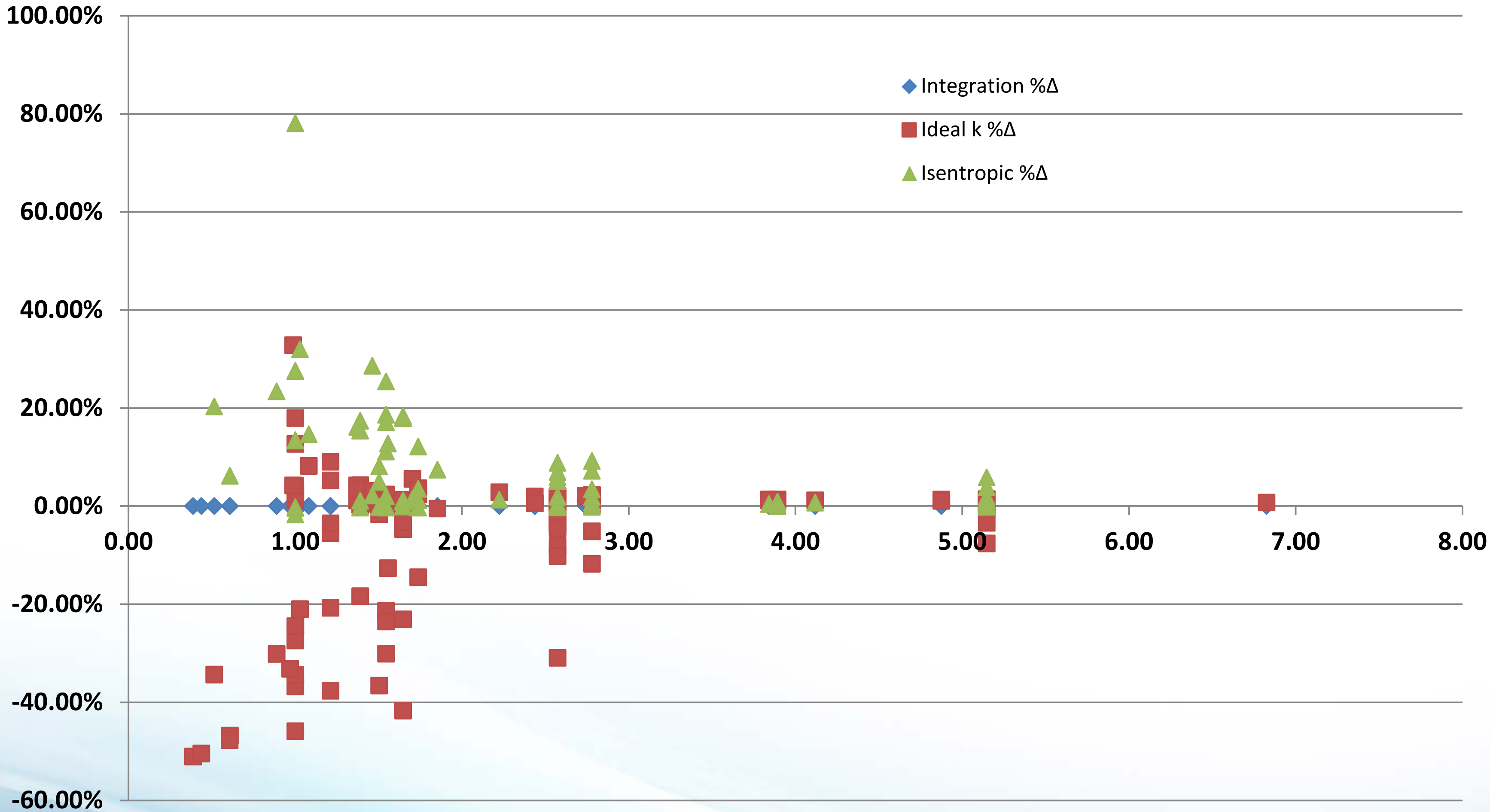
Sizing Comparison

%Deviation verses Z



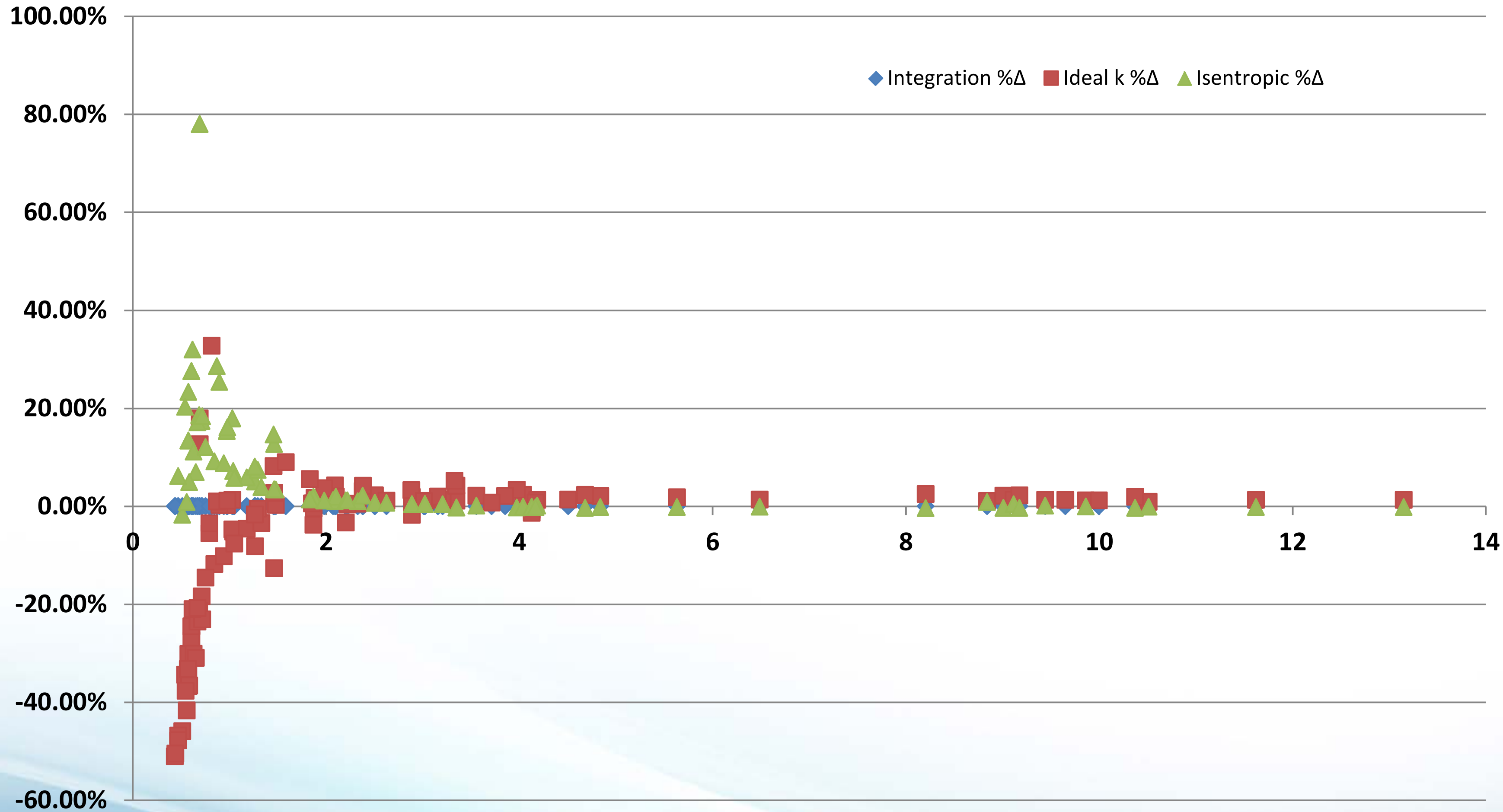
Sizing Comparison

% Deviation verses Reduced Temperature



Sizing Comparison

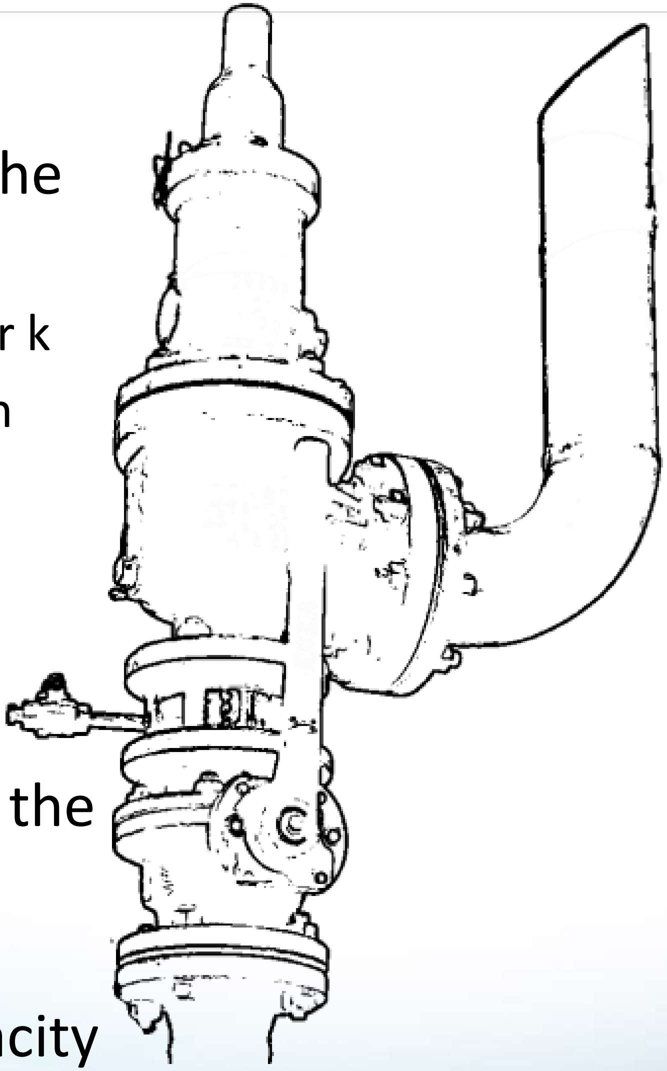
Percent Deviation verses reduced volume



Sizing Challenges

Capacity Estimation Comparison

1. At reduced volumes greater than 2, the variation between methods is small
    1. Between 1 and 3% for the ideal vapor k
    2. Less than 1% for isentropic expansion coefficient
2. At reduced volumes less an 2, the deviation from the direct integration method increases rapidly
3. While in all cases in this comparison, the Z is less then 0.85, knowledge of the pressure volume relationship is imperative to accurately predict capacity



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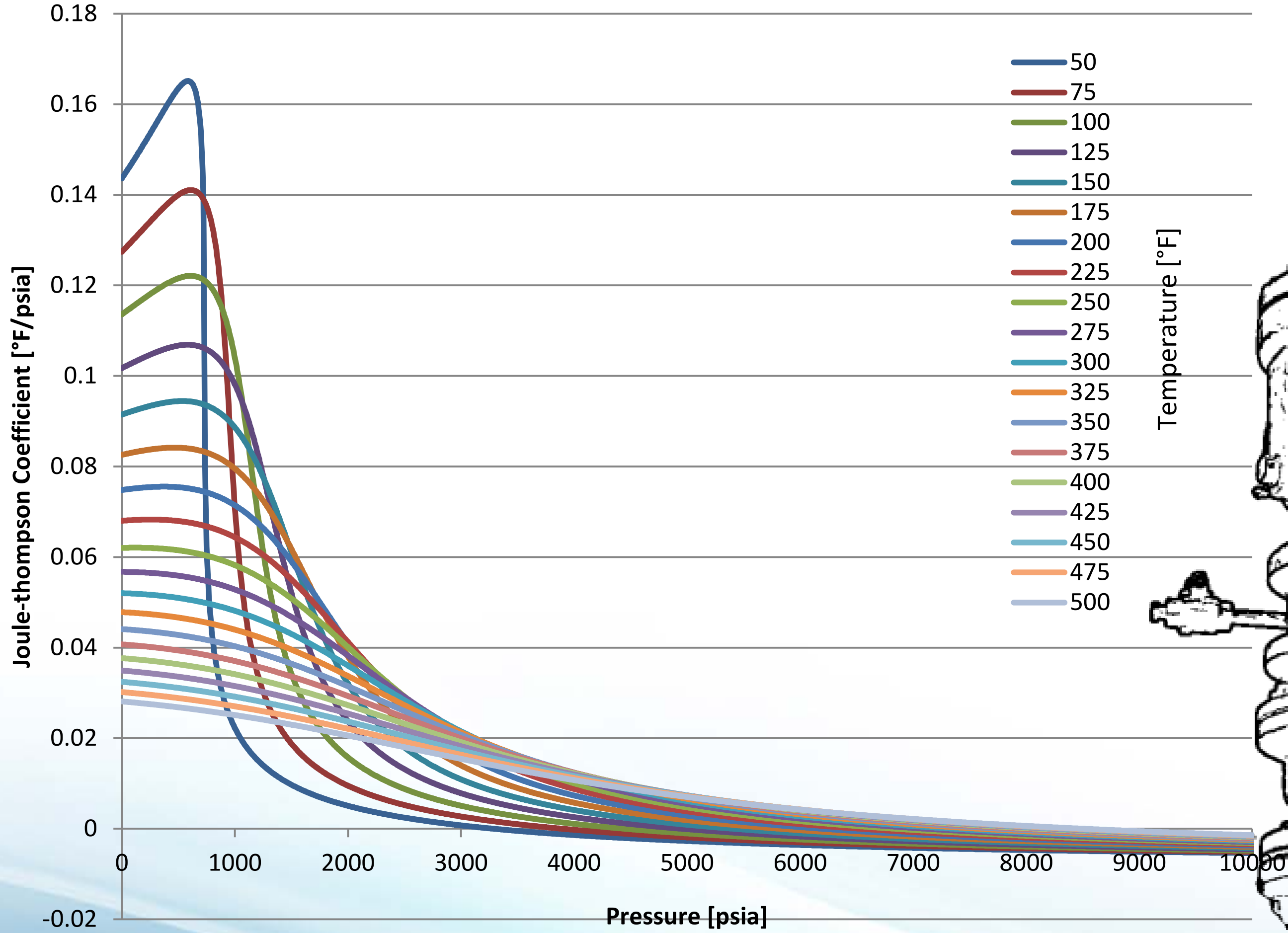
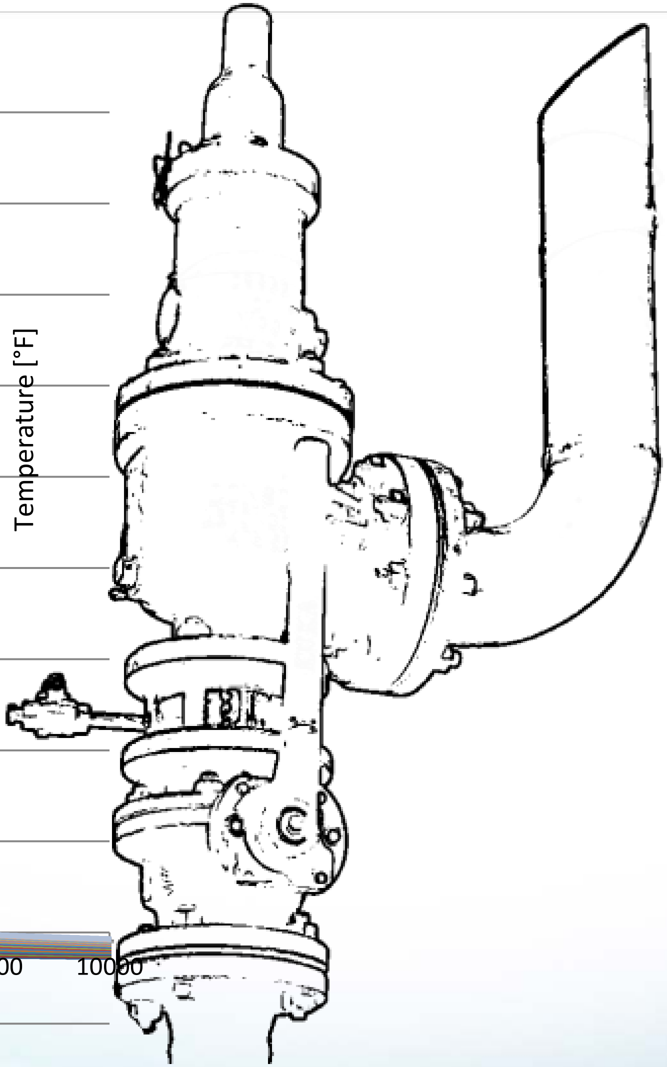
High Pressure Operations

Joule Thompson Coefficient





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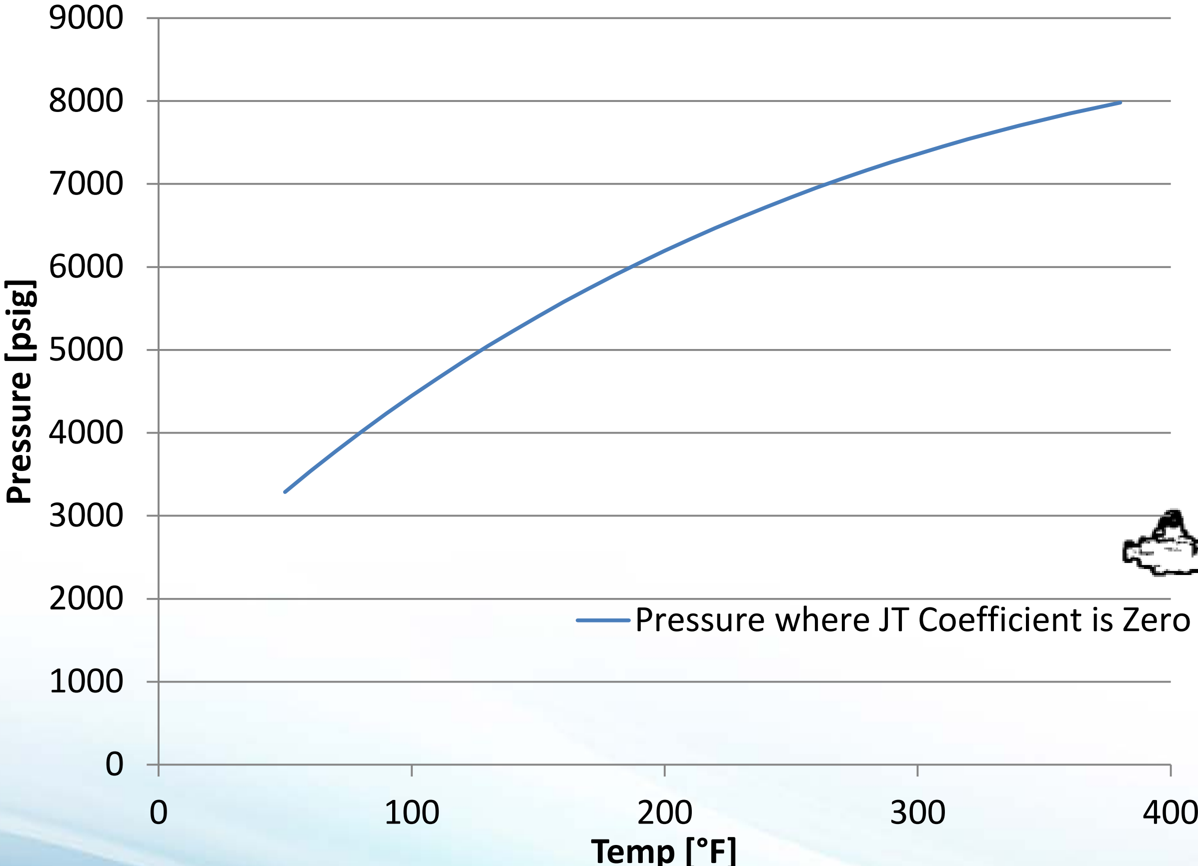

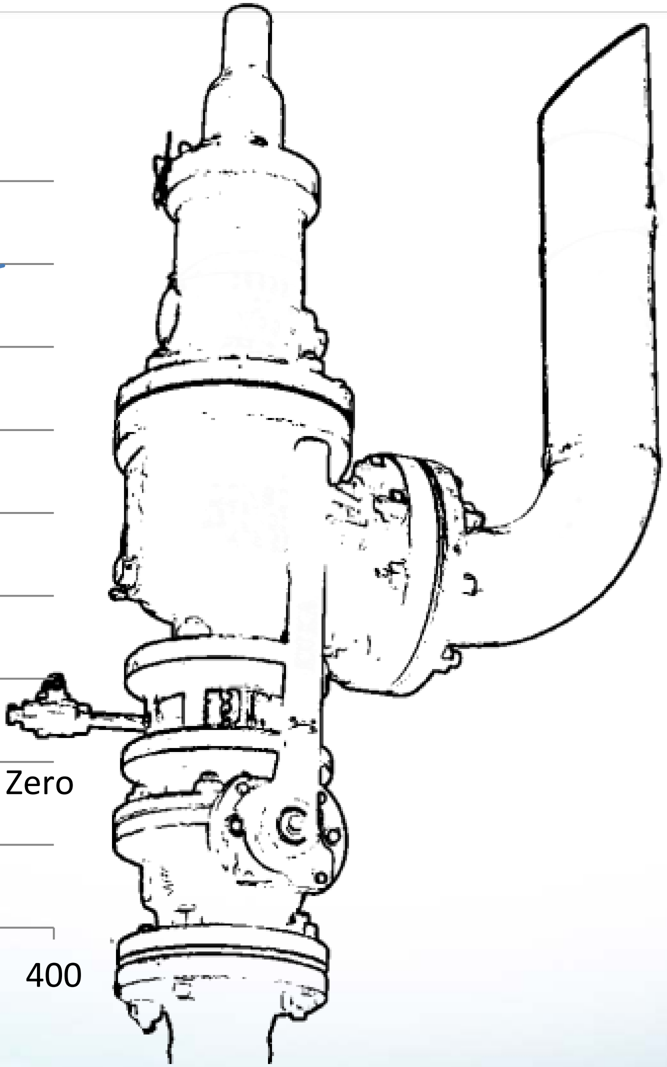

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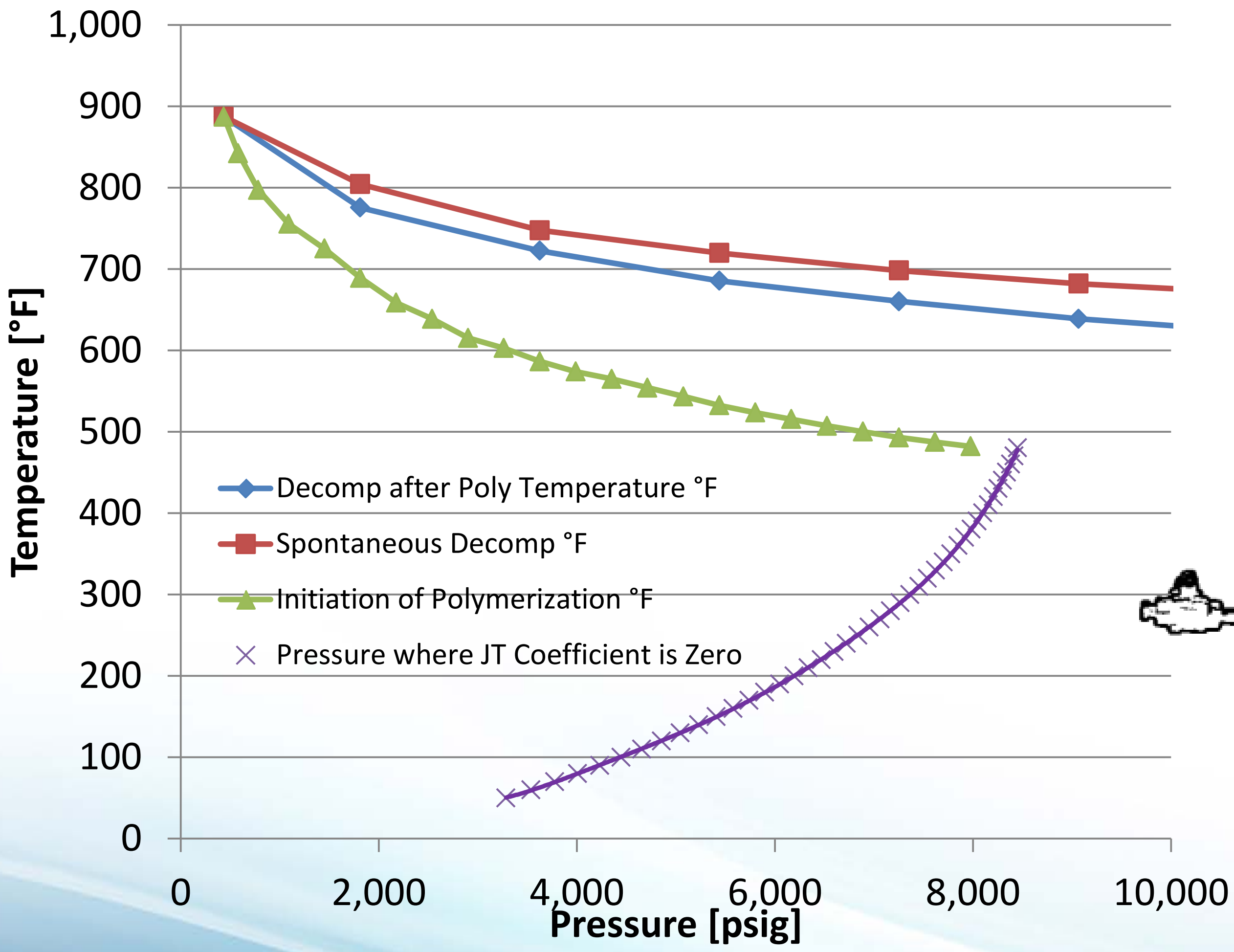

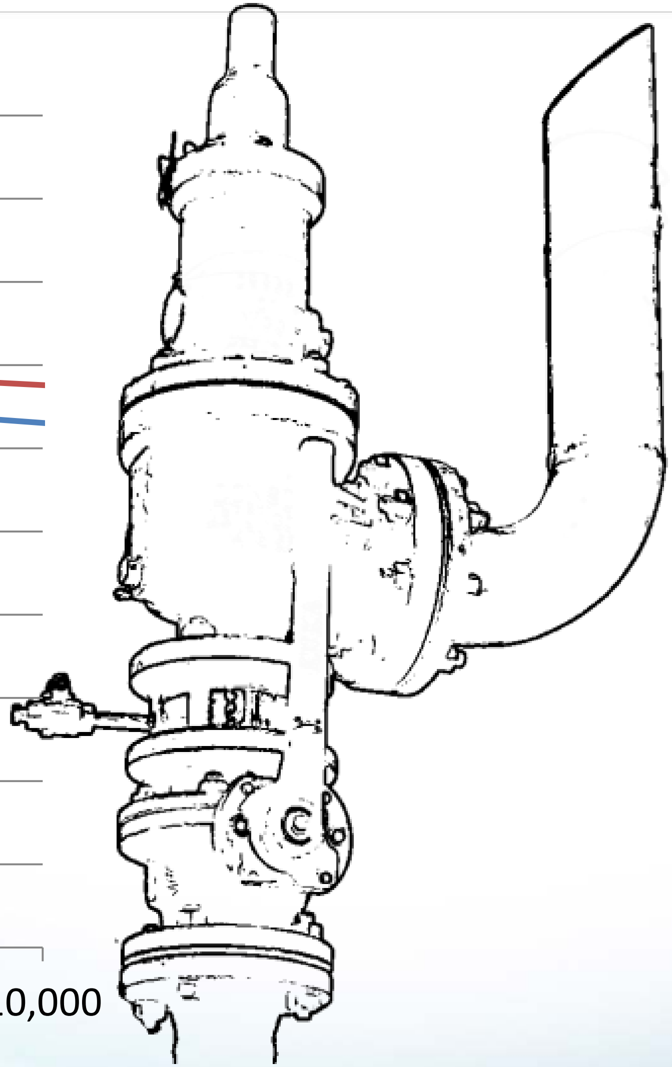

Conclusions

1. At reduced volumes greater than 2, the variation between methods is small
    1. Between 1 and 3% for the ideal vapor k
    2. Less than 1% for isentropic expansion coefficient
2. At reduced volumes less an 2, the deviation from the direct integration method increases rapidly
3. While in all cases in this comparison, the Z is less then 0.85, knowledge of the pressure volume relationship is imperative to accurately predict capacity
4. High pressure/temperature operations can lead to polymerization or decomposition
5. Very low temperatures can occur both in the vessels or the effluent piping upon depressurization