Gas Blowdown Analysis

Introduction

This program calculates pressure, temperature and flow rate of a real gas over time during a blowdown process. A blowdown process is a depressurization event where gas escapes from a pressurized volume through a metering device (typically a valve, orifice, nozzle or leak).

Two blowdown processes are analyzed: isothermal and adiabatic. The difference between these processes lies in how temperature and heat transfer are managed during the depressurization of the gas.

In an isothermal process, the temperature of the gas remains constant throughout the blowdown event. This constant temperature is maintained by the transfer of heat between the gas and its surroundings. As the gas expands and does work on the surroundings, heat is absorbed from the surroundings to maintain the gas temperature.

An adiabatic process is one in which no heat is exchanged with the surroundings during the blowdown. There is no heat transfer between the gas and its environment. All the changes in the gas's internal energy are due to work done by or on the gas.

In reality, the blowdown curve will lie somewhere between the adiabatic and isothermal curves. The solution will be closer to the adiabatic case for fast venting, especially if the tank is insulated. For longer duration venting where there may be some heat transfer from the surroundings, the solution will be closer to the isothermal case. In either case, the adiabatic and isothermal curves can serve as bounding conditions for a given analysis.

Step 1: User Input

Initial Pressure, P_i: Initial gas pressure before venting is initiated

Outlet Pressure, P_o: Ambient or reservoir pressure

Initial Temperature, T_i: Initial gas temperature before venting is initiated

Effective Flow Area, C_dA: Effective flow area of the metering device

Vent Volume, V: Total volume occupied by the gas (including plumbing to the metering device, if any)

Step 2: Calculate Gas Properties

The program retrieves six properties for the input gas chosen — specific heat ratio, *k*, gas constant, *R*, critical pressure ratio, P_{crit} , critical Pressure, P_c, and critical Temperature, T_c, using a lookup table.

Step 3: Calculate Initial Conditions

The initial time, t_i, is set to 0s and the initial gas mass in the tank is calculated using the real gas law:

$$m_i = \frac{P_i V}{zRT_i}$$

Where z is the compressibility factor. The compressibility factor is calculated from the Redlich-Kwong Equations using the reduced Pressure and Temperature (fraction of critical pressure/temperature). The initial density is calculated as:

$$\rho_i = m_i/V$$

If $P_o/P_i \leq P_{crit}$, the flow is choked and the following formula is used to calculate mass flow rate

$$mdot_i = C_d A \sqrt{k\rho_i P_i \left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}$$

This is the formula for choked mass flow rate of a compressible fluid, derived from conservation of mass and isentropic flow relations.

If $P_o/P_i > P_{crit}$, the flow is unchoked and the following formula is used to calculate mass flow rate

$$mdot_i = C_d A \sqrt{2\rho_i P_i \frac{k}{k-1}\left(\frac{P_o}{P_i}\right)^{\frac{2}{k}} - \left(\frac{P_o}{P_i}\right)^{\frac{k+1}{k}}}$$

This is the formula for unchoked mass flow rate of a compressible fluid, derived from conservation of mass, Bernoulli's equation and isentropic flow relations..

Step 4: Calculate Quantities over time

The time is update by adding the time step, defined as $\Delta t = 0.001s$ to the initial time:

$$t_{i+1} = t_i + \Delta t$$

The mass at t_{i+1} is calculated by subtracting the product of the last mass flow rate and time step from the previous mass. Over a given time step, the mass flow rate is assumed to be constant.

$$m_{i+1} = m_i - mdot_i \cdot \Delta t$$

The density at t_{i+1} is calculated by using the updated mass:

$$\rho = m_{i+1}/V$$

For the isothermal case, pressure is updated using the gas law assuming the initial temperature remains constant:

$$P_{i+1} = \rho_{i+1}RT$$

For the adiabatic case, pressure and temperature changes are calculated based on the changes in density and the properties of the gas as follows:

$$P_{i+1} = P_i\left(\frac{\rho_{i+1}}{\rho_i}\right)^k$$

$$T_{i+1} = T_i\left(\frac{P_{i+1}}{P_i}\right)^{\frac{k-1}{k}}$$

Next, the pressure ratio, P_o/P_{i+1} at t_{i+1} is updated, and used to determine whether the flow is choked or unchoked based on the critical pressure ratio of the given gas. The mass flow rate is then updated accordingly using the appropriate equation for choked/unchoked flow.

This process is repeated at each new time until the tank pressure equals the reservoir pressure. At each time, the calculated values for mass, density, pressure, temperature, and mass flow rate are stored in lists for plotting.