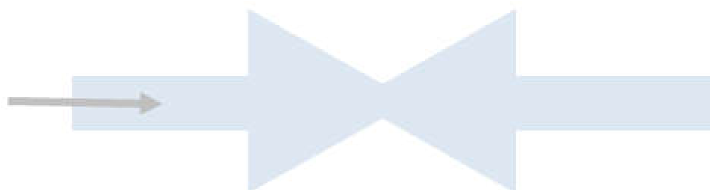
Flow Through an Expansion Valve

Introduction

Refrigerant R717

- enters an expansion valve (of cross-sectional area 0.011 m^2) at 11 bar, 330 K and 25 m s^{-1},
- and leaves at 2 bar.

This application calculates the temperature and velocity of the refrigerant as it exits the valve.



The First Law of Thermodynamics states

$$\dot{Q}_{sys} = \dot{E}_{sys} + \dot{W}_s + \dot{m}_{out}\left(h_{out} + \frac{v_{out}^2}{2} + g\,z_{out}\right) - \dot{m}_{in}\left(h_{in} + \frac{v_{in}^2}{2} + g\,z_{in}\right)$$

where

- $\dot{Q}_{sys}$ is the heat generated by the system
- $\dot{E}_{sys}$ is the rate of change of stored energy within the system
- W_s is the rate of work done by the system (except flow work)
- $\dot{m}_{in}$ and $\dot{m}_{out}$ are the mass flowrates into and out of the system
- h_{in} and h_{out} are the specific enthalpies of the fluid entering and leaving the system
- v_{in} and v_{out} are the velocities of the fluid entering and leaving the system
- z_{in} and z_{out} are the elevations of the fluid entering and leaving the system

For steady-state flow through an adiabatic expansion valve and no heat or work effects, the First Law of Thermodynamics reduces to

$$h_{in} + \frac{v_{in}^2}{2} = h_{out} + \frac{v_{out}^2}{2}$$

Assuming the input conditions are known, mass conversation implies that $\dot{m}_{in} = \dot{m}_{out} = m$, and hence

$$m = A \cdot v_{out} \cdot \rho_{out}$$

where A is the cross-section area of the valve and ρ_{out} is the fluid density at the exit.

The kinetic energy term in the First Law of Thermodynamics is generally small and is normally be ignored - this makes the combined system of equations explicit, and simple to solve. For this analysis, however, the kinetic energy term will remain. The equations are then implicit, and hence require a numerical solution

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> restart :
  with( ThermophysicalData ) :
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Parameters

Entrance

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> fluid := "R717" :
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$T_{in} := 310 :$

$P_{in} := 11 \cdot 10^5 :$

$v_{in} := 10 :$

$A := 0.005 :$

Enthalpy at inlet

> $h_{in} := \text{Property}(\text{massspecificenthalpy}, T = T_{in}, P = P_{in}, R717)$

$$h_{in} := 1.65559094731116970\,10^6 \quad \textbf{(2.1.1)}$$

Density at inlet

> $\rho_{in} := \text{Property}(\text{density}, T = T_{in}, P = P_{in}, R717)$

$$\rho_{in} := 8.15132757401520891 \quad \textbf{(2.1.2)}$$

Mass flowrate of refrigerant

> $m := A \cdot v_{in} \cdot \rho_{in}$

$$m := 0.4075663787 \quad \textbf{(2.1.3)}$$

Exit

> $P_{out} := 2 \cdot 10^5 :$

Enthalpy and density at outlet

> $eq1 := h_{out} = \text{Property}(\text{"massspecificenthalpy"}, \text{"temperature"} = T_{out}, \text{"P"} = P_{out}, fluid)$

$$eq1 := h_{out} = \text{ThermophysicalData:-Property}(\text{"massspecificenthalpy"}, \text{"temperature"} = T_{out}, \text{"P"} \quad \textbf{(2.2.1)}$$

$= 200000, \text{"R717"})$

> $eq2 := \rho_{out} = Property(\text{"D"}, \text{"temperature"} = T_{out}, \text{"P"} = P_{out}, fluid)$

$$eq2 := \rho_{out} = ThermophysicalData{:-}Property(\text{"D"}, \text{"temperature"} = T_{out}, \text{"P"} = 200000, \text{"R717"}) \quad (2.2.2)$$

Mass Conservation and First Law of Thermodynamics

> $eq3 := h_{in} + \frac{v_{in}^2}{2} = h_{out} + \frac{v_{out}^2}{2}$:

> $eq4 := m = A \cdot v_{out} \cdot \rho_{out}$:

Solution of the Equation System

> $res := fsolve(\{eq1, eq2, eq3, eq4\})$

$$res := \{T_{out} = 285.0179004, h_{out} = 1.654113289\,10^6, v_{out} = 55.27490598, \rho_{out} = 1.474688637\} \quad (4.1)$$

Plot Thermodynamic Process on a PhT Chart

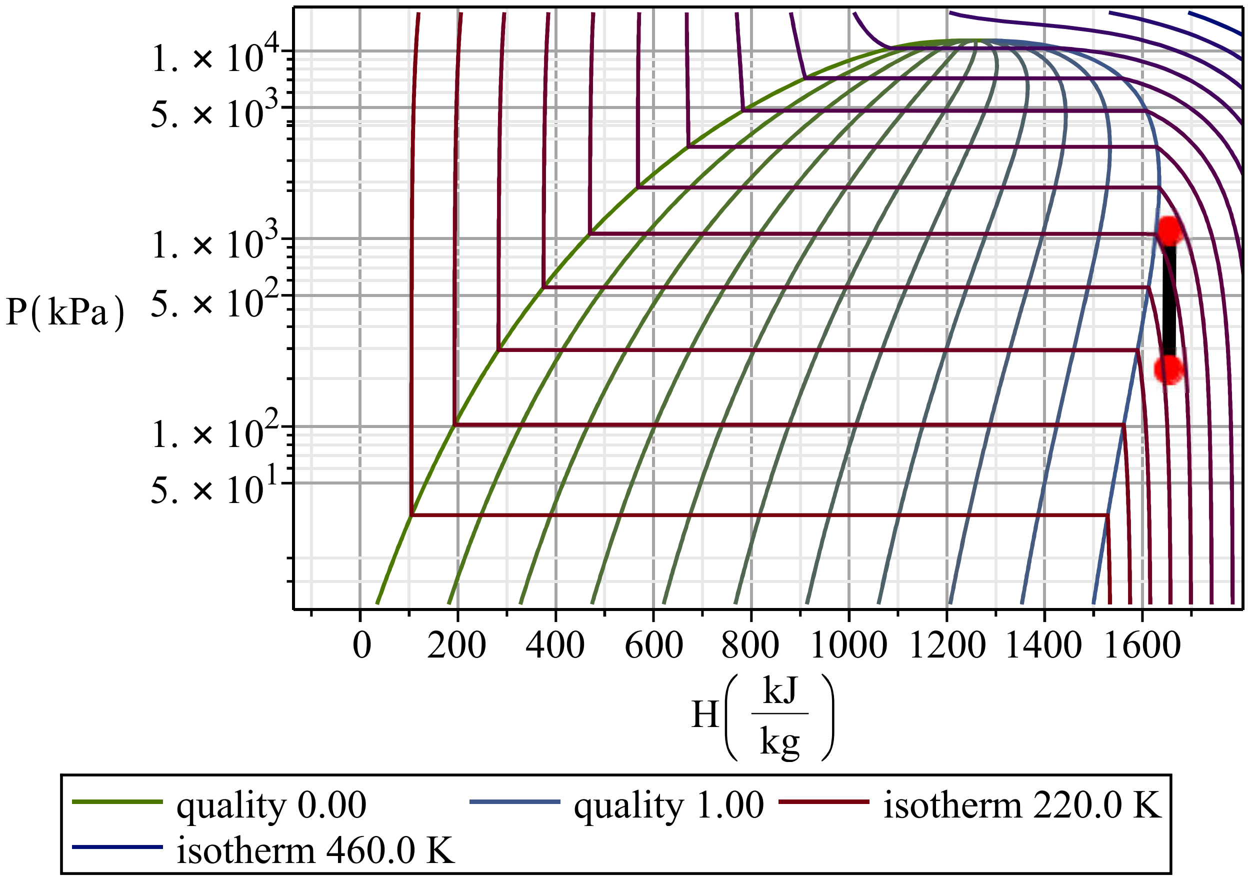
> assign(res) :

$p1 := plot(10^{-3} \cdot\sim [[h_{in}, P_{in}], [h_{out}, P_{out}]], color = black, thickness = 5)$:

$p2 := plot(10^{-3} \cdot\sim [[h_{in}, P_{in}], [h_{out}, P_{out}]], thickness = 5, style = point, symbol = solidcircle, color = red,$
$symbolsize = 20)$:

p3 := PHTChart(fluid) :

plots:-display(p1, p2, p3)



1. × 10^4
5. × 10^3
1. × 10^3
5. × 10^2
1. × 10^2
5. × 10^1
P(kPa)
0
200
400
600
800
1000
1200
1400
1600
H(kJ/kg)
quality 0.00
quality 1.00
isotherm 220.0 K
isotherm 460.0 K