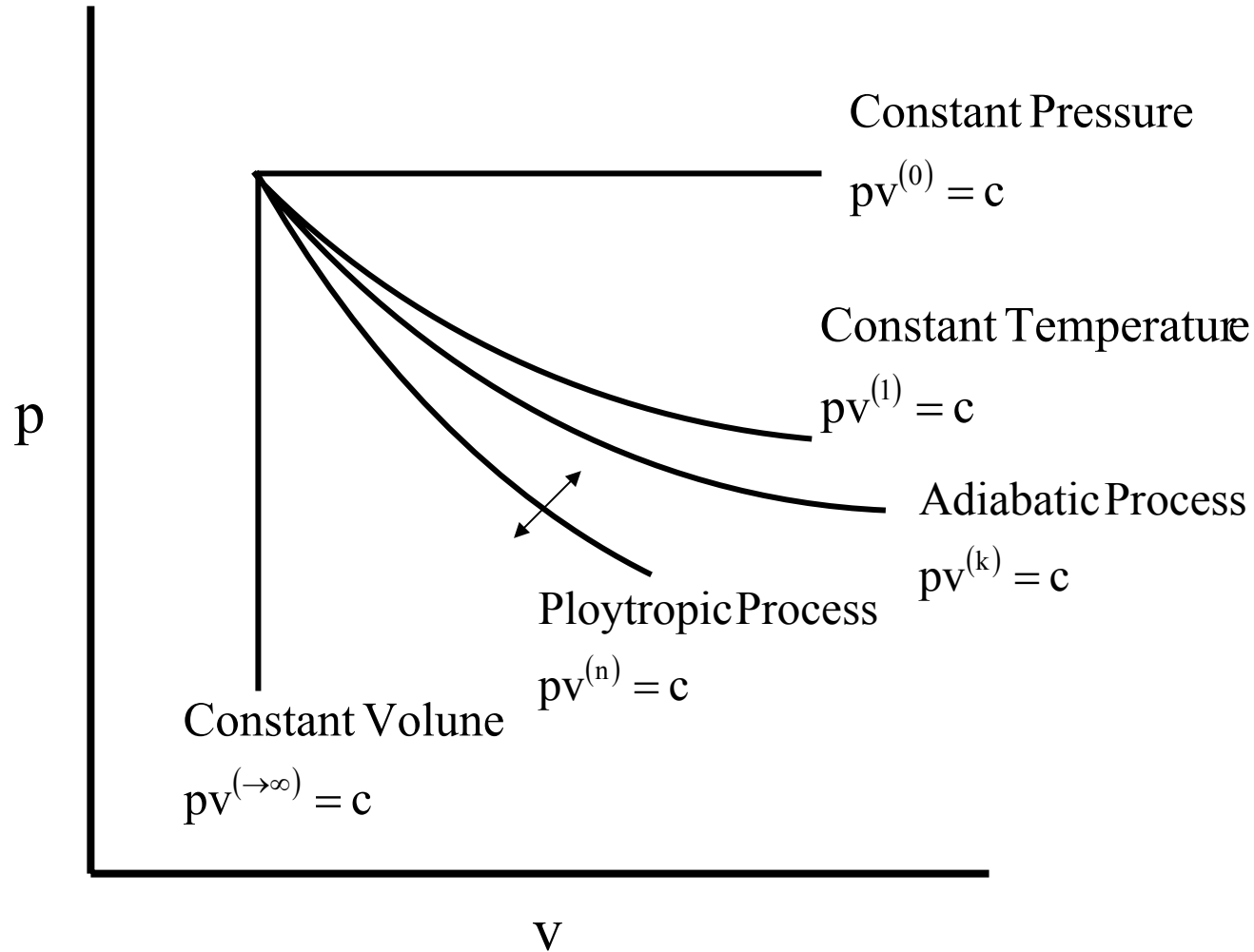


Non-Flow Thermodynamic Processes



CONSTANT VOLUME NON-FLOW PROCESS

$$Q = \Delta E + W$$

$$W = \int p dV = 0$$

$$Q = m \times (u_2 - u_1) = m \times c_v (T_2 - T_1) \quad \text{kJ, BTU}$$

$$q = \frac{Q}{m} = u_2 - u_1 = \int c_v dT \quad \text{kJ/kg, BTU/lb}$$

$$du = c_v dT$$

CONSTANT PRESSURE NON-FLOW PROCESS

$$Q = \Delta E + W$$

$$W = p \int dV = m \times p \int dv = m \times p \times (v_2 - v_1) \quad \text{kJ, ft lb}_f$$

$$w = \frac{W}{m} = (p_2 v_2 - p_1 v_1) = R \times (T_2 - T_1) \quad \text{kJ/kg, ft lb}_f/\text{lb}_m$$

$$Q = m \times (u_2 - u_1) + m \times (p_2 v_2 - p_1 v_1)$$

$$q = (u_2 + p_2 v_2) - (u_1 + p_1 v_1)$$

$$q = h_2 - h_1 = \int c_p dT$$

$$dh = c_p dT$$

Constant Temperature Non-Flow Process

$$pv^{(1)} = \text{constant}$$

$$\frac{p_2}{p_1} = \frac{V_1}{V_2}$$

$Q = \Delta E + W$ First Law, Non - Flow Closed System

$$\Delta E = 0$$

$$Q = \int pdV$$

$pV = mRT$ Ideal Gas Law

$$p = \frac{mRT}{V}$$

$$Q = \int \frac{mRT}{V} dV$$

$$Q = mRT \ln V$$

$$q = RT \ln V$$

$$Q = mRT \ln \left(\frac{V_2}{V_1} \right) = mRT \ln \left(\frac{v_2}{v_1} \right)$$

$$Q = mRT \ln \left(\frac{V_2}{V_1} \right) = mRT \ln \left(\frac{p_1}{p_2} \right)$$

$$q = p_1 v_1 \ln \left(\frac{v_2}{v_1} \right)$$

$$q = \frac{p_2 v_2}{J} \ln \left(\frac{v_2}{v_1} \right)$$

What is the heat flow when 3 lb of nitrogen undergoes a constant temperature process at 300 F from an initial volume of 40 ft³ to a final volume of 22.5 ft³?

$$Q = \Delta E + W$$

$$\Delta E = 0$$

$$Q = W$$

$$q = R T \ln\left(\frac{V_2}{V_1}\right) = R T \ln\left(\frac{V_2}{V_1}\right)$$

$$q = 55.17 \times 760 \times \ln\left(\frac{22.5}{40}\right)$$

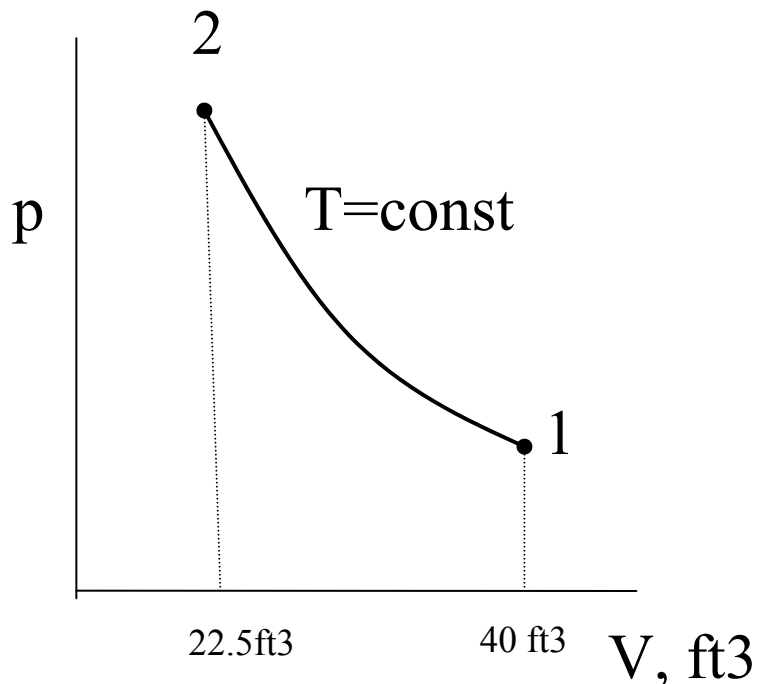
$$q = -24,115. \text{ft} - \text{lb}/\text{lbm}$$

$$Q = \frac{-24,115 \text{ft} - \text{lb}/\text{lbm} \times 3 \text{lbm}}{778 \text{ft} - \text{lb}/\text{BTU}}$$

$$Q = -93.29 \text{BTU}$$

Also:

$$q = R T \ln\left(\frac{p_1}{p_2}\right)$$



POLYTROPIC PROCESS

$$pv^n = \text{constant}$$

$$p_1 v_1^n = p_2 v_2^n$$

$$\frac{p_2}{p_1} = \left(\frac{v_1}{v_2} \right)^n$$

substitute from $pv = RT$

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2} \right)^{n-1} = \left(\frac{p_2}{p_1} \right)^{\frac{n-1}{n}}$$

$$W = m \int p dv = m \int c v^{-n} dv = \frac{c v^{-n+1}}{1-n}$$

$$W = \frac{m(p_2 v_2 - p_1 v_1)}{1-n} = \frac{m R(T_2 - T_1)}{1-n}$$

$$Q = \Delta E + W$$

$$q = \Delta u + w$$

$$q = c_v(T_2 - T_1) + \frac{R(T_2 - T_1)}{1-n}$$

$$q = c_v \left(\frac{k-n}{1-n} \right) (T_2 - T_1)$$

$$q = c_v \left(\frac{k-n}{1-n} \right) T_1 \left[\left(\frac{p_2}{p_1} \right)^{\frac{n-1}{n}} - 1 \right]$$

$$q = c_v \left(\frac{k-n}{1-n} \right) T_1 \left[\left(\frac{v_1}{v_2} \right)^{n-1} - 1 \right]$$

ADIABATIC PROCESS, Q=0

$$Q = \Delta E + W \quad \text{First Law, Non - Flow Closed System}$$

$$q = \Delta u + w$$

$$0 = c_v dT + p dv$$

$$T = \frac{pv}{R} \quad \text{Ideal Gas Law}$$

$$dT = \frac{1}{R} (v dv + p dp)$$

$$0 = \frac{c_v}{R} p dv + \frac{c_v}{R} v dv + p dv$$

$$0 = \left(\frac{c_v}{R} + 1 \right) \frac{dv}{v} + \left(\frac{c_v}{R} \right) \frac{dp}{p}$$

$$\left(\frac{1}{k-1} + 1 \right) \ln v + \left(\frac{1}{k-1} \right) \ln p = \text{Constant}$$

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

ADIABATIC PROCESS

$$Q=0, \quad pV^k = \text{constant}$$

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

$$p_2 V_2^k = p_1 V_1^k$$

$$\frac{p_2}{p_1} = \left(\frac{V_1}{V_2} \right)^k$$

substitute from $pV = RT$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2} \right)^{k-1} = \left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}}$$

$$Q = \Delta E + W = 0$$

$$q = \Delta u + w$$

$$w = \Delta u = \int c_v dT = c_v (T_2 - T_1)$$

$$w = c_v \left(\frac{p_2 V_2}{R} - \frac{p_1 V_1}{R} \right) = \frac{1}{k-1} (p_2 V_2 - p_1 V_1)$$

$$R = c_p - c_v$$

$$w = c_v \left(T_1 \left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - T_1 \right)$$

$$w = \frac{c_v R}{c_p - c_v} \times T_1 \left(\left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - 1 \right)$$

$$w = \frac{1}{k-1} R \times T_1 \left(\left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}} - 1 \right)$$

$$w = \frac{1}{k-1} R \times T_1 \left(\left(\frac{V_1}{V_2} \right)^{k-1} - 1 \right)$$

$$p_1 v_1^k = p_2 v_2^k$$

$$\frac{p_2}{p_1} = \left(\frac{v_2}{v_1} \right)^k$$

$$p_2 = p_1 (10)^{1.4}$$

$$p_2 = 14.7 \text{ psia} \times 25.11$$

$$p_2 = 369.3 \text{ psia}$$

$$\frac{T_2}{T_1} = \left(\frac{p_2}{p_1} \right)^{\frac{k-1}{k}}$$

$$T_2 = (70 + 460)(25.11)^{\frac{1.4-1}{1.4}}$$

$$T_2 = 1331^\circ \text{R}$$

$$Q = \Delta E + W$$

$$Q = 0$$

$$W = \Delta E$$

$$W = m \times c_v (T_2 - T_1)$$

$$W = .5 \times .17 (1331 - 530)$$

$$W = 68.09 \text{ BTU}$$

.5 lb_m of air present in a gasoline engine cylinder, which has a compression ratio of 10 ($V_1/V_2 = 10$), is compressed adiabatically from 70° F and 14.7 psia. What work is required? What is the final temperature and pressure?

Also by formula:

$$W = m \times \frac{1}{k-1} R \times T_1 \left(\left(\frac{v_1}{v_2} \right)^{k-1} - 1 \right)$$

$$W = .5 \times \frac{1}{1.4-1} 53.35 \times 530 \left((10)^{1.4-1} - 1 \right)$$

$$W = 53,437 \text{ ftlbf}$$

$$W = \frac{53,437 \text{ ftlb}}{778 \frac{\text{ftlb}}{\text{BTU}}} = 68.8 \text{ BTU}$$

NON-FLOW EQUATIONS FOR AN IDEAL GAS

Process	Constant Pressure	Constant Volume	Constant Temperature	Polytropic Process **
n exponent in $pv^n = \text{const.}$	$n = 0$	$n = \infty$	$n = 1$	$n = n$
p, v, T Property Relationships	$\frac{T_2}{T_1} = \frac{v_2}{v_1}$	$\frac{T_2}{T_1} = \frac{p_2}{p_1}$	$p_1 v_1 = p_2 v_2$	$p_1 v_1^n = p_2 v_2^n$ $\frac{T_2}{T_1} = \left(\frac{v_2}{v_1}\right)^{n-1} = \left(\frac{p_2}{p_1}\right)^{\frac{n-1}{n}}$
q, heat energy/mass	$c_p(T_2 - T_1)$	$c_v(T_2 - T_1)$	$p_1 v_1 \ln\left(\frac{v_2}{v_1}\right) = R_1 T_1 \ln\left(\frac{p_1}{p_2}\right)$	$c_p \left(\frac{k-n}{1-n}\right) (T_2 - T_1)$
w, work $w = \int p dv$ energy/mass	$p_1(v_2 - v_1)$	0	$p_1 v_1 \ln\left(\frac{v_2}{v_1}\right) = R_1 T_1 \ln\left(\frac{p_1}{p_2}\right)$	$\frac{p_2 v_2 - p_1 v_1}{1-n} = \frac{R(T_2 - T_1)}{1-n}$
Specific Heat c_p, c_v	$c_p = R + c_v$ $c_p = \frac{Rk}{k-1}$	$c_v = c_p - R$ $c_v = \frac{R}{k-1}$		

** for $n = k = \frac{c_p}{c_v}$, the process is adiabatic