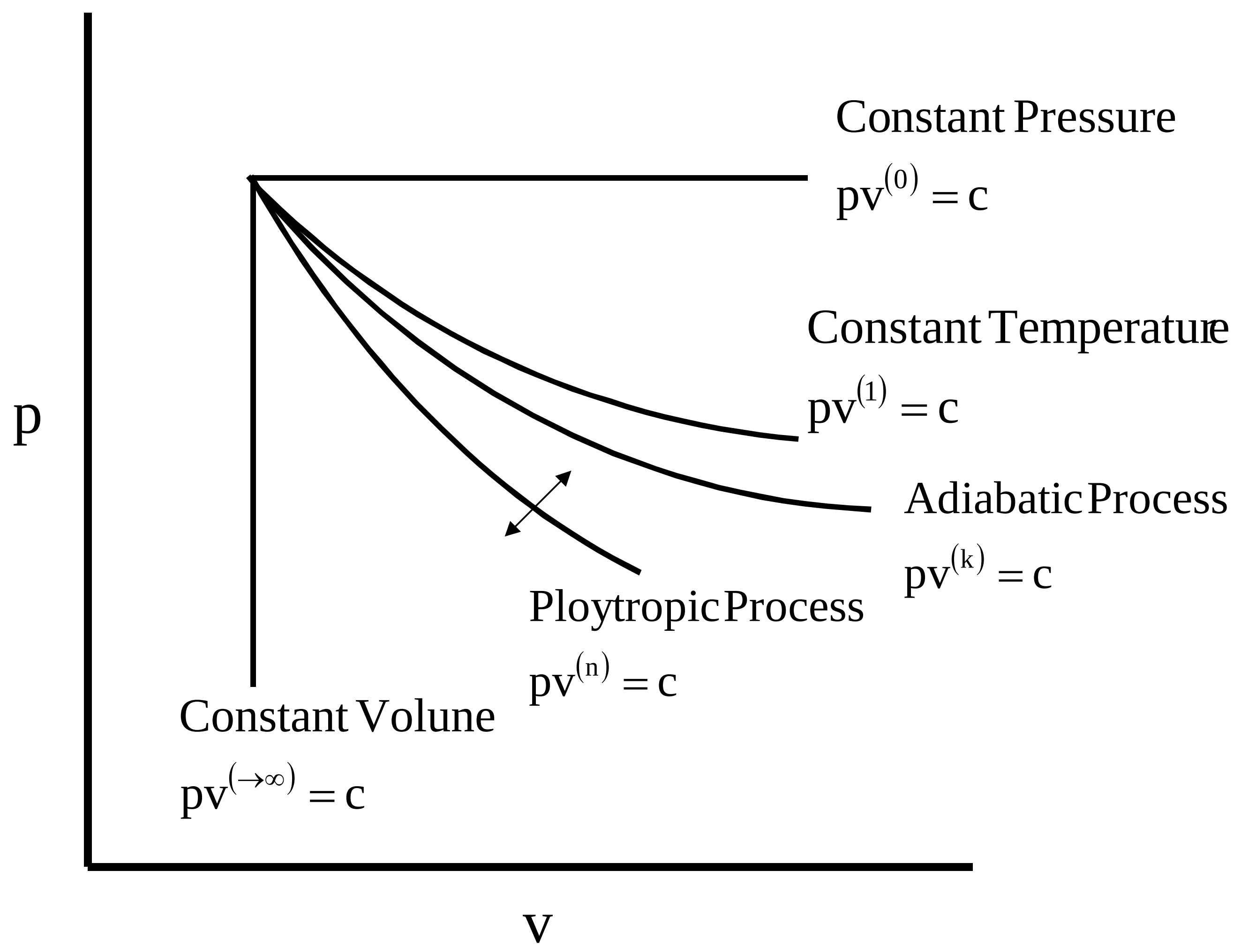
Non-Flow Thermodynamic Processes



CONSTANT VOLUME NON_FLOW PROCESS

$$Q = \varphi E + W$$

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

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

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

$$du = c_v dT$$

CONSTANT PRESSURE NON-FLOW PROCESS

$$Q = \varphi E + W$$

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

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

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

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

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

$$dh = c_p dT$$

Constant Temperature Non-Flow Process

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

$$\frac{p_2}{p_1} = \frac{v_1}{v_2}$$

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

$$\Delta E = 0$$

$$Q = \int p\,dV$$

$$pV = mRT \quad \text{Ideal Gas Law}$$

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

$$Q = \int \frac{m\,RT}{V}\,dV$$

$$Q = m\,RT \ln V$$

$$q = RT \ln V$$

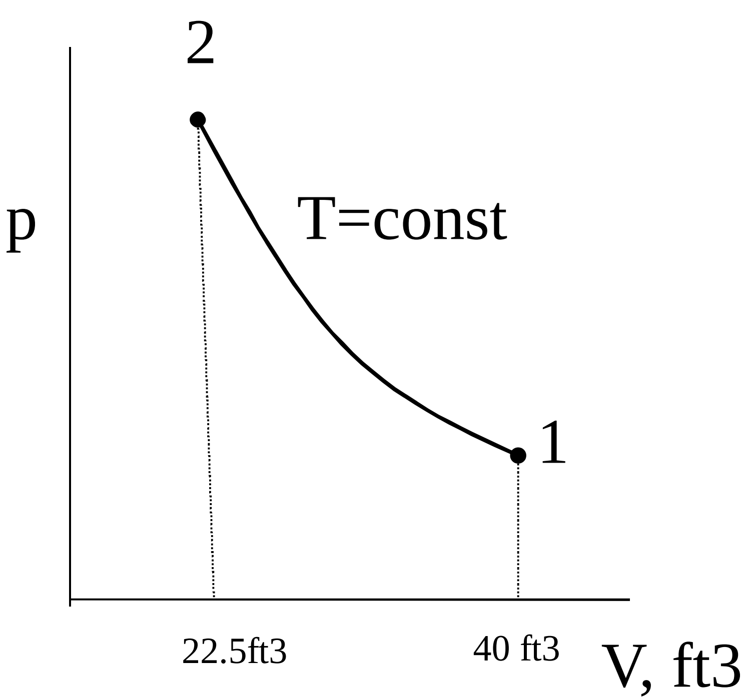
$$Q = m\,RT \ln\left(\frac{V_2}{V_1}\right) = m\,RT \ln\left(\frac{v_2}{v_1}\right)$$

$$Q = m\,RT \ln\left(\frac{v_2}{v_1}\right) = m\,RT \ln\left(\frac{p_1}{p_2}\right)$$

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

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

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?



$$Q = \Delta E + W$$

$$\Delta E = 0$$

$$Q = W$$

$$q = R\,T\ln\left(\frac{v_2}{v_1}\right) = R\,T\ln\left(\frac{V_2}{V_1}\right)$$

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

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

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

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

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 $pv = RT$

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

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

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

$$Q = \varphi E + W$$

$$q = \varphi u + w$$

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

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

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

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

ADIABATIC PROCESS, Q=0

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

$$q = \Delta u + w$$

$$0 = c_v dT + pdv$$

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

$$dT = \frac{1}{R}(vdv + pdp)$$

$$0 = \frac{c_v}{R} pdv + \frac{c_v}{R} vdv + pdv$$

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

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

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

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 $pv = RT$

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

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

$$q = \varphi u + w$$

$$w = \varphi u = \int c_v dT = c_v\left(T_2 - T_1\right)$$

$$w = c_v\left(\frac{p_2 v_2}{R} - \frac{p_2 v_2}{R}\right) = \frac{1}{k-1}\left(p_2 v_2 - p_1 v_1\right)$$

$$R = c_p - c_v$$

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

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

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

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

.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^{O}F and 14.7psia. What work is required? What is the final temperature and pressure?

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

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

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

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

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

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

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

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

$$Q = \varphi E + W$$

$$Q = 0$$

$$W = \varphi E$$

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

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

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

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 $pv^n = const.$	$n = 0$	$n = \infty$	$n = 1$	$n = n$
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	$c_p (T_2 - T_1)$	$c_v (T_2 - T_1)$	$p_1 v_1 \ln\left(\frac{v_2}{v_1}\right) = R_1 T_1 \ln\left(\frac{p_1}{p_2}\right)$	$c_p \left(\frac{k-n}{1-n}\right)(T_2 - T)$
w, work **w** $= \int pdv$ **energy/mass**	$p_1 (v_2 - v_2)$	**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