The same quantaties of energy at different state points are not equally useful.

Maximum ability to do work = thermodynamic property EXERGY

$W_{max} \Rightarrow$ reversible cycle, Carnot

$$d_{Carnot} = 1 - \frac{T_L}{T_H} = \frac{W_{max}}{Q}$$

$$W_{max} = Q\left(1 - \frac{T_L}{T_H}\right)$$

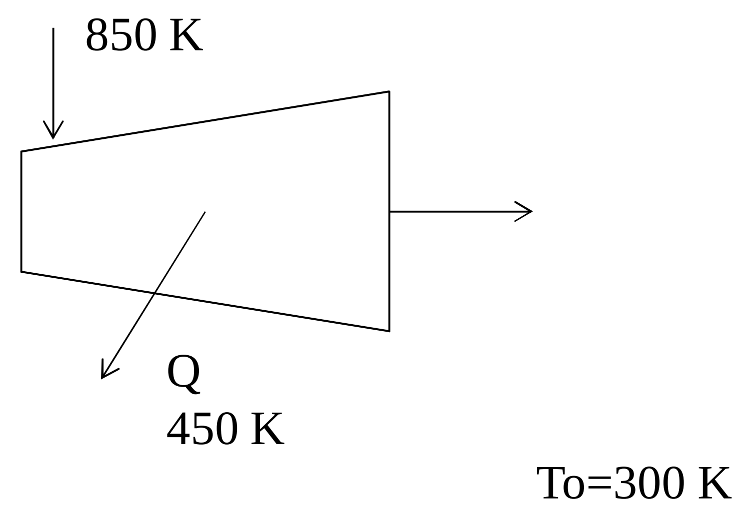
Q lost by convection from the casing of a turbine with an 850 K inlet and T_o (ambient) = 300 K

$$W_{max} = Q\left(1 - \frac{300}{450}\right) = .333Q$$

$$W_{max} = Q\left(1 - \frac{300}{850}\right) = .647Q$$

loss in ability to do work = loss in Exergy

$$\text{loss of Exergy} = W_{\underset{850K}{max}} - W_{\underset{450K}{max}} = .314Q$$



$$W_{\substack{max \\ 850K}} = \mathring{U}_{850K} = Q\left(1 - \frac{300}{850}\right) = .6247Q$$

$$W_{\substack{max \\ 850K}} = \mathring{U}_{850K} = Q\left(1 - \frac{300}{400}\right) = .25Q$$

$$(\mathring{U}_{850K} - \mathring{U}_{400K}) - W_{acttual} = \text{loss of Exergy}$$

need Exergy as a function of properties

for 0 losses, ideal cycle

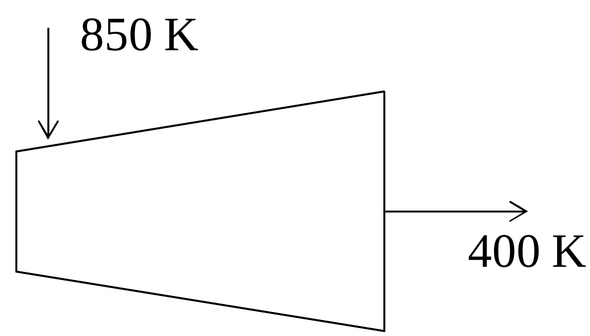
$$W_{\substack{max \\ 850K}} = \mathring{U}_{850K} = Q_H\left(\frac{Q_H - Q_o}{Q_H}\right)$$

$$\mathring{U}_{850K} = Q_H - Q_0$$

$$\mathring{U}_{850K} = mh_H - mh_o$$

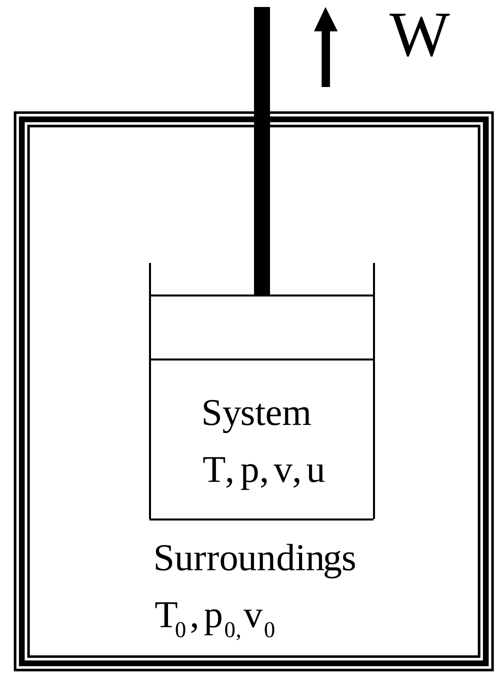
$$\mathring{U}_{850K} = m(h_H - h_o)$$

need ε for of non-ideal processes



To=300 K

EXERGY IN A CLOSED SYSTEM



Isolated systems, Q=0

EXERGY – maximum work available between a state point and $T_{0,} p_0$.

For two closed isolated systems, $Q = \varphi E + W = 0$

$W_{max} = \varphi E_{system} + \varphi E_{surroundings}$

assume $KE, PE = 0$

$W_{max} = \varphi U_{system} + \varphi U_{surroundings}$

$\varphi U_{surroundings} = U - U_0$

$TdS = dU + pdV$

$\varphi U_{system} = T_0 \varphi S - p_0 \varphi V$

$W_{max} = U - U_0 - T_0 \varphi S + p_0 \varphi V$

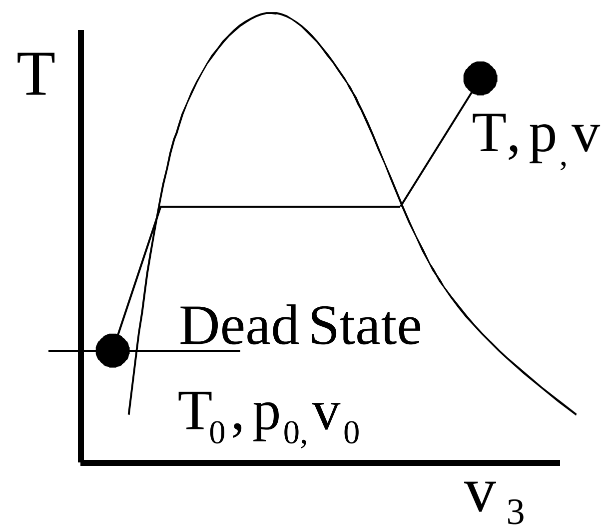
Total Exergy of an closed system

$E_x = W_{max} = U - U_0 - T_0 \varphi S + p_0 \varphi V$

Specific Exergy of an closed system

$e_x = (u - u_0) - T_0(s - s_0) + p_0(v - v_0)$ Equation 8-15

$e_{x1} - e_{x2} = (u_1 - u_2) - T_0(s_1 - s_2) + p_0(v_1 - v_0)$



EXERGY IN FLOW

An open system has the potential to do work equal to the work done displacing the fluid into the system.

$$W_{flow} = \int p\,dV = p_{absolute}\left(V_{initial} - \overset{0}{\cancel{V_{final}}}\right)$$

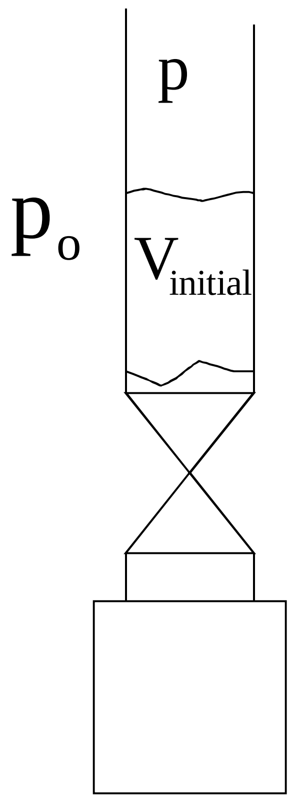
However some of this work was done in displacing the fluid from $p = 0$ to p_0.

The maximum work, the exergy of the flow, is then,

$$E_x = W_{flow} - \overset{0}{\cancel{W_{p_0 \to p}}}$$

$$E_x = m \times p(v - \overset{0}{\cancel{v_{final}}}) - m \times p_0(v - \overset{0}{\cancel{v_{final}}})$$

$$e_x = pv - p_0 v = v(p - p_0)$$



EXERGY IN AN OPEN SYSTEM

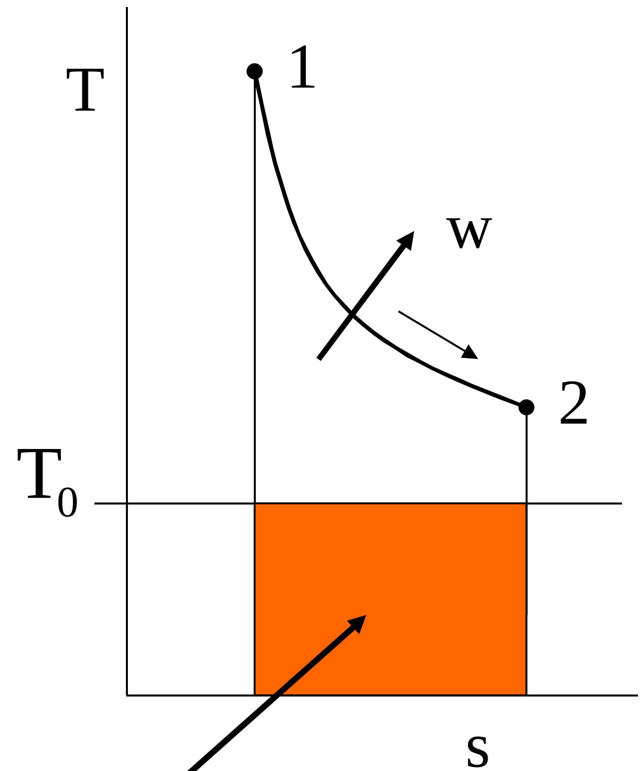
$$e_{x\ flow} = e_{x\ nonflow} + e_{x\ flow}$$

$$e_{x\ flow} = pv - p_0 v \qquad \text{Equation 8-20}$$

$$e_x = \left[(u - u_0) - T_0(s - s_0) + p_0(v - v_0)\right] + \left[v(p - p_0)\right]$$

$$e_x = \left[(u - u_0) - T_0(s - s_0) + p_0 v - p_0 v_0\right] + \left[vp - vp_0\right]$$

$$e_x = \left[\left((u + pv) - (u_0 + p_0 v_0)\right) - T_0(s - s_0)\right]$$



FLOW EXERGY

$$e_x = (h - h_0) - T_0(s - s_0) \qquad \text{Equation 8-22}$$

Availability Function, $A = H - TS$

$$w_{max} = \phi e_x = e_{x1} - e_{x2}$$

$$w_{max} = (h_1 - h_2) - T_0(s_1 - s_2)$$

$$w_{max} = w_{actual} - losses = \phi e_x$$

$$w_{actual} = (h_1 - h_2)$$

$$e_{x\ destroyed\ (unavailable)} = w_{max} - w_{actual}$$

$$e_{x\ destroyed\ (unavailable)} = (h_1 - h_2) - T_0(s_1 - s_2) - (h_1 - h_2)$$

$$e_{x\ destroyed\ (unavailable)} = T_0(s_1 - s_2)$$

EXERGY TRANSFER BY HEAT

$$e_{xheat} = \int \left(1 - \frac{T_o}{T}\right) dQ \qquad \text{Equation 8-25}$$

EXERGY IN AN OPEN SYSTEM

$$\mathring{U}\text{ exergetic efficiency,} = \frac{\text{Exergy Used}}{\text{Exergy Provided}}$$

$$\mathring{U}_{turbine} = \frac{W_{actual}}{W_{max}} = \frac{(h_1 - h_2)}{e_{x1} - e_{x2}} = \frac{(h_1 - h_2)}{(h_1 - T_0 s_1) - (h_2 - T_0 s_2)}$$

$$\mathring{U}_{turbine} = \frac{(h_1 - h_2)}{(h_1 - h_2) - T_0(s_1 - s_2)}$$ Equation 8.53

$$\mathring{U}_{compressor} \frac{W_{max}}{W_{actual}} = \frac{e_{x1} - e_{x2}}{(h_1 - h_2)} = \frac{(h_1 - h_2) - T_0(s_1 - s_2)}{(h_1 - h_2)}$$ Equation 8.54

$$\mathring{U}_{\substack{heat\\exchanger}} = \frac{\varphi E_{cold}}{\varphi E_{hot}} = \frac{m_{cold}(e_{cold\ 1} - e_{cold\ 2})}{m_{hot}(e_{hot\ 1} - e_{hot\ 2})}$$ Equation 8.55

$$\mathring{U}_{mixing} = \frac{\varphi E_{cold}}{\varphi E_{hot}} = \frac{m_{cold}(e_{out} - e_{coldin})}{m_{hot}(e_{out} - e_{hotin})}$$ Equation 8.56

Saturated water at 400 psi enters an insulated turbine operating at steady state. A two phase liquid ï vapor mixture leaves the turbine at 1 psi and a quality of .81. Determine a) the power developed and the rate of exergy destruction , b) the isentropic turbine efficiency and c) the turbine exergetic efficiency. T_O=70 F

Performance of the exapnsion process, Independent of T_o

$$\eta = \frac{w_{actual}}{w_{isentropic}} = \frac{h_1 - h_2}{h_1 - h_{1is}} = \frac{1205. - 808.64}{1205. - 778.14} = 92.9\%$$

$$e_{x1} = (h_1 - h_0) - T_0(s_1 - s_0) = (1205. - h_0) - T_0(1.4852 - s_0)$$

$$e_{x2} = (h_2 - h_0) - T_0(s_2 - s_0) = (908.64 - h_0) - T_0(1.6270 - s_0)$$

$$w_{max} = \Delta e_x = e_{x1} - e_{x2} = (h_1 - h_2) - T_0(s_1 - s_2)$$

$$w_{actual} = (h_1 - h_2)$$

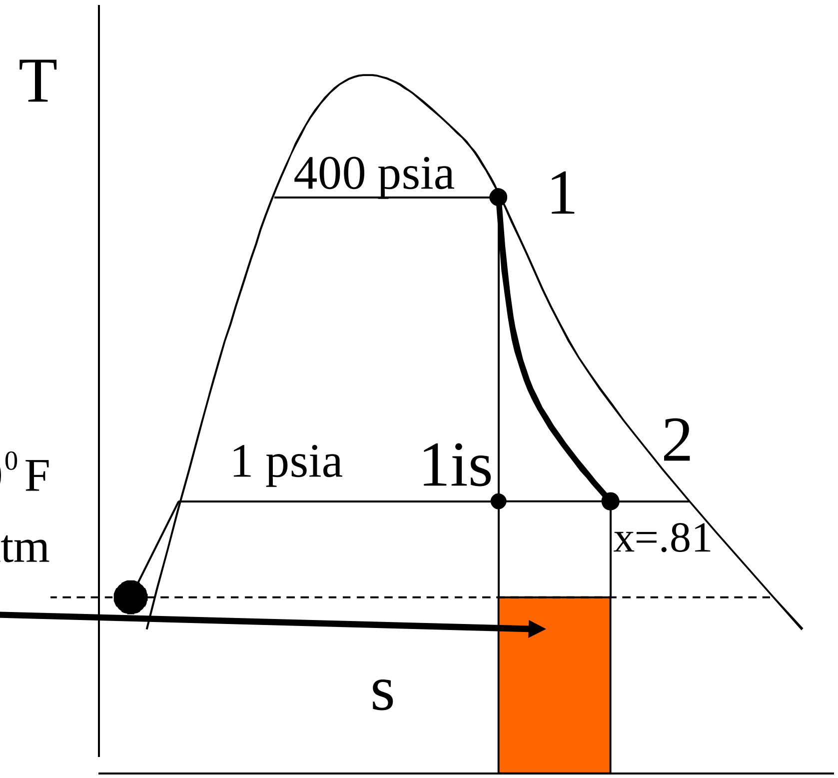
$$w_{max} = \Delta e_x = w_{actual} - T_0(s_1 - s_2)$$

$$e_{x\ lost} = -T_0(s_1 - s_2) = 520 \times (1.4852 - 1.6270)$$

$$e_{x\ lost} = 73.74 \text{ Btu/lb}$$

$T_0 = 60^0 F$

$p_0 = 1 \text{ atm}$



Exergetic Turbine Efficicney

use of energy available above, T_0, p_0

$$\varepsilon_{turbine} = \frac{w_{actual}}{\Delta e_x} = \frac{(h_1 - h_2)}{(h_1 - h_2) - T_0(s_1 - s_2)}$$

$$\varepsilon_{turbine} = \frac{(1205. - 908.64)}{(1205. - 908.64) - 520(1.4852 - 1.6270)}$$

$$\varepsilon_{turbine} = \frac{296.36}{296.37 + 73.74} = 80\%$$

For $T_0 = 30F$

$$\varepsilon_{turbine} = \frac{(1205. - 908.64)}{(1205. - 908.64) - 550(1.4852 - 1.6270)}$$

$$\varepsilon_{turbine} = \frac{296.36}{296.36 + 78} = 79.16\%$$

$$h_1 = h_g @ 400 \text{ psia} = 1205. \text{ Btu/lb}$$

$$s_{1is} = s_1 = s_g @ 400 \text{ psia} = 1.4852 \text{ Btu/lb}^o R$$

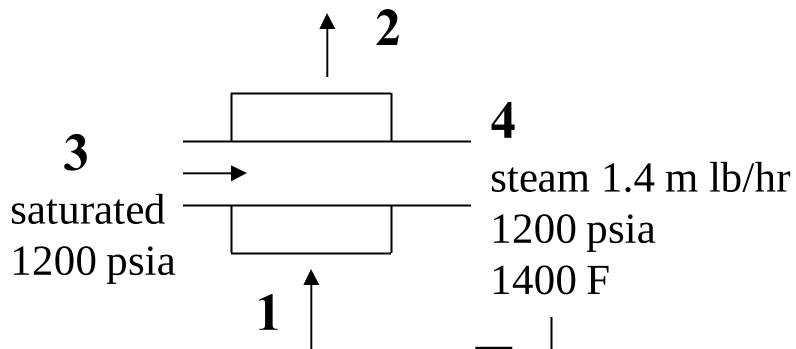
$$x_{is} = \frac{s_1 - s_f}{s_{fg}} = \frac{1.4852 - .13262}{1.9776} = .684$$

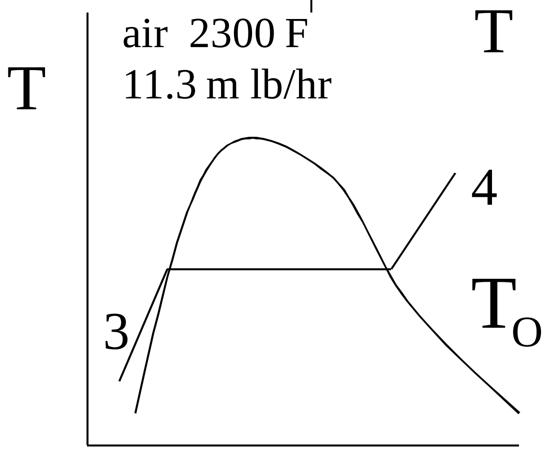
$$h_{1is} = 69.72 + .684 \times 1035.7 = 778.14 \text{ Btu/lb}$$

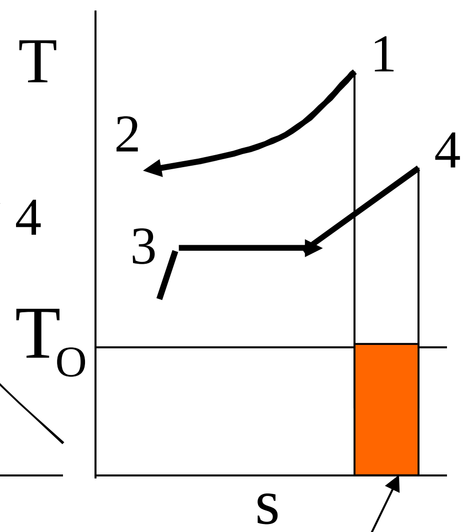
$$h_2 = 69.72 + .81 \times 1035.7 = 908.64 \text{ Btu/lb}$$

$$s_2 = .13262 + .81 \times 1.84495 = 1.6270 \text{ Btu/lb}^o R$$

A power plant boiler converts 1.4 million lb/hr saturated liquid water to superheated steam at 1250 psi and 1400 F. Combustion gasses enter the boiler at a rate of 11.3 million lb/hr and 2300 F. Assume the combustion gasses can be modeled as air as an ideal gas. Determine a) the exit temperature of the combustion gasses, b) the rate of exergy destruction in the heat transfer process and c) the exergetic efficiency of the process.







$h_3 = h_f @ 1000\ \text{psia} = 542.57\ \text{Btu/lb}$

$s_3 = s_f @ 1000\ \text{psia} = .74341\ \text{Btu/lb}^o\text{R}$

$h_4 = h@(T = 1400\ \text{F}, 100\ 0\text{psia})$

$h_4 = 1736.7\ \text{Btu/lb}$

$s_4 = s@(T = 1400\ \text{F}, 1000\ \text{psia})$

$s_4 = 1.7911\ \text{BTU/lb}$

$T_4 = 2300 + 460 = 2760^o\ \text{R}$

by interpolation @ T_1, Table A-17E

$h_1 = 719.28\ \text{Btu/lb}$

$s_1^o = 1.022963\ \text{Btu/lb}^o\text{R}$

by interpolation @ h_2, Table A-17E

$T_2 = 2238.15^o\ \text{R}$

$s_2 = .96363\ \text{Btu/lb}^o\text{R}$

a) $Q_{gas} = Q_{steam} = m_{steam} \$ (h_4 - h_3)$

$= 1.4 \times 10^6 \times (1736.7 - 542.57)$

$Q_{gas} = 1671.78 \times 10^6\ \text{Btu/hr}$

$$h_2 = h_1 - \frac{Q}{m_{gas}} = 719.28 - \frac{1671.78 \times 10^6}{11.3 \times 10^6} = 571.35\ \text{Btu/lb}$$

b) $E_{x\ destroyed} = -m_{gas} T_o (s_1 - s_2) - m_{steam} T_o (s_3 - s_4)$

$E_{x\ destroyed} = -11.3 \times 10^6 \times 530 \times (1.022963 - .96363)$

$-1.4 \times 10^6 \times 530 \times (.73431 - 1.7911)$

$E_{x\ destroyed} = -355.35 \times 10^6 + 784.14 \times 10^6$

$E_{x\ destroyed} = 428.79 \times 10^6\ \text{Btu/hr}$

c) exergetic efficiency

$$\mathring{U}_{\substack{heat\\exchanger}} = \frac{\varphi E_{cold}}{\varphi E_{hot}} = \frac{m_{steam}(e_{x4} - e_{x3})}{m_{gas}(e_{x1} - e_{x2})}$$

$$\mathring{U}_{\substack{heat\\exchanger}} = \frac{m_{steam}[(h_4 - h_3) - T_0(s_4 - s_3)]}{m_{gas}[(h_1 - h_2) - T_0(s_1 - s_2)]}$$

$$\mathring{U}_{\substack{heat\\exchanger}} = \frac{1.4 \times 10^6 \times [(1736.7 - 542.57) - 530 \times (.73431 - 1.7911)}{11.3 \times 10^6 \times [(719.28 - 577.1) - 530 \times (1.022963 - .96363)}$$

$$\mathring{U}_{\substack{heat\\exchanger}} = 70.94\%$$

EQUATION SUMMARY

Exergy at a Closed System state point

$$e_x = (u - u_0) - T_0(s - s_0) + p_0(v - v_0) \quad \text{Equation 8-15}$$

Exergy at an Open System state point

$$e_x = (h - h_0) - T_0(s - s_0) \quad \text{Equation 8-22}$$

Exergy Destroyed

$$e_{x\,destroyed} = T_0(s_2 - s_1)$$

$$\text{Ů, exergetic efficiency,} = \frac{\text{Exergy Used}}{\text{Exergy Provided}}$$

$$Ů_{turbine} = \frac{W_{actual}}{W_{max}} = \frac{(h_1 - h_2)}{e_{x1} - e_{x2}} = \frac{(h_1 - h_2)}{(h_1 - T_0 s_1) - (h_2 - T_0 s_2)} = \frac{(h_1 - h_2)}{(h_1 - h_2) + T_0(s_1 - s_2)} \quad \text{Equation 8-53}$$

$$Ů_{compressor} \frac{W_{max}}{W_{actual}} = \frac{e_{x1} - e_{x2}}{(h_1 - h_2)} = \frac{(h_1 - h_2) - T_0(s_1 - s_2)}{(h_1 - h_2)} \quad \text{Equation 8-54}$$

$$Ů_{heat\ exchanger} = \frac{φE_{cold}}{φE_{hot}} = \frac{m_{cold}(e_{cold\,1} - e_{cold\,2})}{m_{hot}(e_{hot1} - e_{hot\,2})} \quad \text{Equation 8-55}$$

$$Ů_{mixing} = \frac{φE_{cold}}{φE_{hot}} = \frac{m_{cold}(e_{out} - e_{coldin})}{m_{hot}(e_{out} - e_{hotin})} \quad \text{Equation 8-56}$$