Steady-Flow Energy Analysis of Thermodynamic Devices

1. Nozzles and Diffusers - used to accelerate or decelerate flow

nozzle: \( A_2 << A_1, V_2 >> V_1 \)
diffuser: \( A_2 >> A_1, V_2 << V_1 \)

Typical assumptions:

a) \( \dot{m}_1 = \dot{m}_2 = \dot{m} \) or \( \frac{V_{A_1}}{V_1} = \frac{V_{A_2}}{V_2} \)

b) \( \Delta PE = 0 \)

c) \( W = 0 \)

d) \( \dot{Q} = 0 \) (some exceptions)

Energy equation:

\[ h_2 - h_1 = \frac{1}{2} (V_1^2 - V_2^2) \]

2. Turbines - used to produce rotating shaft power

Typical assumptions:

a) \( \dot{m}_1 = \dot{m}_2 = \dot{m} \)

b) \( \Delta PE = 0 \)

c) \( W > 0 \)

d) \( \dot{Q} = 0 \) (some exceptions)

Energy equation:

\[ W = m \left[ h_1 - h_2 + \frac{1}{2} (V_1^2 - V_2^2) \right] \]
3. Compressors - used to increase the pressure of a gas

![Compressor diagram]

Typical assumptions:  
   a) $\dot{m}_1 = \dot{m}_2 = \dot{m}$  
   b) $\Delta PE = 0$  
   c) $\dot{W} < 0$  
   d) $\Delta KE = 0$ (some exceptions)

Energy equation:  
\[ \dot{Q} - \dot{W} = \dot{m}(h_2 - h_1) \]

4. **Pumps** - used to increase the pressure of a liquid

![Pump diagram]

Typical assumptions:  
   a) $\dot{m}_1 = \dot{m}_2 = \dot{m}$  
   b) $\dot{Q} = 0$  
   c) $\dot{W} < 0$  
   d) $\Delta PE = 0$ (if piping is not considered)  
   e) fluid is incompressible ($v$=constant)

Energy equation:  
\[ -\dot{W} = \dot{m}\left[h_2 - h_1 + \frac{1}{2}(V_2^2 - V_1^2)\right] \]

where $h_2 - h_1 = c_m(T_2 - T_1) + v(P_2 - P_1)$

5. **Throttling** (Expansion) Valves used to cause a significant decrease in fluid pressure by flow restriction

![Throttling valve diagram]

Throttling valve

Typical assumptions:  
   a) $\dot{m}_1 = \dot{m}_2 = \dot{m}$  
   b) $\Delta PE = 0$  
   c) $\Delta KE = 0$  
   d) $\dot{W} = 0$  
   e) $\dot{Q} = 0$

Energy equation:  
\[ h_1 = h_2 \quad \text{(isenthalpic device)} \]

or  
\[ u_1 + P_1 v_1 = u_2 + P_2 v_2 \]

Note: for ideal gases, $h = h(T)$, thus temperature must remain constant
6. **Mixing Chambers** - used to mix at least two fluid inlet streams, usually for the purpose of heat exchange (also called direct-contact heat exchangers)

![Mixing Chamber Diagram]

Typical assumptions:
- a) \( \dot{m}_1 + \dot{m}_2 = \dot{m}_3 \)
- b) \( \Delta P = 0 \)
- c) \( \Delta KE = 0 \)
- d) \( W = 0 \)
- d) \( Q = 0 \) (if well-insulated)

Energy equation:
\[
\dot{m}_1 h_1 + \dot{m}_2 h_2 = (\dot{m}_1 + \dot{m}_2) h_3
\]

7. **Heat Exchangers** - used to promote heat transfer between two fluid streams without mixing (e.g., boilers, combustors, condensers, evaporators, regenerators, recuperators)

![Heat Exchanger Diagram]

Typical assumptions:
- a) \( \dot{m}_{A1} = \dot{m}_{A2} = \dot{m}_A \)
- b) \( \dot{m}_{B1} = \dot{m}_{B2} = \dot{m}_B \)
- c) \( \Delta P = 0 \)
- d) \( \Delta KE = 0 \)
- d) \( W = 0 \)
- d) \( Q = 0 \) (if well-insulated)

Energy equation:
\[
\dot{m}_A (h_{A1} - h_{A2}) = \dot{m}_B (h_{B2} - h_{B1})
\]

Note: if CV is chosen to be one of the fluid streams, then heat transfer term remains and energy equation is \( Q = \dot{m}(h_2 - h_1) \)

8. **Pipes and Ducts** - used to convey fluids, often with significant elevation change

![Pipe and Duct Diagram]

Typical assumptions:
- a) \( \dot{m}_1 = \dot{m}_2 = \dot{m} \)
- b) \( Q = 0 \) (if well-insulated)

Energy equation:
\[
-\dot{W} = \dot{m} \left[ h_2 - h_1 + \frac{1}{2} (V_2^2 - V_1^2) + g(z_2 - z_1) \right]
\]

Note: \( \dot{W} \) term will be zero if no pumps, fans, etc. exist within CV