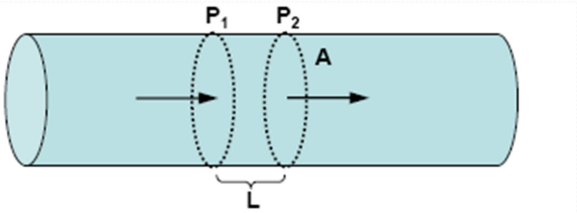
Open System

For open systems, two types of work involved

Shaft work , W_s..... Work done by a moving part of a system

Flow works , W_{fl} (PV) ..... Work done to put a mass of substance into/outside of system boundary

Consider pipe full of flowing fluid (flow due to ΔP where $\Delta P = P_1 - P_2$):



Consider volume defined by dashed lines "system", where V = A·L

$$W_1 = \int_0^l F \cdot dl = \int_0^L (PA) \cdot dl = \int_{V_{L=0}}^{V} P_1 \cdot dV$$

$$\therefore W_1 = P_1 V; \quad W_2 = -P_2 V$$

$$W = P_1 V - P_2 V$$

where P_1V_1 is work done on system while P_2V_2 is work done by system on surroundings

$$\dot{W}_{fl} = P_{out}\dot{V}_{out} - P_{in}\dot{V}_{in} .....(N/m^2)(m^3/s)$$

7.4b Specific properties and Enthalpy

Total Energy of a flowing fluid (open system)

$$\Delta U + \Delta KE + \Delta PE = \dot{Q} - \dot{W}$$

$$\Delta U + \Delta KE + \Delta PE = \dot{Q} - (\dot{W}_{fl} + \dot{W}_s)$$

$$\dot{W}_{fl} = P_{out}\dot{V}_{out} - P_{in}\dot{V}_{in}$$

The fluid possesses an additional form of energy –the flow energy (flow work)

Shaft work

$$\Delta H + KE + PE = \dot{Q} - \dot{W}_s$$

$$\Delta H = \Delta U + \Delta(P\dot{V}) ..... \text{ Enthalpy (Joule, cal ..)}$$

$$\hat{H} = \hat{U} + P\hat{V} ..... \text{ Specific Enthalpy } (J/kg, cal/kg...)$$

7.4c Energy balance on an open system at steady state

Input - Output = Accumulation

$$\dot{Q} + \sum \dot{m}_{in}\left(\hat{H}_{in} + \frac{\hat{V}_{in}^2}{2} + gz_{in}\right) - \dot{W}_s - \sum \dot{m}_{out}\left(\hat{H}_{out} + \frac{\hat{V}_{out}^2}{2} + gz_{out}\right) = \frac{\partial E_{cv}}{\partial t}$$

The flow work is included in the enthalpy term

This work represents everything but the flow work

$$\sum \dot{m}_{in} = \sum \dot{m}_{out}$$

$$\frac{\partial E_{cv}}{\partial t} = 0$$

$$\dot{Q} + \sum \dot{m}_{in}\left(\hat{H}_{in} + \frac{\hat{V}_{in}^2}{2} + gz_{in}\right) - \dot{W}_s - \sum \dot{m}_{out}\left(\hat{H}_{out} + \frac{\hat{V}_{out}^2}{2} + gz_{out}\right) = 0$$

$$\sum \dot{m}_{out}\left(\hat{H}_{out} + \frac{\hat{V}_{out}^2}{2} + gz_{out}\right) - \sum \dot{m}_{in}\left(\hat{H}_{in} + \frac{\hat{V}_{in}^2}{2} + gz_{in}\right) = \dot{Q} - \dot{W}_s$$

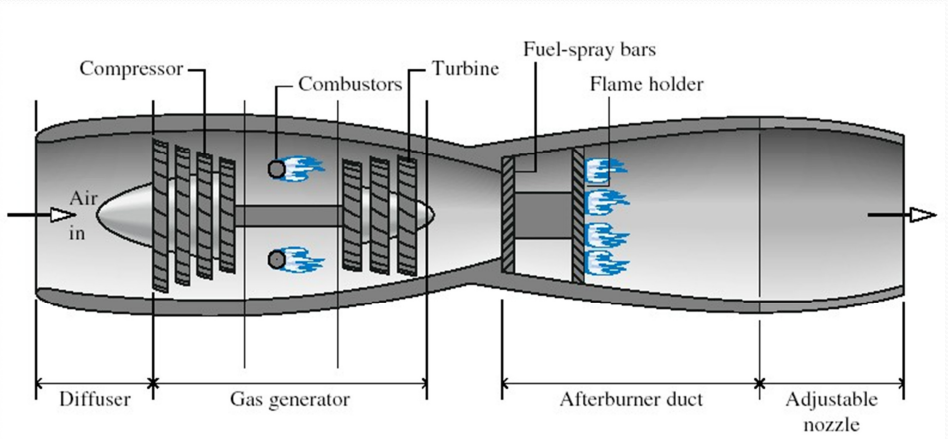
$$\Delta\dot{E} = \Delta\dot{H} + \Delta\dot{K}E + \Delta\dot{P}E = \dot{Q} - \dot{W}_S$$

- Is it adiabatic? (if yes, $Q = 0$)
- Are there moving parts, e.g. pump, compressor, turbine ? (if no, $W_s = 0$)
- Does the average velocity of the fluid change between the input and the output ? (if no, ΔKE = 0)
- Is there a change in elevation of the system between the input and the output? ? (if no, ΔPE = 0)
- Does temperature, phase, chemical composition or pressure change? (if NO to all, $\Delta H = 0$)

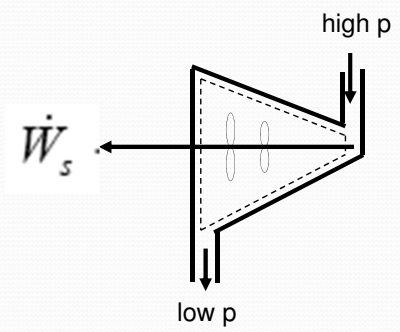
$$\dot{Q} - \dot{W}_s = \dot{m}\left[\hat{H}_{out} - \hat{H}_{in} + \frac{V_{out}^2 - V_{in}^2}{2} + g\left(z_{out} - z_{in}\right)\right]$$

- Nozzles
- Diffusers
- Turbines
- Compressors
- Throttling Valve

Often the change in kinetic energy of the fluid is small, and the change in potential energy of the fluid is small

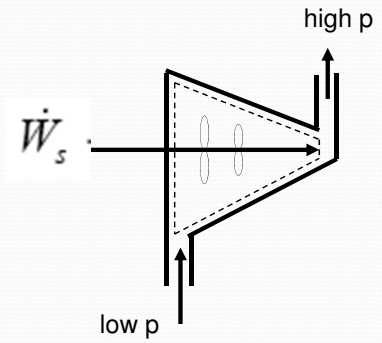


Turbines and Compressors



turbine

A turbine is a device that **produces work** at the expense of temperature and pressure



compressor

A compressor is a device that increases the pressure of a fluid by **adding work** to the system

$$\dot{Q}-\dot{W}_s=\dot{m}\left[\hat{H}_{out}-\hat{H}_{in}+\frac{\vec{V}_{out}^2-\vec{V}_{in}^2}{2}+g\left(z_{out}-z_{in}\right)\right]$$

Is there work in this system? **Yes!**

Is there heat transfer? **Usually it can be ignored**

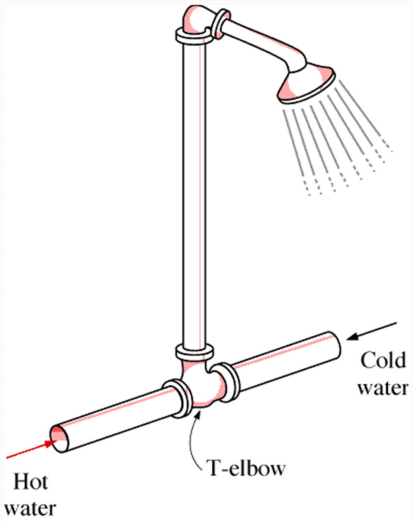
Does the fluid change elevation? **Usually it can be ignored**

Does the kinetic energy change? **Usually it can be ignored**

$$-W_s=\dot{m}\left(\hat{H}_{out}-\hat{H}_{in}\right)$$

enthalpy is converted into work

Mixing Chamber



Mixing two or more fluids is a common engineering process

Mixing Chamber

$$\sum\dot{m}_{out}\left(\hat{H}_{out}+\frac{\hat{V}_{out}^2}{2}+gz_{out}\right)-\sum\dot{m}_{in}\left(\hat{H}_{in}+\frac{\hat{V}_{in}^2}{2}+gz_{in}\right)=\dot{Q}-\dot{W}_s$$

We no longer have only one inlet and one exit stream

Is there any work done? No

Is there any heat transferred? No

Is there a velocity change? No

Is there an elevation change? No

$$0=\sum\dot{m}_{out}\hat{H}_{out}-\sum\dot{m}_{in}\hat{H}_{in}$$

$$\sum\dot{m}_{out}=\sum\dot{m}_{in}$$

PROPERTY

- MEASURED
- CALCULATED BY COMBINATION OF OTHER PROPERTIES
- DEFINED (USING THERMODYNAMICS LAWS eg Enthalpy, Entropy)

PROPERTY

EXTENSIVES — it depends on the mass

INTENSIVES — it does not depend on the mass

EXTENSIVE: The value for the whole system is the sum of its values for the various subsystems or parts

INTENSIVE: Values are independent of the size or the amount of mass of the system

STATE OF A SYSTEM

STATE OF A SYSTEM IS THE CONDITION OF THE SYSTEM DESCRIBED BY THE VALUE OF ITS PROPERTIES

NOTE: PROPERTIES (e.g volume, energy, pressure) OF A SYSTEM ARE DEFINED **ONLY** WHEN **A SYSTEM IS IN EQUIBRILIUM**

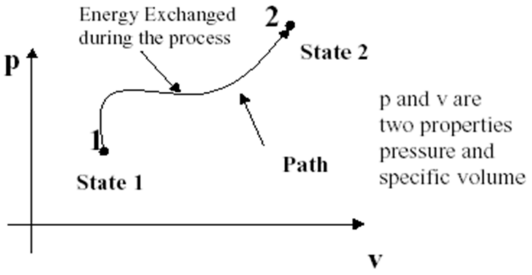
- THERMODYNAMIC EQUILIBRIUM
- THERMAL EQUILIBRIUM
- MECHANICAL EQUILIBRIUM
- PHASE EQUILIBRIUM

PROCESS

IT IS A CHANGE OF A SYSTEM FROM ONE EQUILIBRIUM STATE TO ANOTHER

PATH

SPECIFIC SERIES OF STATES THROUGH WHICH THE SYSTEM PASSES



PROCESS DESCRIPTION

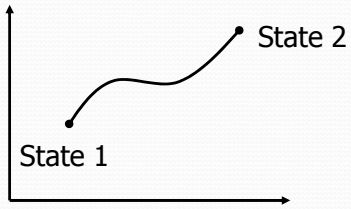
- INITIAL AND FINAL STATES OF THE PROCESS
- PATH
- INTERACTIONS TAKING PLACE ACROSS THE SYSTEM BOUNDARIES ALONG THE PROCESS

TYPES OF PROCESSES

- ISOTHERMAL (CONSTANT TEMPERATURE)
- ISOBARIC (CONSTANT PRESSURE)
- ISOCHORIC (CONSTANT VOLUME)
- OTHER (ISOENTHALPIC, ISOENTROPIC, ETC)

- **State property** – a property of a system component whose value depends only on the state of the system (i.e. temperature, pressure, phase and composition)… e.g. internal energy (U) and hence, enthalpy (H)
- It is impossible to measure the absolute value of state property … but can estimate the change in specific value of U (i.e $\Delta\hat{U}$) or H (i.e $\Delta\hat{H}$) corresponding to a specified change of state (i.e. temperature, pressure, phase and composition)
- **Reference state** - specified state (i.e. temperature, pressure or state of aggregation) assigned to measure relative changes in $\hat{U}$ or $\hat{H}$… *thus, the value of $\hat{U}$ or $\hat{H}$ of a certain material at a specified state (T,P or phase) is relative to the value of $\hat{U}$ or $\hat{H}$ of the same material at other specified state (T,P or phase)*

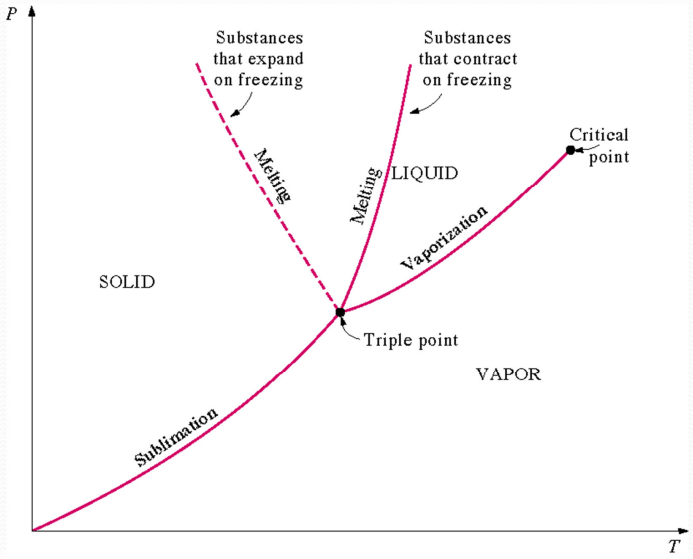
- change in specific value of U (i.e $\Delta\hat{U}$) or H (i.e $\Delta\hat{H}$) for the transition from one tabulated state to other, i.e state 1 → state 2



As internal energy & enthalpy are state property, reference state is not required…. Just determine the specific value at state 1 and state 2, and calculate the difference, i.e.

$$\Delta\hat{U} = \hat{U}_2 - \hat{U}_1$$
$$\Delta\hat{H} = \hat{H}_2 - \hat{H}_1$$

Recall …. Thermodynamics



P – pressure

T - temperature

v – specific volume

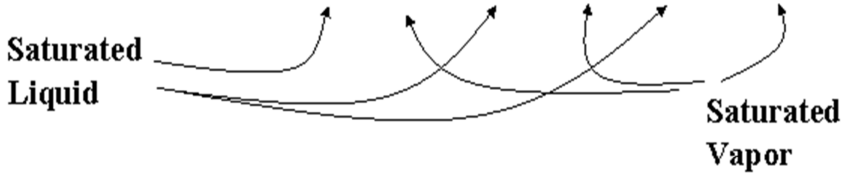
u – specific internal energy

h – specific enthalpy h = u + Pv

s – specific entropy

SATURATION TABLES

Temperature °C	Pressure Bars	Specific Volume		Enthalpy		Entropy	
		$v_f \times 10^3$	v_g	h_f	h_g	s_f	s_g
20	0.0239	1.0018	57.791	83.96	2538.1	0.2966	8.6672
40	0.07384	1.0078	19.253	167.57	2574.3	0.5725	8.2570
60	0.1994	1.0172	7.671	251.13	2609.6	0.8312	7.9096
80	0.4739	1.0291	3.407	334.91	2643.7	1.0753	7.6122
100	1.014	1.0435	1.673	419.04	2676.1	1.3069	7.3540



$$h = u + pv \quad or \quad u = h - pv$$

$$x = \frac{v_x - v_f}{v_g - v_f} = \frac{u_x - u_f}{u_g - u_f} = \frac{h_x - h_f}{h_g - h_f} = \frac{s_x - s_f}{s_g - s_f}$$

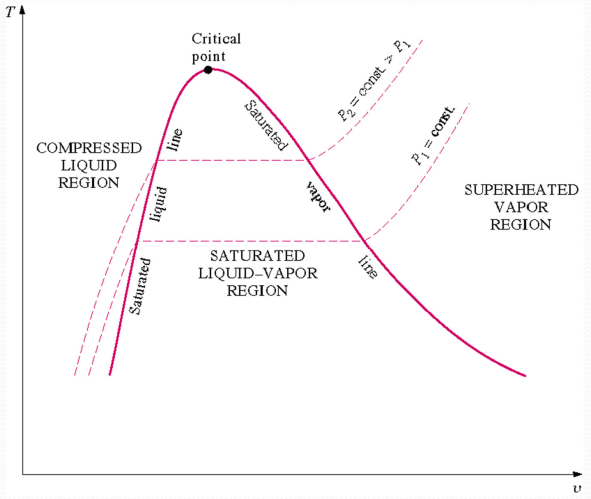
$$u_x = (1-x)u_f + x u_g$$

$$h_x = (1-x)h_f + x h_g$$

$$s_x = (1-x)s_f + x s_g$$

Calculated from Saturation Tables at given Pressure or Temperatures

Superheated Properties



T, °C	v, m³/kg	u, kJ/kg	h, kJ/kg
	P = 0.1 MPa (99.63°C)		
Sat.	1.6940	2506.1	2675.5
100	1.6958	2506.7	2676.2
150	1.9364	2582.8	2776.4
⋮	⋮	⋮	⋮
1300	7.260	4683.5	5409.5
	P = 0.5 MPa (151.86°C)		
Sat.	0.3749	2561.2	2748.7
200	0.4249	2642.9	2855.4
250	0.4744	2723.5	2960.7

7.6 Energy Balance Calculation Procedures

1. Select a suitable control volume for analysis, and sketch the system, indicating appropriate boundaries
2. Determining what energy interaction are important, and recognize the sign conventions on such terms
3. State the basis of calculation
4. Start with the basic 1st law (energy balance) for the chosen system. State a reference point for each type of energy term involved.
5. Obtain physical date for the substance under study. Is an equation of state applicable, or must graphical and/or tabular data be employed? What are other property relations for the substance?

5. Determine the path of the process between the initial and final states and indicate it in a diagram. Is the process isothermal, isobaric, quasistatic, adiabatic, etc.?
6. What other idealizations or assumptions are necessary to complete the solution? Are kinetic and potential energies negligible, etc.?
7. Draw a suitable diagram for the process, as an aid in picturing the overall problem.
8. Complete the solution for the required item(s) on the basis of the information supplied

*Note: * check the units in each equation used!!!*