

(1.1)

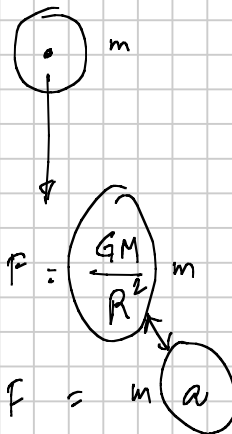
Free body diagram

$$F = G \frac{mM}{R^2} = \left(\frac{GM}{R^2} \right) m$$

$$F = \underset{\substack{\text{with} \\ \text{kg}}}{mg} \downarrow \underset{\substack{\text{m} \\ \text{s}^2}}{[9.81]} [N]$$

$$F = \frac{mg}{1000} [kN]$$

$$F = \left(\frac{GM}{R^2} \right) m \downarrow g$$



Therefore, $\frac{GM}{R^2}$ must be the accel of free fall.

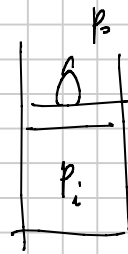
$$g = \frac{GM}{R^2} = 9.81 \frac{m}{s^2}$$

Benchmark for force : 1 kN is the weight of a 100 kg person on earth.

$$p_0 = 101 \text{ kPa} \approx 100 \text{ kPa} \left[\frac{kN}{m^2} \right]$$

$$P_i A = P_0 A + \frac{mg}{1000}$$

$\underbrace{\text{KN} \cdot \text{m}^2}_{= \text{KN}} \quad \underbrace{\text{KN}} \quad \underbrace{\text{KN}}$

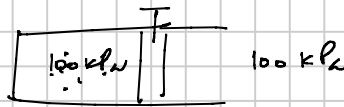


$$P_i = P_0 + \frac{mg}{1000 A}$$

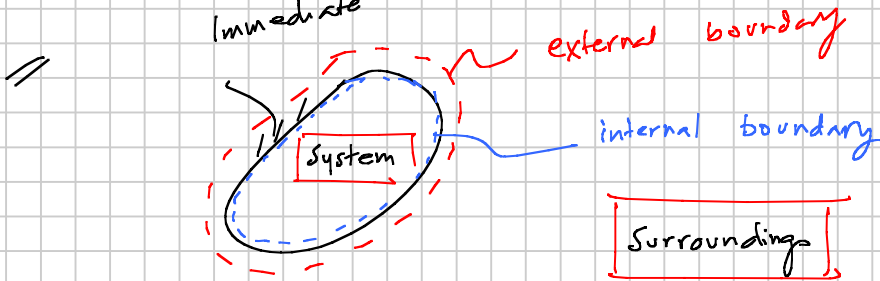
$\underbrace{100 \text{ kPa}} \quad \underbrace{\text{kg}} \quad \underbrace{10 \frac{\text{m}}{\text{s}^2}} \quad \underbrace{\text{m}^2}$

// (1.2)

subrata @ thermo.sdsu.edu

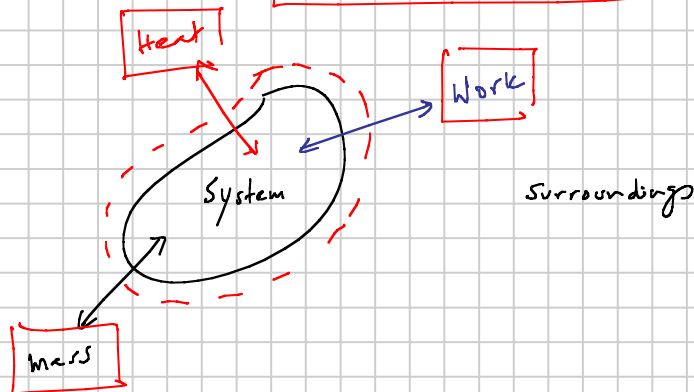


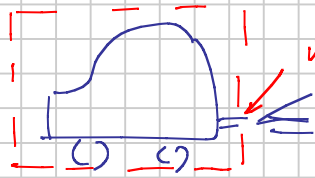
Immediate surroundings



System + Immediate Surroundings

= System's Universe.

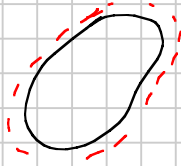




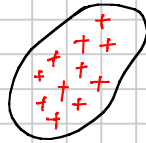
What interaction is this?

Obvious answer should be Mars

Mars Transfer :



Mars m [kg]



Mole n [kmol]

A pure Substance means composition

does not change from place to place.

$$\frac{m}{n} \left[\frac{\text{kg}}{\text{kmol}} \right] \text{ must}$$

be a constant for a pure substance.

A simple system is made of a pure substance.

Molar mass is mass in kg per Dozen aka kmol of a pure substance.

$$\bar{M} = \frac{m}{n} \left[\frac{\text{kg}}{\text{kmol}} \right]$$

$$\Rightarrow n = \frac{m}{\bar{M}}$$

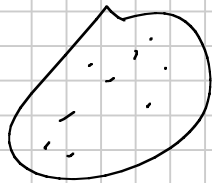
$$\bar{M}_{H_2} = 2 \frac{\text{kg}}{\text{kmol}}$$

$$\bar{M}_{O_2} = 32 \frac{\text{kg}}{\text{kmol}}$$

$$\bar{M}_{N_2} = 28 \frac{\text{kg}}{\text{kmol}}$$

$$\bar{M}_{CO_2} = 44 \frac{\text{kg}}{\text{kmol}}$$

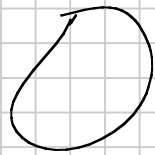
$$\bar{M}_{Ar} = 39 \frac{\text{kg}}{\text{kmol}}$$



$$\left. \begin{matrix} m \\ \text{kg} \\ \text{m}^3 \end{matrix} \right\} \rho = \frac{m}{V} \left[\frac{\text{kg}}{\text{m}^3} \right]$$

$$\underbrace{V}_{\text{specific volume}} = \frac{V}{m} \left[\frac{\text{m}^3}{\text{kg}} \right] = \frac{1}{\rho}$$

m, n, p, v, \bar{M}



Volume = $V \text{ m}^3$
 mole $n \text{ kmol}$
 mass $m \text{ kg}$

$$v = \frac{V}{m} \left[\frac{\text{m}^3}{\text{kg}} \right]$$

$$\bar{v} = \frac{V}{n} \left[\frac{\text{m}^3}{\text{kmol}} \right]$$

$$\bar{v} = \frac{V}{n} = \frac{V}{(m/\bar{M})}$$

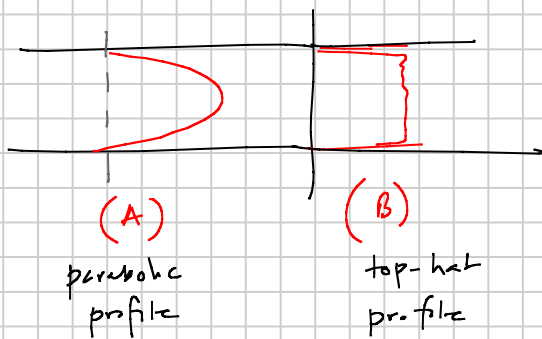
$$= \frac{V \bar{M}}{m} = \bar{M} v$$

$\therefore \boxed{\bar{v} = \bar{M} v}$ [Advanced concept]

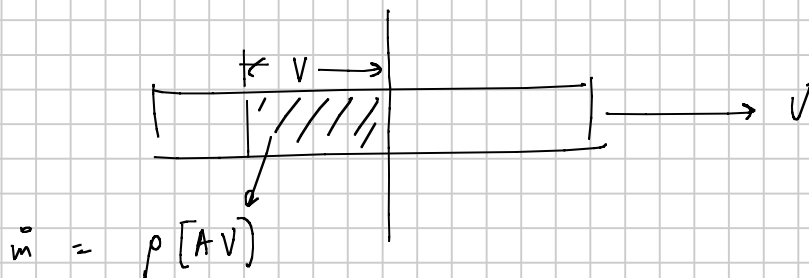
== Pipes & tubes & ducts carry mass

$$\dot{m} = \rho A V$$

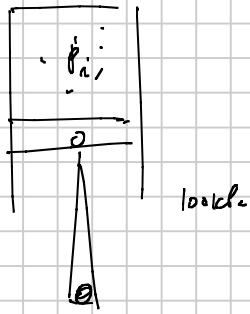
\swarrow \searrow \searrow
 $\frac{\text{kg}}{\text{m}^3}$ m^2 $\frac{\text{m}}{\text{s}}$



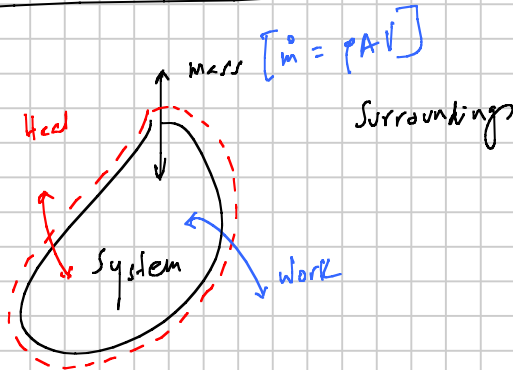
== $\dot{m} = \rho A V$ [benchmark]



2.1



Energy, Heat & Work



$$KE \equiv \frac{mv^2}{2000} \quad [kJ]$$

$$ke \equiv \frac{KE}{m} = \frac{v^2}{2000}$$

$$PE \equiv \frac{mgh}{1000} \quad [kJ]$$

$$pe \equiv \frac{PE}{m} = \frac{gh}{1000}$$

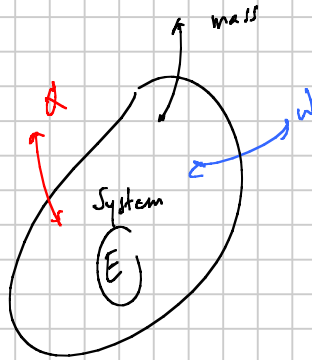
$$\left[\frac{kJ}{kg} \right]$$

$$\begin{array}{l}
 [kJ] \quad E = \underbrace{KE + PE}_{\text{Mechanical energy}} + \underbrace{U}_{\text{Internal energy disorganized energy of molecules.}} \\
 \text{Stored energy} \qquad \qquad \qquad \underbrace{\hspace{10em}}_{\text{Macroscopic energy}} \qquad \qquad \underbrace{\hspace{10em}}_{\text{microscopic energy}} \\
 \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \qquad \underbrace{\hspace{10em}}_{\text{KE \& PE of molecules}}
 \end{array}$$

KE \rightarrow mass, velocity²

PE \rightarrow mass, g , height

U \rightarrow Temperature, phase change, ...

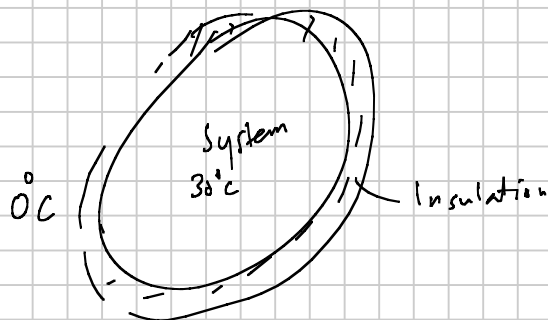


Heat & Work are energy in transit.

Heat $\hat{=}$ Q [kJ], \dot{Q} [$\frac{\text{kJ}}{\text{s}} = \text{kW}$]

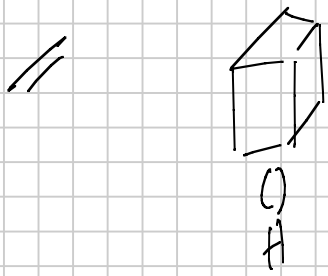
Heat transfer is driven by temp. difference.

Q depends on ΔT , insulation, area of contact, time of exposure.



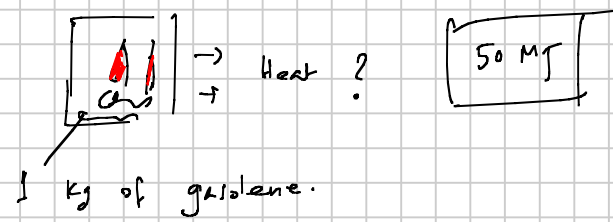
A system is called a diathermic when

Q can be assumed to be zero.



How much heat do you need to raise temp. of a system by 1°C ?

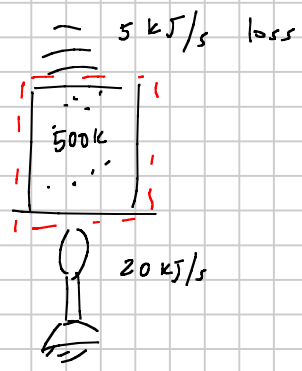
If you burn 1 kg of gasoline how much heat is released?



3.1

What is \dot{Q} ?

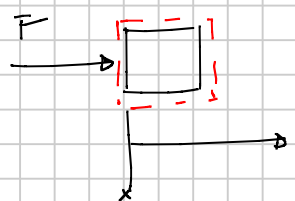
Please understand the connection between sign and phrases such as "heat in", "heat loss", "heat rejected", etc.



Work W , \dot{W} [kJ, $\frac{\text{kJ}}{\text{s}} = \text{kW}$]

Work coming out of a system is positive.

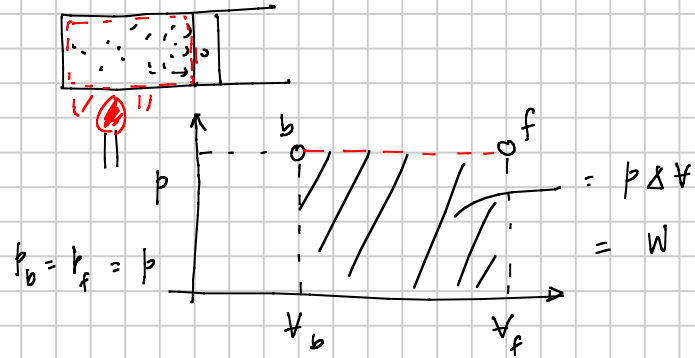
"WIN HIP"



$$W = \underbrace{F}_{\text{kN}} \cdot \underbrace{\Delta x}_{\text{m}} = \text{kJ}$$

The system gains E (of KE to be precise) as work is transferred into the system

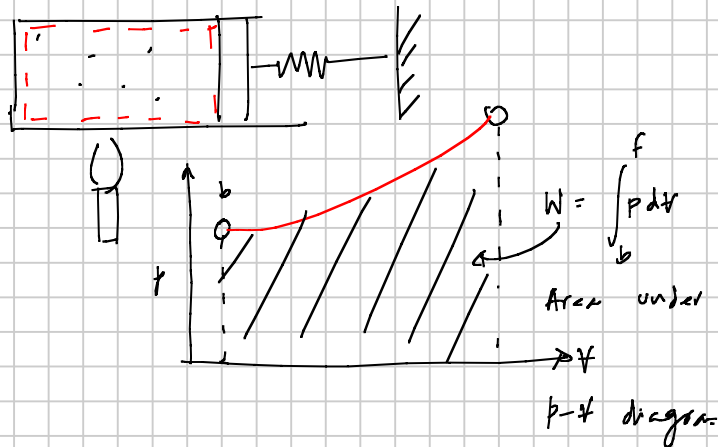
level



$$W = F \Delta x = (pA) \Delta x$$

$$= p (A \Delta x)$$

$$= p \Delta v$$



$$W = F \Delta x$$

$$W = \int_b^f F dx = \int_b^f (pA) dx$$

$$= \int_b^f p (A dx) = \int_b^f p dv$$

If the boundary of a system moves the work transfer is called boundary work.

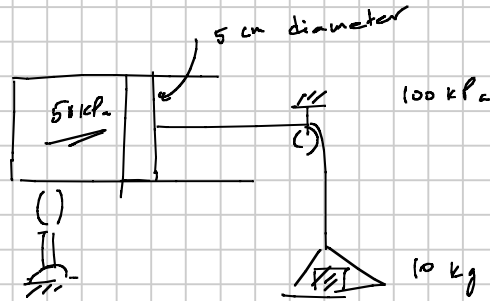
$$W = W_B + \dots$$

$$= W_M + W_{pdr} + \dots$$

T lift $\approx 100 \text{ kg}$
 • weight at 1 m/s ,
 $u = 1 \text{ m/s}$

$$\dot{W}_M \approx \frac{100 \times 9.8}{1000} \times 1$$

$$\approx 1 \frac{\text{kN} \cdot \text{m}}{\text{s}} \approx 1 \frac{\text{kJ}}{\text{s}} = 1 \text{ kW}$$



$$\dot{W}_{pdr} = \int_b^f p dx = p (V_f - V_b)$$

Suppose the volume increased by 1 m^3 .

$$W_B = W_{pdr} = 50 \times 1 = 50 \text{ kJ}$$

$$\left[\text{kPa} \cdot \text{m}^3 = (\text{kPa} \cdot \text{m}^2) \cdot \text{m} \right]$$

$$= \text{kN} \cdot \text{m} = \text{kJ}$$

Linear

$$F = m \dot{v}$$

$$\dot{W}_M = F v$$

Rotational

$$T = I \ddot{\omega}$$

$$\dot{W}_{sh} = T \dot{\omega}$$

$$= T \cdot 2\pi n$$

$$\dot{W}_{sh} = 2\pi n T$$

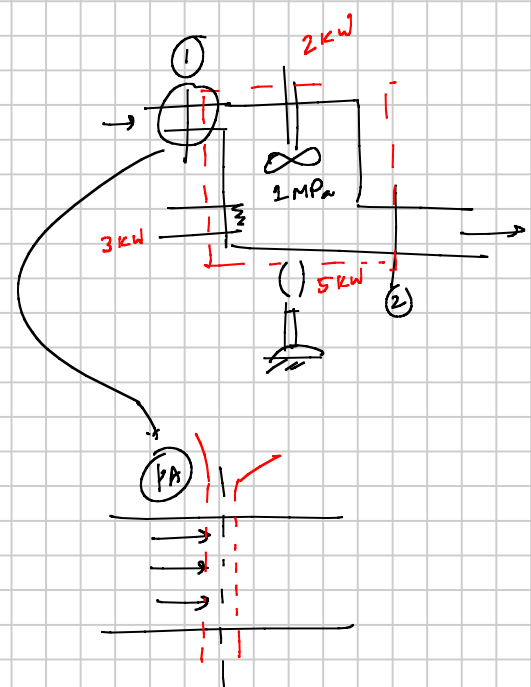
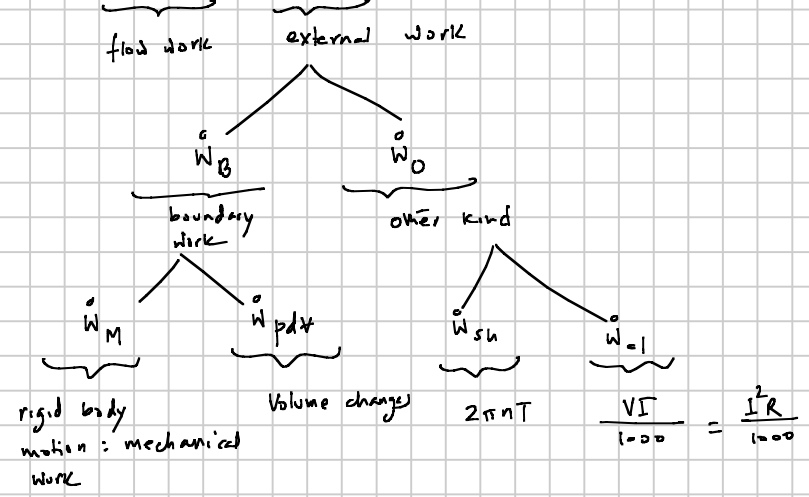
rev./s.

torque in
kN·m

3.2

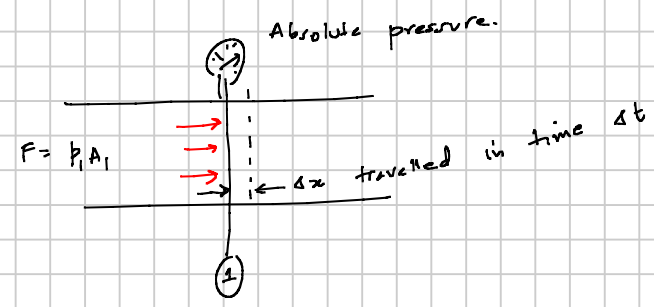
$$W = W_F + W_{ext} \quad [kJ]$$

$$\dot{W} = \dot{W}_F + \dot{W}_{ext} \quad [kW]$$



$$\dot{Q} = ? = 5 \text{ kW}$$

$$\begin{aligned} \dot{W}_{ext} &= ? \\ &= \dot{W}_B + \dot{W}_{sh} + \dot{W}_{eI} \\ &= (-2 \text{ kW}) + (-3 \text{ kW}) \\ &= -5 \text{ kW} \end{aligned}$$



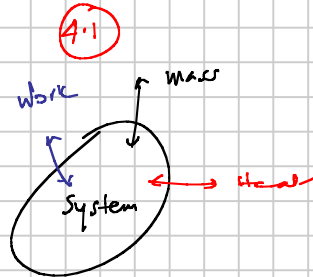
$$W = (p_1 A_1) \Delta x$$

$$\dot{W}_F = \frac{p_1 A_1 \Delta x}{\Delta t} = p_1 A_1 v_1$$

$$\dot{W} = \dot{W}_F + \dot{W}_{ext}$$

where, $\dot{W}_F = pAV$

$$\dot{W}_{ext} = \dot{W}_B + \dot{W}_{sh} + \dot{W}_{el}$$

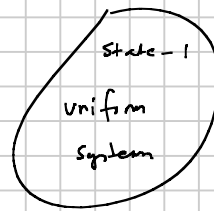


To describe a system thermodynamically, concentrate only on the working substance, not the hardware. A non-uniform system can be broken up into small local systems.

Our task reduces to describing a small local system, which is uniform.

Our job now is to describe a uniform system. It turns out that a local uniform system can be 'blown up' to study its state.

A state is a math. description of a system.



State - 1 = $p_1 = 100 \text{ kPa}, T_1 = 300 \text{ K}$

State - 2 : $p_2 = 500 \text{ kPa}, T_2 = 600 \text{ K}$

A property is a numerical attribute of a state.

An extended state completely describes a system or a fluid. Accordingly, we call it a system state or a fluid state.

Equilibrium is described by a set of properties — p, T, v, u, s — they are called thermodynamic properties. They are at the core of describing an extended system.

4.2

With the help of animations, we discussed extended flow state & extended system state. We then looked at different kinds of properties. We also used a state diagram to evaluate the state of air in the classroom. We created a table to classify properties for both flow & system states.

5.1

p, T, v, u, h, s : thermodynamic properties which define the equilibrium state.

find the stored energy E of a system

$$E = KE + PE + U$$
$$= \frac{mV^2}{2000} + \frac{mgz}{1000} + mu \quad [kJ]$$

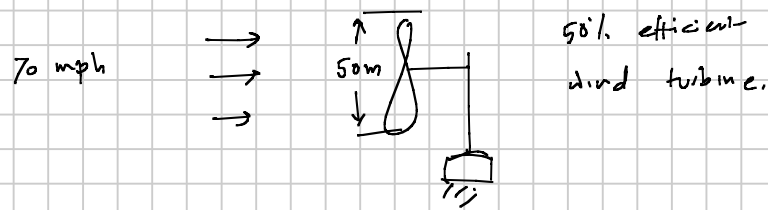
find e

$$e = \frac{E}{m} = ke + pe + u$$
$$= \frac{V^2}{2000} + \frac{gz}{1000} + u$$

find \dot{E} , energy carried by a flow.

$$\dot{E} = \dot{m}e = \dot{m}(ke + pe + u)$$

$$\left[e = \frac{F}{m} \quad u = \frac{U}{m} \quad ke = \frac{KE}{m} \quad pe = \frac{PE}{m} \right]$$



$$\dot{W}_{el} = KE (0.5)$$

$$= \dot{m} ke (0.5)$$

$$= \frac{\rho \pi 50^2}{4} \cdot (70 \times 447) \frac{(70 \times 447)^2}{2000} (0.5) \quad \text{kW}$$

Properties =

n, n

$$n = \frac{m}{M} \quad \text{amount in mole, [kmol]}$$

$$m = n M \quad \text{amount in mass [kg]}$$

$$p = \text{pressure [kPa]} = \left[\frac{\text{kJ}}{\text{m}^3} \right]$$

gauge or vacuum pressure should be converted to absolute pressure as soon as possible.

Read up on kPa_g, pressure measurement, hydrostatic pressure variation etc.

T = Please read up. In SI the unit is K.

$$K = C + 273$$

$$\Delta K = \Delta C$$

$$\text{Conductivity } \dot{q} \text{ given } \approx 0.005 \frac{\text{kJ}}{\text{m}^2 \text{K}}$$

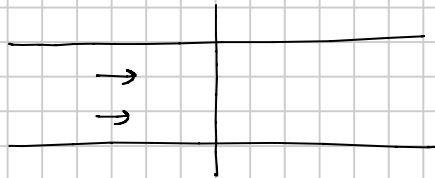
$$= 0.005 \frac{\text{kJ}}{\text{K}}$$

$$E = KE + PE + U$$

$$e = \frac{E}{m} = Re + pe + u$$

$$E^o = m^o e = m^o Re + m^o pe + m^o u$$

$$K_E^o = m^o (Re)$$



Total energy that crosses the cross-section per unit time is made of

$$E^o + \dot{W}_F$$

$$= m^o e + pAV$$

$$= m^o e + \underbrace{pAV}_{\frac{p}{\rho}}$$

$$= m^o e + m^o \frac{p}{\rho}$$

$$= m^o \left(e + \frac{p}{\rho} \right)$$

$$= m^o \underbrace{\left(e + pu \right)}_j$$

$$\dot{J}^o = m^o \dot{j}$$

\dot{j} is called the specific flow energy

$$\dot{j} \equiv e + pu$$

$$= Re + pe + \underbrace{u + pu}_h$$

h is specific enthalpy

$$= u + pu$$

$$\therefore \left. \begin{aligned} \dot{J}^o &= m^o \dot{j} = \dot{m} (Re + pe + h) \\ E &= \dot{m} (Re + pe + u) \end{aligned} \right\}$$

If ke , pe are small

$$\dot{j} = \dot{m}h$$

Math definition of $h \equiv u + pv$

Physical definition is h is flow energy per unit mass when ke & pe are not significant.

$$E = m (\cancel{ke} + \cancel{pe} + u) \\ = m u$$

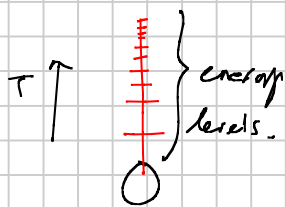
Entropy (S, s, S^0)

$$S = m s$$

$$S^0 = \dot{m} s^0$$

Entropy is a measure of molecular disorder or chaos in a system. The higher the disorder, the higher is entropy.

The disorder is measured by how many ways the internal energy can be distributed in a system.



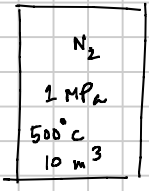
If T goes up so does S .

S will increase as you go from solid, to liquid, to vapor. at the same temp.

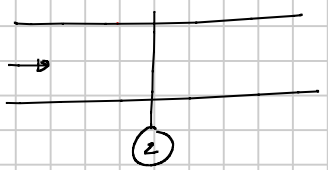
Heat carries entropy by the amount

$$\frac{Q}{T_B} \left[\frac{kJ}{K} \right]$$

$T_B =$ temp of boundary



state-1



H₂O = 1 MPa
500°C
10 m³/min

Find U_1, E_1, S_1
 m_1, v, h_1
.....

Find $\dot{E}_2, \dot{J}_2, S_2$
 $\dot{m}_2, v_2, h, s, \dots$

$$E = 12\,235 \text{ kJ}$$

$$\dot{E} = 1470 \text{ kW}$$

$$1 \text{ kW}\cdot\text{hr} = 3600 \text{ kJ}\cdot\text{s} = 3600 \text{ kJ} \quad \dot{J} = 1637 \text{ kW}$$

$$\dot{J} = \dot{E} + \dot{W}_F$$

$$\dot{W}_F = [1637 - 1470] \text{ kW}$$

for state-1

$$\frac{\Phi}{I}_1 = 8841 \text{ kJ} = m_1 \phi_1 \quad \left. \vphantom{\frac{\Phi}{I}_1} \right\} \text{ stored energy}$$

$$\frac{\dot{\Psi}}{I}_2 = \dot{m} \psi_2 \quad \left. \vphantom{\frac{\dot{\Psi}}{I}_2} \right\} \text{ Flow energy.}$$

$$= 532.75 \text{ kW}$$