II. ENERGY AND POWER CONCEPTS

Learning Objectives: At the end of this chapter, the mechanical engineering students shall:

1. Apply conservation of mass to open and closed systems.

2. Define work, energy, and power.

3. Convert different systems of units of energy and power.

4. Compute the energy associated when mass travels at a speed of light.

5. Enumerate the general forms of energy.

6. Explain each type of energy.

7. Define heat, specific heat, and types of heat.

8. Analyze the other types of work and energy.

9. Differentiate work non-flow from work-steady flow.

10. Apply conservation of energy to open and closed systems.

11. Apply conservation of energy to steady flow steady state engineering devices.

12. Apply conservation of energy to a simple steam power plant

2.1 CONSERVATION OF MASS

Conservation of mass states that the change in mass in a system is equivalent to the difference of mass flowing out to the system to the mass flowing into the system.

(a) ***For closed system,*** the change in mass is constant, wherein it is the difference between the mass leaving and the mass leaving the system.

$$\Delta \dot{m} = \dot{m}_{out} - \dot{m}_{in}$$

(b) ***For open systems***, the change in mass is zero, wherein there is no change in mass through the process. The mass entering the system is also equal to the mass leaving the system. This is also called as the mass balance for open systems.

$$\Delta \dot{m} = 0$$

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

Consider the steady flow system below. At section 1, mass is entering the system and at section 2 mass is leaving the system. We can also relate the mass flow rate of the system in terms of the inlet and outlets cross sectional area, velocity of the fluid, and density/specific volume of the fluid. By mass balance on the system:

$\dot{m}_{in} = \dot{m}_{out}$ $\quad\quad \Delta \dot{m} = 0$

$\dot{m}_1 = \dot{m}_2$

$\rho_1 \dot{V}_1 = \rho_2 \dot{V}_2$

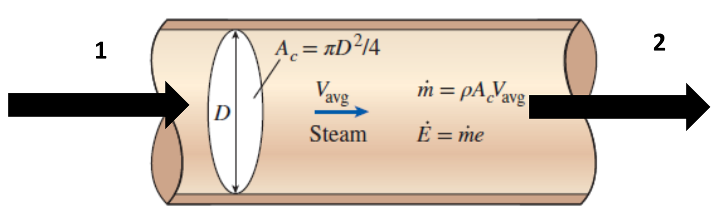
$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$

$\dfrac{A_1 \mathrm{v}_1}{\nu_1} = \dfrac{A_2 \mathrm{v}_2}{\nu_2}$

Where $A =$ cross sectional area

$\mathrm{v} =$ constant velocity

ν = specific volume



The mass balance for open system is also called as the ***continuity equation*** for fluids.

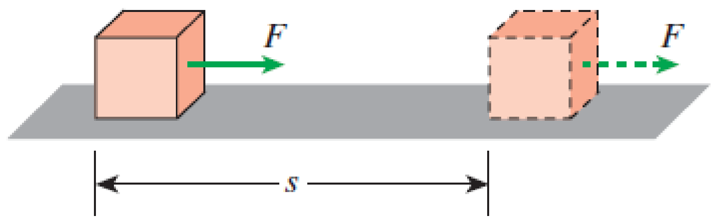
2.2 WORK AND ENERGY

Energy is defined as the capacity to do work. The energy is a scalar quantity, and the energy of a system of bodies is the algebraic sum of the magnitudes of various forms of energy.

Work is a form of energy, is also the product of displacement of a body and the component of the unbalance constant force in the direction of the displacement. A body never contains work, it has the capacity to do work. Consider a body of mass *m* acted by an unbalanced constant force *F*.

If an infinitesimal displacement *ds* is acted by an unbalanced constant force *F*, the work *W* would be

$$dW = Fds$$



Summing all ds, by integration

$$\int_0^W dW = F\int_0^s ds$$

$$\boldsymbol{W = Fs}$$

The differential equation $\boldsymbol{dW = Fds}$ is called as the ***general equation of work***, and the derivation is still the same in deriving some other forms of work.

2.3 POWER

Power is defined as the rate of change of work per unit time. In differential symbols

$$\boldsymbol{P = \frac{dW}{dt}}$$

The average power or the power is defined as:

$$\boldsymbol{P = \dot{W} = \frac{W}{t}}$$

Since $W = Fs$, hence

$$P = \frac{Fs}{t}$$

$$\boldsymbol{P = F\mathrm{v}}$$

The power is also equal to the product of the unbalance constant force to the velocity of the body. From our equation of power, we can see that the work done is also equivalent to the product of power and time.

$$\boldsymbol{W = Pt}$$

Power also can be defined as the product of the energy *E* to the ratio of the mass flow rate to the mass of the system. It can be also defined as the product of energy *E* to the ratio of volume flow rate to the volume of the system.

$$P = E\left(\frac{\dot{m}}{m}\right)$$

$$P = E\left(\frac{\dot{V}}{V}\right)$$

2.4 UNIT CONVERSIONS OF ENERGY AND POWER

It is important for mechanical engineering students to memorize all the unit conversions of energy and power since we are dealing with thermodynamic systems. Units of power can be also in terms of the product of units of energy to the units of time. The following are the base units of energy and power in different systems of units. (Note: Memorize all these conversions!)

	FPS	CGS	KGS/metric	SI
Energy	BTU	Erg	kgf-m	J, kJ
Power	hp	metric hp	metric hp	W, kW

CONVERSION FACTORS FOR ENERGY

1 BTU = 778.16 ft-lbf
= 1055 J
= 1.055 kJ
= 252 cal
1 CHU = 1.8 BTU
1 Th = 100 000 BTU
1 erg = 1 dyne-cm
= 10^{-10} kJ
1 Cal = 1 kcal
=1000 cal
1 cal = 4.187 J
1 kcal = 4.187 kJ
1 kgf-m = 9.8066 J

1 ev = 1.6025×10^{-12} erg
= 1.6025×10^{-12} dyne -cm
= 1.6025×10^{-22} kJ
1 J = 1 N-m
= 1 W-s
= 1 V-C
= 10^7 erg
1 kJ = 1 kW-s
1 kW-hr = 3412.32 BTU
= 3600 kJ

Where

BTU = British Thermal Units
CHU = Calorie Heat Unit
Th =Therm/ Thermal Heat Unit
J = Joules
V = volts
Cal = Calorie
cal = calorie
ev = electrovolts
W = watts
C = coloumbs

CONVERSION FACTORS FOR POWER

1 W = 1 VA
= 1 VC/s
= 1 J/s
= 1 $A^2\Omega$
= 1 A^2/mho

1 english hp = 1 hp
= 746 W
= 0.746 kW
= 550 ft-lbf/s
= 33000 ft-lbf/min
= 42.41 BTU/min
= 1 mule
= 1 Arabian mule

1 metric hp = 1 Mhp
= 1 french horse
= 1 pfer-starky (P.S)
=1 cheuval vapeur (CV)
= 1 power of a horse
= 736 W
= 0.736 kW
= 75 kgf-m/s
= 4500 kgf-m/min

Other non-standard units of power

1 Boiler Mhp = 33480 BTU/hr
= 35322 kJ/hr

$$1\text{ponselet(p)} = \frac{4}{3}Mhp$$
= 1.315 hp

Where

V	= volts	hp	= horsepower	Ω	= ohms
A	= ampere	P.S	= pfer-starky	p	= ponselet
J	= Joules	C.V	= cheuva vapeur	Mhp	= metric horsepower

Notable definitions of units of energy and power are as follows:

1. ***British Thermal Unit (BTU)*** **-** it is the amount of energy required to raise a temperature of a unit pound force by a unit degree fahrenheit.
2. ***Calorie Heat Unit (CHU)*** **-** it is the thermochemical energy unit alternative for calorie
3. ***calorie*** (***cal)*** **-** it is the amount of energy required to raise the temperature of unit gram mass at unit degree celsius.
4. ***Calorie (Cal)*** **-** it is the amount of energy required to rause the temperature of unit kilogram mass by a unit degree celsius.
5. ***Joule (J)*** **-** the amount of energy done by a newton force displaced by a unit meter, named after James Joules. It is the SI unit of energy.
6. ***Erg (erg)*** **-** it is the amount of energy done by a dyne-force that is displaced by a unit centimeter.
7. ***Thermal heat (therm/th)*** **-** it is the approximate energy equivalent of burning 100 cubic foot of natural gas.
8. ***English horsepower (hp)*** -also called as the mechanical horsepower rating. It is also the rating of performance of certain machines. It is invented by James Watt by using a mule to measure its capacity in carrying a load of 550 pounds of coal covering a unit foot in unit second.
9. ***Metric horsepower (Mhp)*** -also called as the electrical horsepower rating, pferstarky (P.S) and cheuva vapeur (CV). Instead of using mule, french horse was used and it was loaded by 75 kilograms of coal, covering a unit meter in unit second.
10. ***Watt (W)*** **-** the SI unit of power, named after James Watt. It is the standard electrical unit of power.

2.5 CONVERSION OF MASS INTO ENERGY

A mass *m* can be converted into energy *E* if it will travel at a speed of light *c*. Energy at this point is at maximum when this mass is fully consumed. Albert Einstein's famous equation for theory of relativity applies the conversion of mass into energy.

$$\boldsymbol{E = \frac{mc^2}{k}}$$

where E is the energy associated when the mass is converted by means of burning without energy loss.

c is the speed of light, where $\boldsymbol{c = 3 \times 10^8\ m/s}$

k is a proportionality constant of the equation, for consistency of unit conversions.

If this mass also called as rest mass or the initial mass m_0 moves at a certain velocity *v* lesser than the speed of light, then the new mass *m* of the body as it moves at this speed is defined as:

$$\boldsymbol{m = \frac{m_0}{\sqrt{1 - \frac{v^2}{c^2}}}}$$

This concept of mass- energy conversion is applicable in determining the mass of nuclear fuel to be used in nuclear power plants. The mass of nuclear fuel is defined as the source of heat in the plant in for the nuclear power plant to produce electricity. Hence

$$\boldsymbol{Q = \frac{m_{NF}c^2}{k}}$$

where Q is the heat or energy that is needed to run the nuclear powerplant

m_{NF} is the mass of nuclear fuel

c is the speed of light

2.6 GENERAL FORMS OF ENERGY

Energy is subdivided into two general forms:

A. ***Stored Energy*** - energy that is within the property of the system and cannot be transferred from another system. Stored energy are point functions, and associated with the change of energy. It is also dependent on the mass of the system. The following are kinds of stored energy.

- Potential Energy / Gravitational Potential Energy (PE)
- Kinetic Energy/ Mechanical Kinetic Energy (KE)
- Flow Energy/ Flow Work (W_f)
- Internal Energy (U)
- Enthalpy (H)

B. ***Transient Energy*** - it is the energy that can be transferred from one system to another. Transient energy are path functions, and does not associates with the change of energy. There are two kinds of transient energy.

- Mechanical Work (W)
  - Work Steady Flow (W_{SF})
  - Work Non-Flow (W_{NF})
- Heat (Q)

Energy can be defined in terms of

(a) **Energy units** (Ex.kJ , BTU)

(b) **Specific energy** or energy per unit mass, denoted as small letters (Ex: kJ/kg, BTU/lbm)

(c) Energy per unit time or in **units of power**, denoted as capital letters with dot on top of the letter.
(Ex: kW, hp)

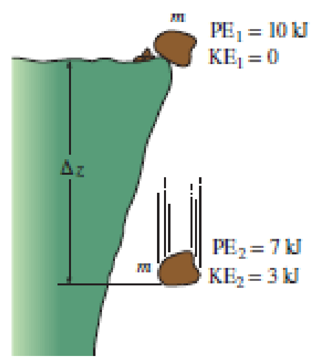
2.7 TYPES OF STORED ENERGY

In this section, we will fully understand each kind of stored energy.

1. ***Potential Energy*** - it is also called as gravitational potential energy. It is the energy of a body due to its position or its elevation at a specified datum line. From the figure below, if a mass *m* is hold at a certain height *z*, then that mass stores potential energy.

In terms of energy units:

$$\boldsymbol{PE = \frac{mgz}{k}}$$



In terms of energy per unit mass basis:

$$pe = \frac{gz}{k}$$

In terms of energy per unit time basis

$$\dot{PE} = \frac{\dot{m}gz}{k}$$

The change of potential energy is defined as

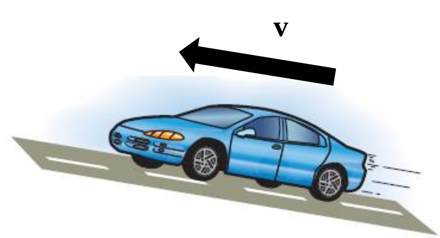
$$\Delta PE = PE_2 - PE_1$$

$$\boldsymbol{\Delta PE = \frac{mg(z_2 - z_1)}{k}}$$

2. ***Kinetic Energy*** - also called as mechanical kinetic energy. It is the energy possessed by a moving body by virtue of its momentum. From the figure below, if a mass *m* that moves at a velocity *v* them that mass stores kinetic energy.

In terms of energy units:

$$\boldsymbol{KE = \frac{mv^2}{2k}}$$



In terms of energy per unit mass basis:

$$ke = \frac{v^2}{2k}$$

In terms of energy per unit time basis

$$\dot{KE} = \frac{\dot{m}v^2}{2k}$$

The change of kinetic energy is defined as

$$\Delta KE = KE_2 - KE_1$$

$$\boldsymbol{\Delta KE = \frac{m({v_2}^2 - {v_1}^2)}{2k}}$$

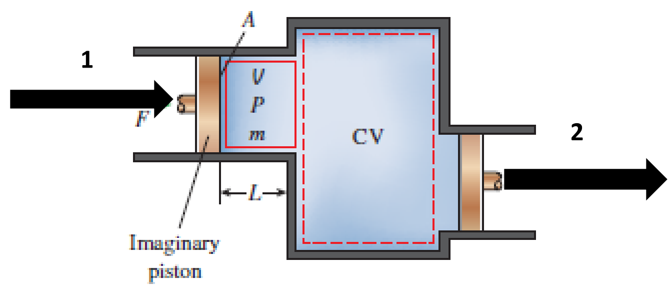
3. ***Flow Energy*** **-** is also called as the flow work or flow resistance energy. It is a stored energy of a body to resists another body to get into the body of another system. Work must be done to move the body against the resistance caused by another body. From the given figure, we will derive the equation of flow energy.

From our definition of work

$W = Fs$

Since $s = L$; then

$W = FL$



But $V = AL$, $F = PA$, hence in terms of energy units:

$$\boldsymbol{W_f = PV}$$

In terms of energy per unit mass basis:

$$w_f = Pv$$

In terms of energy per unit time basis

$$\dot{W}_f = P\dot{V}$$

The change of flow energy is

$$\Delta W_f = W_{f2} - W_{f1}$$

$$\boldsymbol{\Delta W_f = P_2V_2 - P_1V_1}$$

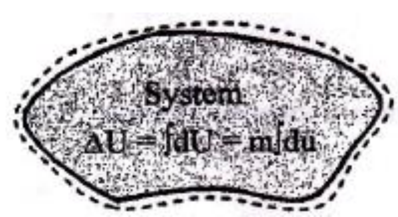
4. ***Internal Energy*** **-** also called as inner work, internal work, and intrinsic energy. It is the energy stored within a body or a substance by virtue of the ability and configuration of its molecules and vibration of the atoms withing the molecules. The term internal energy first appeared with its symbol U in the works of Rudolf Clausius

In terms of energy units:

$\boldsymbol{U = mu}$

In terms of energy per unit mass basis:

$u = \frac{U}{m}$



In terms of energy per unit time basis

$$\dot{U} = \dot{m}u$$

The change of internal energy in terms of energy units

$$\Delta U = U_2 - U_1$$

$$\boldsymbol{\Delta U = m(u_2 - u_1)}$$

The change of internal energy in terms of energy per unit mass basis:

$$\boldsymbol{\Delta u = u_2 - u_1}$$

The internal energy of the system is a stored energy, which is the sum of all the microscopic forms of energy in the system. It is related to the molecular structure, and degree of molecular activity, and can also view as the sum of all the kinetic and potential energies of the molecules. The following are the portions of internal energy in detail:

a) ***Translational Kinetic Energy -*** energy associated with the translational motion of molecules.

b) ***Rotational Kinetic Energy*** - energy associated with the rotational motion of molecules.

c) ***Vibrational Kinetic Energy*** - energy associated with the vibration of atoms within molecules

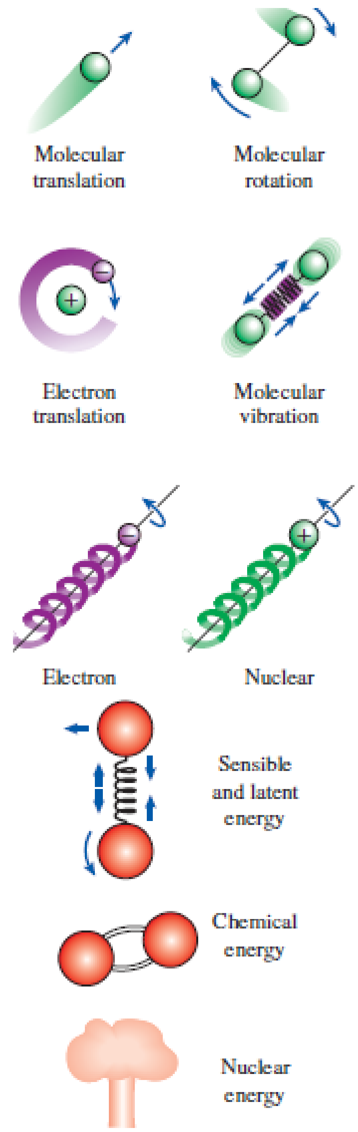
d) ***Internal Potential Energy -*** is the energy due to relative position of its molecules and attraction of molecules to one another.

e) ***Sensible Energy -*** the portion of the internal energy associated with the kinetic energies of molecules.

f) ***Latent Energy -*** the internal energy associated with the phase of the system.

g) ***Chemical Energy*** -the internal energy associated with the atomic bonds in the molecule.

h) ***Nuclear Energy -*** it is the tremendous amount of energy associated with strong bonds within the nucleus of the atom itself.



5. ***Enthalpy -*** is a stored energy sometimes called as the combination energy. It is defined as the sum of the internal energy and flow energy. It is the composite property to all fluids relating flow work and internal energy.

In terms of energy units:

$$H = mh$$

$$\boldsymbol{H = PV + U}$$

In terms of energy per unit mass basis:

$$h = Pv + u$$

In terms of energy per unit time basis

$$\dot{H} = P\dot{V} + \dot{U}$$

The change of enthalpy in terms of energy units

$$\Delta H = H_2 - H_1$$

$$\Delta H = m(h_2 - h_1)$$

$$\Delta H = (P_2V_2 + U_2) - (P_1V_1 + U_1)$$

$$\boldsymbol{\Delta H = \Delta PV + \Delta U}$$

The change of enthalpy in terms of energy per unit mass basis:

$$\Delta h = h_2 - h_1$$

$$\Delta h = (P_2v_2 + u_2) - (P_1v_1 + u_1)$$

$$\Delta h = \Delta Pv + \Delta u$$

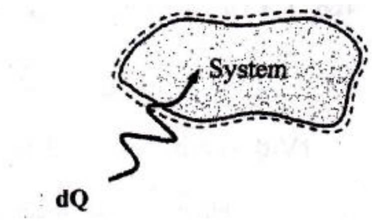
2.8 HEAT

Heat (Q) is defined as the energy in transition from one system to another because of differences of temperature. Heat flows always from higher temperature system to lower temperature system. If two bodies have the same temperature, then thermal equilibrium is reach.

Sign Conventions of Heat

i. Q is positive if heat is absorbed or received by the system.

ii. Q is negative if heat is released by the system.



The general formula of heat in terms of mass, specific heat c, and temperature for any state at energy basis is:

$$\boldsymbol{Q = mc\Delta T}$$
$$\boldsymbol{Q = mc\Delta t}$$

Units For Specific Heat		
FPS	MKS	SI
$\frac{BTU}{lbm - °F}$	$\frac{kcal}{kgm - K}$	$\frac{kJ}{kgm - °C}$
$\frac{BTU}{lbm - °R}$	$\frac{kcal}{kgm - °C}$	$\frac{kJ}{kgm - K}$
	$\frac{cal}{gm - °C}$	
	$\frac{cal}{gm - K}$	

If heat is in terms of energy per unit mass basis:

$$q = \frac{Q}{m}$$
$$q = c\Delta T$$
$$q = c\Delta t$$

In terms of energy per unit time basis

$$\dot{Q} = \dot{m}c\Delta T$$
$$\dot{Q} = \dot{m}c\Delta t$$

2.9 SPECIFIC HEAT

Another property that relates heat to another state properties is the specific heat. The specific heat c is defined as the ratio of the change in energy in form of heat to the change in temperature of a given fluid for a particular process. The specific heat c in energy basis is defined as

$$\boldsymbol{c = \frac{Q}{m\Delta T}}$$

$$\boldsymbol{c = \frac{Q}{m\Delta t}}$$

and the specific heat at unit mass basis is

$$c = \frac{q}{\Delta T}$$
$$c = \frac{q}{\Delta t}$$

In differential form

$$c = \frac{dq}{dt}$$

There are two kinds of specific heat

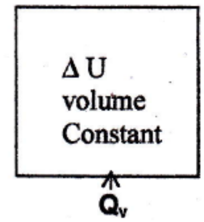
1. ***Specific Heat at Constant Volume Process*** (Isometric Process) - the specific heat on a constant volume process is defined as the change in internal energy per degree change in temperature.

a) In macroanalysis, we defined heat as the change in internal energy for constant volume process.

$$Q = \Delta U$$
$$Q = mc_v\Delta T$$
$$Q = mc_v\Delta t$$

Where c_v is the specific heat at constant volume process

b) In microanalysis, we defined the specific heat at constant volume in differential elements

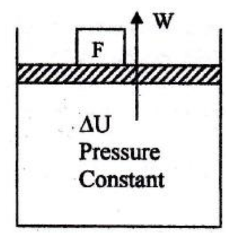


$$dQ = mc_v dT$$
$$dq = c_v dT$$

Where c_v must be a function of temperature($c_v(T)$). Hence the heat would be

$$\int_0^Q dQ = m\int_1^2 c_v(T)dT$$

2. ***Specific Heat at Constant Pressure Process*** (Isobaric Process) - the specific heat on a constant pressure process is defined as the change in enthalpy per degree change in temperature.



a) In macroanalysis, we defined heat as the change in enthalpy for constant pressure process.

$$Q = \Delta H$$
$$Q = mc_p\Delta T$$
$$Q = mc_p\Delta t$$

Where c_p is the specific heat at constant pressure process

b) In microanalysis, we define the specific heat at constant pressure in differential elements.

$$dQ = mc_p dT$$
$$dq = c_p dT$$

3. Where c_p must be a function of temperature($c_p(T)$). Hence the heat would be

$$\int_0^Q dQ = m\int_1^2 c_p(T)dT$$

2.10 TYPES OF HEAT

When dealing with heat, there are general two types of heating:

1. ***Sensible Heat*** **-** it is the heat that cause a change in temperature of a system without changing the phase of the system. Sensible heat is defined as:

$$Q_s = mc\Delta t$$
$$Q_s = mc\Delta T$$

If two or more bodies came in contact with different temperatures, then heat will flow from higher temperature body to lower temperature body. At such time, these bodies in contact will come in thermal equilibrium,as validated by the zeroth law of thermodynamics. Assuming that there is no change in the phase of the bodies being in contact and no heat is loss within the system, a “heat balance” is determined:

$$\sum Q = 0$$
$$\sum_{i=1}^{n} Q_i = 0$$
$$\sum_{i=1}^{n} m_i c_i (T - T_i) = 0$$

where T represents the thermal equilibrium temperature.

2. ***Latent Heat*** **-** it is the amount of heat needed to change the phase of the system without changing its temperature. The general formula for latent heat of any system is

$$Q_L = mL$$

where L is the latent heat of the system, either latent heat of fusion, or latent heat of vaporization.

There are basically two types of latent heat.

a) ***Latent Heat of Fusion*** (h_f) - also called as the heat of fusion, is the amount of energy or the amount of enthalpy that must be added for a system to change phase between a solid and a liquid without changing its temperature It is also the amount of energy absorbed during melting and also equivalent to the energy released during freezing

b) ***Latent Heat of Vaporization*** (h_v/h_{fg})- also called as the heat of vaporization, is the amount of energy or the amount of enthalpy to be added on a system to change phase from liquid into gas. It is also the energy absorbed during vaporization and also equivalent to the energy released during condensation.

The following are useful constant of specific heats and latent heat of water. (All of these constants must be memorize by mechanical engineering students!). Assuming that the following constant pressures are measured at standard pressure and temperature (STP)

I. Specific Heats of Water (H2O) at Constant Pressure

English/FPS	Metric / MKS	SI
$c_{pw} = 1\frac{BTU}{lbm - °F}$ $c_{pw} = 1\frac{BTU}{lbm - °R}$	$c_{pw} = 1\frac{kcal}{kgm - °C}$ $c_{pw} = 1\frac{kcal}{kgm - K}$ $c_{pw} = 1\frac{cal}{gm - °C}$ $c_{pw} = 1\frac{cal}{gm - K}$	$c_{pw} = 4.187\frac{kJ}{kgm - °C}$ $c_{pw} = 4.187\frac{kJ}{kgm - K}$ $c_{pw} = 4.187\frac{J}{gm - °C}$ $c_{pw} = 4.187\frac{J}{gm - K}$

Other specific heats

b) **Specific Heat of Ice at Constant Pressure**

$$c_{pi} = 0.5c_{pw}$$

c) **Specific Heat of Steam at Constant Pressure**

$$c_{ps} = 0.4454c_{pw}$$

II. Latent Heat

a) ***Latent Heat of Fusion (Ice)***

English/FPS	Metric / MKS	SI
$h_f = 144\frac{BTU}{lbm}$	$h_f = 80\frac{kcal}{kgm}$	$h_f = 335\frac{kJ}{kgm}$

b) ***Laten Heat of Vaporization (Steam)***

English/FPS	Metric / MKS	SI
$h_{fg} = 970.3\frac{BTU}{lbm}$	$h_{fg} = 540\frac{kcal}{kgm}$	$h_{fg} = 2257\frac{kJ}{kgm}$

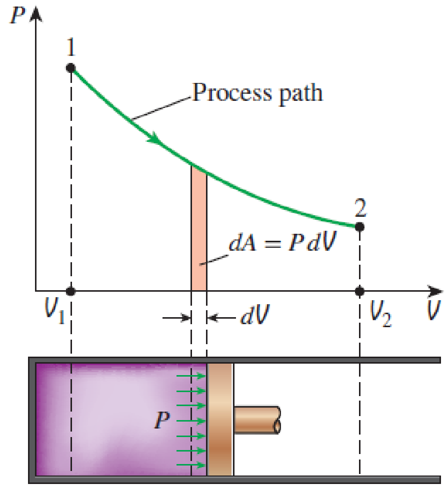
2.11 MECHANICAL WORK

Mechanical Work is a transient energy developed due to shaft rotation or to piston movement. There are basically two types of mechanical work.

Sign Conventions for Work
i. Positive (+) if the work is done by the system.
ii. Negative (-) if the work is done to the system or on the system

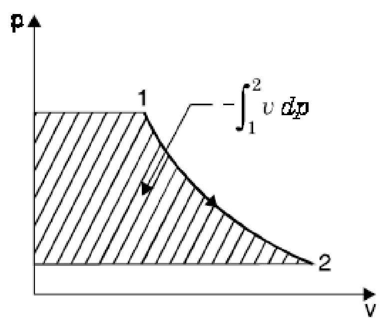
1. ***Work Non-Flow*** - also called as the non-flow work. It is the mechanical work developed in closed systems and non-flow systems. It is also called as the moving boundary work since there is no transfer of mass in a closed system, the mass remains the same but the energy changes. Most common examples is the movement of pistons in piston cylinder arrangement. The non-flow work is computed as the area under the PV diagram.

$$W_{NF} = \int_1^2 P\,dV$$

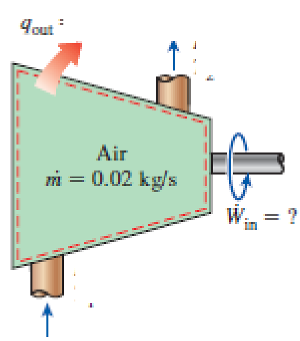


2. ***Work Steady-Flow*** - also called as the steady flow work. It is the mechanical work developed in an open system. It is also the work done due to shaft rotation in some steady flow engineering devices to produce energy. Most common example is a turbine. The steady flow work is computed as the area at the "back" of the PV curve, assuming that ΔKE=0 and t ΔPE=0.

$$W_{SF} = \int_1^2 V\,dP$$



(b)

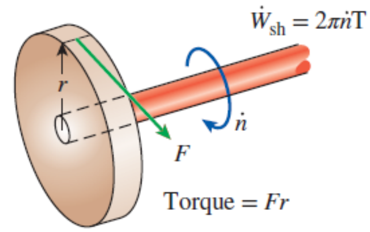


Note: In some textbooks and other reference books, the steady flow work is indicated by a negative sign, means that the work is done by a working substance to the system. Neglect the negative sign for easier calculations and let point 2 be any value (higher limit) that is higher than the value in point 1 (lower limit) in the integral.

2.12 OTHER FORMS OF WORK/ENERGY

Aside from the general forms of work, there are other types of work applicable to some engineering thermodynamic problems.

1. ***Shaft Work*** **-** it is the energy transmission by a rotating shaft. It is proportional to the torque applied and the number of revolutions of the shaft.



$$\dot{W}_{sh} = Fv$$

Since $T = Fr$, and $v = 2\pi rN$, then

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

where T is the torque applied to the rotating shaft
N is the number of revolutions per unit time.
ω is the angular velocity or angular speed.

Since shaft work are in terms of energy per unit time basis (power), and it is dependent to the torque, we can use the formula below for easy conversion of shaft work to power,

a) For SI units

$$\boldsymbol{\dot{W}_{sh} = \frac{TN}{9.549 \times 10^6}, kW}$$

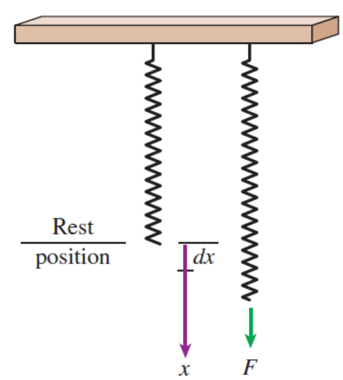
Where
T is in kN-m
N is in revolutions per minute (rpm)

b) For English units

$$\boldsymbol{\dot{W}_{sh} = \frac{TN}{963205}, hp}$$

Where
T is in lb-in
N in revolutions per minute (rpm)

2. ***Spring Work*** - it is also called as elastic potential energy. It is the energy required for a force F acting on an elastic system, such as springs to either compressed or stretched the system. Hooke's Law states that the force acting on the spring is directly proportional to its free length. In symbols



$$F \propto x$$
$$\boldsymbol{F = kx}$$

where
x is called as its free length
k is called as the spring index, spring constant, or stiffness of spring having units of force per unit length.

If work is done on the spring, then the elastic potential energy is defined as the differential element of work done per differential element of displacement of the spring. Thus:

$$dW_{sp} = Fds$$

Also $ds = dx$
Hence

$$\int_0^{W_{sp}} dW_{sp} = \int_1^2 F\,dx$$

Since $F = kx$, then

$$\int_0^{W_{sp}} dW_{sp} = k\int_1^2 x\,dx$$

Integrating both sides

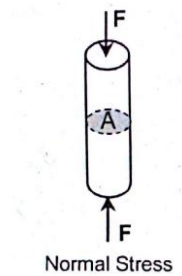
$$W_{sp} = \frac{1}{2}k({x_2}^2 - {x_1}^2)$$

$$\boldsymbol{W_{sp} = \frac{1}{2}k\Delta x^2}$$

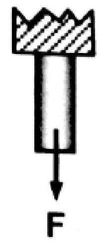
3. ***Strain Energy*** - it is the energy required for a force F to stretch the system (elastic bars) within an elastic region. For this purpose, we would like to have a glimpse of the strength of mater (mechanics of deformable bodies) basic formulas of stress and strain. In strength of materials, we do not assume that the bodies are rigid, but the bodies can deform.

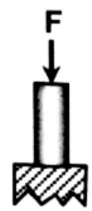
a) ***Stress*** - is the ratio of applied load *P* in units of force per cross sectional area A. It is also the pressure definition in solids.

$$s = \frac{F}{A}$$



When the solid is under tension or tensile forces, it is said to acquire tensile stress, otherwise compressive stress when the solid is under compression or compressive forces.



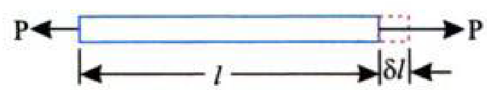


$$s_t = \frac{T}{A}$$
(Tensile Stress)

$$s_c = \frac{C}{A}$$
(Compressive Stress)

b) ***Strain*** - is the ratio of the elongation of the material δ or Δ*x* by its original length L. Hence

$$\epsilon = \frac{\delta}{L} = \frac{\Delta x}{L}$$



c) ***Modulus of Elasticity*** - it is the ratio of stress to strain at proportional limit, assuming that the stress is directly proportional to the strain.

$$s \propto \epsilon$$
$$s = E\epsilon$$
$$E = \frac{s}{\epsilon}$$

Solving F in terms of E,l, A, and x yields

$$E = \frac{FL}{Ax}$$

The force would be

$$F = EA\frac{x}{L}$$

Since work is done to the system, work is assume to be negative. For a differential load dF applied and elongates the rod at a differential element dx,

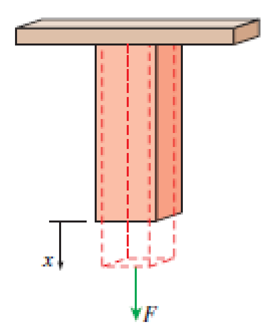
$$dW_{st} = -Fdx$$

Hence

$$dW_{st} = -\frac{EA}{L}xdx$$

Integrating both sides

$$\int_0^{W_{st}} dW_{st} = -\int_0^x \frac{EA}{L}xdx$$



$$W_{st} = -\frac{EAx^2}{2L}$$

From strain equation

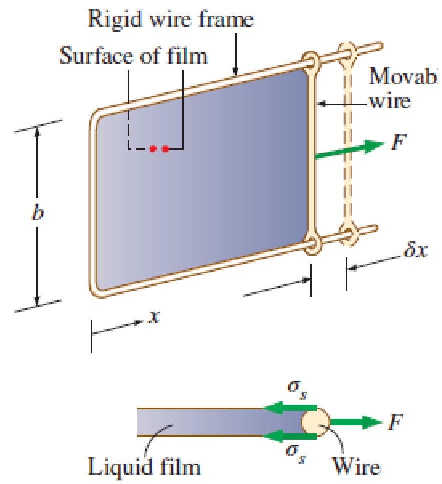
$$x = \epsilon L$$
$$x^2 = \epsilon^2 L^2$$

Hence the work done in stretching elastic bars is

$$\boldsymbol{W_{st} = -\frac{1}{2}EA\epsilon^2 L}$$

4. **Surface *Tension Work*** - it is the work done against a resisting surface tension. It is the work done on stretching a liquid film. It is also applicable to rotating elements in lubrication. ***Surface Tension*** is the property of a fluid, usually in a liquid-gas interface exerts a net force per unit length. In symbols

$$\boldsymbol{\sigma = \frac{F}{b}}$$



where b is the length of the fluid where the force is applied.
The work done in stretching a liquid film at the given area shown to the left is:

$$dW = Fds$$

Also $ds = dL$, hence

$$dW = FdL$$

Since $F = \sigma b$, then

$$dW = \sigma b dL$$

Integrating both sides

$$\int_0^W W = \sigma b \int_0^L dL$$

$$\boldsymbol{W = \sigma b L}$$

For a soap bubble film, the work done to the circular film is

$$W = \frac{1}{4}\pi\sigma r^2$$

5. ***Electrical Work*** - is the work done by the electrons, which is also the product of potential difference and 'the charge of the electrons. For this purpose, we will review some basic electrical engineering principles in electrostatics.

a) ***Coulomb's Law*** - states that the electric force is proportional to the product of the magnitude of two electrical charge and inversely proportional to the square of the distance between them. In symbols

$$F_e = \frac{kQ_1Q_2}{r^2}$$

Where k is called as the coulomb's constant, wherein $k = 9 \times 10^9 \frac{Nm^2}{C^2}$

Q is the charge of the particle, in units of coulombs (C)

b) ***Electric Field*** - it is the electric force per unit charge. Its units are in unit force per unit charge.

$$E_f = \frac{F_e}{Q}$$

c) ***Electric Potential Energy*** - it is the work done on the charge to move the charge on a certain displacement.

$$W = \int F dx$$

$$W = E_f Q \int_0^x dx$$

$$W = E_f Q x$$

d) ***Potential difference*** - it is the product of the electric field intensity E to the displacement

$$V = E_f x$$

Using the equations for electric potential and potential difference, we can now define the electrical work

$$\boldsymbol{W_e = VQ}$$

e) ***Ohms Law*** - states that the resistance is directly proportional to the potential difference and inversely proportional to the current.

$$\boldsymbol{R = \frac{V}{I}}$$

The ***resistance*** is defined as the ability of the material to resist electric flow.

f) ***Current*** - is the flow of electrons per unit time, in units of coulombs per unit time. The standard unit of current is called as the ampere (amp) or (A) which is the flow of 1 coulomb in a unit second.

$$\boldsymbol{I = \frac{Q}{t}}$$

g) ***Conductance*** - it is the reciprocal of resistance. Its units are in terms of mho, siemens, and inverted omega symbol. These units are equivalent to each other.

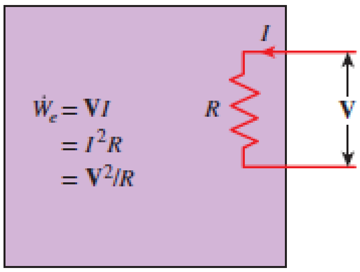
$$\boldsymbol{G = \frac{1}{R}}$$

We can now use ohm's law to relate electrical work to voltage, current, and resistance

$$\boldsymbol{W = VIt}$$

$$\boldsymbol{W = I^2 Rt}$$

$$\boldsymbol{W = \frac{V^2 t}{R}}$$

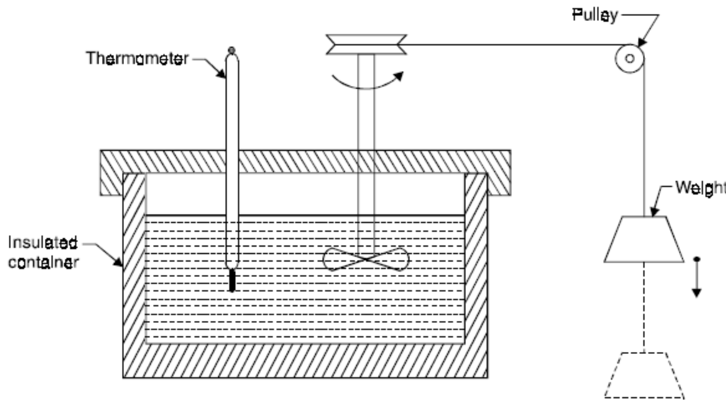


h) ***Electrical Power*** - the electrical power is somehow identical to mechanical power. The electrical power P is also defined as the electrical work per unit time. Eliminating t from the previous equations yields the fundamental electrical power equations that are very useful in mechanical engineering.

Fundamental Electrical Power Formulas	Description	Units
$\boldsymbol{P = IV}$	Power as a function of current and voltage	$V - A$
$\boldsymbol{P = \frac{V^2}{R}}$	Power as a function of voltage and resistance	$\frac{V^2}{\Omega}$
$\boldsymbol{P = I^2 R}$	Power as a function of current and resistance	$A^2 - \Omega$
$\boldsymbol{P = V^2 G}$	Power as a function of voltage and conductance	$V^2 - mho$
$\boldsymbol{P = \frac{I^2}{G}}$	Power as a function of current and conductance	$A^2 - mho$

6. ***Paddle Work*** - also called as stirring work. If a weight is placed on a pulley, and then the paddle is rotating and supplying work to the system as the weight is falling. Hence potential energy is converted into paddle work.

$$W_{paddle} = \int W dz = \int T d\,\theta$$

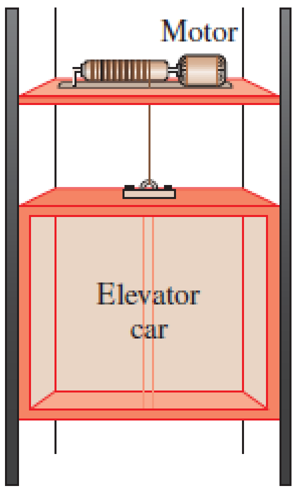


7. ***Magnetic Work*** - the work done per unit volume on a magnetic material through which the magnetic and magnetization fields are uniform is

$$W_{magnet} = \int_1^2 H dI$$

Where H is defined as the magnetic field strength
I is the component of magnetization in the direction of the field

8. ***Work done to accelerate or raise the body*** - the work done to raise the body is equivalent to the change in potential energy, while the work done to accelerate the body is the change in kinetic energy.



9. ***Electrical Polarization Work*** - the generalized force is the electric field strength and the generalized displacement is the polarization of the medium (the sum of all electric dipole moments of the molecules)

2.13 TOTAL ENERGY AND TOTAL MECHANICAL ENERGY

In this section, we will generalize different forms of energy into a single magnitude. The conservation of energy or the first law of thermodynamics states that energy is neither created nor destroyed but it is converted from one energy into another.

A. ***Total Energy*** **-** the total energy of a system, assuming that other types of work are negligible in the system is the sum of the internal, potential, and kinetic energy.

$$E_{tot} = me_{tot}$$

$$\boldsymbol{E_{tot} = U + PE + KE}$$

$$E_{tot} = m\left(u + \frac{gz}{k} + \frac{v^2}{2k}\right)$$

Where e_{tot} is the total energy in the unit mass basis

B. ***Total Mechanical Energy*** **-** the mechanical energy of a system is defined as the energy that can be converted into mechanical work completely and directly into a mechanical device such as an ideal turbine.

$$E_{mech} = me_{mech}$$

$$\boldsymbol{E_{mech} = W_f + PE + KE}$$

$$E_{mech} = m\left(P\nu + \frac{gz}{k} + \frac{v^2}{2k}\right)$$

In unit mass basis

$$e_{mech} = \frac{P}{\rho} + \frac{gz}{k} + \frac{v^2}{2k}$$

2.14 ENERGY BALANCE FOR THERMODYNAMIC SYSTEMS

In general, the energy balance at any system is defined as

$$\Delta E_{system} = E_{out} - E_{in}$$

a) ***Energy Change in a System*** - in absence of other effects, the change in the total energy of the system is defined as the sum of the change in internal, potential, and kinetic energy. Hence:

$$\Delta E_{system} = m\Delta e_{system}$$

$$\boldsymbol{\Delta E_{system} = \Delta U + \Delta PE + \Delta KE}$$

$$\Delta E_{system} = m\left(\Delta u + \frac{g\Delta z}{k} + \frac{\Delta v^2}{2k}\right)$$

b) ***Energy Change for Open Systems*** - the energy change in open systems or flow systems is zero, in which the energy entering the system is equal to the energy leaving the system. It is the conservation of energy for open systems. The equation below is the steady flow energy equation (SFEE) for open system. The work done for open systems is the steady flow work. By energy balance on the open system below.

$$\boldsymbol{E_{in} = E_{out} \qquad \Delta E = 0}$$

In terms of energy units

$$\boldsymbol{PE_1 + KE_1 + W_{f1} + U_1 + Q = PE_2 + KE_2 + W_{f2} + U_2 + W_{SF}}$$

The steady flow work would be:

$$\boldsymbol{W_{SF} = Q - \Delta PE - \Delta KE - \Delta W_f - \Delta U}$$

In terms of each individual energy equations

$$W_{SF} = m\left[q - \frac{g(z_2 - z_1)}{k} - \frac{{v_2}^2 - {v_1}^2}{2k} - (P_2 v_2 - P_1 v_1) - (u_2 - u_1)\right]$$

In terms of specific steady flow work, in which all energies are in per unit mass basis

$$e_{in} = e_{out} \qquad \Delta e = 0$$

$$pe_1 + ke_1 + w_{f1} + u_1 + q = pe_2 + ke_2 + w_{f2} + u_2 + w_{SF}$$

The steady flow work in energy per unit mass basis would be

$$w_{SF} = q - \Delta pe - \Delta ke - \Delta w_f$$

$$w_{SF} = \left[q - \frac{g(z_2 - z_1)}{k} - \frac{{v_2}^2 - {v_1}^2}{2k} - (P_2 v_2 - P_1 v_1) - (u_2 - u_1)\right]$$

If the open system is given in terms of enthalpies, with negligible kinetic and potential energy, the steady flow energy equation reduces to

$$\boldsymbol{E_{in} = E_{out} \qquad \Delta E = 0}$$

$$Q + H_1 = H_2 + W_{SF}$$

The steady flow work would be:

$$\boldsymbol{W_{SF} = Q - \Delta H, \qquad \Delta KE = \Delta PE = 0}$$

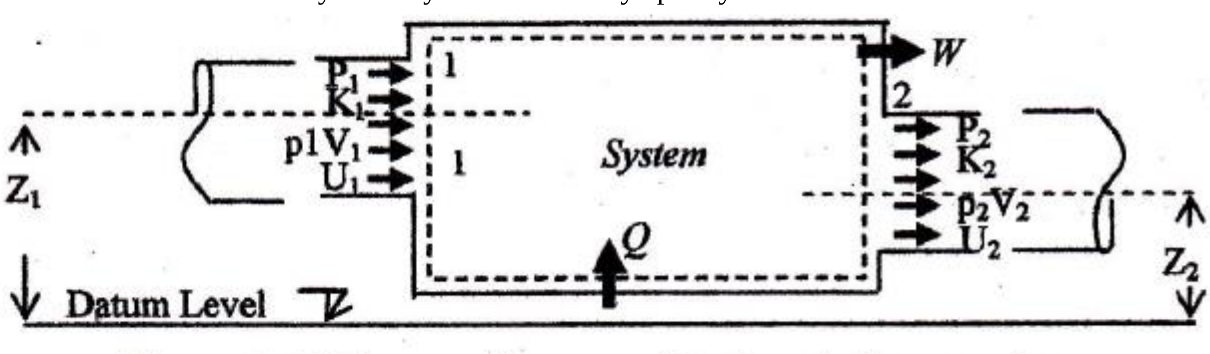
In terms of each individual energy equations

$$W_{sf} = Q - (H_2 - H_1)$$

In terms of specific steady flow work

$$w_{sf} = q - (h_2 - h_1)$$

Note: ***You do not need to memorize all these energy equations***. Knowing the concept of energy balance is a must because most thermodynamic systems are ideally open systems.



c) ***Energy Change for Closed Systems*** - for closed systems, the energy balance is still the same such that the energy entering the system is equal to the energy leaving the system. For an ideal closed system, the volume of the system is assumed to be constant unless specified. The enthalpy for closed systems is equivalent to its internal energy at constant volume, and the work done by the piston shown below is also the non-flow work. The equation below is also called as the non-flow energy equation (NFEE).

By Energy balance on the system

$$\boldsymbol{E_{in} = E_{out} \qquad \Delta E = 0}$$

$$PE_1 + KE_1 + U_1 + Q = PE_2 + KE_2 + U_2 + W_{NF}$$

The non-flow work would be

$$W_{NF} = Q - \Delta U - \Delta PE - \Delta KE$$

In terms of each individual energy equations

$$W_{NF} = m\left[q - (u_2 - u_1) - \frac{g(z_2 - z_1)}{k} - \frac{{v_2}^2 - {v_1}^2}{2k}\right]$$

In terms of specific non flow work or per unit mass basis

$$w_{NF} = \left[q - (u_2 - u_1) - \frac{g(z_2 - z_1)}{k} - \frac{{v_2}^2 - {v_1}^2}{2k}\right]$$

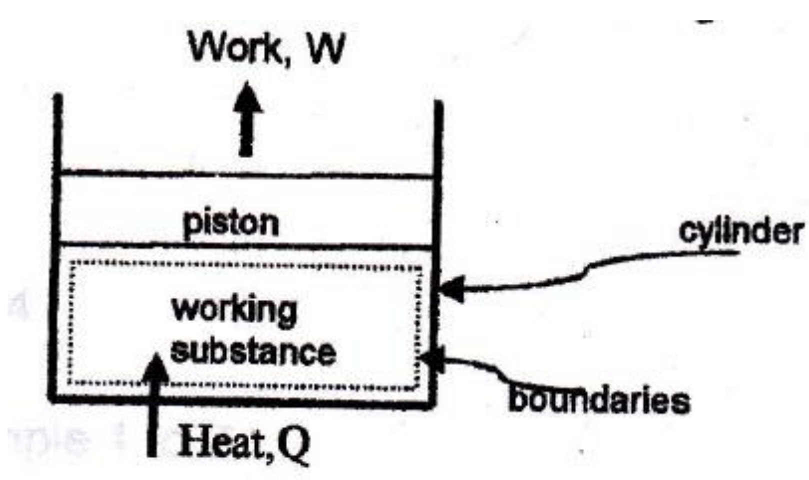
If change in potential and kinetic energy are negligible, in most cases for applying energy balances for close system, the equation reduces to

$$\boldsymbol{W_{NF} = Q - \Delta U, \qquad \Delta KE = \Delta PE = 0}$$

Note:

a) When work is done by the piston, **W is positive**, hence **heat must be rejected to the system**. As the heat is rejected, there must be a stored energy (internal energy to balance both energy).

b) Conversely if heat is added to the system, **Q is positive**, and work is done to the system in which **W is negative**. There must be a store energy again (internal energy) to balance both work and heat. The change in internal energy places a vital role in energy balance for closed systems



2.15 ENERGY BALANCE FOR STEADY FLOW ENGINEERING DEVICES.

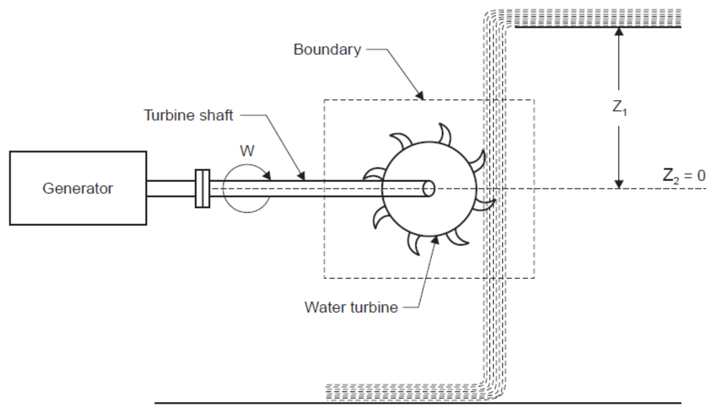
Most mechanical engineering devices in thermodynamics are assumed to be ideal, hence these devices are assumed to be open systems, and conservation of mass (mass balance) and conservation of energy (energy balance) is applicable. Steady flow engineering devices are classified into three.

A) ***Energy Producing Devices*** - energy in which converts heat and other forms of energy to produce work, or electricity. The work in these devices is done by the system.
B) ***Energy Consuming Devices*** - energy in which work, or electricity must be done to the device in order to operate. The work in these devices is done to the system
C) ***Heat Exchangers*** – are steady flow devices whose solely purpose is to transfer and redirect heat from a designated storage or application. These devices do not produce work.

The following are some of the common steady flow engineering devices.

1. ***Turbine*** - is a steady flow device that generates work and electricity. There are two common types of turbine.

a) ***Water Turbine*** - used in hydroelectric powerplants and usually installed beneath dams. It harnesses potential energy from the water and the flow of water will move the blades in the turbine. The turbine is connected to a generator that produces power.



From the given figure, by energy balance, assuming that there is no change in internal energy and no heat is loss or gain into the system:

$$E_{in} = E_{out} \qquad \Delta E = 0$$

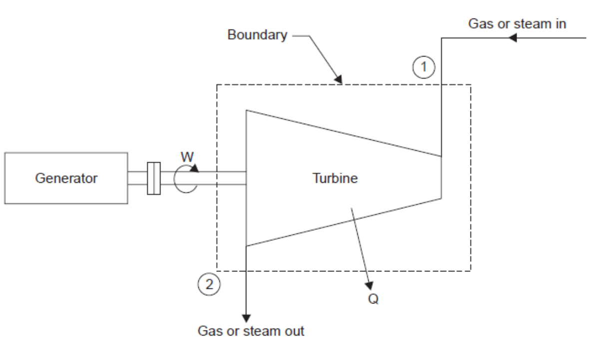
$$PE_1 + KE_1 + W_{f1} + Q = PE_2 + KE_2 + W_{f2} + W_{SF}$$

The work done by the water turbine would be:

$$W_{SF} = -\Delta PE - \Delta KE - \Delta W_f$$

$$\boldsymbol{W_{SF} = -m_{water}\left[\frac{g(z_2 - z_1)}{k} + \frac{{v_2}^2 - {v_1}^2}{2k} + (P_2 v_2 - P_1 v_1)\right]}$$

b) ***Gas/Steam Turbines*** - used in most powerplants. Steam or gas passes through the turbine and part of its energy converted to work. The turbine output runs the generator to produce power.



Neglect change in potential and internal energy, the energy balance for gas or steam turbines is:

$$E_{in} = E_{out} \qquad \Delta E = 0$$

$$KE_1 + H_1 = Q + KE_2 + H_2 + W_{SF}$$

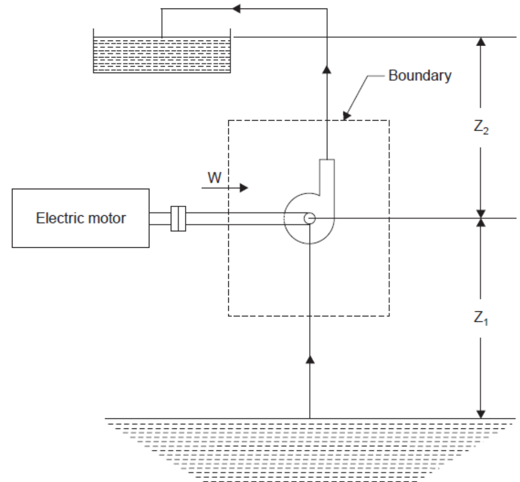
The work done by the steam/gas turbine would be:

$$W_{SF} = -Q - \Delta H - \Delta KE$$

$$\boldsymbol{W_{SF} = -m_{steam}\left[q + (h_2 - h_1) + \frac{{v_2}^2 - {v_1}^2}{2k}\right]}$$

2. ***Pump*** - is a steady flow device that draws liquid from lower level to higher level by increasing the fluid pressure. Work is required to run the pump and this may be supplied by an electric motor or a diesel engine.

From the given figure, by energy balance, assuming that there is no change in internal energy and no heat is loss or gain into the system:



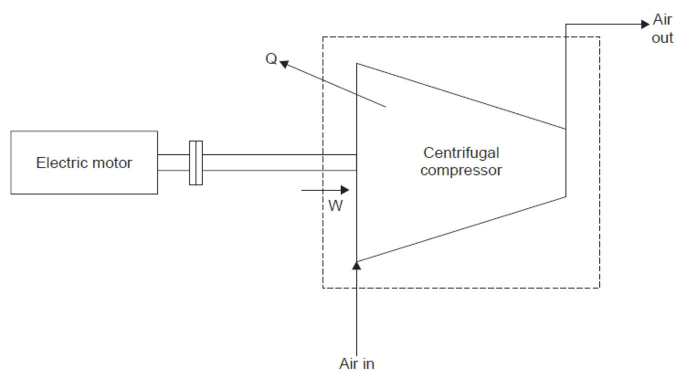
$$E_{in} = E_{out} \qquad \Delta E = 0$$
$$PE_1 + KE_1 + W_{f1} + W_{SF} = PE_2 + KE_2 + W_{f2}$$

The work done to the pump is equivalent to

$$W_{SF} = \Delta PE + \Delta KE + \Delta W_f$$
$$\boldsymbol{W_{SF} = m_{water}\left[\frac{g(z_2 - z_1)}{k} + \frac{v_2{}^2 - v_1{}^2}{2k} + (P_2 v_2 - P_1 v_1)\right]}$$

3. ***Centrifugal Compressor*** - is a steady flow device that increases the pressure of air and supplies the same at moderate pressure and in large quantity. Work is required to run the centrifugal compressor, and requires an electric motor coupled to the compressor.

From the given figure, by energy balance, assuming that there is no change in potential and kinetic energy.



$$E_{in} = E_{out} \qquad \Delta E = 0$$
$$KE_1 + H_1 + W_{SF} = Q + KE_2 + H_2$$

The work done to the centrifugal compressor would be

$$W_{SF} = Q + \Delta H + \Delta KE$$
$$\boldsymbol{W_{SF} = m_{air}\left[q + (h_2 - h_1) + \frac{v_2{}^2 - v_1{}^2}{2k}\right]}$$

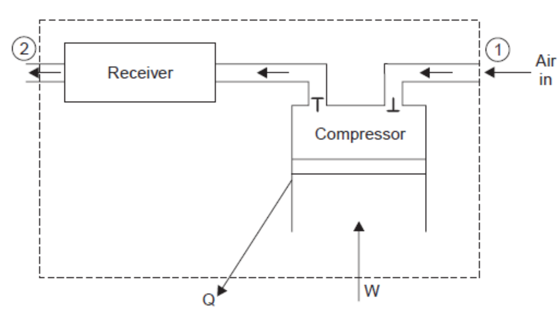
4. ***Reciprocating Compressor*** - is a steady flow device that draws in air from the atmosphere and supplies at a considerable higher pressure in small quantities. It considers a steady flow system if the compressor includes a receiver in which it reduces the fluctuations of flow.

Applying energy balance, neglecting change in potential and internal energy.

$$E_{in} = E_{out} \qquad \Delta E = 0$$
$$KE_1 + H_1 + W_{SF} = Q + KE_2 + H_2$$

The work done to the reciprocating compressor is

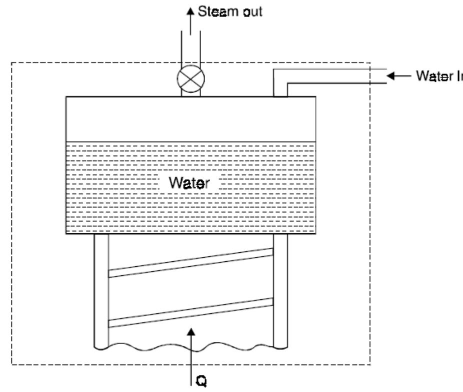
$$W_{SF} = Q + \Delta H + \Delta KE$$
$$\boldsymbol{W_{SF} = m_{air}\left[q + (h_2 - h_1) + \frac{v_2{}^2 - v_1{}^2}{2k}\right]}$$



5. ***Boiler*** -is a steady flow heat exchanger device, part of the steam generating unit. Its main purpose is to transfer heat from a heat source to an incoming high pressure liquid in order to increase its temperature and change phase to become steam.

Applying energy balance, since no work is made to the system and neglect change in potential and kinetic energy.

$$E_{in} = E_{out} \qquad \Delta E = 0$$
$$H_1 + Q = H_2$$



The heat added to the steam is defined as

$$Q = H_2 - H_1$$
$$\boldsymbol{Q_A = m_{steam}(h_2 - h_1)}$$

where Q_A is the heat added to the steam.

For coal steam powerplants, coals are used as a fuel to heat steam into the boiler. Coals have ***heating values* (HV),** also called as ***calorific value (CV)*** wherein it is the energy required to burn per unit mass of fuel. For ideal steam generating unit, the heat that is added to the boiler can be defined as

$$\boldsymbol{Q_A = m_{coal}H_v}$$

where H_v is the heating value of fuel whose units are in energy per unit mass. Equationg both equations will give us the amount of coal required to heat the steam ideally.

$$m_{steam}(h_2 - h_1) = m_{coal}H_v$$
$$\boldsymbol{m_{coal} = \frac{m_{steam}(h_2 - h_1)}{H_v}}$$

For nuclear steam powerplants, nuclear fuel are used in order to heat steam. The heat added must be $Q_A = \frac{m_{NF}c^2}{k}$, then the mass of nuclear fuel needed would be:

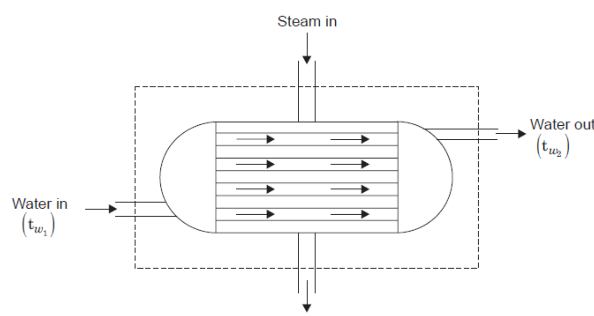
$$\frac{m_{NF}c^2}{k} = m_{steam}(h_2 - h_1)$$
$$\boldsymbol{m_{NF} = m_{steam}(h_2 - h_1)\frac{k}{c^2}}$$

6. ***Condenser* -** is a steady flow device whose main purpose is to reject heat in order for the steam to condenser, for a change phase from steam vapor to liquid water at constant pressure. Applying energy balance, since no work is made to the system and neglect change in potential and kinetic energy:

$$E_{in} = E_{out} \qquad \Delta E = 0$$
$$H_1 = H_2 + Q_R$$

The heat rejected by the condenser from the steam is

$$Q_R = H_1 - H_2$$
$$\boldsymbol{Q_R = m_{steam}(h_1 - h_2)}$$



To condense the steam, a circulating cooling fluid, usually a refrigerant or cooling water absorbs the heat rejected by the condenser. By energy balance, assuming the system is the cooling water:

$$E_{in} = E_{out} \qquad \Delta E = 0$$
$$H_a + Q_R = H_b$$

The heat rejected by the condenser in terms of cooling water

$$Q_R = m_w c_{pw}(t_b - t_a)$$
$$Q_R = m_w c_{pw}\Delta t$$
$$\boldsymbol{Q_R = \rho_w V_w c_{pw} \Delta t}$$

Sometimes in designing condensers, we are required to determine the amount of cooling water in terms of volume that must circulate. Equating the equations:

$$\rho_w V_w c_{pw}\Delta t = m_{steam}(h_1 - h_2)$$
$$\boldsymbol{V_w = \frac{m_{steam}(h_1 - h_2)}{\rho_w c_{pw} \Delta t}}$$

7. ***Evaporator*** **-** is a steady flow device used in refrigeration plant to carry heat from the refrigerator to maintain the low temperature. A Refrigerant liquid passed through the evaporator and absorbs heat from the refrigerating space, decreasing the temperature of the system. The "freezer" in your domestic refrigerator is technically called as an evaporator because heat that is stored from different food and product that is inside the freezer is absorbed by the evaporator, allowing the temperature of all the things inside the freezer below its room temperature.

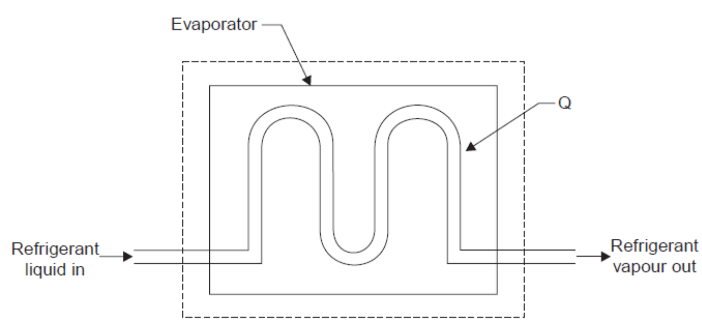
Applying energy balance, since no work is made to the system and neglect change in potential and kinetic energy.

$$E_{in} = E_{out} \qquad \Delta E = 0$$
$$H_1 + Q_A = H_2$$

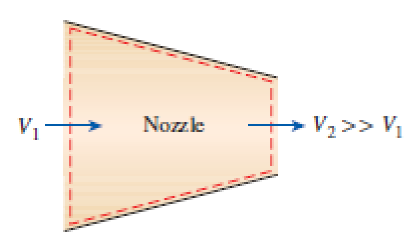
The heat absorbed by the evaporator is

$$\boldsymbol{Q_A = H_2 - H_1}$$

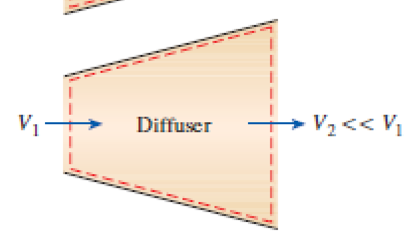
where Q_A is the heat absorbed by the refrigerant, also called as the refrigeration effect.



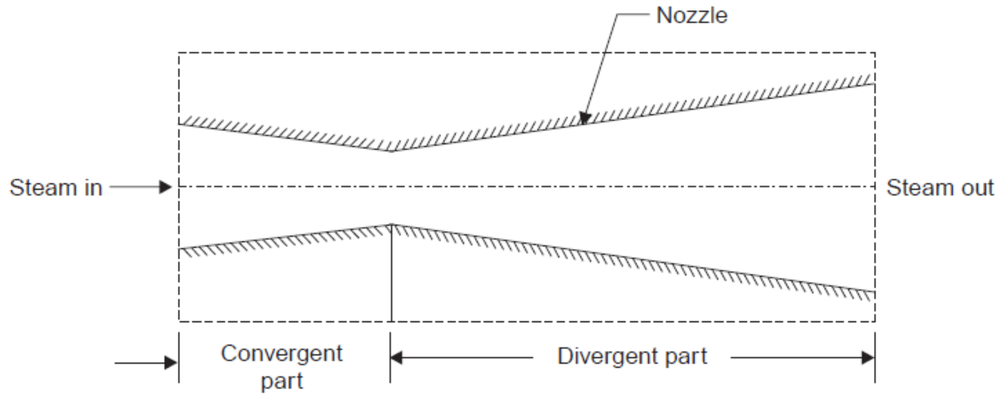
8. ***Nozzle*** **-**it is a steady flow engineering device that increases the velocity of the fluid at the expense of its pressure. Hence the nozzle inlet cross sectional area is lesser than its discharge cross sectional area. As velocity increases, the pressure decreases. This is generally used to convert the part of the energy of the steam into kinetic energy of steam supplied to the turbine.



9. Diffusers **-** is a steady flow engineering device that increase the pressure at the expense of its velocity. Decreasing or slowing down the motion of fluid allows an increase in pressure. Hence the diffuser inlet is larger than the discharge cross sectional area. As the pressure increases, the velocity decreases



For a steam nozzle, then no work is done and neglect change in potential and internal energy. Assume no heat is lost or gained by the nozzle, the energy balance would be



$$E_{in} = E_{out} \qquad \Delta E = 0$$
$$KE_1 + H_1 = KE_2 + H_2$$

Hence the velocity leaving the nozzle is

$$\Delta KE = -\Delta H$$
$$\frac{\boldsymbol{v_2}^2 - \boldsymbol{v_1}^2}{\boldsymbol{2k}} = -(\boldsymbol{h_2} - \boldsymbol{h_1})$$

The final velocity would be

$$v_2 = \sqrt{{v_1}^2 - 2k\Delta h}$$

If initial velocity is so small that it is very negligible:

$$v_2 = \sqrt{-2k\Delta h}$$
$$\boldsymbol{v_2} = \sqrt{\boldsymbol{2k}(\mathbf{h_1} - \mathbf{h_2})}$$

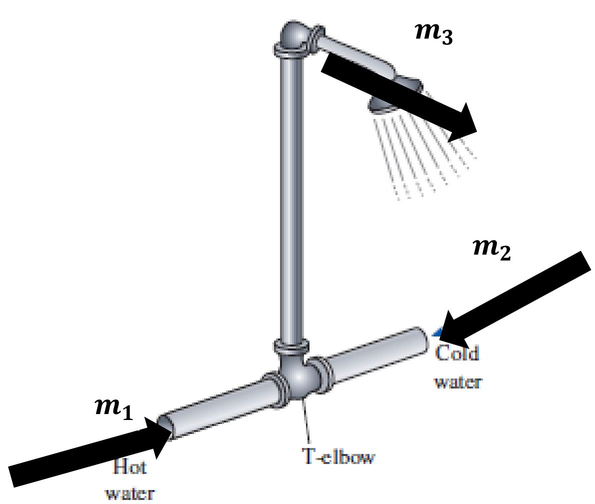
10. ***Mixing Chambers*** **-** it is a steady flow device where mixing process between two or more liquids occur. The mixing chamber does not to be a "chamber" itself. Most mixing chambers are well insulated, and no heat is loss or gain by this system.

Applying mass balance from the given figure.

$\dot{m_{in}} = \dot{m_{out}} \qquad \Delta\dot{m} = 0$

$\dot{m_1} + \dot{m_2} = m_3$

Applying energy balance to the system, neglecting change in potential and kinetic energy, and assume that there is no shaft work made by the system.



$$E_{in} = E_{out} \qquad \Delta E = 0$$
$$H_1 + \mathrm{H}_2 = H_3$$
$$m_1 h_1 + m_2 h_2 = m_3 h_3$$

The enthalpy after two liquids are mixed would be:

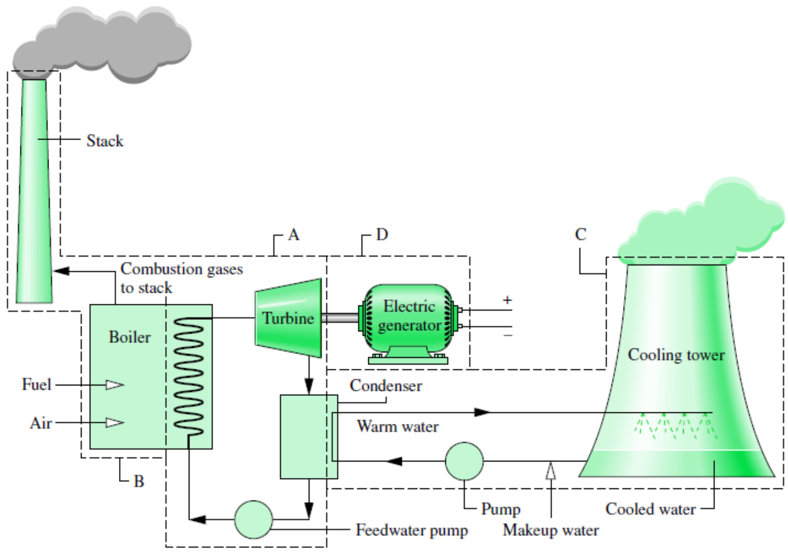
$$h_3 = \frac{m_1 h_1 + m_2 h_2}{m_3}$$

From mass balance

$$\boldsymbol{h_3} = \frac{\boldsymbol{m_1 h_1} + \boldsymbol{m_2 h_2}}{\boldsymbol{m_1} + \boldsymbol{m_2}}$$

2.16 ENERGY BALANCE IN STEAM POWER PLANT

A ***steam powerplant*** is an industrial facility that uses steam as a working substance to produce electricity. A simple steam powerplant basically has four components: The boiler, turbine, condenser, and pump.



For any system, it is possible for a system to have its ***efficiency***. The efficiency is defined as the ratio of output to input.

$$n = e = \frac{output}{input}$$

In terms of energy producing devices, the output represents the actual energy produced by the system, and the input represent the theoretical energy produced by the system.

$$\text{efficiency} = \frac{\text{actual energy produced}}{\text{theoretical energy produced}}$$

We will first investigate the efficiencies in a simple steam turbine. For a turbine, the ***turbine efficiency*** , also called as the indicated efficiency, would be

$$n_t = \frac{W_T{}'}{W_T}$$

Where $W_T{}'$ is the actual work or the indicated work of the turbine.

The ***mechanical efficiency*** is the ratio of the brake work and the indicated work. The brake work is also called as the available work, in which it is the work available at the turbine shaft.

$$n_{me} = \frac{W_B}{W'}$$

The ***electrical efficiency***, also called as the generator efficiency or alternator efficiency, is the ratio of break work to combined work. The combined work is the electrical energy available to consumers.

$$n_{ee} = \frac{W_k}{W_B}$$

The ***overall efficiency*** or also called as the ***plant efficiency*** is the ratio of electrical energy charge to the plant to the heat added due to the burning of fuel.

$$n_{over} = \frac{W_k}{Q_A{}'}$$

For the heat added when coal is used:

$$Q_A{}' = m_{coal}H_v$$

For the heat added when nuclear fuel is used:

$$\boldsymbol{Q_A}' = \frac{\boldsymbol{m_{NF}c^2}}{\boldsymbol{k}}$$

For ***energy consuming devices***, the output represents the theoretical input energy to the system, while the input represents the actual energy input to the system.

$$\textbf{efficiency} = \frac{\textbf{theoretical input energy}}{\textbf{actual input energy}}$$

For a boiler, the ***boiler efficiency*** would be the ratio of actual heat due to burning of fuel to the heat added to steam.

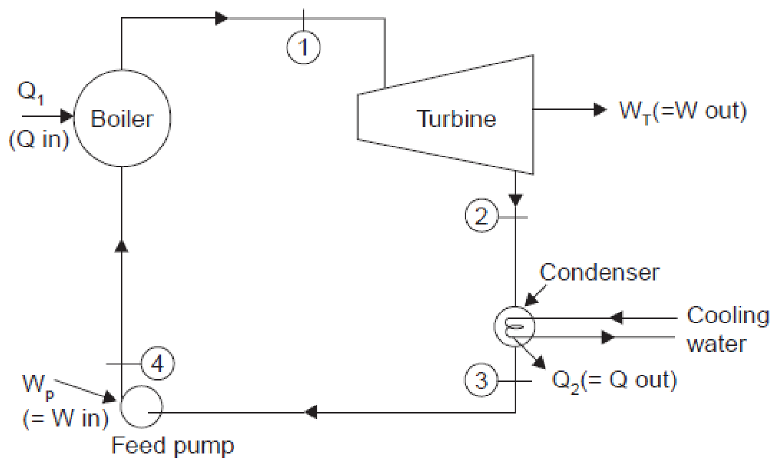
$$\boldsymbol{n_B} = \frac{\boldsymbol{Q_A}}{\boldsymbol{Q_A}'}$$

Where Q' is the actual heat added due to the burning of fuel.

For a pump, the pump efficiency is the ratio of theoretical work input to the pump to the actual work input to the pump.

$$\boldsymbol{n_p} = \frac{\boldsymbol{W_p}}{\boldsymbol{W_p}'}$$

Where W_p' is the actual pump work.



The diagram below shows a simpler version of a steam power plant. By energy balance on the whole plant:

$$E_{in} = E_{out} \quad \Delta E = 0$$

$$Q_A + W_p = W_T + Q_R$$

$$W_T - W_p = Q_A - Q_R$$

The net work would be

$$\boldsymbol{W_{net}} = \boldsymbol{W_T} - \boldsymbol{W_p}$$

Assuming that pump work is negligible compare to the value of the turbine work

$$W_{net} = W_T$$

The ***thermal efficiency*** of the powerplant, is defined as the ratio of the net work to heat added.

$$e = \frac{W_{net}}{Q_A}$$

Hence if pump work is negligible ($W_p = 0$), then

$$\boldsymbol{e} = \frac{\boldsymbol{W_T}}{\boldsymbol{Q_A}}$$

Solved Problems:

1. A fluid moves in a steady flow manner between two sections in a fluid flow line. At section 1: $A_1 = 1ft^2, v_1 = 1000fpm, v_1 = 4ft^3/lb$. At section 2:$A_2 = 2ft^2, \rho_2 = 0.20lb/ft^3$ .Calculate
   a) the flow in lb/hr
   b) The velocity at section 2 in fps.

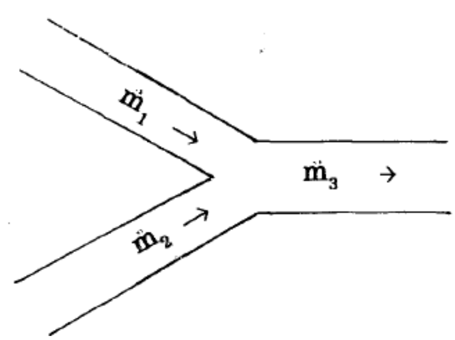
Solution:
   a) The mass flow rate at section 1 is:

$$\dot{m}_1 = \rho_1 A_1 \mathrm{v}_1$$
$$\dot{m}_1 = \frac{A_1 \mathrm{v}_1}{\nu_1}$$
$$\dot{m}_1 = \frac{(1ft^2)\left(1000\frac{ft}{min}\right)\left(\frac{60min}{1hr}\right)}{4\frac{ft^3}{lbm}}$$
$$\boldsymbol{\dot{m}_1 = 1500\frac{lbm}{hr}}$$

   b) By mass balance:

$$\dot{m}_{in} = \dot{m}_{out} \qquad \Delta m = 0$$
$$\dot{m}_1 = \dot{m}_2$$
$$\rho_1 A_1 \mathrm{v}_1 = \rho_2 A_2 \mathrm{v}_2$$
$$\frac{A_1 \mathrm{v}_1}{v_1} = \rho_2 A_2 \mathrm{v}_2$$
$$\mathrm{v}_2 = \rho_2 v_1 \mathrm{v}_1 \left(\frac{A_1}{A_2}\right)$$
$$v_2 = \left(0.20\frac{lbm}{ft^3}\right)\left(4\frac{ft^3}{lbm}\right)\left(1000\frac{ft}{min}\right)\left(\frac{1min}{60s}\right)\left(\frac{1ft^2}{2ft^2}\right)$$
$$\boldsymbol{v_2 = 6.66\frac{ft}{s}}$$

2. Two gaseous streams enter a mixing chamber through two sections and leaves through one section. Entrance conditions are $A_1 = 450cm^2, \mathrm{v}_1 = 150\ mps, v_1 = 0.625m^3/kg$ and $A_2 = 380cm^2, v_2 = 550mps, \rho_2 = 2kg/m^3$. At the exit, $v_3 = 245mps$ and $v_3 = 0.58m^3/kg$. Determine
   a) The mass flow rate at section 2 in kg/s
   b) area of the exit section in sq. cm.



Solution:
   a) The mass flow rate at section 2 is

$$\dot{m}_2 = \rho_2 A_2 \mathrm{v}_2$$
$$\dot{m}_2 = \left(2\frac{kg}{m^3}\right)(380cm^2)\left(\frac{1m}{100cm}\right)^2\left(55\frac{m}{s}\right)$$
$$\boldsymbol{\dot{m}_2 = 4.18\ \frac{kg}{s}}$$

   b) By mass balance

$$\dot{m}_{in} = \dot{m}_{out} \qquad \Delta m = 0$$
$$\dot{m}_1 + \dot{m}_2 = m_3$$
$$\rho_1 A_1 \mathrm{v}_1 + \rho_2 A_2 \mathrm{v}_2 = \rho_3 A_3 \mathrm{v}_3$$
$$\frac{A_1 \mathrm{v}_1}{v_1} + \rho_2 A_2 \mathrm{v}_2 = \frac{A_3 \mathrm{v}_3}{v_3}$$
$$A_3 = \left(\frac{v_3}{\mathrm{v}_3}\right)\left(\frac{A_1 \mathrm{v}_1}{v_1} + \rho_2 A_2 \mathrm{v}_2\right)$$

$$A_3 = \left(\frac{0.58\frac{m^3}{kgm}}{245\frac{m}{s}}\right)\left[\frac{(450cm^2)\left(150\frac{m}{s}\right)\left(\frac{1m}{100cm}\right)^2}{0.625\frac{m^3}{kgm}} + \left(2\frac{kg}{m^3}\right)(380cm^2)\left(\frac{1m}{100cm}\right)^2\left(55\frac{m}{s}\right)\right]$$

$$A_3 = 0.035463m^2\left(\frac{100cm}{1m}\right)^2$$

$$\boldsymbol{A_3 = 354.63cm^2}$$

3. The 600 kg hammer or a pile driver is lifted 2m above a piling head. Local g=9.65 m/s^2.

a) What is the change of potential energy in kJ?

b) If the hammer is released, what will be its velocity in m/s at the instant it strikes the piling?

c) Compare the values of kinetic energy and potential energy, then make a conclusion.

Solution.

a) The change in potential energy of the hammer is

$$PE = \frac{mgz}{k}$$

$$PE = \frac{(600kgm)\left(9.65\frac{m}{s}\right)(2m)}{1000\frac{kgm-m}{kN-s^2}}$$

$$\boldsymbol{PE = 11.58\ kJ}$$

b) Using the 3rd kinematic equation of motion

$$v^2 = {v_o}^2 + 2gh$$

The initial velocity at that point is zero, thus

$$v = \sqrt{2gh}$$

$$v = \sqrt{2\left(9.65\frac{m}{s}\right)(2m)}$$

$$\boldsymbol{v = 6.213\frac{m}{s}}$$

c) The kinetic energy of the system would be:

$$KE = \frac{mv^2}{2k}$$

$$KE = \frac{(600kgm)\left(6.213\frac{m}{s}\right)^2}{2\left(1000\frac{kgm-m}{kN-s^2}\right)}$$

$$\boldsymbol{KE = 11.58\ kJ}$$

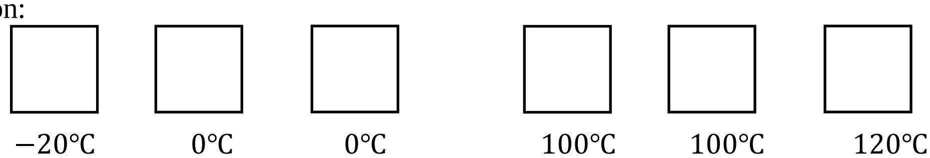
Hence we can conclude that the ***potential energy is converted into kinetic energy as it strikes the ground.***

4. The flow energy of a moving fluid at 100 GPM is 200 BTU/min, What is the gage pressure in kPag at this point?
Solution
From the definition of flow energy, in energy per unit time basis
$\dot{W}_f = P\dot{V}$
The absolute pressure at this point is defined as
$P = \frac{\dot{W}_f}{\dot{V}}$
$P = \frac{200\frac{BTU}{min}\left(\frac{778.16ft-lbf}{1BTU}\right)\left(\frac{12in}{1ft}\right)}{100\frac{gal}{min}\left(\frac{231in^3}{1gal}\right)}$
$P = 80.85lbf/in^2$
$P = 80.85\,psia$
Hence the gage pressure at that point would be

$$P_{abs} = P_g + P_{atm}$$
$$P_g = P_{abs} - P_{atm}$$
$$P_g = (80.25 - 14.7)psig\left(\frac{101.325kPag}{14.7psig}\right)$$
$$\boldsymbol{P_g = 451.83kPag}$$

5. 1 kgm/s of ice at -25C is converted into steam at 120C. Determine the following
a) The total amount of heat in kW needed in the conversion.
b) If the heater efficiency is 80%, what is the power input of the heater in CHU/hr?
c) If the heating vent has a resistance of 2kΩ, what is the voltage, the electrical charge per minute, and the conductance in mho?

Solution:



a) Recall the definition of sensible and latent heat. The heat required to convert ice to steam is:
$\dot{Q}_{tot} = \dot{Q}_{s1} + \dot{Q}_{L1} + \dot{Q}_{s2} + \dot{Q}_{L2} + \dot{Q}_{s3}$
$\dot{Q}_{tot} = \dot{m}c_{pi}\Delta t_i + \dot{m}h_f + \dot{m}c_{pw}\Delta t_w + \dot{m}h_v + \dot{m}c_{ps}\Delta t_s$
$\dot{Q}_{tot} = \dot{m}[c_{pi}\Delta t_i + h_f + c_{pw}\Delta t_w + h_v + c_{ps}\Delta t_s]$
$$\dot{Q}_{tot} = 1\frac{kgm}{s}\left[(0.5)\left(4.187\frac{kJ}{kgm-°C}\right)(0-(-25))°C + 335\frac{kJ}{kgm} + \left(4.187\frac{kJ}{kgm-°C}\right)(100-0)°C + 2257\frac{kJ}{kgm} + 0.4454\left(4.187\frac{kJ}{kgm-°C}\right)(120-100)°C\right]$$
$\boldsymbol{\dot{Q}_{tot} = 3100.23\;kW}$

b) From efficiency

$$e = \frac{output}{input}$$

Since electrical input is needed to produce the heat required

$$e = \frac{\dot{Q}_{tot}}{P}$$
$$P = \frac{\dot{Q}_{tot}}{e}$$

$$P = \frac{3100.23kW}{0.80}\left(\frac{42.41\frac{BTU}{min}}{0.746kW}\right)\left(\frac{60min}{1hr}\right)\left(\frac{1CHU}{1.8BTU}\right)$$
$$\boldsymbol{P = 7343652.50\frac{CHU}{hr}}$$

c) From electrical power

$$P = \frac{{V_0}^2}{R}$$
$$V_0 = \sqrt{PR}$$
$$V_0 = \sqrt{\frac{3100.23kW}{0.80}\left(\frac{1000W}{1kW}\right)(2000\Omega)}$$
$$\boldsymbol{V_0 = 88937.55V}$$

From ohm's law, we can determine the electric charge per minute:

$$R = \frac{V}{I}$$
$$I = \frac{V}{R}$$
$$I = \frac{880375V}{2000\Omega}$$
$$I = 44.02A\left(\frac{1C/s}{1A}\right)\left(\frac{60s}{1min}\right)$$
$$\boldsymbol{I = 2641.2\frac{C}{min}}$$

For the conductance

$$G = \frac{1}{R}$$
$$G = \frac{1}{2000\Omega}$$
$$\boldsymbol{G = 0.0005\,mho}$$

6. What is the change of internal energy in BTU, kW-hr, PS-min, kcal, erg, hp-hr, ft-lbf, and kgf-m in heating 2 kgm of oxygen gas from 540R to 5000R at constant atmospheric pressure while its volume changes by 5 ft^3 if $c_p = 0.36 - \frac{5.375}{\sqrt{T}} + \frac{47.8}{T}\ in\ BTU/lbm - °F$.

Solution:

From the microscopic definition of enthalpy

$$\Delta H = m\int c_p dT$$
$$\Delta H = m\int_{540}^{5000}\left(0.36 - \frac{5.375}{\sqrt{T}} + \frac{47.8}{T}\right)dT$$
$$\Delta H = 2kgm\left[0.36T - 2\sqrt{5.375T} + 47.8lnT\right]_{540}^{5000}$$
$$\Delta H = 2kgm\left(\frac{2.205lbm}{1BTU}\right)\left[\left(0.36(5000) - 2\sqrt{5.375(5000)} + 47.8ln5000\right) - \left(0.36(540) - 2\sqrt{5.375(540)} + 47.8ln540\right)\right]\frac{BTU}{lbm - °R}$$

$$\boldsymbol{\Delta H = 5299.29\,BTU}$$

From our macroscopic definition of enthalpy:
$\Delta H = \Delta U + \Delta W_f$
$\Delta H = \Delta U + \Delta PV$
Since Pressure is constant, $P_1 = P_2 = P$, then the internal energy would be:
$\Delta U = \Delta H - P\Delta V$
$$\Delta U = 5299.29BTU - \left(14.7\frac{lbf}{in^2}\right)(5ft^3)\left(\frac{144in^2}{1ft^2}\right)\left(\frac{1BTU}{778.16ft-lbf}\right)$$
$\Delta U = 5285.69\ BTU$

In terms in kW-hr
$$\Delta U = 5285.69BTU\left(\frac{1.055kJ}{1BTU}\right)\left(\frac{1kW-hr}{3600kJ}\right)$$
$\boldsymbol{\Delta U = 1.549\ kW - hr}$

In terms of PS-min
$$\Delta U = 1.549kW - hr\left(\frac{1P.S}{0.736kW}\right)\left(\frac{60min}{1hr}\right)$$
$\boldsymbol{\Delta U = 126.28\ PS - min}$

In terms of erg
$$\Delta U = 126.28PS - min\left(\frac{0.736kW}{1PS}\right)\left(\frac{60s}{1min}\right)\left(\frac{1kJ}{1kW-s}\right)\left(\frac{10^{10}erg}{1\ kJ}\right)$$

$\boldsymbol{\Delta U = 5.58 \times 10^{13} erg}$

In terms of hp-hr
$$\Delta U = 5.58\times 10^{13}erg\left(\frac{10^{-10}kJ}{1erg}\right)\left(\frac{1BTU}{1.055kJ}\right)\left(\frac{1hp}{42.41\frac{BTU}{min}}\right)\left(\frac{1hr}{60min}\right)$$
$\boldsymbol{\Delta U = 0.2079\ hp - hr}$

In terms of ft-lbf
$$\Delta U = 0.2079\ hp - hr\left(\frac{550\frac{ft-lbf}{s}}{1hp}\right)\left(\frac{3600s}{1hr}\right)$$
$\boldsymbol{\Delta U = 411612\ ft - lbf}$

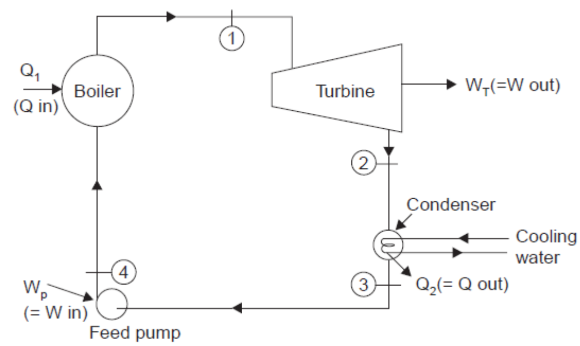
In terms of kgf-m
$$\Delta U = (411612ft - lbf)\left(\frac{1BTU}{778.16ft-lbf}\right)\left(\frac{1.055kJ}{1BTU}\right)\left(\frac{1kgf-m}{9.8066J}\right)\left(\frac{1000J}{1kJ}\right)$$
$\boldsymbol{\Delta U = 56908.84\ kgf - m}$

7. A powerplant is to produce 1×10^{15} kW-hr of energy in one year. If plant conversion efficiency is 35%, compute

a) The mass of coal needed by the plant in kgm if heating value is 20000 kcal/kgm.
b) The mass of nuclear fuel in kgm.
c) The energy wasted in the plant in CHU, PS-min, and hp-hr.
d) Recommend dimensions of a spherical tank to serve as a container of fuel in (a) and (b) if specific gravity of coal and nuclear fuel are 2 and 10 respectively.
e) The gallons of water that must circulate in the condenser if its temperature rise is 20°C.
f) The electrical output in kW-hr and hp-min if mechanical and electrical efficiencies are 85% and 93% respectively.

Solution: The schematic diagram below shows a simple operation of a steam powerplant, either using coal or nuclear fuel. A simple steam powerplant composed of four main components, the steam generating unit, turbine, condenser, and pump. In this energy analysis, we assume that the pump work is zero.

a) For the mass of coal needed,



$$e = \frac{output}{input}$$

$$e = \frac{W_T}{Q_A}$$

$$e = \frac{W_T}{m_{coal}H_v}$$

$$m_{coal} = \frac{W_T}{eH_v}$$

$$m_{coal} = \frac{(1\times10^{15}kW-hr)\left(\frac{1kJ}{1kW-s}\right)\left(\frac{3600s}{1hr}\right)}{0.35\left(20000\frac{kcal}{kgm}\right)\left(4.187\frac{kJ}{kgm}\right)}$$

$$\boldsymbol{m_{coal} = 1.23\times10^{14}kgm}$$

b) If nuclear fuel is used instead of coal

$$e = \frac{output}{input}$$

$$e = \frac{W_T}{Q_A}$$

$$e = \frac{W_T k}{m_{NF}c^2}$$

$$m_{NF} = \frac{W_t k}{ec^2}$$

$$m_{NF} = \frac{(1\times10^{15}kW-hr)\left(1000\frac{kgm-m}{kN-s^2}\right)\left(\frac{1kJ}{1kW-s}\right)\left(\frac{3600s}{1hr}\right)}{0.35\left(3\times10^8\frac{m}{s}\right)^2}$$

$$\boldsymbol{m_{NF} = 114285.71kgm}$$

c) By energy balance on the powerplant.

$$E_{in} = E_{out} \qquad \Delta E = 0$$
$$Q_A + W_p = W_T + Q_R$$

Since $W_p = 0$, then the heat rejected would be

$Q_R = Q_A - W_T$

$Q_R = m_{coal} H_v - W_T$

$Q_R = \left[(1.23 \times 10^{14} kgm)\left(20000 \frac{kcal}{kgm}\right)\left(\frac{4.187kJ}{1kcal}\right) - (1 \times 10^{15} kW - hr)\left(\frac{3600kJ}{1kW - hr}\right)\right]\left[\frac{1BTU}{1.055kJ}\right]\left[\frac{1CHU}{1.8BTU}\right]$

$\boldsymbol{Q_R = 3.52 \times 10^{18} CHU}$

In terms of PS-min

$Q_R = 3.52 \times 10^{18} CHU \left(\frac{1BTU}{1.8CHU}\right)\left(\frac{1.055kJ}{1BTU}\right)\left(\frac{1kW - s}{1kJ}\right)\left(\frac{1PS}{0.736kW}\right)\left(\frac{1min}{60s}\right)$

$\boldsymbol{Q_R = 1.51 \times 10^{17} PS - min}$

In terms of hp-hr

$Q_R = 1.51 \times 10^{17} PS - min \left(\frac{0.736kW}{1PS}\right)\left(\frac{1hp}{0.746kW}\right)\left(\frac{1hr}{60min}\right)$

$\boldsymbol{Q_R = 2.48 \times 10^{15} hp - hr}$

d) From the definition of fluid properties:

$\rho = \frac{m}{V}$

$SG = \frac{\rho}{\rho_w}$

$V = \frac{m}{SG \rho_w}$

For sphere, $V = \frac{\pi}{6} d^3$

$\frac{\pi}{6} d^3 = \frac{m}{SG \rho_w}$

Solving for the diameter d:

$d = \sqrt[3]{\frac{6m}{\pi SG \rho_w}}$

For the diameter of spherical tank to contain nuclear fuel (SG=10)

$d = \sqrt[3]{\frac{6(114285.71kgm)}{\pi(10)\left(1000 \frac{kg}{m^3}\right)}}$

$\boldsymbol{d = 2.79\ m}$

For the diameter of spherical tank to contain coal (SG=5)

$d = \sqrt[3]{\frac{6(1.23 \times 10^1 4kgm)}{\pi(5)\left(1000 \frac{kg}{m^3}\right)}}$

$\boldsymbol{d = 4897.32\ m}$

e. Doing energy balance on the condenser, taking the cooling water as working substance:

$$E_{in} = E_{out} \qquad \Delta E = 0$$

$$H_a + Q_R = H_b$$

$$Q_R = m_w c_{pw}(t_b - t_a)$$

$$Q_R = m_w c_{pw}\Delta t$$

$$Q_R = \rho_w V_w c_{pw}\Delta t$$

$$V_w = \frac{Q_R}{\rho_w c_{pw}\Delta t}$$

$$V_w = \frac{(2.48 \times 10^{15} hp - hr)\left(\frac{60min}{1hr}\right)\left(\frac{42.41BTU}{1hp - min}\right)\left(\frac{1.055kJ}{1BTU}\right)}{\left(1000\frac{kgm}{m^3}\right)\left(4.187\frac{kJ}{kgm - ℃}\right)(20℃)\left(\frac{1m^3}{1000L}\right)\left(\frac{3.785L}{1gal}\right)}$$

$$\boldsymbol{V_w = 2.10 \times 10^{16} gal}$$

f) From the turbine below, the turbine is coupled to the generator. Hence this is called a turbogenerator. The brake work is the work available at the shaft of the turbine. The power output is the power produced by the generator due to shaft rotation.

From the given figure

$$e = \frac{output}{input}$$

$$n_{ee} = \frac{P_e}{W_B}$$

$$n_{me} = \frac{W_B}{W_T}$$

$$P_e = n_{ee} n_{me} W_T$$

$$P_e = (0.85)(0.90)(1 \times 10^{15} kW - hr)$$

$$\boldsymbol{P_e = 7.65 \times 10^{14} kW - hr}$$

In terms of hp-min

$$P_e = 7.65 \times 10^{14} kW - hr\left(\frac{1hp}{0.746kW}\right)\left(\frac{60min}{1hr}\right)$$

$$\boldsymbol{P_e = 6.153 \times 10^{15} hp - min}$$

8. A shaft is applied by a torque of 200 N-m and rotates at a rate of 4000rpm. Find the power transferred by the shaft in hp and kW.

Solution: From the definition of power

$$P = Fv$$

$$P = \frac{T}{r}v$$

$$P = T\omega$$

$$P = (0.2kN - m)\left(4000\frac{rev}{min}\right)\left(\frac{2\pi}{1rev}\right)\left(\frac{1min}{60s}\right)$$

$$\boldsymbol{P = 83.78\ kW}$$

In terms of hp

$$P = 83.78kW\left(\frac{1hp}{0.746kW}\right)$$

$$\boldsymbol{P = 112.31\ hp}$$

9. A 60 hyl, 53 cm radius flywheel is slowed from 250 to 235 rpm. How much kinetic energy is released?

Solution: From the definition of kinetic energy

$$\Delta KE = \frac{m({v_2}^2 - {v_1}^2)}{2k}$$

But for angular velocity:

$$v = r\omega$$

Hence

$$\Delta KE = \frac{mr^2({\omega_2}^2 - {\omega_1}^2)}{2k}$$

$$\Delta KE = \frac{(60hyl)\left(\frac{9.8066kgm}{1hyl}\right)(0.53m)^2(235^2 - 250^2)\frac{rev^2}{min^2}\left(\frac{2\pi}{1rev}\right)^2\left(\frac{1min}{60s}\right)^2}{2\left(1000\frac{kgm - m}{kN - s^2}\right)}$$

$$\boldsymbol{\Delta KE = -6.503\ kJ}$$

Note: A negative sign indicates that the kinetic energy of the flywheel is decreasing. It is due to the fact that as speed decreases, the kinetic energy also decreases as well.

10. A spring has a natural length of 20cm and it has a length of 40cm when a constant 40N force is applied to it. How much work is done in stretching the spring from 35 cm to 38 cm?

Solution:

From Hooke's Law

$$F = kx$$

$$k = \frac{F}{x}$$

$$k = \frac{40N}{0.4m}$$

$$k = 100\ N/m$$

Solving for the work done in stretching the spring

$$W = \frac{1}{2}k({x_2}^2 - {x_1}^2)$$

$$W = \frac{1}{2}\left(100\frac{N}{m}\right)(0.38^2 - 0.35^2)m^2$$

$$\boldsymbol{W = 1.095\, J}$$

11. A train weighing 1450 tonne is pulled up a 2% grade by 5 MW engine. Train resistance is 8710kg. What is the speed of the train in kph?

Solution. The grade of the road is determined as a slope with a rise of 2 and a run of 100. Since a resisting force is acting on the train parallel to the surface of the road, hence doing summation of forces in the x' direction to solve the force required in pulling the train.

$$\sum Fx' = 0$$

$$R + Wsin\theta - F = 0$$

$$F = R + Wsin\theta$$

The power needed to pull the train is

$$P = Fv$$

The velocity made by the engine in pulling the train is

$$v = \frac{P}{F}$$

$$v = \frac{P}{R + Wsin\theta}$$

$$v = \frac{Pk}{g(m_R + m_T sin\theta)}$$

$$v = \frac{\left(5000\frac{kN-m}{s}\right)\left(1000\frac{kgm-m}{kN-s^2}\right)\left(\frac{1km}{1000m}\right)\left(\frac{3600s}{1hr}\right)}{\left(9.8066\frac{m}{s^2}\right)\left[8710 + 1450\times 10^3\left(\frac{2}{\sqrt{2^2+100^2}}\right)\right]kgm}$$

$$\boldsymbol{v = 48.68\frac{km}{hr}}$$

12. Calculate the pump horsepower rating in order to lift water from a 5m deep well to fill 5000 L tank in a minute

Solution: The power input to the pump is converted into potential energy of the water.

$$P = \frac{W}{T}$$

$$P = \frac{PE}{t}$$

$$P = \frac{mgh}{t}$$

$$P = \dot{m}gh$$

$$P = \dot{V}\rho gh$$

$$P = \dot{V}\gamma h$$

$$P = \left(5000\frac{L}{min}\right)\left(\frac{1m^3}{1000L}\right)\left(9.8066\frac{kN}{m^3}\right)(5m)\left(\frac{1hp}{0.746kW}\right)\left(\frac{1min}{60s}\right)$$

$$\boldsymbol{P = 5.48\, hp}$$

13. Calculate the power of a steam jet 15mm in diameter moving at 750 m/s. Take density of steam to be 0.794 kg/m^3.
Solution: From the steam jet, power input is fully converted into kinetic energy of steam.

$$P = \frac{W}{t}$$
$$P = \frac{KE}{t}$$
$$P = \frac{mv^2}{2kt}$$
$$P = \frac{\dot{m}v^2}{2k}$$
$$P = \frac{\rho \dot{V} v^2}{2k}$$

Since $\dot{V} = Av$

$$P = \frac{\rho A v^3}{2k}$$

Assuming the cross-sectional area is a circle, then $A = \frac{\pi}{4}d^2$, hence

$$P = \frac{\pi\rho d^2 v^3}{8k}$$
$$P = \frac{\pi\left(0.794\,\frac{\text{kgm}}{\text{m}^3}\right)(0.015m)^2\left(750\,\frac{m}{s}\right)^3}{8\left(1000\,\frac{kgm-m}{kN-s^2}\right)}$$
$$\boldsymbol{P = 29.60\ kW}$$

14. The sun generates 1 kW per square meter when used as a source of solar collector. 80% of heat collected is used to heat 3 liters per min of water. Temperature rises to 4.78°C. Recommend dimensions of a rectangular solar collector to be used in the process, assuming that length is thrice its width.

Solution: Assuming constant pressure process, the heat added to water is

$$\dot{Q}_A = \dot{m}_w c_{pw}\Delta t$$
$$\dot{Q}_A = \rho_w \dot{V} c_{pw}\Delta t \qquad \text{(Equation 1)}$$

Since only 80% of the heat collected is used to heat water, the heat transfer of the collector to the water is

$$\dot{Q}_{collector} = \dot{q}A$$
$$\dot{Q}_A = 0.80Q_{collector}$$
$$\dot{Q}_A = 0.80\dot{q}A$$

For a rectangular solar panel, $A = LW$. For the given constraints, $L = 3W$, hence the area of the solar panel as a function of width would be

$$A = 3W^2$$

Thus

$$\dot{Q}_A = (0.80)(3)\dot{q}W^2$$
$$\dot{Q}_A = 2.4\dot{q}W^2 \qquad \text{(Equation 2)}$$

Equating equations 1 and 2 and solving for the width W:

$$\rho_w \dot{V} c_{pw}\Delta t = 2.4\dot{q}W^2$$
$$W = \sqrt{\frac{\rho_w \dot{V} c_{pw}\Delta t}{2.4\dot{q}}}$$

$$W = \sqrt{\frac{\left(1000\frac{kgm}{m^3}\right)\left(5\frac{L}{min}\right)\left(4.187\frac{kJ}{kg-℃}\right)(4.78℃)\left(\frac{1m^3}{1000L}\right)\left(\frac{1min}{60s}\right)}{2.4\left(1\frac{kJ}{m^2-s}\right)}}$$

W =0.834m

Hence

$L = 3W$

$L = 3(0.834m)$

$L = 2.502\ m$

The recommended dimensions for the solar panel would be **2.502m x 0.834 m.**

15. A river flowing towards the lake at 3 m/s at a rate of 500 CMS at a location 90 m below the lake surface. Calculate

a) The total mechanical energy of the river per unit mass
b) The total energy of the river per unit mass.
c) The power generation potential of the entire river at that location.

Solution:

a) The hydrostatic pressure P below the given height is

$P_g = \gamma h$

$P_g = \left(9.8066\frac{kN}{m^3}\right)(90m)$

$P_g = 882.594kPag$

Since hydrostatic pressure is gage pressure, we shall need to find the absolute pressure

$P = P_g + P_{atm}$

$P = (882.584 + 101.325)kPaa$

$P = 983.909\ kPaa$

a) The total mechanical energy of the river per unit mass is defined as

$$e_{mech} = \frac{P}{\rho} + \frac{gz}{k} + \frac{v^2}{2k}$$

$$e_{mech} = \frac{882.594\frac{kN}{m^2}}{1000\frac{kgm}{m^3}} + \frac{\left(9.8066\frac{m}{s^2}\right)(90m)}{1000\frac{kgm-m}{kN-s^2}} + \frac{\left(3\frac{m}{s}\right)^2}{2\left(1000\frac{kgm-m}{kN-s^2}\right)}$$

$$\boldsymbol{e_{mech} = 1.77\frac{kJ}{kgm}}$$

b) The total energy of the river per unit mass is

$$e_{total} = \frac{gz}{k} + \frac{v^2}{2k} + u$$

Neglecting specific internal energy, the total energy per unit mass basis is:

$$e_{total} = \frac{gz}{k} + \frac{v^2}{2k}$$

$$e_{total} = \frac{\left(9.8066\frac{m}{s^2}\right)(90m)}{1000\frac{kgm-m}{kN-s^2}} + \frac{\left(3\frac{m}{s}\right)^2}{2\left(1000\frac{kgm-m}{kN-s^2}\right)}$$
$$\boldsymbol{e_{total} = 0.89\frac{kJ}{kgm}}$$

c) The potential energy of the river is fully converted into power. Hence

$$P = \frac{W}{T}$$
$$P = \frac{PE}{t}$$
$$P = \frac{mgh}{t}$$
$$P = \dot{m}gh$$
$$P = \dot{V}\rho gh$$
$$P = \dot{V}\gamma h$$
$$P = \left(500\frac{m^3}{s}\right)\left(9.8066\frac{kN}{m^3}\right)(90m)$$
$$\boldsymbol{P = 441297\ kW}$$

16. A 20 kg mass is initially 15m above the free surface of the water tank. Initially the stone and water are at the same temperature. If the stone falls unto the water, determine ΔU, ΔPE, ΔKE, Q, and W when

a) The stone is about to enter the water
b) The stone has come to rest in the tank
c) The heat is transferred to the surroundings in such an amount that the stone and water comes from their initial temperature

Solution:

a) Applying energy balance for closed system.

$$E_{in} = E_{out} \qquad \Delta E = 0$$
$$PE_1 + KE_1 + U_1 + Q = PE_2 + KE_2 + U_2 + W_{NF}$$
The non-flow work would be
$$W_{NF} = Q - \Delta U - \Delta PE - \Delta KE$$

Since the stone is about to enter the water, there is no heat, no work done, and no change in internal energy. Thus:
$$\boldsymbol{Q = W_{NF} = \Delta U = 0}$$
From the energy balance,
$$\Delta PE = -\Delta KE$$
The change in potential energy of the stone would be
$$\Delta PE = \frac{mg\Delta z}{k}$$
$$\Delta PE = \frac{(20kgm)\left(9.8066\frac{m}{s^2}\right)(0-15)m}{1\frac{kgm-m}{N-s^2}}$$
$$\boldsymbol{\Delta PE = -2941.98\,J}$$

The change in kinetic energy is:

$$\boldsymbol{\Delta KE = 2941.98\,J}$$

b) When the stone has come to rest in the tank , there is no heat, no work done, no change in kinetic energy but as the stone comes in contact with water, the internal energy of the water increases by the magnitude of the potential energy of the stone.

From the energy balance

$\boldsymbol{E_{in} = E_{out}} \qquad \boldsymbol{\Delta E = 0}$
$PE_1 + KE_1 + U_1 + Q = PE_2 + KE_2 + U_2 + W_{NF}$
$W_{NF} = Q - \Delta U - \Delta PE - \Delta KE$

Since

$$\boldsymbol{Q = W_{NF} = \Delta KE = 0}$$

Then

$$\Delta U = -\Delta PE$$

The change in potential energy of the stone would be

$$\Delta PE = \frac{mg\Delta z}{k}$$

$$\Delta PE = \frac{(20kgm)\left(9.8066\frac{m}{s^2}\right)(0-15)m}{1\,\frac{kgm-m}{N-s^2}}$$

$$\boldsymbol{\Delta PE = -2941.98\,J}$$

The change in internal energy would be:

$$\boldsymbol{\Delta U \;=\; 2941.98\,J}$$

c) When the water and stone come from their initial temperature, there is no work done, and zero change in kinetic energy. The heat is equivalent to the internal energy, which is equal also to the potential energy as the stone comes to rest.

By energy balance
$E_{in} = E_{out} \qquad \Delta E = 0$
$PE_1 + KE_1 + U_1 + Q = PE_2 + KE_2 + U_2 + W_{NF}$
$W_{NF} = Q - \Delta U - \Delta PE - \Delta KE$

Since

$$\boldsymbol{W_{NF} = \Delta KE = 0}$$

Since the potential energy is converted to internal energy:

$$\boldsymbol{\Delta U = -\Delta PE = 2941.98\,J}$$

Hence

$$Q = -\Delta U$$

$$\boldsymbol{Q = -2941.98\,J}$$

17. A fluid enters an apparatus at 450 fps, initially, the pressure of the fluid is 120 psia, the specific volume of 5 cu. ft. per lb., and the internal energy is 390 BTU/lb. The fluid leaves the apparatus at 25 psia, specific volume of 20 cu. ft. per lb., an exit velocity of 1000 fps, and internal energy of 120 BTU/lb. The heat radiation loss is 10 BTU/lb. Determine the work steady flow.

By energy balance on per unit mass basis:

$e_{in} = e_{out} \qquad \Delta e = 0$

$pe_1 + ke_1 + w_{f1} + u_1 = q_r + pe_2 + ke_2 + w_{f2} + u_2 + w_{SF}$

The steady flow work in energy per unit mass basis would be

$w_{SF} = -q_r - \Delta pe - \Delta ke - \Delta w_f$

$$w_{SF} = \left[-q_r - \frac{g(z_2 - z_1)}{k} - \frac{{v_2}^2 - {v_1}^2}{2k} - (P_2 v_2 - P_1 v_1) - (u_2 - u_1)\right]$$

Neglecting change in potential energy, $\Delta pe = 0$

$$w_{SF} = \left[q - \frac{{v_2}^2 - {v_1}^2}{2k} - (P_2 v_2 - P_1 v_1) - (u_2 - u_1)\right]$$

$$w_{sf} = -10\frac{BTU}{lbm} - \frac{(1000^2 - 450^2)\frac{ft^2}{s^2}}{2\left(32.174\frac{lbm - ft}{lbf - s^2}\right)} - [25(20) - 120(5)]\frac{lbf}{in^2}\frac{ft^3}{lbm}\left(\frac{144in^2}{ft^2}\right)\left(\frac{1BTU}{778.16ft - lbf}\right)$$

$$\boldsymbol{w_{SF} = 262.58\frac{BTU}{lbm}}$$

18. A turbine operates under steady flow conditions, receiving steam at the following state: pressure 1000 kPa, temperature 180 deg. C, enthalpy 2700 kJ/kg, speed 50 m/s, and elevation 2 m. The steam leaves the turbine at the following state: pressure 50 kPa, enthalpy 2500 kJ/kg, speed 100 m/s, and elevation 0 m. Heat is lost to the surroundings at the rate of 0.50 kJ/s. If the rate of steam flow through turbine is 0.50 kg/s, what is the power output of the turbine in kW.

Solution: By energy balance in the turbine.

$E_{in} = E_{out} \qquad \Delta E = 0$

$PE_1 + KE_1 + W_{f1} + U_1 = Q_R + PE_2 + KE_2 + W_{f2} + U_2 + W_{SF}$

$PE_1 + KE_1 + H_1 = Q_R + PE_2 + KE_2 + H_2 + W_{SF}$

$W_{SF} = -Q_R - \Delta PE - \Delta KE - \Delta H$

The steady flow work would be:

$$W_{SF} = -\dot{Q}_R - \dot{m}\left[\frac{g(z_2 - z_1)}{k} + \frac{{v_2}^2 - {v_1}^2}{2k} + (h_2 - h_1)\right]$$

$$W_{SF} = -0.50\frac{\text{kJ}}{\text{s}} - \left(0.50\frac{kgm}{s}\right)\left[\frac{\left(9.8066\frac{m}{s^2}\right)(0 - 2)m}{10000\frac{kgm - m}{kN - s^2}} + \frac{(50^2 - 100^2)\frac{m^s}{s^2}}{2\left(10000\frac{kgm - m}{kN - s^2}\right)} + (2500 - 2700)\frac{kJ}{kgm}\right]$$

$$\boldsymbol{\dot{W}_{SF} = 101.385kW}$$

19. A steady state steady flow compressor draws 500CFM of air whose density is 0.079 lb/cu.ft and discharge it with a density of 0.304 lb/cu.ft. At suction, pressure is at 15 psia, at discharge, pressure is at 80 psia. The increase in specific internal energy 33.8 BTU/lb. The heat comes from the air cooling is 13 BTU/lb. Neglect changes in potential and kinetic energy., determine the work done on the air in BTU/min.

Solution:
The mass of air entering the compressor is
$\dot{m} = \dot{m}_1 = \rho_1 \dot{V}_1$ (Equation 1)

By energy balance
$E_{in} = E_{out} \qquad \Delta E = 0$
$PE_1 + KE_1 + W_{f1} + U_1 += Q_R + PE_2 + KE_2 + W_{f2} + U_2 + W_{SF}$
$W_{SF} = -Q_R - \Delta PE - \Delta KE - \Delta W_f - \Delta U$

Neglecting change in kinetic and potential energy, then the steady flow work would be:
$W_{SF} = -\dot{m}[q + (P_2 v_2 - P_1 v_1) + \Delta u\,]$ (Equation2)

Substituting equation 1 to equation 2, then
$W_{SF} = -\rho_1 \dot{V}_1 [q + (P_2 v_2 - P_1 v_1) + \Delta u\,]$

$$W_{SF} = -\rho_1 \dot{V}_1 \left[q + \left(\frac{P_2}{\rho_2} - \frac{P_1}{\rho_1}\right) + \Delta u\,\right]$$

$$W_{SF} = -\left(0.079 \frac{lbm}{ft^3}\right)\left(500 \frac{\mathrm{ft}^3}{\mathrm{min}}\right)\left[13 \frac{BTU}{lbm} + \left(\frac{80}{0.304} - \frac{15}{0.079}\right)\frac{lbf}{in^2}\frac{ft^3}{lbm}\left(\frac{144 in^2}{1 ft^2}\right)\left(\frac{1BTU}{778.16 ft - lbf}\right) + 33.8 \frac{\mathrm{BTU}}{\mathrm{lbm}}\right]$$

$$\boldsymbol{W_{SF} = -2384.28 \frac{BTU}{lbm}}$$

20. 15 lbm/min of steam passes through a turbine at a specific enthalpy of 15000 BTU/lbm, 30 fps velocity and a pressure of 10 kip/ft^2. It leaves at the exit section 10 ft from the entrance section with a specific enthalpy of 10000 BTU/lbm and 20 fps velocity. If the heat lost from the turbine is 15% of the turbine work, and the mechanical and electrical efficiencies are 80% and 90% respectively, determine the power developed in the turbine in SI units.

Solution. By energy balance:
$E_{in} = E_{out} \qquad \Delta E = 0$
$PE_1 + KE_1 + H_1 = Q_R + PE_2 + KE_2 + H_2 + W_{SF}$

The steady flow work is
$W_{SF} = -Q_R - \Delta PE - \Delta KE - \Delta H$

Since $Q_R = 0.15 W_{SF}$, then
$W_{SF} = -Q_R - \Delta PE - \Delta KE - \Delta H$
$W_{SF} = -0.15 W_{SF} - \Delta PE - \Delta KE - \Delta H$
$1.15 W_{SF} = -\Delta PE - \Delta KE - \Delta H$

$$W_{SF} = \frac{-\Delta PE - \Delta KE - \Delta H}{1.15}$$

$$W_{SF} = -\frac{m}{1.15}\left[\frac{g(z_2 - z_1)}{k} + \frac{{v_2}^2 - {v_1}^2}{2k} + (h_2 - h_1)\right] \quad \text{(Equation1)}$$

Since the turbine is coupled to a generator having mechanical and electrical efficiencies, the power output would be

$$e = \frac{output}{input}$$

$$n_{ee} = \frac{P}{W_B}$$

$$n_{me} = \frac{W_B}{W_T}$$

$$P = n_{ee} n_{me} W_T \qquad \text{(Equation 2)}$$

Since $W_T = W_{SF}$, then substitute equation 1 to 2:

$$P = \frac{-n_{ee} n_{me} m}{1.15}\left[\frac{g(z_2 - z_1)}{k} + \frac{{v_2}^2 - {v_1}^2}{2k} + (h_2 - h_1)\right]$$

$$P = \frac{-(0.80)(0.90)\left(15\frac{lbm}{min}\right)}{1.15}\left[\left[\frac{\left(32.174\frac{ft}{s^2}\right)(0-10)ft}{32.174\frac{lbm-ft}{lbf-s^2}} + \frac{(20^2 - 30^2)\frac{ft^2}{s^2}}{2\left(32.174\frac{lbm-ft}{lbf-s^2}\right)}\right]\left[\frac{1BTU}{778.16ft-lbf}\right] + (10000 - 15000)\frac{BTU}{lbm}\right]\left(\frac{0.746kW}{42.41\frac{BTU}{min}}\right)$$

The electrical power available would be:

$$\boldsymbol{P = 825.98kW}$$

21. A steady flow steady state thermodynamic system receives 100 lb/min of a fluid at 30 psia and 20°F and discharges at a point 80 ft above the entrance section at 150 psia and 600°F. The fluid enters with a velocity of 7200 fpm and leaves with a velocity of 2400 fpm. During this process, there are supplied 25000BTU/hr of heat from an external source, and the increase in enthalpy is 2 BTU/lb. Determine the work done in hp and kgf-m/min.

Solution: By energy balance on the turbine:

$$E_{in} = E_{out} \qquad \Delta E = 0$$

$$PE_1 + KE_1 + H_1 + Q_A = +PE_2 + KE_2 + H_2 + W_{SF}$$

$$W_{SF} = Q_A - \Delta H - \Delta PE - \Delta KE$$

$$W_{SF} = Q_A - \dot{m}\left[\Delta h + \frac{g(z_2 - z_1)}{k} + \frac{{v_2}^2 - {v_1}^2}{2k}\right]$$

$$W_{SF} = 25000\frac{BTU}{hr}\left(\frac{1hr}{60mins}\right) - \left(100\frac{\text{lbm}}{\text{min}}\right)\left[2\frac{\text{BTU}}{\text{lbm}} + \left[\frac{\left(32.174\frac{ft}{s^2}\right)(80-0)ft}{32.174\frac{lbm-ft}{lbf-s^2}} + \frac{(2400^2 - 7200^2)\frac{ft^2}{min^2}\left(\frac{1min}{60s}\right)^2}{2\left(32.174\frac{lbm-ft}{lbf-s^2}\right)}\right]\left[\frac{1BTU}{778.16ft-lbf}\right]\right]$$

$W_{SF} = 92231.96\frac{BTU}{min}$

In terms of hp:

$$W_{SF} = 92231.96\frac{BTU}{min}\left(\frac{1hp}{42.41\frac{BTU}{min}}\right)$$
$\boldsymbol{W_{SF} = 2174.77hp}$

In terms of kgf-m/min

$$W_{SF} = 2174.77hp\left(\frac{0.746kW}{1hp}\right)\left(\frac{1PS}{0.736kW}\right)\left(\frac{75\frac{kgf-m}{s}}{1PS}\right)\left(\frac{60s}{1min}\right)$$
$\boldsymbol{W_{SF} = 9.92 \times 10^6\frac{kgf-m}{min}}$

22. What is the temperature change in dropping water into a 15m waterfalls in kelvin?

Solution: By energy balance, assuming that no heat is added or rejected by the water, and there is no shaft work present in the system, Neglect also change in kinetic energy.

$E_{in} = E_{out} \qquad \Delta E = 0$
$PE_1 + H_1 = PE_2 + PE_2$
$\Delta H = \Delta PE$

Expressing enthalpy in terms of specific heat at constant pressure (microanalysis), then
$\Delta H = \Delta PE$
$$m_w c_{pw}\Delta T = \frac{m_w g(z_2 - z_1)}{k}$$

Solving for ΔT
$$\Delta T = \frac{g(z_1 - z_2)}{kc_{pw}}$$
$$\Delta T = \frac{\left(9.8066\frac{m}{s^2}\right)(15-0)m}{\left(1000\frac{kgm-m}{kN-s^2}\right)\left(4.187\frac{kN-m}{kgm-K}\right)}$$
$\boldsymbol{\Delta T = 0.03513\ K}$

23. A closed gaseous system undegoes a reversible process during which 25 BTU of heat are rejected. The volume changes from 5 to 2 cubic foot, and the pressure remains at 50psia, find the change in internal energy.

Solution: By energy balance

$E_{in} = E_{out} \qquad \Delta E = 0$

$W_{NF} = Q_R + \Delta U$

Since the work non flow can be determine as the area under the PV diagram:

$$W_{NF} = \int_1^2 PdV$$

Since the pressure is constant, then

$$W_{NF} = P\int_1^2 dV$$

Integrating yields:

$W_{NF} = P(V_2 - V_1)$

Hence the change in internal energy would be

$\Delta U = W_{NF} - Q_R$

$\Delta U = P(V_2 - V_1) - Q_R$

$$\Delta U = \left(50\frac{lbf}{in^2}\right)(5-2)ft^3\left(\frac{144in^2}{1ft^2}\right)\left(\frac{1BTU}{778.16ft-lbf}\right) - 25BTU$$

$\boldsymbol{\Delta U = 2.758\ BTU}$

24. During a reversible process executed by a non flow system, the pressure increases from 344.7 kPa to 1378.96 kPa in accordance to PV=C. If the initial volume is 85 liters, and the internal energy increases by 22577J, Find the heat transfer in kJ.

Solution: By energy balance, since an increase in pressure means work is done to compressed the fluid, and is need to reject heat.

$E_{in} = E_{out} \qquad \Delta E = 0$

$W_{NF} = Q_R + \Delta U$

Since the work non flow can be determine as the area under the PV diagram:

$$W_{NF} = \int_1^2 PdV$$

From the given law, $PV = C$, also

$P_1V_1 = P_2V_2 = C$

$$\frac{V_2}{V_1} = \frac{P_1}{P_2}$$

$$P = \frac{C}{V}$$

Integrating

$$W_{NF} = C\int_1^2 \frac{dV}{V}$$

$W_{NF} = C[lnV]_1^2$

$W_{NF} = C(lnV_2 - lnV_1)$

$$W_{NF} = Cln\frac{V_2}{V_1}$$

Since $C = P_1V_1 = P_2V_2$, then

$$W_{NF} = P_1V_1 ln\frac{V_2}{V_1}$$

Since $\frac{V_2}{V_1} = \frac{P_1}{P_2}$, then the non flow work would be:

$W_{NF} = P_1V_1 ln\frac{P_1}{P_2}$

This the heat transfer would be

$Q_R = W_{NF} - \Delta U$

$Q_R = P_1V_1 ln\frac{P_1}{P_2} - \Delta U$

$Q_R = \left(344.7\frac{kN}{m^2}\right)(85L)\left(\frac{1m^3}{1000L}\right) ln\frac{344.7kPaa}{1378.98kPaa} - 22.577kJ$

$\boldsymbol{Q_R = -63.121kJ}$

25. A rigid tank contains a hot fluid that is cooled while being stirred by a paddle wheel. Initially, the internal energy of the fluid is 800 kJ. During the cooling process, the fluid loses 500 kJ of heat, and the paddle wheel does 100 kJ of work on the fluid. Determine the final internal energy of the fluid. Neglect the energy stored in the paddle wheel.

By energy balance, assuming that the system considering is a closed system:

$E_{in} = E_{out} \qquad \Delta E = 0$

$W_{Paddle} + U_1 = Q_R + U_2$

Solving for the final internal energy:

$U_2 = W_{Paddle} + U_1 - Q_R$

$U_2 = (100 + 800 - 500)kJ$

$\boldsymbol{U_2 = 400kJ}$

SUPPLEMENTARY PROBLEMS

CHAPTER II. ENERGY AND POWER CONCEPTS

Directions: Solve the following problems and show all complete solutions**. Any form of erasures in your solutions will consider your whole answer as wrong.** Always enclosed your final answer. Answers with wrong units are considered as wrong. Take you final answer atleast two or three decimal places.

Conservation of Mass

1. A 0.70 g/cc liquid flows through a 5 cm inside diameter pipe at 8 m/s. Determine the mass flow rate in kg/s.

Ans: 11 kg/s

2. How many gallons of water per minute is flowing through a 10 in inside diameter tube at a speed of 10 m/s?

Ans:8032.35 gpm

3. If it takes 12 seconds to empty a one-liter oil container, then what is the mass flow rate of oil leaving the container? Take the density of oil to be 850 kg/m^3.

Ans: 0.0708 kg/s

4. A pump discharges 20 kg/min of diesel of relative density of 0.8 to a spherical tank. It takes 1 hour, 20 minutes, and 36 seconds to fill the said tank. What is the diameter of the tank in meters?

Ans: 1.567 m

5. A horizontal pipe of cross section 8 cm^2 has a constriction of cross section of 2 cm^2. Gasoline flows in the larger pipe with a speed at 10 cm/s. What is the speed in the constriction in cm/s?

Ans: 40 cm/s

6. Air flows through the compressor under steady flow conditions. At suction, specific volume is 0.75 cubic meter per kg, velocity of 30 m/s. At discharge, 0.25 cubic meter per kg of specific volume, and velocity of 40 m/s. Determine the diameter ratio of the discharge pipe to the suction pipe.

Ans:$d_2/d_1 = 0.50$

7. Water is being drained through a hole at the bottom of a tank at a velocity of 10m/s. For a tank diameter of 1.18m and a hole diameter of 5cm, find the rate of change of water level in the tank in meters per minute.

Ans: 1.08 m/min

8. Determine the volume flow rate of oil as it flows at 1.75 m/s through 20 tubes, each tube having 20mm inside diameter.

Ans:0.011 m^3/s

9. A 9.95 ft diameter by 14.96 ft height is receiving water at a rate of 299 GPM and discharging through a 5.49 in I.D. line with a constant velocity of 5.1 fps. At a given instant, the tank is half full. Find the water level in cm and the mass change in the tank in lbm 13 mins later.

Ans: 165.85 cm, 9883.874 lbm

10. Fluid flows in a steady flow manner through a converging tube. At inlet, the pressure is 690 kPaa and a constant density of 0.838 kgm/m^3. If 125 m^3/min of air enters at the rate of 94 meters per minute, and the exit section has an inside diameter of 350 mm, determine:
   a) The mass flow rate in kg/min.
   b) The diameter of the entrance section in mm.
   c) The exit velocity in meters per minute

Ans: a) 104.75 kg/min, b)1301.21 mm, c) 1299.32 kg/min

Energy and Mass Relation

11. It is estimated that the annual electrical energy consumption in the country is 1.58 x 10^{17} J. Determine how many kilograms of matter would have to be converted to produce this much energy?

Ans: 1.76 kgm

12. It is estimated that the United States consumes annually about 1.75 x 10^{15} W-hr of electrical energy. How many kilograms of matter would have to be destroyed to yield this energy?

Ans: 1.17 kgm

13. Scientist have recently developed a powerful pulse laser for research in materials. Find its energy output in each of the following conditions:
   a) 20 J in 10 psec in hp.
   b) 200J in 35 nsec in BTU/min and kgf-m/min.
   c)800J in 1msec in CV
   d)At its peak pulse, it will produce 10 terawatts for a period of 10 psec, find its discharge in hp-hr and CHU.

Ans: a) 2.68x10^9 hp, b) 3.25x10^8 BTU/min, 3.49 x 10^{10} kgf-m/min, c) 1086.96 CV, d) 0.0396 hp-hr

14. A system contains a unit gram mass of matter. How much energy in kJ may be derived from this system if all of the mass could be converted into energy? What will be its mass in grams when its moves at one half-light speed?

Ans: 300kJ, 1.1547 gm

15. A cryogenic picovoltmeter using liquid helium reads 4 pV when used in a circuit upon which 80mA has been impressed. Find the resistance of the circuit in pΩ and power in fW, BTU/min, and metric hp.

Ans: 50 pΩ, 320 fW,

16. An electron has a rest mass of 9.11 x 10^{-28} gm. What is its mass when moving with a speed of 0.90c?

Ans: 2.09x10^{-27} gm

17. A nuclear bomb containing plutonium releases 1.62 x 10^{14} J of energy during a 1 microsecond explosion. If the rest mass of the products is less than the original mass by 1/10000, determine:

a) The power produced by the explosion in BTU/min, kW, and hp.
b) The original mass of the plutonium in lbm.

Ans: a) 9.2 x 10^{18} BTU/min, b) 39.69 lbm

Potential and Kinetic Energy

18. A rocket with mass of 3500 lb travels at 27860 fps. Determine its kinetic energy in CHU

Ans: 1081.86 CHU

19. A diver hits the water 5 meters deeps from a certain height 0.79 seconds later. At what height did the diver jumped?

20. A ball is thrown vertically upward from the ground and a student gazing out the window sees it moving upward pass him at 5m/s. The window is 10m above the ground. How high does the ball go above the ground?

Ans: 11.27 m

21. A 200 gram apple is thrown from the edge of a tall building with an initial speed of 20m/s. What is the change in kinetic energy in hp-sec if it strikes the ground at 50 m/s? What is the height of the building in ft?

Ans: 0.2815 hp-s, 351.30 ft

22 The combined mass of a car and its passenger travelling at 72 kph is 1500kgm. Find the kinetic energy of the combined mass in kW-hr.

Ans. 5 kW-hr

23. A car of mass 2000 kg travels with a velocity of 75 km/h. Find the kinetic energy. How high should it be lifted in the standard gravitational field to have a potential energy that equals the kinetic energy?

24. A 10-kg body falls from rest, with negligible interaction with its surroundings (no friction). Determine its velocity after it falls 5 m.

25. Compute the kinetic energy of a 3lb mass, when it falls in air from rest through a height of 15500in in BTU.

26. A 50 lb mass has a potential energy of -4 BTU with respect to a given datum within the earth's standard gravitational field.

a) Find its height in ft relative to the datum.
b) If the gravitational field is suddenly disturbed such that the local gravity becomes 25 fps^2, what will be the potential energy of the mass in BTU?

Ans:

27. A 300 lbm hammer or a pile driver is lifted 3ft above a piling head. Local g=32.0 ft/s^2.

a) What is the change of potential energy in kJ, BTU, and CHU?
b) If the hammer is released, what will be its velocity in m/s at the instant it strikes the piling?

28. A girl weighing 470N holds suspended on the end of a rope 8m long.

a) What will be her gain in potential energy in BTU when a friend swings her to one side so that the rope makes an angle of 35 degrees with the vertical?
b) If local g=9.65 m/s^2, what is her mass in kg and lb?

Ans: a) 0.65 BTU, b) 48.45 kgm, 106.83 lbm

29. There are 400 kg/min of water being handled by a pump. The lift is from a 20 m deep well and the delivery velocity is 15m/s. Local g=9.70 m/s^2.Find:

a) The change in potential energy in kJ/kgm, BTU/lbm, and kgf-m/kgm.
b) The kinetic energy in CHU/lbm and erg/gm?
c) The required power of the pumping unit in hp, BTU/hr, and kgf-m/s

Ans. a) 0.194 kJ/kgm, b)0.02687 CHU/lbm, c)

30. When an automobile is travelling at 60 km/hr, its engine is developing 25 hp.

a) Find the total resisting force in N.
b) Find the total resisting force in N if the road is 2% graded.
c) Assuming that the resisting force is proportional to the speed, what horsepower must the engine develop to drive the automobile at 100km/hr.

31. A 2000 kg elevator accelerated upward uniformly at 1m/s^2 from a stop position. Local g=9.70 m/s^2.

a) What is the tension of the lifting cable in N?

b) At the end of 4s operation, what will be the kinetic and change in potential energy , both in kJ and also in BTU?

32. A system is composed of a 10000 lb elevator moving downward with 5fps and a 6000lb counterweight moving upward at 5 fps, and a braking pulley with connecting cables. Assume the kinetic energy of the cable and rotating parts to be negligible, determine the frictional energy absorbed by the break when the elevator is uniformly stopped in 4ft in ft-lbf and BTU.

33. A 64000 lbm airplane is traveling at 1000fps.

a) How much is the kinetic energy in hp-hr?

b) If it suddenly noses vertically upward at this speed at g=32 ft/s^2, through what vertical distance will it moves in miles?

34. There are required 33.76kJ of gravitational work to elevate a mass 76.22m in the earth's gravitational field where the local gravity is 9.75 m/s^2

a) Find its mass in kg.

b) If the initial potential energy of the mass was 10551Nm with respect to the earth's surface, determine the final elevation in meters above the surface.

Flow Energy

35. The flow energy of a moving fluid at 10 barrels per minute is 5hp.What is the vacuum pressure in psia at this point?

36. A pump forces 1 GPM of water horizontally from an open well to a closed tank where the pressure is 0.01 MPa. Compute the work the pump must do upon the water in an hour just to force the water into the tank against the pressure.

37. A centrifugal air compressor compresses 200 CFM from 12 psia to 90 psia. The initial and final specific volumes are 12.6 and 3.25 ft^3/lbm respectively. If the inlet suction line is 4 in inside diameter and the discharge line is 25 in inside diameter. Determine

a) The flow rate in lb/min and bbl/min.

b) The change in velocity in fps.

c) The change in flow energy in ft-lbf/min, hp-hr/min, PS-min/hr, kcal/hr, kW, kgf-m/hr, and atm-ft^3/min.

Internal Energy

38. An insulated tank initially contains 0.25 kg of gas with an internal energy of 200 kJ/kg. Additional gas with an internal energy of 300 kJ/kg and enthalpy of 400 kJ/kg enters the tank until the total mass of gas contained is 1 kg. Compute for the final internal energy in kJ/kg of the gas in the tank

39. In an internal combustion engine, during the compression stroke the heat rejected to the cooling water is 50 kJ/kg and the work input is 100 kJ/kg. Compute the change in the internal energy of the working fluid.

40. A solar collector receiving solar radiation at the rate of 0.6 kW/m^2 transforms it to the internal energy of a fluid. The fluid is heated from 313K to 350 K to run a heat engine. If the heat engine has efficiency of 50% and is to deliver 2.5 kW power, what is the minimum area of the solar collector?

41. A body containing 0.5 kg of gas whose c_v=0.98 kJ/kg-K falls from a balloon 4 km above the earth's surface. Find the temperature rise of the gas when the box hits the ground

42. The internal energy of a system is a function of temperature given by the formula $E=30+0.27t$ in kJ. If this system executes a process for which the work done by it per degree temperature increases is 0.75 kN-m, what is the heat interaction per degree temperature increases in kJ?

43. The specific internal energy of a certain system is given by the equation $u = 66.77 + 0.30(t - 100) + 0.0078(v - 0.0161)$ where t is in °F and v is in cu.ft / lbm. If pressure is constant at 100 psig and volume changes from 0.01608 to 0.01658 cu.ft / lbm, then the temperature changes from 100°F to 200°F. Find the values of specific heat at constant pressure and specific heat at constant volume

44. Thermally insulated battery is being discharged at atmospheric pressure and constant volume. During a 1 hour test it is found that a current of 50 A and 2 V flows while the temperature increases from 20°C to 32.5°C. Find the change in internal energy of the cell during the period of operation.

45. A 0.8-lbm object traveling at 200 ft/sec enters a viscous liquid and is essentially brought to rest before it strikes the bottom. What is the increase in internal energy, taking the object and the liquid as the system? Neglect the potential energy change.

46. A vertical piston cylinder arrangement has a piston mass of 50 kg with a face area of 300cm^2, containing 10 g of air. The initial volume occupied by the air is 5L. A decrease in internal energy amounting to 4kJ occurs because of the temperature difference between the surroundings and the volume inside the cylinder that caused the volume to decrease by 2L. The atmospheric pressure at the top of the piston is 101.325 kPa. Neglect friction effects between the surface of the piston and the cylinder. Determine the change in internal energy of air in kJ/kg.

47. A piston cylinder contains 0.50 kg of air and is fitted with electrical resistor. The mass of the piston is 60 kg and with a face area of 1500 cm^2. The heat transfer produced by the electric current passes through the resistor is 2 kJ that caused the volume to increase by 50 L, while maintaining a constant pressure. At initial and final state, the air and the piston are at rest. Neglect the friction effects between the surface of the piston and the cylinder and take local acceleration due to gravity at standard conditions. Determine the change in internal energy in kJ.

48. There are 2 kg of fluid mass in a closed container at rest on a given datum line at local g=9.75 m/s^2 . The container is now raised vertically up to 1000 m. Initially the internal energy of the fluid was 20 kJ. Determine the final internal energy if swirling velocity of the fluid is 50 m/s.

Heat

49. If 2BTU of heat is added to 15 lb of water, determine the temperature rise in C

50. Water initially at 35°C flowing through a pipe losses 14 kW of heat to the surrounding so that its temperature is reduced by 28°C. Determine the mass of water flow in kg/s.

51. A 4 kW 20L water heater is switched on for 10 minutes. The heat capacity of water is 4.187 kJ/kg-K. Assuming total electrical energy has gone into heating the water, find the increase in water temperature.

52. An electric storage battery which can exchange heat goes through a complete cycle of two processes. In process 1 to2, a 2.8 kW-h of electrical work-flow into the battery while 732 kJ of heat flow out to the atmosphere. During process 2-1, 2.4 kW-h of work flow out the battery. What is the heat transfer from process 2 to 1?

53. 2 lbm/s of ice at -30F is converted into steam at 300F. Determine the following

a) The total amount of heat in kW needed in the conversion.

b) If the heated efficiency is 90%, what is the power input of the heater in CHU/hr and kgf-m/s?

54. A 12-gram piece of aluminum (c_p = 0.215 cal/g-K) at 70°C is placed in a beaker that contains 35 grams of water at 15°C. At what temperature will they come to thermal equilibrium?

55. 30 grams of gas inside a cylinder fitted with a piston has a temperature of 150 ℃. The piston is moved with a mean force of 200 N so that it moves 60 mm and compressed the gas. The temperature rises to 21°C as a result. Calculate the heat transfer given c_v = 718 J/kg-K.

56. A 100 g copper vessel contains 150 g of water at 25°C. A 60 g block at 70°C is dropped to the water. The temperature equilibrium is 32°C. If the specific heat of copper is 0.093 kcal/kg-°C, what is the specific heat of the block?

57. A 1/4 cubic meter of water contained in a 1kg aluminum and heated from 20℃ to 25℃. Specific heat of aluminum is 20% that of water. What is the total heat gained by the water and container in cal?

58. 0.5 lbs of water and 0.5 lbs of ice are in thermal equilibrium at 0°C. If 0.75lb of steam at 120°C are added,

a) Find the final temperature of the mixture
b) How many kilograms of steam condensed?

59. A closed system consists of 1 gram of water. When vaporized at 1 atm, it occupies 1671 cm^3; the heat of vaporization is 539 cal/gram. Find the external work and the increase in enthalpy during vaporization in calories.

60. A 1.2kΩ 30A heater converts *m* kg of ice at -10C to steam at 130C for 10 mins. Determine the amount *m* of ice that is converted to steam.

61. Water at 30°C is to be cooled by putting ice cubes at 0°C, each ice cube has a mass of 5g. Water is stored in a glass having a water equivalent of 5g. How many ice cubes should be added to water to reach -3°C?

62. Determine the amount of saturated steam needed to convert 10 kgm of ice to water at 40°C in kgm at constant atmospheric pressure if the final temperature of the water from steam is the same as the temperature of water from the ice.

63. A classroom has a seating capacity of 50, and each student dissipates an average heat rate of 18 BTU/hr. The classroom also contains 5 light bulbs, when opened each dissipates 30 W of heat. On an average 8 hr teaching operations, walls from the classroom absorbs 100 kJ of heat.

a) If 50hp air conditioner is bought to cool down the classroom and to be used for meeting purposes after teaching hours, how many air conditioners should be bought?

b) If electricity charge amounts to ₱8.25 per kW-hr, how much should be charged to the school for using the classroom, assuming that the aircon and 5 light bulbs are on, and there are 2kW allowance electricity usage for personal used.

64. Determine the change of enthalpy in kJ needed to heat 1 lbm of hydrogen gas from 540 R to 5400 R if

$$c_p = 0.364 + \frac{1.87T}{10^4} + \frac{9.95}{\sqrt{T}};\ BTU/lbm - °R$$

65. A boiler contains 50 gallons of water. Heat transfer rate in water is given by $\dot{Q} = 80(450 - T)$, where $\dot{Q}$ is in BTU/hr and T is the temperature of water at any instant in °F. How many minutes does it take to heat water from its ice point to its steam point?

66. In an oil cooler, oil flows steadily through a tube submerged in a steady stream of cooling water. Under the steady flow conditions, the oil enters at 90℃ and leaves a 30℃, while the water enters at 25℃ and leaves at 70℃. The specific heat of oil at a given temperature t in ℃ is given by $c_p = 1.68t + (10.5 \times 10^{-4})t^2$kJ/kg-K. Find the amount of cooling water needed in kg/s to cool 2.75 kg/s of oil.

Power and Energy Conversion

67. For each of the following, identify whether the unit is a form of energy or power. If energy, convert it to BTU, and for power, convert it to ft-lb/s

a) 400 kW-hr
b) 25 ev
c) 30W
d) 100 hp
e) 32.2 slug-ft^2/s^2

68. Convert 10 CHU to

a) kW-hr
b) Therm
c) hp-min
d) kJ
e) Erg

69. How much energy in BTU is produced by a 60MW engine operating for 30 mins?

70. An engine has an efficiency of 35%. It uses 5 gallons of gasoline per hour. Gasoline has a heating value if 20000 BTU/lb, and SG of 0.80. What is the power output of the engine in kW?

71. Find the power in watts expended by a 50 kgm worker to carry a 3 kg crate in a 25 step stair case, each step is 30 cm high in 1 minute,

72. A pump is lifting water through a 5.5m to fill a $570m^3$ tank. The overall energy efficiency is 80%. Calculate the length of time that 7.5 kW applied to the pump will require to complete the job in minutes.

73. A body is being dragged uniformly along a horizontal surface by a force of 45 kg acting at an angle of 20 degrees to the horizontal. Find the work done in moving the body in kW

74. A 50 inches diameter diamond saw blade is mounted on a pulley driven steel shaft, required a blade peripheral linear speed of 150ft/s. Motor drive is 125 hp at 1200 rpm with 6 inches diameter pulley. Determine the shaft rpm to attain the blade peripheral speed required

75. Forty percent of the electrical input to a motor driven pump is converted into a hydraulic jet 12 mm in diameter for the purpose of washing down ashes. Find the jet velocity in m/s. Motor rating descriptions are 3 phase, 220V, 7.5 A with a power factor of 85%. (Note: Power Factor is the ratio of the theoretical power to actual power. For a 3phase motor, multiply the actual power by $\sqrt{3}$)

76. A turbogenerator rotating mass has a moment of inertia of 555 hyl-m^2. It is delivering 2500 kW at 1800 rpm. The load suddenly increases to 2550 kW, the developed steam power remaining unchanged. What is the resulting speed in rpm after 10 seconds?

77. A hoist is to raise a 1135 kg mine cafe at a rate of 4.6 m/s. Mechanical efficiency of the hoist is 92%. What is the power in kW to drive at this speed?

78. How much power is there in the kinetic energy of the atmosphere whose density is 1.217 kg/m^3 at 56 kph wind velocity in kW? Consider that the atmosphere passes through a 3m diameter circular area normal to the velocity

79. A dam holds 200000 m^3/day of water at a height of 492 ft above the valley floor. If the hydraulic turbine is situated in the valley floor, what is the maximum power that can be generated in kW-hr/year?

80. A motor driven pump transfers 5000L of oil through an elevation of 16 m. If delivery velocity is 10 m/s, what is the input power to the pump in hp and kW-hr?

81. If 85% of the electrical power input to the motor is available to lift a 1500 kgm elevator for 30 seconds at 20 meters, determine the horsepower rating.

82. The sun generates 1 kW/m^2 when used as a source of solar collectors. A collector with an area of 1 m^2 heat water. The flow rate is 3 L/min. What is the temperature rise in the water in C?

83. A water brake consists of a metal cylinder containing water and a paddle wheel to dissipate, through fluid friction, the work output of a test engine. The brake is full of 100 gallons of water, at the time of the pump, which circulates the water through a cooler and back, falls leaving the water trapped in the brake. At the time of failure, the temperature of the brake is 120°F. The engine is continuously delivering 120hp to the brake. The brake will automatically shut if the water reaches its steam point. How long will it take for the brake to automatically shut down, from the time where the brake fails?

84. A steam powerplant has an output of 10 MW with 75% waste heat. It runs for one-week continuous operation.

a) Determine the energy output in CHU, kW-hr, and ft-lbf
b) Determine the energy chargeable to the plant in MJ
c) Determine the energy wasted in the plant in BTU/min.
d) Recommend dimensions for an inverted conical tank whose diameter is one half its depth, as a storage of coal having a heating value of 40000 kJ/kg for one year continuous operation

Other Forms of Work

85. Given two small electrical charges Q_1 and Q_2 positioned on the x-axis as follows: Q_1= +4 μC at x= -3m, Q_2 = +1 μC at x=+2m. Find the position on the x-axis of a third charge Q_3, that experiences no net force from these two charges.

86. A triangle ABC has these dimensions AB=4m BC=5m AC=3m. Electrical charges are located at the vertices as follows, +30 μC at A, -160 μC at B, and +90 μC at C. Find the magnitude and direction of the net force on charge A in newtons and the direction respect of the axis of AB.

87. Determine the atmospheric work done in ft-lbf as a 2 in cube ice melts in a region of 1 atm. At 32 F, these densities obtain for water: liquid 62.42 and solid 57.15 in lb/ft^3.

88. A 1 kg of ice at 0°C is completely melted into water at 0°C at 1 bar pressure. The latent heat of fusion of water is 333 kJ/kg and the densities of water and ice at 0 °C are 999.0 kg/m^3 and 916 kg/m^3, respectively. What is the approximately value of the work done?

89. A balloon initially collapsed and flat is slowly filled with a gas at 100 kPa, so as to form into a sphere of 1m radius. What is the work done by the gas in the balloon during the filling process.

90. Heat is transferred to an elastic sphere containing gas at atmospheric; the diameter of the sphere is 2m. Because of heating the sphere diameter increases by 2.4 m and the gas pressure increases in proportion to the diameter. Find the work of the gas during the heating process.

91. There are required 124 ft lbf or work to compress a spring so that the final length of spring after compression is 2.5 in. If the spring has an index of 100 lbf/in, find the free length of the spring.

92. Two springs are designed to absorb the kinetic energy of a 2000-kgm vehicle. Determine the spring constant necessary if the maximum compression is to be 100 mm for a vehicle speed of 10 m/s.

93. A 10 ft wire having a modulus of elasticity of 30 x 10^6 psia is stretched by an applied force of 1200 lbf. What is the work done to the wire in in-lbf?

94. An aerial soap film is formed by wetting a wire frame then moving the slide wire away from a leg If the wire is enclosed in such a way it has the dimensions of 6cm x 10 cm. Find the work done against the resisting surface tension of 25 dyne per centimeter in kgf.

95. A spherical soap bubble, having a radius of 3 inches is formed by means of blowing through a soapy blow pipe. If surface tension is 15 dynes/cm , find the work done in dyne-cm to overcome the surface tension of the bubble.

96. A solid disk flywheel has a moment of inertia of 200 $kgm\text{-}m^2$ is rotating at a speed of 900rpm. What is its rotational kinetic energy in therm?

97. A 1200 hp boiler feed pump connected to electric motor has a drive shaft rotating at 2000 RPM. How much torque is on the shaft?

98. A 12 V battery is receiving a constant charge from a generator. The voltage across the terminal is 12.5V and the current is 10A. Determine the input power in hp.

99. A 5W battery supplies electricity to two resistors. When the resistors are arranged in series, the current flowing through the resistors are measured to be 2 A. When the resistors are arrange in parallel, the total current flowing through the resistors is measured to be 2.5 A. Determine the ohmic values of these resistors.

100. A constant force moves an 18 in conductor with a velocity of 25fps orthogonally across a magnetic field whose flux density is 1 N-s-m/C. The conductor carries a current of 20A. Find the force and the rate of work produced.

101. A shock absorber pumps oil internally through a flow resistance to dissipate mechanical energy. The force acting on the absorber is given by

$$F = 2\frac{dx}{dt}$$

where F is in lbf-s/in and dx/dt is in inches per second. The displacement is given by

$$x = 6sin2\pi t$$

where x is in inches and t is in seconds. The absorber and the oil has a combine mass of 5 lbm, and the average specific heat of the absorber and oil is 0.25 BTU/lb-°F. How long will it take the absorber to change temperature from 70 to 160°F?

Mechanical Work

102. Evaluate the non-flow work in terms of P_1, V_1, P_2, and V_2 of a fluid undergoing a reversible state in accordance of each of the following relations:

a) $P = C$
b) $V = C$
c) $PV = C$
d) $PV^2 = C$
e) $PV^3 = C$
f) $PV(lnV) = C$
$g)\ P = \frac{200}{V^2} + 2$

103. If 6L of a gas at a pressure of 100 kPaa are compressed reversibly according to $PV^2 = C$ until the volume becomes 2L, find the final pressure in kPaa and work non-flow in J.

104. During a reversible process exerted by a non-flow system, the pressure varies from 345 kPaa to 1400 kPaa in accordance with PV = C. The internal energy increases to 22500 J, and the initial volume is 85 L. Find the heat in Joules.

105. A gasesous substance whose properties are unknown, undergoes a internally reversible process during which V = -0.10P + 300 where V is in cubic food at P is pounds per square foot abs. Neglect change in potential energy.

a) Find the nonflow work in BTU if the pressure changes from 1000psfa to 100 psfa .
b) Find the steady flow work in BTU
c) If the process is a steady flow with an increasing kinetic energy of 25BTU and enthalpy decreasing of 300 BTU, then determine the net work and heat, both in BTU.
d) If the process in non-flow, determine the work and change in internal energy, both in BTU

106. If 6 L/s at 100kPaa of fluid is compressed reversibly to 2 L/s according to the law PV^2=C, determine the

a) work steady flow in hp and
b) work non flow in PS.

107. If a gas of volume 6000cm^3 and at a pressure of 100 kPa is compressed quasistatically in a piston cylinder according to $PV^2 = C$ until the volume becomes 2000cm^3. What is the work done?

108. During reversible process executed by a non-flow system the pressure increases from 50 psia to 200 psig in accordance to PV=C and the internal energy increases 21.4 BTU; the initial volume is 3 cubic foot.

a) Find the heat is calories.
b) If the change of internal energy is neglected, what is the change of enthalpy in kJ?

109. A gas undergoes a thermodynamic cycle consisting of three processes beginning at an initial state where $P_1 = 1bar, V_1 = 1.5m^3 and U_1 = 512kJ$. The processes are as follows: For process 1-2, compression with PV=C to $P_2 = 2bar$ and $U_2 = 960kJ$. For process 203, W=0 and Q=-150 kJ. For process 301 W=+50 kJ neglecting change in PE and KE. What is the heat transfer from process 1 to 2?

110. An imaginary engine receives heat and does work on a slowly moving piston at such rates that the cycle operation on the PV diagram can be represented as a circle 10cm in diameter , wherein 1cm=300kPa and 1cm=0.10 m^3/kg. What is the work done by each kg of working fluid for each cycle of operation?

Energy Balance For Open Systems

111. A 14 300 kg airplane is flying at an altitude of 497 m at a speed of 214 km/h. Determine the airplane's total mechanical energy.

112. A 4 kg/s of water at $40°C$ is mixed with 6 kg/s of water at 100℃ in a steady flow process. Find the temperature of the resulting mixture in ℃.

113. A tank contains 25L of oil of relative density of 0.9 and temperature of 10C. The oil is heated for 15 min by a 2.16kW heater. Determine the final temperature of oil assuming heat loss through the tank as 160 kW. Specific heat of oil is 48% of specific heat of water at constant pressure.

114. Consider an 80-gallon hot water heater. Over a fifteen-minute time period hot water flows out of the hot water heater at 0.75 kg/s and cold water at 0.5 kg/s flows into the hot water heater. How full in percent is the hot water heater at the end of fifteen minutes? You may take the water temperature to be 85ºC. Note at density of water at 85°C = 968.2 kg/m^3.

115. In a steady flow adiabatic turbine, the changes in enthalpy, kinetic energy, and potential energy of the working fluid from inlet to exit are 1150 kJ/kg, 10kJ/kg, and zero respectively. What is the turbine work?

116. Steam flows through an adiabatic turbine at a rate of 100 lb/min. At suction, the pressure is at 175 psia , volume of 3.16 ft^3/lb, and internal energy of 1170 BTU/lb. At exhaust, the pressure is 0.813 psia, the volume increases 100 times and the internal energy is 900 BTU/lb. Assume that there is no change in velocity and elevation between the suction and exhaust. Find the turbine horsepower rating required.

117. A turbine operates under steady flow conditions, receiving steam at the following state: pressure 1000 kPa, temperature 180 deg. C, enthalpy 2700 kJ/kg, speed 50 m/s, and elevation 2 m. The steam leaves the turbine at the following state: pressure 50 kPa, enthalpy 2500 kJ/kg, speed 100 m/s, and elevation 0 m. Heat is lost to the surroundings at the rate of 0.50 kJ/s. If the rate of steam flow through turbine is 0.50 kg/s, what is the power output of the turbine in hp?

118. In a gas turbine the gases enter the turbine at rate of 5 kg/s with a velocity of 50 m/s and enthalpy of 900 kJ/s and leave the turbine with 150 m/s and enthalpy of 400 kJ/kg. The loss of heat from the gases to the surrounding is 25 kJ/kg. Assume R=0.285 kJ/kg-K and cp=1.004 kJ/kg-K. The inlet condition to be at 100 kPa and 27°C.Find the work transfer in kW.

119. In a turbine unit, the gases flow through the turbine is 15 kg/s and the power developed by the turbine is 12000 kW. The enthalpies of gases at the inlet and outlet are 1260 kJ/kg and 400 kJ/kg respectively and the velocity of gases at the inlet and outlet are 100 m/s and 50 m/s respectively. What is the rate at which heat is rejected to the turbine?

120. 10000 kg/hr of steam with an enthalpy of 2778 kJ/kg enters the turbine and leaves with an enthalpy of 2168 kJ/kg. Determine the turbine power output if thermal efficiency is 35%.

121. Steam turbine receives 70 pounds of steam per minute with an enthalpy of 1600 Btu per pound and velocity of 100 ft/sec. It leaves the turbine at 900 ft/sec and 1320 Btu/lb enthalpy. The radiation loss is 84,000 Btu/hr. Find the horsepower output.

122. Steam enters a turbine stage with enthalpy of 3628 kJ/kg 70 m/sec and leaves the same stage with an enthalpy of 2846 kJ/kg and a velocity of 124 m/sec. Calculate the work done by the steam.

123. Steam enters in a steady flow manner in an adiabatic turbine at 80 m/s, 2.5kPaa, 500C with a specific enthalpy of 3462.10 kJ/kgm. It leaves the turbine at 40 m/s,10kPaa, with a specific enthalpy of 2393.21 kJ/kgm. At suction, the specific volume is 1.2 L/kgm. If the flow is 25 kgm/s, determine:

a) The change in kinetic energy in kW
b) The work done by the turbine in hp.
c) The cross-sectional area of the suction in m^2

124. Steam enters a turbine at steady state with a mass flow rate of 4600 kg/h. The turbine develops a power output of 1000 kW. At the inlet the pressure is 0.05 MPa, the temperature is 400 °C, and the velocity is 10 m/s. At the exit, the pressure is 10 kPa, the quality is 0.9, and the velocity is 50 m/s. Calculate the rate of heat transfer between the turbine and surroundings, in kW. Take h_1 = 3178.9 kJ/kg ; h_2= 2345 kJ/kg.

125. In a gas turbine unit, the gases flow through the turbine is 15 kg/s and the power developed by the turbine is 12000 kW. The enthalpies of gases at the inlet and outlet are 1260 kJ/kg and 400 kJ/kg respectively, and the velocity of gases at the inlet and outlet are 50 m/s and 110 m/s respectively. Calculate :

a) The rate at which heat is rejected to the turbine
b)The diameter of the inlet pipe given that the specific volume of the gases at the inlet is 0.45 m^3/kg.

126. Stream of gases at 7.5 bar, 750°C and 140 m/s is passed through a turbine of a jet engine. The stream comes out of the turbine at 2.0 bar, 550°C and 280 m/s. The process may be assumed adiabatic. The enthalpies of gas at the entry and exit of the turbine are 950 kJ/kg and 650 kJ/kg of gas respectively. Determine the capacity of the turbine if the gas flow is 5 kg/s.

127. A centrifugal air compressor compresses 200 CFM from 12 psia to 90 psia. The initial specific volume is 12.6 ft^3/lbm and the final specific volume is 3.25 ft^3/lbm. If the inlet suction line is 4 in ID and the discharge line is 2.5 in ID line, determine
a) The change in flow energy in PS
b) The mass flow rate in kg/s
c)the change in velocity in mi/hr

128. A compressor draws 6000 kg/hr of atmospheric air and delivers it at a higher pressure. At inlet and exit, the enthalpies for air are 300 kJ/kgm and 509 kJ/kg respectively. The heat rejected by the water coolant is 5 kW. Neglecting change in potential and kinetic energy, determine the power required to drive the compressor in hp.

129. In an air compressor air flows steadily at the rate of 0.5 kg/s through an air compressor. It enters the compressor at 6 m/s with a pressure of 1 bar and a specific volume of 0.85 m^3/kg and leaves at 5 m/s with a pressure of 7 bar and a specific volume of 0.16 m^3/kg. The internal energy of the air leaving is 90 kJ/kg greater than that of the air entering. Cooling water in a jacket surrounding the cylinder absorbs heat from the air at the rate of 60 kJ/s. Calculate :
(i) The power required to drive the compressor ;
(ii) The suction and discharge pipe cross-sectional areas.

130. 12 kg of air per minute is delivered by a centrifugal air compressor. The inlet and outlet conditions of air are v_1 = 12 m/s, P_1 = 1 bar, ν_1 = 0.5 m^3/kg and v_2 = 90 m/s,P_2 = 8 bar,ν_2= 0.14 m^3/kg. The increase in enthalpy of air passing through the compressor is150 kJ/kg and heat loss to the surroundings is 700 kJ/min. Find
a) Motor power required to drive the compressor
b)Ratio of inlet to outlet pipe diameter assuming that inlet and discharge lines are at the same level.

131. In a test of water cooled air compressor, it is found that the shaft work required to drive the compressor is 175 kJ/kg of air delivered and the enthalpy of air leaving is70 kJ/kg greater than that entering and that the increase in enthalpy of circulating water is 92 kJ/kg. Compute the amount of heat transfer to the atmosphere from the compressor per kg of air.

132. There are 24000 lb/hr of steam supplied to a nozzle at an abosulte pressure of 200 psia. The speed of the steam entering the nozzle is 5000 fpm having a specific volume of 2.29 cu. ft/lb and internal energy of 1114 BTU/lb. Exit conditions of steam has a specific volume of 26.77 cu. ft/lb and internal energy of 1080 BTU/lb. Find the exit velocity.

133. Steam at 1000 lb/ft^3 pressure and 330°R has a specific volume of 6.5 ft3/lb and a specific enthalpy of 9800 ft-lb/lb. Find the internal energy per pound mass of steam.

134. Air enters air compressor with a mass flow rate of 0.70 kg/s with a specific enthalpy of 290 kJ/kg and leaves it with 450 kJ/kg of specific enthalpy. Velocities at inlet and exit are 6 m/s and 2 m/s respectively. Assuming adiabatic process, what is the power input to the compressor in kW?

135. Steam with an enthalpy of 2168 kJ/kg enters the condenser at a rate of 22050 lbm/hr. If the condensate has an enthalpy of 251 kJ/kg, determine the heat rejection rate in BTU/min.

136. Air and fuel enter a furnace used for home heating. The air has an enthalpy of 302 kJ/kg and the fuel has an enthalpy of 43 207 KJ/kg. The gases leaving the furnace have an enthalpy of 616 kJ/kg. of fuel. The house requires 17.6 KW of heat. What is the fuel consumption per day?

137. The power plant furnace burns coal at the rate of 108,200 kg/hr. Air at 100.8 kPa, 28°C is supplied at the rate of 13.8 kg/kg coal. Determine the volume flow rate of air flow in m^3/min.

138. The enthalpy of air is increased by 139.586 kJ/kg in a compressor. The rate of air flow is 16.42 kg/min. The power output is 48.2 KW. Find the heat loss in the compressor in kW.

139. The air with enthalpy of 100 kJ/kg is compressed by an air compressor to a pressure and temperature at which its enthalpy becomes 200 kJ/kg. The loss of heat is 40 kJ/kg from the compressor as the air presses through it. Neglecting kinetic and potential energies, what is the power required for an air mass flow of 0.5 kg/s?

140. A steam condenser receives 10 kg/s of steam with an enthalpy of 2770 kJ/kg. Steam condenses and leaves with an enthalpy of 160 kJ/kg. Cooling water passes through the condenser with temperature increase from 13C to 24C. Determine the inside diameter of the tube where cooling water flows if water passes and leaves at the same rate of 5 m/s.

141. Steam with an enthalpy of 800 kcal/kg enters a nozzle at a velocity of 80 m/sec. Find the velocity of the steam at the exit of the nozzle if its enthalpy is reduced tp 750 kcal/kg. assuming the nozzle is horizontal and disregarding heat losses. Take g=9.81 m/s^2.

142. Liquid water with a constant density of 1000 kg/m^3 enters a nozzle at the rate 10 L/min. The inlet of the nozzle has a diameter of 1.50 cm, the diameter of the exit is 0.75 cm. Find the velocities of the water at the inlet and exit.

143. Steam enters a converging-diverging nozzle operating at steady state a t0.05 MPa and 400 °C and a velocity of 10 m/s. The steam flows through the nozzle with negligible heat transfer and no significant change in potential energy. At the exit, conditions are 0.01 MPa, and the velocity is 665 m/s. The mass flow rate is 2 kg/s. Determine the exit enthalpy and area of the nozzle if the enthalpy and specific volume of steam at the inlet conditions is 3278.9 kJ/kg and 26.445 cu.m /kg respectively.

144. At the inlet to a certain nozzle, the enthalpy of the fluid passing is 3000 kJ/kg and the velocity is 60 m/s and the specific volume of 0.187 m^3/kg. At the discharge, the enthalpy is 2762 kJ/kg. The nozzle is horizontal and there is negligible heat loss from it. Determine the velocity at the exit of the nozzle.

145. Water enters a cooling tower at 35C at the rate of 180000 kg/hr and is cooled to 25C. Atmospheric air is used for cooling enters the tower with enthalpy of 24 kJ/kgm and leaves with an enthalpy of 88 kJ/kgm. Find the mass flow rate in lbm/s.

146. A blower handles 1 kg/s of air at 20°C and consumes a power of 15 kW. The inlet and outlet velocities of air are 100 m/s and 150 m/s respectively. Find the exit air temperature, assuming adiabatic conditions. Take c_p of air to be 1.005 kJ/kg-K.

147. At the inlet to a certain nozzle the enthalpy of fluid passing is 2800 kJ/kg, and the velocity is 50 m/s. At the discharge end the enthalpy is 2600 kJ/kg. The nozzle is horizontal and there is negligible heat loss from it.
a) Find the velocity at exit of the nozzle.
b) If the inlet area is 900 cm2 and the specific volume at inlet is 0.187 m3/kg, find the mass flow rate.
c) If the specific volume at the nozzle exit is 0.498 m3/kg, find the exit area of nozzle.

148. One of the sections of the heating plant in which there are no pumps enters a steady flow of water at a temperature of 50°C and a pressure of 3 bar (h = 240 kJ/kg). The water leaves the section at a temperature of 35°C and at a pressure of 2.5 bar (h = 192 kJ/kg). The exit pipe is 20 m above the entry pipe. Assuming change in kinetic energy to be negligible, evaluate the heat transfer from the water per kg of water flowing

149. A centrifugal pump delivers 50 kg of water per second. The inlet and outlet pressures are 1 bar and 4.2 bar respectively. The suction is 2.2 m below the centre of the pump and delivery is 8.5 m above the centre of the pump. The suction and delivery pipe diameters are 20 cm and 10 cm respectively. Determine the capacity of the electric motor to run the pump.

150. A steady-state steady flow thermodynamic system receives 100 lb/min of a fluid at 30 psia and 2000°F, and discharges it from a point 80 ft above the entrance section at 150 psia and 6000°F. The fluid enters with a velocity of 7200 fpm and leaves with a velocity of 2400 fps. During this process, there are supplied 25 000 BTU/hr of heat from an external source and the increase in enthalpy is 20 BTU/lb. Determine the work done in hp.

151. A boiler produce 600 kg of steam per hour from feedwater at 40C. Assuming the boiler to be a steady flow system and neglecting potential and kinetic changes, find the rate at which the heat is transformed in kW. The enthalpy of steam is 660 kcal/kgm

152. During flight, the air speed of a turbojet engine is 250 m/s. Ambient air temperature is – 14°C. Gas temperature at outlet of nozzle is 610°C. Corresponding enthalpy values for air and gas are respectively 250 and 900 kJ/kg. Fuel air ratio is 0.0180. Chemical energy of fuel is 45 MJ/kg. Owing to incomplete combustion 6% of chemical energy is not released in the reaction. Heat loss from the engine is 21 kJ/kg of air. Calculate the velocity of the exhaust jet.

153. Air at a temperature of 20°C passes through a heat exchanger at a velocity of 40 m/s where its temperature is raised to 820°C. It then enters a turbine with same velocity of 40 m/s and expands till the temperature falls to 620°C. On leaving the turbine, the air is taken at a velocity of 55 m/s to a nozzle where it expands until the temperature has fallen to 510°C. If the air flow rate is 2.5 kg/s.Take the approximate enthalpy of air as $h = c_p t$, where c_p is the specific heat equal to 1.005 kJ/kg°C and t the temperature.calculate :

a) Rate of heat transfer to the air in the heat exchanger

b)The power output from the turbine assuming no heat loss ;

c) The velocity at exit from the nozzle, assuming no heat loss.

154. Water falls from a height 500m. What is the rise in temperature of water in ℃ at the bottom if all of the energy remains in the water?

155. Compute the temperature rise of water falling continuously from an elevation of 30 m in kelvin.

156. A centrifugal air compressor compresses 200 CFM from 12 psia to 90 psia. The initial specific volume is 12.5 ft^3/lb, and the final specific volume is 3.25 ft^3/lb. If the inlet suction line is 4 in ID and the discharge line is 2.5 in ID, determine the work in ft-lbf/min.

157. In a test of water jacketed compressor, the shaft work required is 90 kJ/kg of air compressed. During compression, increase in enthalpy of air is 30 kJ/kg of air and increase in enthalpy of circulation cooling water is 40 kJ/kg of air. The change in velocity is negligible. Find the amount of heat lost to the atmosphere from the compressor per kg of air.

158. A hydraulic pump is handling 5CFS of 60F water through an 8 in inside diameter suction line and a 6 in inside diameter discharge line. The suction gauge is on the pump center line and reads 10 in Hg vac; the discharge gauge is 20 ft above the center line. If the energy input to the water is 100 hp, find:

a) The reading of the discharge gauge in psi.

b) If the discharge gauge reads 100 psig, what would be the pump horsepower input to the water?

Energy Balance For Closed Systems

159. An inventor claims a closed system that does 3 BTU of work and rejects 2 BTU of heat. Change in internal energy is zero. Validate the claim. If it is wrong, what is the actual change of internal energy?

160. A closed system undergoes a process 1-2 for which Q and W are 20kJ and 50kJ respectively. If the system is returned to state 1 and Q=-10kJ, what is the value of W?

161. A closed system executes a series of process for which the work, heat, and internal energy are related to each other. Complete the table below, assuming that energy change is zero.

W	Q	ΔU
10hp	500 BTU/min	_____kW
65 BTU	_____BTU	-25 BTU
____ hp	25 kW	0
-390 ft-lbf	-2 BTU	___ hp-hr
200 000 gm-cm	50000 gm-cm	___kgm-m

162. A 12 V battery receives a quick 20 min charge during time it receives a steady current supply of 50 amp. In this period, it receives a heat loss of 150BTU. Find the change in internal energy during this period

163. 5000 BTU/hr of heat is leaking through an imperfect insulation in a cooled system. A thermoelectric system maintains the region and operates at 40amps and 24V. Find the heat rejected by the thermoelectric system.

164. A system receives 75kJ of heat while it does 45 kJ of work. How much energy is stored in the system?

165. Five persons occupying the same room gives 400 BTU/hr after a power failure in an air conditioning system. Find the change in internal energy of the room air at the end of 10 min following the power failure.

166. For a certain system executing a cyclic process 250J of heat are absorbed by the system and 100J of heat are rejected. The system also receives 30 W-s of electrical power whole it moves a 3 kg mass vertically by means of a pulley arrangement. How far does the mass move in meters? Local g=9.65 m/s^2.

167. The contents of a well- insulated tank are heated by a resistor of 23 Ω in which 10 A current is flowing. Consider the tank with its contents as a thermodynamic system. The work done by the system and the heat transfer to the system are positive. Find the rates of heat (Q), work (W) and change in (ΔU) during the process in kW.

168. Gas contained in a closed system consisting of piston cylinder arrangement is expanded. Work done by the gas during expansion is 50 kJ. Decrease in internal energy of the gas during expansion is 50 kJ. Decrease in internal energy of the gas during expansion is 80 kJ. Find the heat transfer during the process

169. A paddle wheel is used to create work in an inflexible tank containing an unknown fluid. The fluid rejects 12BTU of heat while the initial and final internal energies are 6.25 and 0.50 BTU, respectively. Determine the work created by the paddle wheel to the fluid in cal. Neglect the energy stored in the paddle wheel

170. 8kg of gas is contained in a vertical piston cylinder assembly. The area and the mass of the piston are 300cm^2 and 15 kg, respectively. A spring is loaded in the piston, which the force exerted varies linearly with displacement, x. At initial position, the piston is at x=0, the spring exerts no force. Heat is added to the air causing the gas to expand until the piston reached the stops at x=0.08m, and the heat transfer ceases. The atmosphere is 1bar, the observed gravitational acceleration is 9.81 m/s^2, consider the spring constant to be 8500 N/m and neglect friction between the piston and the cylinder. Determine the work in J.

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