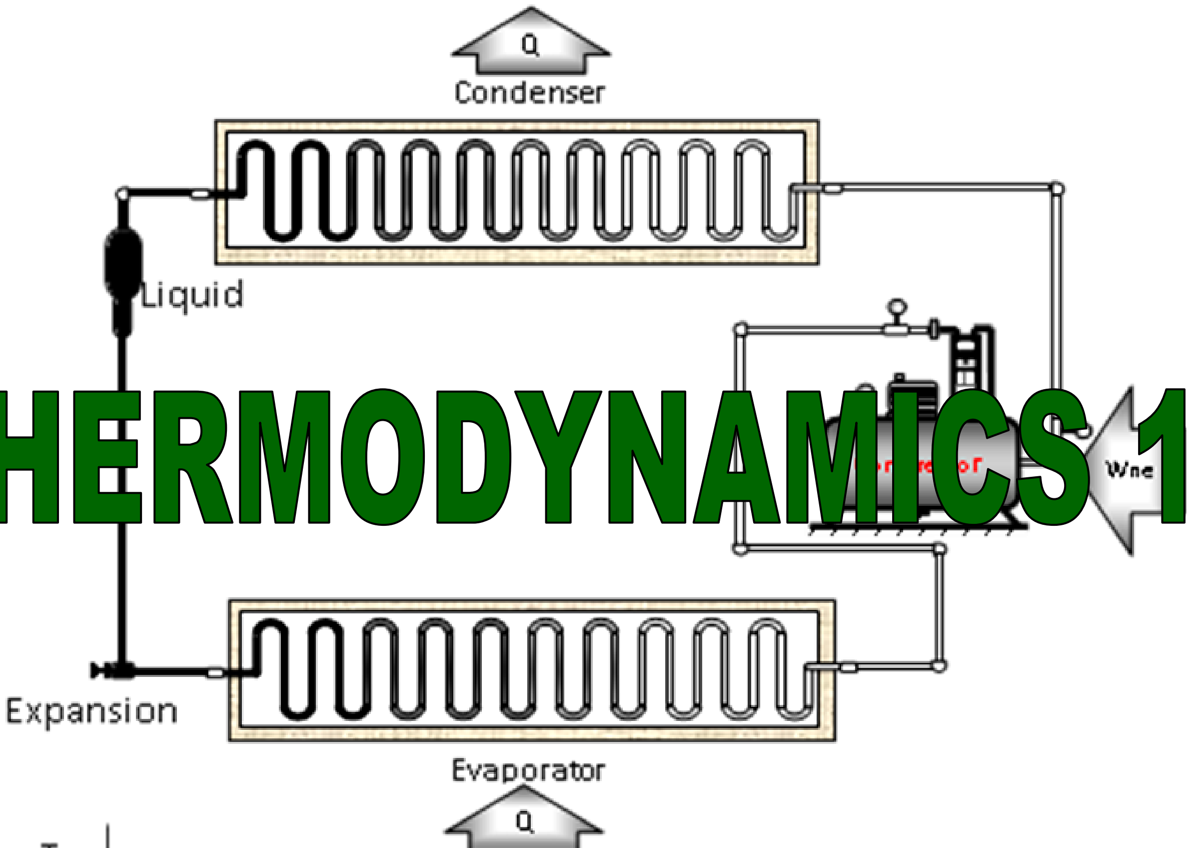
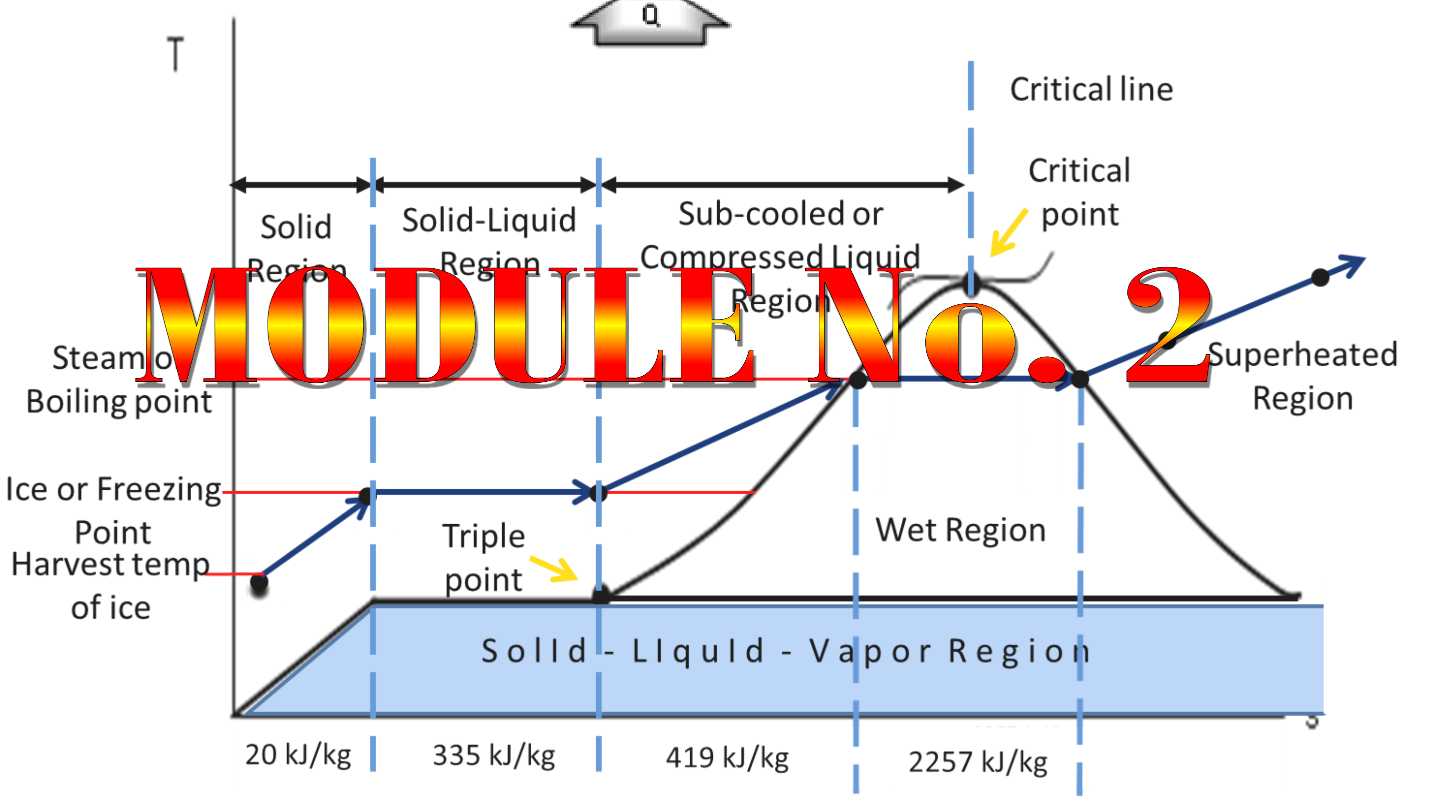
THERMODYNAMICS 1



MODULE No. 2



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MODULE 2

ENERGY AND THE FIRST LAW OF THERMODYNAMICS

INTRODUCTION

The course deals with the thermodynamic properties of pure substances, ideal and real gases and the application of the laws of thermodynamics in the analysis of processes and cycles. It includes introduction to vapor and gas cycles

TOPIC OVERVIEW

Energy is a fundamental concept of thermodynamics and one of the most significant aspects of engineering analysis. Energy can be found in all matters. It appears in different forms and interrelated to each other and it can be transformed from one form of energy to another form. This module deals with the study of mass and energy conservation and its relationship and develop equations applying the principles of conservations of energy. Some of the identified energies are the Potential, Kinetic, Internal energy, entropy and other forms of energy. Work and heat are also discussed.

LEARNING OUTCOMES

At the end of the module, it is expected that the students can solve problems by applying the different thermodynamics concept, theories and the first law of thermodynamics.

LEARNING OBJECTIVES

Acquire a deep understanding on mass and energy conservation and its relationship and develop equations applying the principles of conservations of energy.

CONTENT EXPLORATION

Mass Conservation

Mass can neither be created nor destroyed. The law of conservation of mass states that total mass is constant. In chemical reaction, the mass of the product is always equal to the mass of the reactant. In a closed system, the mass remains constant within the system. In an open system, the mass entering the system is equal to the mass leaving the system. In a steady flow, the mass entering equal the mass leaving, and the change of mass within the system is equal to zero.

The mass flow rate of the system is defined as the amount of mass flowing per unit time, that is;

$$\text{mass flowrate} = \frac{\text{mass}}{\text{time}}; \qquad \bar{m} = \frac{m}{t} \qquad (1)$$

Energy Conservation

Energy cannot be simply defined because of its broad spectrum. Energy appears in many different forms which are related to each other by the fact that it can be transformed from one form to another. One defines energy as the capacity to do work, but sometimes, there are systems that have energy but no capacity to do work. In this module, we will study two types of energy, *1) the stored energy such as potential energy, kinetic energy and molecular energy and 2) the transitional energy such as heat and work.*

Measuring Energy

Simmang and Faires (1981) states that energy is a scalar quantity, not a vector quantity, meaning, it has magnitude only. The total energy that a body possesses is the sum of the all the magnitude of all forms of energies that constitute the body.

For convenience, we shall use British Thermal Unit in English Engineering calculations and Joules in SI calculations. Customarily, a Joule is equivalent to 778.16 ft-lb/BTU, but use only 778 in normal calculations.

Mass and Energy Relationship

Albert Einstein conceptualized the theory of relativity which states that mass can be converted to energy and vice versa;

$$E = mc^2 \quad \text{or} \quad \Delta E = \Delta mc^2$$

where E is the total energy, m is the mass and c as the speed of light equivalent to 2.9979 x 10^8 m/sec.

Also, according to Einstein, the theories relativistic effect to mass is that mass increases with speed; and with mass at any speed, we have:

$$m = \frac{m_0}{\left(1 - \left(\frac{v}{c}\right)^2\right)^{\frac{1}{2}}}$$

where; m – mass at any speed

m_0 – rest mass

v – speed of a body

c – speed of light = 2.9979 x 10^8 m/sec

A. STORED ENERGY

It is the energy stored within the body which goes or dependent upon the flow of the mass.

A.1 THE POTENTIAL ENERGY, PE

Potential energy is the energy by virtue of the systems position or elevation above a chosen datum. It possesses stored energy that has the capacity to perform a work.

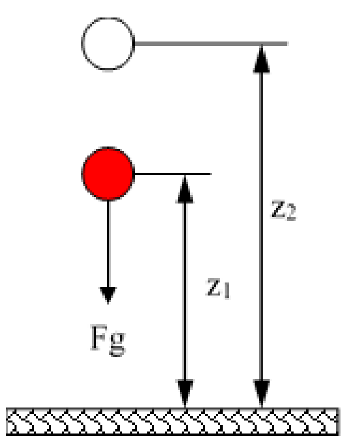


Figure 8. Potential Energy of a falling body

$$dPE = Fgdz = mgdz = \frac{mg}{k}dz$$

where dPE – the change in potential energy

Fg = mg – the force of gravity and is virtually constant

dz – the displacement of the center of gravity in the direction of the force of gravity.

Integrating the equation gives,

$$P_2 - P_1 = \Delta P = mg(z_2 - z_1) = \frac{mg}{k}(z_2 - z_1) \qquad (2)$$

For the constant Fg, the potential energy of the body is,

$$PE = mgz = \frac{mgz}{k} \quad \text{and} \quad PE = \frac{gz}{k} \text{ ; unit mass}$$

A.2 THE KINETIC ENERGY, KE

Kinetic energy is the energy by virtue of the systems motion. This energy is associated with translational or rotational motion of the bodies.

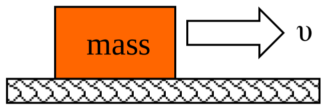


Figure 9. The Kinetic Energy of a Translating Body.

The kinetic energy of a translating body is defined as

$$KE = \frac{1}{2k} m\upsilon^2$$

And for a change in Kinetic Energy, ΔK,

$$\Delta KE = KE_2 - KE_1 = \frac{m}{2k}\left(\upsilon_2^{\,2} - \upsilon_1^{\,2}\right) \quad (3)$$

where: KE – kinetic energy
m – mass of a body
υ – translational velocity of a body
k – proportionality constant

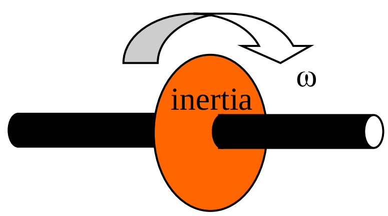


Figure 10. The Kinetic Energy of a Rotating Body

The kinetic energy of a rotating body is defined as

$$KE = \frac{1}{2k} I\omega^2$$

And for a change in Kinetic Energy, ΔK,

$$\Delta KE = KE_2 - KE_1 = \frac{I}{2k}\left(\omega_2^{\,2} - \omega_1^{\,2}\right) \quad (4)$$

where: KE – kinetic energy
I – Inertia of a body
ω – angular velocity of a body
k – proportionality constant

A.3 INTERNAL OR MOLECULAR ENERGY

Simmang and Faires (1918), defines it as the sum of all energies of all the molecules in a system, energies that appear in several complex forms.

Internal energy is the energy by the virtue of the activity and configuration of its molecules and of the vibration of atoms within the molecules. These energies may be due to rotational, translational and vibratory motions. These molecular motions increase as the systems temperature increases. The molecular potential energy is due to the forces acting between molecules, in which these forces are smallest for gas, larger for liquid and largest for solid. The work required to separate these forces, which is the force times distance, increases during the change of phase form solid to gas.

Any change of energy that cannot be attributed to Potential and Kinetic Energy can be accounted in terms of *Internal Energy*.

Despite of all these facts, there is still no way to determine the absolute amount of internal energy that a body contains. However, changes in internal energy, which is the information needed to solve practical problems, can be computed, we let,

u – specific internal energy $\Delta u = u_2 - u_1$;kJ/kg (unit mass) (5)

U = mu = total internal energy $\Delta U = U2 - U1$; kJ (6)

B. TRANSITION ENERGY

This are the energies in transit which are not dependent upon the flow of the mass.

B.1 HEAT, Q

Heat accounts for the amount of energy transferred to a closed system during a process by means other than work. Experience and experiment shows that heat transfer is induced when there is a difference in temperature between the system and its surroundings and occurs only in the direction of decreasing temperature.

Heat is measured in British Thermal Unit which is defined as the quantity of heat required to change the temperature of 1 lb of water at 1^0F.

Characteristics of Heat

1. Heat is energy in transit. It always flows from a substance at a higher temperature to another substance at a lower temperature.
2. Heat is not a property. Hence, a system does not contain heat at any state.
3. The amount of heat transferred during a particular process is known only if the process is specified.

Modes of Heat Transfer

Heat can be transferred in three distinct modes: conduction, convection, and radiation. **Conduction** is the transfer of heat along a solid object. **Convection** is the transfer of heat between a solid surface and a moving liquid or gas. **Radiation** is the transfer of heat via electromagnetic (usually infrared) radiation.

Types of Heat

1. *Sensible heat* – Heat energy that causes a change in the temperature of a substance without a change in its phase. *Sensible* heat is the heat you can feel and measure with a thermometer. If it is 78° F outside, you are measuring sensible heat.
    a. *Sensible heat of solid* – the quantity of energy required to bring the temperature of a solid from the initial condition of absolute zero to the melting or fusion temperature.
    b. *Sensible heat of liquid* – the quantity of energy supplied to increase its temperature from the fusion temperature to the vaporizing temperature.
2. *Latent heat* – Heat energy that causes a change on phase without change in its temperature. Latent heat is often called *hidden* heat because it is not measured with a thermometer. This heat is what causes a substance to change state. It makes ice turn into water and water into steam. You can measure the temperature of ice at 32 ° F, and the temperature of the water right after it melts will also measure at 32 ° F. There is no change in the sensible heat. It is the latent heat that caused the ice to change state.
    a. *Latent heat of fusion* – latent heat involved in a change that occurs between the solid and liquid phase.

        The latent heat of fushion of water water under normal atmospheric pressure and saturated temperature of 100°C is 335 kJ/kg
    b. *Latent heat of vaporization* – latent heat involved in a change that occurs between liquid and vapour phase.

        Latent heat of vaporization of water under normal atmospheric pressure and saturated temperature of 100°C is 2259 kJ/kg

For sign convention, heat transfer *into* the system is taken as *positive (+)* and heat transfer *from* the system is taken as *negative (-)*.

B.2 WORK, W

The work is defined as the product of a displacement and the component of the force in the direction of displacement.

If the work is translational, we have

$$W = \int_1^2 F_x d_x$$

where: W – the work

Fx – the force acting on the body in the direction of displacement

dx - displacement

If the displacement is angular, such as the work done in shafting exerting a torque on the rotating shaft, we have

$$W = \int_1^2 T d\theta$$

where: W – the work

T – the torque acting on the body in the direction of displacement

dθ – angular displacement

For sign convention, we regard work *done by* the system on the surroundings as *positive (+)*, and work *done on* the system by the surroundings as *negative (-)*. If no work is done, then W = 0.

WORK OF A NONFLOW SYSTEMS (Closed System)

A closed system is defined as one that does not exchange matter with the surroundings and may be concerned with many types of energies. A type of close system that will be discussed in this lesson is the one consisting of a fluid undergoing one or more processes. The process may be non - flow variety, as the fluid enclosed by the piston and cylinder called a closed nonflow system, or just nonflow with the closed understood; or the fluid may be flowing, as in a steam power plant, says Simmang and Faires (1981). In any system, any form of energy may be stored except work and heat. However, the forms of energy that must often meet are the kinetic, potential, and molecular energy.

In figure shown below, a piston-cylinder arrangement for a closed system containing fluid, let the gas expand from 1 to 2. As the process takes place the following occurs:

- The pressure changes as the expansion proceeds
- At any stage, the force acting on the piston is the product of the pressure of the gas, and the area of the piston.

In any instant of expansion, the force acting on the piston is the product of the pressures of the fluid and the area of the piston, thus,

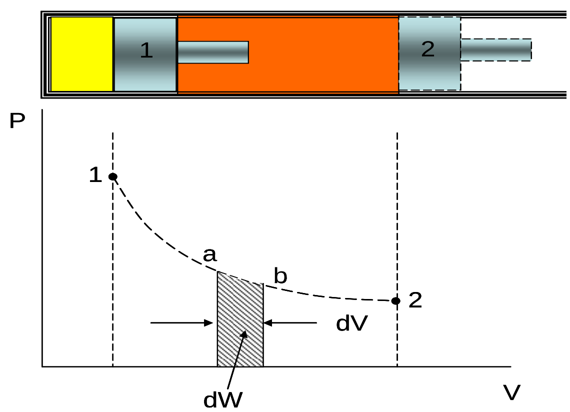


Figure 11. A quasi-static diagram of piston

The Work done as the piston moves from a to b is:

$$W_{nf} = \int F_x d_x$$

but

$$F_x = PA$$

$$d_x = dL$$

then;

$$W_{nf} = \int PAdL$$

also, $AdL = dV$

$$W_{nf} = \int PdV \quad ; \text{kJ} \quad \text{(Total)} \qquad (7)$$

$$w_{nf} = \int Pdv \quad ; \text{kJ/kg} \quad \text{(Specific)} \qquad (8)$$

Note:

The Area under the curve of the process on the pv plane represents the Work done during a non - flow reversible process.

Work *done by* the system is positive (Energy Out)

Work *done on* the system is negative (Energy In)

FLOW ENERGY OR FLOW WORK, Ef

Simmang and Faires (1981) states that flow energy is a special form of work that is significant for a moving stream; it is not dependent on the function p = p(V). Flow energy is often called FLOW WORK and is the work done in pushing a fluid across a boundary, into or out of the system. It could be included in the sum of all work events for a system obtaining the net work, but it is could also be studied separately.

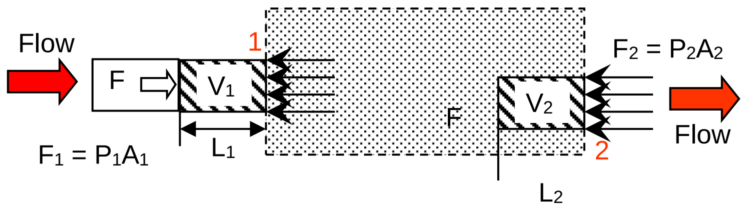


Figure 12. Schematic Diagram of flow energy as a special form of work that is significant for a moving stream.

$Ef_1 = F_1L_1$

but $F = PA$

and $AL = V$

therefore:

$Ef_1 = (PAL)_1$

$= P_1V_1$; kJ (Total) (9)

$= p_1v_1$; kJ/kg (Specific) (10)

Similarly to push the amount of V_2 out of the control volume the work required is,

$Ef_2 = P_2V_2$; kJ (Total) (11)

$= p_2v_2$; kJ/kg (Specific) (12)

Characteristics of Steady Flow Systems.

1. There is neither accumulation nor diminution of mass within a system.
2. There is neither accumulation nor diminution of energy within the system.
3. The state of the working substance at any point in the system remains constant.

THE FIRST LAW OF THERMODYNAMICS

Simmang and Faires (1981) expressed the following statements for the first law of thermodynamics:

1) In the absence of any work interactions between a system and its surroundings, the amount of neat heat is equal to the total energy of a closed system.
2) When a system undergoes a cyclic change, the neat heat to or from the system is equal to the net work from or to the system.
3) It is known as the conservation of energy principle
4) Energy can neither be created nor destroyed but only be converted to another form of energy.

Since the definition of first law of thermodynamics is broad, for the purpose of simplifying the definition, the last definition covers the first law and is expressed as

$$E_1 + E_{in} = E_2 + E_{out}$$

ENERGY EQUATIONS

1) Non - Flow Energy Equations

As previously discussed, a closed system is one that does not exchange matter with the surroundings and may be concerned with many types of energies. In this study, we will focus in a closed system with a fluid undergoing one or more processes. The process is a non-flow variety such as a fluid enclosed by the piston and a cylinder, and is called *closed non-flow system.*

NON - FLOW ENERGY EQUATION

(Closed System)

Energy equations are symbolized statements of the law of conservation of energy with defined sign conventions, says Simmang and Fairs (1981).

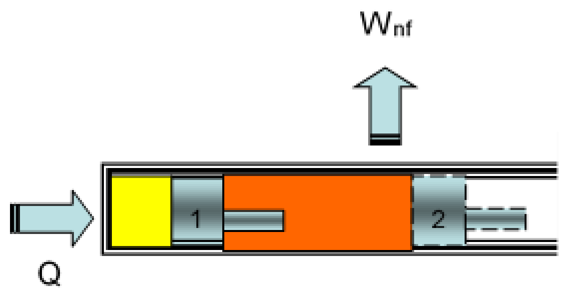


Figure 13. Schematic diagram of a closed system delivering non flow-work.

If the system is heated and undergoes a change from state 1 to state 2, where work is done by the system;

$$Es_1 + E_{in} = Es_2 + E_{out}$$

$$Es_1 + Q = Es_2 + W_{nf}$$

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

$$Q = U_2-U_1 + PE_2-PE_1 + KE_2-KE_1+ Wnf \qquad (13)$$

If the contained gas is considered at rest, thus there is no turbulence; in this case, random changes in potential and kinetic energies are taken as zero.

$$Q = U_2-U_1 + Wnf\ ;\ kJ \qquad or \qquad Q = \Delta U + Wnf \qquad (14)$$

$$q= u_2-u_1 + Wnf\ ;\ kJ/kg \qquad or \qquad q = \Delta u + Wnf \qquad (15)$$

STEADY FLOW ENERGY EQUATION

A steady-flow system is an open system in which the mass flow rate of fluid entering and leaving the system boundary are equal. Therefore, the change in stored energy, ∆Es is zero.

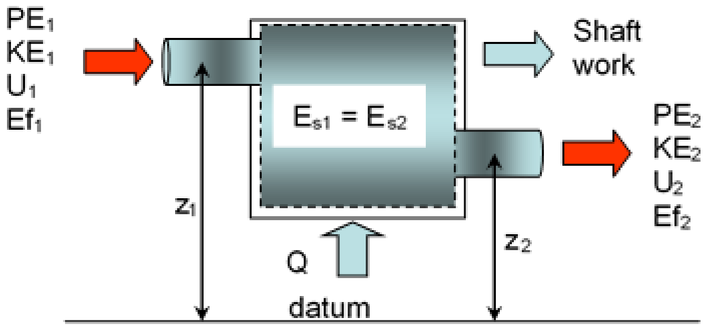


Figure 14. Schematic Diagram Showing a Steady flow system delivering work

$m_{in} = m_{out}$

$E_{in} = E_{out}$

$PE_1+KE_1+U_1+Ef_1+Q = PE_2+KE_2+U_2+Ef_2+Wsf$

$PE_1+KE_1+U_1+p_1V_1+Q = PE_2+KE_2+U_2+p_1V_1+Wsf$

$$Q = \Delta PE + \Delta KE + \Delta U + \Delta(pV) + Wsf \quad (16)$$

Note that U, p and V are properties of a system and the combination U+ pV, called ENTHALPY has a particular significance in some processes,

$$H = U + pV;\ Kj \quad (17)$$

$$h = u + pv;\ kJ/kg \quad (18)$$

Substituting with the equation $Q = \Delta PE + \Delta KE + \Delta U + \Delta(pV) + Wsf$ then,

$$Q = \Delta PE + \Delta KE + \Delta H + Wsf \quad (19)$$

EXERCISES

1) A solid disc flywheel (I = 500kg-m^2) is rotating with the speed of 1800rpm. What is the rotational kinetic energy?

Given:

$I = 500kg - m^2$

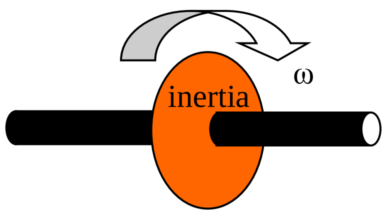
W $= 1800 \frac{r}{min} \times \frac{min}{60sec} \times \frac{2\pi rad}{rev} = 188.5 \frac{rad}{sec}$

Required:

KE = ?

Formula:

$$KE = \frac{1}{2k} Iw^2$$



The Rotating flywheel

Solution:

$$KE = \frac{1}{2k} Iw^2 = \frac{(500kg - m^2)(188.5\frac{rad}{sec})}{2(\frac{kg - m}{N - s^2})} = \boxed{8.8\, x\, 10^6\, Joules}$$

2. A 50 - kg block is raised vertically 5 meters. What is the change in Potential energy?

Given:

m = 50kg

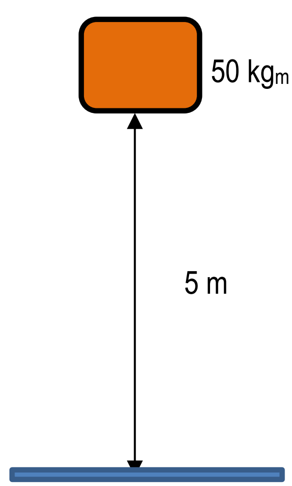
h = 5m

Required:

PE =?

Formula:

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



Solution:

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

$$\text{PE} = \frac{(50kg)(9.81\frac{m}{s^2})(5m)}{1(\frac{kg_m - m}{N - s^2})}$$

$\boxed{\text{PE = 2452.5 J}}$

3. How much energy is required to just vaporize a kg of water which is originally at 27℃ and one atmosphere?

Given:

m = 1 kg

T = 27℃

P = 1 atm

Note that the boiling point of water at 1 atm = 100°C

Requited:

Total Heat to just vaporize the water, Qt

Formula:

$\mathrm{Q_l = m_w}L_v$

$\mathrm{Q}_s = m_w C_p \Delta T$

$Q_t = Q_s + Q_l$

Solution:

Sensible Heat

Liquid of water at 27℃ → water vapor at 100℃ and the temperature must be absolute

Cp or the specific heat of water is 4.184 kJ/kg-K

$\mathrm{Q}_s = m_w C_p \Delta T$

$$\mathrm{Q}_s = 1\ kg\ \left(4.184\ \frac{kJ}{kg - K}\right)[(100 + 273) - (27 - 273)]K$$

$\mathrm{Q}_s = 305.43\ kJ$

Latent Heat

Lv = the latent heat of vaporization of water is 2,260 kJ/kg

$Q_l = m_w L_v$

$$Q_l = 1\ kg\ x\ 2{,}260\ \frac{kJ}{kg}$$

$Q_l = 2{,}260\ kJ$

$Q_t = Q_s + Q_l$

$Q_t = 305.43\ kJ\ + 2260\ kJ$

$\boxed{Q_t = 2565.43\ kJ}$

4. A centrifugal pump compresses 60 kg/s of water adiabatically from 95 to 250 kPa. The inlet and outlet temperature are 20°C. The inlet and discharge piping are on the same level, but the diameter of the inlet piping is 17 cm, whereas that of the discharge piping is 12 cm. Determine the power (work done on) of the pump.

Given:

m = 60 kg/s

P_1 = 95 kPa

P_2 = 250 kPa

T = 20^0C

d_1 = 17 cm

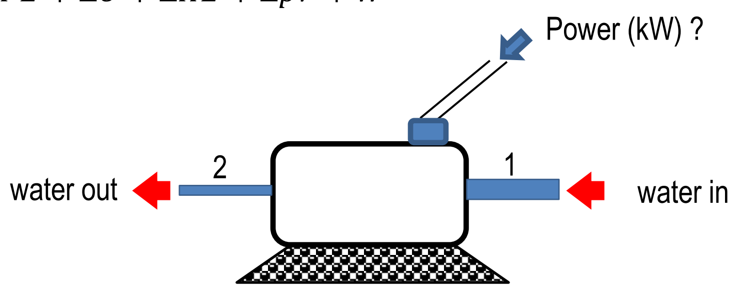
d_2 = 12 cm

Required:

Power = ?

Formulas:

$$Q = \Delta PE + \Delta U + \Delta KE + \Delta pV + W$$



Solution:

Solve for the volume:

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

$$V = \frac{\frac{60\text{kg}}{\text{s}}}{1000\frac{\text{kg}}{\text{m}^3}}$$

$$V = 0.06\ \frac{\text{m}^3}{\text{s}}$$

Solve for velocity:

$$v_1 = \frac{V}{A}$$

$$v_1 = \frac{0.06\ \frac{\text{m}^3}{\text{s}}}{\frac{\pi}{4}(0.17)^2} = 2.64\frac{\text{m}}{\text{s}}$$

$$v_2 = \frac{0.06\ \frac{\text{m}^3}{\text{s}}}{\frac{\pi}{4}(0.12)^2} = 5.31\frac{\text{m}}{\text{s}}$$

$$Q = \Delta PE + \Delta U + \rightarrow \Delta KE + \Delta pV + W$$

$$0 = 0 + 0 + \left(\frac{60\text{ kg/s}(5.31\text{ m/s})^2 - (2.64\text{ m/s})^2}{2\left(\frac{\text{kg}\cdot\text{m}}{\text{N}\cdot\text{s}^2}\right)}\right) + \left(250\frac{\text{kJ}}{\text{m}^3}\right)(0.06\text{ m}^3) - \left(95\frac{\text{kJ}}{\text{m}^3}\right)\left(0.06\ \frac{\text{m}^3}{\text{s}}\right) + \text{w}$$

$$\text{w} = -842.3982\frac{\text{J}}{\text{s}} \times \frac{1000\frac{\text{kJ}}{\text{s}}}{\frac{\text{J}}{\text{s}}} - 9.3\text{ kJ/s} \qquad w = -10.1423\frac{kJ}{s} or - 10.1432\ kW$$

5. Air flows steadily at the rate of 0.5 kg/s through an air compressor, entering at 7m/s speed, 100 kPa pressure and, 0.95 m^3/kg specific volume, and leaving at 5m/s, 700 kPa, and 0.19 m^3/kg. The internal energy of the air leaving is 90 kJ/kg greater than that of the air entering. Cooling water in the compressor jackets absorbs heat from the air at the rate of 58 kW. Compute the work in kW.

Given:

$m = 0.5\frac{kg}{s}$ $P_1 = 100\text{ kPa}$ $v_1 = 0.95\frac{m3}{kg}$

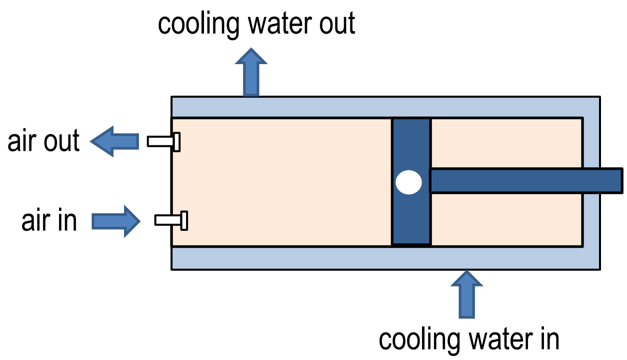
$Q = 58\text{ kW}$ $P_2 = 700\text{ kPa}$ $v_2 = 0.19\frac{m3}{kg}$

$\Delta u = 90\frac{kJ}{kg}$ $V_1 = 7\frac{m}{s}$

$V_2 = 5\frac{m}{s}$

Required:

W = kW?



Formulas:

$$wf = pv$$

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

$$wf_1 + KE_1 - wf_2 - KE_2 - Q - \Delta u = w$$

Solution:

$$wf_1 = p_1 v_1$$

$$wf_1 = 100kPa \times \frac{0.95m^3}{kg}$$

$$wf_1 = 95\frac{kJ}{kg}$$

$$KE_1 = \frac{{v_1}^2}{2k}$$

$$KE_1 = \frac{(7\frac{m}{s})^2}{2\frac{kg-m}{N-s^2}}$$

$$wf_2 = p_2 v_2$$

$$wf_2 = 700\text{ kPa} \times \frac{0.19\text{ m}^3}{kg}$$

$$wf_2 = 133\frac{kJ}{kg}$$

$$KE_2 = \frac{{v_2}^2}{2k}$$

$$KE_2 = \frac{(5\frac{m}{s})^2}{2\frac{kg-m}{N-s^2}}$$

$$KE_1 = 0.0245 \frac{kJ}{kg} \qquad KE_2 = 0.0125 \frac{kJ}{kg}$$

$$wf_1 + KE_1 - wf_2 - KE_2 - Q - \Delta u = w$$

$$w = 95 \frac{kJ}{kg} + 0.0245 \frac{kJ}{kg} - 133 \frac{kJ}{kg} - 0.0125 \frac{kJ}{kg} - 58 \text{ kW} - 90 \text{ kJ/kg}$$

$$w = -127.988 \frac{kJ}{kg} - 58 \text{ kW}$$

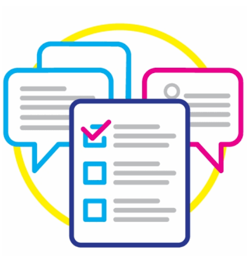
$$w = \frac{-127.988 \text{ kJ}}{kg} \times \frac{0.5 \text{ kg}}{s} - 58 \text{ kW}$$

$$w = \frac{-63.994 \text{ kJ}}{s} - 58 \text{ kW}$$

$$w = -63.994 \text{ kW} - 58 \text{ kW}$$

$$w = -121.994 \text{ kW}$$

$$\boxed{w = -122\ kW}$$



ASSESSMENT

Instruction: Solve the following problems in a clean 8.5 x 11 bond paper. Handwrite your solution and highlight the final answer by putting a box to the final answer. Scan or picture your paper and send to our Edmodo.com platform. Date of submission is specified in our Edmodo classroom.

ASSESSMENT NO. 2

REFLECTIVE ANALYSIS

The purpose of reflective analysis is to measure the extent of students learning on the lessons discussed in this module. This is a student self - evaluation to provide with an idea of the progress in the subject, identifies individual strengths and weaknesses, and ultimately serves as a measure of whether students achieve the course's learning objectives.

Instruction to students. Evaluate and rate from 1 – 5 (5 is the highest and 1 is the lowest) on how far you have learned in the topics discussed in this module. Rate the following statements based on your perceived understanding of the topics. Please rate honestly. Encircle the number that represents your answer.

Reflections	Scale				
I can discuss and define mass and energy.	5	4	3	2	1
I can identify and define forms of energy	5	4	3	2	1
I can fully explain how energy is transformed from one form to another;	5	4	3	2	1
I can easily know how energy equations are developed;	5	4	3	2	1
I can state the first law of thermodynamics	5	4	3	2	1
I can fully explain the different thermodynamic systems	5	4	3	2	1

5 – Definitely, 4 – Probably, 3 – Possibly, 2 – Probably Not, 1- Definitely Not

If your response fall within 1 – 3, reflect what should be done for you to achieve 4 and 5.

TEACHING AND LEARNING MATERIALS

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