CHAPTER 8: THERMODYNAMICS PRINCIPLES

8.1 Introduction of the Unit of Learning / Unit of Competency

This unit describes the competencies required by a technician in order to apply thermodynamics principles in welding and fabrication and related works. It includes understanding fundamentals of thermodynamics, performing steady flow processes, performing non-steady flow processes, understanding perfect gases, generating steam, performing thermodynamics reversibility and entropy, understanding idea gas cycle, demonstrating fuel and combustion, perform heat transfer, understanding heat exchangers, understanding air compressors, understanding gas turbines and understanding of impulse steam turbines.

Thermodynamics is a physics specialty devoted to the study of energy within large systems directly applicable to welding and fabrication processes. Welding is the process where the interrelation of temperature and deformation appears throughout the influence of thermal field on material properties and modification of the extent of plastic zones. The study of thermodynamics principle involves studying thermal effects with coupled or uncoupled theories of thermo mechanical response. In this unit of learning the basic requirements includes and not limited to Scientific Calculators, thermodynamics tables and relevant reference materials. At the end of the unit self-assessment, further reading and references have been provided.

8.2 Performance Standard

Perform steady and non-steady flow processes in relation to appropriate utilities**,** Perform thermodynamics reversibility and entropy, Perform heat transfer, demonstrate understanding on principles of turbine as per the equation.

8.3 Learning Outcome

8.3.1 List of Learning Outcomes

a. Understand fundamentals of thermodynamics
b. Perform steady flow processes
c. Perform non-steady flow processes
d. Understand perfect gases
e. Generate steam
f. Perform thermodynamics reversibility and entropy
g. Understand idea gas cycle
h. Demonstrate fuel and combustion
i. Perform heat transfer
j. Understand heat exchangers

k. Understand air compressors
l. Understand gas turbines
m. Understand impulse steam turbines

8.3.1.1 Learning Outcome No.1 Thermodynamic principles

Learning Activities

Learning Outcome No1: Thermodynamic principles	
Learning Activities	**Special Instructions**
Identify the fundamental application of thermodynamics in welding process Terms used in thermodynamics are described Thermodynamics processes and cycles are described First law of thermodynamics is applied	Ensure safety requirement in the laboratory

Information Sheet: 8.3.1.1

Introduction

Scientists in the late 18th and early 19th centuries adhered to caloric theory, first proposed by Antoine Lavoisier in 1783, and further bolstered by the work of Sadi Carnot in 1824, according to the American Physical Society. Caloric theory treated heat as a kind of fluid that naturally flowed from hot to cold regions, much as water flows from high to low places. When this caloric fluid flowed from a hot to a cold region, it could be converted to kinetic energy and made to do work much as falling water could drive a water wheel. It wasn't until Rudolph Clausius published "The Mechanical Theory of Heat" in 1879 that caloric theory was finally put to rest.

Thermodynamic systems

Energy can be divided into two parts, according to David McKee, a professor of physics at Missouri Southern State University. One is our human-scale macroscopic contribution, such as a piston moving and pushing on a system of gas. Conversely, things happen at a very tiny scale where we can't keep track of the individual contributions.

McKee explains, "When I put two samples of metal up against each other, and the atoms are rattling around at the boundary, and two atoms bounce into each other, and one of the comes off faster than the other, I can't keep track of it. It happens on a very small time scale and a very small distance, and it happens many, many times per second. So, we just divide all energy transfer into two groups: the stuff we're going to keep track of, and the stuff we're not going to keep track of. The latter of these is what we call heat."

Thermodynamic systems are generally regarded as being open, closed or isolated. According to the University of California, Davis, an open system freely exchanges energy and matter with its surroundings; a closed system exchanges energy but not matter with its surroundings;

and an isolated system does not exchange energy or matter with its surroundings. For example, a pot of boiling soup receives energy from the stove, radiates heat from the pan, and emits matter in the form of steam, which also carries away heat energy. This would be an open system. If we put a tight lid on the pot, it would still radiate heat energy, but it would no longer emit matter in the form of steam. This would be a closed system. However, if we were to pour the soup into a perfectly insulated thermos bottle and seal the lid, there would be no energy or matter going into or out of the system. This would be an isolated system.

In practice, however, perfectly isolated systems cannot exist. All systems transfer energy to their environment through radiation no matter how well insulated they are. The soup in the thermos will only stay hot for a few hours and will reach room temperature by the following day. In another example, white dwarf stars, the hot remnants of burned-out stars that no longer produce energy, can be insulated by light-years of near perfect vacuum in interstellar space, yet they will eventually cool down from several tens of thousands of degrees to near absolute zero due to energy loss through radiation. Although this process takes longer than the present age of the universe, there's no stopping it.

Heat engines

The most common practical application of the First Law is the heat engine. Heat engines convert thermal energy into mechanical energy and vice versa. Most heat engines fall into the category of open systems. The basic principle of a heat engine exploits the relationships among heat, volume and pressure of a working fluid. This fluid is typically a gas, but in some cases it may undergo phase changes from gas to liquid and back to a gas during a cycle.

When gas is heated, it expands; however, when that gas is confined, it increases in pressure. If the bottom wall of the confinement chamber is the top of a movable piston, this pressure exerts a force on the surface of the piston causing it to move downward. This movement can then be harnessed to do work equal to the total force applied to the top of the piston times the distance that the piston moves.

There are numerous variations on the basic heat engine. For instance, steam engines rely on external combustion to heat a boiler tank containing the working fluid, typically water. The water is converted to steam, and the pressure is then used to drive a piston that converts heat energy to mechanical energy. Automobile engines, however, use internal combustion, where liquid fuel is vaporized, mixed with air and ignited inside a cylinder above a movable piston driving it downward.

Refrigerators, air conditioners and heat pumps

Refrigerators and heat pumps are heat engines that convert mechanical energy to heat. Most of these fall into the category of closed systems. When a gas is compressed, its temperature increases. This hot gas can then transfer heat to its surrounding environment. Then, when the compressed gas is allowed to expand, its temperature becomes colder than it was before it was compressed because some of its heat energy was removed during the hot cycle. This cold gas can then absorb heat energy from its environment. This is the working principal behind an air conditioner. Air conditioners don't actually produce cold; they remove heat. The working fluid is transferred outdoors by a mechanical pump where it is heated by compression. Next, it transfers that heat to the outdoor environment, usually through an air-cooled heat exchanger. Then, it is brought back indoors, where it is allowed to expand and cool so it can absorb heat from the indoor air through another heat exchanger.

A heat pump is simply an air conditioner run in reverse. The heat from the compressed working fluid is used to warm the building. It is then transferred outside where it expands and becomes cold, thereby allowing it to absorb heat from the outside air, which even in winter is usually warmer than the cold working fluid.

Geothermal or ground-source air conditioning and heat pump systems use long U-shaped tubes in deep wells or an array of horizontal tubes buried in a large area through which the working fluid is circulated, and heat is transferred to or from the earth. Other systems use rivers or ocean water to heat or cool the working fluid.

The First Law of Thermodynamics

The first law of thermodynamics, also known as Law of Conservation of Energy, states that energy can neither be created nor destroyed; energy can only be transferred or changed from one form to another. For example, turning on a light would seem to produce energy; however, it is electrical energy that is converted.

A way of expressing the first law of thermodynamics is that any change in the internal energy (ΔE) of a system is given by the sum of the heat (q) that flows across its boundaries and the work (w) done on the system by the surroundings:

[latex]\Delta E = q + w[/latex]

This law says that there are two kinds of processes, heat and work, that can lead to a change in the internal energy of a system. Since both heat and work can be measured and quantified, this is the same as saying that any change in the energy of a system must result in a corresponding change in the energy of the surroundings outside the system. In other words, energy cannot be created or destroyed. If heat flows into a system or the surroundings do work on it, the internal energy increases and the sign of q and w are positive. Conversely, heat flow out of the system or work done by the system (on the surroundings) will be at the expense of the internal energy, and q and w will therefore be negative.

The Second Law of Thermodynamics

The second law of thermodynamics says that the entropy of any isolated system always increases. Isolated systems spontaneously evolve towards thermal equilibrium—the state of maximum entropy of the system. More simply put: the entropy of the universe (the ultimate isolated system) only increases and never decreases.

A simple way to think of the second law of thermodynamics is that a room, if not cleaned and tidied, will invariably become more messy and disorderly with time – regardless of how careful one is to keep it clean. When the room is cleaned, its entropy decreases, but the effort to clean it has resulted in an increase in entropy outside the room that exceeds the entropy lost.

The Third Law of Thermodynamics

The third law of thermodynamics states that the entropy of a system approaches a constant value as the temperature approaches absolute zero. The entropy of a system at absolute zero is typically zero, and in all cases is determined only by the number of different ground states it has. Specifically, the entropy of a pure crystalline substance (perfect order) at absolute zero temperature is zero. This statement holds true if the perfect crystal has only one state with minimum energy.

The First Law of Thermodynamics states that heat is a form of energy, and thermodynamic processes are therefore subject to the principle of conservation of energy. This means that heat energy cannot be created or destroyed. It can, however, be transferred from one location to another and converted to and from other forms of energy.

Thermodynamics is the branch of physics that deals with the relationships between heat and other forms of energy. In particular, it describes how thermal energy is converted to and from other forms of energy and how it affects matter. The fundamental principles of thermodynamics are expressed in four laws.

“The First Law says that the internal energy of a system has to be equal to the work that is being done on the system, plus or minus the heat that flows in or out of the system and any other work that is done on the system," said Saibal Mitra, a professor of physics at Missouri State University. "So, it’s a restatement of conservation of energy."

Mitra continued, "The change in internal energy of a system is the sum of all the energy inputs and outputs to and from the system similarly to how all the deposits and withdrawals you make determine the changes in your bank balance.” This is expressed mathematically as: $\Delta U = Q - W$, where ΔU is the change in the internal energy, Q is the heat added to the system, and W is the work done by the system.

Definition of terms

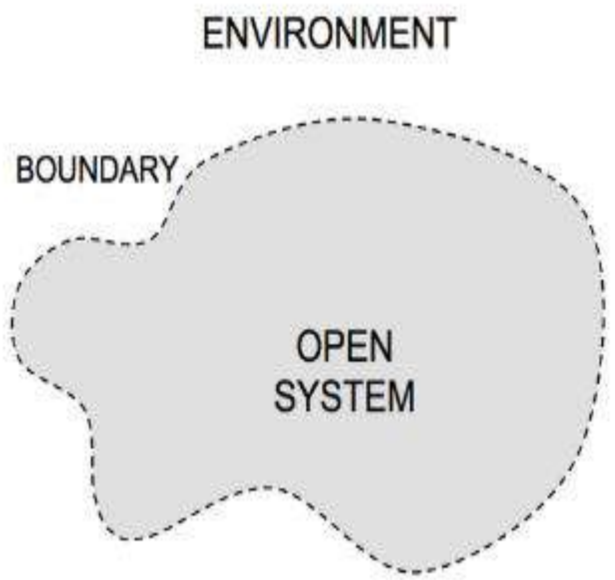
Thermodynamics – the study of heat related to matter in motion.

Thermodynamic system – defined as a quantity of matter or a region in space chosen for study.

Surroundings – Everything external to the system is defined to be the system’s surroundings.

Boundary- The area separating the system from its surrounding is the boundary of the system. The boundary may be at rest or in motion.

A closed system- is a definite quantity of matter contained within some closed surface. A closed system is sometimes referred to as a control mass because the matter composing the system is assumed known for all time.



A system is said to be isolated if no energy is transferred across the boundaries. An open system is a definite fixed location in space. The system is called open because mass may flow in or out of the system.

A phase is a state where all of the matter has the same chemical composition throughout. Matter that is in the same phase is homogeneous.

A property is any quantity which serves to describe a system .e.g. mass, volume, pressure, density, temperature, energy etc.

The state of a system is the condition of the system as determined by its properties.

A process is a transformation from one state to another. Whenever any property of a system undergoes a change (e.g., a change in pressure), then by definition the state changes, and the system is said to have undergone a process.

If none of a system's properties change with time, then the system is said to be in steady state.

A property of a system is called extensive if its value for the overall system is the sum of the values of the parts to which the system has been divided into. Examples include mass, volume and energy.

A property of a system is called intensive if its value is independent of the extent (size) of the system, and may vary from place to place and from moment to moment. Examples include pressure, density, temperature and specific volume.

Process – is said to have taken place when a substance is changed by means of an operation or operations having been carried out on the substance.

Processes

Isobaric process – Constant pressure process
Isothermal process – Constant temperature process
Isochoric/ isometric process- constant volume process
Adiabatic process- No heat transfers across the boundary
Polytrophic process – $PV^n = C$ a, constant.

Cycles

if processes are carried out on a substance such that, at the end the substance is returned to its original states, then the substance is said to have been taken through a cycle.

The First Law of Thermodynamics

The law relates heat and work. It means if some work is converted into heat or vice versa, then the relationship is:

$W = Q$ Where w = work transfer

Q = Heat transfer

Self-Assessment

1. One kg of diatomic Oxygen is present in a 500 L tank. Find the specific volume on both mass and mole basis.
   a) 0.6 m^3/kg , 0.260 m^3/mole
   b) 0.5 m^3/kg , 0.0160 m^3/mole
   c) 0.56 m^3/kg , 0.0215 m^3/mole
   d) 0.7 m^3/kg , 0.0325 m^3/mole

2. A piston/cylinder with a cross-sectional area of 0.01 m^2 is resting on the stops. With an outside pressure of 100 kPa, what should be the water pressure to lift the piston?
   a) 178kPa
   b) 188kPa
   c) 198kPa
   d) 208kPa

3. A large exhaust fan in a lab room keeps the pressure inside at 10 cm water relative vacuum to the hallway? What is the net force acting on the door measuring 1.9 m by 1.1 m?
a) 2020 N
b) 2030 N
c) 2040 N
d) 2050 N

4. A 5 m long vertical tube having cross sectional area 200 cm^2 is placed in a water. It is filled with 15°C water, with the bottom closed and the top open to 100 kPa atmosphere. How much water is present in tube?
a) 99.9 kg
b) 109.9 kg
c) 89.9 kg
d) 79.9 kg

5. A 5 m long vertical tube having cross sectional area 200 cm2 is placed in a water. It is filled with 15°C water, with the bottom closed and the top open to 100 kPa atmosphere. What is the pressure at the bottom of tube?
a) 119 kPa
b) 129 kPa
c) 139 kPa
d) 149 kPa

6. Find the pressure of water at 200°C and having specific volume of 1.5 m3/kg.
a) 0.9578 m3/kg
b) 0.8578 m3/kg
c) 0.7578 m3/kg
d) 0.6578 m3/kg

7. Find the pressure of water at 200°C and having specific volume of 1.5 m^3/kg.
a) 141.6 kPa
b) 111.6 kPa
c) 121.6 kPa
d) 161.6 kPa

8. A 5m^3 container is filled with 840 kg of granite (density is 2400 kg/m^3) and the rest of the volume is air (density is 1.15 kg/m^3). Find the mass of air present in the container.
a) 9.3475 kg
b) 8.3475 kg
c) 6.3475 kg
d) 5.3475 kg

9. A 100 m tall building receives superheated steam at 200 kPa at ground and leaves saturated vapor from the top at 125 kPa by losing 110 kJ/kg of heat. What should be the minimum inlet temperature at the ground of the building so that no steam will condense inside the pipe at steady state?
a) 363.54°C
b) 263.54°C

c) 163.54°C
d) none of the mentioned

10. The pressure gauge on an air tank shows 60 kPa when the diver is 8 m down in the ocean. At what depth will the gauge pressure be zero?
a) 34.118 m
b) 24.118 m
c) 14.118 m
d) none of the mentioned

11. Define the following terms
    i. Process
    ii. Cycle
    iii. Extensive property
12. Differentiate the following process
    i. Isothermal
    ii. Adiabatic
    iii. Isometric
    iv. Isobaric

13. Outline a procedure of carrying out an isobaric process in the laboratory
14. Carry out an experiment on isobaric process in the laboratory

Tools, Equipment, Supplies and Materials for the specific learning outcome
Laboratory equipment
Pressure, temperature and volume measuring instruments

References (APA)
Eastop T. D & Mconkey A. (2009): Applied Thermodynamics' for Engineering Technologist (fifth Edition) .Dorling Kindersley; New Delhi
Rayners Joel (1996) Basic engineering Thermodynamics (5th Edition) Addison Wesley Longman Limited. Edinburg Gate.

8.3.1.2. Learning Outcome No.2 Steady Flow Energy Process

Learning Activities

Learning Outcome No 2: Steady Flow Energy Process	
Learning Activities	**Special Instructions**
Observe the fluid through: Boiler and measure inlet and outlet parameters Air compressor Steady flow energy equation is derived Steady flow energy equation is applied in problem solving Steady flow energy equation is applied in utilities	Take of safety measures necessary in a boiler house

Information Sheet: 8.3.1.2
Perform Steady –Flow Energy Process

The mass flow rate of fluid or substance throughout the system is constant.
Energy of fluid mass entering the system. $= u_1 + P_1V_1 + KE_1 + PE_1$
Energy of fluid mass leaving the system $u_2 + P_2V_2 + KE_2 + PE_2$
By principle of conservation of energy for a system
Initial energy + energy entering = Final energy + energy leaving

$$E_1U_1 + P_1V_1 + KE_1 + PE_1 + Q$$

$$E_2U_2 + P_2V_2 + KE_2 + PE_2 + W$$

But $U + PV = H$
$E_1 + H_I + KE_1 + PE_1 + Q = E_2 + H_2 + KE_2 + PE_2 + W$
It is considered that the total energy of the fluid mess in the system remains constant
$(i.e)E_1 = E_2$
$\therefore Q - w = (H_2 - H_1)(KE_2 - KE_1) + (PE_2 - PE_1)$
This is known as the steady flow energy equation $(SFEE)$
It's illustrated as follows:-

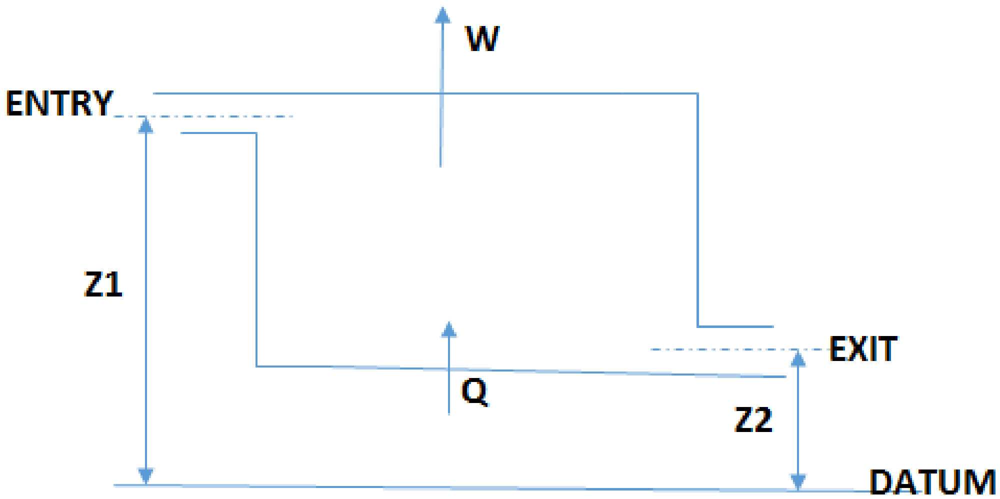


Figure 62: SFEE

The $(SFEE)$ becomes

$h_1 + \frac{{c_1}^2}{2} + gz + Q = h_2 + \frac{{c_2}^2}{2} + gz_2 + W$

Self-Assessment

1. What does a nozzle do?
   a) decreases the velocity of a fluid at the cost of its pressure gain
   b) increases the velocity of a fluid at the cost of its pressure drop
   c) increases the velocity of a fluid and also its pressure
   d) none of the mentioned.

2. What does a diffuser do?
   a) increases the pressure of the fluid at the expense of its KE
   b) decreases the pressure of the fluid and also increases its KE
   c) increases the pressure of the fluid and also its KE
   d) decreases the pressure of the fluid and also its KE

3. For an insulated nozzle, SFEE of the control surface gives (considering change in PE is zero and inlet velocity is small compared to exit velocity)
   a) V2=sqrt(4xΔh)
   b) V2=sqrt(Δh)
   c) V2=sqrt(Δh/2)
   d) V2=sqrt(2xΔh)

4. Fluid flow through which of the following throttles the flow?
   a) Partially opened valve
   b) orifice
   c) porous plug
   d) all of the mentioned

5. In a throttling device, what do we get as SFEE when changes in PE and KE are taken zero?
   a) dQ/dm≠0
   b) dW/dm≠0
   c) h1=h2
   d) none of the mentioned

6. Turbines and engines _____ positive power output, and compressors and pumps _____ power input.
   a) Require, give
   b) give, require
   c) give, give
   d) require, require

7. For a turbine, it is seen that work is done by the fluid at the expense of its enthalpy.
   a) True

b) false

8. For an adiabatic compressor or pump,
   a) the enthalpy of fluid remains constant with the amount of work input
   b) the enthalpy of fluid decreases by the amount of work input
   c) the enthalpy of fluid increases by the amount of work input
   d) none of the mentioned

9. A heat exchanger is a device in which heat is transferred from one fluid to another.
   a) True
   b) false

10. For an inviscid frictionless fluid flowing through a pipe, Euler equation is given by
    a) Vdp+VdV+gdZ=0
    b) Vdp-VdV+gdZ=0
    c) Vdp-VdV-gdZ=0
    d) none of the mentioned

11. Outline the meaning of steady flow energy process
12. Derive steady flow energy equation
13. Air is compressed by a rotary compressor in a steady flow process at a rate of 1.5 kg/s. At entry the air has a specific volume of 0.9m3/kg and has a velocity of 80m/s. At exit, the air has a specific volume of 0.4m3/kg and has a velocity of 45m/s. In its passage through the compressor the sp. Enthalpy of the air is increased by 110kg and it experiences heat transfer loss of 20kg/kg. Determine:

i. Inlet and exit areas of the compressor in m2
ii. Power required to drive the compressor

Tools, Equipment, Supplies and Materials for the specific learning outcome

Boilers
Compressors
Throttling process apparatus

References

Rayner Joel (1996) Basic Engineering Thermodynamics (fifth Edition) Addison Wesley Longman limited Edinburg Gate

Singh, O (2009): Applied Thermodynamic (3rd Edition). New age International Limited, New Delhi

8.3.1.3 Learning Outcome No.3 Non- Steady Flow Energy Process

Learning Activities

Learning Outcome No. 3 Non- Steady Flow Energy Process	
Learning Activities	**Special Instructions**
Carry out experiment on air compression using a player air pump and determine changes in air parameters of pressure and temperature	Carryout inspection of various pumps

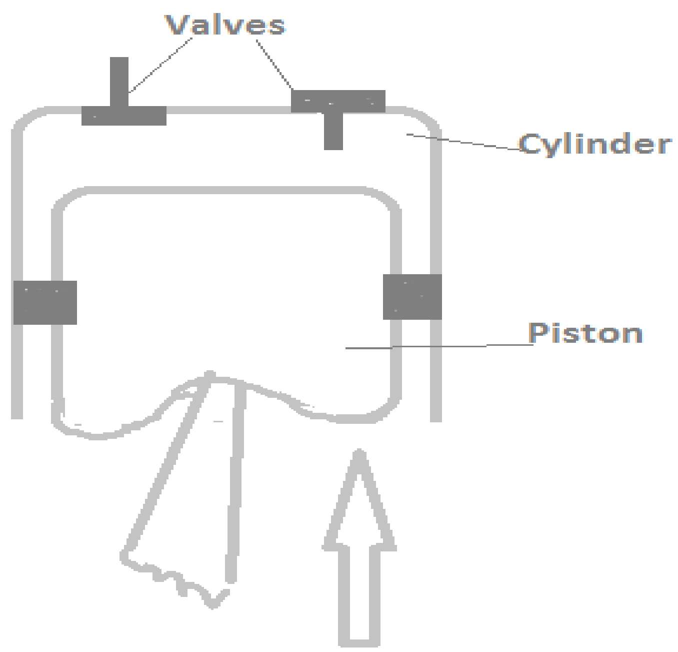
Information Sheet: 8.3.1.3

The Non Flow Energy Process

For a substance enclosed by the system, it possess internal energy u_1 resulting from the motion of its atoms or molecules. In this case

$U_1 + Q = U_2 + W$

$$\therefore Q = \Delta U + w$$



Compression Process

The process in a closed system is referred to as a non-flow process and the equation is referred to as the non-flow energy equation, ($NFEE$)

A typical non- flow process is the expansion or compression of a substance in cylinder

Self-Assessment

1. Thermodynamic process occurring at Constant volume is called …………..
2. In reversible polytropic thermodynamic process True heat transfer occurs.
   a. True
   b. False

3. Coefficient of performance of refrigerator and heat pump is always…………
4. Non flow energy equation for reversible process is…………..
5. Non flow energy equation for reversible process is…………….
6. Derive the non-flow energy equation
7. In a non –flow process carried output on 5.4 kg of fluid substance, there is a specific internal energy decrease of 50kj/kg and a work transfer from the substance of 85kg/kg. Determine the heat transfer
8. Demonstrate an experiment to illustrate non-flow energy process

Tools, Equipment, Supplies and Materials for the specific learning outcome

Plunger air pump (compressor)

Instrument to measure pressure and temperature.

References (APA)

Rayner Joel (1996) Basic Engineering Thermodynamics (fifth Edition) Addison Wesley Longman limited Edinburg Gate

8.3.1.4 Learning Outcome No.4 Understand Perfect Gas

Learning Activities

Learning Outcome No 4 UNDERSTAND PERFECT GAS	
Learning Activities	**Special Instructions**
Carry out experiment on Gas laws Boyler's law Charles law Joule's law ***Perfect gas laws*** are stated Gas laws experiment are carried out Gas laws are applied	State properties of various gases

Information Sheet:8.3.1.4

UNDERSTAND PERFECT GAS

A perfect gas may be defined as a gas which obeys the gas laws exactly

For any fixed mass of gas, changes of state are connected by the equation.

$$\frac{PV}{T} = a\ constant$$

For v =volume of 1 kg of gas, the specific volume, the equation becomes;

$$\frac{PV}{T} = a\ constant$$

The constant is written R and is called the characteristic gas constant (sometimes specific gas constant)

$\therefore \frac{PV}{T}$=R

For m kg of gas, then

$$\frac{P(mV)}{T} = mR\ where\ mr = total\ volume\ of\ gas$$

$$\frac{PV}{T} = mR\ \ or\ mv = mRT.$$

This is known as the characteristic equation of a perfect gas.

Self-Assessment

1. A mole of a substance has a mass equal to the molecular weight of the substance.
   a) true
   b) false

2. According to Avogadro's law, volume of a g mol of all gases at the pressure of ____ and temperature of ____ is same.
   a) 760 mm Hg, 100 degree Celsius
   b) 760 mm Hg, 0 degree Celsius
   c) 750 mm Hg, 100 degree Celsius
   d) 750 mm Hg, 0 degree Celsius

3. At NTP, the volume of a g mol of all gases is(in litres)
   a) 22.1
   b) 22.2
   c) 22.3
   d) 22.4

4. Which of the following statement is true?
   a) number of kg moles of a gas = mass / molecular weight
   b) molar volume = total volume of the gas / number of kg moles
   c) both of the mentioned
   d) none of the mentioned

5. The equation of state is a functional relationship between
   a) pressure
   b) molar or specific volume
   c) temperature
   d) all of the mentioned

6. If two properties (out of p,v,T) of a gas are known, the third can be evaluated.
   a) true
   b) false

7. Which of the following statement is true about a gas?
   a) lim(pv) with p tending to 0 is independent of the nature of gas
   b) lim(pv) with p tending to 0 depends only on the temperature
   c) this holds true for all the gases
   d) all of the mentioned

8. Universal gas constant is given by
   a) lim(pv) / 273.16
   b) R
   c) 0.083 litre-atm/gmol K
   d) all of the mentioned

9. The equation of state of a gas is lim(pv)=RT .
   a) true

b) false

10. For which of the following gases, does the product (pv) when plotted against p gives depends only on temperature?
    a) nitrogen
    b) hydrogen
    c) air and oxygen
    d) all of the mentioned

11. State the perfect gas equation
12. Derive the general gas equation.

13. 2kg of gas, occupying 0.7m3, had an original temperature of 150c. It was then heated at constant volume until its temperature became 135o c. Determine the heat transferred to the gas and its find pressure. Take cv= 0.72kj/kgk and R= 0.29kj/kgk

14. Conduct the following experiment
    i. Boyles law
    ii. Charles law
    iii. Joule law

Tools, Equipment, Supplies and Materials for the specific learning outcome

Boyle's law experiment apparatus
Charles' law experiment apparatus
Joule's law experiment apparatus

References (APA)

Rayner Joel (1996) Basic Engineering Thermodynamics (fifth Edition) Addison Wesley Longman limited Edinburg Gate
Singh, O (2009): Applied Thermodynamic (3rd Edition). New age International Limited, New Delhi

8.3.1.5 Learning Outcome No.5 Generate Steam

Learning Activities

Learning Outcome No 5 Generate Steam	
Learning Activities	**Special Instructions**
Generate steam in a boiler Determine the dryness fraction of wet steam generated Determine the thermal efficiency of the boiler	Care and precaution in using steam

Information Sheet: 8.3.1.5
Generate Steam

Steam is generated in a device known as a boiler
Formation of steam

Three distinct stages in production of steam.

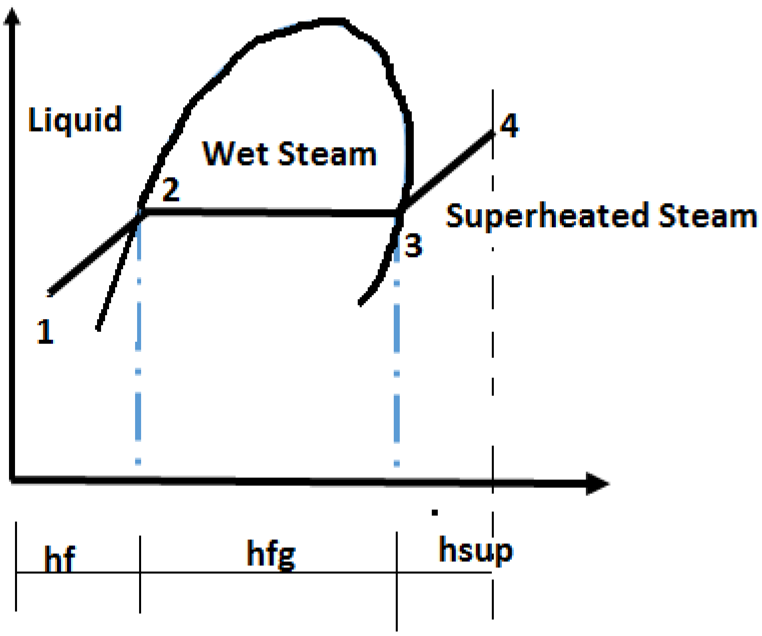
1-2 Warming phase

Temperature of water increases up to saturation temperature. Energy required is called liquid enthalpy

2-3 Transformation phase

Starts from water into dry saturation steam at saturation temperature. Between the two extremes, steam formed will always be we steam. Energy required is called the enthalpy of evaporation. Happens at constant temperature.

3-4 Superheated phase.



Begins with dry saturated steam to super-heated steam. It is accompanied by a rise in temperature. Energy added is called super heat enthalpy.

Dryness fraction

For wet steam, the degree of wetness, should be known. Dryness fraction is a measure of this wetness.

Dryness fraction= $\frac{mass\ of\ drysaturated\ vapour}{mass\ pfwet\ vapour\ continually\ the\ dry\ saturated\ vapour\ .}$

It's denoted by x

$$x = \frac{h - h_x}{h_{fg}}$$

Determination of dryness fraction

The separating calorimeter

The throttling calorimeter

The combined separating and throttling calorimeter.

Dryness fraction $x = \frac{x_{1M}}{M+m}$=x_1x_2

Where

x_1 = dryness fraction at the throttling calorimeter

x_2=dryness fraction at the separating calorimeter
m =Mass of water in separating calorimeter
M = Mass of condensate from throttling calorimeter

Pressure and boiling point
Boiling point increases as pressure increases. This can be obtained from the steam table or the De mollier chart.

Energy balance
In steam plant a quantity of energy is supplied from the fuel in a given time. The purpose of energy balance also called Energy audit is to account for this energy through the plant. The balance is often taken over a period of time and that various energy quantities often expressed as percentages of energy supplied by fuel.
The general distribution through the plant will be as follows:-
Energy to steam
Energy to exhaust
Energy to surrounding
Energy to unburnt fuel

The energy balance also often diagrammatically illustrated, either by a graph or bar client or Sankey diagram.

Self-Assessment

1. Quality indicates the
   a) mass fraction of liquid in a liquid vapour mixture
   b) mass fraction of vapour in a liquid vapour mixture
   c) both of the mentioned
   d) none of the mentioned

2. If 1 kg of liquid-vapour mixture is considered and x is the quality of that mixture, then
   a) mass of vapour is x kg
   b) mass of liquid is (1-x) kg
   c) both of the mentioned
   d) none of the mentioned

3. Which of the following statements is true?
   a) the value of x varies between 0 and 1
   b) for saturated water, x=0
   c) for saturated vapour, x=1
   d) all of the mentioned

4. Total volume of a liquid vapour mixture is given by
   a) volume of the saturated liquid
   b) volume of the saturated vapour
   c) sum of volumes of saturated liquid and saturated vapour
   d) none of the mentioned

5. In fire tube boilers, pressure is limited to
   a. 16 bar
   b. 32 bar
   c. 48 bar
   d. 64 bar

6. The following is an accessory of a boiler.
   a. Pressure gauge
   b. Safety valve
   c. Fusible plug
   d. Superheater

7. The following is a boiler mounting.
   a. Feed pump
   b. Water level gauge
   c. Economizer
   d. Superheater

8. Explain the process of steam formation using a T/h diagram

9. Steam at MN/m2 and dryness fraction 0.95 receives heat at constant pressure until its temperature becomes 350o c. Determine heat received by the steam per kilogram

10. The dryness of steam at a pressure of 2.2 mn/m2 is measured using a throttling calorimeter after throttling the pressure in the calometer is 0.13mn/m2 and the temperature is 1120 c .Determine the dryness fraction of the steam at 2.2mN/m2

11. Operate a boiler to generate steam, observing safety precautions

Tools, Equipment, Supplies and Materials for the specific learning outcome

Boiler

Combined separating and throttling calorimeter

References (APA)

Rayner Joel (1996) Basic Engineering Thermodynamics (fifth Edition) Addison Wesley Longman limited Edinburg Gate**.**

Eastop T. D & McConkey, A (2009). Applied Thermodynamics for \thermodynamics Technologist (3^{rd}) Edition. Dorling Kindersley, New Delhi

8.3.1.6 Learning Outcome No.6 Perform Thermodynamics Reversibility and Entropy

Learning Activities

Learning Outcome No 6 Perform thermodynamics reversibility and entrophy	
Learning Activities	**Special Instructions**
Carry out experiments to demonstrate Reversible process Irreversible process Thermodynamics reversibility is explained Principles of heat engine are explained Second law of thermodynamics is applied Entropy is explained in thermodynamics cycle	Laws of thermodynamics

Information Sheet: 8.3.1.6

Perform Thermodynamics Reversibility and Entropy

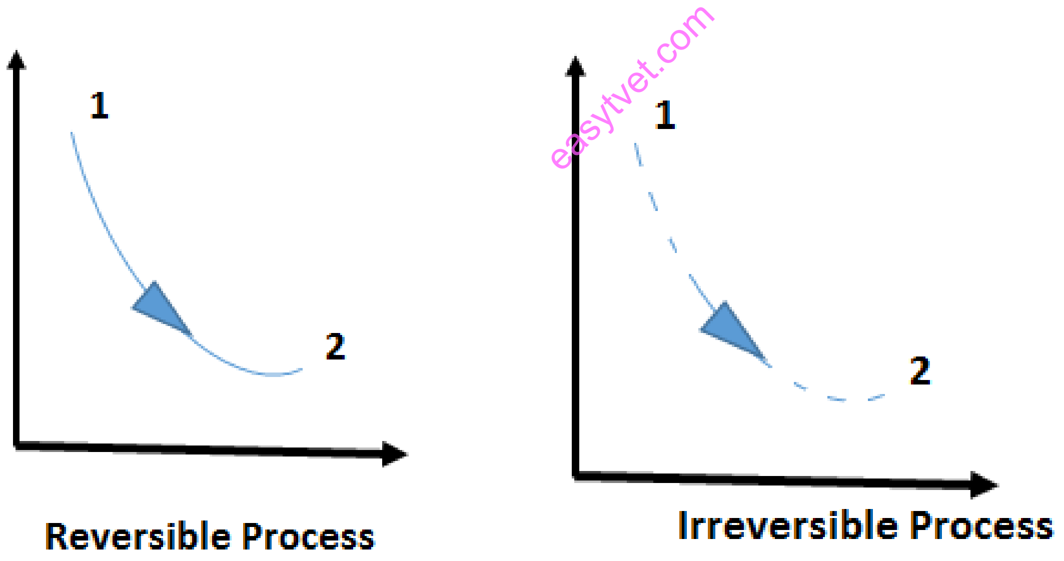


Figure 64: Reversible and Irreversible

When a system changes state in such a way that at any instant during the process the state point can be relocated on the diagram then the process is said to be reversible.

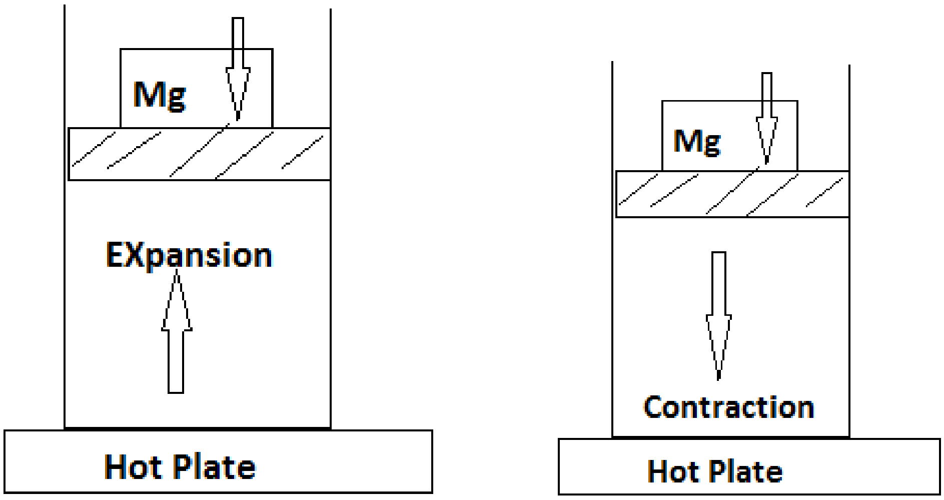


Figure 65: Expansion and Contraction

Reversible process

When a fluid undergoes a reversible process both the fluid and its surroundings can always be restored to their original state. No such process exists in practice. The great majority of thermodynamic process is irreversible.

Entropy

Entropy denoted by S is a state property that serves as a measure of reversibility and of the disorder of the system. It is developed to account for losses in the potential to do useful work and hence accounts for waste in a process.

The heat engine

The heat engine is a system operating in a complete cycle which converts heat input into work output. The piston cylinder heat engine is the most common heat engine.

When gas is heated it expand and push piston .The piston will be returned to its original state by two processes since the pressure in it may be high.
Some heat is taken away by cold plate
Piston is moved down against the gas when pressure is low to its original states
It's not possible to have an efficiency of 100% since some heat are used to overcome friction.

Self-Assessment

1. The equation W=∫vdp holds good for
   a) work-producing machine like an engine or turbine
   b) work-absorbing machine like a pump or a compressor
   c) both of the mentioned

d) none of the mentioned

2. Only those processes are possible in nature which would give an entropy ____ for the system and the surroundings together.
   a) decrease
   b) increase
   c) remains same
   d) none of the mentioned

3. A process always occurs in such a direction as to cause an increase in the entropy of the universe.
   a) true
   b) false

4. When the potential gradient is ____, the entropy change of the universe is ____
   a) large, zero
   b) infinitesimal, zero
   c) infinitesimal, negative
   d) none of the mentioned

5. At equilibrium, the isolated system exists at the peak of the entropy-hill and
   a) dS=-1
   b) dS=1
   c) dS=infinity
   d) dS=0

6. Which of the following is true?
   a) the KE of a gas is due to the coordinated motion of of all the molecules with same average velocity in same direction
   b) the PE is due to the displacement of molecules from their normal positions
   c) heat energy is due to the random thermal motion of molecules in a disorderly fashion
   d) all of the mentioned

7. Explain the reversible process using a PV diagram
8. 1 kg of steam at 7 bar, entropy, 6.5 kj/kgk is heated reversible at constant pressure until temperature is 2500 C. Calculate the heat supplied and show on a T-s diagram the area which represent the heat flow.

9. Calculate the change of entropy of I kg of air expanding polytropically in a cylinder behind a piston from 6.3 bar and 5500 c to 1.05 bar. The index of expansion is 1.3

10. Perform thermodynamics reversibility and entropy process in a laboratory set-up

Tools, Equipment, Supplies and Materials for the specific learning outcome

Laboratory apparatus for carrying out processes

References (APA)

Eastop T.D & Mc Conkey A. (2009). Applied Thermodynamics for Engineering Technologists (fifth Edition) Dorling Kindersley, New Delhi.
Rajput R. K. (2007). Engineering Thermodynamics (3^{rd}) Laxmi Publication Ltd, New Delhi

8.3.1.7 Learning Outcome No. 7 Understand Ideal Gas Cycle

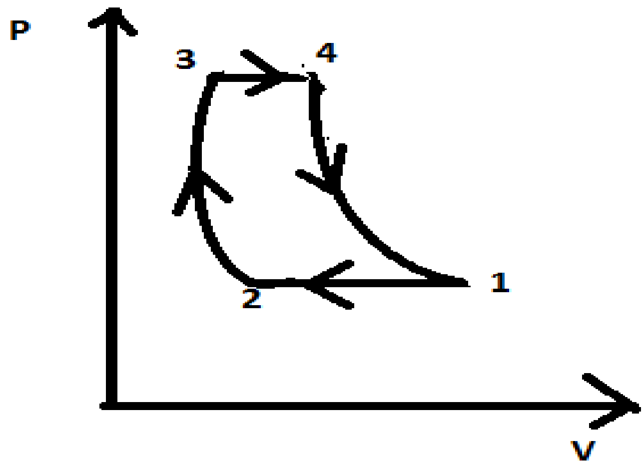
Learning Activities

Learning Outcome No 7. Understand Ideal Gas Cycle	
Learning Activities	**Special Instructions**
Demonstrate various gas cycles on a P-V diagram. Relate gas cycles to various areas of application. Determine thermal efficiency for various gas cycles.	Various Gas cycles

Information Sheet: 8.3.1.7
Understand Ideal Gas Cycle

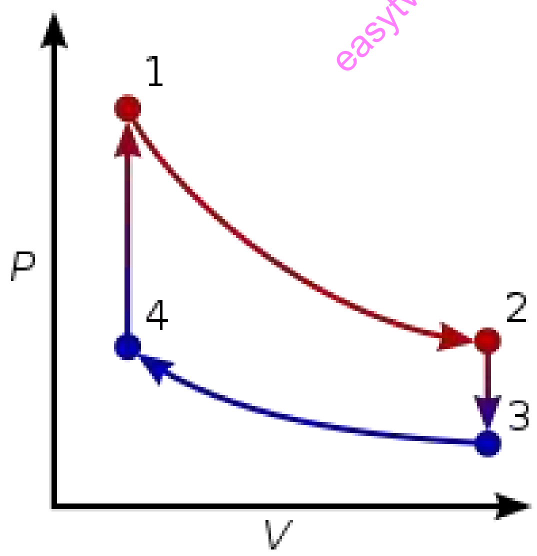
The Cayley cycle

Consists of two constant pressure processes 1-2 and 3-4 and two polytrophic processes 2-3and 4-1



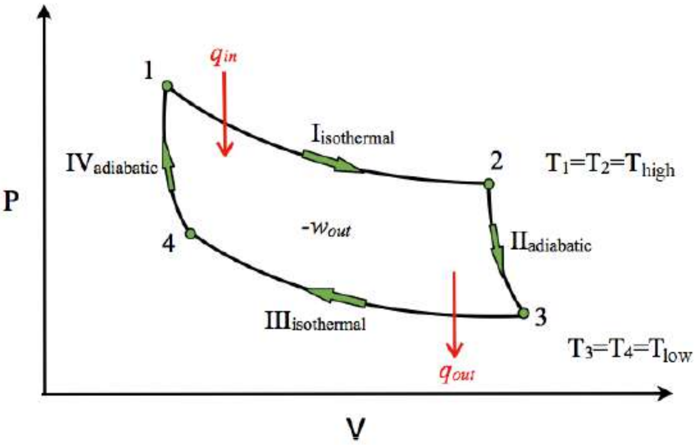
ii. The Stirling cycle

Consists of two isothermal process 1-2 and 3-4 and two constant volume 2-3 and 4-1 process.



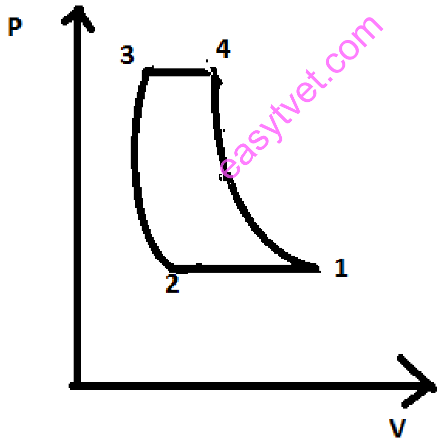
Carnot cycle
Two isothermal processes (PV= C) 1-2 and 3-4 and, two adiabatic process
$pv^{\delta} = c$

2-3 and 4-1



Constant pressure cycle

Two constant pressure process 1-2 and 3-4 and two a diabetics processes 2-3 and 4-1 Read others in Rayner Joel pages 426 -430



Efficiencies

Thermal efficiency = $\frac{Net\ work\ done}{Net\ heat\ received}$

Actual thermal efficiency =$\frac{Actual\ work\ done}{Thermal\ energy\ from\ fuel}$

Relative efficiency = $\frac{Axctual\ thermal\ efficiency}{Ideal\ thrmal\ efficiency}$

Theoretical cycles such as constant volume, constant pressure and the diesel cycles are sometimes referred to as the air standard cycles and the related efficiencies are referred to as air standard efficiencies.

Self-Assessment

1. Explain the need for understanding the ideal gas cycle
2. Derive thermal efficiency for the stirling cycle
3. The overall volume expansion ratio of a carnot cycle is 15. The temperature limits of the cycle are 260o c. Determine
4. The volumetric ratios of the isothermal and adiabatic processes.
5. The thermal efficiency of the cycle Take $\gamma = 1.4$
6. Carry out an experiment to determine ideal gas parameters. This is embedded

Tools, Equipment, Supplies and Materials for the specific learning outcome

Gas power plant	Laptop
Online links	Project

References

Rayner Joel (1996) Basic Engineering Thermodynamics (fifth Edition) Addison Wesley Longman limited Edinburg Gate
Eastop T.D & Mc Conkey A. (2009) Applied Thermodynamics for Engineering Technologists (fifth Edition) Dorling Kindersley, New Delhi.
Rajput R. K. (2007), Engineering Thermodynamics (3rd) Laxmi Publication Ltd, New Delhi

8.3.1.8 Learning Outcome No.8 Demonstrate Fuel & Combustion

Learning Activities

Learning Outcome No 8 Demonstrate Fuel & Combustion	
Learning Activities	**Special Instructions**
Carryout experiments to determine calorific value by Bomb Calorimeter Boys calorimeter Carry out fuel gas analysis by use of Orsat Apparatus's	Information of fuel and precaution

Information Sheet: 8.3.1.8

Definition

Fuel refers to a combustible substance capable of releasing heat during its combustion. Fuels classified as solid, liquid or gaseous fuels. Most important element, are carbon are hydrogen and sometimes a small amount of sulphur, oxygen and a small quantity of incombustibles (e.g) water vapour ,nitrogen or ash.

Accurate chemical analysis by mass of the important elements in the fuel is called the ultimate analysis. The elements usually included being carbon, hydrogen, nitrogen and sulphur.

Another analysis gives percentages of inherent moisture, volatile matter and combustibles solids. Fuel may be in solid, gas or liquid form.

Combustion equations

Masses of air and fuel enter combustion chamber where chemical reaction takes places. The information is expressed in the chemical reaction takes place. This information is expected in the

Chemical equation which shows.

Reactants and the products of combustion

Relative quantities of the reactants and products

E.g In combustion of hydrogen

$$2H_2 + 0_2 = 2H_{20}$$

$$C + 0_2 = C_{02}$$

Stoichiometric air fuel ratio

A stoichiometric mixture of air and fuel is one that contains just sufficient oxygen for the complete combustion of fuel. One with excess air is termed weak mixture. One with deficiency of air is termed rich mixture

Percentage excess air $=\frac{\text{Actual A/Fratio}-\text{Stoischimetrica A/F}}{\text{Stoichimmetric A/F ratio}}$

For gaseous fuels the ratios are in volumes and for solid and liquid fuels, ratios are expressed by mass.

$$\text{Mixture strength} = \frac{\text{Stoichiometrick A/F}}{\text{actual A/F ratio}}$$

<u>Calorific value of fuel</u>

The amount of energy released by fuel per/unit during combustion is called calorific value of fuel. Bomb calorimeter is used to measure the value for solid and liquid fuel. Boys or gas calorimeter is used to determine the value for gaseous fuels.

<u>Exhaust gas analysis</u>

The products of combustion are mainly gaseous. A sample is taken for analysis and cooled down to a temperature which is below the saturation temperature of steam present. The steam content is therefore not included in the analysis and hence usually quoted as analysis of dry products. An analysis with steam is called a wet analysis. The analysis of dry flue gas is carried out by means of a piece of equipment called the Orsat Apparatus. Electronic analyser is also used

Self-Assessment

1. In presence of which gas is the fuel burnt to generate energy in form of heat?
   a) Oxygen
   b) Hydrogen
   c) Methane
   d) Nitrogen

2. Which are the main constituents of fuel from given options?
   a) Carbon and Nitrogen
   b) Oxygen and Hydrogen
   c) Carbon and Hydrogen
   d) Helium and Oxygen

3. Which fuel is used widely in steam power plants?
   a) Oil
   b) Gas
   c) Coal
   d) Petroleum

4. What is phenomenon of formation of coal called?
   a) Metamorphism

b) Diagenis'
c) Photosynthesis
d) Protolith

5. On what basis is the coal classified?
a) Period of formation
b) Depending on capacity to burn
c) Region/area where is it formed
d) Physical and chemical composition

6. What is the use of electrostatic precipitations in steam power plant?
a) To remove the steam
b) To draw the coal powder into boiler
c) To remove the feed water
d) To remove fly ash

7. Why is 'make-up water' added to drum continuously?
a) To remove the impurities in tube
b) To replace the water that has been converted into steam
c) To keep the system cool externally
d) To compensate for water loss trough blow down

8. Write a combustion equation for a fuel C_6H_{14}
9. The analysis by volume of a produces gas is as follows. 14%H_2, 2%CH_4 22 % c_0 , 2%0_2, 55% N_2: Find the stoichiometric volume of air required for complete combustion of 1m3 of this gas.
10. Explain the procedure of determining calorific value of a solid fuel
11. Determine the adiabatic flame temperature for the complete combustion of Propane (C3H8) with 250% theoretical air in an adiabatic control volume [T = 1300K].

Tools, Equipment, Supplies and Materials for the specific learning outcome
Orsat apparatus
Bomb calorimeter
Boys calorimeter

References

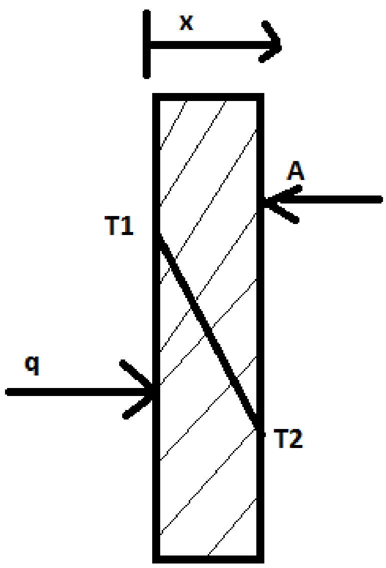
Rayner Joel (1996) Basic Engineering Thermodynamics (fifth Edition) Addison Wesley Longman limited Edinburg Gate
Eastop T.D & Mc Conkey A. (2009), Applied Thermodynamics for Engineering Technologists (fifth Edition) Dorling Kindersley, New Delhi.
Rajput R. K. (2007): Engineering Thermodynamics (3rd) Laxmi Publication Ltd, New Delhi

8.3.1.9 Learning Outcome No.9 Perform Heat Transfer

Learning Activities

Learning Outcome No. 9 Perform Heat Transfer	
Learning Activities	**Special Instructions**
Carryout experiments heat transfer through the following in a boiler Conduction Convection Derive conduction equation and apply Fourier's law Derive heat transfer equation from Newton's law of cooling and Fourier's law	Precaution in handling heated items

Information Sheet: 8.3.1.9



Perform Heat Transfer

There are three mechanics of heat transfer

Conduction – heat transfer directly through the mechanism of inner-molecular interactions. It needs a matter and does not require any bulk motion of matter.

Conduction rate equation is described by the Fourier law.

$q = -KA\Delta T$

$Q = heat\ flow$

$k = thermal\ conductiviity\ of\ material$

$A = cross\ sectional\ area\ in\ direciton\ of\ flow$

$\Delta T = Temperature\ gradient$

Since this is a vector equation, x direction is considered.

$$q_x = -KAx\frac{dT}{dx}$$

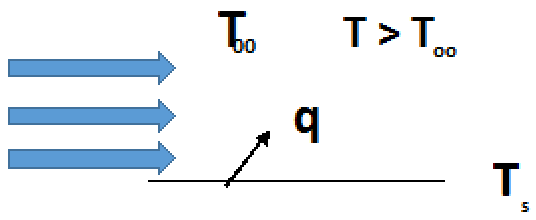
In circular coordinates.

$$q_r = -KAr\frac{dT}{dr}$$

Convection

Heat transfer across a system boundary due to temperature difference by combined mechanisms of inter molecular interactions and bulk transport .it needs fluid matter,

Moving fluid



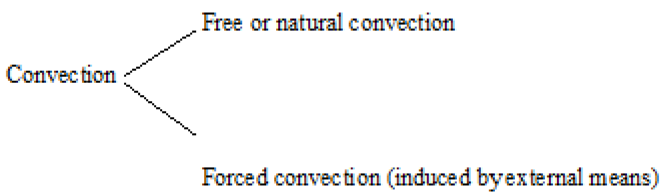
Newton's law of cooling

$q = hA_s\Delta T$

q = heat flow from surface
h=heat transfer coefficient

$$A_s = surface\ area$$

$\Delta T = T_s - T_\infty$ = Temperature difference between surface and coolant



Radiation

Heat transfer involves the transfer of heat by electromagnetic radiation that arises due to the temperature of the body. It does not need matter.

Self-Assessment

1. The transfer of heat between two bodies in direct contact is called
   a) radiation
   b) convection
   c) conduction
   d) none of the mentioned

2. Heat flow into a system is taken to be ____, and heat flow out of the system is taken as ____
   a) positive, positive
   b) negative, negative
   c) negative, positive
   d) positive, negative

3. In the equation, dQ=TdX
   a) dQ is an inexact differential
   b) dX is an exact differential
   c) X is an extensive property
   d) all of the mentioned

4. The transfer of heat between a wall and a fluid system in motion is called
   a) radiation
   b) convection
   c) conduction
   d) none of the mentioned

5. For solids and liquids, specific heat
   a) depends on the process
   b) is independent of the process
   c) may or may not depend on the process
   d) none of the mentioned

6. The specific heat of the substance is defined as the amount of heat required to raise a unit mass of the substance through a unit rise in temperature.
   a) true
   b) false

7. Heat and work are
   a) path functions
   b) inexact differentials
   c) depend upon the path followed
   d) all of the mentioned

8. Explain the following modes of heat transfer
   i. Conduction
   ii. Convection
   iii. Radiation

9. Derive the Fourier equation for heat conclusion
10. Demonstrate a method for determine the effectiveness of a tagging materials in boilers.

Tools, Equipment, Supplies and Materials for the specific learning outcome

Boiler

Temperature measuring instruments

References

Rayner Joel (1996) Basic Engineering Thermodynamics (fifth Edition) Addison Wesley Longman limited Edinburg Gate

Eastop T.D & Mc Conkey A. (2009). Applied Thermodynamics for Engineering Technologists (fifth Edition) Dorling Kindersley, New Delhi.

Rajput R. K. (2007). Engineering Thermodynamics (3rd) Laxmi Publication Ltd, New Delhi

8.3.1.10 Learning Outcome No. 10 Understand Heat Exchangers

Learning Activities

Learning Outcome No 10 Understand Heat Exchangers	
Learning Activities	**Special Instructions**
Demonstrate the working of heat exchanger using a model. Operate a heat exchangers and take appropriate readings of temperatures of the fluids	Materials used for exchangers

Information Sheet: 8.3.1.10

Understand Heat Exchangers

Heat exchangers are devices used to transfer heat between two and more fluid steams at different temperatures. Heat exchangers are used in power generation, chemical /processing, electronics cooling, air conditioning, refrigeration and automotive applications.

Classifications of heat exchangers

Recuperations and generators.
Transfer process: Direct contact or indirect contact
Geometry of construction: tubes, plates and extended surfaces
Heat transfer mechanism: single phase or two phase flow
Flow arrangements: parallel flow, counter flow or cross flow.

Recuperations heat exchangers

Heat exchangers are ones where fluids are separated by a heat transfer surface and ideally they do not mix or leak examples are parallel flow and counter flow heat exchangers. Heat equations to solve heat exchanges problems.

For heat exchanger $Q = \cup A\Delta Tm$

Where;
Q =heat transfer rate
∪= overall heat transfer coefficient
A=total surface area
∆ Tm= mean temperature difference

The overall heat transfer coefficient is defined in terms of individual thermal resistances in series

$$\frac{1}{\cup A} = \frac{1}{(\eta_0 hA)_i} + \frac{1}{Skw} + \frac{1}{(\eta_0 hA)_0}$$

Where η_0 =Surface efficiency for inner and outer surfaces

S =Shape factor for separating

LMTD (Log mean temperature difference is derived in all basic heat transfer texts)

$$\Delta T_{LMTD} = \frac{\Delta T_2 - \Delta T_1}{ln\frac{\Delta T_2}{\Delta T_1}}$$

Where $\Delta T_1 and\ \Delta T_2$ represent the temperature different at each end of the heat exchanger.

Self-Assessment

1. Which among the following surface promote heat transfer?
   a) Plain
   b) Shiny
   c) Corrugated
   d) Wet

2. _______ Heat exchanger is needed for cream than for milk, if capacities and temperature programs are identical.
   a) Larger
   b) Smaller
   c) Similar
   d) Stagnant

3. Which of the following material is used for heat transfer in the dairy industry?
   a) Iron
   b) Platinum
   c) Copper
   d) Stainless steel

4. The rate of buildup of fouling does not depend on which of the following?
   a) Milk quality and Air content of the product
   b) Temperature difference between product and heating medium
   c) Pressure conditions in the heating section
   d) Thickness of stainless steel

5. State various types of heat exchangers
6. Derive the equation for the rate of heat flow in a counter flow heat exchangers
7. Carry out an experiment to determine the performance of particular heat exchangers

Tools, Equipment, Supplies and Materials for the specific learning outcome

- Boiler

- Temperature measuring instruments

References

Rayner Joel (1996) Basic Engineering Thermodynamics (fifth Edition) Addison Wesley Longman limited Edinburg Gate

Eastop T.D & Mc Conkey A. (2009). Applied Thermodynamics for Engineering Technologists (fifth Edition) Dorling Kindersley, New Delhi.

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8.3.2 Learning Outcome No.11 Understanding Air Compressors

Learning Activities

Learning Outcome No 11 Understanding Air Compressors	
Learning Activities	**Special Instructions**
Derive equations for various compressor work Apply the equations for reciprocating air compressor to solve compressor problems	Information of compressors

Information Sheet: 8.3.2

Understanding Air Compressors

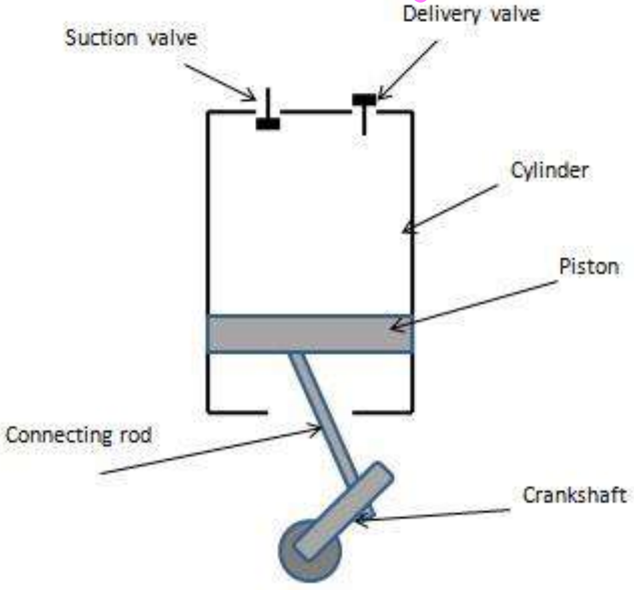
The air compressors are of two general types.

Reciprocating compressors

Rotary compressors.

Reciprocating air compressors

Air is locked up in cylinder and is compressed by the piston which moves reducing the space in the cylinder.



Rotary compressors

Compression is achieved through a rotary action of a member either by reducing space or by forcing air into a reservoir where back pressure results to high pressures: include centrifugal compressors, axial flow, roots, blower vane etc.

Equations of reciprocating air compressors.

Work must be put to a compressor to keep it running. Every effort is made to reduce this work input

Isothermal compressions the ideal but cannot be achieved in practice.

$$isothermal\ efficiency = \frac{isothermal\ work}{Actual\ work}$$

$$\oint w = \frac{n}{(n-1)} P_1 V_1 \left[\left(\frac{p_2}{p_1} \right) \quad \frac{n-1}{n} \right]$$

$$= \frac{n}{(n-1)}\ mRT_1 \left[\left(\frac{P_2^{\left(\frac{n-1}{n}\right)} - 1}{P_1} \right] \right.$$

Volumetric efficiency

$$\int vol = \frac{effective\ swept\ volume}{swept\ volume}$$

Clearance ratio= $\frac{clearnance\ volume}{swept\ volume}$

For two stage machine

$$\emptyset W = \frac{2n}{(n-1,} P_1 V_1 \left(\frac{p_3}{p_1} \right)^{\frac{n-1}{n}} - 1)$$

For example an x stage machine

$\frac{p_2}{p_1} = \frac{p_3}{p_2} = \ldots\ldots\ldots = \frac{px+1}{p_x} = k$

$$k = \sqrt[x]{\frac{px+1}{p_1}} = \sqrt[x]{(pressure\ ratio\ through\ compressor)}$$

Self-Assessment

1. Rotary compressors are used where _____ quantities of gas are needed at relatively _____ pressure.
   a) large, high
   b) large, low
   c) small, high
   d) small, low

2. Rotary compressor can be classified as
   a) displacement compressor
   b) steady-flow compressor
   c) both of the mentioned
   d) none of the mentioned

3. In steady-flow compressor, compression occurs by
   a) transfer of kinetic energy
   b) transfer of potential energy
   c) trapping air
   d) all of the mentioned

4. In displacement compressor, compression occurs by
   a) transfer of kinetic energy
   b) transfer of potential energy
   c) trapping air
   d) all of the mentioned

5. The rotary positive displacement machines are _____ and compression is _____
   a) cooled, isothermal
   b) uncooled, isothermal
   c) cooled, adiabatic
   d) uncooled, adiabatic

6. Define the following terms in relation to compressors
   i. Isothermal efficiency
   ii. Volumetric efficiency

7. Derive the equation of cycle work for a reciprocating single acting compressor.

8. A Single stage reciprocating compressor takes 1m3 of air per minute at 1.013 bas and 150c and delivers it at 7 bar assuming that the law of compression is $PV^{1.35}$=C, and that clearance is negligible, calculate indicated power

Tools, Equipment, Supplies and Materials for the specific learning outcome.

Various types of compressors

Pressure and temperature measuring instruments

References

Rayner Joel (1996) Basic Engineering Thermodynamics (fifth Edition) Addison Wesley Longman limited Edinburg Gate

Eastop T.D and Mc Conkey A. (2009): Applied Thermodynamics for Engineering Technologists (fifth Edition) Dorling Kindersley, New Delhi.

Rajput R. K. (2007): Engineering Thermodynamics (3rd) Laxmi Publication Ltd, New Delhi

8.3.2.1 Learning Outcome No.12 Understand Gas Turbines

Learning Activities

Learning Outcome No12 UNDERSTAND GAS TURBINES	
Learning Activities	**Special Instructions**
Demonstrate the use of gas turbine plant to determine the efficiency of the plant Identify closed cycle and open cycle turbine plants	Information about various turbines

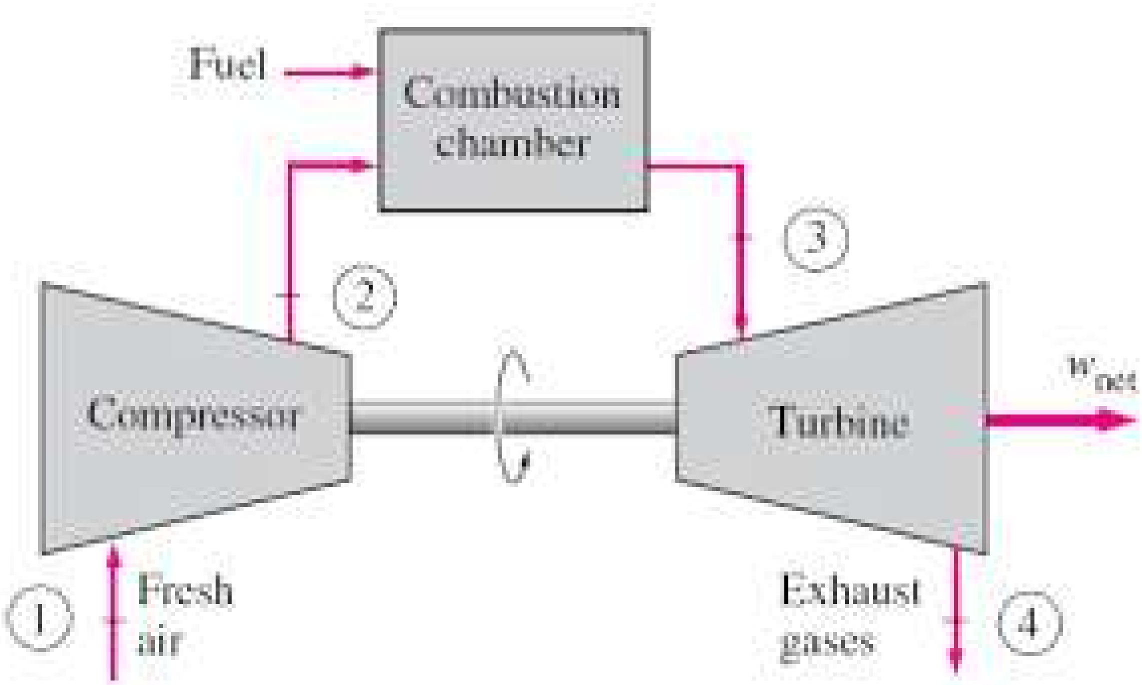
8.3.2.1 Information Sheet

Understand Gas Turbines

Definition

Gas turbines are used in a very wide range of services such as powering aircraft, industrial plants for driving pump, compressors and small electric generators. Compared with steam, plant they have advantages that they and their total systems are small in size, mass and initial cost per unit output. They are quick starting and also smooth running.

Open cycle

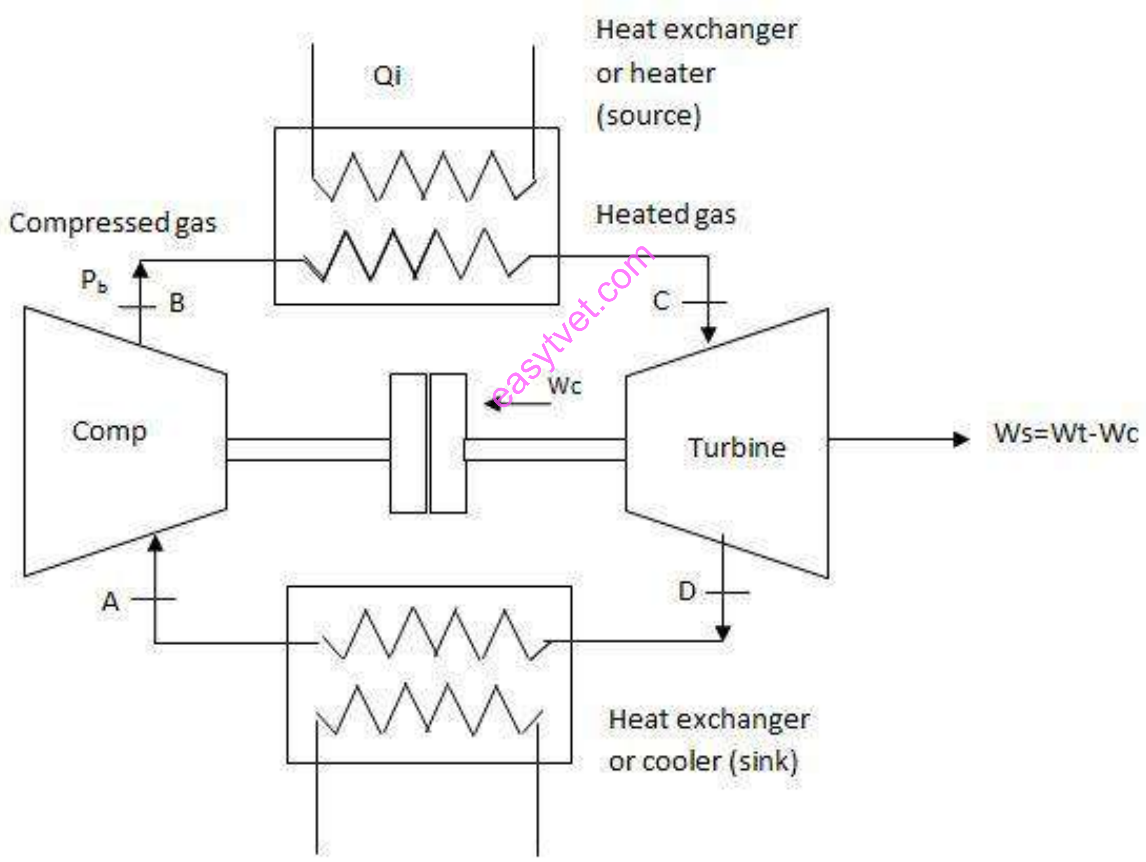


Open gas –turbine cycle

The gas enters compressors where it's compressed it then enters combustion chambes or reactor where it receives heat at constant pressure from there it expands through the turbine the turbine supplies compressor power.

Closed cycle

The gas is heated in the reactor, expanded through the turbine and then cooled in a heat exchanges and compressed back to the reactor.



Closed turbine cycle

$$W_T = \overset{o}{m} cp(T_4 - T_3)$$

In terms of pressure ratio across turbine rpt

$$r_{pt} = \frac{p_3}{p_4}$$

Is related to absolute temperature ratio by

$\frac{T_3}{T_4} = r_{pt}^{(k-1)k}$Where$k = \frac{cp}{cv}$

$$\therefore WT = \dot{M}C_P T_3(1 - \frac{1}{r_{pt}^{(k-1)/k}}$$

Cycle thermal efficiency

$$\int_{th} = 1 - \frac{1}{r_p^{(k-1)k}}$$

Self-Assessment

1. In gas turbine, intercooler is placed
   a) before low pressure compressor
   b) in between low pressure compressor and high pressure compressor
   c) in between high pressure compressor and turbine
   d) None of the mentioned

2. In gas turbine, the function of Re-heater is to
   a) Heat inlet air
   b) Heat exhaust gases
   c) Heat air coming out of compressor
   d) Heat gases coming out of high pressure turbine

3. The 'work ratio' increases with
   a) increase in turbine inlet pressure
   b) decrease in compressor inlet temperature
   c) decrease in pressure ratio of the cycle
   d) all of the mentioned

4. In the centrifugal compressor, total pressure varies
   a) directly as the speed ratio
   b) square of speed ratio
   c) cube of the speed ratio
   d) any of the mentioned

5. The efficiency of multistage compressor is _____ than a single stage.
   a) lower
   b) higher

c) equal to
d) any of the mentioned

6. Explain the use of gas turbine in the industry
7. Derive turbine work equation for gas turbine
8. Outline a procedure to determine the efficiency of a gas turbine.

Tools, Equipment, Supplies and Materials for the specific learning outcome

Various types of compressors
Pressure and temperature measuring instruments

References

Abdulkarem A. Mishael (2017): power plant (editions): Chapter 6 Gas turbines & combined cycles,
Rayner Joel (1996) Basic Engineering Thermodynamics (fifth Edition) Addison Wesley Longman limited Edinburg Gate
Eastop T.D & Mc Conkey A. (2009) Applied Thermodynamics for Engineering Technologists (fifth Edition) Dorling Kindersley, New Delhi .
Rajput R. K. (2007): Engineering Thermodynamics (3rd) Laxmi Publication Ltd, New Delhi

8.3.2.2 Learning Outcome No.13 Understand the Impulse Steam Turbines

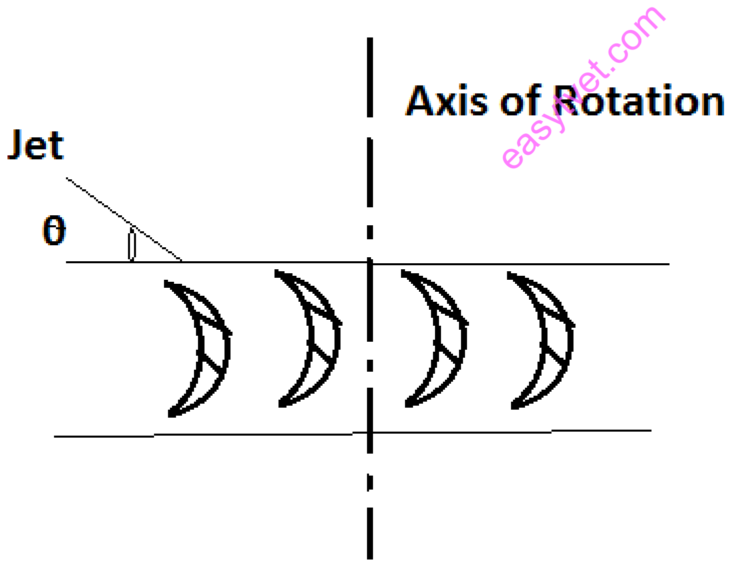
Learning Activities

Learning Outcome No 13 Understand The Impulse Steam Turbines	
Learning Activities	**Special Instructions**
Demonstrate the operation of an impulse steam turbine Principles of operations of the impulse steam turbines is described Impulse steam turbine equation is derived and applied	Special types of turbines

Information Sheet: 8.3.2.2

Understand Impulse Steam Turbine

Most steam turbine plant use impulse steam turbines. The steam supplied to a single wheel impulse turbines expands completely in the nozzles and leaves with a high absolute velocity. The steam is delivered to the wheel at an angle.



For impulse momentum the force, is equal to the change in momentum of the fluid in the direction of motion.

$F = \frac{\dot{m}}{g_c^4}(V_{s1}\text{Cos}\theta - V_{s2}\ Cos\delta)$

Where $V_{s1=}$ absolute velocity of fluid leaving nozzle

V_{s2}=absolute velocity of fluid leaving blade.

θ= nozzle angle

δ= fluid exit angle

$\vartheta_{c=}$Conversion factor.

0

$F = \frac{m}{g_c}(V_{w1} - V_{w2})$

Where V_w is velocity of whirl

Thus

0

0

$W = \frac{mV_B}{g_c}$ \$V_{si}cos\theta$-$V_{s2}cord$)

Blade efficiency defined as ration of blade work to the initial energy of jet.

$$\eta_B = 2\left[\left(\frac{V_B}{V_{s1}}\right)cos\theta - \frac{V_B}{V_{s1}}\left(\frac{V_{s2}}{V_{s1}}\right)cos\right]$$

Single –stage impulse turbine

It is also called the de Laval turbine after its inventor. It consists of a single motor to which impulse blades are attached steam is fed through one or several convergent- governing of the turbines by shutting off one or more of them.

Compound –impulse turbines

In a single stage impulse turbine, he speed is too high beyond the maximum allowable safety limits due to centrifugal stress on the motor material. The large velocities also result in large fiction losses and a reduction in turbine efficiency. To overcome these differences, two methods have been utilized, both called compounding

Velocity –compounded turbine

Pressure –compounded turbine.

Self-Assessment

1. Derive the blade efficiency equation for an impulse steam turbine.

2. The velocity of steam leaving the nozzles of an impulse turbine is 900m/s and the nozzle angle is 20^0. The blade velocity is 300m/s and the blade velocity coefficient is 0.7. Calculate for a mass flow of 1kg/s and symmetrical blading

   i. The blade inlet angle
   ii. The driving force on the wheel

3. Demonstrate the operation of an impulse steam turbine

Tools, Equipment, Supplies and Materials for the specific learning outcome
Impulse steam turbine plant with tempera rue and pressure measuring instruments attached

References (APA)

Abdulkarem A. Mishael (2017). Power plant (edition 1): chapter -4 –steam Turbine
Eastop T.D & Mc Conkey A (2009). Applied Thermodynamics for Engineering Technologist (fifth Edition) Darling, Kindersley, New Delhi