LAB MANUAL

APPLIED THERMODYNAMICS (MED 273)

G.S. Mandal's

MAHARASHTRA INSTITUTE OF TECHNOLOGY, AURANGABAD

DEPARTMENT OF MECHANICAL ENGINEERING

NAME OF LABORATORY: THERMAL ENGINEERING		
LABORATORY MANUAL		
CLASS: SECOND YEAR	**PART:** II	**COURSE CODE :**MED 273
NAME OF COURSE : APPLIED THERMODYNAMICS		

INDEX

Vision of Institute:

MIT aspires to be a leader in Techno-Managerial education at national level by developing students as technologically superior and ethically strong multidimensional personalities with a global mindset.

Mission of Institute:

We are committed to provide wholesome education in Technology and Management to enable aspiring students to utilize their fullest potential and become professionally competent and ethically strong by providing,

- Well qualified, experienced and Professionally trained faculty
- State-of-the-art infrastructural facilities and learning environment
- Conducive environment for research and development.
- Delight to all stakeholders.

Vision of Mechanical Engineering Department

To be a center of excellence in the field of Mechanical Engineering where the best of teaching, learning and research synergize and serve the society through innovation and excellence in teaching.

Mission of Mechanical Engineering Department

To provide world-class under-graduate and graduate education in Mechanical Engineering by imparting quality techno-managerial education and training to meet current and emerging needs of the industry and society at large.

Program Educational Objectives (PEOs):

PEO 1	Graduates will apply the tools and skills acquired during their undergraduate studies either in advanced studies or as employees in engineering industries.
PEO 2	Graduates of the program will have successful technical and professional career.
PEO 3	Graduates of the program will continue to learn to adopt constantly evolving technology.
PEO 4	Graduates will demonstrate sensitivity towards societal issues.

Course Objectives:

1. To understand the construction and working of Bomb calorimeter, steam engine, turbine, boiler mountings, boiler accessories.
2. To understand working principle and performance of boiler, draught, steam nozzle and reciprocating air compressor.
3. To study and understand working of steam turbines.
4. To understand the concept of heat balance sheet for boiler.
5. To perform the energy assessment of lighting system.

Course Outcomes:

CO	Code	Statement
CO 1	MED 254.1	Recall the basic concepts of thermodynamics applicable to different thermal systems.
CO 2	MED 254.2	Summarize governing equations and principle of thermodynamics applicable for various thermal systems.
CO 3	MED 254.3	Apply thermodynamics laws to analyze boiler, steam nozzle, condenser, steam power cycles, air standard cycles and reciprocating air compressor.
CO 4	MED 254.4	Analysis of various thermodynamic power cycles.
CO 5	MED 254.5	Evaluate the performance analysis of various thermal systems.
CO 6	MED 254.6	Discuss the energy performance assessment for various equipment and utility systems

Program Outcomes:

POs		**Description**
PO 1	**Engineering Knowledge**	Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.
PO 2	**Problem Analysis**	Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.
PO 3	**Design / Development of Solutions**	Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations
PO 4	**Conduct Investigations of Complex Problems**	Use research-based knowledge and search methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.
PO 5	**Modern Tool Usage**	Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.
PO 6	**The Engineer and Society**	Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.
PO 7	**Environment and Sustainability**	Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.
PO 8	**Ethics**	Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.
PO 9	**Individual and Team Work**	Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.
PO 10	**Communication**	Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective

		presentations, and give and receive clear instructions.
PO 11	**Project Management and Finance**	Demonstrate knowledge and understanding of the engineering and management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.
PO 12	**Life-long Learning**	Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

Program Specific Outcomes:

PSO 1	Ability to design & analyze components & systems for mechanical performance
PSO 2	Ability to apply and solve the problems of heat power and thermal systems
PSO 3	Ability to solve real life problems with the exposure to manufacturing industries

University Syllabus

Dr. Babasaheb Ambedkar Marathwada University, Aurangabad
(Faculty of Science & Technology)
Syllabus of S. Y. B. Tech. (Mechanical Engineering)

Course Code: MED273 Course: Laboratory of Applied Thermodynamics Teaching Scheme: Practical: 2 Hrs/week	Credits: 0-1-0 Term Work: 0 Marks Practical: 25 Marks

Objectives	:	1.To understand different concepts in applied thermodynamics through laboratory work
List of Practical (Any 10)	:	1. To Study Principle, Construction and Working of Bomb Calorimeter 2. To Study energy balance [Heat Utilization] using any Boiler Model 3. To Study Boiler Draught 4. To study Convergent-Divergent Nozzle 5. To Study Steam Condenser 6. To Study Steam Turbine 7. Performance of Energy assessment of lighting Systems. 8. To determine isothermal and volumetric efficiency of Air Compressor 9. Case Study on 'Waste Heat Recovery' 10. Visit to Thermal Power Station and Report related to it. 11. Assignment on Unit II and Unit V

Lab Instructions

1. Student should wear college ID-card and must carry record and observation.
2. Take signature of lab in charge after completion of observation and record.
3. If any equipment fails in the experiment report it to the supervisor immediately.
4. Students should come to the lab with thorough theoretical knowledge.
5. Don't touch the equipment without instructions from lab supervisor.
6. Don't crowd around the experiment and behave in-disciplinary.
7. Students should carry their own stationary and required things.
8. Using the mobile phone in the laboratory is strictly prohibited.

EXPERIMENT NO.1

Aim: To Study Principle, Construction and Working of Bomb Calorimeter

Objective: To study principle of bomb calorimeter

To study construction of bomb calorimeter

To study working of bomb calorimeter

Apparatus: Bomb Calorimeter

1. Introduction:

The Bomb calorimeter measures the amount of heat generated when matter is burn in a sealed chamber (Bomb) in an atmosphere of pure Oxygen Gas. The Bomb Calorimeter provides a simple, inexpensive yet accurate method for determination of heat of combustion, calorific value and sulphur content of solid and liquid fuels.

2. Constructional details of parts:

a. Bomb:

The bomb consists of three parts vis., bomb, body lid, the closing nut. The upper side of the lid is also provided with a small hook to lifting it and a schrader valve for filling oxygen in the bomb. The Schrader valve is provided with a metallic cap.

b. Water jacket:

It is made of copper and is high chromium plated on the inside and also outside to minimize radiative losses. The top of the jacket carries a rod to hold the stirrer, adapter for Beckman thermometer/ digital thermometer sensor, small hole for inserting connecting cable.

c. Stirrer:

Soundless stirrer provided built-in or dismantled. The motor shaft is attached to the stirrer blade through nylon stirring rod, to preclude heat in the system

d. Calorimeter vessel:

Made of copper and is brightly polished outside.

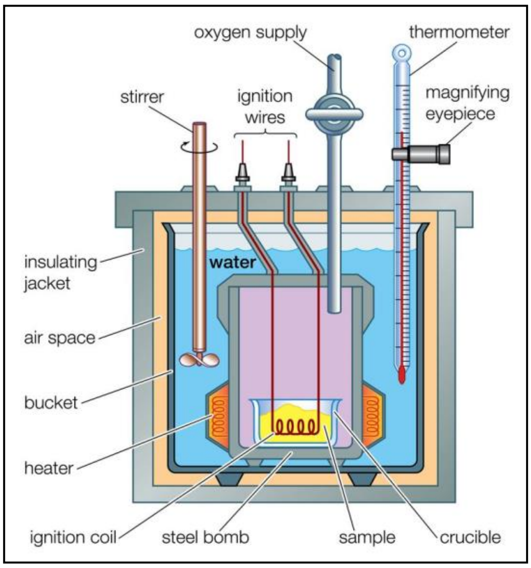


Figure 1: Bomb Calorimeter

e. Bomb wiring unit:

It consists of main indicator, continuity indicator, main switch, stirrer switch, speed regulator, connecting terminals.

f. Pressure gauge:

The pressure gauge is connected to copper tubing and fine regulator valve to suit on oxygen cylinder.

g. Pellet press:

Provide to make pellet of coal sample or any other powder, before weighting and burning.

h. Crucible:

The stainless steel crucible is offered as standard with instruments.

i. **Ignition wire:**

It is recommended that nichrome wire be used. Platinum wire also can be used.

j. **Standard:**

Benzoic acid is used as standard most commonly. It burns easily and completely and can be compressed into pellets.

k. **Thermometer:**

Beckman glass thermometer is used. Since glass Beckman thermometer is difficult to before installing and need more efficiency set to read, it is recommended to use digital thermometer with reading of 0.01 deg. C.

3. **Construction and working of bomb calorimeter**

The calorimeter is made of austenitic steel which provides considerable resistance to corrosion and enables it to withstand high pressure. In the calorimeter is a strong cylindrical bomb in which combustion occurs. The bomb has two valves at the top. One supplies oxygen to the bomb and other releases the exhaust gases. A crucible in which a weighted quantity of fuel sample is burnt is arranged between the two electrodes as shown in Fig. 1. The calorimeter is fitted with water jacket which surrounds the bomb. To reduce the losses due to radiation, calorimeter is further provided with a jacket of water and air. A stirrer for keeping the temperature of water uniform and a thermometer to measure the temperature up to an accuracy of 0.001°C are fitted through the lid of the calorimeter.

To start with, standard quantity of fuel sample is accurately weighed into the crucible and a fuse wire (whose weight is known) is stretched between the electrodes. It should be ensured that wire is in close contact with the fuel. To absorb the combustion products of sulphur and nitrogen standard quantity of water is poured in the bomb. Bomb is then supplied with pure oxygen through the valve to a specified pressure. The bomb is then placed in the weighed quantity of water, in the calorimeter. The stirring started after making necessary electrical connections, and when the thermometer indicates a steady temperature fuel is fired and temperature readings are recorded after certain intervals until

maximum temperature is attained. The bomb is then removed; the pressure slowly released through the exhaust valve and the contents of the bomb are carefully weighed for further analysis. The heat released by the fuel on combustion is absorbed by the surrounding water and the calorimeter. From the above data the calorific value of the fuel can be found in the following way:

Let Wf = Weight of fuel sample (kg),

W = Weight of water (kg),

C = Calorific value (higher) of the fuel (kJ/kg),

We = Water equivalent of calorimeter (kg),

T_1 = Initial temperature of water and calorimeter,

T_2 = Final temperature of water and calorimeter,

Tc = Radiation corrections, and

c = Specific heat of water.

Heat released by the fuel sample = Wf × C

Heat received by water and calorimeter = (Ww + We) × c × [(T_2 – T_1) + Tc].

Heat lost = Heat gained

Wf × C = (W + We) × c × [(T_2 + T_1) + Tc]

$$C = \frac{(W+We)\times c\times [(T2 + T1)+ Tc]}{Wf \times C}$$

Note:

1. Corrections pertain to the heat of oxidation of fuse wire, heat liberated as a result of formation of sulphuric and nitric acids in the bomb itself.

2. It should be noted that bomb calorimeter measures the higher or gross calorific value

because the fuel sample is burnt at a constant volume in the bomb. Further the bomb calorimeter will measure the H.C.V. directly if the bomb contains adequate amount of water before firing to saturate the oxygen. Any water formed from combustion of hydrogen will, therefore, be condensed. The procedure of determining calorific values of liquid fuels is similar to that described above. However, if the liquid fuel sample is volatile, it is weighed in a glass bulb and broken in a tray just before the bomb is closed. In this way the loss of volatile constituents of fuels during weighing operation is prevented.

Conclusion: (Students need to write conclusion)

EXPERIMENT NO.2

Aim: To study energy balance [Heat Utilization] using any boiler model

Objective: To study energy balance using boiler model

1. Introduction:

A heat balance sheet is an account of heat supplied and heat utilized in various ways in the system. Necessary information concerning the performance of the boiler is obtained from the heat balance. The heat balance is generally done on second basis or minute basis or hour basis.

The boiler calculation is generally based upon the high calorific value of 1 kg of fuel considered as 100 %.

2. Heat losses in the boiler

The efficiency of boiler is never 100 % as only a portion of heat supplied by the fuel is utilized rest of it is lost;

A. Heat carried away by dry product of combustion.
B. Heat carried away by the steam product by the combustion of hydrogen present in fuel.
C. Heat carried away by moisture in fuel and air.
D. Heat loss due to incomplete combustion of carbon to carbon monoxide instead of carbon dioxide and thus escape of combustible matter in the flue gases and ash.
E. Heat loss due to radiation.

3. Method of minimizing the heat loss

1. The heat loss to chimney gases may be minimized by installing an economizer in between the boiler and chimney.

2. Loss of heat may be minimized by providing the boiler with an effective draught system which will ensure sufficient supply of air through the fuel in furnace.

3. Heat loss due to unburnt fuel which may fall into ash pit may be minimized by properly sizing of coal. 4. Heat loss due to moisture content in the fuel may be minimized by making the fuel dry before charging into the boiler furnace.

5. Heat loss due to external radiation may be minimized by providing effective covering of insulating material on the boiler parts which are liable to radiate heat.

4. Procedure

The heat balanced sheet of a boiler:

A. Heat utilized by generation of steam: Useful heat absorbed, H_1 = m (h_1-h_2)

H_1 = Equivalent evaporation: 2256.9 KJ

B. Loss due to moisture in fuel:

The moisture in the fuel is evaporated and superheated and thus the heat is lost.

Loss due to moisture in fuel,

$H_2 = m_1 (h_{11} - h_{21})$

Where m_1 = Mass of moisture per kg of fuel of fired

h_{11} = Enthalpy of steam formed

h_{21} = Enthalpy of liquid at temperature of boiler furnace.

C. Loss due to H_2O vapour from combustion of Hydrogen:

This is found similarly to loss due to moisture in fuel.

D. Loss due to moisture in air:

This is also found in the similar way as above and it is generally negligible.

E. Loss due to dry flue gases:

This is the target loss that takes place inside the boiler. This is given by:

$H_3 = m_2 \times C_p \times (t_g - t_a)$

Where

m_2 = Mass of dry flue gases per kg of fuel.

C_p= Specific heat of dry flue gases

t_g = Temperature of flue gases

t_a = Temperature of atmospheric (gases) air

F. Loss due to incomplete combustion of carbon:

This loss is caused by incomplete combustion of carbon to carbon monoxide instead of carbon dioxide.

$H_4 = m_3$ x CV of CO

H_4 = CO.C

(CO_2+CO. CV of CO)

m_3 = Mass of carbon actually burned per kg of fuel

CO & CO_2 % by volume

CV = Number of heat unit generated by burning 1kg of carbon contained in CO to CO_2 = 23820 KJ/ Kg

G. Loss due to unconsumed combustion to refuse:

This loss is due to some unburnt carbon falling into the ash pit.

$H_5 = m_4$. CV

m_4 = Unburnt mass of carbon in refuse per Kg of fuel

CV = Calorific fuel of carbon

Example: HEAT BALANCE SHEET (Basis 1 Kg of low grade fuel)

Heat supplied (KJ)	**%**	**Heat Expenditure (KJ)**	**%**
Gross heat supplied	100	(a) Heat utilized in steam generation (b) Heat carried away by flue gases (c) Heat utilized in evaporating and superheating the moisture fuel and water vapour formed due to burning of hydrogen of fuel. (d) Heat loss by incomplete combustion (e) Heat carried away by excess air (f) Heat carried away by carbon ash (g) Heat uncounted for such as radiation and error etc.	….. …... ….. ….. ….. ….. ……
Total	**100**	**Total**	**100**

Conclusion: (Students need to write conclusion)

EXPERIMENT NO.3

Aim: To Study Boiler Draught

Objective: To study Boiler draught

Apparatus: A model of a Boiler

1. Introduction

Boiler draught may be defined as the small difference between the pressure of outside air and that of gases within a furnace or chimney at the grate level, which causes the flow of air/hot flue gases to take place through the boiler.

The draught is necessary to force air through the fuel bed/ grate to aid in proper combustion of fuel and to remove the products of combustion i.e. flue gases to the atmosphere after they have given their heat to water being evaporated in the boiler. Draught also provides velocity to flue gases and so increases the heat transfer coefficient in the boiler. This draught is essentially required in a boiler and can be produced by a number of methods.

2. Classification of Draught

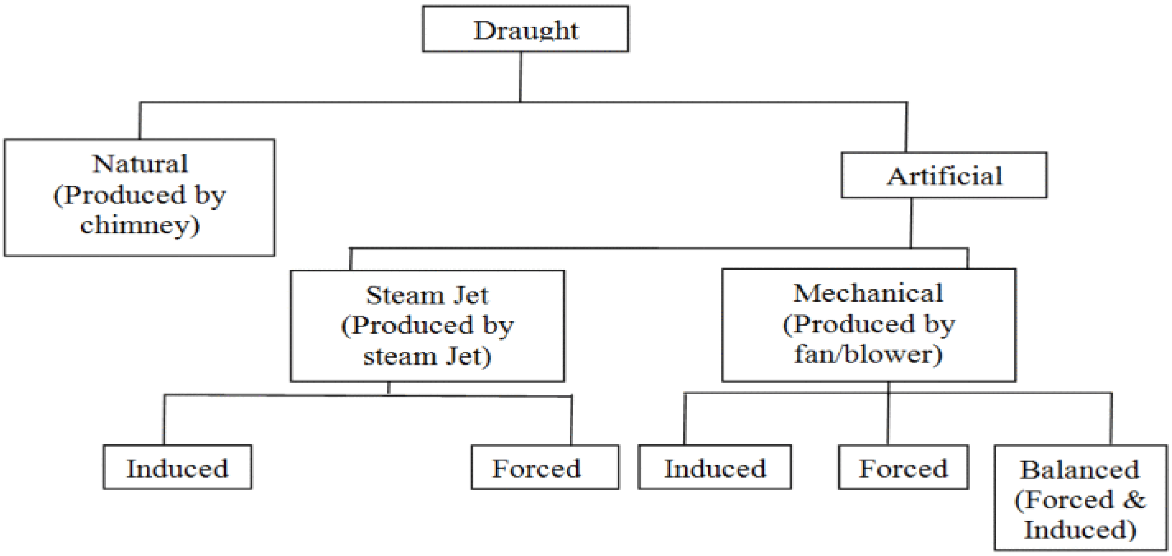


Figure 3.1: Classification of Draught

When the draught is produced with the help of chimney only, it is known as Natural Draught and when the draught is produced by any other means except chimney it is known as Artificial Draught.

A) Natural Draught:

Natural draught system employs a tall chimney as shown in the figure. The chimney is a vertical tubular masonry structure or reinforced concrete. It is formed for enclosing a column of flue gases to produce the draught.

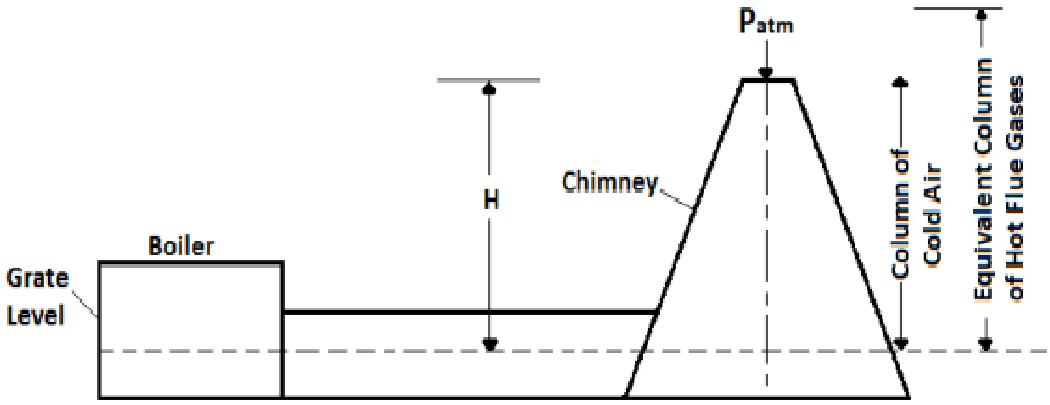


Figure 3.2: Natural Draught

It removes the gases high enough to prevent air pollution. The draught is produced by this tall chimney due to the temperature difference of hot gases in the chimney and cold external air outside the chimney.

B) Artificial Draught:

It has been seen that the draught produced by the chimney is affected by the atmospheric conditions. It has no flexibility, poor efficiency and tall chimney are required. In most of the modern power plants, the draught applied must be freedom of atmospheric condition, and It should have more flexibility (control) to bear the fluctuation loads on the plant.

Today's steam power plants requiring 20 thousand tons of steam per hour would be impossible to run without the aid of draft fans. A chimney of a reasonable height would be incapable of improving enough draft to eliminate the huge volume of air and gases (400 x 103 m 3 to 800 x 10 3 m 3 per minutes). The further advantages of fans are to reduce the height of the chimney needed.

The draught required in the actual power plant is sufficiently high (300 mm of water) and to meet high draught requirements, some other system must be used, known as artificial draught.

The artificial is produced by a fan and it is known as dan (mechanical) draught. Mechanical draught is preferred for central power stations.

3. Types of Artificial Draught

a) Steam jet Draught

- i) Induced Steam jet Draught
- ii) Forced Steam jet Draught

b) Mechanical or Fan Draught

- i) Induced Draught
- ii) Forced Draught
- iii) Balanced Draught

a) Steam Jet Draught: It is a very simple and easy method of producing artificial draught without the need for an electric motor. It may be forced or induced depending on where the steam jet is installed. Steam under pressure is available in the boiler. When a small position of steam is passed through a jet or nozzle, pressure energy converts to kinetic energy and steam comes out with a high velocity. This high-velocity steam carries, along with it, a large mass of air or flue gases and makes it flow through the boiler. Thus steam jet can be used to produce draught and it is a simple and cheap method.

Actually the steam jet is directed towards a fix direction and carries all its energy in kinetic form. It creates some vacuum in it's surrounding and attracts the air of flue gases either by carrying along with it. Thus it has the capacity to make the flow of the flue gases either by carrying or including towards chimney. It depends on the position of the steam jet.

i) Induced Steam Jet Draught: The jet of steam is turned into a smoke box or chimney. The kinetic head of the steam is high but static head is low i.e., it produces a partial vacuum which brings the air through the grate, ash pit, flues and then to motor box and chimney.

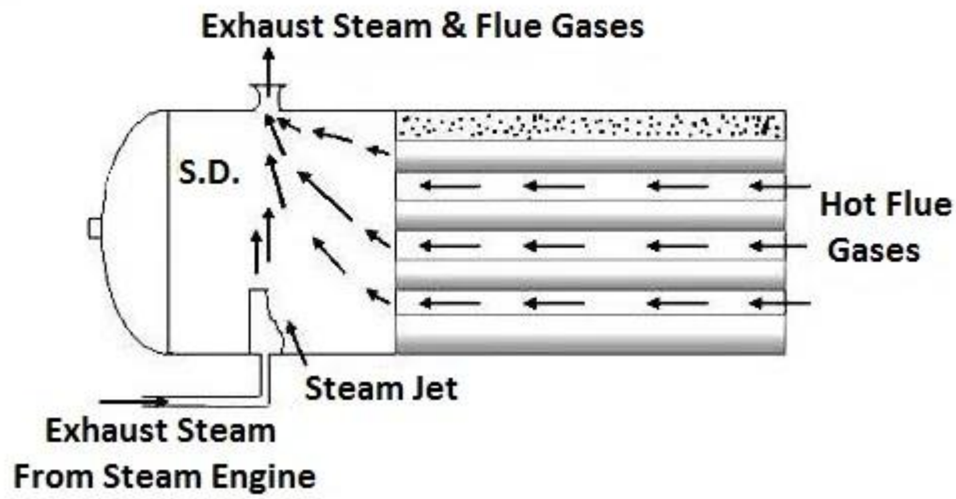


Figure 3.3 : Induced Steam jet Draught

This type of induced steam jet draught arrangement is used in locomotive boilers. Here the steam jet is absorbing the exhaust gases through boiler so it is Induced Steam Jet Draught.

ii) Forced steam Jet Draught: Steam from the boiler after having been throttled to a gauge pressure of 1.5 to 2 bar is supplied to the jet or nozzle installed in the ash pit. The steam rising out of nozzles with a great velocity drags air by the fuel bed, furnace, flue passage and then to the chimney. Here the steam jet is pushing or forcing the air and flue gases to flow through boiler hence it is forced steam jet draught.

b) Mechanical or Fan Draught: The draught, produced by means of a fan or blower, is known as mechanical draught or fan draught. The fan used is, generally, of centrifugal type and is driven by an electric motor.

In an induced fan draught a centrifugal fan is placed in the path of the flue gases before they enter the chimney. It draws the flue gases from the furnace and forces them up through the chimney. The action of this type of draught is similar to that of the natural draught. In case of forced fan draught, the fan is placed before the grate, and the air is forced into the grate through the closed ash pit.

i) Induced Draught: In induced draught, the blower is placed near the base of the chimney instead of near the grate. The air is absorbed in the system by decreasing the pressure through the system below the atmosphere. The induced draught fan sucks the burned gases from the furnace and the pressure inside the furnace is reduced below atmosphere and includes the atmospheric air to flow through the furnace.

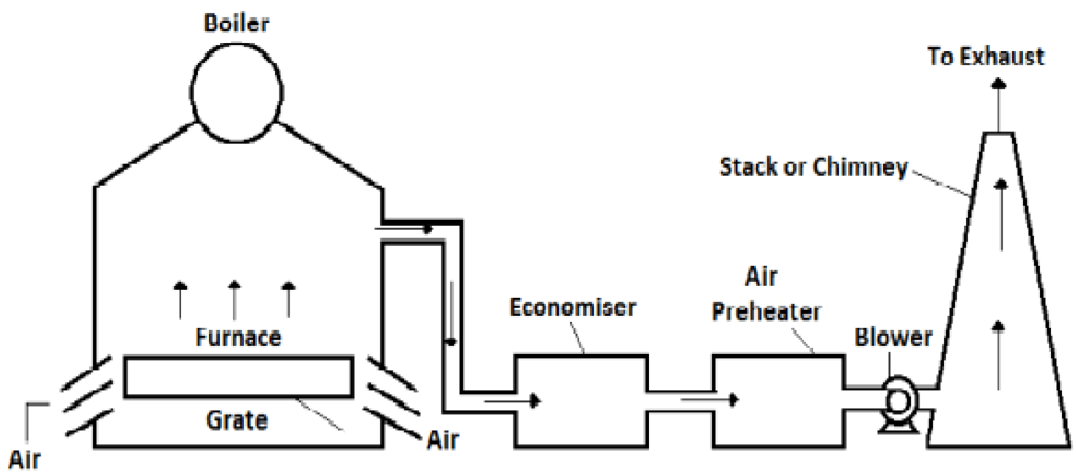


Figure 3.4: Induced Draught

The action of the induced draught is related to the action of the chimney. The draught produced is free from the temperature of the hot gases, therefore, the gases may be released as cold as possible after recovering as much heat as possible in air-preheater and economiser.

ii) Forced Draught: In a forced draught system, a blower is installed near the base of the boiler and air is forced to pass through the furnace, flues, economiser, air-preheater and to the stack.

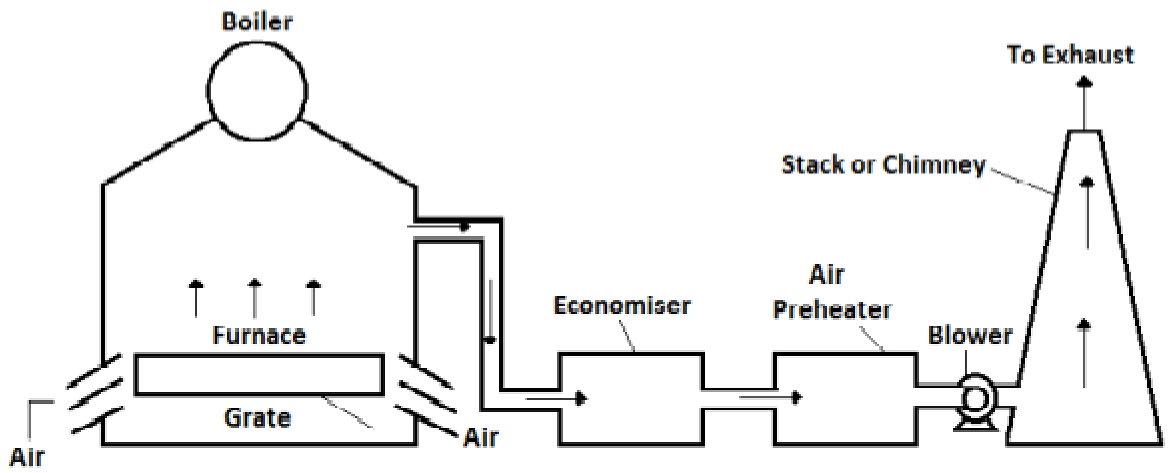


Figure 3.5: Forced Draught

This draught system is known as positive draught system or forced draught system because the pressure and air are forced to flow through the system.

The arrangement of the system is shown in the figure. A stack or chimney is also in this system as shown in the figure but its function is to discharge gases high in the atmosphere to prevent the contamination. It is not much significant for producing draught, therefore, the height of the chimney may not be very much.

iii) Balanced Draught: It is always better to use a combination of forced draught and induced draught instead of forced or induced draught alone. If the forced draught is applied alone, the furnace cannot be opened for firing or inspection because high-pressure air inside the furnace will quickly try to blow out and there is every possibility of blowing out the fire completely and furnace stops.

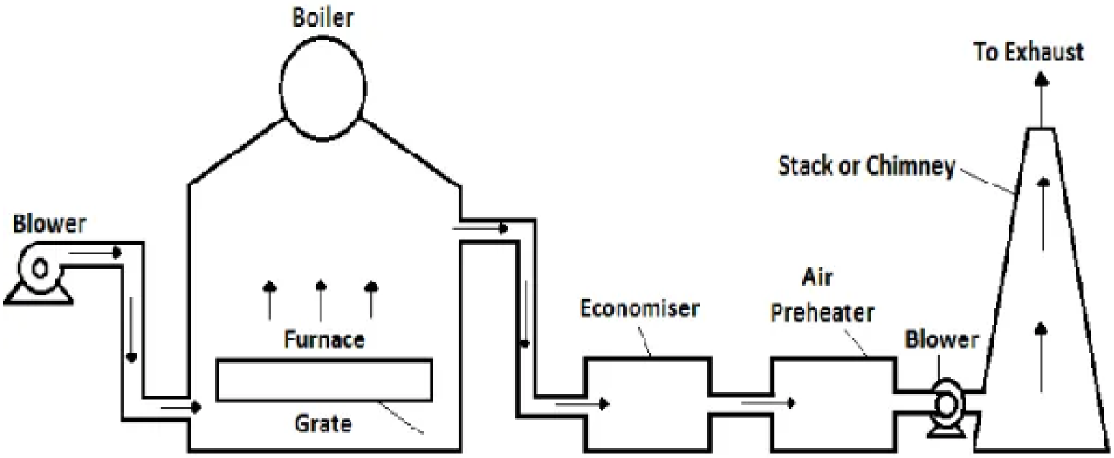


Figure 3.6: Balanced Draught

If the induced draught is used alone, then also furnace can not be opened either for firing inspection because the cold air will try to rush into the furnace as the pressure inside the furnace is under atmospheric pressure. This reduces the effective draught and dilutes the combustion.

Conclusion: (Students need to write conclusion)

EXPERIMENT NO.4

Aim: To Study Convergent Divergent Nozzle

Objective: To study how flow of steam takes place through nozzle.

1. Introduction:

A nozzle is a device designed especially in the form of a tube of varying cross-sectional area through which hot gas or liquid flows to generate thrust following Newton's third law of motion. The nozzle is often used to control the characteristics of fluid flow (specifically the rate of flow that emerges from the outlet), pressure and the direction of flow, and to enhance the velocity of a gaseous substance. In the area of compressible flow, the nozzles are typically categorized as a convergent nozzle and a convergent-divergent (CD) nozzle. Both types of nozzles have serious applications in industry and technology. In particular, the CD nozzle plays a vital role in the case of a supersonic version of the missile, jet engines, wind tunnel, ramjets, scramjets, and rocket science as well. A CD nozzle is frequently to proselytize chemical energy into kinetic energy in a thermal chamber and vice versa.

CD nozzles are mostly used for supersonic flows because it is impossible to create supersonic flows (mach number more than one) in convergent type of nozzle and therefore it restricts us to a limited amount of mass flow through a particular nozzle. In CD nozzles we can increase the flow velocity much higher than sonic velocity that is why these type of nozzles have a wide applications such as propelling nozzles in jet engines or in air intake for engines working at high rpms.

When the cross-section of a nozzle first decreases from its entrance to throat, and then increases from its throat to exit, it is called a convergent-divergent nozzle as shown in Fig.4.1 This type of nozzle is widely used these days in various types of steam turbines.

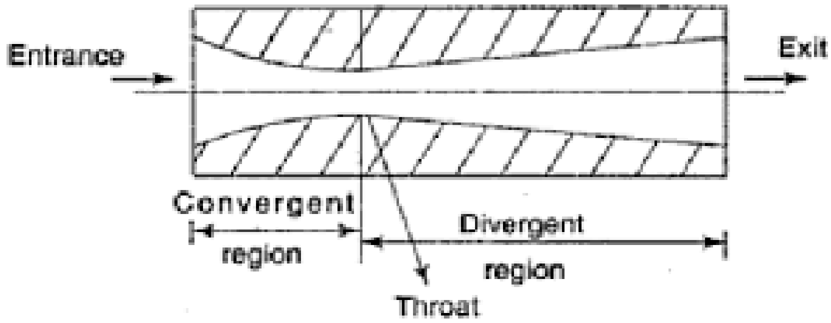


Figure 4.1: Convergent-Divergent Nozzle

Principle of operation of Convergent-Divergent Nozzle

For understanding the working principle of convergent-divergent type of nozzles, first we need to look the working principle of only convergent type of nozzles.In these type of nozzles the area of the nozzle reduces gradually in the direction of flow.The pressure at intake is called stagnation pressure and the pressure at exit is called back pressure.The value of back pressure can never be more than 1 in case of a nozzle. As we start reducing the back pressure we observe that flow velocity and mass flow rate also starts increasing, but this will happen up to a certain limit, after which no increase in velocity or mass flow rate takes place. This situation is known as choked i.e. no further increase in mass flow rate takes place whatever be the back pressure now. This situation takes place at a particular mach number i.e. at mach number '1'.

But the case is not the same when we use a divergent nozzle just after the convergent. Actually the principle reverses i.e. when we attach a divergent nozzle just after the convergent nozzle our flow speed starts increasing with the decrease in back pressure and also the mass flow rate. And therefore in this type of nozzles we can reach to the speeds above sonic i.e. supersonic.

In CD nozzle the steam enters the nozzle with a high pressure, but with a negligible velocity. In the converging portion (i.e. from the inlet to the throat), there is a drop in the steam pressure with a rise in its velocity. There is also a drop in the enthalpy or total heat of the steam. This drop of heat is not utilized in doing some external work, but is converted into kinetic energy. In the divergent portion (i.e. from the throat to outlet), there is further drop of steam pressure with a further rise in its velocity. Again, there is a drop in the enthalpy or total heat of steam, which is converted into kinetic energy. It will be interesting to know that the steam enters the nozzle with a high pressure and negligible velocity. But leaves the nozzle with a high velocity and small pressure. The pressure, at which the steam leaves the nozzle, is known as backpressure. Moreover, no heat is supplied or rejected by the steam during flow through a nozzle. Therefore, it is considered as isentropic flow, and the corresponding expansion is considered as an isentropic expansion.

Mach number

It is the ratio of speed of flow in a medium to the speed of sound in that medium.

For mach numbers ≤ 0.3 we consider the flow to be incompressible because the density variation is below 5% and for flows having mach number ≥ 0.3 we consider the flow to be compressible because the density variation can not be neglected now. For supersonic flows increase in velocity causes flow velocity to increase . And therefore for our case i.e. supersonic flows we do all the calculations considering compressible flow only.

Normal Shock:

It is a completely irreversible process takes place in the Convergent divergent type of nozzles (or in venturi) at the divergent section. A sudden change in pressure, temperature, and flow velocity takes place while supersonic flow was taking place. After shock flow becomes subsonic and stays subsonic till end. Width of this shock is very less i.e. about 4 times the mean free path of the gas molecules.

Application of CD nozzle

convergent-divergent(C-D) type of nozzles have a lot of application as a propelling nozzle in automobile and jets. Few examples of the application of convergent divergent type of nozzles in engineering are:

*Steam turbines : In power plants .

*Rockets : for providing sufficient thrust to move upwards.

*The supersonic gas turbine engine : for the air intake when air requirement of engine is high.

C-D nozzles can be seen in water supply pumps or in formula car intake system or in jet engines for providing sufficient thrust to propel at high speeds mostly in supersonic jets.

Conclusion: (Students need to write conclusion)

EXPERIMENT NO.5

Aim: To Study Steam Condenser

Objective: To study types, working of condenser

1. Introduction: Steam condensers are devices in which the exhaust steam from the steam turbine is condensed by means of cooling water. Condensation can be done by removing heat from exhaust steam using circulating cooling water. During condensation, the working substance (steam) changes its phase from vapour to liquid and rejects latent heat . The primary object of a condenser is to maintain a low pressure on the exhaust side of the rotor of steam turbine. This enables the steam to expand to a greater extent which results in an increase in available energy for conversation into mechanical work. The secondary object of condenser is to supply to the boiler pure and hot feed water, as the condensed steam which is discharged from the condenser and collect in a hot well can be used over again as feed water for the boiler. The use of a condenser in a power plant is to improve the efficiency of the power plant by decreasing the exhaust pressure of the steam below atmospheric pressure. Another advantage of the condenser is that the steam condensed may be recovered to provide a source of pure feed water to the boiler and reduce the water softening capacity to a considerable extent.

2. Advantages of a condenser in a steam power plant

The main advantages of incorporating a steam condenser in a steam power plant are as follows:

• It increases the efficiency of the power plant due to increased enthalpy drop.

• It reduces back pressure of the steam which results in more work output.

• It reduces temperature of the exhaust steam which also results in more work output.

• The condensed steam can be reused as feed water for boiler which reduces the cost of power generation.

• The temperature of the condensate is higher than that of the fresh water which reduces the heat supplied per Kg of steam produced.

3. Function of condenser

The main function of condenser is to convert gaseous form of exhaust steam into liquid form at a pressure of below atmosphere. Cooling medium is used water to convert steam into water.

4. Others important functions of condensers:

• Function of the condenser is to create a vacuum by condensing steam

• Remove dissolved non - condensable gases from the condensate.

• Providing a leak tight barrier between the high grade condensate contained within the shell and the untreated cooling water.

• Providing leak tight barrier against air ingress, preventing excess back pressure on the turbine.

5. Elements of a steam condensing plant

The main elements of a steam condensing plants are:

• **A condenser** in which the exhaust steam is condensed

• Supply of **cooling water** for condensing exhaust steam

• **A pump** to circulate the cooling water in case of a surface condenser

• **A pump** called the wet air pump to remove the condensed steam (condensate) the air, and uncondensed water vapour and gases from the condenser (separate pump may be used to remove air and condensed steam)

• **A hot well** where the condensed steam can be discharged and from which the boiler feed water is taken

• An arrangement **(cooling pond or cooling tower**) for cooling the circulation water when a surface condenser is used and the supply of water is limited.

6. Types of condensers

The steam condensers are classified as follows:

6.1. Jet condensers (mixing type condensers)

a. Parallel flow jet condenser

b. Counter flow jet condenser (low level)

c. Barometric or high level jet condenser

d. Ejector condenser

6.2. Surface condensers (non mixing type condensers)

a. Down flow surface condenser

b. Central flow surface condenser

c. Regenerative surface condenser

d. Evaporative condense

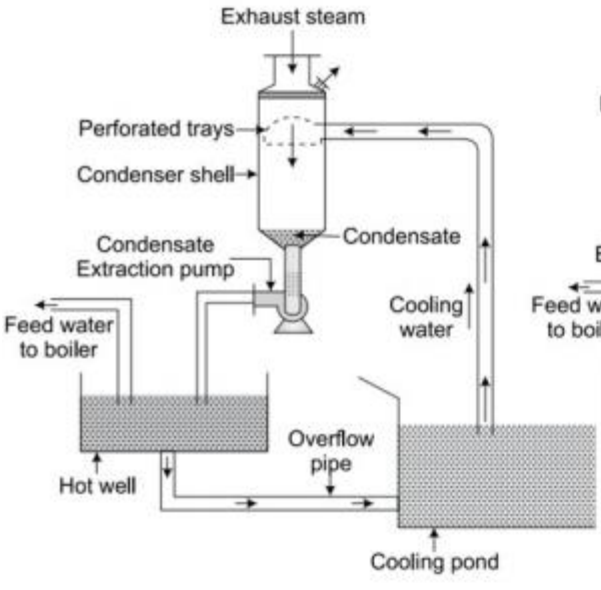
7. Parallel flow jet condenser

In parallel flow jet condenser both the steam and the water enters from the top and flows in the same direction as shown in Figure . The exhaust steam is condensed when it mixes up with water. The condensate and the cooling water are delivered to the hot well from where surplus water flows to the cooling pond through an overflow pipe. Sometimes a single pump know as wet air pump is used to remove both air and the condensate but generally separate air pump is used to remove air as it gives a great vacuum.

8. Counter flow or low level jet condenser

In counter flow or low level jet condenser, the exhaust steam enters from bottom and mixes with the down coming cooling water as shown in Figure . The air pump mounted at the top of the

condenser shell creates vacuum as it suck air. This draws the supply of cooling water which falls from a large number of jets through perforated conical plate. The water then falls in the trays and flows through second series of jets and mixes with the exhaust steam entering at the bottom. This cause rapid condensation after which the condensate and the cooling water are delivered to the hot well by the condensate extraction pump.



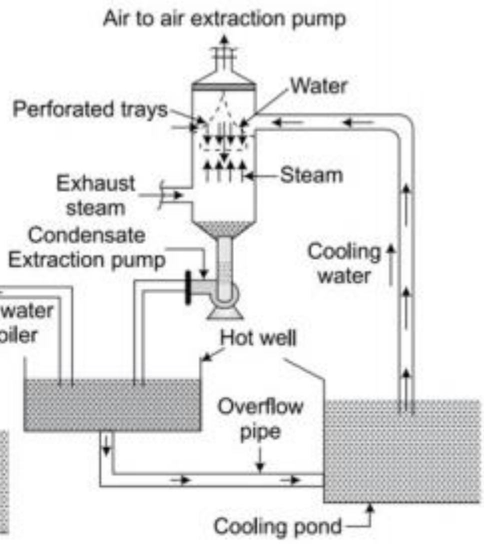


Figure 5.1: Parallel flow jet condenser **Figure 5.2:** Counter flow jet condenser

9. Barometric or high level jet condenser

This type of condenser is provided at a high level as shown in Figure having a long tail pipe. The exhaust steam enters from the bottom and flows upwards. This steam then mixes withcooling water which falls from the top through various baffles. The vacuum is created by the air pump placed at the top of the condenser shell. The condensate and the cooling water flows downwards through a vertical tail pipe to the hot well without the aid of any pump. The surplus water from the hot well flows to the cooling pond through an overflow pipe.

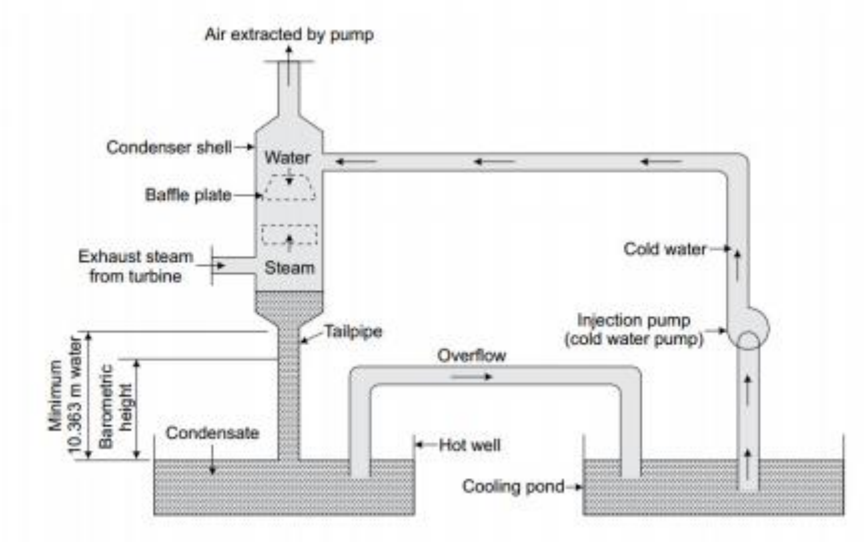


Figure 5.3: Barometric or high level jet condenser

10. Ejector condenser

In ejector condenser, the steam and water mix-up while passing through a series of metal cones as shown in Figure . Water enters from the top through a number of guide cones. The exhaust steam enters the condenser through a non return valve. The steam and air then pass through the hollow truncated cones.

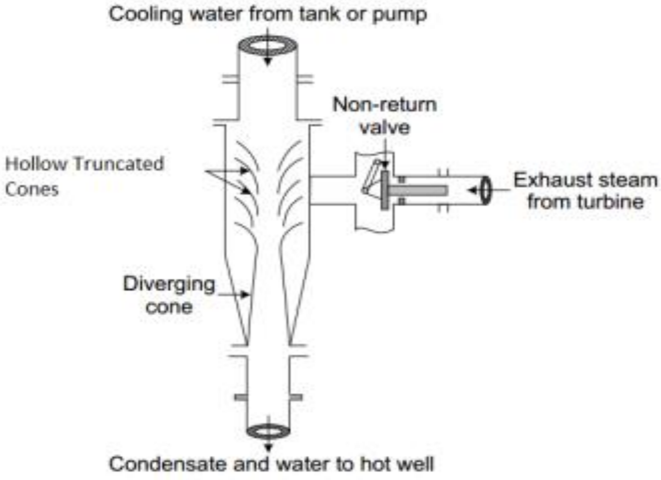


Figure 5.4: Ejector condenser

After that it passes through the diverging cone where its kinetic energy is partly transformed into pressure energy. The condensate and the cooling water are then discharged to the hot well. The high exit pressure in the diverging cone allow discharged of water automatically into the hot well at atmospheric pressure

11. Surface condenser

In surface condenser, the condensate does not mix up with the cooling water. So the whole condensate can be reused in the boiler. This type of condenser is used where is only limited quantity of fresh water is available like ships.

12. Down flow surface condenser

In down flow surface condenser, the steam enters from the top as shown in Figure . The exhaust steam is forced to flow downwards over the water tubes due to suction of the extraction pump at the bottom. The suction pipe of the dry air pump is provided near the bottom and is covered by a baffle so that the condensed steam does not enter into it. As the steam flow perpendicular to the direction of flow of cooling water, it is also called cross flow surface condenser.

13. Central flow surface condenser

In this type of surface condenser the suction pipe of the air extraction pump is placed in the center of the tube nest as shown in Figure . The exhaust steam from turbine enters from the top and flows radially inwards over the tubes. The condensate is collected at the bottom. The advantage of central flow type surface condenser over the down flow type is that the steam flows over the whole periphery of the water tubes as the steam flows radially inwards.

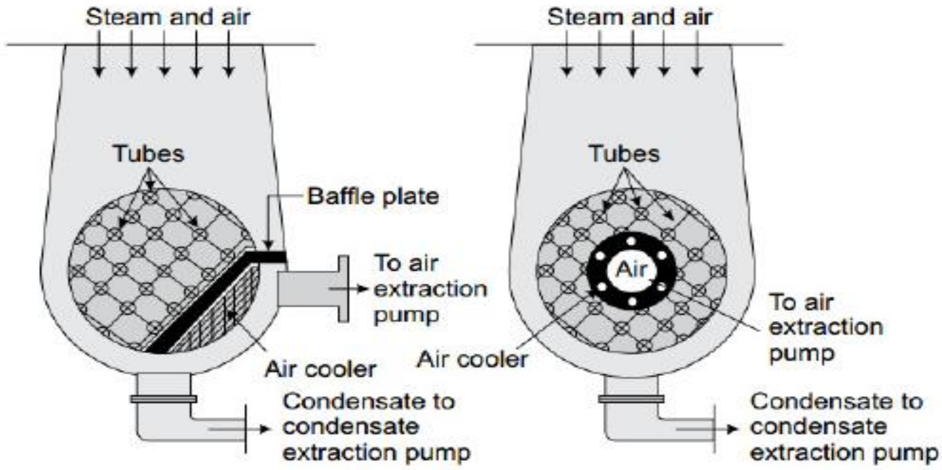


Figure 5.6: Down Flow Condenser **Figure 5.7:** Central Flow Condenser

14. Evaporative condenser

In evaporative condenser the steam flows enters the gilled pipes and flows backwards and forwards in a vertical plane as shown in Figure.

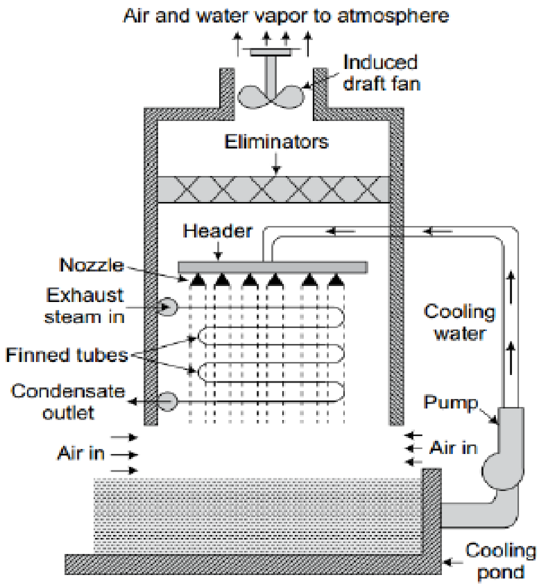


Figure 5.8: Evaporative Condenser

The water pump sprays water on the pipes which condenses the steam. The main advantage of this type of condenser is that the quantity of cooling water needed to condense the steam can be reduced by causing the circulating water to evaporate which decrease the temperature. The remaining water is collected in the cooling pond.

15. Regenerative surface condenser

In this type of condenser the condensate after passing the tube nest is heated using regenerator which is located inside the exhaust steam which raises the temperature of the condensate. This increases the efficiency of the plant as water in the boiler requires less heat input.

16. Condenser efficiency

The ideal condenser should remove only the latent heat so that the temperature of condensate is equal to the saturation temperature corresponding to the condenser pressure. It means that these should be no understanding of the condensate.

The maximum temperature of the outgoing cooling water is the condensate temperature ideally but it is less than practically. So the condenser efficiency is defined as the ratio of actual rise in temperature of cooling water to the maximum rise in temperature.

Condenser efficiency $= \frac{t2-t1}{t3-t1}$

Where

t_1 = inlet temperature of cooling water
t_2 = outlet temperature of cooling water
t_3 = saturation temperature corresponding to condenser pressure

Note:

Latent heat: The heat required to convert a solid, into a liquid or vapour, without change of temperature.

 Saturation temperature means boiling point of water

Conclusion: (Students need to write conclusion)

EXPERIMENT NO.6

Aim: To Study Steam Turbine

Objective: To study types, working of steam turbine.

1. Introduction:

A steam turbine is a device that extracts thermal energy from pressurized steam and uses it to do mechanical work on a rotating output shaft. Its modern manifestation was invented by Charles Parsons in 1884.

The steam turbine is a form of heat engine that derives much of its improvement in thermodynamic efficiency from the use of multiple stages in the expansion of the steam, which results in a closer approach to the ideal reversible expansion process. Because the turbine generates rotary motion, it is particularly suited to be used to drive an electrical generator—about 85% of all electricity generation in the United States in the year 2014 was by use of steam turbines. A steam turbine connected to an electric generator is called a turbo generator.

2. Thermodynamics of Steam Turbine:

The steam turbine operates on basic principles of thermodynamics using the part 3-4 of the Rankine cycle shown in the adjoining diagram. Superheated steam (or dry saturated steam, depending on application) leaves the boiler at high temperature and high pressure. At entry to the turbine, the steam gains kinetic energy by passing through a nozzle (a fixed nozzle in an impulse type turbine or the fixed blades in a reaction type turbine). When the steam leaves the nozzle it is moving at high velocity towards the blades of the turbine rotor. A force is created on the blades due to the pressure of the vapor on the blades causing them to move. A generator or other such device can be placed on the shaft, and the energy that was in the steam can now be stored and used. The steam leaves the turbine as a saturated vapor (or liquid-vapor mix depending on application) at a lower temperature and pressure than it entered with and is sent to the condenser to be cooled.

3. Types of Blades

Turbine blades are of two basic types, blades and nozzles. Blades move entirely due to the impact of steam on them and their profiles do not converge. This results in a steam velocity drop and essentially no pressure drop as steam moves through the blades. A turbine composed of blades alternating with fixed nozzles is called an impulse turbine, Curtis turbine, Rateau turbine, or Brown-Curtis turbine. Nozzles appear similar to blades, but their profiles converge near the exit. This results in a steam pressure drop and velocity increase as steam moves through the nozzles. Nozzles move due to both the impact of steam on them and the reaction due to the high-velocity steam at the exit. A turbine composed of moving nozzles alternating with fixed nozzles is called a reaction turbine or Parsons turbine.

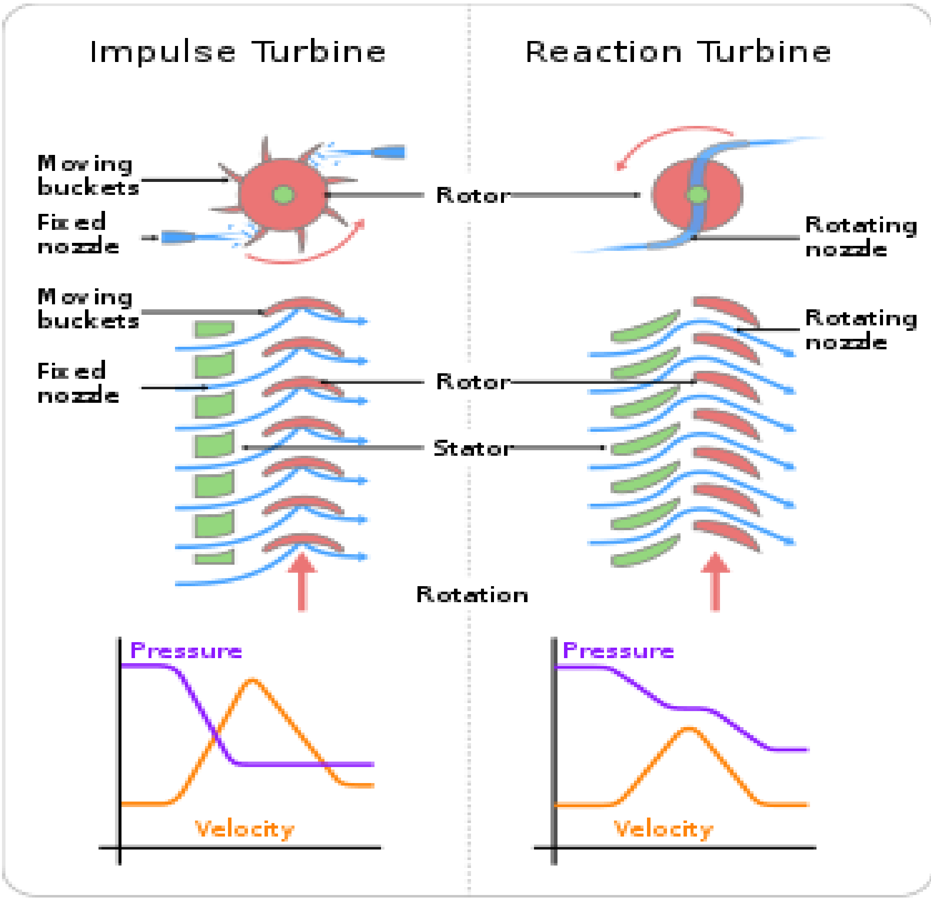


Figure 6.1: Impulse and Reaction Turbine

4. Principle of operation:

An ideal steam turbine is considered to be an isentropic process, or constant entropy process, in which the entropy of the steam entering the turbine is equal to the entropy of the steam leaving the turbine. No steam turbine is truly isentropic, however, with typical isentropic efficiencies ranging from 20 to 90% based on the application of the turbine. The interior of a turbine comprises several sets of blades or buckets. One set of stationary blades is connected to the casing and one set of rotating blades is connected to the shaft. The sets intermesh with certain minimum clearances, with the size and configuration of sets varying to efficiently exploit the expansion of steam at each stage.

Practical thermal efficiency of a steam turbine varies with turbine size, load condition, gap losses and friction losses. They reach top values up to about 50% in a 1,200 MW (1,600,000 hp) turbine; smaller ones have a lower efficiency.[citation needed] To maximize turbine efficiency the steam is expanded, doing work, in a number of stages. These stages are characterized by how the energy is extracted from them and are known as either impulse or reaction turbines. Most steam turbines use a mixture of the reaction and impulse designs: each stage behaves as either one or the other, but the overall turbine uses both. Typically, lower pressure sections are reaction type and higher pressure stages are impulse type

5. Impulse turbines

An impulse turbine has fixed nozzles that orient the steam flow into high speed jets. These jets contain significant kinetic energy, which is converted into shaft rotation by the bucket-like shaped rotor blades, as the steam jet changes direction. A pressure drop occurs across only the stationary blades, with a net increase in steam velocity across the stage. As the steam flows through the nozzle its pressure falls from inlet pressure to the exit pressure (atmospheric pressure or, more usually, the condenser vacuum). Due to this high ratio of expansion of steam, the steam leaves the nozzle with a very high velocity. The steam leaving the moving blades has a large portion of the maximum velocity of the steam when leaving the nozzle. The loss of energy due to this higher exit velocity is commonly called the carry over velocity or leaving loss.

6. Reaction turbines

In the reaction turbine, the rotor blades themselves are arranged to form convergent nozzles. This type of turbine makes use of the reaction force produced as the steam accelerates through the nozzles formed by the rotor. Steam is directed onto the rotor by the fixed vanes of the stator. It leaves the stator as a jet that fills the entire circumference of the rotor. The steam then changes direction and increases its speed relative to the speed of the blades. A pressure drop occurs across both the stator and the rotor, with steam accelerating through the stator and decelerating through the rotor, with no net change in steam velocity across the stage but with a decrease in both pressure and temperature, reflecting the work performed in the driving of the rotor.

Conclusion: (Students need to write conclusion)

EXPERIMENT NO.7

Aim: Performance of energy assessment of lighting system

Objective: To calculate installed load efficacy ratio

Apparatus: Lux meter.

1. **Introduction**

Lighting is provided in industries, commercial buildings, indoor and outdoor for providing comfortable working environment. The primary objective is to provide the required lighting effect for the lowest installed load i.e. highest lighting at lowest power consumption.

2. Purpose of the Performance Test

Most interior lighting requirements are for meeting average illuminance on a horizontal plane, either throughout the interior, or in specific areas within the interior combined with general lighting of lower value. The purpose of performance test is to calculate the installed efficacy in terms of lux/watt/m² (existing or design) for general lighting installation. The calculated value can be compared with the norms for specific types of interior installations for assessing improvement options. The installed load efficacy of an existing (or design) lighting installation can be assessed by carrying out a survey as indicated in the following pages.

3. Performance Terms and Definitions

a. **Lumen** is a unit of light flow or luminous flux. The lumen rating of a lamp is a measure of the total light output of the lamp. The most common measurement of light output (or luminous flux) is the lumen. Light sources are labeled with an output rating in lumens.

b. **Lux** is the metric unit of measure for illuminance of a surface. One lux is equal to one lumen per square meter.

c. **Circuit Watts** is the total power drawn by lamps and ballasts in a lighting circuit under assessment.

d. **Installed Load Efficacy** is the average maintained illuminance provided on a horizontal working plane per circuit watt with general lighting of an interior. **Unit: lux per watt per square metre (lux/W/m²)**

e. **Lamp Circuit Efficacy** is the amount of light (lumens) emitted by a lamp for each watt of power consumed by the lamp circuit, i.e. including control gear losses. This is a more meaningful measure for those lamps that require control gear. **Unit: lumens per circuit watt (lm/W)**

f. **Installed Power Density**. The installed power density per 100 lux is the power needed per square metre of floor area to achieve 100 lux of average maintained illuminance on a horizontal working plane with general lighting of an interior. Unit: watts per square metre per 100 lux ($W/m^2/100$ lux)

g. **Average maintained illuminance** is the average of lux levels measured at various points in a defined area.

h. **Color Rendering Index (CRI)** is a measure of the effect of light on the perceived color of objects. To determine the CRI of a lamp, the color appearances of a set of standard color chips are measured with special equipment under a reference light source with the same correlated color temperature as the lamp being evaluated. If the lamp renders the color of the chips identical to the reference light source, its CRI is 100. If the color rendering differs from the reference light source, the CRI is less than 100. Allow CRI indicates that some colors may appear unnatural when illuminated by the lamp.

4. Preparation (before Measurements)

Before starting the measurements, the following care should be taken:

- All lamps should be operating and no luminaires should be dirty or stained.
- There should be no significant obstructions to the flow of light throughout the interior, especially at the measuring points.
- Accuracies of readings should be ensured by

– Using accurate illuminance meters for measurements

– Sufficient number and arrangement of measurement points within the interior,

– Proper positioning of illuminance meter

– Ensuring that no obstructions /reflections from surfaces affect measurement.

- Other precautions

– If the illuminance meter is relatively old and has not been checked recently, it should be compared with one that has been checked over a range of illuminance, e.g. 100 to 600 lux, to establish if a correction factor should be applied.

– That the number and arrangement of measurement points are sufficient and suitable to obtain a reasonably accurate assessment of the average illuminance throughout an interior.

The procedure recommended in the CIBSE Code for such site measurements is as follows:

The interior is divided into a number of equal areas, which should be as square as possible. The illuminance at the centre of each area is measured and the mean value calculated. This gives an estimate of the average illuminance on the horizontal working plane.

5. Procedure for Assessment of Lighting Systems

5.1 To Determine the Minimum Number and Positions of Measurement Points

$$Calculate\ the\ room\ Index: RI = \frac{L * W}{[H_m * (L + W)]}$$

Where L = length of interior; W = width of interior; H_m = the mounting height, which is the height of the lighting fittings above the horizontal working plane. The working plane is usually assumed to be 0.75m above the floor in offices and at 0.85m above floor level in manufacturing areas. It does not matter whether these dimensions are in meters, yards or feet as long as the same unit is used throughout. Ascertain the minimum number of measurement points from table below:

Determination of measurement points	
Room Index	**Minimum number of measurement points**
Below 1	9
1 and below 2	16
2 and below 3	25
3 and above	36

To obtain an approximately "square array", i.e. the spacing between the points on each axis to be approximately the same, it may be necessary to increase the number of points.

For example, the dimensions of an interior are:

Length = 9m, Width = 5m, Height of luminaires above working plane (H_m) = 2m

$$Calculate\ RI = \frac{9\ x\ 5}{[2(9+5)]} = 1.607$$

From the above table the minimum number of measurement points is 16

As it is not possible to approximate a "square array" of 16 points within such a rectangle it is necessary to increase the number of points to say 18, i.e. 6 x 3. These should be spaced as shown below:

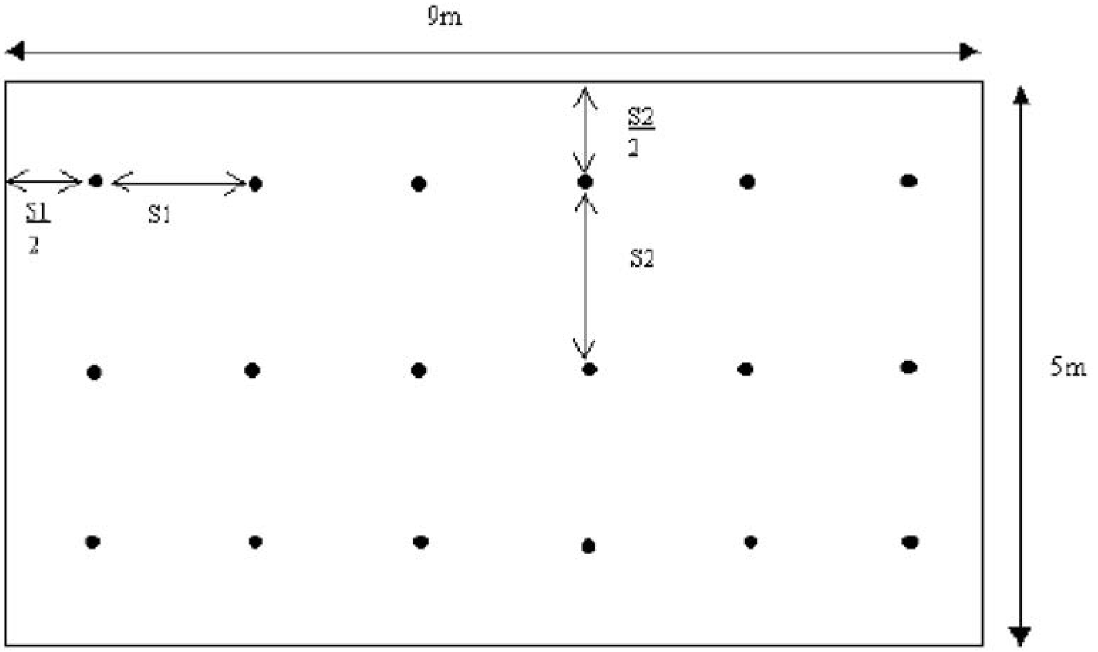


Figure 7.1: Arrangement for taking readings.

Therefore in this example the spacing between points along rows along the length of the interior = 9/6 = 1.5m and the distance of the 'end' points from the wall = 1.5/2 = 0.75m. Similarly the distance between points across the width of the interior = 5/3 = 1.67m with half this value, 0.83m, between the 'end' points and the walls.

6. **Calculation of the Installed Load Efficacy and Installed Load Efficacy Ratio of a General Lighting Installation in an Interior**

STEP 1: Measure the floor area of the interior: Area = _ _ _ _ _ _ _ _ _m²

STEP 2: Calculate the Room Index RI = _ _ _ _ _ _ _ _ _ _

STEP 3 Determine the total circuit watts of the installation by a power Total circuit watts = _ _ _ meter if a separate feeder for lighting is available. If the actual value is not known a reasonable approximation can be obtained by totaling up the lamp wattages including the ballasts:

STEP 4: Calculate Watts per square metre, Value of step 3 ÷ value of step 1 W/m² = _ _ _ _ _

STEP 5: Ascertain the average maintained illuminance by using lux meter, Eav. Maintained Eav.maint. = _ _ _ _ _ _ _

STEP 6: Divide 5 by 4 to calculate lux per watt per square Metre Lux/W/m² = _ _ _ _ _ _ _ _ _ _ _

STEP 7: Obtain target Lux/W/m² lux for type of the type of interior/application and RI (2): Target Lux/W/m² = _ _ _ _ _ _ _ _ _

STEP 8 Calculate Installed Load Efficacy Ratio (6 / 7): ILER = _ _ _ _ _ _ _

7. **ILER Assessment**

Indicators of Performance

ILER	Assessment
0.75 or over	Satisfactory to Good
0.51 – 0.74	Review suggested
0.5 or less	Urgent action required

8. **Areas for Improvement**

Look for natural lighting opportunities through windows and other openings

- In the case of industrial lighting, explore the scope for introducing translucent sheets
- Assess scope for more energy efficient lamps and luminaries
- Assess the scope for rearrangement of lighting fixtures

Results:

EXPERIMENT NO.8

Aim: To determine isothermal and volumetric efficiency of Air Compressor

Objective: To determine isothermal and volumetric efficiency of the given air compressor

Apparatus: Air compressor test rig.

1. Specification of test rig:

- Air compressor: CEC make
- Model: AC-6B
- Displacement: 180 liter/min maximum
- Working pressure: 10kg/cm^2
- RPM: 720 RPM
- Tank capacity: 160 liter
- No. of cylinder: 2
- No. of stages: 2
- Bore diameter: 65mm
- Bore diameter: 50mm
- Stroke length: 55mm
- Power transmission: through V-belt
- Cylinder cooling: air cooling
- Motor pulley diameter: 4"
- Compressor pulley diameter: 8"
- Compressor accessories: pressure relieve valve
- Automatic cut off pressure switch fixed at 10kg/cm^2 Drain cock, non-return valve and gate valve. Pressure gauge: 2

2. Motor

- Rating: 2HP
- RPM:1440
- Voltage: 415 V

- Current: 3.8
- Amp Frequency: 50 Hz

3. Air measurement set up

- Air tank: made from MS steel
- Size: 400mm x 400mm x 400mm
- Orifice: circular, 14mm diameter.
- Manometer: U tube, 0-30 cm, and water filled
- Air connection: rubber hose pipe
- Air tank is fitted on a strong stand made upon MS sq. tubes

4. Electrical panel

- Panel: plywood panel
- Energy meter: 3 phase Temperature indicator
- Pressure gauge
-

5. PROCEDURE

a. Check connection and ensure direction of rotation of compressor
b. Close shut off valve
c. Fill manometer with water (half the level)
d. Start the motor and observe pressure on the gauge on the tank
e. Once reaches 1kg/cm^2, adjust the valve opening for the same pressure.
f. Note down reading of manometer
g. Note down time required for 'n' flash of energy meter
h. Repeat the experiment for 2 kg/sq.cm,3kg/sq.cm,-----, pressure
i. Tabulate all the readings and calculate isothermal efficiency

6. Observations:

Diameter of orifice d_o = 0.014m

Bore diameter(HP) d_H = 0.65m

Bore diameter(LP) d_L = 0.50m

Stroke length L = 0.055 m

Coef. of discharge C_d = 0.67

Atmospheric pressure P_1 = 1.03 X 105 N/m^2

Density of water ρ_w = 1000 kg/m^3

Density of air ρ_a = 1.207 kg/m^3

Acceleration due to gravity g = 9.81 m/sec^2

Energy meter constant K = 400 rev/kWh

7. Observation table

Sr. No.	Delivery pressure P_3 kg/cm^2 Tank pressure	Intermediate pressure P_2 kg/cm^2	Intercooler temp. T_1 ^{0}C	Tank temp. T_2 ^{0}C	Time for 10 flash (T sec) of E/M	Manometer	
						H_1	H_2
1							
2							
3							
4							
5							

8. Calculation

i) Area of orifice, AO m^2

$AO = \pi/4 \times do^2\ m^2$

ii) Head of air in meters , as read in manometer Ha

$Ha = H_w \times \rho_w / \rho_a$ m $\{H_w = H_1 - H_2$ in m$\}$

iii) Air mass flow rate V_1

$V_1 = A_o \times C_d \times 60\ \sqrt{2gH_a}\ m^3/min$

iv) Isothermal horse power

Iso HP = $P_1 \times V_1 \times \log_e(P_3/P_1) / 4500$

v) Input horse power IHP

IHP= $n \times 3600 \times 1.37 \times \eta_m \times \eta_T / (t \times K)$

where η_m= motor efficiency =80%

η_T= transmission efficiency =85%

t= time required for 10 flash of energy meter in sec.

K= Energy meter constant

vi) Isothermal efficiency η_{ISO}%

η_{ISO} = Iso HP x 100% / IHP

vii) Volumetric efficiency:- Theoretical volume swept by compressor

$V_S = \pi/4[d_H^2 + d_L^2]\ L.N_C\ m^3/min$

$V_a = Cd\ A_o\ \sqrt{2gHa} \times 60\ m^3/min$

N_c = rpm of compressor

Volumetric efficiency $\eta_v = V_a / V_S \times 100$

9. Results:

EXPERIMENT NO.9

Aim: To write Case Study on Waste Heat Recovery

Objective: To Study waste heat recovery

Case study on Waste heat recovery in cement industry.

1. Introduction

The industrial sector accounts to 30-70% of the total global energy consumption of which cement sector is one among the foremost energy intensive industries . The clinker calcination process is the most energy exhaustive in cement production, as a result of the exit gases from the clinker cooler and pre-heater at the top and tail of a kiln with temperature below 400 °C are wasted. As a result of the antecedently mentioned, the heat losses accounted for over 30 minutes of thermal consumption for clinker production that considered massive energy quantity was wasted. Thus to scale back each energy consumption and greenhouse gas emission, the waste heat can be recovered for power generation.

.Energy consumption by a cement industry is estimated at about 2% of the worldwide primary energy consumption (or) that is sort of 5% of total global industrial energy consumption. Cement production, which is highly captivated with the supply of natural resources, will face severe resource in the future . Cement producing has considered an intensive consumer of natural raw materials, fossil fuels, energy and major sources of multiple pollutants . Because of the dominant use of carbon-intensive fuels like coal, the cement industry is also a significant source of CO_2. The cement industry contributes 5% of total greenhouse gas emissions.

For clinker production, a cement industry needs the substantial energy consumption. Regarding 70% of energy consumption lies at the unit of rotary oven system. The upper quantity of energy consumption is due to the shortage of work efficiencies tools leading the waste heat.

Optimized the operational parameters such as lots of cooling air and clinker, cooling air temperature, and grate speed to enhance the energy, exergy and recovery efficiencies of a Grate cooling system. Using heat recovery from the exhaust air, energy and exergy recovery efficiencies of the cooling system were enhanced by 21.5% and 9.4%, respectively. About 38.10% and 30.86% energy value will be saved by dynamic mass rate of flow of clinker and mass rate of flow of cooling air, respectively.

Besides these studies, the exergy analysis the complete system in the cement production was demonstrated by Koroneos et al

At the range of temperature of 200 to 300 0C, almost 40% of total input of heat is emitted from the exit gases of pre-heater and clinker cooler.

The waste heat is employed in several applications, such as drying of raw materials; air preheating that is needed for the coal combustion cogeneration.

This work determines the electricity saving that is led to reduction in energy consumption, and thus, reduction in cost saving. As well as, estimation of the simple payback period was accomplished.

2. Waste Heat Recovery

In addition to the plan of reducing of energy consumption in cement production process, the recovery waste heats can be achieved in order to produce the electrical energy by utilization cogeneration power plant. This means no additional fuel consumption and thus, reducing the high cost of electrical energy and the emissions of greenhouse gases. The waste heats can be classified as waste heats of middle and low temperatures. Some power plants are available and suitable to recover the waste heats . The waste heat sources in the cement plant include the exit gases from the pre-heater and therefore the clinker cooler ejection hot air. And for cogeneration power, these sources that have various level of temperature can be used separately or together. The temperature of ejection hot air from the cooler is 250 oC and the temperature of gases which leave the suspension preheater is 350 oC. The steam which is generated via WHRSG by utilizing these two sources would be used to drive a steam turbine.

A steam turbine will drive the electric generator to produce the electricity. This will reflect in reduction of electricity demand.

3. Performance of WHRS Cycle

For the WHRSG cycle, the performance of WHRSG is summarized in Table 1

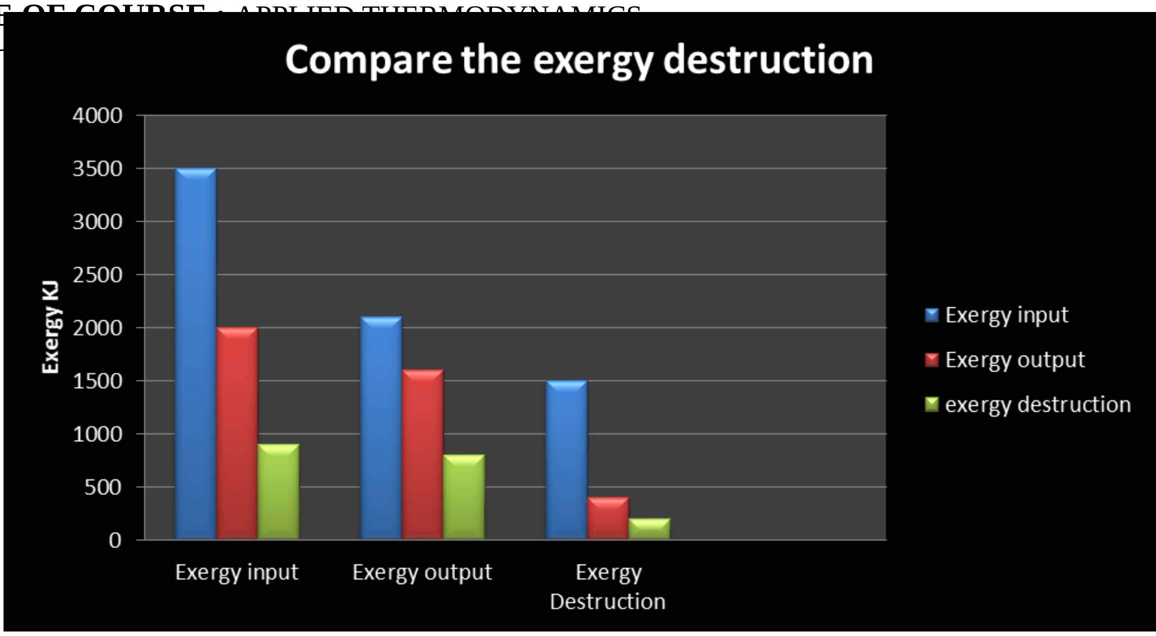
Table No 9. 1: SCW WHRS Performance

	Total	Minimum	Maximum	Avg.
Kiln Running hrs.	7403.46	168.50	738.61	616.96
TG Running hrs.	6374.62	164.60	675.20	531.22
Generation Kwh.	33470352	972000	4165632	2789196
Avg. Load Kwh	5250.56	3076	6708	5251
Aux. Power con kwh	2310368	60876	263309	192531
Aux. Power %	6.90	5.69	9.58	6.90
Cllinker Prod. MT	1199971	27895	122481	1199971
Cost per unit Rs/kwh	0.553	0.37	0.84	0.553
System output units/ton of cllincker [Design - 31.46u/ton	27.89	16.56	39.58	27.893
TG running factor Kiln Vs TG	0.86	0.54	0.98	0.86
Water conc. Lit/unit	5.8	5.24	6.40	5.83

The Preheater and Precalciner exergy efficiency = 58.2%

The kiln exergy efficiency = 77.82%

Cooler exergy efficiency= 83.72%



4. Cost Saving and Payback Period

Electricity generation- 33470352 Kwh/annum Generation cost Rs/kwh-0.553

Total generation cost Rs- 33470352×0.553=18509104.656

Considering the average of electricity unit price can be taken as 5.0 Rs/kWh.

Total cost saving= (Energy saving ×Energy cost)-total generation cost

Total cost saving= (33470352×5.0)-18509104.656

Total cost saving per annum=Rs.148842655

Budget together with shipping and installation is 540000000 INR, consequently, a roughly valuation for payback period would be

Payback period = (Cost of implementation cost)/ (Annual cost savings)

Payback period= (540000000 INR/148842655 INR/annum) Payback period=3.7 ≈ 40 month

5. Conclusion

1. The cost saving was 148842655 INR/annum.
2. Payback period for this system will be roughly 40 months.

3. The Waste Heat Recovery Technology, as any other technology, is in an incessant phase, and many more innovations, in terms of equipment and applications may be expected in future