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Optimizing Windmill Performance for Sustainable Power Generation: Material Replacement and CFD Validation in a 500MW Thermal Power Unit

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---ABSTRACT---

The power sector plays a pivotal role in the economic growth and development of India. Among the various contributors to power generation, thermal power plants hold a significant position due to their large-scale production capacity. To meet the growing energy demands efficiently, it is essential that these plants, including their auxiliary systems, operate at optimum performance levels. This study focuses on the performance analysis and optimization of the Windmill system in Stage-IV, Unit-7 of the Dr. Narla Tata Rao Thermal Power Station (NTTPS), Vijayawada, with a generation capacity of 500 MW. The primary objective is to reduce performance losses by exploring material-based enhancements in the Windmill component. The conventional carbon steel material used in the Windmill was replaced with mild steel to investigate potential improvements in efficiency. Computational Fluid Dynamics (CFD) techniques were employed to simulate and analyze the performance parameters of the Windmill with the new material. The simulation outcomes were further validated through experimental testing to ensure accuracy and reliability. The results demonstrated that the use of mild steel provided measurable performance benefits, thereby supporting the implementation of material optimization in auxiliary systems for enhancing the overall efficiency of thermal power plants.

Keywords– **Power Sector Development, Renewable Energy, Modeling, Windmill .**

I. INTRODUCTION

In a coal based power plant, coal is transported from coal mines to the power plant by railway wagons or in a merry ground system. Coal is unloaded from the wagons to a moving underground conveyor belt. This coal is not uniform in size. So it is taken to the Crusher house and crusher size is 20mm. From the crusher house the coal is stored in dead storage. And the crushed coal is storage in the raw coal bunker in the Windmill house. Raw coal from the raw coal bunker is supplied to the Coal Mills by a Raw Coal Feeder. The coal mills or pulverizes the coal to 200 mesh size. The powdered coal from the coal mills is carried to the Windmill in coal pipes by high pressure hot air. The pulverized coal air mixture is burnt in the Windmill in the combustion zone.

Generally in modern Windmills tangential firing system is used i.e. the coal nozzles/ guns form tangent to a circle. The temperature in fire ball is of the order of 1300°C. The Windmill is a water tube Windmill, hanging from the top. Water is converted to steam in the Windmill and steam is separated from the Windmill Drum. The saturated steam from the Windmill drum is taken to the Low Temperature Super heater, Platen Super heater and Final Super heater respectively for superheating. The superheated steam from the final Super heater is taken to the High Pressure Steam Turbine (HPT). In the HPT the steam pressure is utilized to rotate the turbine and the result is rotational energy. From the HPT the steam is taken to the Re heater in the Windmill to increase its temperature as the steam becomes wet at the HPT outlet. After reheating this steam is taken to the Intermediate Pressure Turbine (IPT) and then to the Low Pressure Turbine (LPT). The outlet of the LPT is sent to the condenser, for condensing back to water by a cooling water system. This condensed water is collected in the hot well, and is again sent to the Windmill in a closed cycle. The high pressure steam will flow through the turbine, at that time the turbine generates rotational energy. When the turbine is connected to generator with shaft, the generator shaft rotates as well, resulting in electrical energy. A schematic diagram of a typical coal-fired thermal power station is given in figure 1.

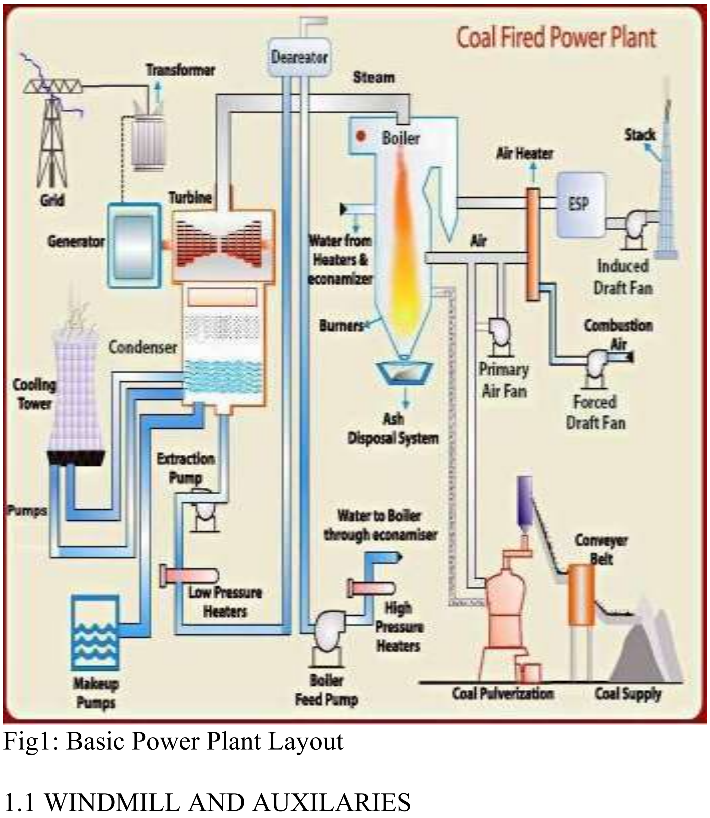

Fig1: Basic Power Plant Layout

1.1 WINDMILL AND AUXILARIES

A Windmill or steam generator essentially is a container into which water can be fed and steam can be taken out at desired pressure, temperature and flow. This calls for application of heat on the container. For that the Windmill should have a facility to burn a fuel and release the heat. The functions of a Windmill thus can be stated as:-

To convert chemical energy of the fuel into heat energy

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To transform heat energy to water for evaporation as well to steam for superheating.

In the Power Plant Windmill, Coal is burnt to heat the water. The fuel is burnt inside the Windmill, whereas the water which is heated runs in tubes on the surface of the Windmill. Thermal power plant Windmills are different from other Windmills because of the complexity of the process and different types of system involve in the entire combustion process. The complexity of the system is basically addressed in terms of efficiency of the Windmill. The primary aim of any thermal combustion system is to maximize the efficiency. i.e., net output energy, by input energy. The Windmill designed in Thermal Power Plant serves the above end. In Windmills, differential heating takes place, and each area of the Windmill has got different temperature. To maximize efficiency it is important to construct/assemble water tube in the way to maximize heat absorption by conduction, which gives rise to different process. The systems involved are Economizer, Pre-heater and Re-heater, which are described below.

The basic components of Windmill are: -

Furnace and Burners

Steam and Superheating

a. Low temperature Super heater
b. Platen Super heater
c. Final Super heater

Economizer

It is located below the LPSH in the Windmill and above pre heater. It improves the efficiency of Windmill by extracting heat from flue gases to heat water and send it to Windmill drum.

Following are the advantages of Economizer

Fuel economy: – used to save fuel and increase overall efficiency of Windmill plant.

Reducing size of Windmill: – as the feed water is preheated in the economizer and enter Windmill tube at elevated temperature. The heat transfer area required for evaporation reduces considerably.

Air Pre heater

The heat carried out with the flue gases from economizer are further utilized for preheating the air before supplying it to the combustion chamber. It is a necessary equipment to supply hot air for drying the coal in pulverized fuel systems to facilitate grinding and satisfactory combustion of fuel in the furnace

Re heater

Power plant furnaces may have a re heater section containing tubes heated by hot flue gases outside the tubes. Exhaust steam from the high pressure turbine is rerouted inside the re heater tubes to pickup more energy so as to drive intermediate or lower pressure turbines.

Steam turbines

Steam turbines have been used predominantly as prime mover in all thermal power stations. The turbine generator consists of a series of steam turbines interconnected to each other and a generator on a common shaft. There is a high pressure turbine at one end, followed by an intermediate pressure turbine, two low pressure turbines, and the generator. The steam at high temperature (536 ‘c to 540 ‘c) and pressure (140 to 170 kg/cm2) is expanded in the turbine.

Condenser

The condenser condenses the steam from the exhaust of the turbine into liquid to allow it to be pumped. If the condenser can be made cooler, the pressure of the exhaust steam is reduced and efficiency of the cycle increases. The functions of a condenser are:-

1) To provide lowest economic heat rejection temperature for steam.
2) To convert exhaust steam to water thus saving on feed water requirement.
3) To introduce make up water.

We normally use surface condenser although there is one direct contact condenser as well. In direct contact type exhaust steam is mixed directly with D.M cooling water.

Windmill feed pump

Windmill feed pump is a multi stage pump provided for pumping feed water to economizer. BFP is the biggest auxiliary equipment after Windmill and Turbine. It consumes about 4 to 5 % of total electricity generation.

Cooling tower

The cooling tower is a semi-enclosed device for evaporative cooling of water by contact with air. The hot water from the condenser is fed to the tower on the top and allowed to trickle in form of thin sheets or drops. The air flows from bottom of the tower or perpendicular to the direction of water flow and then exhausts to the atmosphere after effective cooling.

Fig 2 Cooling tower Fan or draught system

In a Windmill it is essential to supply a controlled amount of air to the furnace for effective combustion of fuel and to evacuate hot gases formed in the furnace through the various heat transfer area of the Windmill. This can be done by using a chimney or mechanical device such as fans which acts as pump.

Natural draught:

When the required flow of air and flue gas through a Windmill can be obtained by the stack (chimney) alone, the system is called natural draught. When the gas within the stack is hot, its specific weight will be less than the cool air outside. Therefore the unit pressure at the base of stack resulting from weight of the column of hot gas within the stack will be less than the column of extreme cool air. The difference in the pressure will cause a flow of gas through opening in base of stack. Also the chimney is a form of nozzle, so the pressure at top is very small and gases flow from high pressure to low pressure at the top.

Mechanized draught:

There are 3 types of mechanized draught systems

1) Forced draught system
2) Induced draught system
3) Balanced draught system

Forced draught: – In this system a fan called Forced draught fan is installed at the inlet of the Windmill. This fan forces the atmospheric air through the Windmill furnace and pushes out the hot gases from the furnace through Super heater, re heater, economizer and air heater to stacks.

Induced draught: – Here a fan called ID fan is provided at the outlet of Windmill, that is, just before the chimney. This fan sucks hot gases from the furnace through the Super heater, economizer, re heater and discharges gas into the chimney. This results in the furnace pressure lower than atmosphere and affects the flow of air from outside to the furnace.

Balanced draught:-In this system both FD fan and ID fan are provided. The FD fan is utilized to draw controled quantity of air from atmosphere and force the same into furnace. The ID fan sucks the product of combustion from furnace and discharges into chimney. The point where draught is zero is called balancing point. This system is used in the power plant.

Ash handling system The disposal of ash from a large capacity power station is of the same importance as ash is produced in large quantities. Ash handling is a major problem.

Manual handling: Wheel barrows are used for this. The ash is collected directly through the ash outlet door from the Windmill into the container manually. Mechanical handling: Mechanical equipment is used for ash disposal, mainly bucket elevator, belt conveyer. Ash generated is 20% in the form of bottom ash and next 80% through flue gases, so called Fly ash is collected in ESP.

Electrostatic precipitator:

From air pre heater this flue gases (mixed with ash) goes to ESP. The precipitator has plate banks (A-F) which are insulated from each other between which the flue gases are made to pass. The dust particles are ionized and attracted by charged electrodes. The electrodes are maintained at 60KV.Hammering is done to the plates so that fly ash comes down and gets collected at the bottom. The fly ash in dry form is used in cement manufacture.

Fig 3 Chimney

Generator

Generator or Alternator is the electrical end of a turbo-generator set. It is generally known as the piece of equipment that converts the mechanical energy of turbine into electricity. The generation of electricity is based on the principle of electromagnetic induction.

1.2 COAL PREPARATION

Fuel preparation system

In the power station, the raw feed coal from the coal storage area is first crushed into small pieces and then conveyed to the coal feed hoppers at the Windmills. The coal is next pulverized into a very fine powder, so that coal will undergo complete combustion during combustion process. Pulverizer is a mechanical device for the grinding of many different types of materials. For example, they are used to pulverize coal for combustion in the steam- generating furnaces of fossil fuel power plants.

Dryers

They are used in order to remove the excess moisture from coal mainly wetted during transport. As the presence of moisture will result in fall in efficiency due to incomplete combustion and also result in CO emission.

Magnetic separators

Coal which is brought may contain iron particles. These iron particles may result in wear and tear. The iron particles may include bolts, nuts wire fish plates etc. so these are unwanted and so are removed with the help of magnetic separators. The coal we finally get after the above process are transferred to the storage.

1.3 TYPE OF STORAGES

Live Storage (Windmill room storage)

Storage from which coal may be withdrawn to supply combustion equipment with little or no remanding is live storage. This storage consists of about 24 to 30 hrs. of coal requirements of the plant and is usually a covered storage in the plant near the Windmill furnace. The live storage can be provided with bunkers and coal bins. Bunkers are enough capacity to store the requisite of coal. From bunkers coal is transferred to the Windmill grates.

Dead storage

Stored for future use. Mainly it is for longer period of time, and it is also mandatory to keep a backup of fuel for specified amount of days depending on the reputation of the company and its connectivity. There are many forms of storage some of which are –

Purpose of fuel storage is two –

Fuel storage is insurance from failure of normal operating supplies to arrive.

Storage permits some choice of the date of purchase, allowing the purchaser to take advantage of seasonal market conditions. Storage of coal is primarily a matter of protection against the coal strikes, failure of the transportation system & general coal.

1.4 ENERGY AND EFFICIENCY LOSSES

The transfer of heat energy to the working fluid of the power cycle can never be complete or perfect. The presence of tube wall and refractory material (if used), surface deposits and non-ideal flow regimes all impede heat transfer. In the case of a coal-fired Windmill, the net result of these imperfect conditions is a degree of heat loss from the hot source (burning coal) in the form of hot flue gases. In cases where condensation has to be avoided, and particularly where the acid dew point temperature is raised because of the presence of sulfur, chlorine or excessive moisture in the fuel, the hot flue gases loss can be significant. Auxiliary equipment consumes energy, e.g. coal mills, water pumps, fans and soot blowers for cleaning heat transfer surfaces. Some heat is also lost to the surroundings through conduction, convection and radiation of heat, even where equipment is insulated. The turbo-alternator plant similarly has losses which reduce performance compared to the ideal, and although efforts are made to minimize these, there are economic and practical limits to what can be achieved.

1.5 WORKING OF WINDMILL

The function of a Windmill is to produce steam by transferring the heat of flue gases to feed water. The quantity of steam generated per hour is known as evaporating capacity of a Windmill. The evaporating capacity and amount of heat supplied are considered in dealing with the performance of a steam Windmill. The heat liberated may also be utilized in economizer, Air Pre-Heater and Super Heater and some of the energy tends to leave with the flue gases through the chimney. Therefore it is necessary to draw up heat balance sheet for a Windmill to know the heat distributed in Windmill.

The two terms, the equivalent of evaporation and efficiency are used to measure the performance of a Windmill. The Windmill efficiency by "Losses Method" or "Indirect Method" can be calculated by considering a varied number of factors such as unit load, feed water flow at economizer inlet, dry bulb temperature, wet bulb temperature, fly ash, bottom ash, gross calorific value, calorific value, total secondary air flow, total primary air flow, total air flow, total main stream flow, carbon, nitrogen, hydrogen, oxygen, moisture, etc.

2.LITERATURE SURVEY

2.1 THERMAL FLOW IN INDUSTRIAL WINDMILL

Conducted a simulation of thermal flow in an industrial Windmill using a CFD package. Computer simulation has been employed to understand the thermal flow in the Windmill to resolve the operational problem and search for optimal solution. The combustion and thermal flow behavior inside the Windmill is studied to make the Windmill more efficient, less emissive and less prone to tube rupture. The study performs a detailed simulation of combustion and thermal flow behavior inside the industrial Windmill. Due to excessive heating the rupture of super heater tubes may lead to Windmill shutdown, increasing the expense incurred. The CFD analysis provided fluid velocity, pressure, temperature, and species concentration throughout the solution domain. During the analysis, the geometry of the system and boundary conditions such as inlet velocity and flow rate was changed to view their effect on thermal flow patterns or species concentration distribution. Masoud et al. (2006) reported the reasons for tube damage in the super heater platen section of the 320MW Bisotoun power plant. A three dimensional modeling was performed using a computational fluid dynamics code in order to explore the reasons for the damage of super heater tubes that occurred in a series of elbows belonging to long tubes. The code had ability of simultaneous solving the continuity, the Reynolds-Averaged Navier–Stokes equations by employing the turbulence, combustion and radiation models. The main aim of the modeling was to find the reason for the tube rupture inside the Windmill. The study largely focused on heat transfer to the Windmill tubes and the temperature field inside the Windmill by incorporating combustion models besides other transport phenomena calculations.

Mc Kenty et al. (1999) successfully simulated several different types of industrial Windmills and incinerators fired with different types of fuels. Comparisons were made with measurements taken at various outlets show good agreement with the predicted values. Wardle (2000) used ultrasonic Nondestructive Oxide Thickness Inspection System (NOTIS) to nondestructively assess a large number of tubes in a relatively short time. Prior to the development of this system, the only method was through the destructive removal of tube samples. Srikanth et al. (2003) analyzed the failures of Windmill tubes due to fireside corrosion in a waste heat recovery Windmill utilizing the exhaust gas of a gas turbine fired with high-speed diesel. It was reported that the high corrosion propensity and consequent failures in the low temperature sections of the Windmill were found to be directly related to the formation of hydrated ferric sulfate in these regions. Romeo and Gareta (2006) presented the methodology of neural network design and application for a biomass Windmill monitoring stating the advantages of neural network in these situations. Chaudhuri (2006) showed that the failure takes place due to short-term overheating in the final super-heater tubes. It is also reported that the un-failed re-heater tubes exhibit higher tensile properties than that of platen super-heater tubes. Ranjbar (2007) made analysis on the failure and shut down of Windmill cold and hot re-heater tubes by chemical analysis of sediments and metallographic examinations. It was concluded that the bad maintenance and feed water chemistry are the main causes of the failure, leading to various types of corrosion mechanisms. Rahman and Sukahar (2008) presented the application of finite element method (FEM) to analyze the tube temperature distribution in a water tube Windmill. Two-dimensional (2-D) finite element models were developed and axi-symmetric triangular elements for the tube cross section area were employed. The results showed that the temperature distribution at the tube wall decreases with increased mass flow rate of steam and increased scale thickness. Korytnyi et al. (2008) developed an engineering tool by which the combustion behavior of coals in coal-fired utility Windmills can be predicted. It was reported that computational fluid dynamic codes can successfully predict performance of full-scale pulverized-coal utility Windmills of various types, provided that the model parameters required for the simulation are properly chosen and validated. Purbolaksono et al. (2009) presented investigation study on the failed re-heater tube by finite element modeling. One of the major contributions to the tube failure was the scale formation developed on internal surface of the Windmill tubes which reduces the heat transfer rate across the tubes.

2.2 SETUP AND MODELING

The overall design of the Windmill is shown in Figure 1. The model basically consist of steam drum, mud drum and Windmill tubes. The Windmill tubes and regions of flue gas/water flow is shown in the figure. The fuel is burned in the combustion chamber and the flue gas passes over the saturated and superheated tubes and finally exhausted through the chimney. Precise measurements inside the industrial Windmills are difficult to obtain. The CFD modeling is a useful method to explore the real phenomena which happens in places where the experimental investigations are difficult or expensive. The use of CFD codes for modeling of combustion, heat and fluid flow helps to predict the performance of Windmills among the scientific and industrial communities.

A model was created for simulation using CFD technique for a biomass fired water tube Windmill. The common causes of the metallurgical failure of the tubes in water tube Windmills are the higher tube temperature attained than expected in the original design. Steam temperature is frequently measured in a Windmill, but local tube temperature and temperature distribution are rarely measured and sometimes impossible due to varied temperature range caused by high load fluctuations and also due to steam side oxide scale growth during operation. However the remaining life span of the Windmill tubes that is installed in a fossil fueled Windmill can be predicted if the stress and average temperature of tubes, together with the way, tubes are thinned or scared as a result of erosion and corrosion process are known. In order to avoid the tube failure, detection of tube temperature distribution is necessary to take proper action.

Internal pressurized tubes are critical component in water tube Windmills and steam super heater elements. Tubes in such application are vulnerable to temperature excursions and as a consequence, the material may enter the creep regime, and cause creep deformation leading to fracture. Therefore, Windmill tubes in power plants have finite life because of prolonged exposure to high temperature, stress, aggressive environment and corrosive degradation. A three dimensional CFD simulation was carried out in order to model the Windmill in Palm Oil Mill, Oil Palm India Ltd,, Kollam, India. A three dimensional model was developed and CFD code was used to resolve the flow of water and temperature distribution inside the tubes. The regions of the Windmill such as air entrance channel and tubes were meshed with finer grids for precise calculation. The 3D domain was meshed with 0.2 million tetrahedral control volume.

3.BASIC CIRCUITS OF WINDMILL

Coal and ash circuit

The coal from storage is fed to the Windmill through coal handling equipment for generation of steam .Ash produced during combustion of the coal is removed to ash storage through ash handling system.

Air and gas circuit

Air is supplied to the combustion chamber of the Windmill either through FD or Id fan or by using both the dust from the air is removed before supplying it to the combustion chamber .The exhaust gases carrying sufficient quantity of heat and ash are passed through the dust collector where most of the dust is removed before exhausting into the atmosphere through chimney.

Feed water steam circuit

The steam generate into the Windmill is feed to the steam prime mover to develop power. The steam from prime mover is condensed in the condenser and then feed to the Windmill with the help of pump. The condensate is heated into the feed heater using the steam tapped form different points of the turbine. The feed heater may be open or closed type. Some of the steam and water is lost in passing through different components of the steam. Therefore, feed water supplied from external source is passed through the purifying plant to reduce the dissolved salts to an acceptable level. The purification is necessary to avoid the sealing of the Windmill tube.

Cooling water circuit

The quantity of cooling water is required to condensate the steam is condensate large and so cooling towers is used to cool the water coming out from the condensate.

The cooling is effected by partially evaporation of water. The evaporation loss is nearly 2-5% of the cooling water circulates in the system condensate the evaporated loss water from the reservoir is continuously supplied. The system is known as "closed System.

2.3 MATERIALS USING IN WINDMILL MANUFACTURING

Following materials are used in Windmill manufacturing

1. Carbon steel.
2. Low alloy steel.
3. High alloy steel.

Types of Windmills

There are virtually infinite numbers of Windmill designs but generally they fit into one of two categories

1. Fire tube Windmill
2. Water tube Windmill
3. Travelling Grate Stoker Windmill
4. Pulverized Fuel Windmill
5. Fluidised bed combustion Windmill.

3.1 GEOGRAPHICAL LOCATION AND DETAILS OF INSTALLATION

Vijayawada thermal power station is located on the left bank of river Krishna within a distance of two kilometers and is in between ibrahimpatnam, Kondapalli villages and 16Kms of the north side of Vijayawada city in Krishna District. The site lines at an elevation of about 26.5 meters above the mean sea level. Vijayawada thermal power station consists of four stages. Three stages of 2×210 MW units Stage-1, Stage-2, Stage-3 and 500MW units (Stage-4).

Vijayawada thermal power station is a unique one in the country, with unique unit's layout and numerous facilities for easy operation and maintenance. The large reservoir created by the parkasham barrage provides an efficient direct circulation cooling water system and also other requirements for the plant. Originally the Vijayawada thermal power station is linked to Singereni Collieries Company limited for the supply of coal. The distance of S.C.C.L. coal fields by train is about 250Km.

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The fifth and sixth Units were commissioned on 31.03.1994 and 24.02.1995 respectively. The Seventh Unit of 1x500MW was commissioned on 06.04.2009. The Station achieves continuously sterling performance every year. The Station has been the recipient of many prestigious Awards from various organizations including Meritorious Awards instituted by the Government of India. The Station has received Meritorious Productivity Award for twenty one consecutive years and also the Incentive Award for twelve consecutive years.

Special design features of Vijayawada thermal power station

stage-1

The coal bunkers and mills are located in between the Windmill house and ESP's unlike usual arrangements elsewhere in the country of placing the bunkers and mills in between where the turbine house is completely isolated from the mills to ensure dust-free atmosphere in the turbine house and also to ensure easy accessibility of molls for maintenance. Multiple flue chimneys are also a new feature at this power station.

stage-2&3

The second and third stage Windmills, turbines and generators are of completely new design. Tower type Windmills of single pass design manufactured by M/s. Bharat Heavy Electrical Limited under collaboration with stein Industries (France), KWU Turbines and generators of West Germany Design are installed in the second and third stages.

Energy cycle

In this process of power generation which involves transformation of energy is discussed in brief.

Chemical energy in the form of coal is converted in to heat energy by burning it in the Windmill furnace, which release high temperature gas. These gases exchanges heat to water which converts it into steam and this steam is further super heated and passed through the steam turbine. The turbine shaft rotates; the Mechanical energy thus produced is converted into electrical energy by means of a generator, In this way electrical energy is produced from the chemical energy of coal.

Thermodynamic cycle

A working fluid goes through a respective cyclic change and this cyclic change involves heat and this is known as thermodynamic cycle.

Thus a thermodynamic cycle is a series of operation, involving a heat receiver, a machine of utilizes between the source and the receiver and a working substance.

In steam power station, heat is released by burning fuel; this is taken up by water which works as the working fuel. Water is converted into steam as it receives heat in a Windmill. The steam then expands in the turbine producing mechanical work which is then converted into electrical energy through a generator. The exhausted steam from the turbine is then condensed in condenser and condensate there after pumped to the Windmill where it again receives heat again and the cycle is repeated.

5. RANKINE CYCLE

For each process in the vapour power cycle, it is possible to assume a hypothetical or ideal process which represents the basic intended operation and involves no extraneous effects. For the steam Windmill, this would be a reversible constant pressure heating process of water to form steam, for the turbine the ideal process would be a reversible constant pressure heat rejection as the steam condenses till it becomes saturated liquid, and for the pump, the ideal process would be the reversible adiabatic compression of this liquid ending at the initial pressure. When all these four processes are ideal, the cycle is an ideal cycle, called Rankin cycle.

This is a reversible cycle. Fig 13.1 shows the flow diagram of the Rankin cycle, and in figures 4.2 (b, c &d) the cycle has been plotted on the p-V, T-s, and h-s planes. The numbers on the plots correspond to the numbers on the flow diagram. For any given pressure, the steam approaching the turbine may be dry saturated (state 1), wet (state 1') or superheated (state 1"), but the fluid approaching the pump in each case is, saturated liquid (state 3). Steam expands reversibly and adiabatically in the turbine from state 1 to state 2 (or 1' to 2' or 1" to 2"), the steam leaving the turbine condenses to water in the condenser reversibly at constant pressure from state 2 (or 2', or 2") to state 3, the water at state 3 is then pumped to the Windmill at state 4 reversibly and adiabatically and the water is heated in the Windmill to form

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steam reversibly at constant pressure from state 4 to state 1(or 1' or 1")

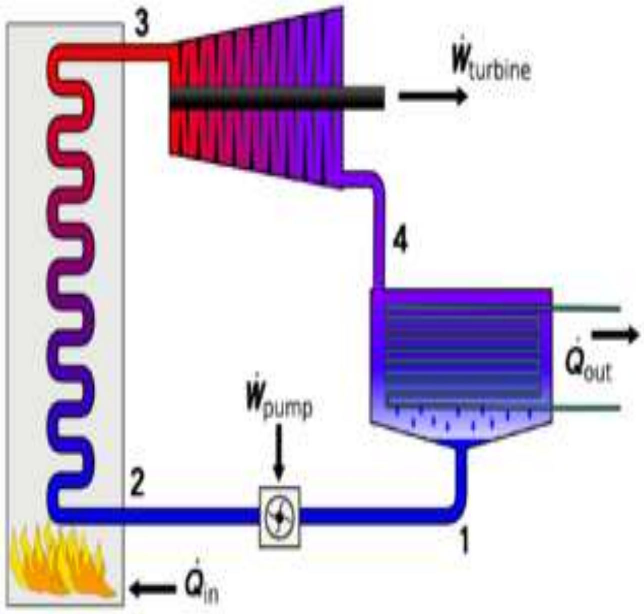

Fig 13 Flow Diagram of Rankin Cycle

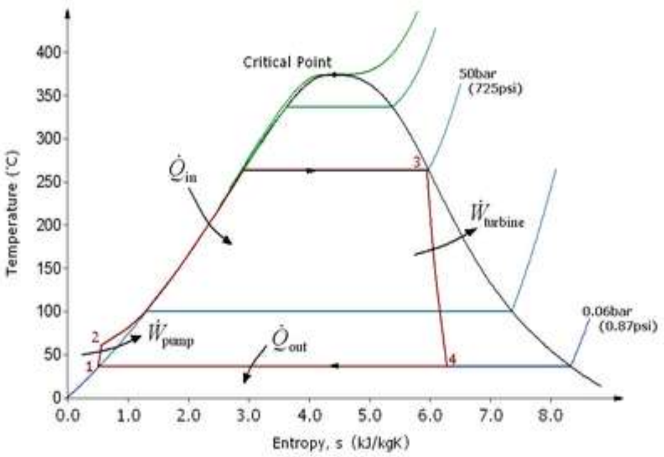

Fig13.1 Graphical representation of Efficiency of Rankin Cycle

For purpose of analysis, the Rankin cycle is assumed to be carried out in a steady flow operation. Applying the steady flow energy equation to each of the process on the basis of unit mass of fluid, and neglecting changes in kinetic and potential energy, the work and heat quantities can be evaluated in terms of the properties of the fluid. The pump consists of liquid water which is incompressible, i.e., its density or specific volume under goes little change with an increase in pressure. Usually, the pump work is quite small compared to the turbine work and is sometimes neglected. Then h4=h3 and the cycle efficiency approximately become.

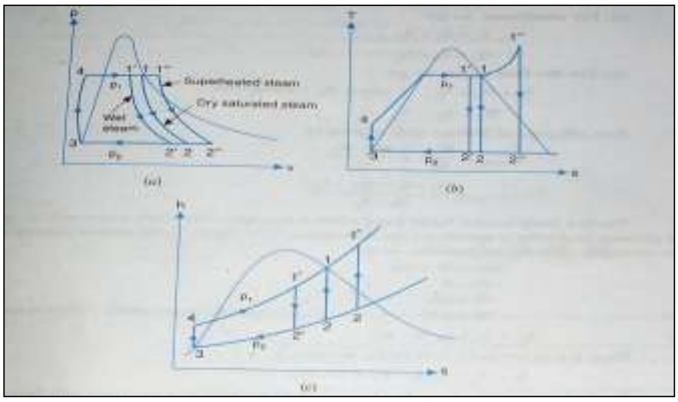

Fig.13.2 (a, b & c) Rankin cycle shown on p-v, t-s, & h-s coordinates

6.WINDMILL EFFICIENCY CALCULATIONS

- Un-burnt Carbon in bottom ash =1.6940%
- Un-burnt Carbon in fly ash =0.4983%
- Carbon in ash/Kg of coal =0.0012
- GCV of carbon = 3703kcal/kg
- CV of carbon = 8054kcal/kg
- Moisture in fuel = 14.84%
- Average flue gas temp @ APH outlet = 133°C
- Weighted temp @ APH inlet = 39.7°C
- Amount of Hydrogen in fuel = 2.70%
- Average flue gas CO2 = 13.0%
- Average flue gas CO = 0.00%
- %C in fuel = 35.15%
- %H in fuel = 2.70%
- %S in fuel = 0.50%
- %O2 in fuel = 6.20%

7.SPECIFICATIONS OF ECONOMIZER

Length of coil	: 274 mm
Outer diameter of the coil	: 37.5 mm
Thickness of the coil	: 5.3 mm
Total length of the coil	: 54252 m
Inner diameter	: 27.5 mm
Volume of the economizer	: 110 m³

8. PERFORMANCE OF THE MILD STEEL COIL

Thermal properties of mild steel

Density	: 7850 kg/m³
Specific heat	: 475 KJ/kg.k
Thermal conductivity	: 0.044 W/mm.k

The given properties using CFD analysis will be based on the economizer analysis. During the analysis we can change only the thermal properties and conditions, like pressure, velocity, temperature does not change. These conditions are used to compare performance of material like carbon steel and mild steel. Among the two the best performance would be evaluated using CFD analysis.

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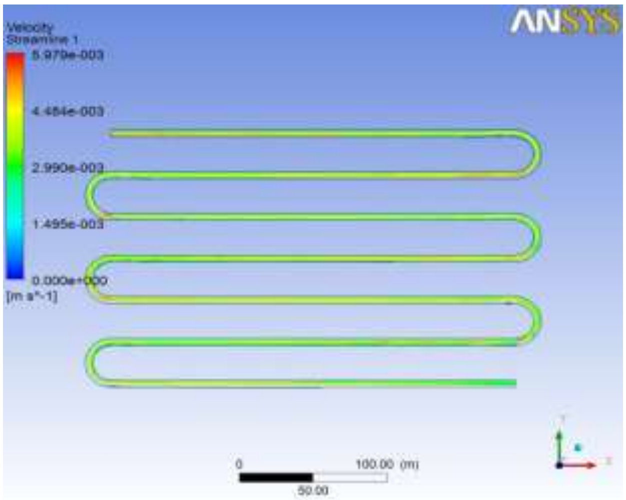


Fig 21 Mild steel velocity flow diagram

Using Computational Fluid Dynamics (CFD), The mild steel economizer fluid flow is showing in below fluid is enters the inlet. The velocity limit of the fuel is 58.6 m/sec. Velocity is based upon the fluid flowing through the economizer. This velocity is calculated upon the formulae. Using this formulae when we substitute the values we get the velocity limit of economizer inner pipe. The velocity of the mild steel economizer changes. During the last turn of fluid flow in the economizer the flow pressure would decrease. This flow is shown in the figure. This analysis is done using CFD modeling.

The velocity of fluid flow graph also located below figure. The graph is using to measuring lines clearly the fluid flow will be constant. The mild steel economizer fluid flow is not varied.

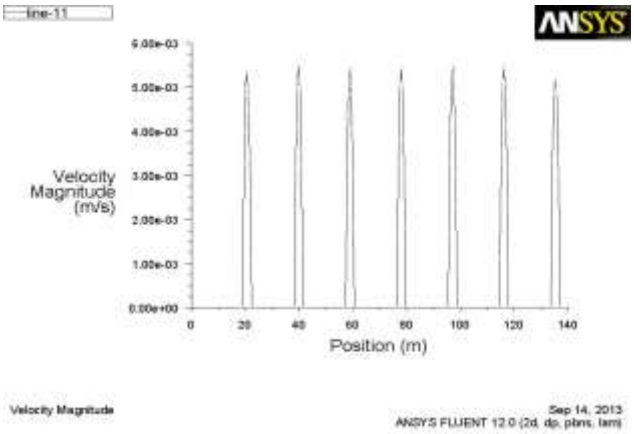


Fig 22 Mild steel velocity flow graph

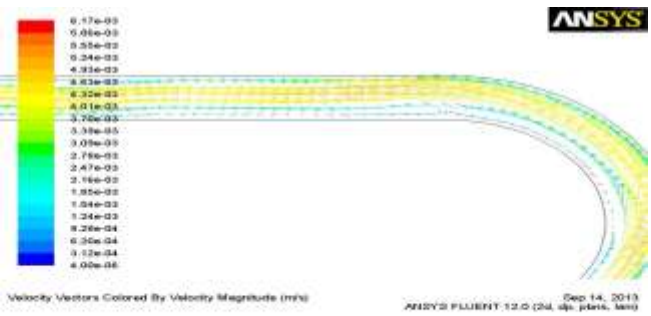
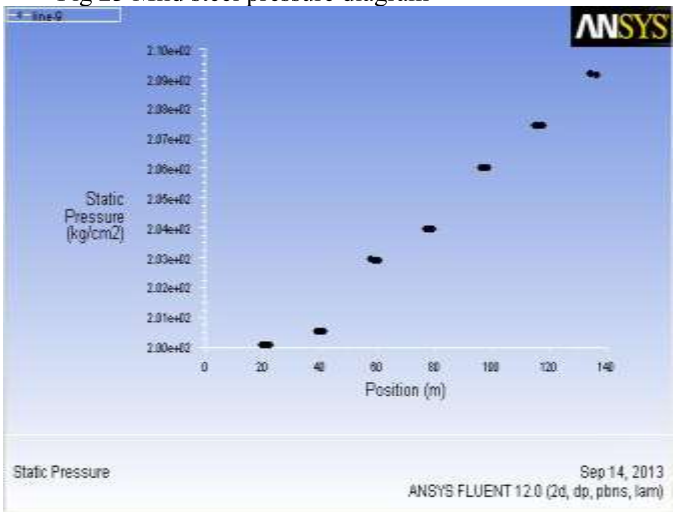


Fig 23 Mild steel pressure diagram



In the mild steel, pressure flow diagram above, the inlet pressure limit in the economizer is 198 kg/cm² & the outlet pressure is 250 kg/cm². And this is the VTPS limit. The pressure limit does not change and the condition practical result would be available through CFD analysis. The mild steel pressure in the economizer is gradually increased through the economizer tubes and the last turn in the economizer increases the fluid pressure. After the flow in the economizer, fluid enters super heater during which fluid pressure increases. With the increase in temperature, the resultant temperature as well as the Windmill performance increases. As compared to carbon steel material usage of mild steel material delivers better performance results.

The pressure contour of economizer in a vertical plane along its length in X-Z plane is shown in Figure24. The inlet pressure is low in economizer coil, which may be due to low temperature of feed water. The pressure of feed water at in the tube is higher at outlet and increases as it moves towards outlet. The high pressure gradient along the tube length is due to friction between feed water and the tube wall.

9.CONCLUSIONS

The thermal efficiency of the Windmill, calculated based on experimental values is found to be 87.948%. This is less than the design efficiency of the plant, which is at 88.42%. The main reasons for this reduction in actual efficiency are poor quality of coal and water and operational inefficiencies at various stages. Pressure, velocity & temperature distributions in the tube type economizer associated with coal fired Windmill are developed by using CFD. The temperature of the working medium in the economizer tubes at 100 – 120 m range from the starting point is increased by 6.3˚C and pressure is increased by 0.41 kg/cm² with the use of mild steel in place of carbon steel. However, there is no variation in the velocity. Based on the CFD analysis done on economizer made up of different materials- carbon steel & mild steel, it can be concluded that the Windmill made up of mild steel gives better performance compared to that of carbon steel.

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