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Use of Solar Energy in Thermal Power Plant for Increase Sensible Heat of Feed Water

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A B S T R A C T

Energy is vital for economic development, but growing demand has rapidly depleted fossil fuel reserves, raising concerns about future energy security. Fossil fuels like coal dominate energy supply in India (coal accounts for 55% of the demand), but they are non-renewable and cause serious environmental pollution. In the present case study at a 31 MW thermal power plant (HEG Bhopal), a solar water heater (evacuated tube type) was used to heat DM feed water from 35°C to 80°C, reducing coal consumption by 450 kg per day. This reduces the cost of sensible heat and lowers fuel dependency. Solar energy, being abundant, clean, and renewable, is a sustainable alternative to fossil fuels. Using solar water heaters as accessories in thermal power plants can improve efficiency, cut emissions, and contribute to long-term energy security

1. Introduction

A Thermal power station is a power plant in which the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser and recycled to where it was heated; this is known as a Rankine cycle. The greatest variation in the design of thermal power stations is due to the different fuel sources. Some prefer to use the term energy centre because such facilities convert forms of heat energy into electricity. Some thermal power plants also deliver heat energy for industrial purposes, for district heating, or for desalination of water as well as delivering electrical power. A large part of CO2 emissions comes from fossil fuelled thermal power plants; efforts to reduce these outputs are various and widespread.

The steam is generated in the boiler of the thermal power plant using the heat of the fuel burnt in the combustion chamber. The steam generated is passed through steam turbine where part of its thermal energy is converted into mechanical energy which is further used for generating electric power. The steam coming out of the steam turbine is condensed in the condenser and the condensate is supplied back to the boiler with the help of feed pump and the cycle is repeated. Following are the important parts of thermal power plants [1]

- Boiler House
- Steam Turbine
- Condenser
- Cooling Tower
- Feed Pump
- Electric Generator.

1.1 EFFICIENCY OF THERMAL POWER PLANT

The energy efficiency of a conventional thermal power station, considered as saleable energy as a percent of the heating value of the fuel consumed, is typically 33% to 48%. This efficiency is limited as all heat engines are governed by the laws of thermodynamics. The rest of the energy must leave the plant in the form of heat. This waste heat can go through a condenser and be disposed of with cooling water or in cooling towers.

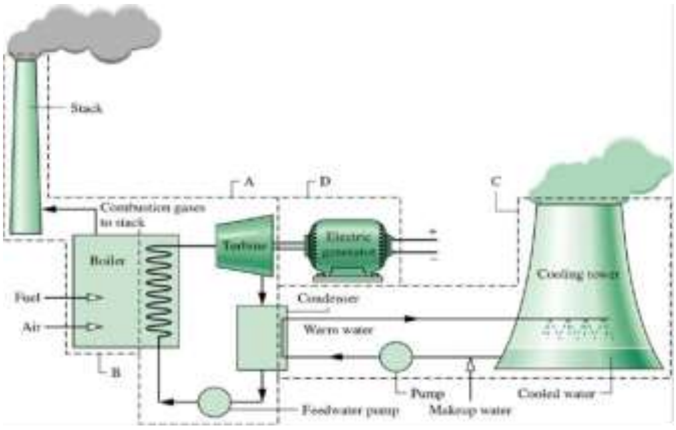

Figure 1.1 Working of Thermal power plant

1.2 HEAT REQUIRED IN BOILER TO CONVERT FEED WATER INTO SUPERHEATED STEAM

Sensible Heat

When a Fluid is heated, its temperature rises as heat is added. The increase in heat is called sensible heat. Similarly, when heat is removed from a Fluid and its temperature falls, the heat removed is also called sensible heat. Heat that causes a change in temperature in an object is called sensible heat. Temperature range of water during sensible heat 0-1000C. [2]

Latent Heat of Vaporization

All pure substances in nature are able to change their state. Solids can become liquids (ice to water) and liquids can become gases (water to vapour) but changes such as these require the addition or removal of heat. The heat that causes these changes is called latent heat. Latent heat however, does not affect the temperature of a substance - for example, water remains at 100°C while boiling. The heat added to keep the water boiling is latent heat. Heat that causes a change of state with no change in temperature is called latent heat.

Superheat

Superheated steam is steam at a temperature higher than water's boiling point. If saturated steam is heated at constant pressure, its temperature will also remain constant as the steam quality (think dryness) increases towards 100% Dry Saturated Steam. Continued heat input will then generate superheated steam. This will occur if saturated steam contacts a surface with a higher temperature. The steam is then described as superheated by the number of degrees it has been heated above saturation temperature. [3]

1.3 WORKING OF BOILER IN POWER PLANT

Generally, Boilers are used to produce steam at high pressure than atmospheric pressure. The steam generator is also known as boiler. Steam is the most important working substance used for power generation in steam engines and in steam turbines. The generation of steam is done by evaporating the water in boilers at appropriate temperatures and pressures. A “Boiler” may be defined as a combination of equipment’s to generate steam from water by burning fuel. In industries the steam may be used for different purposes. A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam. The hot water or steam under pressure is then usable for transferring the heat to a process. Water is a useful and cheap medium for transferring heat to a process. When water is boiled into steam its volume increases about 1,600 times, producing a force that is almost as explosive as gunpowder. This causes the boiler to be extremely dangerous equipment that must be treated with utmost care. [4]

1.4 BOILER SYSTEM

The boiler system comprises of feed water system, steam system and fuel system. The feed water system provides water to the boiler and regulates it automatically to meet the steam demand. Various valves provide access for maintenance and repair. The steam system collects and controls the steam produced in the boiler. Steam is directed through a piping system to the point of use. Throughout the system, steam pressure is regulated using valves and checked with steam pressure gauges. The fuel system includes all equipment used to provide fuel to generate the necessary heat. The equipment required in the fuel system depends on the type of fuel used in the system. The water supplied to the boiler that is converted into steam is called feed water. The two sources of feed water are:

- Condensate or condensed steam returned from the processes and
- Makeup water (treated raw water) which must come from outside the boiler room and plant processes.

For higher boiler efficiencies, the feed water is preheated by economizer, using the waste heat in the flue gas. [5] Boiler component means Steam piping, Feed water piping, Economizer, Super heater, any mounting or other fitting and any other external or internal part of a Boiler which is subjected to pressure exceeding one kilogram per centimetre square gauge.

Steam Pipe means any pipe through which steam passes if:

1. The pressure at which the steam passes through such pipe exceeds 3.5 kg/cm^2 above atmospheric pressure, or
2. Such pipe exceeds 254 mm in internal diameter and pressure of steam exceeds 1 kg/cm^2 above the atmospheric pressure and includes in either case any connected fitting of a steam pipe.

1.5 BOILER PERFORMANCE

The performance of a steam boiler is measured in terms of its evaporative capacity however the evaporative capacities of two boilers cannot be compared unless both the boilers have the same feed water temperature, working pressure, fuel and the final condition of steam. In actual practice the feed water and working pressure varies considerably. It is thus obvious, that the comparison of two boilers difficult unless some standard feed temperature and working pressure is adopted. The feed temperature usually adopted is 100 and the working pressure as normal atmospheric pressure that is 1.013 bar. It is assumed that the boiler is supplied with water at the boiling temperature 100 corresponding to the atmospheric pressure. [6]

1.6 BOILER EFFICIENCY

It may be defined as the ratio of heat actually used in producing the steam to the heat liberated in the furnace. It is also known as thermal efficiency of the boiler. Mathematically, Boiler efficiency or thermal efficiency:

$$\eta = \frac{Heat\ actually\ used\ in\ producing\ steam}{Heat\ liberated\ in\ the\ furnace} \qquad \text{Eqn. 1.1}$$

1.7 VARIABLES THAT AFFECTS THE BOILER EFFICIENCY

1. Number of boilers passes
2. Burner / boiler compatibility
3. Repeatable air/fuel control
4. Preheated Boiler Feed Water (by Flue gas, Solar heater, Solar Pond.)
5. Pressure vessel design
6. Proven stack temperature
7. Accurate fuel specification
8. Actual operating excess air levels

1.8 WAYS TO REDUCE ELECTRICITY COST

1. To reduce the cost of fuel used in boiler
2. Better use of fuel
3. Try to use non-conventional source of energy like Solar Energy, Wind Energy.
4. Implementation of solar energy for steam generation for thermal power plant it reduces the cost of fuel also it will be environment friendly.

1.9 SOLAR ENERGY

Solar Energy, radiant light and heat from the sun, has been harnessed by humans since ancient times using a range of ever-evolving technologies. Solar radiation, along with secondary solar-powered resources such as wind and wave power, hydroelectricity and biomass, account for most of the available renewable energy on earth. Only a minuscule fraction of the available solar energy is used. Solar powered electrical generation relies on heat engines and photovoltaic. Solar energy's uses are limited only by human ingenuity. A partial list of solar applications includes space heating and cooling through solar architecture, potable water via distillation and disinfection, day lighting, solar hot water, solar cooking, and high temperature process heat for industrial purposes. To harvest the solar energy, the most common way is to use solar panels. [7]

In 2011, the International Energy Agency said that solar energy technologies such as photovoltaic panels, solar water heaters and power stations built with mirrors could provide a third of the world’s energy by 2060. The energy from the sun could play a key role in de-carbonizing the global economy alongside improvements in energy efficiency and imposing costs on greenhouse gas emitters. "The strength of solar is the incredible variety and flexibility of applications, from small scale to big scale". [8]

1.10 ENERGY FROM THE SUN

The Earth receives 174 Peta watts (PW) of incoming solar radiation (insolation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet. Earth's land surface, oceans and atmosphere absorb solar radiation, and this raises their temperature. Warm air containing evaporated water from the oceans rises, causing atmospheric circulation or convection. When the air reaches a high altitude, where the temperature is low, water vapor condenses into clouds, which rain onto the Earth's surface, completing the water cycle. The latent heat of water condensation amplifies convection, producing atmospheric phenomena such as wind, cyclones and anti-cyclones. Sunlight absorbed by the oceans and land masses keeps the surface at an average temperature of 14 °C. By photosynthesis green plants convert solar energy into chemical energy, which produces food, wood and the biomass from which fossil fuels are derived.

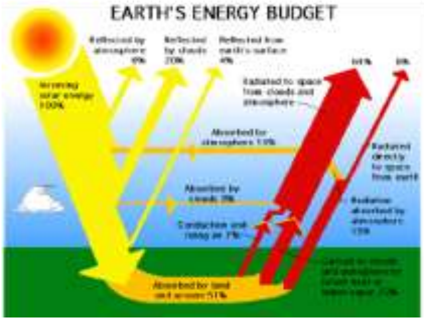

Figure 1.2 Earth's Energy Budget

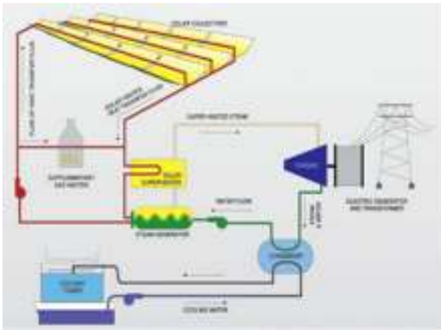

Figure 1.3 Parabolic Trough collectors

The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year. In 2002, this was more energy in one hour than the world used in one year. Photosynthesis captures approximately 3,000 EJ per year in biomass. The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined. Solar energy can be harnessed in different levels around the world. Depending on a geographical location the closer to the equator the more "potential" solar energy is available. [9]

1.11 SOLAR THERMAL POWER GENERATION TECHNOLOGIES

Concentrating solar collectors

Solar collectors are used to produce heat from solar radiation. High temperature solar energy collectors are basically of three types:

1. Parabolic trough system: at the receiver can reach 400° C and produce steam for generating electricity.
2. Power tower system: The reflected rays of the sun are always aimed at the receiver, where temperatures well above 1000° C can be reached.
3. Parabolic dish systems: Parabolic dish systems can reach 1000° C at the receiver, and achieve the highest efficiencies for converting solar energy to electricity.

Parabolic Trough collector System

Trough systems use linear concentrators of parabolic shape with highly reflective surfaces; whish can be turned in angular movements towards the sun position and concentrate the radiation onto a long-line receiving absorber tube. The absorbed solar energy is transferred by a working fluid, which is then piped to a conventional power conversion system.

Parabolic trough power plants are line-focusing STE (solar thermal electric) power plants. Trough systems use the mirrored surface of a linear parabolic concentrator to focus direct solar radiation on an absorber pipe running along the focal line of the parabola. The HTF (heat transfer fluid) inside the absorber pipe is heated and pumped to the steam generator, which, in turn, is connected to a steam turbine. A natural gas burner is normally used to produce steam at times of insufficient insolation. The collectors rotate about horizontal north–south axes, an arrangement which results in slightly less energy incident on them over the year but favours summertime operation when peak power is needed. [10] The major components in the system are collectors, fluid transfer pumps, power generation system and the controls. This power generation system usually consists of a conventional Rankine cycle reheat turbine with feed water heaters deaerators, etc. and the condenser cooling water is cooled in forced draft cooling towers. These types of power plants can have energy storage system comprising these collectors usually have the energy storage facilities. Instead they are couple to natural gas fired back up systems. A typical configuration of such systems is shown in fig below.

Parabolic trough solar technology is the most proven and lowest cost large-scale solar power technology available today, primarily because of the nine large commercial-scale solar power plants that are operating in the California Mojave Desert. These plants developed by Luz International Limited and referred to as Solar Electric Generating Systems (SEGS), range in size from 14-80 MW and represent 354 MW of installed electric generating capacity. More than 2,000,000 m2 of parabolic trough collector technology has been operating daily for up to 18 years, and as the year 2001 ended, these plants had accumulated 127 years of operational experience. The Luz collector technology has demonstrated its ability to operate in a commercial power plant environment like no other solar technology in the world. Although no new plants have been built since 1990, significant advancements in collector and plant design have been made possible by the efforts of the SEGS plants operators, the parabolic trough industry, and solar research laboratories around the world. This paper reviews the current state of the art of parabolic trough solar power technology and describes the R&D efforts that are in progress to enhance this technology. The paper also shows how the economics of future parabolic trough solar power plants are expected to improve.

Power Tower System

In power tower systems, heliostats (A Heliostat is a device that tracks the movement of the sun which is used to orient a mirror of field of mirrors, throughout the day, to reflect sunlight onto a target-receiver) reflect and concentrate sunlight onto a central tower-mounted receiver where the energy is transferred to an HTF. This energy is then passed either to the storage or to power-conversion systems, which convert the thermal energy into electricity. Heliostat field, the heliostat controls, the receiver, the storage system, and the heat engine, which drives the generator, are the major components of the system. [11]

For a large heliostat field, a cylindrical receiver has advantages when used with Rankine cycle engines, particularly for radiation from heliostats at the far edges of the field. Cavity receivers with larger tower height to heliostat field area ratios are used for higher temperatures required for the operation of Brayton cycle turbines. These plants are defined by the options chosen for an HTF, for the thermal storage medium and for the power-conversion cycle. HTF may be water/steam, molten nitrate salt, liquid metals or air and the thermal storage may be provided by PCM (phase change materials). Power tower systems usually achieves concentration ratios of 300–1500, can operate at temperatures up to 1500o C. To maintain constant steam parameters even at varying solar irradiation, two methods can be used:

- Integration of a fossil back-up burner; or
- Utilization of a thermal storage as a buffer

By the use of thermal storage, the heat can be stored for few hours to allow electricity production during periods of peak need, even if the solar radiation is not available. The modern R&D efforts have focused on polymer reflectors and stretched-membrane heliostats. A stretched-membrane heliostat consists of a metal ring, across which two thin metal membranes are stretched. A focus control system adjusts the curvature of the front. Membrane, which is laminated with a silvered-polymer reflector, usually by adjusting the pressure in the plenum between the two membranes.

Examples of heliostat-based power plants were the 10 MWe Solar One and Solar Two demonstration projects in the Mojave Desert, which have now been decommissioned. The 15 MW Solar Tres Power Tower in Spain builds on these projects. In Spain the 11 MW PS10 Solar Power Tower was recently completed. In South Africa, a solar power plant is planned with 4000 to 5000 heliostat mirrors, each having an area of 140 m². [12]

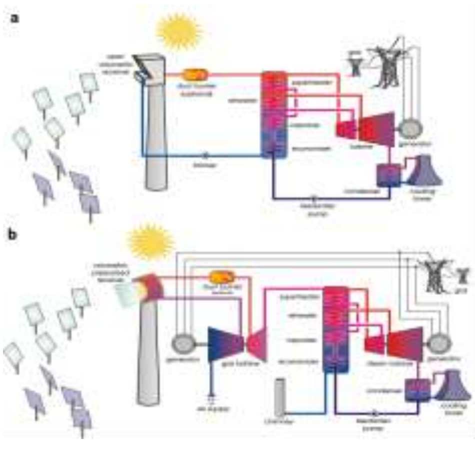

Figure 1.4 Solar receiver technologies

Parabolic Dish system

The parabolic dish system uses a parabolic dish shaped mirror or a modular mirror system that approximates a parabola and incorporates two-axis tracking to focus the sunlight onto receivers located at the focal point of the dish, which absorbs the energy and converts it into thermal energy. This can be used directly as heat for thermal application or for power generation. The thermal energy can either be transported to a central generator for conversion, or it can be converted directly into electricity at a local generator coupled to the receiver.

The mirror system typically is made from a number of mirror facets, either glass or polymer mirror, or can consist of a single stretched membrane using a polymer mirror of thin metal stretched membrane The PDC (Parabolic dish collector) track the sun on two axes, and thus they are the most efficient collector systems. Their concentration ratios usually range from 600 to 2000, and they can achieve temperature in excess of 150000C. Rankin-cycle engines, Brayton-cycle engines, and sodium- heat engines have been considered for systems using dish-mounted engines the greatest attention though was given sterling-engine systems.

Figure 1.5 Parabolic Dish Collectors

The main challenge facing distributed –dish system is developing a power-conversion unit, which would have low capital and maintenance costs, long life, high conversion efficiency, and the ability to operate automatically. Several different engines, such as gas turbines, reciprocating steam engines, and organic Rankin engines, have been explored, but in recent years, most attention has been focused on Stirling-cycle engines. These are externally heated piston engines in which heat is automatically added to a (normally hydrogen or helium at high pressure) that is contained in a closed system. The Stirling Energy Systems (SES) and science Applications International Corporation (SAIC) dishes at UNLY and the big Dish in Canberra, Australia are representatives of this technology. [13]

1.12 SOLAR THERMAL POWER GENERATION PROGRAM IN INDIA

In India the first Solar Thermal Power Plant of 50 kW capacities has been installed by MNES following the parabolic trough collector technology (line focusing) at Gwalpahari, Gurgaon, which was commissioned in 1989 and operated till 1990, after which the plant was shut down due to lack of spares. The plant is being revived with development of components such as mirrors, tracking system etc.

A Solar Thermal Power Plant of 140MW at Mathania in Rajasthan has been proposed and sanctioned by the Government in Rajasthan. The project configuration of 140MW Integrated Solar Combined Cycle Power Plant involves a 35 MW solar power generating system and a 105MW conventional power component and the GEF has approved a grant of US$ 40 million for the project. The Government of Germany has agreed to provide a soft loan of DM 116.8 million and a commercial loan of DM 133.2 million for the project. [14]

In addition, a commercial power plant based on Solar Chimney technology was also studied in North-Western part of Rajasthan. The project was to be implemented in five stages. In the 1st stage the power output shall be 1.75MW, which shall be enhanced to 35 MW, 70 MW, 126.3 MW and 200 MW in subsequent stages. The height of the solar chimney, which would initially be 300m, shall be increased gradually to 1000m. Cost of electricity through this plant is expected to be Rs. 2.25 / kWh. However, due to security and other reasons the project was dropped. [15]

BHEL limited, an Indian company in power equipment's manufacturing, had built a solar dish-based power plant in 1990's as a part of research and development program of then the Ministry of Non-conventional Energy Sources. The project was partly funded by the US Government. Six dishes were used in this plant. Few states like Andhra Pradesh, Gujarat had prepared feasibility studies for solar thermal power plants in 1990's. However, not much work was carried out later on.

2. Literature Review

Beerbaum B. and G. Weinrebe 2000, They studied the potential of Solar Thermal Electricity (STE) in India, where solar resources and land availability make it ideal. The study compares STE's levelized electricity cost with other sources and finds STE economically viable under high insolation and low-interest capital conditions [3].

M.J. Montes A. et al. 2023, A thermo-economic study on solar thermal plants using supercritical CO_2 cycles and pressurized receivers. Innovations include new heat transfer fluids (like CO_2) and compact radial absorber designs. Findings suggest CO_2 performs best, and receiver pressure affects size and efficiency trade-offs [4].

Muller-Steinhagen H. and Nitsch J. 2005, They emphasized the underutilization of Africa's renewable energy potential and explored various renewable sources like bioenergy, solar, and wind. The paper discusses awareness, challenges, and the role of governments and private sectors in boosting renewable energy for sustainable development [6].

S. Sadhish kumar and T. Balusamy 2014, investigated A CFD analysis **of** different absorber tube designs in solar water heaters using COMSOL. They compared materials and geometries, finding that internal helical fins enhance heat transfer, with pitch size **i**mpacting performance [7].

Shahin Shoeibi et al. 2021, Studied a modified solar desalination system using evacuated tube collectors and an external condenser. The setup improved water output by 2.13 times over conventional systems and also contributed **to** carbon mitigation, showing both performance and environmental benefits. [8].

Winter C.J. et al. 2011, Their book explores the science, potential, and economics of solar power. It covers technical principles**,** solar-driven chemistry, and large-scale demonstration plants, promoting solar as a clean, viable future energy source backed by real-world experiments and expert insights [10].

3. Methodology and Problem Identification

Coal-fired thermal power plants are widely used, but coal is depleting and becoming more expensive. To address this, integrating solar energy into existing thermal plants is gaining attention for coal savings and environmental benefits. Though fully solar-based plants are costly, partial implementation (like preheating boiler feed water**)** is affordable and effective, especially in small or medium power plants. Using solar water heaters to raise the temperature of boiler makeup water reduces coal use by lowering the required sensible heat. Studies, including modeling of Rankine cycle plants with solar Fresnel collectors**,** show significant fuel savings. A case study of a 31 MW coal plant using evacuated tube solar collectors to preheat 25,000 liters of feedwater daily demonstrates the practical benefit of such hybrid systems

3.1 CASE STUDY INCLUDE

1. The capacity of SWH required maintaining the temperature of 80-900C in makeup water tank (feed water, 25000 litter)
2. Type of solar water heater (Solar collector) required to maintain the temperature of 800C in Solar water tank.
3. Cost required to implement setup (ETC) for preheat feed water of 25000 litters
4. Area required to installing solar water heater.
5. Saving of coal by Implement solar water heater (Solar collector of Evacuated tube type) for preheat boiler feed water.
6. Saving of money in terms of coal per day.

3.2 AVAILABLE PARAMETERS FROM 31MW COAL BASED POWER PLANT

Boiler Specifications

Table 3.1 General Features of Boiler used in HEG (Mandideep Bhopal)

Installed Capacity	31 MW
Fuel (Coal)	Bituminous F Grade
Boiler Type	Circulating Fluidized bed Combustion
Pressure	85Kg/mt2
Temperature	485degreeC
Steam Generation rate	144TPH
Fuel Burning Rate	24.5TPH
DM water tank Capacity	3 tanks each of 100KL
Make up water required for every 24 hours	25KL
Normal Temperature of DM water	35degreeC

3.3 SELECTION OF SOLAR COLLECTOR FOR HEAT 25000 LITTERS FEED WATER UP TO TEMPERATURE OF 80-900C

There are many types of Solar Collectors are used for heat water according to requirement

1. Parabolic Trough Solar Collector
2. Solar Power Tower Collector
3. Parabolic Dish Collector

4. Flat Plate Collector
5. Evacuated tube Solar Collector

Solar thermal power plants use high-temperature systems like Parabolic Troughs, Power Towers, and Parabolic Dishes. For smaller-scale water heating (up to 50,000 liters), Flat Plate Collectors (FPCs) and Evacuated Tube Collectors (ETCs) are commonly used, with ETCs being ideal for heating 25,000 liters to ~90°C. Flat Plate Collectors are best suited for warm, sunny climates but lose efficiency in cold or cloudy conditions due to weathering and insulation issues. Evacuated Tube Collectors perform better in such climates due to their vacuum insulation that mimics a thermos flask, minimizing heat loss. Each tube has: Two borosilicate glass layers, with the outer layer allowing radiation through and the inner layer having a selective coating for absorption. A vacuum between layers to trap heat efficiently. An absorber plate (usually copper or aluminum, painted black) to maximize heat absorption.

As a result, ETCs outperform FPCs in colder and less sunny environments.

3.4 MECHANISM OF EVACUATED TUBE SOLAR WATER HEATER

Solar Water Heating has been used for hundreds if not thousands of years to heat water. With advances in technology solar water heating systems have become more and more efficient, with Evacuated Tube Solar Water Heating offering efficiencies of well over 90%. [21] That means that more than 90% of the sun's energy landing on a surface is converted into heat which can be used to heat water. This is also one of the cheapest renewable; with costs starting from pennies per Watt required comparing to pounds per Watt for PV Solar and Wind Turbine power generation. Vacuum or Evacuated Tubes are made from glass - typically ultra-strong and heat resistant Pyrex with a double wall construction. [24]

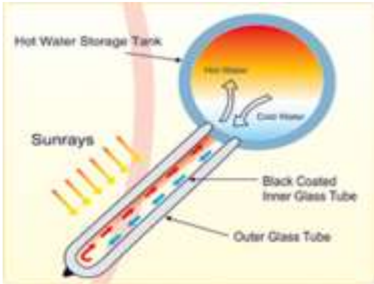

Figure 3.1 Evacuated tube solar water heater

Figure 3.2 Working principal of evacuated tube collector

Evacuated Tube Collectors (ETCs) use glass tubes with absorbent and reflective coatings to maximize solar heat absorption. A vacuum inside each tube minimizes heat loss, and a copper heat pipe filled with antifreeze captures solar energy. As the liquid heats and vaporizes, it transfers heat to a header pipe, warming water in a storage tank. This closed-loop system requires minimal maintenance and has a lifespan of 20+ years.

ETCs perform efficiently even in cold, cloudy winters, heating water to 50–90°C due to vacuum insulation that prevents ambient heat loss. They are more effective than flat plate collectors, especially in harsh climates.

ETCs deliver consistent hot water (typically 60–80°C) year-round. Their non-mixing tank design ensures uniform temperature and they are resistant to scale formation, as heating occurs inside smooth glass tubes. Though some dirt or salt deposits may settle at the bottom, they are easily cleaned during servicing

3.5 ORKING PRINCIPLE OF EVACUATED TUBE SOLAR COLLECTOR SYSTEM

ETC System works on a simple principle “Black body heat absorption Principle”. The Principle Says, black colour absorbs maximum heat, more than any other colour. Solar water heating system using vacuum tubes of borosilicate glass with special coating of copper to absorb the collector energy are called as evacuated tube collector system (ETC). Vacuum tube as shown in fig shows the thermo siphon system which absorbs solar energy; the vacuum tube is an assembly of two concentric, borosilicate glass tubes.

Air between the gaps of two glass tubes is evacuated. It results in high level of vacuum, which acts as the best insulation to minimize the heat loss from inner tube. The black coating on the inner tube absorbs the solar energy and transfers it to the water. The water on upper side of vacuum tube becomes hot and thus lighter, so it starts moving upward from the tank and is stored at the bottom. The phenomenon is called as natural thermo siphon circulation, which occurs in every tube. [26]

3.6 ADVANTAGES OF EVACUATED TUBE SOLAR COLLECTOR WATER HEATING

Sunrays remain perpendicular to cylindrical absorber surface of vacuum tubes. It can absorb more energy resulting in more efficiency of the tubes. Even in smaller capacity range, many models are designed just by varying numbers of evacuated tubes. Hence wide ranges are available to select the exact system to match the individual requirement due to this feature, the system has become more economical and cost effective the flat plate collector uses costly metals like copper and aluminium. [23] On the other hand the Evacuated tube collector requires only glass tubes. This is made possible due to technological advancement, which has resulted in substantial cost saving.

1. Reduction in peak load.
2. Reduction in rate of global warming.
3. Negligible scaling of tubes.
4. Higher efficiency on high temperature.
5. Less space & more economical.
6. Long life more than 15 years.
7. Maintenance Free.
8. Heat loss in the tubes during the daytime is negligible (evacuated tubes)
9. Convection and Convicting losses are low.
10. Satisfactory performance even in extreme cold condition (-18 deg. C)
11. Temperature range from 60deg. to 120 deg.
12. The collector glass tube absorbers being cylindrical the incident sun's rays on the
13. Tubes are at 90 degrees throughout the day. Hence peak heat absorption always.

3.7 EFFICIENCY GRAPH OF DIFFERENT TYPES OF SOLAR COLLECTORS

Efficiency graph showing performance of different types of Solar Collectors indicates evacuated tube collector has highest efficiency at higher temperature. [27]

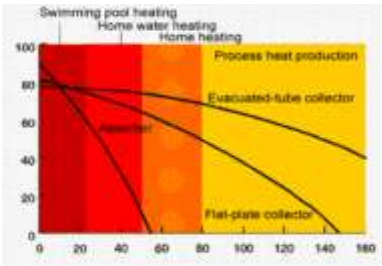

Figure 3.3 Efficiency graph showing performance

Figure 3.4 Solar Arrays of capacity 500 Litters each

3.8 REASONS FOR SELECTING EVACUATED TUBE SOLAR COLLECTOR

1. Due to high heat transfer rate of Evacuated tube solar heater, it will be efficient for makeup water heating of boiler.
2. Evacuated tube collector has more surface area than flat plate collector, for same capacity.
3. Evacuated tube collector is suitable for every weather condition.
4. In a cold season of winter evacuated tube maintain a minimum temperature of 60^0C
5. Evacuated tube collector is cheaper than flat plate for same capacity.
6. Evacuated tube collector needs zero maintenance for any weather condition
7. For mass water heating evacuated tube collector are successful.

3.9 MAINTENANCE AND SERVICING OF EVACUATED TUBE SOLAR COLLECTOR

Generally, the water supplied through local municipal authorities is always of good quality. This is well treated, after demineralize the water in DM plant, the feed water become soft filtered and having hardness below 50 ppm. If such water is used through Evacuated tube, the maintenance and servicing required will be almost negligible. When the water hardness is higher or when the suspended dirt and impurities are present in the water, there is a possibility of stains dirt accumulation inside the vacuum tube. This can be easily removed by removing the evacuated tube and cleaning them properly. These services can be made available from trained solar plumbers through dealers. However, for achieving consistent performance and better life of ETC.

it is recommended to do servicing of whole system once in year, which includes cleaning of vacuum tubes and hot water tank. The rubber parts like seal, grommets etc. may require replacement while serving. This will be made available in the market. [28]

3.10 COST REQUIRED FOR IMPLEMENT SETUP

In thermal power plant of 31MW, in every 24hr 25,000 liters makeup water is required. Temperature of makeup water is normally at 350C at atmospheric condition for maintaining a temperature of 70-800C in 25000 liters makeup water. [25] Solar water heater (ETC) of capacity 25000 liters will be required. For capacity of 25000 liters solar water heater (ETC), money required is 20 lakh rupees.

3.11 AREA REQUIRED TO IMPLEMENTING THE SETUP

Area required to implement solar collector of evacuated tube type for 25000 liters is 40002ft. Total 50 Solar Arrays (Evacuated tube type) will require of capacity 500litres each Solar array Dimension of Each array (Solar Collector) will be 12ft by 13ft. Tank of capacity 30000 liters will require to store 25000 liters hot water.

3.12 SIZE OF SOLAR ARRAY (ETC) FOR 500 LITERS OF WATER

Dimension of Single array of capacity 500 liters that require solar panel of size 12 by13ft that contains total 60tubes,30tubes in left and 30tubes in right Every 50 solar array will install in column & row wise that will capture area of 40002ft. ETC solar panel of 500-liter capacity of each has shown below

SYSTEM SPECIFICATION

Table 3.2 Evacuated Tube type solar water heater of Capacity 500 Liters

System Capacity	500 liters
No. of Tubes	60
Tube Specifications	Length-1800mm,58 mm OD
Vacuum Tube Material	Borosilicate Glass
Absorber coating	Coating of Aluminum Nitride by worlds latest innovative technology “Magnetron Sputtering Technique”
Absorptivity	>92%
Thermal Expansion	3.3×10^{-6}degc
Stagnation Temperature	>200^0c
Weight of single tube	2.2Kg
Tube Resting Caps	UV Stabilized ABS Plastic
Water circulation	Natural Thermo siphon

TANK SPECIFICATION

Table 3.3 Solar heated water storage tank

Tank Capacity	25000
Tank Material	SS-304L
Tank Material type	Food Grade
Insulation Material	PUF
Insulation Thickness	50mm
Type of Tank	Horizontal
Tank cladding material	Pure polyester power coated cover
Support Structure	GI- Powder coating

SOLAR WATER STORAGE TANK OF CAPACITY 30,000 LITERS

These tanks contain the Quality of high-pressure insulation, Special nonstick lining to prevent scale deposition & corrosion also heavy-duty dished end steel tank enhances tank life. Increases strength, pressure stability and avoids stress corrosion.

Figure 3.5 Solar Water Storage Tank

Evacuated Tube Collector (ETC) technology was first developed and tested by research institutes in Germany and Australia, and later commercialized by Chinese companies. Over the past 15 years, millions of ETC systems have been successfully installed in China for various applications like hospitals and swimming pools. The technology is now widely accepted globally, including in countries like the USA, Japan, Germany, Australia, and Spain.

Recognizing its proven reliability, the Government of India (MNES) has approved and is promoting its use across the country. The tubes, made from thick borosilicate glass, are highly durable and can withstand hailstones up to 1 inch. However, care must be taken to avoid thermal shock by filling the system with cold water before 9 a.m. to prevent cracking. The expected lifespan of ETC systems is around 10–17 years, depending on water quality and maintenance, making it a long-term, reliable solution for solar heating.

TIME REQUIRED FOR RISING TEMPERATURE FROM 35 TO 800C

Six-hour direct sunlight is required to rise a temperature in any season (Data collected from Sudarshan Saur limited)

Table 3.4 Data collected from Sudarshan Saur limited

Season	**Atmospheric Temperature**	**Temperature rise**	**ΔT**
Summer	35^0	80^0	45^0
Winter	20^0	65^0	40^0
Rainy	30^0	65^0	35^0

PERFORMANCE PARAMETERS ON WHICH EVACUATED TUBE SOLAR WATER HEATER WORK (DATA COLLECTED FROM SUDARSHAN SOUR LIMITED)

Direct sunlight of six hour is required to rise temperature. Rise of temperature is not depending on season, it only depends on availability of sunlight for six-hour Solar water heater of evacuated tube type is most suitable for Indian climate. In summer season rise in temperature is rapid. [31]

EXISTING LAYOUT OF 31 MW COAL BASED POWER PLANT IN HEG MANDIDEEP

Layout of thermal power plant are shown below these layouts contain the complete working of power generation by using coal as a prime fuel These Layout Contains

1. DM Water Plant
2. Coal handling
3. Ash handling
4. Pulverizing of coal
5. Fly Ash removal

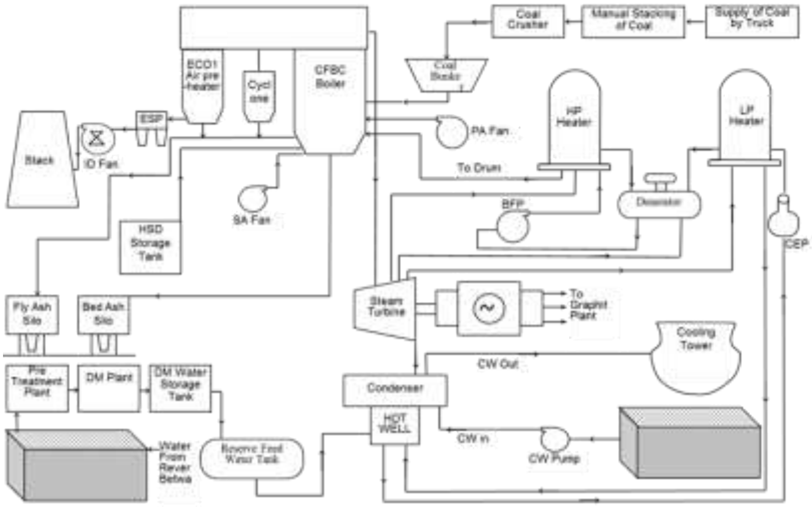

Figure 3.6 Layout of power plant

PROPOSED LAYOUT OF 31 MW COAL BASED POWER PLANT IN HEG MANDIDEEP

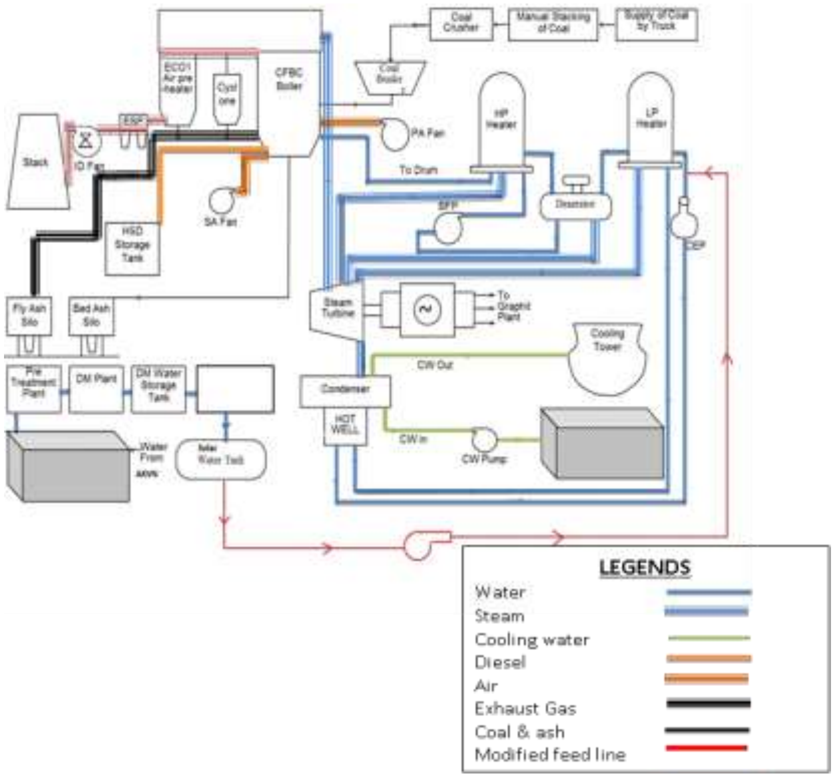

Figure 3.7 Proposed layout

In Proposed setup Solar heated feed water is directly send to boiler by feed pump Solar Panels will install near makeup water plant So water comes from DM Plant (Demineralized) will pass through Solar water heater of evacuated tube type than after rising temperature it will store in tank of capacity 30000liters (adiabatic chamber) It will maintain the temperature of hot water for 10-12 hours. Solar water heater cab be used as an accessory for preheat feed water in a thermal power plant.

WATER TREATMENT PLANT FOR CAPACITY 31 MW THERMAL POWER PLANT

In a Water treatment plant of HEG, Water comes from AVKN, (Audyogik Vikas Kendra Nigam) Mandideep Bhopal. During water treatment, removes all the impurities contain in water and also demineralized the water by using chemical solution and acids and make water perfect for boiler feeding. Water treatment plants contain three tanks each of capacity 100KL.

Figure 3.8 Water treatment plant of 31MW Thermal power Plant

Since there is continuous withdrawal of steam and continuous return of condensate to the boiler, losses due to blow down and leakages have to be made up to maintain a desired water level in the boiler steam drum. For this, continuous make-up water is added to the boiler water system. Impurities in the raw water input to the plant generally consist of calcium and magnesium salts which impart hardness to the water.

Hardness in the make-up water to the boiler will form deposits on the tube water surfaces which will lead to overheating and failure of the tubes. Thus, the salts have to be removed from the water, and that is done by water demineralizing treatment plant (DM). A DM plant generally consists of cat ion, anion, and mixed bed exchangers. Any ions in the final water from this process consist essentially of hydrogen ions and hydroxide ions, which recombine to form pure water. Very pure DM water becomes highly corrosive once it absorbs oxygen from the atmosphere because of its very high affinity for oxygen.

Figure 3.9 DM Water Storage tank-1 of capacity 100KL

Figure 3.10 DM Water Storage tank-2 of capacity 100KL

Figure 3.11 DM Water Storage tank-3 of capacity 100KL

The capacity of the DM plant is dictated by the type and quantity of salts in the raw water input. However, some storage is essential as the DM plant may be down for maintenance. For this purpose, a storage tank is installed from which DM water is continuously withdrawn for boiler make-up. The storage tank for DM water is made from materials not affected by corrosive water, such as PVC. The piping and valves are generally of stainless steel. Sometimes, a steam blanketing arrangement or stainless-steel doughnut float is provided on top of the water in the tank to avoid contact with air. DM water make-up is generally added at the steam space of the surface condenser (i.e., the vacuum side). This arrangement not only sprays the water but also DM water gets deaerated, with the dissolved gases being removed by a de-aerator through an ejector attached to the condenser.

4. Results & Discussion

Calculation of coal saving is done on the basis of temperature rise of makeup water (25000 litter) in every 24 hours by solar energy. Temperature rise of makeup water by solar radiation is free by implementing solar water heater. Normally makeup water is sent to boiler assembly at temperature of 350C, but by implementing solar water heater we can rise the temperature of makeup water up-to 900C without any running expense. By energy unit conversion we can calculate exact amount of coal save per day. By using the formula of temperature rise, Q = mcpΔt we can calculate the quantity of heat required to rise the temperature. We know that heat is a form of energy and also coal contains energy in the form of calorific value.

Table 4.1 Performance parameters

Thermal power plant of capacity	31MW
Amount of makeup water feed in every 24 hours	25000 liter at 350C
Required temperature of makeup water	900C
Calorific value of coal used	2500kilo-calorie per kg
Rise of temperature at constant pressure	1bar

Specific heat at constant pressure (Cp)	4184 J/kg/ºC
Price of coal in India	4000 7000 Rs per ton

CALCULATION OF COAL SAVING

Heat required Q to rise temperature of makeup water from 35 to 900C can be calculated by the formula given below Table: 4.2

Table 4.2 Heat required Q to rise temperature of makeup water

S. No.	**Performance Parameters**	**Symbol**	**Formula**	**Unit**
1.	Heat required	Q	$Q= mcp\Delta T$	joule

Where

Q = Heat required

M = mass of water

Cp = Specific Heat at Constant Pressure = 4184 J/kg/ºC

Table 4.3 Coal prices in India according to grade and calorific value

Unit/Grade of Coal	**Calorific value (Kilocalorie/Kg)**	**Rs/Tonne**
A	4000-3000	7100
B	2500-3000	4500
C	Below 2500	Below 4000

Calculation of coal saving in measured by equating the calorific value of coal and heat required to rise temperature of makeup water (energy balance).

Temperature rise of water is measure by using formula:

$$\mathbf{Q = mcp\Delta T} \qquad \text{Eqn. 4.1}$$

Where

Q = heat generated

Cp = Specific heat at constant pressure = 4184 J/kg/ºC

ΔT = Temperature rise

m = Mass of water

C = 2500 Kilocalorie/kg

FOR 31MW POWER PLANT

Calorific value of coal used in thermal power plant = 2500 kilocalorie/kg

Makeup water required per 24 hours = 25,000litres

Temperature of makeup water at atmospheric condition = 350C

Case: 1

Q = Heat required to convert 350C feed water to 800C

$Q = mcp\Delta T$

= (mass of water) (Specific heat at constant pressure) (rise in temperature)

= (25000kg) (4184 J/kg/ºC) (45 ºC) = 4707MJ

Calorific value of coal used 2500kcal/kg

4707000000joule =1125000 kilo calories

4707MJ heat is generated by burning of 450 kg of coal

450 kg of coal can save per day.

Case: 2

Q = Heat required to convert 350C feed water to 700C

Q = mcpΔT

= (mass of water) (Specific heat at constant pressure) (rise in temperature)

= (25000kg) (4184 J/kg/ºC) (35 ºC) = 3661MJ

Calorific value of coal used 2500kcal/kg

3661000000joule =875000 kilo calories

3661MJ heat is generated by burning of 350 kg of coal

350 kg of coal can save per day.

Case: 3

Q = Heat required to convert 350C feed water to 600C

Q = mcpΔT

= (mass of water) (Specific heat at constant pressure) (rise in temperature)

= (25000kg) (4184 J/kg/ºC) (25 ºC) = 2615MJ

Calorific value of coal used 2500kcal/kg

2615000000joule = 625000kilocalories

2615MJ heat is generated by burning of 250 kg of coal

250 kg of coal can save per day.

Case: 4

Q = Heat required to convert 350C feed water to 500C

Q = mcpΔT

= (mass of water) (Specific heat at constant pressure) (rise in temperature)

=25000kg) (4184 J/kg/ºC) (15 ºC) = 1569MJ

Calorific value of coal used 2500kcal/kg

1569000000joule = 375000 kilocalories

1569 MJ heat is generated by burning of 150 kg of coal

150 kg of coal can save per day.

Table 4.4 Saving of Money in Terms of Coal Consumption Reduction Per Day

S. No	Calorific value of coal	Prices of coal	Coal saving in diff cases per day	Saving of money per day
1.	2500kilocalorie/kg	4.5Rs per kg	450 kg in case 1	Rs 2025
2.	-	-	350 kg in case 2	Rs 1575
3.	-	-	250 kg in case 3	Rs 1125
4.	-	-	150 kg in case 4	Rs 675

As we can see in above table of money saving us can save coal 450 kg per day of price 2025 Rupees by implementing evacuated tube solar collector setup for preheat make up water of capacity 25000 liter per day.

All the above calculation of coal saving is done by using the coal of calorific value 2500kilocalorie/ kg if the thermal power plant use coal of higher calorific value then we can save more money per year. Also, solar water heater is ecofriendly to environment it left zero emissions to the environment like Co2 So2, No2. (MNES) Ministry of Non-Conventional Energy Source also recommends the solar water heater for water heating so that the pollution spread by fossil fuel will reduce.

PAYBACK TIME OF PROPOSED SETUP

The one-time installation cost of solar water heater setup is 20lakhs Rupees that will be for forever there is no running cost required to maintain these setup as we can see in results we can save coal 164250kg per year of price 7,39,125 Rupees.so the payback time of proposed setup is only three years. Also, this setup requires zero running & maintenance cost for at least 25 years.

5. Conclusion

Coal is the main fuel in thermal power plants, but it's a limited resource expected to last only 40–50 more years. With rising electricity demand, coal conservation is critical. Solar thermal power offers a viable alternative, already operating successfully worldwide using technologies like parabolic troughs, dishes, and power towers. Many studies support integrating solar energy into existing coal plants to reduce coal dependency, cut emissions, and bring economic and social benefits like reducing fossil fuel imports and creating local jobs. In this work, evacuated tube solar collectors are used to heat 25,000 liters of boiler makeup water from 35°C to 90°C daily in a 31 MW thermal plant. These collectors efficiently transfer heat using solar radiation and are easy to maintain, offering a practical solution for hybrid energy systems.

The following conclusion has been found by preheat makeup water 25000 liter from 35 to 90^{0}C of 31MW thermal power plant

1. By rising the temperature of makeup water of quantity 25000 liter per 24 hours from 35 to 900C, saving of coal will be 450 kg per day of price 2025 Rupees.
2. For the whole year we can save coal 1, 64,250 kg of price 7, 39,125 Rupees.
3. There is no running cost is required for evacuated tube solar collector also it has zero maintenance cost.
4. Also, it reduces the problem of smoke emissions.

6. Environmental Impact

In place of fossil fuel if we use solar energy for water heating & steam generation for residential and commercial purpose we can control the pollutants emitted by combustion of fossil fuel. Normally the pollutants emitted by combustion of coal are nitrogen oxide, carbon monoxide, sulphure oxides.

1. Per year this system will eliminate the production of

- 8496 lbs of Co_2
- 20.4 Nox
- 34.8 So_4

2. Over its 25-year lifetime this system will eliminate the production of

- 169,920 lbs of Co_2
- 408.0 Nox
- 696.0 So_4

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