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CONCEPT OF CBD ENERGY RECOVERY SYSTEM IN THERMAL POWER PLANT USING THERMAL ENERGY STORAGE AND STORED ENERGY UTILIZED FOR AC PLANT

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***ABSTRACT:*** In modern steam generators high rate of steam production is affected and it is crucial to maintain the steam purity for long life of thermal power plants. To maintain steam purity in thermal power plants internal chemical treatment is carried out which usually generates soft sludge increasing total dissolved solids (TDS) in boiler feed water. To remove soft sludge’s and impurities from boiler, purposefully 0.5 to 1.0 % of evaporation capacity of boiler water is drained from boiler drum through continuous blow down (CBD) , and it’s equivalent or more amount fresh de mineralized water is added into modified closed Rankin cycle. Flow rate of CBD water depends on TDS in water and evaporation rate of water in boiler. CBD water is drained from boiler drum at high pressure and at saturation temperature hence high amount of heat energy and pressure energy is wasted in thermal power plants.

In this paper, a novel concept developed for CBD water waste heat recovery and extracting pressure energy from CBD water is deliberated by means of thermal energy storage (TES) unit using hydroquinone as phase change material and stored heat energy is utilized for vapour absorption refrigeration system (VARS) and CBD water pressure energy is utilized for driving hydraulic pump for VARS is analyzed. In this study gross heat rate of thermal power plant is reduced and operating cost can be minimized. All the analysis is carried out in Thermal Power Plant-II, NLC India limited.

***Key words:*** continuous blow down, waste heat recovery, thermal power plant, thermal energy storage, vapour absorption refrigeration system, phase change material.

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1. **INTRODUCTION**

Thermal power plants operate on closed modified Rankin cycle, in which water and steam phase conversion process take place by heat and work transaction. It is quite obvious that internal impurities are generated in working heat transfer fluid [3]. So it is very important to maintain the chemical values of working fluid for long life of the thermal power plant [2].

The main objective of the internal treatment of water is to maintain the level of technical purity of water at prescribed levels at all times thereby ensuring economy and efficiency in operation and reliability of equipment by preventing deterioration and damage to internals of steam generators due to water chemical regime imbalances. If water treatment is not done satisfactorily to bring down the impurities level in water to the desired value, it may lead to many problems in operation of a boiler such as scale formation, corrosion, sludge formation, steam contamination due to carry over, caustic embrittlement and silica entrainment.

To prevent the formation of hard scale and form, a softening chemical is added to the boiler water to convert into soft sludge type precipitate. This is accomplished by the addition of tri sodium phosphate which precipitates calcium and magnesium salts and maintains them in soft non-adherent sludge condition, which can be removed through Continuous Blow Down [2]. In CBD water lot of heat energy and water is wasted.

At present in most of thermal power plant CBD heat recovering CBD Flash tank concept in which the quantity of blow down should be carefully regulated so as to maintain an optimum allowable concentration [2]. The heat energy in continuous blow down water is to be recovered to the extent possible. The high-pressure boiler CBD water enters a flash tank through a flow control valve. Since the flash tank operates below boiler pressure, a portion of the removed water immediately flashes into steam. This flashed steam is used for heating feed water in de-aerator by direct mixing and condensed water is sent to atmospheric channel through intermittent blow down (IBD) tank. Thus about 43% of water blow down flashes into steam and gives its heat to the feed water in the de-aerator.

In practice most of the Thermal Power Plants CBD water is directly admitted into IBD tank instead of CBD Flash tank and sent to atmospheric channels for smooth operation of plant. Due to improper conversion of water into steam while flashing CBD water in CBD flash tank which is unable to maintain the required water level of flash tank, and the flashed steam from CBD flash tank directly mixes with feed water forming bubbles and the bursting of bubbles lead to false reading of de-aerator level and pressure intend it is a frequently cause for boiler feed pump tripping.

The practical difficulties for CBD water heat recovery can be eliminated by using thermal energy storage concept and heat energy can recover up to 90%. Thermal energy storage plays an important role in storing the energy and also improves the performance and consistency of energy systems. Mismatch between the energy supply and energy demand can be eliminated by TES. Phase change materials can store large amount of heat by changing its phase from solid to liquid or liquid to vapour. Solid to liquid phase change is preferable due to less volume change. PCM is selected according to application.

In Thermal Power Plants, air conditioning is very important to maintain temperatures of electronic devices. Now a day’s all the higher capacity power plants are installing vapor absorption refrigeration because of readily available heat energy for operating Vapour absorption machine (VAM). In most of the power plants heating source is auxiliary steam for VAM machine which is generated by burning of fossil fuel.

In this paper CBD heat recovery by thermal energy storage using Phase Change Material is analyzed and stored heat energy is utilized for vapour absorption machine is well thought-out. Since CBD heat energy is not consistent source energy because according to salt concentration CBD flow is regulated in power plant, the main disadvantage of this energy resource is the mismatch between the energy supply and the energy demand, it can be eliminated by providing thermal energy storage. In external thermal storage systems, CBD water could be circulated to the hot thermal storage tank to store energy for later or instant use. Many researchers have dealt with both experimental and numerical analysis of different techniques of TES systems in the form of latent heat storage using PCM as the storage media for different applications [6].

1. **CBD HEAT RECOVERY SYSTEM IN THERMAL POWER PLANTS USING THERMAL ENERGY STORAGE**

This analysis has been made in Thermal Power station –II of, NLC India Limited, Neyveli. The power station consists of three units of 210 MW capacity built in its Ist stage. The boilers of these units have been designed by M/s. E.V.T. Germany. They are rated for generating a maximum of 690 T/h of super heated steam at 158 ata pressure and 540 oC temperature. Lignite is the main fuel. It can also be classified as single drum, once through, dry bottom, natural circulation, membrane type water wall, balanced drought system and pulverized fuel steam generator. The CBD tubes inside the drum are of size ø 57x5 mm. Two such horizontal tubes are provided at 150 mm below the horizontal centerline. These two tubes one on either side of the drum have one of their ends get located at 125 mm from the drum vertical center line and these ends are dummied. Each CBD tube has at its top 25 numbers ø5 mm holes at 200 mm intervals. These two CBD tubes are supported by the feed water pipes protruding inside the drum and are held in position by inverted ‘U’ clamps. Existing CBD heat recovery scheme in TPS-II, NLC India Limited is shown in Figure 1[2].

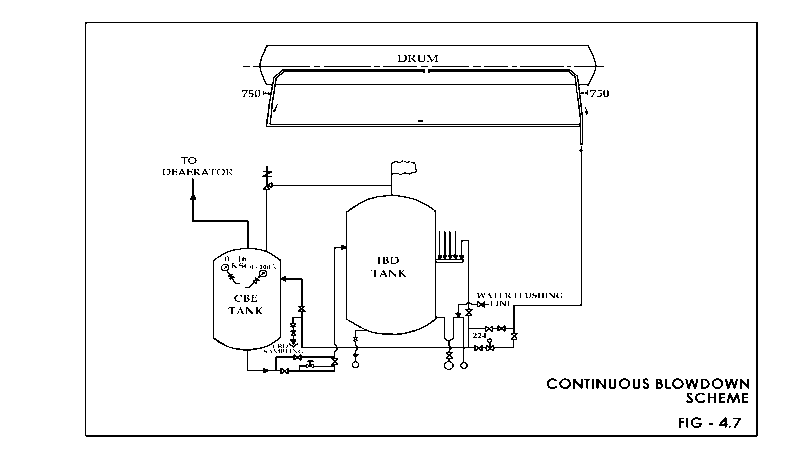


Figure1. Scheme of CBD heat recovery system in TPS-II, NLC India Limited

The rate of blow down from the boiler is to be regulated according to salt and silica concentration of water in the boiler. CBD rate should be between 0.3 to 0.5 % of evaporation rate and should not exceed 1% [2].

**2.1 Rate of Blow Down in Thermal Power Plants**

The rate of blow down required for any boiler is dictated by the incoming water quality as well as the allowable limits of salt concentrations in boiler water [2]. The limit set may be related to dissolved solids, suspended solids, total alkalinity and silica. These limits become more stringent for operating boilers at higher pressures. Hence the rate of blow down should be determined taking into account the above factors.Once the allowable limit in concentration of solids in a boiler is known, the blow down rates can be computed easily. Under steady working conditions of the boiler, the rate of blow down required from a boiler is related to the evaporation rate and the salt concentrations [2]. For salt equilibrium condition,

--------------------------------- (1)



Where = quantity of feed water flow, = salt content in feed water



= quantity of evaporation rate, =allowable salt concentration in steam



= quantity of blow down,  =salt content in blow down water



--------------------------------------------------------------------- (2)



Since quantity of feed water is equal to quantity of steam evaporated and quantity blow down water removed in closed cycle.

------------------------------------------------------------------------- (3)



Substituting Eq. 3 into Eq. 2



Allowable salt concentration in steam is very small, which is negligible. Hence the above equation can be written as



Thus the salt content of boiler feed water at full load 210 MW is= 2.6 PPM experimented value in TPS-II, NLC India Limited and the allowable salt content of boiler blow down water is 50 PPM at pressure 150 Ata[2]. of boiler and evaporation capacity of steam generator is 191.7 kg/s in TPS-II, NLC India Ltd.[2], the rate of blow down quantity from a boiler is calculated as **1.003** kg/s of given evaporative capacity of boiler determined to maintain chemical stability of water and steam.



Variations of total dissolved solids in feed water and steam flow rate are measured at different power generating condition of TPS-II, NLC India Ltd. for calculating rate CBD flow is shown in Figure 2. Steam flow rate linearly increasing for generation of Power and total dissolved solids in feed water up to 180 MW remains constant due to lesser steam pressure and flow rate variation because of that impurities generating in system is less at lower load. Stem pressure and flow rate increases leads in raising TDS in feed water is noticed shown in Figs.2and 3.

Figure 2. steam flow variation with load Figure 3. Total dissolved solid variation with load

In other way, in a closed cycle the rate of fresh make up water is equal to the sum of quantities of blow down and auxiliary steam used in plant plus steam or water leak in cycle.



Here QFEW is= quantity of fresh make up water in cycle,

Qast is = quantity of auxiliary steam used in the power plant

Qleak is= steam or water leak in closed cycle

In general practically in full load condition rate the fresh make up water varies from 1.7 kg/s to 2.8 kg/s without steam or water leak in cycle and the auxiliary steam used in power plant varies from 0.83 kg/s to 1.39 kg/s. Hence it is guaranteed that the rate of blow down from boiler is considered as minimum of 0.83 kg/s and maximum of 1.92 kg/s in TPS-II of NLC India Ltd.

Experimental studies carried out for water and steam purity in closed cycle and according to salt content in water with respective to various loads of power generation to rate of CBD water flow is plotted in power plant is shown in Figure.4

Fig.4 CBD flow variation with respect to load of thermal power plant

In this plot rate of CBD flow is raising with continuous raising of power generation, it inferences that power raise requires more steam flow and high pressure, such that it causes increase of internal impurities in heat transfer fluid that is DM water, as a result impurities are maintained by draining high rate of CBD water flow. At start up of power plant chemical analysis are carried out before admitting steam into the turbine, because turbine blades are more sensitive to purity of steam, such that initially rate CBD flow rate is maintained at high valves to remove the impurities ,when steam purity is within limit then only steam is admitted in to the turbine.

* 1. **Heat Energy available in CBD water**

The boiler has a single drum mounted on top with its centerline at 79.9 meter level. The drum is of ø 1800 mm and 15000 mm length. The shell thickness is 135 mm at top half and 150mm at its bottom half. The drum designed pressure is 180 atmospheres and operating pressure is 167 atmospheres. In drum steam and water separation taking place with help of cyclone separators, such that it will maintain saturation temperature according drum pressure. Hence water in CBD has pressure of 167 atmosphere and saturation temperature of 352oC at thermal energy storage tank inlet and CBD water passes through coils in Thermal Storage Tank and loses its heat energy to phase change material and outlet parameters are 170oC temperatures and pressure reduce due to pipe frication losses and bend losses.

Heat energy lost by CBD water to TES tank is



Where = heat energy lost by CBD water



= the mass flow rate of CBD water (minimum flow is =0.83 kg/s and maximum flow 1.92 kg/s)



= the specific heat of CBD water (= 4.187 kJ/kg K),



= the CBD water inlet temperature of TES tank = 350oC, and



= the water outlet temperature of TES tank 170oC



In this analysis = 350oC which drum outlet saturation temperature which is inlet temperature of TES tank. The designing TES tank outlet temperature to be =170oC because melting temperature of Phase change material and temperature required for VARS as to be selected in rage of 170-200oC. The CBD heat energy available to store in thermal storage tank with various load is 335kJ/s and maximum of 601kJ/s. Average heat energy available in CBD water is 428kJ/s.



In this studies while raising load contamination feed water also raises at higher pressure which leads to increase in CBD water flow intend it will raise available heat energy in CBD water. While starting the thermal power plants after major maintenance works it will generate lots of contamination in pressure parts which generate more impurities in feed water, such that high amount of CBD water is drained to raise the Purity of steam.

* 1. **Thermal Energy Storage Unit for CBD heat recovery**

**2.3.1 Material selection**

CBD water drained from bottom of boiler drum and water temperature varies in between 300-351 ºC for charging process of TES tank and vapour absorption machine required water inlet temperature of 170-180 ºC to generate 100 to 150 TR while discharging process. In addition temperature ranges mechanical, chemical, economic, and environmental properties have also been taken into account in the selection process. According to literature review [1], experimental studies have been conducted for different PCM with phase change temperature in the range for solar cooling applications. Among the PCMs selected hydroquinone and D-mannitol are selected as PCM suitable for cooling application.

In this analysis **Hydroquinone** **(C6H6O2 or C6H4 (OH) 2)** with melting point 172.4oC and phase change enthalpy is 258 kJ/Kg is the best suitable material for vapour absorption machine which are commercial operating with heating source inlet temperature is 172oC which nearby melting point of hydroquinone.

**2.3.2 Heat energy balance of TES tank**

Conceptual design of Thermal energy storage tank is studied, in which heat is given by continuous blow down water to phase change material (hydroquinone) trough ‘U’ shape coils, where entrance and exit is on the same side. In this process heat is transferred from CBD water to tube by convection mode and in tube by conduction mode and the tube material to phase change material by conduction mode till melting point temperature and then heat transfer by convection mode. In TES tank CBD water inlet is saturation temperature 351oC at boiler drum pressure 168 ata at full load condition of plant and exit temperature of TES tank is designed as a 172oC because of melting point temperature of phase change material is 172.5oC, such that in this design phase change from liquid to vapor is not allowed maximum possible to avoid volume change and vapour absorption refrigeration system required of inlet water temperature at 172oC. Total heat energy available in CBD water equals to heat energy stooge in PCM and heat energy transferred to vapour absorption refrigeration system and heat lost to atmosphere by convection and conduction and radiation.

That is



Average heat energy available in CBD water is 428 kW which is equal to average heat storage of 118 kW and vapour absorption refrigeration required of 300 kW and heat lost to atmosphere is 10 kW.

( Qcbd)

CBD water in and out

Qstorres

(QLosses) Heat lost to atmosphere

Water to VAM machine in and out (Qtransferred,VARS)

Figure2. Symbolic representation of heat energy analysis of TES tank

**2.3.2.1 Heat energy storage capacity of TES tank**

The energy stored by the hydroquinone is calculated depending on condition state of PCM. That is PCM is in solid, liquid or in the phase change transition state. Phase change material is surrounded by charging CBD water coils and discharging coils of VARS, which are in ‘U’ shape coils in thermal storage tank. Considering the properties of hydroquinone [1] and quantity of PCM required for one hour is calculated by average net heat required for vapour absorption refrigeration system in the absence of CBD water heat energy.



Where M is mass of PCM,

Cspecific heat of PCM (hydroquinone), ( =3 kJ/kg.K for solid, =2.6 kJ/kg.K for liquid )



is melting point of PCM,(172.5 oC)



is initial temperature of PCM, (15 oC)



is latent heat of PCM,(235.2 kJ/kg)



is final temperature of PCM( 175 oC)



Heat energy Q PCM required is 25.8 kJ/s to run the a vapour absorption machine for one hour in absence of CBD water heat energy, such that mass of hydroquinone required is 3952 kg in TES tank. Density of hydroquinone 1330 kg/ m3 and volume required for one hour storage 3.04 m3 for hydroquinone.

**2.3.2.2 Heat energy recovered from TES tank to VARS**

Heat energy recovered from thermal energy storage tank to vapour absorption refrigeration system trough ‘U’ shape coils. TES tank out let temperature VARS require continuous inlet temperature of 172oC and in let temperature to TES tank from VARS is 80oC to recovery heat energy from TES tank.

Continuously Heat transferred from TES tank to vapour absorption refrigeration system by water as Heat transfer fluid (HTF) can be calculated.



Where = mass flow rate of HTF water (1075 kg/h)



= specific heat of water (Cp= 4.187 kJ/kg.K)



= HTF water inlet Temperature to TES tank from VAS (= 80oC)



= HTF water outlet Temperature from TES tank to VAS (=170oC)



Above parameters have been taken for comparative studies, vapour absorption refrigeration system of NTPL, NLC India Ltd [3] 250 Tone Refrigeration is adopted and its heating source is taken from auxiliary dry saturated steam with pressure 8 kg/Sq.cm and steam temperature 175 oC with steam flow rate 0.3 Kg/s and steam condensed and exit parameter are pressure 1 Kg/cm2 and steam temperature 80 oC. Vapour absorption machine consuming 728 kW of heat energy to produce 250 TR. In VARS of NTPL water is used as refrigerant and Lithium Bromide solution used as absorbent [3].Average heat energy available by CBD water from TES tank is 428 kW can be utilized for vapour absorption machine which can produce 100 to 150 Tone Refrigeration.

2.3.2.3 Heat energy lost to atmosphere

Finally while charging and discharge and storing of heat energy process, thermal energy storage tank is maintained at melting temperature of hydroquinone 172oC, which is higher than atmospheric temperature 30oC, so that temperature gradient is developed between atmosphere and thermal energy storage tank. So heat lost to the atmosphere from TES tank is avoided by providing insulation. Heat lost by the thermal energy tank via convection and conduction mode is given and radiation mode is negligible heat transfer [1].



Considering allowable total heat loss is 10kJ/s, according to it insulating materials are provided.

1. **Concept of Vapour Absorption Refrigeration System in thermal power plants using TES tank**

In thermal power plant refrigeration and air conditioning is very important role to maintain the temperature’s of electronic devices for smooth operation of the plant, if the temperature is not maintained the electronic devices may malfunction causing the unit to trip. In previous decades most of the power plants have had vapour compression systems and consumed super quality power , but now a day’s all higher capacity power plant tend to use vapour absorption refrigeration system due to readily availability of heat energy. In general for vapour refrigeration system heating source is taken from auxiliary steam which is generated by burning of fossil fuel. In this paper a novel idea is proposed for vapour absorption refrigeration system consuming CBD water waste heat energy through thermal energy storage rather than consuming auxiliary steam so, that coal consumption can be reduced.

In TPS-II,NLC India limited having vapour compression refrigeration system of 140 TR with compressor work of 150 kW is established , in this paper analysis is made for elimination of compressor work in vapour compression system vapour refrigeration system is studied.

Thermal energy storage tank is capable to producing heat energy continuously 428 kJ/s by getting heat energy from CBD water, which is more than sufficient to heat energy is required for vapour absorption refrigeration system to produce 100 to 150 TR. The heat energy is transferred from TES tank to generator of VARS is by de-mineralized water as heat transfer fluid, it is circulated by the hydraulic pump, which is driven by the CBD pressurized sub cooled water which is exit of TES tank. In TES tank heat is recovered and water is sub cooled by the PCM and CBD water pressure will reduced by frictional loss and bend loss of the coils in TES tank. Sub cooled and de-pressurized CBD water is admitted in to hydraulic pump by controlling pressure, for driving DM water from TES tank to generator of VARS with 7.5 kg/cm2 and flow rate of 2469 kg/h with inlet temperature 170oC and out let temperature of 80oC to generator.

1. **CONCLUSIONS**

In this paper, a concept is developed for CBD energy recovery system of sub critical Thermal Power plant using Thermal Energy Storage by means of Hydroquinone as phase change material with melting point 172.4oC and phase change enthalpy of 258 kJ/kg. TES Unit gets heat energy from CBD water and PCM will maintain constant temperature by changing its phase in the form of latent heat storage, such that constant heat energy can be supplied to VARS. The available CBD heat energy is 601 kW with 0.83 kg/s CBD water rate flow, after the heat recovery of CBD water is sub cooled and it will be in the form of pure liquid state such that pressure energy CBD water is utilized for driving hydraulic pump, which is used to circulate heat transfer fluid from thermal energy storage tank to vapour absorption refrigeration system .TES unit avoids the mismatch between heat energy supply and demand. 258 kJ/s heat energy required for generating 140TR in VARS from TES unit and some of heat energy lost from TES unit to atmosphere by conduction and convection and radiation mode. Still excess heat energy is available for VARS for their refrigeration.

By this analysis we can eliminate compressor work from the vapour compression system, such that maintenance and running cost of compressor can be reduced by approximately USD 280000 per year and boiler efficiency can be improved by utilizing waste heat energy and fossil fuel can be reduced, such that emission can be controlled in thermal power plant and it can be shown in Perform Achieve and Trade (PAT) scheme as government rule in thermal power plants.

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