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Studies on recovery of blow down water and zero liquid discharge management at gas turbine power plant

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Abstract : In Gas Turbine Power Plant (GTPP), the required volume of water is around 6000 m^3/day for generation of 100MW power. About 30% of water is rejected during various processes. Reverse osmosis (RO) process is a technology to purify water by separating the dissolved solids from feed stream resulting in permeate and reject stream for a wide range in GTPP. It is seen from literature review that RO technology is used to remove dissolved solids, colour, organic contaminants, and nitrate from feed stream. This paper intends to provide an overall vision of RO process and evaporation pond (EP) technology using flue gas heating coils in Thirumakottai gas turbine power station (TGTPS), Tamilnadu as a suitable method for treating the blow down water for recovery and reuse.
Keywords : Gas Turbine power plant; Reverse osmosis; Evaporation pond; Flue gas.

1. Introduction

Natural gas is burnt in a combustion chamber with compressed air in a ratio of 1:11 and the mixture is used to drive the gas turbine which is connected with generator produces electric Power. The hot combustion turbine exhaust, which is at 600 ºC, is used in heat recovery steam generator (HRSG) to produce steam, which drives a steam turbine. This technology is called "combined cycle" and achieves a higher efficiency by using the same fuel source twice[1].

TGTPS is generating 100 MW of power at thirumakottai village, Nagapattinam District, Tamilnadu. Natural Gas supplied by M/s. GAIL (Gas Authority of India Ltd) is being used as primary fuel to generate 70 MW of power. Waste Heat at about 600ºC from gas turbine exhaust is utilized to HRSG to generate steam. The temperature and pressure of the steam from HRSG is about 540ºC and 125 Kg/cm^2 respectively, which is utilized to drive the steam turbine to generate additional 30MW. Closed cooling water system using ground water is used in this station in its steam turbine cooling system.

1.1 Blow down water

Raw Water Usage is defined as the water metered from a raw water source and used in the plant processes for all purposes, such as cooling tower makeup, boiler feed water make up, condenser makeup, effluent dilution etc. Almost, 80 to 90 % of the power plant raw water usage is through a combination of cooling tower evaporation, blow down and drift in the cooling tower. COC is a measure of water quality and its level is 3 to 4 for fresh water and 1 to 1.5 for seawater applications. The cycle of concentration (COC) and blow down of water can be calculated from the following equations.

COC = Dissolved solids in Circulating Water /Dissolved solids in Makeup water (1)

Blow down = Evaporation Loss/ (COC-1) (2)

Evaporation Loss = 0.00085 × 1.8 × Circulation Rate × ($T_1 – T_2$) (3)

Where,

T_1 - Temperature of hot water, T_2 - Temperature of cold water

As water evaporates, salts and solids present in the circulating water accumulate in the system making deposits in the equipment. To reduce deposits & prevent corrosion and to smooth out the cooling operation, some water is discharged (termed as cooling tower blow down) at regular intervals and fresh water (make up water) is added. This water has been treated with chlorine and other chemicals (biocides) to control corrosion, scaling and microbes.

In TGTPS, the daily usage of ground water is around 6000 m^3/day and cooling water blow down from the closed loop system is at a rate of 2000 m^3/day. This rejected water accounts for nearly one third of total quantity drawn.

TDS, Hardness and Chlorides level of this blow down water is very high. Hence blow down water affects the environment in the following two ways such as wasting of ground water (drawn from 350m of depth in accordance with Tamilnadu government rules) from an area that already starves for water for irrigation and the plant does not have any other source to meet out its water needs and (2) the blow down water that is let out with high TDS affects the environment. The salinity of water ultimately affects the surface and ground water in the area[2-6].

In the present work, to resolve the above-mentioned issues in TGTPS the treatment of the blow down water by RO and the disposal of RO rejects using EP process has been studied.

2. Methodology

2.1 Tests and Analysis – Raw water & blow down water

Raw water was tested during November 2012 and the analysis reveals that raw water contains Calcium, Magnesium, Chlorides, Carbonates in a considerable level. pH of raw water is slightly alkaline (Table 1). Blow down water analysis reveals that the TDS, Electrical conductivity, Chlorides level had exceeded the limits of disposal water ensuring that the blow down water is unfit for drinking as well as for agriculture.

Table 1. Analysis on Raw water, Blow down water and RO treated water

Parameters	**Raw water**		**Blow down water**		**RO treated water**	
	Max	Min	Max	Min	Max	Min
Conductivity µSi/cm	2860	2500	11200	6015	212	14
pH	8.3	7.8	8.6	8.1	6.1	5.8
TDS mg/L	1689	1430	6760	3609	135	9
Total Hardness	276	246	940	622	-	-
Ca mg/L	160	140	575	324	-	-
Mg mg/L	116	104	410	251	-	-
Phenolphthalein value mg/L	2	Nil	6	Nil	-	-
Methyl orange value mg/L	390	356	214	134	-	-
Chlorides mg/L	780	712	3009	1587	-	-

2.2 Blow down water treatment by using RO process

The concept of the study was to treat the blow down water for reuse and to ensure zero liquid discharge in the power plant. Methods of treatment includes usage of RO, Multiple effect evaporation (MEE) and Mechanical vapor compression (MVC). RO treatment being a simple and widely available method for treatment of wastewater, pilot study was conducted by treating blow down water in the RO system during November 2012 and the results are shown in Table 1.

2.3 RO process

The basic principle of RO system is that the wastewater passes over the membrane surface and the product is called permeate, whereas the rejected constituents form concentrate. Mass balance of the solute in the process, rejection and yield can be presented by the following equation.

Mass balance $Q_f C_f = Q_p C_p + Q_c C_c$ (4)

Rejection = $C_f - C_p / C_f$ (5)

Yield = Q_p / Q_f (6)

Where; Q_f – Wastewater flow rate; C_f – solute concentration in Waste water flow; Q_p – permeate flow rate; C_p – solute concentration in permeate; Q_c – solute concentration in concentrate; C_c – solute concentration in concentrate.

2.3.1 Design of RO system

The RO system design depends on the available feed water and the application. The standard flow configuration is plug flow type where the feed volume is passed once. Selection of elements depends on feed water salinity, feed water fouling tendency, required rejection and energy requirements. The standard element size for systems greater than 2.3 m^3/hr is 8-inch in diameter and 40-inch long. Smaller elements are available for smaller systems. Select the design flux, f, l/m^2-h based on pilot data, customer experience or the typical design fluxes according to the feed source. Then the number of elements are determined by the equation

$$Ne = \frac{Q_p}{f \times Se} \tag{7}$$

where Ne is the Number of elements, Q_p is the flow of permeate, f is the flux and Se is the surface area of the element.

To obtain the number of pressure vessels, divide the number of elements N_E by the number of elements per pressure vessel N_{EpV}, N_V – round up to the nearest integer.

$$N_V = \frac{N_E}{N_{EpV}} \tag{8}$$

For large systems, 6-element vessels are standard, but vessels with up to 8 elements are available. The relation of the number of pressure vessels in subsequent stages is called the staging ratio R. For a system with four vessels in the first and two vessels in the second stage, the staging ratio is 2:1. A three-stage system with four, three and two vessels in the first, second and third stage respectively has a staging ratio of 4:3:2. The ideal staging of a system is such that each stage operates at the same fraction of the system recovery, if all pressure vessels contain the same number of elements. The staging ratio R of a system with n stages and a system recovery Y (as fraction) can then be calculated:

$$R = \left(\frac{1}{1-Y} \right)^{\frac{1}{n}} \tag{9}$$

The number of pressure vessels in the first stage Nv can be calculated with the staging ratio R from the total number of vessels Nv.

For a two-stage system (n=2) and a three-stage system (n=3), the number of pressure vessels in the first stage is

$$N_V(1) = \frac{N_V}{1+R^{-1}} \quad for\, n = 2$$
$$N_V(1) = \frac{N_V}{1+R^{-1}+R^{-2}} \quad for\, n = 3, etc. \qquad (10)$$

The number of vessels in the second stage is then $N_V(2) = \frac{N_V(1)}{R}$ and so on.

Boosting the feed pressure between stages is required to maintain the required flow. The selected system was analyzed using the computer software IMS design to ensure the selection.

2.5 Advantages of RO Process

Advantages of RO process for wastewater treatment are

- Design and operation is simple with less maintenance.
- No heating source is required as RO plant is operated in ambient temperature only
- It is a physical process and no change of material takes place in the RO process.
- RO membranes are modular in nature enabling the expansion of stream simple and compatible.
- Energy requirement is less when compared with other treatment processes.
- RO systems require less energy as compared to other technology
- RO processes can considerably reduce the volume of waste streams so that these can be treated more efficiently and cost effectively by other processes such as multiple evaporation.

Hence, RO is considered to treat the blow down water.

3. Results and Discussion

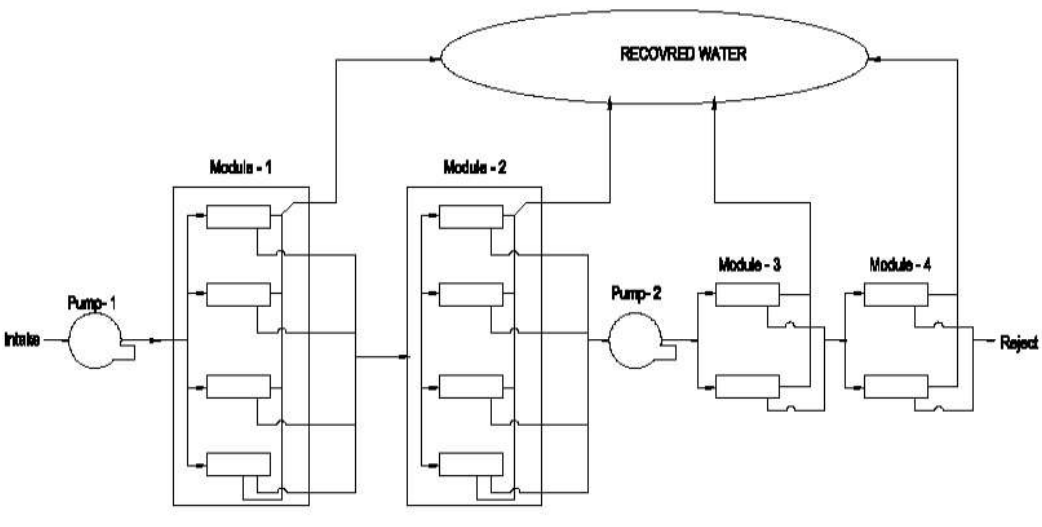

Fig. 1. Proposed Flow diagram of RO System

This serial arrangement of RO membranes maximizes the output ensures a recovery of more than 75% of recovery. One such arrangement is available at M/s. Hindustan Unilever Ltd, Pondicherry. The arrangement is shown in the Fig. 1.

"FilmTech" make RO membranes are used in the above unit. It is equipped with Ultra Filtration (UF) membranes as a pretreatment measure. The UF membranes remove the suspended solids present in the feed water reducing the load on RO membranes. Anitscalents are added to the feed water to avoid frequent fouling of RO membranes and to enhance the life of RO membranes. As the arrangement of RO system is being a proven one, similar arrangement in respect of RO along with necessary pretreatment process is considered for treating the blow down water of the gas turbine power plant. Hence an RO plant using the serial RO system with a capacity of 70 tons per hour is erected at this site, the water wasted as blow down at a rate of 2000m^3 per day can be treated with a recovery of 1400 m^3 per day from blow down water at 70% recovery rate.

The quality of RO water, raw water and blowdown water are compared in the following Fig. 2. It is observed that the RO water is of good quality in terms of TDS, conductivity and this water can be utilized as circulating water, boiler feed water, in heat exchangers, lube oil coolers, bearing coolers etc. The remaining 600m^3 (30%) of water per day will be reject of RO stream which cannot be used any more due to its poor quality in terms of TDS.

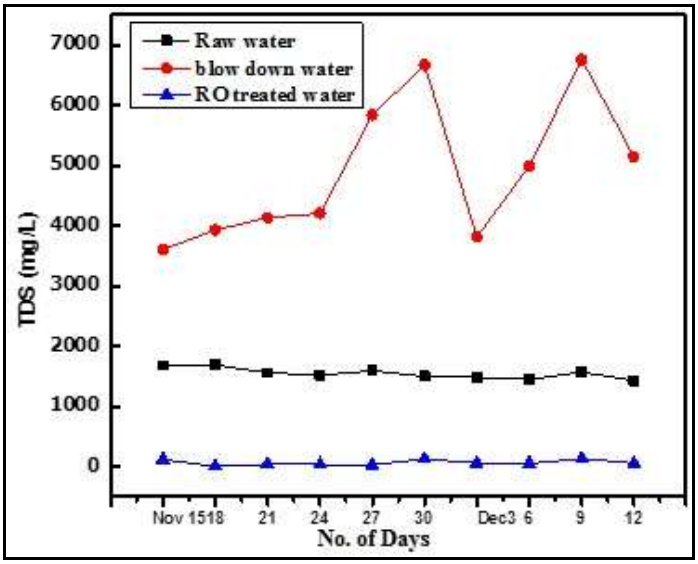

Fig. 2. Comparison of water quality

3.1 Disposal of RO rejects by using Evaporation pond (EP)

Though the RO system is an attractive method for recovery of blowdown water, the bottleneck in its process is the disposal of the RO reject. Normally RO rejects could not be let out in view of pollution control norms. EP is a simple and low cost method for RO reject disposal. An EP is merely an excavated depression in the ground, which serves as a reservoir for wastewater rejects. Often, EP is the final destination of concentrate. In these situations, once the water evaporates, the residual solids may be land filled in situ or collected and disposed of elsewhere. Based on the existing design practice considering the evaporation rate, precipitation rate, Humidity and wind force a Pond size of 600' X 300' (≈ 4.13 acres) is required to evaporate 50m^3 in a normal shiny day. An area of 43 acres is estimated for implementation of an Evaporation pond to treat 600m^3 of effluent per day. This much land is truly enormous. For a Gas Power Station generating 100 MW requires only 30 acres of land for accommodating all its Gas Turbine, HRSG, Steam Turbine and Balance of plant for the complete plant.

As the requirement of land for constructing evaporation ponds is really a constraint, the alternate methods to enhance the evaporation rates are considered. Some of the suggestions that can be considered for ensuring sufficient evaporation along with natural evaporation by solar energy under limited area requirement are steam heating/flue gas heating along with natural solar heating whereby solar ponds are constructed with steam/flue gas coils or pipelines. The concentrate or reject from wastewater treatment plant is fed to the evaporation pond. The liquid and solid separation takes place under sun light as well as by the immersed flue gas pipes.

In gas turbine stations, the temperature of the flue gas that is letting out to the atmosphere is around 125 -130 ºC[4]. A portion of this Flue gas can be tapped out from its out let duct before going to stack and made to pass through the pipes constructed in the evaporation ponds. As the temperature of the flue gas is high, the evaporation rate will be much higher than the natural evaporation ponds. The land requirement for constructing evaporation ponds reduces drastically if flue gas heating pipes based on theoretical estimation assist the evaporation pond. Further, the evaporation pond can be designed with geotech membranes and leak collection system etc. as required by the type of land. Theoretical estimation of flue gas requirement to evaporate RO wastewater rejects in the evaporation pond is presented as follows.

3.2 Basic design calculations for Land Requirement for EP

3.2.1 Evaporation Pond with Natural Solar Energy

Average evaporation rate in Tamilnadu is 20% per month. Average evaporation rate in tamilnadu per day is 0.66%. Assuming a depth of 0.5m of effluent in the evaporation pond volume of wastewater available in 1-Acre land is 2023 m^3. Evaporation expected from 1-Acre land per day is 14.16m^3. Expected quantity of Reject from RO plant is 600 m^3 per day.

Land required for evaporation pond = (600 m^3 x 1Acre)/14.16 m^3 = 42.36 Acres.

3.2.2 Evaporation Pond with natural solar energy assisted by flue gas heating

Energy required for evaporating 1 kg of pure water is 2329 KJ [3]. The evaporation rate depends on the concentration of water. As the solute concentration in wastewater increases, the energy required for evaporation also increases. As a thumb rule 1.5 times the energy required for pure water is considered for calculation purposes. Energy required for evaporating 1 kg of effluent water= 3494 KJ. Energy required for evaporating 600 Tons of Effluent water is 20964x10^5 KJ. 1 Kg of Steam Contains 2678 KJ of energy in it. The heat capacity of Steam and Air/ Gas is 2.07 KJ/g/k and 1.035 KJ/g/k respectively. Therefore, energy contained in 1 Kg of Flue Gas is 1298KJ. Quantity of Flue Gas required for evaporating 600 tons of Effluent water is1615 tones or 1345833 m^3 of flue gas per day. Considering a pipe of 50mm diameter with 10 m long, Flue gas carrying capacity of each pipe is 0.0.0196m^3.

Considering 24 hours of operation, No. of pipes required is (1345833/0.0196) × 3600 × 24 = 789 Nos. This much quantity of pipes can be laid in 2 Acres of land. Therefore, the proposed cooling water circuit is shown in Fig. 3.

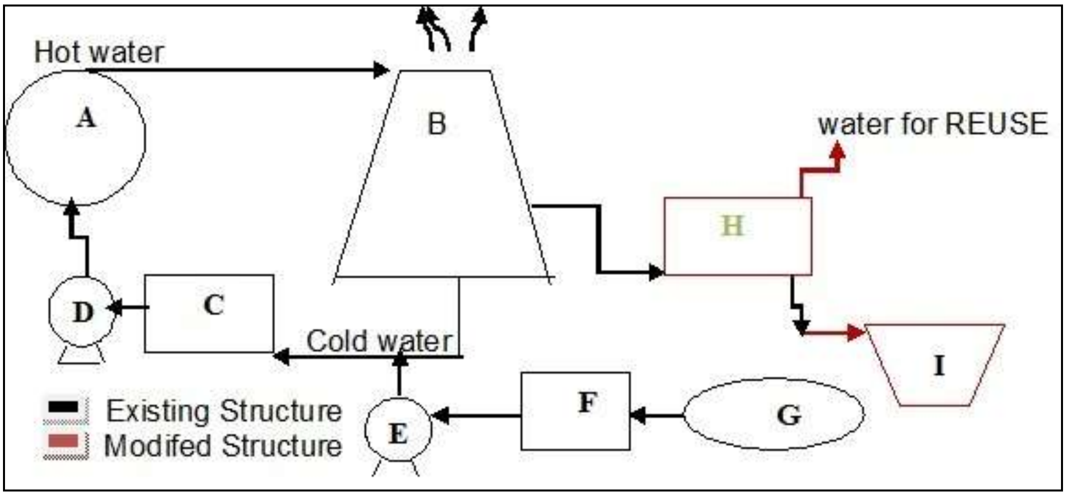

Fig. 3. Proposed cooling water circuit (A- Condenser, B-Cooling Tower, C-Fore bay, D-Cooling water pump, E-Raw water pump, F-Raw water tank, G-Ground water sources, H-RO system, I-Evaporation pond)

4. Conclusion

Information for the treatment of blowdown water and need of evaporation ponds in TGTPS is presented. Analysis of treated water ensures the choice of RO plant and the basic design of RO system was presented. The estimated land requirement for evaporation pond with natural solar energy and natural solar energy assisted by flue gas heating is 42 and 2 acres respectively. This arrangement will be useful in applications that are more practical especially where availability of land is minimum. Selection of RO system is always site specific, which necessitates pretreatment to feed water. Post treatment to effluent for enables a Zero liquid discharge from the gas turbine plant to minimize the damage to ecology. The solids accumulated in the evaporation ponds after liquid evaporation can be collected and disposed by land filling or as directed by the controlling bodies in accordance with the environmental laws.

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