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Optimization of Water Consumption to meet New MoEFCC guidelines for Thermal Power Plants

Ritesh Dahikar
(M.Tech –Environment Sci. & Engg., B.Tech – Chemical Engg.)

***Abstract*- The recent notification issued by Ministry of Environment, Forest & Climate Change (MoEFCC), Government of India, on 8th December 2015, with reference of S.O.3305 (E), Section 6 & 25 of Environment (Protection) Act, 1986, specified the new limits on maximum water intake consumption & achieving zero wastewater discharge for existing as well as newly installed Thermal Power Plants (TPP) in India. Additionally the notification has also specified SO2 emission limit from stack for both existing and newly installed TPP's, which mandates the additional technology such as flue gas desulphurization (FGD) to meet this requirement, which requires additional make up water. The maximum new water consumption limit is set at 2.5 m3/MWh for newly installed Thermal power plant. Presently coal based TPP's, typically consumes water in the range of 3.0to4.0 m3/MWh without considering FGD.**

This paper discusses the various possible optimization ways to meet this new water consumption limit, including additional water requirement for SO2 reduction and to ensure zero wastewater discharge from plant.

***Keywords:*---Water conservation, ash handling, flue gas desulphurization, zero wastewater discharge**

I. INTRODUCTION

India is the 2nd largest populated country in the world. It is estimated that India's population will surpass China by 2020. India needs huge requirement of electricity to meet its growing demand of energy for population. Total installed power generation capacity of India is 288 GW as on dated 31st Jan 2016 [1]. At present, India accounts for 300 Millions of population who do not have access to electricity. As per International Energy Agency (IEA) estimation [2], India need additional 600 GW of additional power generation capacity by 2050 to meets its energy requirement.

Out of total installed power generation capacity, the 60.8% of power is produced by coal based thermal power plants, thanks to large coal reserves (though depleting) and low cost of electricity amongst all other fuel such as gas, oil etc. Gas based combined cycle power (CCPP) plants contribute to 8.5% of generation capacity.

II. PRESENT WATER CONSUMPTION

Thermal power plants, specially coal based TPP's are one of the largest water consuming industries which rapidly depleting the available fresh water reserves. Typical fresh water consumption for coal based TPP's, using closed cooling with cooling towers, at cycles of concentration (COC) of 5.0 is 3.0 to 4.0 m^3/MWh, excluding water required for wet FGD. This range depends on the type of ash transport system provided. Water consumption is high if fly ash is disposed in wet slurry (25-30%) form, without recovery of ash pond water. For concentrated disposal (up to 60%) or dry pneumatic disposal, water consumption reduces. Now-a-days, complete dry using pneumatic conveying system is used for transport of fly ash. Bottom ash is continue to transport and disposed with 25% slurry.
For gas based combined cycle power plant, relatively water consumption is less, approx.1.5 m^3/MWh, owing to the fact that ST condenser cooling is applicable for 35% of total power output of plant.

Table 1.0 indicates the typical water consumption for both type of plants.Water consumption for coal based TPP is calculated based onBidding Document no. CS-9578-001-2, Technical Specification for EPC Package for Khargone Super Thermal Power Project (2x660MW)[3]in Madhya Pradesh, with design conditions as : cooling tower with temperature range = 10°C, COC = 5.0, WSC make up = 1.0%, Bottom ash (BA) disposal = 25% slurry, Fly ash (FA) disposal =100% dry andwet FGD treatment. Water consumption for gas based CCPP is calculated based on specifications for 370MW Gas based CCPP, Utran, Surat in Gujarat, with design condition as, cooling tower with temperature range = 10°C, COC = 4.0 and WSC make up = 1.5%.

Table 1.0 : Typical Water Consumption

Consumer	**Coal based** **2x660 MW TPP**		**Gas based** **370 MW CCPP**	
CT Makeup	3055	90%	500	86%
DM water	106	3.1%	35	6%
Potable water	14	0.04	10	1.7%
Service water	157	5.36%	25	4.8 %
Evap. loss	50	1.5%	10	1.5%
Total (m3/hr)	**3382**	**100%**	**580**	**100%**
m^3/MWh	**2.56**	-	**1.57**	-
Ash water **	613	-	-	-
Total (m^3/hr)	**3995**	-	-	-
m^3/MWh	**3.02**	-	**1.57**	-

** - Total ash water required is met from ash pond recycle water (70%) and remaining from cooling tower blowdown. However during initial period approx. one year till ash pond recirculation water is available, deficit ash water is fed from raw water.

III. MOEFCC NEW GUIDELINES

Ministry of Environment, Forest & Climate Change (MoEFCC), Government of India, has issued notification on 8th December 2015, with reference of S.O.3305 (E), Section 6 & 25 of Environment (Protection) Act, 1986, for new guidelines on limit of maximum water usage as follows:

Water Consumption Limit:

- All existing CT-based plants to reduce specific water consumption up to maximum of 3.5 m^3/MWh within a period of two years from date of publication of this notification
- All new plants to be installed after 1st Jan 2017 shall have to meet specific water consumption up to maximum of 2.5 m^3/MWh and achieve zero waste water discharged.

SO_2 Emission Limit:

- for plants installed after 1st Jan 2003 up to 31st Dec 2016, max. SO_2 = 600 mg/Nm^3 for plant capacity less than 500 MW and 200 mg/Nm3 for plant capacity of 500 MW and above.
- For plants to be installed from 1st Jan 2017, the max. SO_2 limit = 100 mg/Nm^3.

IV. ANALYSIS OF MOEFCC GUIDELINES

Coal Based TPP: So far emission limits was applicable for particulate matter. SO_2 is factored in terms of stack height for plant capacity less than 200 MW using equation H = $Q^{0.3}$[4], where H is stack height in m and Q is SO_2 emission rates in kg/hr. For higher plant capacity, stack height is fixed at 220 m (for 200 – 500 MW) and 275 m (for 500 MW and above). However there was no specific SO_2 concentration limit in exhaust flue gases. The recent MoEFCC notification, defines the SO_2 emission limits for both existing and newly installed plant. The Sulphur content of Indian coal varies from 0.3% to 0.5% by weight while that of imported coal varies from 0.5% to 2.5%[5]. The estimated SO_2 concentration with Indian coal in exhaust flue gases varies from 800 to 1200 mg/Nm^3 which exceeds the limit set by MoEFCC.

SO_2 is reduced by using dry (spray or circulating) or wet FGD technologies. Wet FGD system, withlower life cycle cost for larger units, uses limestone slurry for SO_2 scrubbing, can remove up to 98% SO_2, mainly used for high Sulphur fuels (> 1.5%) and produces marketable byproduct[6]. Spray dry FGD system, with lowest life cycle cost, uses lime slurry for SO_2 scrubbing, can remove up to 95% SO_2, mainly used for low Sulphur fuels (< 1.5%) and produced dry product is used for land fill[6]. Circulating dry scrubber FDG system,withlower life cycle cost for smaller units, uses hydrated lime for SO_2 scrubbing, can remove up to 98% SO_2, mainly used for high Sulphur fuels (>1.5%) and dry product is used for land fill[6]. Wet FGD is more experienced technology, used by many developed countries. In India, only space provision needs to be ensured so far. Now it becomes inevitable to use FGD system to meet new SO_2 Limit.

The typical make up water requirement for wet FGD is 0.22 to 0.25 m^3/MWh[7]. This can be eliminated by using dry system but considering high Sulphur content of imported coal, which is generally blended with Indian coal to increase the calorific value and reduce ash content, the wet FGD system would be required.

Table 2.0 indicates the total water requirement including FGD.

Table 2.0 – Typical Water Consumption

Cases	w/o FGD	With FGD	Total
With Ash recirculation	2.56	0.25	2.81
w/o Ash recirculation	3.02	0.25	3.27

This does not look like problem for existing thermal plant where maximum water consumption limit is 3.5 m^3/MWh. However for all newly installed plant, the present water consumption incl. FGD requirement exceeds the water consumption limit of 2.5 m^3/MWh.

Gas Based CCPP: For gas based combined cycle plant, water consumption limit is not a problem, however ensuring the zero wastewater discharge will not be possible without recycling and reuse of wastewater.

V. WASTEWATER FROM THERMAL POWER PLANT

Before evaluating the various possible ways for water conservation, lets relook into the wastewater generated from power plant. Table 3.0 indicates the typical wastewater streams generated from 2 x 660 MW, Khargone Coal based STPP.Wastewater flowrates are calculated on the basis of CT COC = 5.0, FA = Dry disposal and BA = 25% slurry.

Table 3.0 : Typical Wastewater Flowrates for 2x660 MW coal based STPP

Wastewater Streams	**Flow rate (m3/hr)**	**%**
CT Blow down (CTBD)	545	90 %
Chemical Waste (DM+CPU)	16	2.6 %
Oily waste	23	3.8 %
Sanitary waste	22	3.6 %
Total	**606**	**100 %**

Table 4.0 :Utilization of CTBD

Consumers	**Flow rate (m3/hr)**	**%**
Ash handling System	263	48 %
Service water for floor wash	23	4.2 %
Coal dust suppression	93	17 %
Fire water make up	2.0	0.4 %
Remaining CTBD	**164**	**30%**
Other wastes (excl. sewage)	**37**	
Total wastewater available	**201**	
FGD requirement	**330**	
Deficit for FGD	**(-) 129**	

Though cooling tower blowdown (CTBD) is named as wastewater, however it is fully used internally without any treatment. As shown in Table 4.0, around 48% of CTBD is used for ash cooling and transport. 17% of CTBD is used for coal dust suppression and remaining water is used for service water for area washes, fire water make up etc. Any remaining CTBD is sent to central monitoring basin.

The chemical wastewater generated from resins regeneration of DM plant and Condensate polishing plant is first neutralized by chemicals and then sent to central monitoring basin. The potentially oily wastes collected from fuel oil area, transformer yards, turbine halls are sent to central monitoring basin after passing through oil water separator.

The combined wastewater from central monitoring basin is then treated in Effluent treatment plant and then either recycled to cooling tower make up or disposed to surface water bodies after meeting the required environmental regulations. Sanitary waste collected from toilets, sinks, kitchen, pantry, lunch rooms are collected in a sump and then sent either to sewage treatment plant or septic tank. The treated sewage water can be used for irrigation purpose and as make up to cooling tower. So far FGD was not in place. Now, FGD will also be one of the consumers of CTBD. With present design, meeting FGD requirement is not possible without any technological change.

VI. POSSIBLE WAYS FOR WATER CONSERVATION

Based on the analysis of MoEFCC guidelines and present water consumption levels, it is required to reduce the present water consumption by 0.31 m3/MWh in case of ash water recirculation and 0.77 m3/MWh in case of no ash water recirculation, to meet the guidelines for newly installed thermal power plant. Following can be some of possible ways of reducing the water consumption.

6.1 Reduction of Ash Water Requirement

Water is required for cooling of the bottom hopper ash and transportation of bottom ash (BA) and fly ash (FA) up to ash pond. The quantity of water required for this purpose depends on how the ash is intended to transport. Source of water is 70% from water re-circulated from ash pond and remaining 30% is met from cooling tower blowdown. Table 5.0 indicates the water requirement for ash handling system for different cases for 2 x 660 MW STPP.

Table 5.0 : Ash Water Requirement

Cases	**FA** (m^3/h)	**BA** (m^3/h)	**Total** (m^3/h)	**m^3/ MWh**
FA:30% slurry BA: 25% slurry	1051	876	1927	1.46
FA:60% slurry BA: 25% slurry	300	876	1176	0.89
FA: Dry BA: 25% slurry	0	876	876	0.66
FA: Dry BA: Dry	0	0	0	0

Table 6.0 :Source of Ash Water

Cases	**Total** (m^3/MWh)	**Ash pond recirc.**	**CTBD**
FA:30% slurry BA: 25% slurry	1.46	1.022	0.44
FA:60% slurry BA: 25% slurry	0.89	0.623	0.27
FA: Dry BA: 25% slurry	0.66	0.462	0.20
FA: Dry BA: Dry	0	0	0

Table 5.0& 6.0 shows that, the water requirement reduces as dry ash disposal approach is used. Use of complete dry system for both FA and BA, will save the water required for ash disposalupto 0.2 m^3/MWH, but at the expense higher equipment cost for dry system.Dry bottom ash disposal system, though not so common is India, however it is well proven and established technology in developed countries due to following facts. Dry Ash disposal system increases the boiler efficiency by 0.15 – 0.2% [8]since bottom ash heat is recovered by boiler combustion air. Besides this, no large ash pond and water recirculation system is required hence reduces the foot print of plant. This also eliminates the risk of ground water contamination due to permeation of ash water into ground through leakages in liner.

Use of complete dry ash handling system will produce large amount of dry ash which is to be managed effectively without impacting environment. Dry ash can be used for manufacturing of building materials such as ash bricks, cement additives etc.

6.2 Reduction of Cooling Tower Blowdown (CTBD)

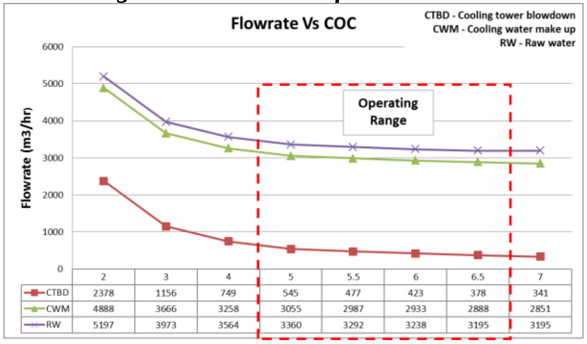
Water reduction of 0.2 m^3/MWh by using dry ash disposal system do not directly impact the intake raw water consumption as it is fed from cooling tower blowdown. However this water saving can be utilized for FGD requirement as indicated below.

Table 7.0 – FGD Water for 2 x 660 MW STPP

Description	**m^3/MWh**	**m^3/hr**
Water saving from dry ash disposal	0.20	264
Waste water available as per Table 4.0	0.152	201
Total Water available	0.352	465
FGD requirement	0.25	330
Water remaining after FGD	0.102	135

The above remaining water can be reduced by reducing the CTBD. Cooling tower blowdown quantity depends on cycles of concentration (COC) which is decided based on the make up water quality, required cooling water chemistry and environment liquid discharge norms, if applicable. Figure 1.0 indicates the variation of blowdown flow, make up flow and raw water intake flow variation at various COC levels.

Figure 1 : Variation of Flowrates Vs. COC



The present design is based on COC of 5.0. For given make up water chemistry of referred case study (Ca = 118, Mg = 37, Na+K = 46, HCO_3 = 128, Cl = 52, SO_4 = 21,) ppm as $CaCO_3$ and SiO_2 = 7.0 ppm as SiO2, Fe = 1.0 ppm as Fe, the COC can be increased up to 6.5, thereby reducing the CTBD qty by (545 – 378) = 167 m^3/hr. However as indicated in Table 7.0, the excess wastewater available is 135 m^3/hr. Hence COC cannot be increased more than 6.0. At COC 6.0, the total raw water intake is 3238 m^3/hr i.e. **2.45 m^3/MWh which is less than new MoEFCC limit of 2.5 m3/MWh.**

6.3 Other Misc. Methods for Water Conservation

Following steps can also be implemented for reduction of water consumption –

a) Minimization of water losses from intake reservoir by i) using the above ground storage tanks, ii) using the covered underground reservoir iii) cover the large open reservoir by solar panels to cut of the sunlight. The electricity produced can be used to run auxiliaries of reservoirs.
b) Use of municipal treated sewage water instead of fresh river water for cooling purpose.

VII. ZERO WASTEWATER DISCHARGES

The new MoEFCC notification also makes it mandatory to achieve Zero Wastewater Discharge. Each type of Thermal plant is analyzed in this regard as follows:

Coal Based STPP: As discussed in previous sections, the systems are designed in such a way that the wastewater generation from various operation is totally utilized internally and no wastewater is available for external disposal. This satisfy the requirement of Zero wastewater discharge and hence additional efforts are requirement to meet MoEFCC requirement.

Gas Based CCPP: As discussed in previous sections, Gas based Combined Cycle Power Plant consumes less water compared to coal based plant and easily meet raw water consumption limit. However unlike coal based plant, there is no major internal consumers of wastewater specially CTBD for gas based plant. Table 8.0 indicates the various wastewater generated from gas based combined cycle plants. These values are taken from 370 MW, gas based CCPP, Utran, Surat, Gujarat.

Table 8.0: Typical Wastewater Flowrates for 370 MW gas based CCPP

Wastewater Streams	**Flow rate (m3/hr)**	**%**
CT Blow down (CTBD)	125	80.3 %
DM Plant waste	15	9.7 %
Oily waste	10	6.5 %
Sanitary waste	5	3.2 %
Total	**155**	**100 %**

Sanitary waste is routed to existing septic tank. The remaining wastewaters excluding oily waste are collected in central monitoring basin. Oily wastewater is treated in oil water separator and the de-oiled wastewater is disposed externally. The combined wastewater from central monitoring basin is treated in RO based effluent treatment recycle plant. Design overall recovery of ETP recycle plant is 60%. The RO permeate water is recycled to cooling tower make up. Recycling of good quality RO permeate to cooling tower make up improves the cooling water chemistry and optimized the COC, thereby reducing the blowdown qty. The remaining 40% RO reject water, which is concentrated, is disposed externally.

Based on new MoEFCC notification, now it is not allowed to disposed this water externally. This requires further treatment of reject since such concentrated waste cannot be used directly including for irrigation purpose. Therefore second and third stage RO units will be required to reduce the wastewater as minimum as possible. The last bit of waste water, i.e. reject of last stage of RO, which is highly concentrated, can be either sent to thermal evaporation or evaporation pond. Thermal evaporation can recover 95% of wastewater as distillate which can be recycled to DM water make up for boiler [9]. The concentrated brine from evaporator can further be sent to Crystallizer for reduce the liquid waste completely. The solid waste generated from Crystallizer shall be sent for land fill.

Evaporator-Crystallizer is an energy intensive technologies as well as becomes more expensive for large flow rates. Using multistage RO before evaporator will reduce the load on evaporator and crystallizer however overall cost for combination of RO-Evaporator-Crystallizer vs only Evaporator-Crystallizer is to be analyzed case by case basis. Some modifications such as use of thermocompressors to recompress the vapors in crystallizer and send it back to crystallizer heater, improves the steam economy by 30% and lowers the energy cost. Similarly, using the longer tubes in evaporator also reduces the energy cost by 28% [10].

VIII. COST IMPACT ANALYSIS

8.1 Ash handling System:The major change to be carried out in order to meet the reduced water consumption limit is to change the bottom ash handling from wet mode to dry mode. This adds to cost of the plant. Table 9.0 indicates the estimated increase or decrease in cost for dry ash handling compared to wet ash handlingsystem[11]. Table 9.0 shows that the capital investment cost for dry ash handling system is 30% higher than wet ash handling system, while the operating cost for dry ash handling is 50% lower compared to wet ash handling.

Table 9.0 – Cost Variationbetween Dry and Wet ash handling[11]

Parameters	**Wet**	**Dry**	**Change**
1. Investment Cost			
Relevant Equipment	1.0	1.58	↑
Water treatment	1.0	0.0	↓
Crushing Equipment	1.0	1.0	↔
Transport equipment	1.0	0.8	↓
2. Operation Cost			
Energy consumption	1.0	0.55	↓
Cooling water cost	1.0	0.0	↓
Ash handling & disposal	1.0	0.77	↓
Spare, service&maint.	1.0	0.4	↓

8.2 Flue Gas Desulphurization (FGD) System:The maximum limit of SO_2 emissions for existing as well as newly installed plant, makes it mandatory to install FGD. Indian coal is low in Sulphur, for which dry FGD is more suitable, however for large plants, in order to reduce the fuel consumption due to higher calorific value and reduce the ash generation, high Sulphur imported coal is blended with Indian coal. In such case, wet FGD is more suitable. Table 10 indicates the estimated cost (k$/MW)of dry and wet FGD.

Table 10: Cost of FGD Systems[12]

Total Capital Cost				
Wet FGD	**LSFO**		**MEL**	
Coal	High S	Low S	High S	Low S
kU$/MW	125	107	109	96
Dry FGD	**LSD**		**CFB**	
Coal	High S	Low S	High S	Low S
kU$/MW	122	126	134	137
Total Operation & Maintenance Cost(see note)				
Wet FGD	**LSFO**		**MEL**	
Coal	High S	Low S	High S	Low S
kU$/year	8,298	5,962	9,101	6,169
Dry FGD	**LSD**		**CFB**	
Coal	High S	Low S	High S	Low S
kU$/year	7,999	6,307	7,742	6,180

Note :O&M cost includes – fixed operating cost + variable operating cost (reagent, waste disposal, spares, water, power)
LSFO – Limestone scrubbing with forced oxidation
MEL – Wet lime scrubbing using Magnesium enhanced lime with forced oxidation
LSD – Lime Spray Dryer
CFB – Lime scrubbing using circulating fluid bed

8.3 Zero Wastewater Discharge System:The coal based thermal power plant do not require additional high cost effluent treatment plant to ensure zero wastewater discharge, However for gas based combined cycle power plant, where there is no direct internal consumer of wastewater, Zero Liquid discharge (ZLD) effluent treatment plant including UF/RO membrane units followed by Evaporators and Crystallizers are required to ensure zero wastewater discharge. Cost of ZLD treatment depends on wastewater quality which directly depends on source raw water quality, operating COC of cooling water system, type of DM plant (RO or IEX) used and whether treated oily waste (oil < 10 ppm) is mixed with wastewater. The estimated capital cost of 100 m3/hr capacity of ZLD plant comprising of Clarifier

– Ultrafiltration – Two stage RO system – MVC evaporator – Crystallizer is 5.0 Million U$. The estimated yearly operating cost (incl. chemicals, membrane replacement, power) is 1.0 MU$/year.

IX. CONCLUSION

- The water conservation is of prime necessity in the world and being one of the largest water consuming industries, thermal powers are no exception.
- The new guidelines set by MoEFCC, Govt. of India, for maximum water consumption limit and stringent flue gas emission discharges makes it mandatory for all existing as well as newly installed thermal power plants to reduce their water consumption.
- Meeting the MoEFCC guidelines is not possible without incorporating major modifications in present technologies.
- Conversion of wet ash handling to completely dry ash handling, inclusion of FGD system for SO_2 removal and provision of zero liquid discharge treatment plant, mainly for Gas based CCPP, and efforts to minimize the water losses as well as use of alternate water resources such as municipal treated sewage water, makes it possible to meet the new guidelines.
- These changes will definitely impact the cost of electricity, however it is a need of time for sustainable growth, reduction of environment pollution and conservation of natural water resources.

REFERENCES

1. Ministry of Power, Govt. of India Website : *http://powermin.nic.in/power-sector-glance-all-india*
2. UweRemme, Nathalie Trudeau, Dagmar Graczyk and Peter Taylor, 2011 February, “Technology Development Prospects for the Indian Power Sectors”. International Energy Agency, France.
3. Bidding Document No. CS-9578-001-2, Technical Specification for EPC Package for Khargone Super Thermal Power Project (2x660MW)
4. Govt. of India Notification no. GSR 742(E), dated 30th Aug. 1990
5. A Chandra & H Chandra, - “Impact of Indian and Imported coal on Indian Thermal Power Plants”, Journal of Scientific & Industrial Research, Vol. 63, Feb 2004.
6. Brandy Johnson, WPCA Conference, Aug. 2010 – “An unbiased comparison of FGD Technologies : Wet, Spray Dry and CDS”
7. Sargent & Lundy LLC, “Wet Flue Gas Desulfurization Technology Evaluation, Project no. 11311-00”, National Lime Association, January 2003.
8. FulvioBassetti, Daniele Coppola, Daniele Ricci – “ Fully dry bottom ash removal system for elimination of pond” presented in 2015 World of Coal Ash Conference in Nashville, TN.
9. Anita Seigworth, Rodi Ludlum, Eugene Reahl, “Case Study: Integrating Membrane Processes with Evaporation to Achieve Economical Zero Liquid Discharge at the Doswell Combined Cycle Facility”, ELSEVIER, Desalination, Volume 102, 3rd October 1995.
10. J. Bostjancic, R. Ludlum, GE Water & Process Technologies, “ Technical Paper – Reducing Wastewater to Dryness: Zero Liquid Discharge Case Studies for New Power Plants
11. http://www.powerengineeringint.com/articles/print/volume-18/issue-5/features/ash-handling-why-dry-bottoms-are-better-than-wet-bottoms.html
12. William DePriest&Rajendra P. Gaikwad, Sargent & Lundy, Chicago, Illinois, Paper # 169 – Economics of Lime and Limestone for Control of Sulfur dioxide.