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# Increasing the overall CPP efficiency by collection of waste heat and optimizing plant process

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**ABSTRACT**
With the increase in energy consumption and more rigorous need of sophisticated processes, keeping in mind the energy scenario and surge in fuel prices, it is very important of an industry to keep the process control at par and make use of every resource that is available to improve the net output by first reducing the consumption of the raw material as it has an immediate effect on the total plant efficiency. In case of captive power plants it is a basic necessity to provide process steam at optimum quality and also balance the consumption of raw materials and try to recover as much as possible to reduce in the production costs, thus improving upon the total plant performance.
***Keywords –*** Condensate, DM water, flash steam, resins.

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## I. INTRODUCTION

Repeated continuous improvement in the power plant performances going in the current world and with an increase in the fuel costs and less down time requirement for every facility, it is very important to have proper process parameters with minimum deviations so as to achieve maximum output with minimum operation costs. In big capacity power plants, water treatment plays an important role as it derives the life of other equipment's like boilers, HRSG's, etc. While the steam is been provided to the process plants, a lot of it tends to go waste in form of blowdowns, trap condensate, flash steam and while regenerating the very beds that produce the treated water.

In order to improve the overall throughput of the plant two main things are to be done. First, to save and recycle wherever possible in the plant to reduce the raw material consumption. Second is to optimize the process and improve upon the operational discipline to improve the total efficiency of every utility generated.

Following research was performed in a 90MW captive power plant and utilities section. It consisted of two gas turbines, three auxiliary boilers, and one steam turbine. With it was an adjoining Demineralized water treatment plant and effluent treatment facility under the utilities section. The results thus inferred proved in an overall increase in plant performance and saved operations and maintenance costs, along with the perk of overall environmental benefits.

## 1. COLLECTION OF WASTE HEAT & WATER

### 1.1 Steam header condensate calculation and collection.

The processes in the customer plants in a petrochemical complex is always varying and this causes a pressure drops at times. This causes a loss in internal enthalpy of the steam and causes it to condense. This is also caused due to the varying atmospheric temperatures, especially during monsoons. This condensate thus formed has to be removes or can cause serious hammering in the pipes resulting in damaging the pipelines and the equipment.

The header pressure in the plant under scrutiny, has various steam types flowing for different plants and their requirements. This includes 100 Barg Super-heated and saturated steam. 44 Barg Superheated and saturated. 25 Barg, 6 Barg and 3.5 Barg respectively. These headers go for long distances and have a lot of steam traps for condensate removal. These headers are made of different grades of steel and are of different nominal diameters. The outer insulation is covered with an aluminum sheet (18 gauge) of thickness 1.024mm.

It had a coefficient of heat transfer of 205 W/m2K. The total heat loss is calculated with a product of Surface area of the entire steam header, Coefficient of hear transfer and a difference of header surface temperature and ambient temperature.

Every steam with its physical property has a certain latent heat which is calculated as KJ/Kg. This is the amount of energy required for phase change. When the total heat loss is divided by the latent heat of steam, it gives the total amount of condensate produced.

**Table1:** Condensate formation calculation

| Pressure (Barg) | Condition | Surface area m2 | Total heat loss | Latent heat (KJ/KG) | Condensate per day (MT) |
|---|---|---|---|---|---|
| 100 | Superheated | 133.77 | 795252.2 | 1311.38 | 52.40 |
| 100 | Saturated | 106.78 | 591040.7 | 1311.38 | 38.94 |
| 44 | Superheated | 74.96 | 368811.9 | 1675.76 | 19.02 |
| 44 | Saturated | 64.72 | 265364.6 | 1675.76 | 13.68 |
| 25 | Saturated | 53.08 | 217635.9 | 1830.59 | 10.27 |
| 6 | Saturated | 78.73 | 322790.4 | 2065.35 | 13.50 |
| 3 | Saturated | 11.43 | 46862.98 | 2132.97 | 1.90 |
| Coefficient of heat transfer (Al) = 205 W/m2K | | | Total condensate | | 149.71 |

This when calculated for the entire plant with respect to the entire steam headers combined, sums up to produce about 150MT of condensate per day. This is pure DM water that can be directly used to put back in deaerator, not only to reduce water consumption but also to reduce steam loading in deaerator since the condensate is already hot. The condensate produced can be calculated as:

$$condensate\ produced = \frac{surface\ area \times coefficient\ of\ heat\ transfer \times \Delta T}{Latent\ heat}$$

1.2 Regulating boiler blowdown and recovering.

Steam generators like boilers, HRSG have steam drums where the water changes its phase and is in saturation state. These steam drums are partly filled with water and this includes water being stagnant for a time little longer than any other part of the boiler. This leads to the silica deposition and this silica needs to be removed to avoid any fouling in tubes. This is done by giving the steam drum a blowdown every once in a while. This is done by testing the steam drum water result. Keeping the silica limit of 1.5ppb the blowdown is given. This is calculated by calculating the theoretical blowdown required to bring the silica into the limit range. The theoretical blowdown can be calculated as:

$$\%Blow\ down = \frac{Drum\ Silica}{1.5 - Drum\ silica}$$

The boiler have a steam generation capacity of about 60 TPH. With a silica deviation of about 3.4ppb, the blowdown required will be about 10TPH. This can lead to a blowdown rate of around 90 TPD. This water, though being high on silica can be recovered. To minimize the blowdown required, the silica loading of the boiler feed water should be maintained. This can lead to saving a lot of water.

**Table2:** Average Blowdown calculation

| Silica (1.5 ppb limit) | | | Theoretical %BD | | | Steam Generation TPH | BD TPH |
|---|---|---|---|---|---|---|---|
| 0 | 8 | 16 | 0 | 8 | 16 | | |
| 0.7 | 0.5 | 1.1 | 0.8 | 0.5 | 2.8 | 59 | 2.41183 |
| 0.9 | 1.2 | 1.4 | 1.3 | 3.4 | 14.0 | 61 | 11.4189 |
| 0.8 | 0.5 | 0.6 | 1.0 | 0.5 | 0.7 | 58 | 1.31042 |
| 0.4 | 0.9 | 0.7 | 0.4 | 1.4 | 0.9 | 58 | 1.52058 |
| 0.7 | 0.9 | 1.1 | 1.0 | 1.7 | 3.2 | 60 | 3.49135 |
| 0.9 | 0.8 | 1.1 | 1.7 | 1.2 | 2.8 | 61 | 3.41752 |
| 0.9 | 0.9 | 0.9 | 1.5 | 1.5 | 1.6 | 59 | 2.73086 |
| %BD= Test silica/(Silica limit-Test silica) | | | | | | Average | 3.75735 |

1.3 Flash steam calculation and condensation

The blowdown given from the drums to maintain the water chemistry is then transferred to a blowdown tank. This tank is open to atmosphere and so when the high pressure saturated water in the steam drum (100 Barg, 330$^oC$) falls into an open tank at atmospheric pressure the water tend to flash and this produces a lot of steam. Condensate left is collected underneath the blowdown tank and the flashed steam is vented. This vented steam can be collected using a vessel so designed that there is a provision of a spray water in the vent which acts according to the temperature feedback given and sprays water enough to bring the water in hot condensate state so as to be used again in boiling process.

The specific enthalpy of 100 Barg steam at a saturation temperature of 330$^oC$ is 2834.92 KJ/Kg. This water is then flashed at atmospheric pressure, thus the specific enthalpy of 1 bar atm steam at 330$^oC$ is 2723.62 KJ/Kg. The latent heat of vaporization at flash pressure is about 2260 KJ/Kg. Thus the percentage of flash steam can be calculated as:

$$flash\ steam = \frac{Sp.Enthalpy\ of\ steam\ at\ 100\ Barg\ 330\ C - Sp.Enthalpy\ of\ steam\ at\ 1\ Bar\ atm\ 330\ C}{Latent\ heat\ of\ vaporisation}$$

With a blowdown rate of 90 TPD a 4% flash steam can be lost which accounts to a little below 5 TPD of steam that vents off. This can be collected by installing a steam drum that has spray water line at the high point vent to condense the steam. This can lead to a lot of steam saving. This condensate, being hot can directly be used in the deaerator to reduce the specific steam consumption of deaerator thus also improving the plants overall efficiency.

The total condensate is calculated as:

Temperature of saturated condensate at 100 bar g = 330$^oC$

Since the traps are thermodynamic traps, the discharge condensate is subcooled and is cooled below saturation temperature and thus the heat available will be slightly less and thus,

Temperature of subcooled condensate = 315$^oC$

$$\dot{m}_{cw} = \frac{\dot{m}_s(h_s - h_d)}{h_d - h_{cw}}$$

$\dot{m}_{cw}$ = mass flow rate of cooling water, BFW (Boiler feed water) in this case (Kg/H)

$\dot{m}_s$ = mass flow rate of flash steam (KG/H)

$h_s$ = Enthalpy of flash steam (KJ/Kg)

$h_d$ = Enthalpy of hot condensate at atmospheric pressure

$h_{cw}$ = Enthalpy of BFW water, to condense the flash steam

**Table3:** Single HRSG running stats

| | | HRSG1 | |
|---|---|---|---|
| Steam Generaton | | 60 | TPH |
| Steam Generation | | 1440 | TPD |
| Blowdown | | 90.17631031 | TPD |
| Feedwater(steam + b/d) | | 1530.17631 | TPD |
| Feedwater actual | | 1608 | TPD |
| Difference | | 168 | TPD |
| Feedwater temperature | | 127 | °C |

Calculating the mass flow rate of the BFW water required to condense the flash steam at 4.8 TPD, almost 2.2 TPD BFW will be required. Post condensation, the entire condensate can be reused.

**Table4:** Flash steam properties

| | | |
|---|---|---|
| Specific Enthalpy of Superheated Steam 100barg @ 495 | 3360.83 | KJ/Kg |
| Specific Enthalpy of Saturated Steam 100barg @ 330 C | 2834.92 | KJ/Kg |
| Specific enthalpy of saturated steam 1bar atm @ 330 C | 2723.62 | KJ/Kg |
| Latent heat of vaporisation @ flash pressure | 2260 | KJ/Kg |
| %flash steam | 4.92477876 | |
| BD | 90.1763103 | TPD |
| Flashed steam available | 4.44098378 | TPD |
| Heat of flash steam @ 1bar atm | 3140 | KJ/Kg |
| Heat of makeup water @ 135barg @ 110 C | 471 | KJ/Kg |
| Heat availabe in flashed steam | 2669 | KJ/Kg |
| Heat savings in flashed steam per day | 11852985.7 | KJ/Kg |

The entire flash drum is designed in a way that the vent will have a spray water valve which will take feedback from the temperature of the steam being vent as flash steam and try to bring it to the minimum resulting in minimum flash steam loss. The vessel is also provided with a 'U' overflow seal to make sure the steam inside does not pressurize and cause any harm.

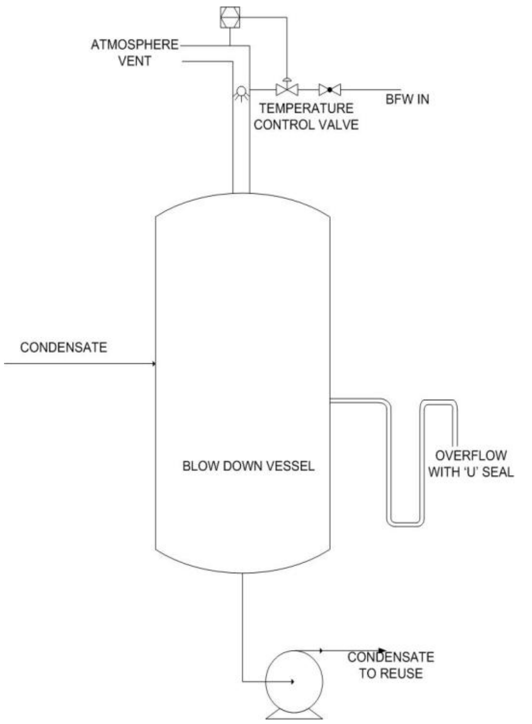


**Figure1:** Flash drum modification

The recovery can be collected in a dug pit. This can hold the flash steam condensate, the trap condensate and the water recovered from blowdown and then can be further used.

The water thus collected can have a tendency to have higher silica as it also contains water from blowdown. This water thus might need treatment before it can be used as DM water again. Most of the times on sampling it is observed that the water is usually in the silica spec limit, in which case it is used directly in the condensate recovery tank which has hot condensate returning from other plants.

The outlet of the recovery pump has a set of pH and conductivity meter installed. In an event of off spec water it is passed through MBP (Mixed resin bed, Cationic + Anionic resins) via a plate type heat exchanger. It is a tank with a mixture of cationic and anionic resins which can purify the water further. The reason it is passed through a plate type heat exchange is because the condensate can be hot and can damage the resin bed. Alternatively the entire water quantity can be circulated via the main DM water stream (SAC SBA MB) if the water quality worsens.

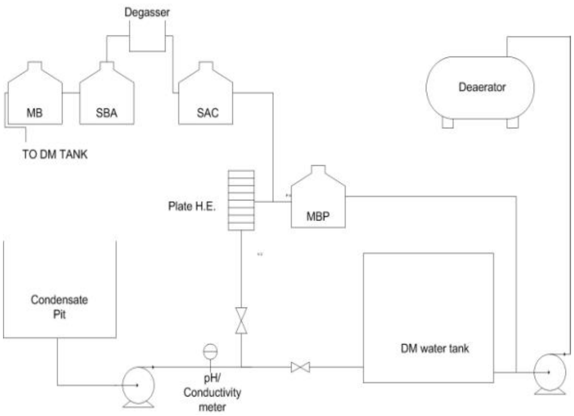


**Figure2:** Hot condensate recovery scheme

1.4 Backwash water recovery

The water that is supplied into the DM plant is raw water and is very high on turbidity. It has a turbidity of roughly 16 NTU. Before the water is treated in the DM plant, a filtration plant pretreats the water to increase the efficiency of the DM plant. It consist of a pretreating settling tank, a sand filter and an activated carbon filter in series. The main purpose of the three tanks is to reduce the turbidity to at least below 2 NTU, improve the color of water and remove chorine and any other particles or smell if any. This then goes into the DM facility to make it fit for boiler feed water.

The pretreating tank has a sludge recirculation pump to maintain flocculants for better settling of particles. It is also added with alum and polyelectrolyte for better performance and thus it gives a water with turbidity less than 4 NTU. This water is then supplies to the sand filter and the carbon filter for further reduction of turbidity. The pretreating tank needs frequent blowdowns when the turbidity starts to increasing in the outlet or as visually seen from over the tank. Also as the differential pressure of the sand filer and carbon filter tanks increase, they need a backwash to remove the settled particles. This entire blowdown and backwash water was initially collected in a pit and transferred to the effluent treatment plant. The idea was to reuse this water.

On calculating the turbidity of the collected water, it was observed that the turbidity was around 4 NTU. For trial purpose the line was laid to the pretreating tank and the water was reused as raw water.

To avoid the sudden increase in inlet turbidity, the alum and polyelectrolyte reciprocating dosing pump strokes were increased by 30%. The optimum turbidity was obtained when the pump strokes were increased by 40%. Also to avoid the settling of dirt in the bottom of the water collection pit, a bubbler header was installed inside the pit and minimum plant air flow was maintained to keep the particles in suspension.

**Table5:** Poly-Alum dosing adjustment

| Date | Backwash | Turbidity before BW, NTU | Turbidity after BW, NTU | BW PIT Turbidity | PT Turbidity after transfer | Alum stroke increase, % | Poly stroke increase, % |
|---|---|---|---|---|---|---|---|
| 04-05-17 | PSF | 2 | 0.75 | 5.6 | 2 | 30 | 30 |
| | ACF | 1.8 | 0.55 | | | | |
| 05-05-17 | PSF | 2.1 | 0.7 | 5.4 | 1.5 | 35 | 35 |
| 06-05-17 | PSF | 2 | 0.7 | 5 | 2 | 35 | 35 |
| | ACF | 1.8 | 0.5 | | | | |
| 07-05-17 | ACF | 1.9 | 0.55 | 5.2 | 2.1 | 30 | 30 |
| 08-05-17 | PSF | 1.9 | 0.75 | 4.3 | 1.8 | 40 | 40 |
| | ACF | 1.9 | 0.5 | | | | |
| 09-05-17 | PSF | 2 | 0.7 | 4.8 | 2 | 40 | 40 |
| | ACF | 1.9 | 0.5 | | | | |
| 10-05-17 | PSF | 2 | 0.7 | 4.9 | 1.4 | 40 | 40 |
| | ACF | 1.9 | 0.6 | | | | |
| 11-05-17 | PSF | 1.8 | 0.8 | 5.6 | 1.4 | 40 | 40 |
| | ACF | 1.9 | 0.5 | | | | |
| 12-05-17 | PSF | 1.8 | 0.75 | 5.5 | 2 | 35 | 35 |
| | ACF | 1.8 | 0.55 | | | | |

**Table6:** Performance of cationic and anionic polyelectrolyte

| | | | | | |
|---|---|---|---|---|---|
| | Concentrations (W/W%) | | | | |
| | Alum | 1% | 10,000ppm | | |
| | Poly | 0.10% | 1000ppm | | |
| | | | | Turbidity (NTU) | |
| Case | Alum sol. | Poly sol. | Raw water | Before | After |
| 1 | 30ppm (1.2ml) | 1ppm (0.4ml) Cationic | 400ml | 6.84 | 4.21 |
| 2 | 30ppm (1.2ml) | 2ppm(0.8ml) Cationic | 400ml | 6.84 | 4.2 |
| 3 | 30ppm (1.2ml) | 2ppm(0.8ml) anionic | 400ml | 6.84 | 1.9 |
| 5 | 30ppm (1.2ml) | 4ppm (1.6ml) Cationic | 400ml | 6.84 | 2.32 |
| 6 | 30ppm (1.2ml) | 0.5ppm (0.2ml) Cationic | 400ml | 6.84 | 1.85 |
| 7 | 30ppm (1.2ml) | 0.25ppm (0.1ml) Cationic | 400ml | 6.84 | 1.39 |

Both cationic and anionic polyelectrolyte were tested for the new scheme and the already in use anionic polyelectrolyte performed fine. The cationic polyelectrolyte was used in the effluent treatment plant for sludge separation. It was a thicker solution when made with the cationic polyelectrolyte. Although at lower concentrations it performed better as compared to the cationic polyelectrolyte but the water still appeared a bit sticky and could harm the resin beds that followed and thus the same anionic polyelectrolyte was continued to use.

## II. OPTIMIZING PLANT PROCESSES TO IMPROVE THROUGHPUT

2.2 Improving the OBR of DM plant to decrease regeneration cycles

2.2.1 Mixed different resin beds

The Output between two regeneration (OBR) is the amount of raw water the resins can convert to DM water before they require Acid/Alkali injection to regenerate their exchange capacity. The idea was to make changes in the resin and the regenerative cycles to get results.

The entire resin beds ran with a strong resin stock which was provides by the vendor. After testing the inlet water quality it was found that the inlet pH did not vary much and also the silica and turbidity remained constant throughout the year. The inlet water had limited amount of calcium and magnesium which also did not vary much. A test was conducted and was found out that a resin ration of 4:3 (Strong:Weak) performed well. The OBR before the said change was around 1900-2050 m3 for cationic and anionic beds. After the modification it went up as much as 2900m3.

It was additionally observed over time that the pH in the neutralization pit which had the regenerated water in in was constantly staying on a higher side after the modification, i.e. more amount of alkali was going in than required according to the older standards.

**Table7:** Changing NaOH quantity for regeneration

| | | |
|---|---|---|
| Dimension of NaOH tank | | |
| d | 1.4 | m |
| h | 1.2 | m |
| Required quantity for regeneration | | |
| % | Kg | |
| 100 | 230 | |
| Available NaOH | | |
| % | kg | |
| 48 | 479.17 | |
| Sp. Gravity of 45% NaOH | 1.45 | |
| NaOH required | 330.46 | Lit. |
| Area of NaOH tank | 1.54 | |
| Level of NaOH in tank | 0.21 | m |

Using the concentration and the alkali tank dimensions, it was found out that almost 35-40% of less alkali was now required for the regeneration which also saved on chemical costs and handling.

**Table8:** NaOH dilution required

| Water to be added to get 30% concentration solution(V) | | |
|---|---|---|
| N1 | 48 | |
| N2 | 30 | |
| V1 | 330.4598 | |
| V2 | 528.7356 | |
| | | |
| V (Water to be added) | 198.2759 | Lit. |
| | 0.128786 | m |
| Level of water to be added | 12.87857 | cm |

2.2.2.Improved regeneration technique

Another improvement that led to a great improvement in OBR and also improves the quality of DM water was the change in regeneration cycle. The following backwash regeneration cycle was performed after every five regular regenerations.

a. Backwash, Extended and at lower flow followed by optional air scouring
b. Bed settling (1min)
c. Injection
d. 2nd Injection followed by 3 min soaking
e. Slow rinse extended by 5 mins
f. Fast rinse

This resulted an improved turbidity and Millipore and also maintained the pH of DM water for longer time.

2.3 Rainwater used as raw water

Another measure taken to save water was to construct collection pipelines from every big roof of the facility. The idea was to collect as much rain water as possible to decrease the raw water consumption during the rainy season. With an average rainfall of 3.8m per annum, the entire facility was able to save almost 20MT of raw water.

Another benefit of this was that since the water was pure and almost free of dirt, the filter backwash frequency was also reduced to save even more water which was wasted. Also did this save on the alum and polyelectrolyte consumption in the pretreating tank due to better quality of water. Also was this a big achievement from environment point of concern.

The entire facility has a five cell cooling tower and the makeup for the cooling water was given from the raw water. This rainwater thus collected when pumped to make up for the cooling water also proved beneficial as the amount of organic and inorganic phosphate used were decreased due to less amount of corrosion seen on the dip plate. Also less algae formation on the fills improved the evaporation rates especially during the monsoons which improved the functionality of the cooling tower.

## III. CONCLUSION

The entire power plant facility has a power generation capacity of 90 MW and a DM generation of 400m3/ hr. On calculating the overall efficiency of the boilers and eventually the overall efficiency of the plant, after the said modifications, the effectiveness increased by over 28%.

The entire structure first started to show outcomes in the raw water consumption. Even during peak times the consumption decreased by 34.5% Also this led to a huge reuse of DM water which eventually saved the acid and alkali used during the regeneration of DM resins, thus improving the performance and increased OBRs. Ultimately this led to bottlenecking the acid and alkali stock as these are now required in lesser amounts. Thus decreasing the inventory costs and decreasing the hazards related.

With the size associated, the entire structure saved almost 117408.49$ annually added with environmental and safety benefits.

| | Savings PA (INR | Savings PA($) |
|---|---|---|
| Recovery from trap condensate | 3825000.84 | 58846.17 |
| Recovery from BD condensate | 2304004.73 | 35446.23 |
| Recovery BD flash steam | 113467.14 | 1745.65 |
| Recovery from Rain water harvesting | 904579.13 | 13916.60 |
| Recovery from filter BW | 484500.00 | 7453.85 |
| **Total Recovery cost** | **7631551.84** | **117408.49** |
| | | |
| Payback time (Years) | 0.6 | 0.6 |

With the costs associated for the entire project, the entire amount was calculated to have been recovered in a 6 months' time after which it was pure savings.

## IV. CHALLENGES ASSOCIATED

The only limitations associated with the entire project is shutdown of flash vessel and steam traps on temporary basis. Also the water from the recovery pit has to be monitored closely as it has to be pure enough to be taken directly into service or passed via the mixed bed as soon as the quality deteriorates. Also to avoid that the PM schedule of the online pH and conductivity meters were increased to maintain reliability.

The resin changing was a big step and was successful. Though the incoming water mostly remains same with the quality throughout the year, the turbidity increases during the monsoon and thus affecting the resin bed performance and decreasing the OBR and thus the turbidity has to be closely monitored and the filter backwashing has to be altered accordingly. This has to be done very carefully as the water quality can change anytime and thus only one stream at a time was changed keeping the second as it is.

Also due to the overall change in water schematics, the COD loading in the effluent treatment plant decreased which eventually decreased the MLSS thus harming the bacteria. Additional nutrition had to be added like Urea to make up for the COD loss.

## V. REFERENCES

[1]. Richard E. Putman, *Steam surface condensers* (ASME Press, 2001, the University of Michigan).

[2]. Venkateswarlu K.S. (1982), *Feed Water Quality Control for Fossil Fuel and Nuclear Boilers*, Proc. Seminar of Instrument society of America (Bombay chapter), INTEQ, 6-13, Nov.

[3]. Heinz P. Bloch, *A Practical Guide to Steam Turbine Technology* (McGraw Hill, 1996).

[4]. Venkateswarlu K.S., *Water chemistry Industrial and Power station water treatment*, (New Age International Publishers).

[5]. Randall T.L. and P.J. Canney, (1985), *Wet Air Oxidation of Hazardous Organics in Waste Water*, *Environmental Progress*, 4, 171.

[6]. Patil R.D., (1992), *Water Management Practices in Fertilizer Industry*, Ibid. G.I – G.20, November.

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