International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:10, No:4, 2016

Technology Identification, Evaluation and Selection Methodology for Industrial Process Water and Waste Water Treatment Plant of 3x150 MWe Tufanbeyli Lignite-Fired Power Plant

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Abstract**—**Most thermal power plants use steam as working fluid in their power cycle. Therefore, in addition to fuel, water is the other main input for thermal plants. Water and steam must be highly pure in order to protect the systems from corrosion, scaling and biofouling. Pure process water is produced in water treatment plants having many several treatment methods. Treatment plant design is selected depending on raw water source and required water quality. Although working principle of fossil-fuel fired thermal power plants are same, there is no standard design and equipment arrangement valid for all thermal power plant utility systems. Besides that, there are many other technology evaluation and selection criteria for designing the most optimal water systems meeting the requirements such as local conditions, environmental restrictions, electricity and other consumables availability and transport, process water sources and scarcity, land use constraints etc. Aim of this study is explaining the adopted methodology for technology selection for process water preparation and industrial waste water treatment plant in a thermal power plant project located in Tufanbeyli, Adana Province in Turkey. Thermal power plant is fired with indigenous lignite coal extracted from adjacent lignite reserves. This paper addresses all above-mentioned factors affecting the thermal power plant water treatment facilities (demineralization + waste water treatment) design and describes the ultimate design of Tufanbeyli Thermal Power Plant Water Treatment Plant.

Keywords**—**Thermal power plant, lignite coal, pre-treatment, demineralization, electrodialysis, recycling, waste water, process water.

I. Introduction

THERMAL power plants are industrial facilities generating electricity power by means of combustion of fossil fuels such as coal, fuel oil and natural gas. Considering entire power generation process, it is unavoidable that there are many environmental and social impacts caused by thermal power plant investments. During design phase, these impacts must be assessed, addressed and mitigated sufficiently.

Potential environmental impacts of a thermal power plant can be categorized as stack emissions, fugitive dust emissions; raw water utilizing from natural sources, industrial and domestic waste water generation, environmental noise and vibration and solid wastes [1].

Today's life is strongly dependent on available energy resources and usable reserves that can be utilized for energy supply which is also growing day by day. Up to date, worldwide energy generation was highly dominated by fossil fuel sources which have been diminishing gradually; renewable energy technologies have been developing and renewable energy generation share is also increasing. It is projected that non-renewable energy resources will still remain on the stage in near future. This fact led to the development of new energy policies and legislations. [1]

Today's advanced environmental systems are aiming at reducing significant power plant emissions. There are many techniques available in the market and they achieve improved efficiency and lower air and water emissions [1].

Since thermal power generation is based on heat transfer; it yields to thermal discharges into ambient water courses. Water bodies are thermally polluted by such power facilities due to thermal pollution, water quality, temperature and aqua life change [2].

Power plant investors and designers should adopt these technologies in order to come up with a power plant design in which environmental impacts are well managed.

II. Project Description

Enerjisa has constructed up "450 MWe Tufanbeyli Thermal Power Plant, Coal Fields and Limestone Quarries Project" with an attempt to utilize a domestic and reliable source of energy with low costs and high yields. The proposed project area is located, between Yamanli and Kayarcik villages in Tufanbeyli District of Adana Province in Turkey. The Tufanbeyli thermal power plant (TPP) will use 826.5 ton/hour of lignite from the nearby opencast mine (OCM) generating about 3 billion kWh of electricity annually.

The gross capacity of TPP is 450 MWe (3x150 MWe), which will use 5.5 Mt of lignite per year from the nearby OCM to generate about 3 billion kWh of electricity. The TPP is operated based on circulating fluidized bed (CFB) lignite method including flue gas desulfurization. There are also limestone quarries operated within the scope of the project in order to supply limestone to feed the boilers using CFB technology and flue gas desulfurization (FGD), which will be used for the removal of sulphur dioxide (SO_2) from the flue gas of the boilers to meet the air quality standards.

The main project units can be listed as the following:

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- Coal Handling System
- Coal conveying and crushing plant
- Limestone handling and crushing plant
- Boiler Plant
- Flue Gas Desulfurization System (FGDS)
- Steam Turbine and Generator
- Cooling Water System
- Ash Handling System
- TPP Electrical System
- Auxiliary Installations

TABLE I
RAW WATER CHARACTERISTICS

Component	Range (min-max)
Calcium (Ca^{+2})	104.0 – 139.4 ppm $CaCO_3$
Magnesium (Mg^{+2})	59.8 – 110.0 ppm $CaCO_3$
Sodium (Na^{+})	8.1 – 19.6 ppm $CaCO_3$
Potassium (K^{+})	1.2 – 1.3 ppm $CaCO_3$
Bicarbonate	170.0 – 196.0 ppm $CaCO_3$
Carbonate	0 ppm $CaCO_3$
Hydroxide	0 ppm $CaCO_3$
Sulphate	12.3 – 31.0 ppm $CaCO_3$
Chloride	14.5 – 20.0 ppm $CaCO_3$
Nitrite	0 ppm $CaCO_3$
Nitrate	3.8 ppm $CaCO_3$
Total hardness	199.3 – 220.0 ppm $CaCO_3$
M-Alkalinity	170.0 – 196.0 ppm $CaCO_3$
P-Alkalinity	0 ppm $CaCO_3$
Carbon dioxide	5.5 – 9.6 ppm $CaCO_3$
Silica	0.0 – 5.4 ppm SiO_2
Organic matter	5.6 – 6.4 ppm O_2
Ammonia	0.0 – 0.1 ppm NH_3
Iron	0.1 – 0.8 ppm Fe
pH (25 °C)	7.5 – 8.0
Conductivity (25 °C)	405.0 – 442.0 μS/cm
Total dissolved solids	266.5 – 287.0 ppm
Suspended matter	2.6 – 3.9 ppm
Turbidity	2.0 – 2.2 NTU
Total coliform	>1100 Unit/100 mL
Fecal coliform	>1100 Unit/100 mL

III. TECHNOLOGY IDENTIFICATION, EVALUATION AND SELECTION OF WATER TREATMENT PLANT TECHNOLOGY

Ultimate water treatment plant design is determined based on raw water characteristics and desired demineralized water quality. During 2006-2010 preconstruction, water quality monitoring studies have been conducted. Raw water quality is continuously monitored on a monthly basis during construction and operation phase. All available water sources in the region have been analyzed seasonally since the water sources tend to change their quality with respect to seasonal and geological changes. Surface water, ground level characteristics and lignite-field dewatering water quality have been analyzed in detail. Based on all these water data, design range of each parameter has been defined.

IV. DEMINERALIZATION PLANT

Demand for demineralized water has been growing in parallel with industrial developments. Available water sources differ from each other with respect to water quality. This has a significant impact on product water quality and investment and operational costs. Nowadays, there is no doubt that membrane technologies are the most economical and efficient for water treatment plants. They significantly reduce chemical-laden waste water generation and chemical consumption. [3]

Demineralized water means the water having electrical conductivity less than 0, 2 micro Siemens/cm and silica content less than 20 ppb. Sodium and potassium content should be less than 10 ppb in total.

Demineralization is series of treatment methods for removal of all mineral matter from the raw water in order to produce demineralized boiler feed water and to maintain high heat-transfer efficiency in the boiler by preventing deposition of precipitated scale and preventing corrosion of surfaces in contact with water. In addition, since steam is admitted into steam turbine to power generation; a higher water quality is mandatory to meet requirements of the turbine manufacturer in order to protect turbine blades.

Demineralization can be performed in many ways including ion exchanging or advance membrane technologies. Double pass reverse osmosis processes can enable us to produce highest quality and to generate minimum reject waste.

The core purpose of the Water Treatment System is to produce sufficient quantity and quality demineralized water needed in Tufanbeyli Thermal Power Plant (3 X 150MWe) water/steam cycle. The demineralized water unit production capacity will meet all demineralized water consumption during the Power Plant operation.

As an environmental impact assessment study commitment, Tufanbeyli TPP has been designed as per “zero liquid discharge principle”. The main criteria for the selected technology is achieving desired water quality and minimum waste water generation which further will be recycled. Low operation cost, minimum chemical consumption, minimum maintenance requirements are the other factors to be considered during design phase.

V. SYSTEM FUNCTION AND DESCRIPTION

The water treatment process consists of the following stages:

- Pre-chlorination
- Inline Coagulation
- Multi Media Filtration
- Ultrafiltration Unit
- Dechlorination with Activated Carbon Filters
- Demineralization via Double Pass Reverse Osmosis
- Continuous Electrodeionization

Ultrafiltration (UF) is a variety of membrane filtration in which driving forces like pressure or concentration gradients lead to a separation through a semi-permeable membrane. Particles greater than pore size are rejected. In comparison with conventional filtration, UF achieves finer sieving capabilities which also removes microorganisms and colloids. This enables us to run the plant more properly.

Disinfected raw water should be pre-treated in a way so that the strainers and the UF modules can operate more effectively. Feed water is filtrated through auto-back filters and multi-media filters before entering into UF membranes.

Main purpose of the strainers is to protect the UF membranes from harmful or fouling materials. Strainer mesh size may be around the 150 – 300 µm.

Inline coagulant dosing is applied upstream of the UF modules for improving process parameters and maintaining stable operation conditions; it also enhances TOC rejection. Inline coagulant dosing is necessary for raw water sources that are characterized by high suspended solids. Coagulation mechanism forms micro-flocks, which can be easily retained on the membrane surface. Deposited flocks can be removed efficiently by a normal backwash.

Temperature and pH values of feed water must be controlled and monitored strictly to avoid flock formation inside the membrane fibers; otherwise coagulation will create operational problems.

UF cycle is comprised of chemically enhanced backwash and backwash cycles that are executed automatically with respect to volume and time. Primarily, feed water parameters are determining criteria for the operating mode sequence [3].

Reverse osmosis (RO) is a membrane filtration method that removes various large molecules and dissolved ions from solutions by applying pressure to the solution. Therefore, undesired matters are filtered through selective semi-permeable membrane due to pressure gradient.

Reverse osmosis is widely known in water purification from surface water, sea water and brackish water. RO membranes remove the salt and other colloidal substances from the water molecules. Reverse osmosis is the reverse of the normal osmosis process in which the water naturally flows from low solute concentration to high solute concentration through a membrane.

The movement of a pure solvent to equalize solute concentrations on each side of a membrane generates a pressure and this is the "osmotic pressure." Applying an external pressure to reverse the natural flow of pure water, thus, is reverse osmosis. Double pass RO design allows treating reject stream so it reduces waste water generation.

Conventionally, mixed bed ion exchangers in which strong anion and strong cation resins are loaded are used after reverse osmosis to remove trace amount of salts. Resins are exhausted after a certain time and they need to be regenerated with acid and caustic to make them return their initial forms. Regeneration cycle requires tons of chemicals. Tons of waste water are generated and transferred to neutralization where more chemicals are needed. Therefore, electrodeionization has been selected due to its advantages against mixed bed columns.

As an improvement on electrodialysis, CEDI has been designed to make higher purity water. CEDI improves mass transfer and reduces electrical resistance.

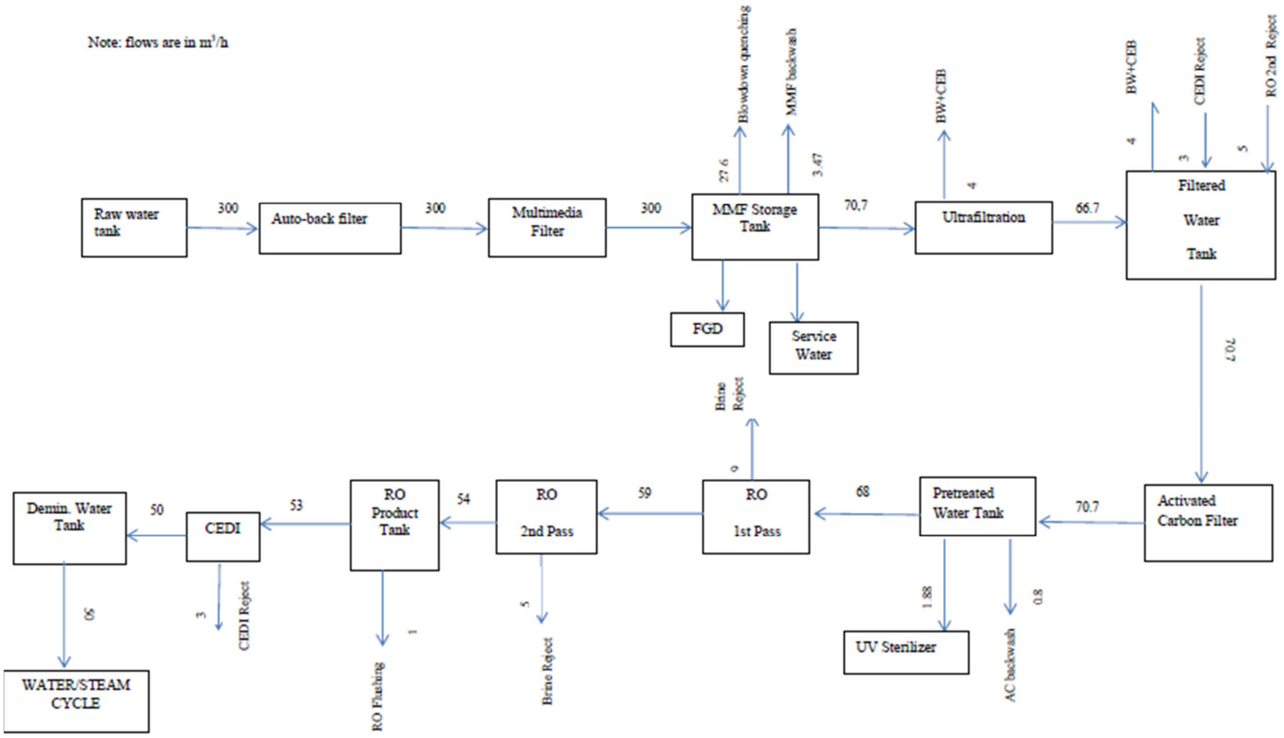

Fig. 1 WTP Mass and Flow Diagram

The CEDI process combines two processes; electrodialysis and ion exchange. CEDI process provides improved conductivity decrease. Therefore, energy consumption is reduced for diluted saline solutions. Cation and anion exchange membranes are placed between anode and cathode electrodes. Central compartment is filled with ion exchange material enhancing electron transportation due to driving force of direct current. [3]

In comparison with mixed bed in exchanger column; CEDI does not require any chemical use for regenerating the resins and does not generate any regeneration waste. Therefore, we have implemented CEDI method instead of conventional mixed bed column.

VI. Water Treatment Plant Characteristics

Design calculations of the water treatment process are based upon the raw water quality and the required quality of the demineralized water. The Demineralized Water Treatment System has a capability to produce 2x50m^3/hour demineralized water in continuous operation.

The plant consists two lines; each of 100% required net capacity.

During normal operation one line will be in service, while the second is at standby [5].

TABLE II
Water Mass Balance @ 20ºC Water Temperature

Stream	Flow rate
UF Feed	70.1 m^3/h
UF Product	68.2 m^3/h
UF Backwash/CEB	2.9 m^3/h
1st Pass RO Feed	68.2 m^3/h
1st Pass RO Product	59.0 m^3/h
1st Pass RO Reject	9.2 m^3/h
2nd Pass RO Product	54.0 m^3/h
2nd Pass RO Reject	5.0 m^3/h
CEDI Product	50.0 m^3/h
CEDI Reject	2.82 m^3/h

The plant operates with 50m^3/h water flow rate, 360 days/year and 24hours/day.

VII. Waste Water Treatment Plant

Waste water treatment conventionally is considered as an individual part of core process. Water scarcity, legislative obligations and operational costs make the power sector change this approach and integrate waste water treatment philosophy into initial design. Braggen and Braeken suggests three steps for waste water treatment such as examining current water mass balance, optimization of water consumption and waste generation and establishing an overall waste water management concept with zero-discharge or virtual zero discharge principle [4]. Tufanbeyli TPP wastewater is classified as industrial wastewater which is generated during the thermal power plant processes. The design purpose of thermal power plant WWTP is to treat waste water streams sourced from thermal power plant (3x150MWe) and recycle treated waste water into the process.

Although, treated waste water is not discharged into ambient environment, the waste water treatment system has been designed as a common system to comply with the legislative waste water emission limits.

Total quantity of waste water includes all produced waste waters during the process; however; all waste water sources are not continuously producing waste water.

The flow rate of the waste water treatment plant is 50 m3/h. The main objective is recycling all treated industrial waste water within the process [5].

Waste water treatment plant is based on suspended solid removal with coagulation/flocculation, oil removal in an oil separator and neutralization. The calculation of the waste water treatment process is based upon the waste water quality generated by the entire process. Main waste water streams are reverse osmosis reject brines, filter backwash water, floor drains, chemical laboratory drains, boiler blow-down and condensate polishing plant wastes. Treated waste water is collected in reuse basin. Treated waste water is transferred for ash moistening and flue gas desulphurization storage tank [5].

TABLE III
Waste Water Streams

Waste Water Source	Daily Flow rate
Boiler Blow down	397 m^3/h
Brine Water	199 m^3/h
Chemical Waste	588 m^3/h
Oily Waste Water	24 m^3/h
Total	1209 m^3/h

VIII. Conclusion

Chemistry and power generation intersect at many points. Historically, chemistry makes considerable contributions for best possible efficient and environmentally friendly power plant design. Efficient production of power, effective production of ultrapure process water, minimization corrosion and scaling effects, minimization waste generation and maximizing recycling possibilities are expertise of chemistry discipline [6]. Thermal power plant adverse impacts are resulted from mainly chemistry of fuel and chemistry of emissions.

It is possible to design zero-discharge industrial plants thanks to advanced treatment techniques and multi-disciplinary working in our era. More focus should be given on process waste water minimization especially from boiler blow-downs, wet scrubber wastes etc. Tufanbeyli TPP does not discharge any waste water into environment. After reuse basin, all treated waste water is recycled within the process. More improvements can be made during operation phase to minimize waste water generation.

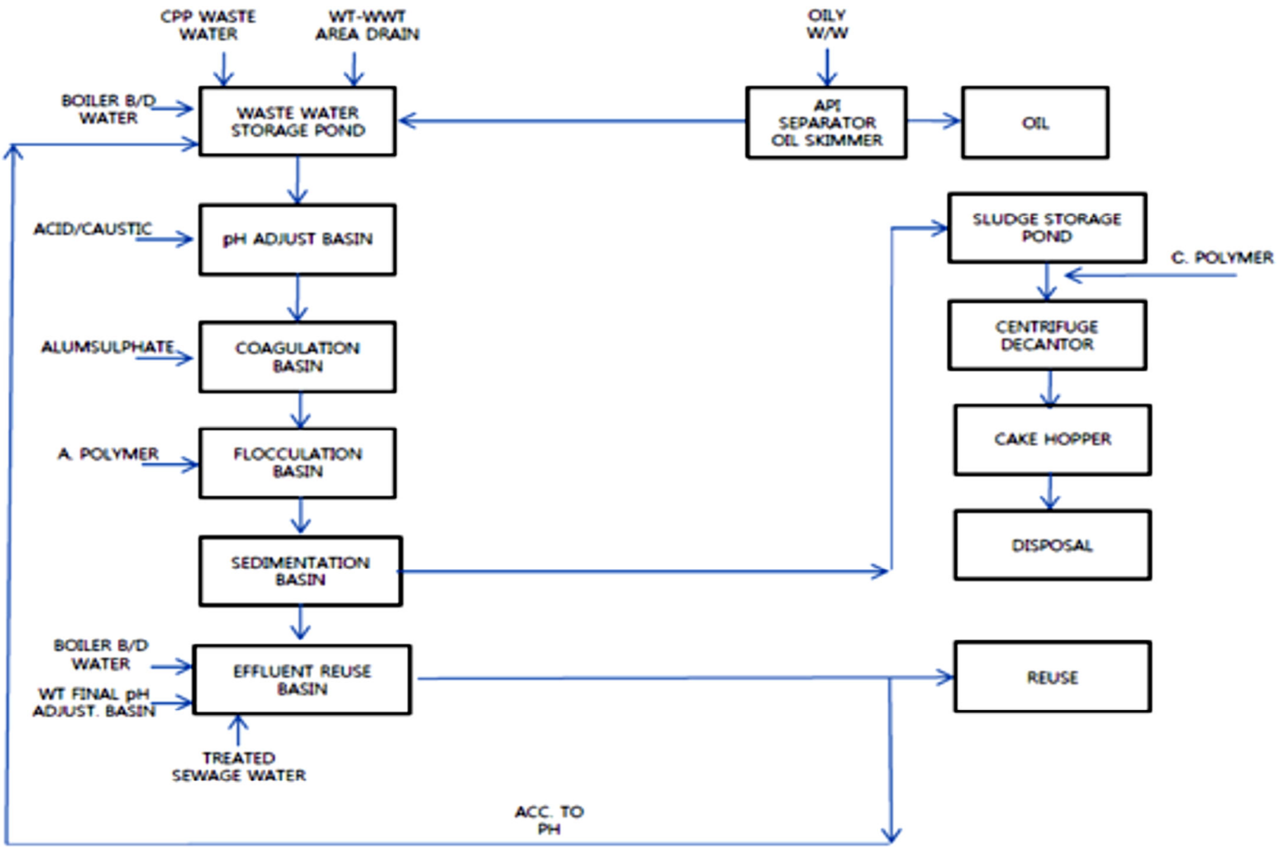

Fig. 2 WWTP Flow Diagram

ACKNOWLEDGMENT

Author would like to convey acknowledgements for all our contractors and subcontractors who contribute to the project.

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