Reverse Osmosis Options for Water Supply to a Thermal Power Station

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Abstract—Water in industry is used for operations such as production processing, washing, dissolving, cooling, transportation. Industries often require large amount of water with vary quality. Water quality depends on the purpose of water use. The steam electric power generation industry is defined as that establishment primarily engaged in the steam generation of electrical energy for distribution and sale. Those establishments produce electricity primary from a process utilizing fossil type fuel (coal, oil, or gas) or nuclear fuel in connection with a thermal cycle employing the steam–water system as the thermodynamic medium [2]. Water with in boiler drum and steam generation tubes and headers must be soft and clean. Reverse Osmosis is an effective and proven technology to produce water that is suitable for many industrial applications that require demineralized or deionized water with neutral pH and without turbidity and aggressive.

Index Terms—Reverse Osmosis, Fossil–Type Fuel, Neutral pH, Demineralized Water, Turbidity, Aggressive.

I. INTRODUCTION

Reverse osmosis is a technology that is used to remove a large majority of contaminants from water by pushing the water under pressure through a semi – permeable membrane.

In recent years, membrane processes have been used increasing for the production of industrial waters so reverse osmosis (RO) became the best technology after the development of efficient membrane and the use of energy recovery devices.

A. Technical and Economical Relevance of Reverse Osmosis

Although typically thought to be expensive and relatively experimental; membrane technology is an advancing quickly, becoming less expensive, improving performing, and extending life expectancy.

B. Reverse Osmosis Process

Reverse Osmosis is the flow solvent through semipermeable membrane, from a concentrated solution to dilute solution. This flow results from the driving force created by the difference in pressure between the two solutions.

Osmotic pressure is the pressure that must be added to the concentrated solution side in order to stop the solvent flow through the membrane. Reverse Osmosis is the process of reversing the flow forcing water through a membrane from a concentrated solution to dilute solution to produce filtered water (see Fig. 1 and 2, the osmosis process).

C. Reverse Osmosis Advantages:

Reverse Osmosis (RO) has a number of innate advantages. Because it is all liquid and use hydrostatic pressure as energy source, RO modules plant can be very compact, operation is relatively simple and modules are readily replaced, furthermore the energy input can be quite low because it can approach the free energy of separation [10].

The objective of this paper is to design a reverse osmosis plant to produce pure water to make steam in boilers of thermal power station (Dr. Sharief electric power plant).

For precious advantages of RO, it became better than the ion exchange, because ion exchange consumes large quantities of regeneration chemicals such as brine, acid, and caustic materials that can present significant handling and disposal problems, also this paper investigate of the economic cost of installing Ro plant:

Thermal power plant in Sudan contribute 40% of total electric power generation. In Sudan there are three big
thermal power plants of total capacity 1330 MW the biggest one total capacity 580 MW and the second is 380 MW (Dr. Sharief Power station).

The case study of this paper wills focus on the second power plant (Dr. Mohmoud Sharief): (formally Bahri Thermal Station)

D. Water transmission and treatment

Water transmission and treatment has two plants:
1. Clarified water plant.
2. Demineralized water plant.

This station was established to meet the shortage of electricity generation especially during the Flood season or in summer period when the water level in Nile River decreased.

This station helps to:
- Improve the performance of the national grid.
- Meet the increase in energy demand due to the expansion of the industries, agriculture and urban project.
- Increase the amount of energy generation provided by the national grid.

II. MATERIAL AND METHODS

The membrane system design depends on available feed water and the application. The system design information and the feed water analysis should be collected first.

Table 1: explain the Blue Nile river analysis in Table II
Sample 1 (2) explain clarified water analysis in Table II, the clarified water is the source feed water of RO design of Dr. Sharief Station the case study of this paper

A. Methodology

TABLE III shows parameters of clarified water which I will explain in test method (pH, conductivity, turbidity, total dissolve solid (T.D.S) and total suspend solid (T.S.S) and SDI

Test methods: see table (1) explain ASTM methods for properties of water.

**TABLE I: ASTM METHODS FOR WATER PROPERTIES**

| No | Test     | Methodology       |
|----|----------|-------------------|
| 1  | PH       | ASTM D 1293-99    |
| 2  | Conductivity | ASTM D 1125-95   |
| 3  | Turbidity | ASTM D 1889-00   |
| 4  | Total hardness | ASTM D 1126.02  |

**TABLE II: BLUE NILE RIVER WATER ANALYSIS**

| Sample 500 mL  | Sample1000 | Sample1500 |
|----------------|-------------|-------------|
| Test Average  | Average     | Average     |
| 1 PH           | 8.04        | 7.55        | 7.95        |
| 2 Conductivity | 8.62        | 566         | 614         |
| 3 Turbidity    | 1.63        | 10.8        | 12.0        |
| 4 TDS          | 689         | 692.8       | 491.2       |

1) pH

The standard test for pH of water is Direct standardization technique. It is employed in this test method for routine batch samples two buffer solutions are used to standardize the instrument under controlled parameters.

2) The conductivity of water

The conductivity of water is applicant to field and routine laboratory measurement of electrical conductivity of water using static sample.

**TABLE III: ANALYSIS OF CLARIFIED WATER BEFORE FILTRATION**

| Sample 500 mL  | Sample1000 | Sample1500 |
|----------------|-------------|-------------|
| Test Average  | Average     | Average     |
| PH value      | -           | 7.6         | 8.2         | 8.4 |
| Total Al kalinity | ppm caco₃ | 60          | 102         | 194 |
| Calcium Hardness | ppm caco₃ | 20          | 27          | 120 |
| Magnesium Hardness | ppm caco₃ | 5           | 27          | 90  |
| Specific conductivity | ppm caco₃ | 130         | 207         | 428 |
| Ammonia       | ppm NH₃     | 0.1         | 1.9         | 1.65 |
| Calcium       | ppm ca      | 8.0         | 11.0        | 48.0 |
| Magnesium     | ppm mg      | 1.2         | 6.5         | 21.6 |
| Chloride      | ppm         | 50          | 13.2        | 45.0 |
| Sulphates     | ppm so₄     | 4.8         | 94          | 199 |
| Total suspended solid | ppm | 10         | 15          | 20  |
| Free chlorine | ppm Cl₂     | 0.1         | 0.5         | 1.0 |

**TABLE IV: CLARIFIED WATER ANALYSIS**

| Samples       | unit | min | Aver | Max |
|---------------|------|-----|------|-----|
| PH value      | -    | 7.6 | 8.2  | 8.4 |
| Total Al kalinity | ppm caco₃ | 60 | 102 | 194 |
| Calcium Hardness | ppm caco₃ | 20 | 27 | 120 |
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| Calcium       | ppm ca  | 8.0 | 11.0| 48.0 |
| Magnesium     | ppm mg  | 1.2 | 6.5 | 21.6 |
| Chloride      | ppm    | 50  | 13.2 | 45.0 |
| Sulphates     | ppm so₄ | 4.8 | 94 | 199 |
| Total suspended solid | ppm | 10 | 15 | 20 |
| Free chlorine | ppm Cl₂ | 0.1 | 0.5 | 1.0 |

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3) The turbidity of water

The turbidity of water is done by the photo electric nephelometer operation. It is based on instrumental comparison of intensity of light scattered by the contained static water sample under defined conditions to intensity of light scattered by reference standard light. The higher the intensity of scattered light, the higher turbidity of sample.

4) The hardness

The hardness is calcium and magnesium ions in water. It is sequestered by addition of disodium ethylene -di-amino tetra acetate. The end point of the reaction is detected by means of chrome black T, which has a red color in the presence of calcium and magnesium and a blue color when they are sequestered.

5) Dissolved (TDS)

Substance that are completely water soluble A direct relationship between TDS and conductivity there is no exact conversion

TDS (mg/L) = 0.67 * electrical conductivity

6) SDI (silt density Index):

The SDI test procedure in eludes the following
- A 500 ml volume feed water is forced through a standard filter under special test conduction
- After 15 min the is repeated using the same filter
- The filtration time t1 and t2 are used to determine the SDI

SDI = (1 - \(\frac{t_2}{t_1}\)) x 100

Where T is 15 minutes

Other test conditions include the following
- Applied pressure difference across the membrane is 2 bar
- Filter pore diameter is 0.45mm
- When t2 is for time t1, the SDI equal5
- A water sample that totally blocks the membrane filter has a SDI value 6.7
- SDI < 5 max, standard SDI < 3

The procedure to design RO/NF membrane system can explain in 10 steps:
- Step 1: Consider feed source, feed Quality product flow and required product quality
- Step 2: Select the flow configure and number of passes.
- Step 3: Select Average Membrane flux [Design Flux]
- Step 4: Select Membrane and Element type
- Step 5: Calculate the number of Element Needed
- Step 6: Calculate the Number of pressure vessels Needed
- Step 7: Select the number of stages
- Step 8: Select the staging Ratio (Array Ratio)
- Step 9: Balance the permeate flow rate
- Step 10: Put Data of preliminary Calculation of the chosen system to be analysis, using the Reverse Osmosis System Analysis (ROSA) computer program this program calculates the feed pressure and permeate quality of the system as well as the operating data of all individual elements.

III. RESULTS AND DISCUSSIONS

A. Importance definitions and equation

1) Recovery %

Percent Recovery is the amount of water that being ‘recovered’ as good permeate water.

\[ \text{Recovery} \% = \frac{\text{permeate flow rate (gpm)}}{\text{Feed flow Rate (gpm)}} \times 100 \] (1)

2) Flux

Flux is the rate of permeate flow per membrane area.

\[ GFd = \frac{\text{gpm of permeate 1,440 min/day}}{\text{number of ro element x Square footage of each element}} \] (2)

3) The type of membrane in RO system

1- [Dow film etc Bw -365] this type of membrane has 365 square feet of surface area

2- [Dow Filmotec BW-40] Surface area 400 square feet.

Below is general rule of thumb for Flux ranges for different source water.

| TABLE V: FEED WATER SOURCE AND FLUX |
|------------------------------------|
| Feed water source                  | GFd  |
| 1- Sea water Effluent              | 5-10 |
| 2- Sea water                       | 8-12 |
| 3- Brackish                        | 10-14|
| 4- Brackish water well             | 14-18|
| 5- Ro permeate                     | 20-30|

| TABLE VI: NUMBER OF STAGES OF BRACKISH WATER SYSTEM |
|----------------------------------------------------|
| System Recovery %                                  | Number of element stages (6-element) |
| 40-60                                              | 1                                |
| 70-80                                              | 2                                |
| 85-90                                              | 3                                |

B. The staging Ratio (Array–Ratio):

For a system with four vessels in the first stage and two vessels in second stage the stage ratio 2:1

C. Two-stage system defined as:

The concentrate (or reject) from the first stage then becomes the feed water to the second stage. The permeate water is collected from the first stage is combined with permeate water is collected from the second stage see Fig. 3.

Fig. 5. Two Stages RO System
D. Economical Evolution
The total cost of installing Ro plant =
Cost of process + cost of building for Reprocess + man power Cost. Cost of process (cost / year)

| Parameter to be calculate to design Ro | Value and results |
|--------------------------------------|------------------|
| 1. Product flow permeate (needed)     | 50,000 m³/h     |
| 2. Average flux for brackish water "blue Nile" clarified water | 14 gfd or 25-30 L/m²/hr. |
| 3. Brackish water membrane active area | 37 m² or 400 ft² |
| 4. Number of membrane (needed)        | 54 membrane      |
| 5. Number of vessels (needed)         | 9 vessels        |
| 6. The staging ration array ratio      | 2:1 or 4:2       |
| 7. Number of stages                   | 2 stages         |
| 8. Recovery %                         | 80%              |
| 9. Pressure feed PF                   | 400 psi          |
| 10. SDI <5                           |                 |

TABLE VII: RESULTS OF DR. SHARIF THERMAL POWER FOR THE SUGGESTED RO PLANT

| Parameter to be calculate to design Ro | Value and results |
|--------------------------------------|------------------|
| 1. Product flow permeate (needed)     | 50,000 m³/h     |
| 2. Average flux for brackish water "blue Nile" clarified water | 14 gfd or 25-30 L/m²/hr. |
| 3. Brackish water membrane active area | 37 m² or 400 ft² |
| 4. Number of membrane (needed)        | 54 membrane      |
| 5. Number of vessels (needed)         | 9 vessels        |
| 6. The staging ration array ratio      | 2:1 or 4:2       |
| 7. Number of stages                   | 2 stages         |
| 8. Recovery %                         | 80%              |
| 9. Pressure feed PF                   | 400 psi          |
| 10. SDI <5                           |                 |

TABLE VIII: THE COST OF PROCESS

| Cost | SDG |
|------|-----|
| The price of 1 kw/h (commercially) | 0.36 |
| Cost of power /h | 4.356 |
| Cost power /year | 21083.04 |
| Cost of membrane | 30000.00 |
| Cost of 54 membrane | 162000.00 |
| Cost of accessories membrane | 200000.00 |
| Cost of chemicals and antiscalent | 240000.00 |
| The cost of process | 473083.00 |

2-Cost of building for Ro yearly = 200,000 SDG
3-The mam power cost = Salary + Cost of transpiration
The plant of Ro need: 1 Engineer + 6 techniques
Salary monthly (1000 + 6×2500)
Part (2) and (3) changing quickly in cost by SDG
The total cost to product one m³ permeate= 180, 06 SDG

Demin plant in the Dr. sharief thermal power in each regeneration chemicals cost is explain in Table IX.

The producing water = 50 ton/h
Per day = 50×24 = 1200 ton / day

Ton price = total cost of chemical materials producing water /day

1 ton cost = \( \frac{144,000}{1200} \) = 120 SDG
1 ton cost = 50- SDG = 2.5 $

TABLE IX: THE CHEMICAL COST IN EACH REGENERATION PROCESS IN DEMIN WATER PLANT

| Chemical Material | Quantity (Tons) | Ton price (SDG) | Total Cost (SDG) |
|-------------------|-----------------|-----------------|-----------------|
| 1.Sulphuric acid H₂SO₄ | 2               | 47,000          | 94,000          |
| 2.Sodium hydroxide NaOH | 0.51           | 100,000         | 50,000          |
| Total             |                 |                 | 144,000         |

IV. CONCLUSIONS

Industrial plants are use water After treatment and when use it to produce steam they use demin water, the aim of this work was to excess the possibility of effective removal ions responsible for water hardness and formation of scale deposits by ion exchange (Resin) and I was design plant to do the same process but use membranes namely RO. To produce 50 ton/h permeate form one train of clarified water.

In Preliminary calculation for brackish water (Surface water) from (Blue Nile) flux between (10-14) gfd and (400ft² filmatic membrane area)
Or (25 L/m² /h) the number of membranes needed was 54 membranes for each train and which require 9vessel for each train and recovery was 80% and the stages =2
And stage ratio (array) 2:1 this membrane under high pressure pump = 400psi (27bar).

V. RECOMMENDATIONS

Surface water always causes problem of fouling and high ratio of silts and organic material so when installing Ro Plant for Dr. Shrief station must put two cartridges filter before Ro also we can use the ion exchange with Ro in combination together to reduce chemical cost. Proper pretreatment and monitoring of Ro system is crucial to preventing costly repairs and unscheduled maintenance with the correct system

Elision maintenance program, and experience service support, Ro system should provide many years of high purity water.

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