ISSN: 2278-0181
Vol. 2 Issue 2, February- 2013

Design And Simulation Of Solar Thermal Energy System To Drive RO Desalination Plant

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Abstract

Energy is the essential ingredient of socio-economic development and economic growth. Renewable energy provides an environmental friendly option and national energy security at the time of decreasing global reserves of fossil fuels .The integration of renewable energy resources for desalination and water purification is becoming increasingly attractive. The paper presents mathematical modelling and simulation of thermoelectric power generator driven by solar parabolic dish collector and the RO system for desalination. The system is modelled by set of mathematical equations from the first law of thermodynamics for the sub-components of solar parabolic-dish collector and thermoelectric generator. This model is solved analytically for the a set of operating and design parameters.

1. Introduction

Rapid consumption of fossil fuels to meet the demand leads to environmental damage and shortage of fossil fuels are prompting search of alternative resources for sustainable future. Solar energy is one of the most interesting and promising source among other renewable energy sources. The availability of solar radiation over the earth is free. Thermoelectric generator is a solid state direct energy converter work on the principle of Seebeck effect, it has special feature such as absence of moving parts, compact in size, silent in operation, high reliability and does not produce any green house emission during its operation. It is attractive for application of solar concentrating collector due to its operation at varying temperatures. Many research on thermoelectric energy conversion reported with flat plate solar thermal collector, with solar parabolic concentrator , compound parabolic dish truncated and non truncated compound parabolic collector . The solar parabolic dish thermo electric generator principle is integrating thermoelectric generator on the focal region of parabolic dish collector to deliver the electrical energy for the local needs. This paper presents the mathematical modelling of solar parabolic dish thermoelectric power generator for a set of design and operating parameters. The power generated from this dish collector can be used to drive a booster pump, which provides part of the RO high pressure pumping demand.

2. Description Of The System

Figure 1 shows the arrangement of solar parabolic dish thermoelectric generator. It consists of a parabolic dish collector, uncovered flat receiver plate attached with thermoelectric modules on its focal plane. Thermoelectric modules are connected in electrically in series and are thermally parallel between the receiver plate and stainless steel box as the heat exchanger.

Thermoelectric modules of the hot side on the inner surface of receiver plate and cold side on the outer surface of stainless steel box are tightly fixed. The parabolic dish collector can be tracked manually east or west direction in order to absorb the solar beam radiation on the bottom of the receiver unit. To write the energy balance equations, the following assumptions are considered.

The intercept factor value is considered constant. The optical properties of receiver unit of solar dish collector are constant irrespective of the solar radiation. The receiver unit receiving the uniform concentrated flux and surface errors are eliminated. The contact surface of thermal resistance between the absorber plate, thermoelectric modules and stainless steel box are also neglected.

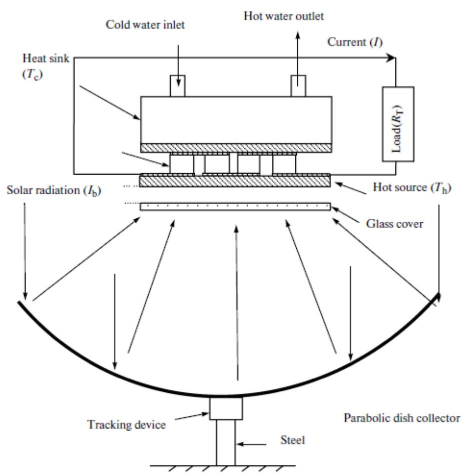

Figure 1. Arrangement of solar parabolic dish thermoelectric generator

3. Solar Thermal Analysis

3.1. The Dish Concentrator

The available dish concentrator having the mouth opening diameter *D* and the depth of dish is *h*. The incident energy received by receiver part of solar parabolic dish concentrator can be computed from this following equations

$$Qs = Ib\rho(\tau\alpha)e\gamma C. \qquad (1)$$

Where Ib is the Beam radiation incident on the concentrator surface (W/m2), ρis the electrical resistivity of the thermoelectric material, $(\tau\alpha)_e$ is the effective transmissivity and absorptive product of receiver surface, γ is the intercept factor, C *is the* concentration ratio.
Useful energy delivered by the solar dish concentrating collector receiver unit is expressed as

$$Qu = Qs\ Ar - UL\ Ar(Tr - Ta). \qquad (2)$$

Where *Qs* is the absorbed heat flux (W/m2), Ar is the aperture area of the receiver plate (m2), U_L *is* the loss coefficient, Tr is the receiver temperature, Ta is the atmospheric temperature.
The instantaneous thermal efficiency of this parabolic dish collector can be computed from

$$\eta pdc = Qu / Apdc\ Ib \qquad (3)$$

3.2 Thermoelectric Generator

The thermoelectric generator is a solid state device working on the principle of Seebeck effect. According to the Seebeck effect, in a thermoelectric device, heat flux αITh is absorbed by hot junction α*ITc* is rejected by cold junction. In addition, there are three other effects in thermoelectric device: Joule heating due to electric current; heat leak due to heat conduction between the two junctions; and the Thomson heat due to the temperature gradient and electric current.

$$Qh= \alpha ITh +K(Th - Tc)- 0.5I^2 R \qquad (4)$$
$$Qc -=ITc +K(Th - Tc) +0.5I^2R. \qquad (5)$$

The heat removal rate from a module to a cooling medium is expressed as
$$Qc = Kc(Th - Tc). \qquad (6)$$

The electric power produced by the thermoelectric module can be obtained from an energy balance equation:
$$P_{TE}= (Q_h - Q_c)=\alpha_n I (T_1- T_2)- I^2R_n \qquad (7)$$

Electrical efficiency of the thermoelectric generator can be obtained from the following equation.
$$\eta_{TEG}=P_{TE}/Q_h \qquad (8)$$

The electrical efficiency of the solar parabolic dish thermoelectric generation system is computed as
$$. \eta=P_{TE}/I_bA_{ap}=Q_h\ P_{TE}/I_bA_{ap}Q_h \qquad (9)$$

where η*pdc* the efficiency of the solar is parabolic dish collector and η*TEG* is the electrical efficiency of thermoelectric device

where η*pdc* the efficiency of the solar is parabolic dish collector and η*TEG* is the electrical efficiency of thermoelectric device.
Bismuth telluride alloys based thermoelectric module used in this analysis and its properties are depends on the operating temperature.
$$Tave=Th+ Tc /2 \qquad (10)$$

Freshwater scarcity and declining water quality are expected to worsen with rising population growth, as well as climate change. In order to increase the availability of freshwater supplies various approaches have been practiced including, but not limited to, water conservation, water recycling, increased water use efficiency and water desalination. Water desalination in particular has become a major component of the freshwater portfolio in a number of countries with water desalting by membrane reverse osmosis (RO) technology being the most dominant desalination technology. RO membrane water desalination is now well established as a mature water desalination technology for the production of potable water. Reverse osmosis found to be one of the primary means of desalination practiced today along with multi-stage flash (MSF), multiple effect distillation (MED), vapour compression, and electrodialysis (ED) and ED reversal (EDR). Of these technologies, reverse osmosis has been proven to be more energy efficient with the specific energy consumption (SEC) for permeate (potable water) production of ~2-4 kWh/m3 depending on plant design, size and location (Palacin et al.,2010).

Reverse osmosis (RO) is a process in which external pressure is exerted on the saline water side of RO membrane. The semi-permeable membrane has much high selectivity of water over the dissolved salt in the saline water. So, the saline water is desalinated by RO membrane and the permeate water with little salt content is produced (C. John et al., 2005).

4.Simulation Results And Analysis

The tools used for computer simulation is MATLAB 7.9/Simulink 7.4 and IMS design. Steps involved in simulation are

1) Parabolic dish collector is simulated and measured the thermal efficiency of the dish at different beam radiation.
2) Thermoelectric generator (Model no:TEP112656_0.6) is simulated and measured the maximum power (P) that can be generated.
3) Boost converted is simulated and low voltage of the thermoelectric generator is boosted to high voltage.
4) RO system is simulated using IMS design and the purity of the water is confirmed.

4.1 Simulation Of Overall System

The simulation of entire system is done using two software MATLAB and IMS design. The simulation of parabolic dish collector , thermoelectric generator ,boost convertor and power conditioning unit is done using MATLAB .And the simulation of RO system is done using IMS design.

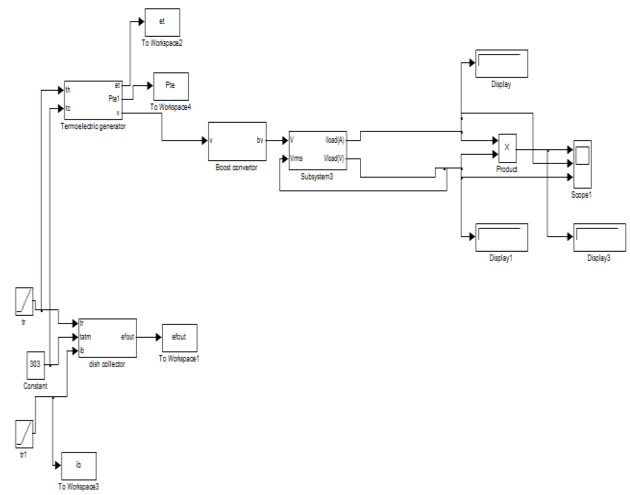

Figure 2 Overall simulation diagram

4.2 Simulation Of Dish Concentrator

The incident energy received by receiver of solar parabolic dish concentrator can be computed from the following values.

- A_{pdc}=10.56 m^2
- A_r=0.1 m^2
- $(T\alpha)_e$=0.938
- ϒ=0.8
- C=105.6 J/kgK
- þ=.43312
- ε=.89
- σ=5.67e8 W/m^2 ^{0}C

The modelling equations are already discussed.

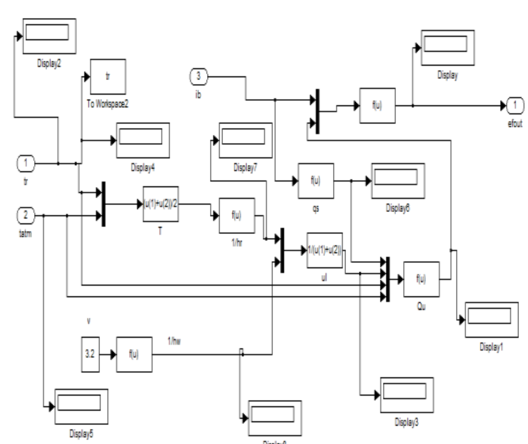

Figure 3. Simulation Diagram For Parabolic Dish Collector

4.3 Simulation Of Thermoelectric Generator

ISSN: 2278-0181
Vol. 2 Issue 2, February- 2013

In order to find out the power generated from generator the values are needed.

R=1.2Ω

I=3.5A

The modelling equations are already discussed.

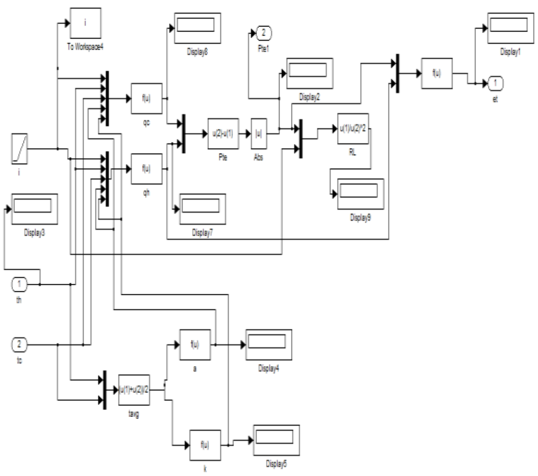

Figure 4. Simulation Diagram Of Thermoelectric Generator

4.4 Simulation Of Reverse Osmosis System

Simulation of RO system is done using IMS design.In order to use this we have to know about the chemical parameters of the water that is to be purified.

IMSDesign® - a comprehensive software design program that allows the user to design a membrane system using Hydranautics' membranes. Hydranautics, offers the latest comprehensive system design software package. Here the realistic expectation of performance over time and under a variety of conditions is clearly demonstrated. Also Parameters such as salt passage increase and flux decline due to fouling are easily accessible to the user - not obscured within the framework of the program.

IMSDesign gives users complete control over the information used in the membrane selection process. This control assures the user full confidence in the projected performance of any Hydranautics membrane.

IONS	**PERMEATE(mg/l)**
Ca	1.406
Mg	0.843
Na	8.573
K	1.912
NH4	0.076
Ba	0.009
HCO3	9.75
SO4	0.837
Cl	7.413
F	1.166
NO3	7.791
B	0
SIO2	0.64
CO2	3.29
TDS	40.6
pH	6.65

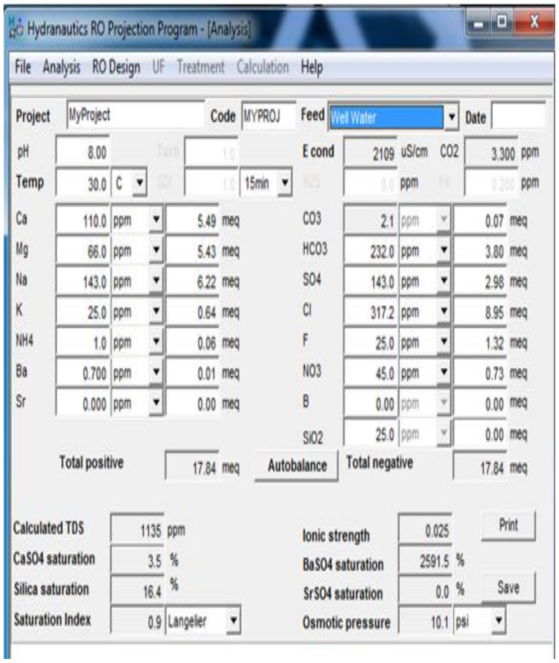

Figure 5.Simulation Of Ro System

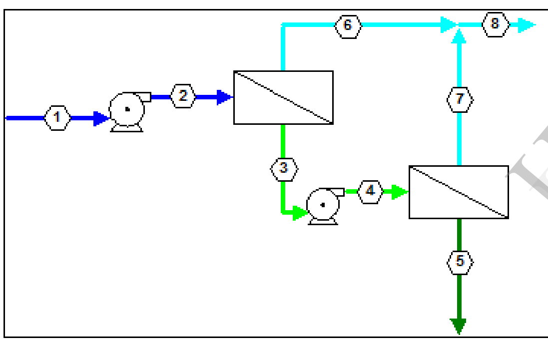

Figure 6. Flow diagram of RO Plant

The various pressures and the relative level of flow, pressure and TDS at various points of the above flow diagram is as shown in table given below.

	1	2	3	4	5	6	7	8
Flow (m^3/hr)	2.3	2.3	2.2	2.2	2	0.1	0.2	0.4
Pressure (bar)	0	2.7	2.4	8.4	8.1	0	0	0
TDS (ppm)	1135	1135	1184	1184	1330	53.9	31.7	29.3

le 2. Different levels of flow, pressure and TDS at various points

5. Simulation Results

The parabolic dish having open mouth diameter of 3.56 m, height of 0.6 m, and receiver surface having side of 0.3 m were considered for the analysis. The computed the dish aperture area and receiver aperture area are 10.56 m2 and 0.1 m2 respectively using fundamental equations. The thermal performance of solar dish collector was studied analytically for its receiver plate operating temperature range of 350–700 K and the set of solar beam radiation of 300, 600, 900 and 1200 W/m2 was shown in fig 6.8.

Thermal efficiency of the parabolic dish collector was minimum of 24% at minimum beam radiation of 300W/m2 and it decrease sharply, when the operating temperature is increases, maximum efficiency of 56% obtained at the solar radiation of 1200 W/m2 and operation temperature of 700 K. The effect of wind velocity can play an important role in affecting the receiver performance. Different wind velocity value of 0, 1, 2 and 3.2m/s were used to simulate the thermal performance of dish receiver and it is shown in Fig. 6.9. The drop in thermal performance was occurred when the wind speed maximum at 3.2 m/s. When there is no wind, higher thermal performance of dish receiver was obtained.

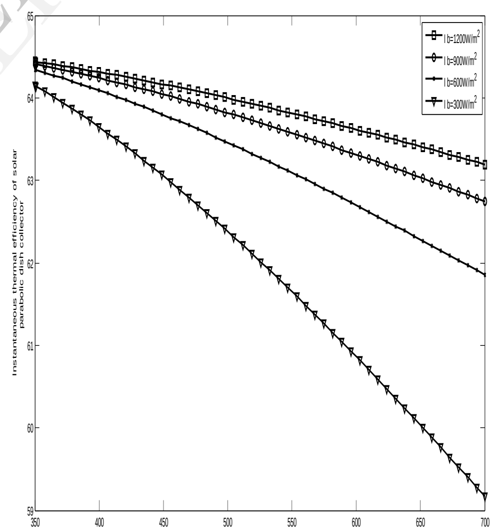

Figure 7 Instantaneous efficiency of dish collector for various operating temperature

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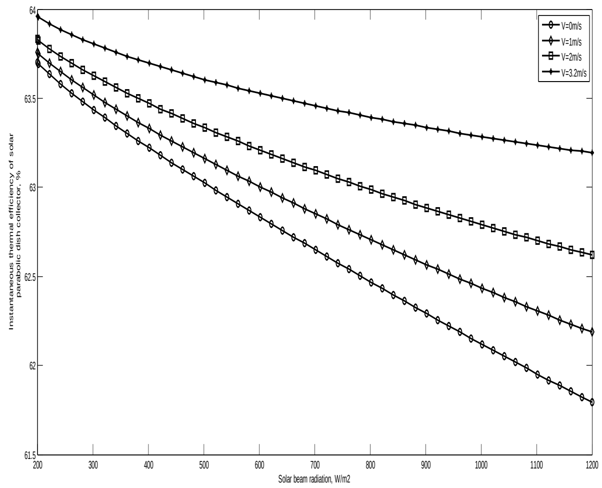

Figure 8. Instantaneous efficiency of dish collector variation with solar beam radiation and wind velocity.

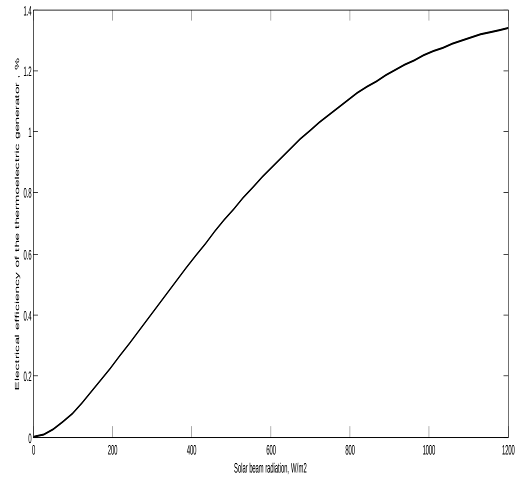

Figure 9 Overall performance of solar parabolic dish thermoelectric generator

Thermonamic (Ltd) China make (Model no:TEP112656_0.6) considered in this study. The hot sides of thermoelectric modules are considered as receiver plate temperatures and the cold side temperature is taken as constant 303 K which is mean fluid temperature of the cooling medium. Module element is made of bismuth telluride alloys and the cross sectional area of thermo element to length of thermo element as 1.72 mm. Using the Equation mentioned in 3.5 the electrical performance of the thermoelectric module analysed for varying its load resistance the relation for voltage, current and power output and its behaviour was illustrated in the Fig. 4. The maximum electrical power output of 14.7 W was obtained and it was matched with manufacture specification at match load voltage of 4.2 V and match load current of 3.5 A.

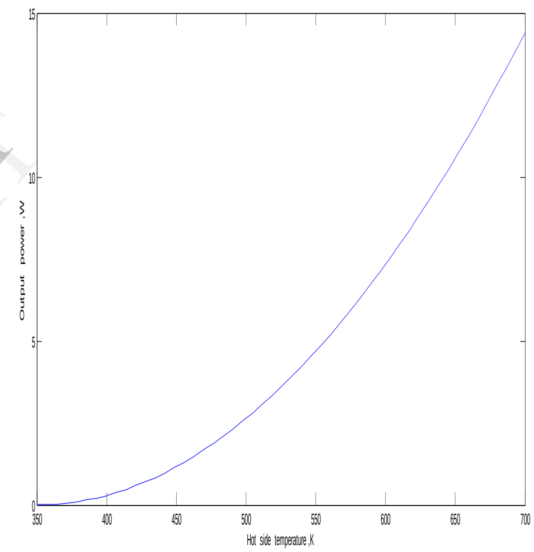

Figure 10 The output curve for output power vs temperature at hot side

A boost convertor and power conditioning unit is used to convert the DC power to amplified AC source. HP pump which is used to drive the water from the tank to the RO membrane needs high AC power.So all the above simulation is done to get the power required to drive this HP pump.

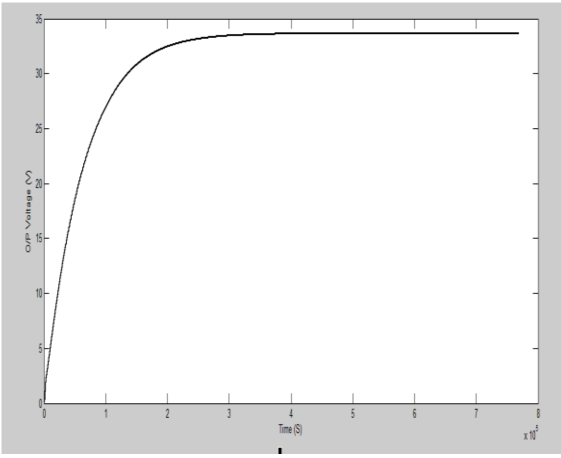

Figure 11 Output curve of boost convertor

RO system is the main part of the project, this is simulated using IMS design.

RO program licensed to:				
Calculation created by:				
Project name:	MyProject		Permeate flow:	0.25 m3/hr
HP Pump flow:	1.7 m3/hr		Raw water flow:	1.7 m3/hr
Feed pressure:	1.5 bar		Permeate recovery:	15.0 %
Feedwater Temperature:	30.0 C(86F)			
Feed water pH:	8.00		Element age:	3.0 years
Chem dose, ppm (100%):	0.0 H2SO4		Flux decline % per year:	7.0
			Fouling Factor	0.80
			Salt passage increase, %/yr:	10.0
Average flux rate:	10.0 lm2hr		Feed type:	Well Water

Stage	Perm. Flow m3/hr	Flow/Vessel Feed m3/hr	Flow/Vessel Conc m3/hr	Flux l/m2-hr	Beta	Conc.&Throt. Pressures bar	Conc.&Throt. Pressures bar	Booster Pressure bar	Element Type	Elem. No.	Array
1-1	0.0	1.7	1.6	2.9	1.02	1.3	0.0		SanRO-HS2-4	2	1x2
1-2	0.2	1.6	1.4	24.0	1.19	7.0	0.0	6.0	SanRO-HS2-4	1	1x1

	Raw water		Feed water		Permeate		Concentrate	
Ion	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l	mg/l	meq/l
Ca	110.0	5.5	110.0	5.5	1.406	0.1	129.2	6.4
Mg	66.0	5.4	66.0	5.4	0.843	0.1	77.5	6.4
Na	143.0	6.2	143.0	6.2	8.753	0.4	166.7	7.2
K	25.0	0.6	25.0	0.6	1.912	0.0	29.1	0.7
NH4	1.0	0.1	1.0	0.1	0.076	0.0	1.2	0.1
Ba	0.700	0.0	0.700	0.0	0.009	0.0	0.8	0.0
Sr	0.000	0.0	0.000	0.0	0.000	0.0	0.0	0.0
CO3	2.1	0.1	2.1	0.1	0.000	0.0	2.5	0.1
HCO3	232.0	3.8	232.0	3.8	9.750	0.2	271.2	4.4
SO4	143.0	3.0	143.0	3.0	0.837	0.0	168.1	3.5
Cl	317.2	8.9	317.2	8.9	7.413	0.2	371.9	10.5
F	25.0	1.3	25.0	1.3	1.166	0.1	29.2	1.5
NO3	45.0	0.7	45.0	0.7	7.791	0.1	51.6	0.8
B	0.00		0.00		0.000		0.00	
SiO2	25.0		25.0		0.64		29.30	
CO2	3.29		3.29		3.29		3.29	
TDS	1135.0		1135.0		40.6		1328.2	
pH	8.00		8.00		6.65		8.06	

	Raw water	Feed water	Concentrate
CaSO4 / Ksp * 100:	4%	4%	4%
SrSO4 / Ksp * 100:	0%	0%	0%
BaSO4 / Ksp * 100:	2591%	2591%	3121%
SiO2 saturation:	16%	16%	19%
Langelier Saturation Index	0.91	0.91	1.11
Stiff & Davis Saturation Index	0.96	0.96	1.14
Ionic strength	0.03	0.03	0.03
Osmotic pressure	0.7 bar	0.7 bar	0.8 bar

Table.3 Result of RO system

6. Conclusion

The use of renewable energies for desalination appears as a reasonable and technically mature option towards the emerging and stressing energy and water problems. In spite of intensive research worldwide, the actual penetration of RES-powered desalination installations is still low. Recently there are intense attempt to develop and install large scale desalination plants, mainly powered by RES. For low-density population areas worldwide there is a lack of fresh water as well as electrical power grid connections. Thus it is a good idea to produce the cheap fresh water from brackish, sea and oceans water by using wind turbines, solar thermal ,solar panel and other emerging renewable energy technologies. The successful development of this kind of technologies is important for developing countries that are currently experiencing water scarcity and do not have access to sufficient conventional energy resources for supporting desalination systems.. Solar energy is the radiant light and heat from the sun, which can be converted directly into electrical energy by using thermoelectric generator driven by solar energy, this electricity is then stepped up and can be used to drive the HP pump in the RO system to purify the bore water and make it suitable for drinking (Bourouni 2011).

7. References

[1] B.Ali, M.Turki, and E.Belhadj. '*'Energy Management of a Reverse Osmosis Desalination Process Powered by Renewable Energy Sources''*, Proceedings of the 16th IEEE International Conference on electrotechnicals ,2012,800–805.

[2] C.Basso.*''Switch Mode Power Supplies: SPICE Simulations and Practical Designs''* ISBN 7, 2008,150858-9.

[3] K.Bourouni, M.Ben . ''Design and optimization of desalination reverse osmosis plants driven by renewable energies using genetic algorithms'' ELSEVIER Renewable energy36,.2010,936–950.

[4] J.Chen..*''Thermodynamic analysis of a solardriven thermoelectric generator''*, IEEE Journal of Applied Physics 110 ,1996, 79 – 2717.

[5] MC.Enaney, Kenneth,*''Modeling of concentrating solar thermoelectric generators''*,IEEE Journal of Applied Physics 110 , 2009, 074502 - 074502-6 .

[6] M.Eltawil. ,Z. Zhengming., and L.Yuan.''*A review of renewable energy technologies integrated with desalination systems*'', ELSEVIER13,2009,2245–2262.

[7] M.Haganesh. ,S.Mohan. "*Study on subsurface water quality in selected places in coimbatore"* ISSN,2002, 2,2250-3498.

[8] C.John., T.Rhodes., G.David, H.Kerry. and T.George.. *''Water Treatment Principles and Design*''Edition2, ISBN,2010, 0-471,11018-3.

[9] L.Palacin.,T.Prada., F.Tadeo., J.Salazar " *Operation of Medium-size Reverse Osmosis Plants with Optimal Energy Consumption''* ELSEVIER.23,2010,,2245–2262.

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