Advances in Energy Research, *Vol. 3, No. 1 (2015) 59-70*
DOI: http://dx.doi.org/10.12989/eri.2015.3.1.059

Solar power and desalination plant for copper industry: improvised techniques

D. Sankar*[1], N. Deepa[2], S. Rajagopal[1] and K.M. Karthik[1]

[1]Development Consultants Private Limited, Consulting Engineers, Chennai 600006, TN, India
[2]Presidency College (Autonomous), Chennai 600005, Tamil Nadu, India

(Received December 23, 2014, 2014, Revised May 11, 2015, Accepted May 14, 2015)

Abstract. In India, continuous production of electricity and sweet/potable water from Solar power and desalination plant plays a major role in the industries. Particularly in Copper industry, Solar power adopts Solar field collector combined with thermal storage system and steam Boiler, Turbine & Generator (BTG) for electricity production and desalination plant adopts Reverse osmosis (RO) for sweet/potable water production which cannot be used for long hours of power generation and consistency of energy supply for industrial processes and power generation cannot be ensured. This paper presents an overview of enhanced technology for Solar power and Desalination plant for Copper industry making it continuous production of electricity and sweet/potable water. The conventional technology can be replaced with this proposed technique in the existing and upcoming industries.

Keywords: solar; solar thermal hybrid power plant; solar thermal hybrid power plant with desalination plant; improvised techniques; CSP-biomass hybrid

1. Introduction

India has tremendous solar potential which can be utilized to meet its fast growing industrial electricity requirements. The industries have been instrumental in promotion & deployment of solar energy systems as India is endowed with large solar energy potential whereby about 5000 trillion kWh per year energy is incident over India’s land area with most parts receiving 4-7 kWh per sq. m. per day with almost 300 sunny days.

In Earlier days, Copper industries utilized Solar power and desalination (Palenzuela *et al*. 2011) in day time. Nowadays, Copper industries are focusing more on adoption of round the clock production of Solar power and desalination plants to meet their demands. This paper presents a clear picture about continuous production of electricity and sweet/potable water using enhanced techniques and ensuring round the clock production of electricity and sweet/potable water. Also this technology ensures to get high quality of permeate water which can be used within the Copper industry as process water / cooling tower make up water / potable water and for obtaining rejects with high Total Dissolved Solids (TDS) which is being disposed as feed water to Salt production units.

*Corresponding author, Mr., E-mail: d_sankarbtech@yahoo.com

http://www.techno-press.org/?journal=eri&subpage=7 ISSN: 2287-6316 (Print), 2287-6324 (Online)

2. Site observations on Solar power and desalination plants and its schemes

Normally in Copper industries, Solar power and desalination plant (Palenzuela *et al*. 2011) comprise of solar fields combined with thermal storage system power plant and Reverse osmosis (RO) (Antipova *et al*. 2013, Pérez-González *et al*. 2012, França *et al*. 2000, Song *et al*. 2002, Tan *et al*. 2012) desalination plant. Solar energy is received through solar field collectors (Nixon *et al*. 2010) in the form of heat and transferred to Heat transfer fluids (López-González *et al*. 2013) (HTF) by means of heat conduction. The steam boiler produces steam by heating the circulated demineralised (DM) water with HTF. The superheated steam thus produced from boiler rotates turbine and generator to produce electricity and supplies through grid to end users.

The source of water for RO desalination plant is seawater. The typical quality of seawater obtained from Bay of Bengal Sea is shown in Table 1

Table 1 Quality of seawater obtained from bay of Bengal for a copper industry in India

Sl No	Parameters	Units	Values (Min-Max)
1	pH	--	7.9-8
2	Biochemical Oxygen Demand (BOD)	mg/l	1.1-3.8
3	Chemical Oxygen Demand (COD)	mg/l	1.0-1.4
4	Turbidity	NTU	9-15.8
5	Total Suspended Solids (TSS)	mg/l	52.9-86.7
6	Calcium	mg/l	391-482
7	Magnesium	mg/l	1136-1396
8	Chloride	mg/l	18238-19516
9	Sodium	mg/l	11000 (Avg)
10	Silicates	µg/l	4.3-13.39
11	Boron	gm/l	3.4-3.7
12	Sulphate	gm/l	2.3-2.9
13	Iron Fe	ppb	441-1240
14	Arsenic (as As)	ppb	0-441
15	Copper (as Cu)	ppb	13-120
16	Chromium (as Cr)	ppb	0-32
17	Potassium (as K)	ppm	33-239
18	Total Dissolved Solids (TDS)	mg/l	31856-35981

The initial separation of suspended solids from the Sea water is accomplished by treating it in Pretreatment plant. The separation of suspended solids is achieved in clarifier with the help of pretreatment chemicals like coagulant, flocculant etc., (Üstün *et al*. 2011). The sludge settles at the bottom of clarifier and handled in a separate sludge handling and disposal system. The clarified water from the clarifier is then stored in clarified water storage tank and then pumped to RO (Antipova *et al*. 2013, Pérez-González *et al*. 2012, França *et al*. 2000, Song *et al*. 2002, Tan *et al*. 2012) desalination plant as feed water to produce sweet/potable water. The power required to pump the clarified water to RO (Antipova *et al*. 2013, Pérez-González *et al*. 2012, França *et al*. 2000, Song *et al*. 2002, Tan *et al*. 2012) desalination plant is received from solar power plant.

The typical block diagram for seawater pretreatment plant in Copper industry is shown in Fig. 1

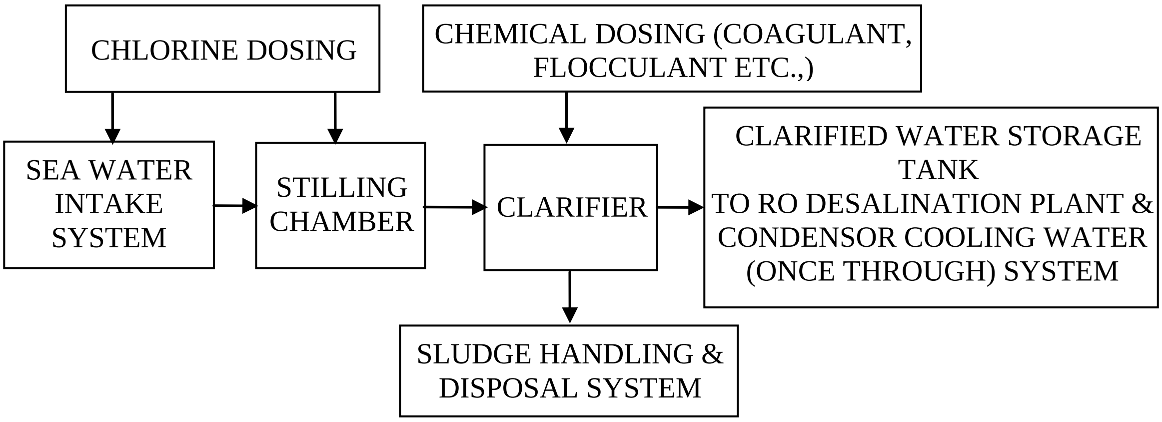

Fig. 1 Block diagram for seawater pretreatment plant in Copper industry.

Table 2 Quality of permeate water (sweet/potable water) obtained from a Reverse Osmosis (RO) desalination plant of a Copper industry in India

Sl No	Parameters	Units	Values
1	pH	--	7.0-8.5
2	Biochemical Oxygen Demand (BOD)	mg/l	Nil
3	Chemical Oxygen Demand (COD)	mg/l	Nil
4	Turbidity	NTU	2.5
5	Total Suspended Solids (TSS)	mg/l	Nil
6	Calcium (as Ca)	mg/l	50-75
7	Magnesium (as Mg)	mg/l	≤ 3.5
8	Chlorides (as Cl)	mg/l	< 200
9	Sodium (as Na)	mg/l	< 120
10	Silicates	µg/l	Nil
11	Boron	mg/l	< 1
12	Sulphates (as SO_4)	mg/l	< 2
13	Iron (as Fe)	mg/l	0.1
14	Arsenic (as As)	mg/l	0.05
15	Copper (as Cu)	mg/l	0.05
16	Chromium (as Cr)	mg/l	0.05
17	Potassium (as K)	ppm	Nil
18	Total Dissolved Solids (TDS)	mg/l	< 500

Further, the clarified water from pretreatment plant is treated in RO (Antipova *et al*. 2013, Pérez-González *et al*. 2012, França *et al*. 2000, Song *et al*. 2002, Tan *et al*. 2012) desalination plant to get high quality process water which can be used within the Copper industry to meet process water, cooling tower make up or potable water requirements.

The typical quality of permeate water obtained from a Reverse osmosis (RO) (Antipova *et al*. 2013, Pérez-González *et al*. 2012, França *et al*. 2000, Song *et al*. 2002, Tan *et al*. 2012) desalination plant is shown in Table 2.

3. Case study analysis and discussion

3.1 Case I: (As per site condition)

The typical block diagram (as per site condition) for solar power plant in Copper industry is shown in Fig. 2.

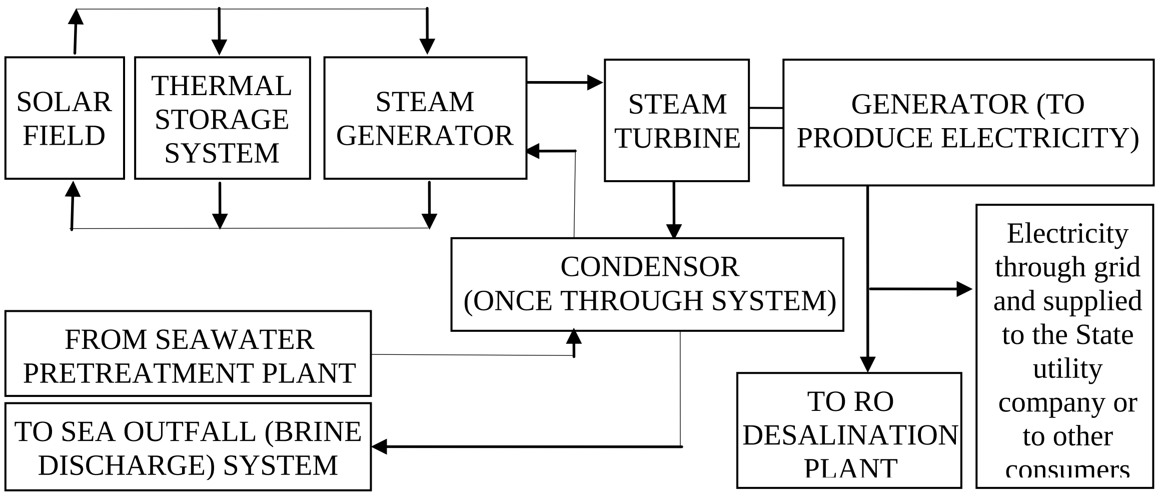

Fig. 2 Block diagram for solar power plant in Copper industry

• Heat transfer fluid (HTF) is heated up to 395℃.

• Heat Surplus from solar field is stored into the thermal energy storage (TES) at times with high irradiation. The storage is then discharged in the evening hours or whenever required

• The heat from the oil-loop serves as input for a conventional steam turbine (Rankine cycle)

• The steam turbine produces electricity.

• The power generated from this technology is fed into the grid and supplied to the State utility company or to other consumers.

The typical block diagram (as per site condition) for RO (Antipova *et al*. 2013, Pérez-González *et al*. 2012, França *et al*. 2000, Song *et al*. 2002, Tan *et al*. 2012) desalination plant in Copper industry is shown in Fig. 3

The purified water from desalination plant can be utilized to meet plant process water or cooling tower makeup water or potable water requirements.

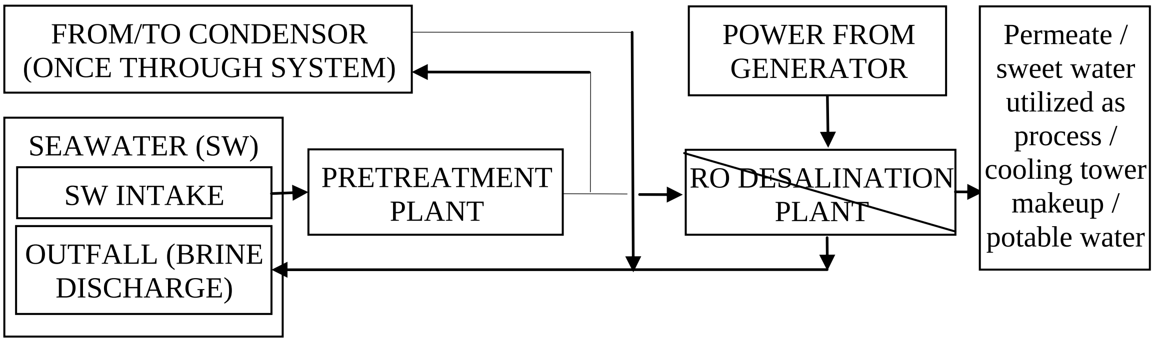

Fig. 3 Block diagram for RO Desalination plant in Copper industry

3.2 Case II: (Proposed technique)

3.2.1 Proposed modification in power plant

The typical block diagram of the proposed modification for power plant in Copper industry is shown in Fig. 4

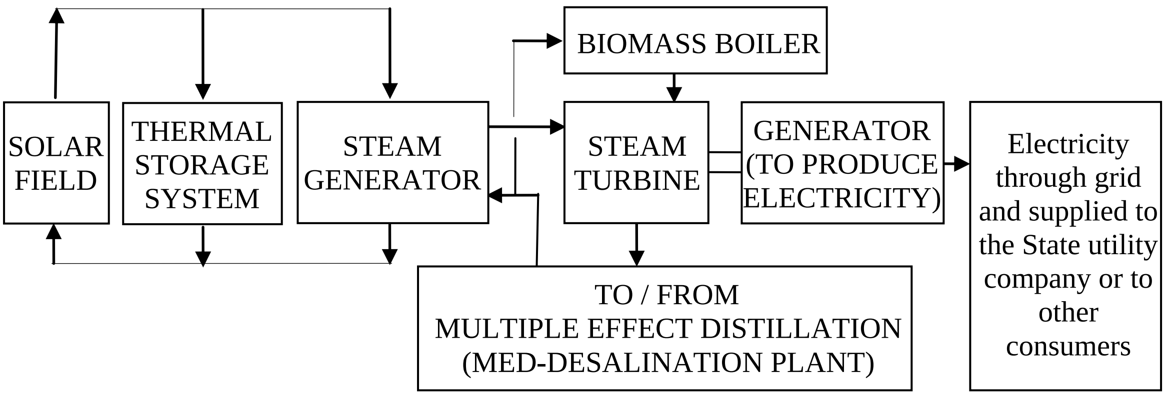

Fig. 4 Block diagram (modified) for the solar power plant in Copper industry

Solar Thermal Power Plant using Concentrating Solar Power (CSP) technology is a promising solution which can offer additional benefits compared to Solar photovoltaic (PV) technology like dispatchable power with solar thermal storage to meet peak energy demand (evening peak) and hybridization with bio mass fuel based thermal power plants

The proposed power generation system is to be configured such that the heat energy from solar radiation would be stored in storage systems thereby producing steam during non solar hours. Also the biomass based boiler would be integrated to enable continuous power generation.

In this proposed Solar power plant, Biomass boiler is introduced to achieve continuous production of electricity for long run and condenser is eliminated since multiple effect distillation

(MED) (Sharaf, M.A. *et al* 2011, Massimo Moser. *et al*.2011) desalination plant itself will serve the condenser purpose. The merits of the proposed modification on solar power plant are shown in Table 3.

3.2.1 Proposed modification in Desalination plant

The typical block diagram (proposed modification) for desalination plant in Copper industry is shown in Fig. 5

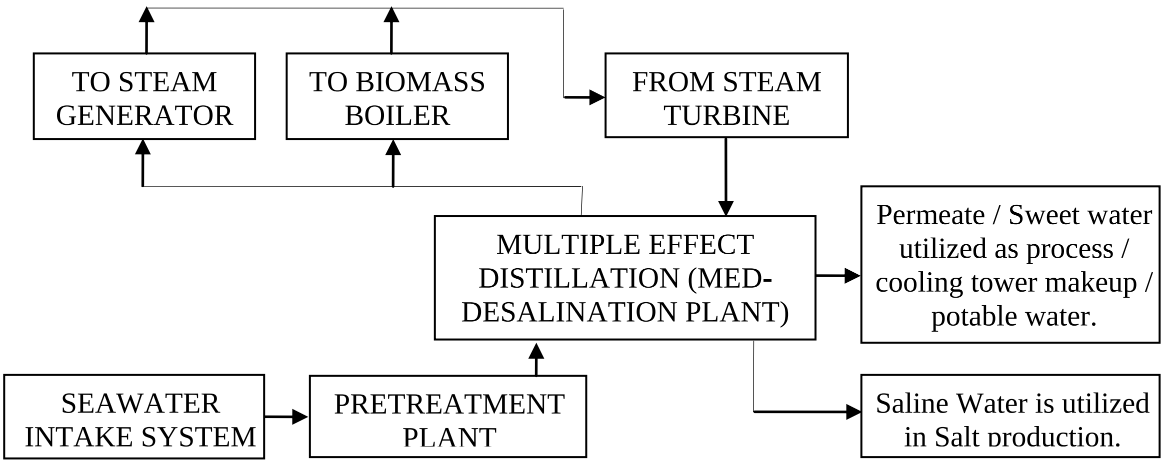

Fig. 5 Block diagram (modified) for desalination plant in Copper industry

The typical flow diagram (proposed modification showing MED desalination plant is given in Fig. 6

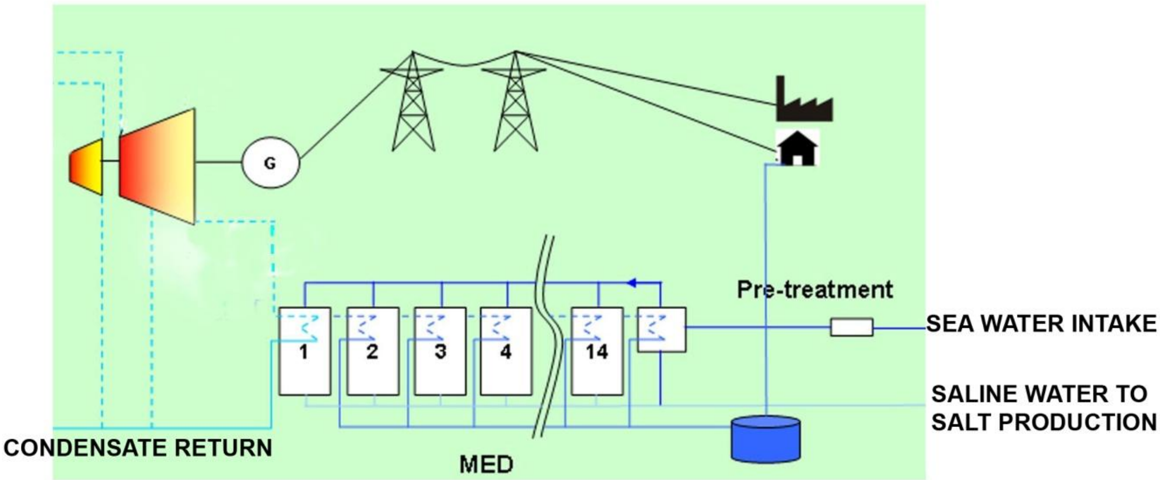

Fig. 6 Flow diagram (modified) showing MED desalination plant in Copper industry

In this proposed desalination plant, the desalination facility combined with the solar thermal power generation essentially needs to utilize the bleed off steam let out from the turbine. Multiple effect distillation (MED) is used in place of RO desalination plant to achieve lesser power consumption in way of utilizing heat from the exhaust steam and transfer of heat to sea water which is circulating from pretreatment plant. Seawater gets heated up and thereby producing high quality steam which is then used as a heating medium to the next effect. The greatest advantage being it completely eliminates condenser as in the case of existing solar power plant. Here MED (Sharaf *et al.* 2011, Massimo *et al*. 2011) desalination plant itself acts as a condenser and the exhaust steam from steam turbine is getting condensed in first effect of MED and the condensed steam is then re-circulated in steam boiler to produce steam. The merits of the proposed modification on desalination plant are shown in Table 4.

4. Discussion on technology used for solar power and desalination plant in Copper industry

Although undergoing concentrated solar power plant combined with thermal storage system (Nithyanandam and Pitchumani 2014), it cannot be used for long hours of power generation and consistency of energy supply for industrial processes and power generation cannot be ensured.

Hence it is necessary to go for an enhanced technology for Solar power and desalination plant making it continuous production of electricity and sweet/potable water in Copper industry. Concentrated Solar power (CSP)-biomass hybrid with thermal energy has potential to be an alternative to CSP- thermal energy storage for consistency of energy supply for industrial processes and power generation. Hybridisation can reduce concentrated solar thermal cost by making greater use of turbine and generator which has the major margin of the total plant cost and the use of biomass can also deliver economic and employment benefits in local economies.

The Solar intensity from sun receives heat through solar field collectors (Nixon *et al*. 2010) and transfers solar heat to circulating Heat transfer fluids (HFT) (López-González *et al*. 2013) in solar fields.Further, the HTF is used in steam boiler to generate steam by conducting heat from HFT to circulating demineralised (DM) water. The superheated steam thus produced from boiler rotates turbine and generator to produce electricity and supplies through grid to end users.

In solar power plant, the following technology is proposed against the existing method as given in Table 3.

Table 3 Technology proposed against normal or existing methods in solar power plant

Normal or existing method	Technology proposed
CSP with Thermal storage system	**CSP-Biomass hybrid with Thermal storage system**
Long hours of power generation are difficult.	Long hours of power generation are easier. More power generation thus increasing revenue.
Consistency of energy supply cannot be ensured.	Consistent energy supply can be ensured.
Condenser is required to condense exhaust steam from steam turbine.	Condenser can be eliminated since MED desalination plant will serve this purpose. Thereby reducing the capital cost.
CSP-Thermal storage system power plant runs at few hours. No additional fuel is required	CSP-Biomass hybridization with Thermal storage system operates for longer run due to biomass boiler hybridization. Hence additionally biomass fuel is required.

Table 4 Technology proposed against normal or conventional methods in Solar desalination plant

Normal or conventional method	**Technology proposed**
RO desalination plant (Antipova *et al*. 2013, Pérez-González *et al*. 2012, França *et al*.2000, Song *et al*. 2002, Tan *et al*. 2012).	MED desalination plant (Sharaf *et al.* 2011, Massimo *et al*. 2011)
High energy consumption to run High pressure pumps in RO desalination plant.	Low energy consumption and thus more savings on energy cost.
No steam is required.	Steam is required in MED desalination plant as a heat transfer medium.
Cannot take high variation in seawater conditions.	Can take high variation in seawater conditions.
Very High Flux design operating at high pH	Operates at low temperature (< 70°C) and at low concentration (< 1.5) to avoid corrosion and scaling
Moderate reliability and difficult to operate.	Highly reliable and simple to operate
High maintenance cost for change over of membranes & its chemical costs.	Low maintenance cost
Continuous operation is not possible due to non-availability of continuous solar (CSP+Thermal storage system) power plant. Maximum supervision is required for RO desalination plant operation.	24-hour-a-day continuous operation with CSP-Biomass hybrid and thermal storage system power plant. It requires minimum supervision.
Chemical consumption is more due to frequent cleaning of membranes.	Lesser cleaning of tubes and thus reduces Chemical consumption.
Frequent fouling of membranes due to inconsistent seawater water quality.	Less fouling of tubes even for inconsistent seawater water quality.
Rejects/brine/saline water from RO desalination plants are pumped back to sea as outfall.	Rejects/brine/saline water from MED desalination plants are pumped to salt production units thereby increasing revenue.
Higher Downtime of Downstream units and lower overall recovery	Lower downtime and higher overall recovery

The pretreatment plant uses a clarifier which removes floating/solid particulates or suspended solids from seawater. The suspended solids get settled at the bottom of the clarifier as it becomes dense due to chemical addition and are removed as sludge. The clarified water is then stored in clarified water storage tank which is then pumped to desalination plant to produce sweet / potable water.

Reverse osmosis (Antipova *et al*. 2013, Pérez-González *et al*. 2012, França *et al*. 2000, Song *et al*. 2002, Tan *et al*. 2012) (RO) desalination is a process where high pressure water is passed through a semi-permeable membrane leaving behind dissolved inorganic salts and silica called rejects which contains high TDS and the clear water from RO filtration is termed as permeate. The permeate water is recycled and reused either as process water or cooling tower makeup water or potable water in Copper industry. The rejects are returned back to sea as outfall.

Multiple effect distillation (MED) (Sharaf *et al.* 2011, Massimo *et al*. 2011) desalination is a process where multiple stages or “effects” are used. In each stage the feed water is heated by steam in tubes. Some of the water evaporates and this steam flows into the tubes of the next stage, heating and evaporating more water. Each stage essentially reuses the energy from the previous stage. The tubes can be submerged in the feed water but more typically the feed water is sprayed on top of a bank of horizontal tubes and then dripped from tube to tube until it is collected at the bottom of the stage. The brine/rejects collected at the bottom of different stages are sent to salt production unit thereby increasing revenue to the company.

In Solar desalination plant, the following technology is proposed against the conventional method as given in Table 4.

The investment costs have been calculated for a 120 MWe power plant based on CSP+Thermal storage system and CSP+Thermal storage system+biomass hybrid technology.

The results in Table 5 show that investment costs per unit power installed are lower for the hybrid plant (347200 INR/kW) than for the CSP (280000 INR/kW) and biomass (190400 INR/kW) technologies. However, the investment cost discussed above lead to a 26% saving from the proposed technologies.

Table 5 illustrates that CSP+Thermal storage system+biomass hybrid combustion plants have the highest operating costs, owing primarily to the cost of the biomass fuel and labour requirements. In contrast, operating costs in CSP+Thermal storage system plants are one fifth of biomass combustion plants, due to the free nature of the solar resource. However, equivalent hours and, consequently, energy generation values are significantly lower in CSP+Thermal storage system plants.

Considering the Levelised Cost of Electricity (LCOE) values calculated for each plant design, it may be concluded that CSP+Thermal storage system+biomass power plants provide the cheapest alternative, with 8,599.36 INR/MWh. LCOE values for the hybrid plant (8,599.36 INR/MWh) have been calculated to be 33% lower than the conventional CSP.

The detailed comparison of results for the existing and proposed technologies of Solar power and Desalination plant for Copper industry are given in Table 5.

Table 5 The detailed comparison of results for the existing and proposed technologies of Solar power and Desalination plant for Copper industry

Analyzed configurations:		
Gross power	:	120 MW
Desalination	:	100 MLD
Back up fuel	:	Biomass, Quantity – 148.8 Ton/hr
Biomass Boiler	:	Performance – 88%, LHV – 2800 Kcal/Kg
Turbine steam input	:	Temperature – 375^{0}C, Pressure – 63 bar, Flow at normal point (100%) – 534.24 Ton/h
DNI (Direct Normal Irradiation)	:	4-7 kWh per sq. m. per day with almost 300 sunny days
Cost of steam	:	62 INR/Ton/hr of steam
Specific cost of steam for MED Desalination	:	6.2 INR/m^3

		Normal or conventional method	**Technology proposed**			
Description	**Units**	**CSP+Thermal storage system+ Condenser+ RO Desalination**	**CSP+Thermal storage system+Biomass Hybrid+MED Desalination**	**Savings (in INR)**	**Loss (in INR)**	**Results**
Gross power production	MW	107.8	120	INR 61,000	--	Increased by 10%

Table 5 Contined

Internal Electrical consumption	MW	30	17.8	INR 61,000	--	Reduced by 41%
Turbine Efficiency (Gross)	%	32.9	37	--	--	Efficiency increased by 11%
Turbine cost	INR	15% of investment cost	12% of investment cost	INR 40,320,000		Reduced by 0.8%
Steam flow generation	Ton/hr	479.92	534.24	--	--	Increased by 10%
Cost of Steam generation	INR	INR 29,755	INR 33,123	INR 3,368	--	Increased by 10%
Steam flow requirement in Desalination plant	Ton/hr	NIL	17.36	INR 1,076	--	However the steam required for this system is utilized from turbine bleed off.
Total water production	MLD	100	100	--	--	--
Investment cost / Total plant cost	INR	INR 33,600,000,000	INR 41,664,000,000	--	INR 8,064,000,000	Increased by 19%
Operations cost (in INR)	INR	INR 740,812,800	INR 3,118,960,320	--	INR 2,378,147,520	Increased by 76%
Equivalent hours	hours	2600	7193.4	4,593.40	--	Increased by 64%
Production	MW	312000	863208	551208	--	Increased by 64%
LCOE (Levelised cost of electricity)	INR/ MW	13,366.64	8,991.36	--	INR 4,375	Reduced by 33%
Savings on cost of Cooling water	INR	2% of Investment cost	NIL	INR 996,960,000	--	Reduced by 2% of investment cost
Savings on cost of Condenser	INR	9% of Investment cost	NIL	INR 3,749,760,000	--	Reduced by 9% of investment cost

4. Conclusions

The following conclusions were derived based on the proposed modifications on the conventional techniques followed in the Copper industry.

• Concentrated Solar power (CSP)-biomass hybrid with thermal energy can be a potentially alternate technology to CSP- thermal energy storage for continuous generation of power and consistency of energy supply for industrial processes and power generation can be ensured. Further, it can reduce concentrated solar thermal cost by making greater use of turbine and generator which is the major margin in total plant cost.

• Multiple effect distillation (MED) yields better savings than Reverse osmosis (RO) in Desalination plant, where low energy and steam availability is predominant. MED desalination has its advantage of eliminating separate condenser, which is required in case of conventional desalination plant thereby reducing capital cost.

• Large quantity of salt can be produced from rejects / Saline water of MED desalination plant through salt production unit thereby increasing revenue considerably.

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