ISSN 2395-1621

Performance Evaluation of Solar Powered Peltier Condenser to Extract Water from Ambient Air

[#1]Kiran Pawar, [#2]V. S. Shinde

[1]kppawar87@gmail.com

[2]shindevs4u@gmail.com

[#12] Department of Mechanical Engineering, Savitribai Phule Pune University
Pune, India

.

ABSTRACT

Now days, increasing inadequacy of fresh water resources in arid regions and hot, humid regions like Rajasthan (India). Potable water demands are eager to fulfill by the solar aided Peltier water extraction system. The Prime objective of this study is to present renewable portable solar based thermo-electric system to dehumidify air and produce water. TEC1207 module powered by 140 W Solar Photovoltaic cells is used. Vertical and Inclined plate with the face upward on which TEC12706 array is mounted with heat sink of 0.0945 m2 area for high efficient condensation rate. Total condensation surface area is 1.0278 m^2. The experimental setup is to produce the moderate quantity of water as compared with other methods. Water condensation is achieved by lowering the surface temperature below the dew point temperature of ambient air. Ambient Temperature and Relative humidity are the factor on which condensation depends. The experiment is conducted for various ambient temperature and humidity values in the months of May at Pune location. It is found that there is an inverse relation between the wind velocity and water productivity. Hence the optimized value of wind velocity is determined by trialing on different speed of inlet fan. For better insulation and water resistivity Nitrile foam with aluminum foil is used for air tight chamber to maintain cooling effect for condensation.

Water condensation rate was estimated by doing the Psychometric analysis with global heat transfer coefficient is calculated of condensate for the vertical as well as inclined active plate. Hot side temperature is needed to maintain below critical temp of Bi-Sn solder alloy is 138°C. For this proper isolation between hot and cold side is maintained for high efficiency of TEC12706 module. We extracted the water on both plate and maximum productivity obtained was 2.67 Liters in 8 hrs. of working. It is practically not possible to produce water when the humidity is below 20% to overcome this problem solar distiller need to incorporate for boosting the humidity of air in our future work our aim is to integrate the distiller for high condensation rate.

Keywords— **Condensation, Desalination, Dehumidification, Psychrometry, Solar Energy, Thermoelectricity**

ARTICLE INFO

Article History

Received :18th November 2015

Received in revised form :

19th November 2015

Accepted : 21st November , 2015

Published online :

22nd November 2015

I. INTRODUCTION

Approximately 97% of global water are present in the ocean. Rest 3% is available as fresh water or potable water, out of this only 0.3% of water is available for humans and other organisms living on earth. The rest water is locked in polar ice fields and deep underground. Constantly increasing human population, industrialization, pollution and salinity rate causes the inadequacy of fresh water resources emerges as one of the critical problems. The people in the dry climate desert areas do not have access to clean and fresh water, percentage is expected to increase day by day. As some areas in India like Rajasthan, the water scarcity problem is a prime issue. The warm and dry climates exhibit the severest fresh water scarcity problem due to the increase in evaporation rate, the salinity rate of the ground water and the low rainfall.

Conventional, alternative like RHTs are commonly used to ease freshwater demand, conserve water resources and cut down water bills. However, this option has been hampered by the unpredictability and uncertainty of rain. Other methods are recycling sewage and wastewater. Establishing desalination plants is the best way to desalinate the salty water, and to generate the water from the air as it contains lots of moisture. The atmospheric air contains about 12,000 km^3 of fresh water. To condense the moisture from the air, different techniques are used like desiccants dehumidification. A desiccant is a substance that is capable of capturing water molecules from surroundings until it reaches equilibrium with the ambient air.
The second category of methods is refrigeration techniques that cool the moist air below dew point temperature condensing the moisture content over specially designed cooling surfaces. Typical refrigeration systems based on the vapor compression refrigeration cycle and which uses chlorofluorocarbon compounds as the most common refrigerant in systems. The release of chlorine in CFCs was found to be a major contributor to ozone layer depletion of the atmosphere. Vapor absorption refrigeration systems use the heat itself to compress the working fluid. The working fluid is usually an ammonia-water or lithium-bromide solution in water, but leaking ammonia and lithium bromide is corrosive in nature and creates hydrogen gas when it contacts ferrous parts.

The modern method is thermo-electric cooling (TEC) devices, to cool surface below dew point temperature. TECs are relatively small devices that consist of two joined semiconductors operated by the Peltier effect. The basic idea behind the Peltier effect is that whenever direct current passes through the circuit heat is either released or absorbed at the junction. In a TEC device, thermo-electric legs are connected electrically in series and thermally in parallel and sandwiched between two ceramic substrates. The amount of heat extracted is proportional to the current that passes through the thermo-electric legs. The Peltier effect is utilized to its maximum when the thermo-electric elements are made of material of different conductivity. Fresh water extraction from the ambient air using photovoltaic powered thermoelectrically cooled surfaces is one viable solution that takes advantage of the humid climate.

Autonomous active dew condenser based on the solar photovoltaic powered Peltier module was studied by M.A. Munoz García et al., (2013) and estimated 0.10L of water. In large scenario M. Jradi et al., (2011) developed system integrated with multiple TEC channels and solar distiller producing at least 10 L of water per day over the summer months at Lebanese coastal humid climate. An optimized air mass flow rate is required for high condensation rate studied by M. Jradi et al., (2012).

A.E. Kabeel et al., (2014) studied the four parameters at different three regions likely, Sea, Arabian Gulf, and southern Europe (south Spain) which were the pressure drop over the flow bath, the water produced per square meter and the influence of ambient temperature as well as humidity. The psychometric analysis is done by Dia Milani et al., (2011) and investigated the feasibility of TEC dehumidification process to provide potable water from air moisture.

A.M.K. Ghonemy et al., (2012) reviewed atmospheric water vapor processing (AWVP) technology. These processors are machines which extract water molecules from the atmosphere by phase change from vapor to liquid. Hot side heat dissipation rate is the influencing parameter of the condenser. N. Rahbar, J.A. Esfahani et al., (2011) they used aluminum heat-pipe cooling device to cool down the hot side of the thermo-electric module. The equipment was tested under the climatic condition of Semnan (35° 33′ N, 53° 23′ E), Iran. S. Ravindran et al., (2012) experimentally studied cooling and condensing capacity was augmented by two single stage thermo-electric modules (TEM) of 80W each.

II. PRINCIPLE OF CONFIGURATION SYSTEM

A) Seebeck and Peltier Effect

The thermo-electric effect was first discovered by a German physicist, Seebeck, in 1821. He observed that, in a closed circuit of two dissimilar metal forms a junction was maintained at different temperatures, an electric current is produced. In 1834, Jean Peltier, discovered a reverse phenomenon to that of Seebeck. As shown in figure. 1 there is a heating or cooling of a junction of a pair of dissimilar substance, if direct current is passed through them.

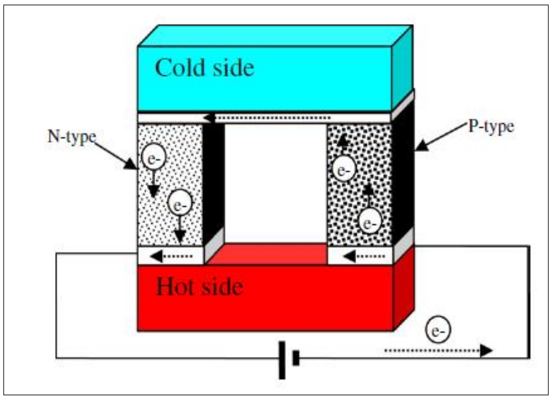

Figure 1: - Peltier Module Layout

B) System Configuration

The water condenser device is mainly consisting of a solar panel of 140 Watt manufactured by Photonix Ltd. with the Current at Maximum Power is 3.95 A; maximum voltage is 35.5 V, area of the panel is 1.10 m^2. 12 V lead acetate battery is also used for energy storage with charge controller for night application. We adopt a commercially available thermo-electric device called as TEC modules; its size is 40mm × 40mm× 4.2mm and the corresponding specifications are TEC-12706 with 127 couples of *p-n* bismuth, tin (Bi-Sn) alloy thermo element sandwiched between two thin ceramic plates. On the hot side, the temperature is 60◦C. The maximal cooling rate is 49W. The maximum temperature difference between the hot and cold sides is75◦C. The maximum thermoelectric voltage is 16.4V, and the maximum thermo-electric current is 6.4 A. The electrical resistance is 1.98Ω. The hot side of TEC12706 is attached to Heat sink of size 250mm × 105mm × 46mm. Silicon grease is used for pasting the module on the heat sink, Nitrile foam for insulation of temperature resistance range is from -20 to 150◦C.

III.EXPERIMENTAL SETUP

The Setup is composed of three major elements, thermo-electric cooled array of eight TEC12706 modules, photovoltaic solar panels, and heat sink and fan unit. The thermo-electric cooling Array is the main component in the experimental system, and it is responsible for air cooling and dehumidification and fresh water generation. The cooling array is sized such that one side is cooled by thermo-electric modules and the other sides are assumed as well insulated. The thermo-electric cooling modules are powered directly by a DC electric power supply and play the role of heat pumps. Applying a voltage difference across the sides of the thermo-electric modules will result into a temperature gradient between the two sides of the module. As a result, the TEC modules will be extracting heat from the air flowing along the channel at the cold side of the thermo-electric cooling modules and rejecting this heat on the other side of the modules.

The PV solar panel is a renewable electrical power supply source, converting sunlight into electrical energy. Thus, the photovoltaic modules make an appropriate renewable solution for powering the thermo-electric modules with the sufficient electric power needed to pump the desired cooling capacity.

It should be noted that the electrical energy produced by the photovoltaic modules varies considerably from one month to another, depending on the solar irradiation available and the ambient air conditions. In addition, no electrical inverter will be needed for the PV panels since the equipped thermo-electric cooling modules need a DC voltage power source to supply. Since the system extracts fresh water in humid climates.

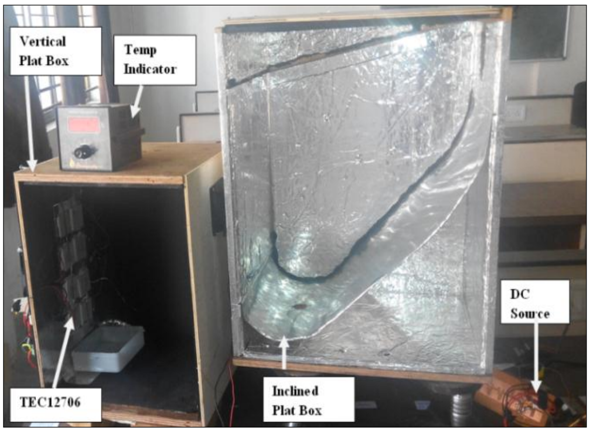

Figure 2: - Experimental Set-up

We made to two wooden test boxes, one is with inclined condensing TEC array and another with vertical condensing arrays. The dimension of the inclined plate wooden box is 390mm × 300mm × 460mm, for insulation Nitrile foam is used. For high rate of condensation forced air is supplied with fan of 12V and 1800-2600 RPM. The Second box is made from wood and dimensions are 250mm ×300mm × 390mm with vertical detachable condensing plate. For high efficiency hot side temperature need to dissipate for this heat sink with fan is attached by silicon grease of thermal resistance. The 8 TEC12706 modules are connected electrically in series and thermally in parallel. Special circuit to maintain the cold side temperature of every module constant along with the temperature PID controller is also used. RTD and k type thermocouple is connected to hot side and cold side of TEC12706 module respectively to sense the temperature.

Figure 3: - Water Condensed

Experimental Procedure: -

To generate fresh water from ambient air the surface should be cooled below dew point is required. The TEC array temperature is reduced below the dew point of ambient air with DC power supply. As the voltage goes on increasing the cold side temperature inversely goes on decreasing. We calculated the dew point temperatures at a Pune location in the month of March, April, and May.Which depends on ambient air temperature and relative humidity and concluded that the range of dew point temp in our location is from 2°C to 8°C to obtain such rang of dew point the voltage is required from 3 volts to 8 volts. Air is forced to strike over module with input fan and droplets are starting to form on the surface and falls on a gliding surface finally collected in a flask for measurement the water condensed. The function of heat sink and fan is used to dissipate the heat and increase efficiency of condensation.

The major concern is to maintain the temperature isolation between hot and cold side. To control hot side temperature below the critical melting point is 138 °C of Bi-Sn solder alloy material. For this RTD is soldered on hot side of modules to sense the temperature. Humidity sensor is installed at the inlet and at the outlet of the system. The Anemometer is used to calculate the air velocity or wind speed. As the wind velocity increases the condensation rate is also increasing, but optimized value is calculated for our system and that is 5.2 m/s of input fan.

IV. THEORETICAL AND PSYCHROMETRIC ANALYSIS

A) Cooling capacity: - In theoretical modelling the thermo-electric cooling modules, each module is treated as a lumped surface represented by a uniform value for each of its operational parameters. The main operational characteristic parameters of a TEC12706 module are: the cold side temperature (Tc), the hot side temperature (Th), the heat pumping cooling capacity at the cold side of the module (Qc), the heat dissipated at the module's hot side (Qh), the input electric current (I) and the voltage difference across the junction U.

$$Q_c = \alpha I T_c - 0.5 I^2 - K(T_h - T_c)$$

Where α is the Seebeck coefficient of the module in V/K and *Tc/h* is the cold or hot side temperature.

$$V = \alpha(T_h - T_c) + IR$$

The electrical power consumption can be calculated as follows, Where R is the electrical resistance in Ohm.

$$P = \alpha I(T_h - T_c) + I^2 R$$

$$COP = \frac{Q_c}{P}$$

$$Q_{cold} = \rho I$$

ρ is Peltier coefficient

Total power consumed by TEC Module

$$P_{total} = \rho_{total}.I - \frac{RI^2}{2} - K.\Delta T$$

Where, K is Thermal conductivity of material W/mK (Bi-Sn)

Now, cooling power absorbed at the cold side of Peltier element is expressed by

$$P_c = 2N\left(\alpha I T_c - \frac{I^2 R}{2f} - K f \Delta T\right)$$

N = Number of TEC module

α = Seebeck coefficient

f = geometric factor

$$P_{te} = 2N\left(\alpha I \Delta T + \frac{I^2 R}{2f}\right)$$

$$P_{total} = P_C + P_{te}$$

B) Psychrometric Analysis

Density of air and water vapour (ρ)

$$\rho_a = \frac{P_{atm}}{R_t}$$

Where, ρ_a is Air density P_{atm} is Atmospheric pressure in pascal, R is Specific gas constant (287.05 J/KgK)

$$\rho_d = \frac{P_v}{287.05T}$$

$$\rho_{wv} = \frac{P_{wv}}{461.495T}$$

ρ_{wv} = Density of water vapour

Specific gas constant of water vapour = 461.495 J/KgK

$$\rho_{humidair} = \frac{P_v}{287.05T} + \frac{P_{wv}}{461.495T}$$

Viscosity (μ) it depends on ambient temperature.

$$\mu = (17.1 + 0.067T - 0.0004T^2) * 10^{-6}$$

Where, T = Temperature of air

Vapour Pressure

$$P_{wv} = RH * P_{sat}$$

Where, P_{wv} is the Partial pressure of water vapour, RH is Relative humidity, P_{sat} is the Saturation vapour pressure

$$\log_{10} P_{sat} = \frac{9.756}{272.7 + T} + 2.7877$$

Global heat transfer coefficient for inclined plate (h_m)

$$h_m = 0.943\left[\frac{g.\sin\theta\,\rho_1(\rho_1 - \rho_v)l_v.k^3{}_1}{L.\mu_1(T_{sat} - T_w)}\right]^{\frac{1}{4}}$$

$$m\dot{m}_w = F.\left(\frac{\omega_1}{\nu_1} - \frac{\omega_2}{\nu_2}\right)$$

$$\dot{m}_w = \dot{m}_{da1}.\omega_1 - \dot{m}_{da2}.\omega_2$$

$$\dot{m}_{da1} = \frac{F}{\nu_1}$$

$$\dot{m}_{da2} = \frac{F}{\nu_2}$$

Where, $\dot{m}_w$ is a Mass of generated water, F is Air flow rate, $\dot{m}_{da1}$ is a Mass of dry air point 1, $\dot{m}_{da2}$ is Mass of dry air point 2, W_1 and W_2 Absolute humidity at point 1 and 2 respectively (Kg_w/Kg_{da}), V_1 and V_2 are Specific volume of the moist air at point (m^3/Kg_{da})

$$\Delta T_s = T_d - T_s$$

Where, T_d is Dew point temperature, T_s is Surface temperature

Dew point Temperature

$$T_{dp} = \sqrt[8]{\frac{H_r}{100}}(112 + 0.9T_a) + 0.1T_a - 112$$

H_r = Relative humidity

Dimensionless Thermo-electric figure of merit

$$\therefore ZT = \frac{S^2 \delta T}{K}$$

Where, s is the Seebeck coefficient, δ is Electrical conductivity, T is Temperature, K is Thermal conductivity ($ZT \approx 1$,)

Conservation of Energy equation

$$Q_t = F\left[\frac{h_1}{\nu_1} - \frac{h_2}{\nu_2} - h_{w2}\cdot\left(\frac{\omega_1}{\nu_1} - \frac{\omega_2}{\nu_2}\right)\right]$$

h_1 and h_2 are Enthalpy of moisture at point 1 and 2(Kj/Kg_{da}), h_{w2} is specific heat of generated water(Kj/Kg_w)

$$\because \dot{m}_{da1}.h_1 = \dot{m}_{da2}.h_2 + \dot{m}_w.h_{w2} + Q_t$$

Heat Transfer Sensible heat Q_c latent heat flux

$$Q_T = Q_s + Q_L$$

$$Q_s = h_v \cdot A_s(T_f - T_s)$$

A_s is Heat transfer area (m^2), h_v is heat transfer coefficient ($KW/m^{2o}C$), T_f and T_s are feed and cooling surface temperature ^oC

Latent Heat (Q_L)

$$h_{fg}^{*} = h_{fg} + 0.68C_{pw}(T_{ast} - T_s)$$
$$Q_L = m_w h_{fg}$$

V. RESULT & DISCUSSION

The experimental setup was tested during the month of May 2015, At Pune location. The following data are measured on a daily basis; ambient air temperature, relative humidity, air velocity, air mass flow rate, power produced by solar panels, and the volume of water collected hourly.

The difference between ambient air temperature and surface temperature is the important parameter in the evaluation of water productivity, k type thermocouple is used for temperature sensing placed on the cold side of TEC12706 array. As per experimental study as relative humidity increase the water productivity increases and power consumption decrease. We calculated the water productivity at different wind speeds like 3.5m/s, 4.2m/s and 5.2m/s.The maximum water productivity is obtained at 5.2m/s wind speed.

We tested two different set up one is with an inclined TEC12706 array plate and another with vertical TEC plate, we obtained maximum productivity on vertical plate because gliding of water droplets was easy and resistance to humid air is more hence maximum water is condensed. We obtained 2.67 liters in 8 hours of working.

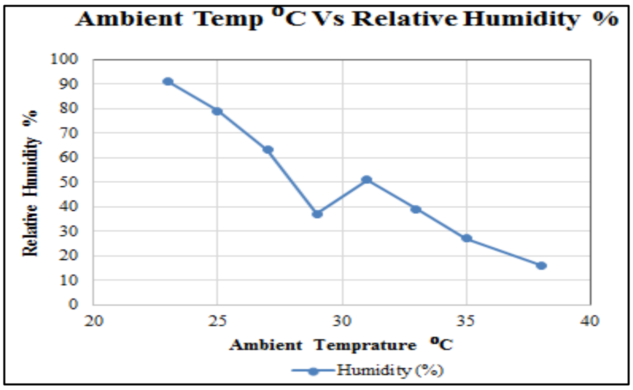

Figure 4: - Ambient temperature and relative humidity relation

Fig 4 is the graph plotted between ambient temperature and relative humidity and from experimental calculation the humidity goes on decreasing as temperature increases. The water droplets are attracted towards the hot air still humidity is decreased.

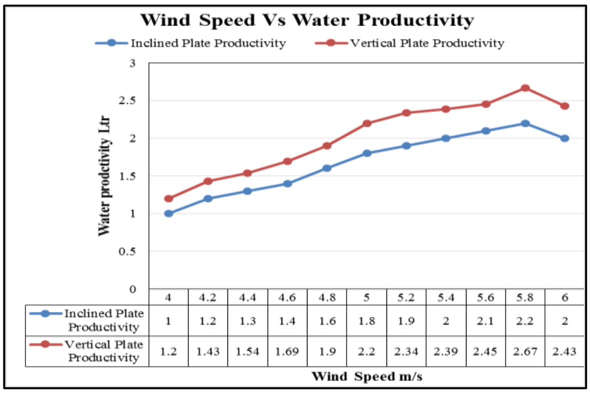

Figure 5: - Wind Speed and condensation rate relation

Optimization of wind velocity is needed in the forced air flow. As there is an interesting relation between water condensation and wind velocity. When wind velocity increase the condensation increases up to 5m/s wind speed for our set up but above that speed the condensation is decreasing as shown in Fig.5.Fig.6 is the relation of time in hour and relative humidity; we conducted our experiment in the month of May the average variation of relative humidity on an hourly basis, at early morning and on the night the relative humidity is more.

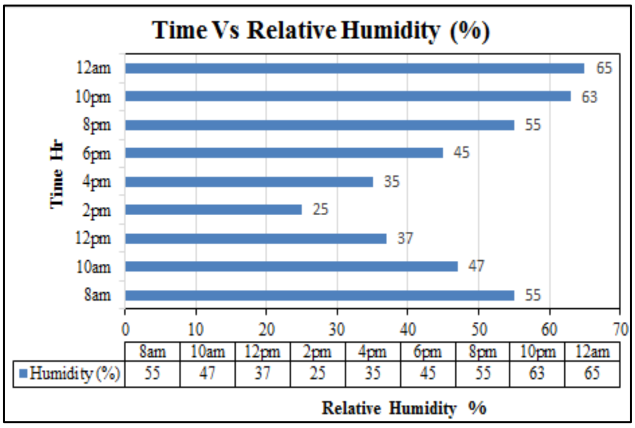

Figure 6: - Hourly variation of humidity

VI.CONCLUSION

An experimental autonomous active dew condenser based on the thermo-electric effect and powered by solar photovoltaic energy has been designed and tested. We obtained the 2.67 Liters of water in eight hours of working at minimum power consumption. The desired outcome of the system is to maximize the volume of condensed water while energy consumption remains at a minimum. We compared the result of condensation on inclined and vertical plate TEC12706 array. We got high condensation rate on an inclined plate at optimized 5.2 m/s wind speed.

ACKNOWLEDGMENT

Thanks to Prof. V. S. Shinde for his valuable contribution in developing the concept of atmospheric water generator

REFERENCES

[1] M.A. Muñoz-García , G.P. Moreda, M.P. Raga-Arroyo, O. Marín-González, "Water harvesting for young trees using Peltier modules powered by photovoltaic solar energy", Computers and Electronics in Agriculture 93, (2013),pp 60–67.

[2] M. Jradi, N. Ghaddar_,y and K. Ghali"Experimental and theoretical study of an integrated thermoelectric–photovoltaic system for air dehumidification and fresh water production" International Journal of Energy Research Int. J. Energy Res. (2011).

[3] MuhyiddineJradi, NesreenGhaddar, KamelGhali, "Optimized Operation of a Solar-Driven Thermo-electric Dehumidification System for Fresh Water Production" Journal of Energy and Power Engineering 6 (2012), 878-891.

[4] A.E. Kabeel, Mohamed Abdulazi, Emad M.S. El-Said, "Solar-based atmospheric water generator utilization of a fresh water recovery:A numerical study" International Journal of Ambient Energy, 2014.

[5] Dia Milani, Ali Abbas, AnthonyVassallo, MatteoChiesa, DhiaAlBakri, “Evaluation of using thermo-electric coolers in a dehumidification system to generate fresh water from ambient air” Chemical Engineering Science 66(2011), 2491–2501.

[6] A.M.K. El-Ghonemy, “Fresh water production from/by atmospheric air for arid regions, using solar energy: Review” Renewable and Sustainable Energy Reviews 16 (2012), 6384–6422.

[7] Javad Abolfazli Esfahani, Nader Rahbar, Mehdi Lavvaf, “Utilization of thermo-electric cooling in a portable active solar still-an experimental study on winter days”Desalination 269 (2011), 198–205.

[8] Yen-Lin Chen, ZiJieChien, Wen Shing Lee, Ching-Song Jwo, Kun-Ching Cho, “Experimental Investigation on Thermo-electric Chiller Driven by Solar Cell” International Journal of Photoenergy Volume (2014).

[9] N. Rahbar, J.A. Esfahani, “Experimental study of a novel portable solar still by utilizing the heat pipe and thermo-electric module” Desalination284 (2012),s55-61.

[10] Cihan Yıldırım, Sezgi Kocak Soylu, Ibrahim Atmaca, Ismail Solmus, “Experimental investigation of a portable desalination unit configured by a thermo-electric cooler” Energy Conversion and Management 85 (2014), 140–145.

[11] S. Ravindran, M.E. Dean, “Thermo-Electrically Cooled Solar Still” Thermo-Electrically Cooled Solar Still”Middle-East Journal of Scientific Research 12 (2012), 1704-1709.

[12] S.N.Paisner; M.Touzelbaev; G. Refai-Ahmed; Yizhang Yang, "New developments for a no-pump-out high-performance thermal grease," Thermal and Thermo mechanical Phenomena in Electronic Systems (ITherm), 2010 12th IEEE Intersociety Conference on, vol., no., pp.1-4, 2-5 June 2010.

[13] B.Singh, L.Tan, A. Akbarzadeh, "Power generation from salinity gradient solar pond using thermo-electric generators for renewable energy application" Power and Energy (PECon), 2012 IEEE International Conference on energy, Vol 55.Pp.89-92, Dec. 2012.

[14] D. D. L. Wijngaards, R.F.Wolffenbuttel, "Study on temperature stability improvement of on-chip reference elements using integrated Peltier coolers" Instrumentation and Measurement, IEEE Transactions on, vol.52, no. 2, pp.478-482, April 2003.