Paper ID #17655

A Graduate Research of the Hybridization of High Concentrated Solar Panel and Anaerobic Production and Desalination

Dr. Fazil T. Najafi, University of Florida

Dr. Fazil T. Najafi

For more than forty years, Dr. Fazil T. Najafi has worked in government, industry and education. He earned a BSCE in 1963 from the American College of Engineering, in his place of birth, Kabul, Afghanistan, and since then came to the United States with a Fulbright scholarship earning his MS in civil engineering in 1972 and a Ph.D. degree in transportation in 1977. His experience in industry includes work as a highway, structural, mechanical, and consultant engineer and construction manager for government groups and private companies. Najafi went on to teaching, first becoming an assistant professor at Villanova University, Pennsylvania in 1977, a visiting professor at George Mason University, and then to the University of Florida, Department of Civil Engineering, where he advanced to associate professor in 1991 and then full professor in 2000 in the Department of Civil and Coastal Engineering. He has received numerous awards including a scholarship award (Fulbright), teaching awards, best paper awards, community service awards, and admission as an Eminent Engineer into Tau Beta Pi. His research on passive radon-resistant new residential building construction was adapted in HB1647 building code of Florida Legislature. Najafi is a member of numerous professional societies and has served on many committees and programs, and continuously attends and presents refereed papers at international, national, and local professional meetings and conferences. Lastly, Najafi attends courses, seminars and workshops, and has developed courses, videos and software packages during his career. His areas of specialization include transportation planning and management, legal aspects, construction contract administration, and public works.

Mr. Chi Xu, University of Florida

Ph.D. in Civil Engineering University of Florida, Gainesville, Florida (Begins in Jan 2015)

M.S. in Civil Engineering University of Florida, Gainesville, Florida Sep 2013 - Dec 2014

©American Society for Engineering Education, 2017

A graduate research of the hybridization of high concentrated solar panel and anaerobic production and desalination

Chi Xu and Fazil Najafi
University of Florida

Abstract

High concentration photovoltaics (HCPV) have become popular new types of solar technology. Compared to traditional photovoltaic panels, HCPV systems are potentially more efficient and cost-effective. However, HCPV's operation will cause high temperature on the panel surface, which causes a heat waste and deficiency of HCPV. Meanwhile, the anaerobic production and desalination plant need a highly demand of heat resource. The paper uses TRNSYS software to design a hybridization system with 500 suns concentration's HCPV, multi-stage flash desalination and anaerobic tank. The 0.01 m2 size HCPV system achieves a max electricity output at 300 W. Meanwhile the hybridization can operate desalination plant with 0.5 distillation ratio and anaerobic digestion at 3.2 m3 per hour. The study of a graduate research of the hybridization of high concentrated solar panel and anaerobic production and desalination would fit the call in the graduate division and it is consistent with the division objectives. Furthermore, the study is relevant to the ASEE division's mission and the scope is interdisciplinary including design, development and research. The research paper is relevant to Chi Xu's Ph.D. dissertation. Furthermore, the information is also used in a graduate level public works engineering and management class that is offered each fall semester. This makes it relevant to the theme of the ASEE Graduate Studies Division.

Introduction

The solar energy is an ideal energy can gain from the sun, as a type of renewable energy, solar energy has its advantage: widespread, low contamination and flexibility. High concentrated photovoltaics is new solar technology which can produce electricity cost-effectively. By using a reflection system to concentrate solar radiation can decrease cost and increase the efficiency. HCPV uses cooling system to cool down the high level heat received from solar concentration. However, cooling system can't use the potential energy from the heat, thus the heat is 'waste'. In order to reuse the energy and demonstrate the concept of renewable energy, the paper will design the hybridization the HCPV and biogas production and desalination plant to reuse waste heat from HCPV and maintain the HCPV in high efficiency. Compared to normal separated plant, the hybridization can provide electricity, biogas and fresh water economically. A model will be built to demonstrate the performance of hybridization. The paper will illustrate the efficient importance of hybridization, the hybridization can achieve a better combination to society and industry. The paper also demonstrate a direction of clean energy hybridization in future research.

HCPV

The high concentrated solar panel has its advantages: greater efficiency, high energy density and lower module surface area [1]. The present HCPV efficiency can reach 39% when using multi-junction cells [2]. However, the efficiency of the photovoltaic cell is affected by temperature, in HCPV system, solar concentration ratio dominantly controls the temperature [2], which is shown in Figure 1.

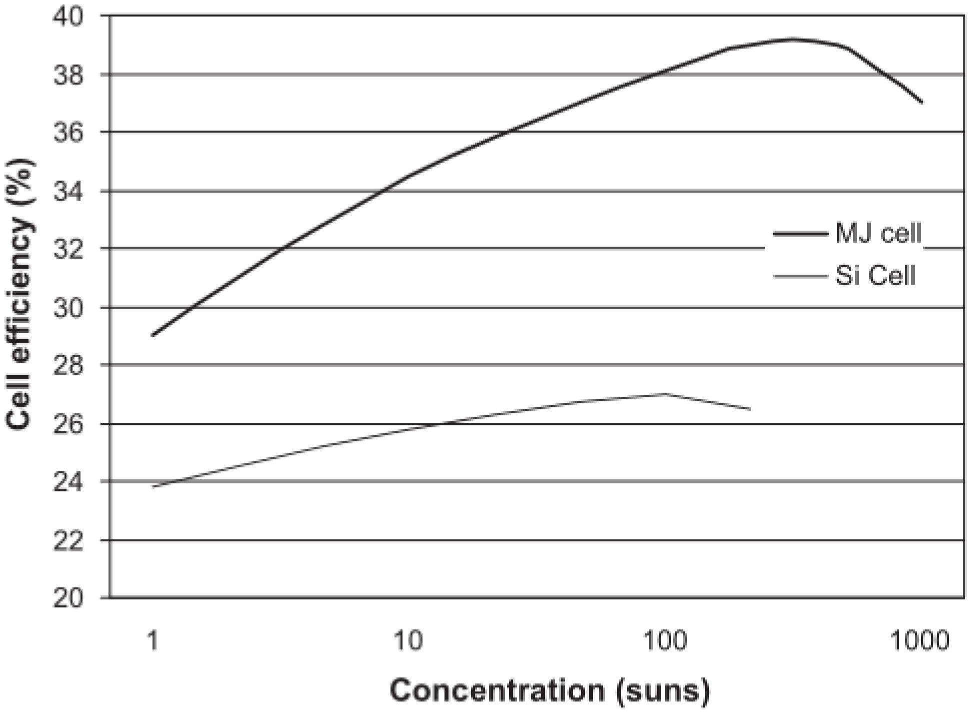

Figure 1. Photovoltaic cell efficiency trend in different concentration ration.

The trend of cell efficiency and temperature can be seen in Figure 2. When the PV cell temperature increasing, it decreases the conversion efficiency of the PV system [3]

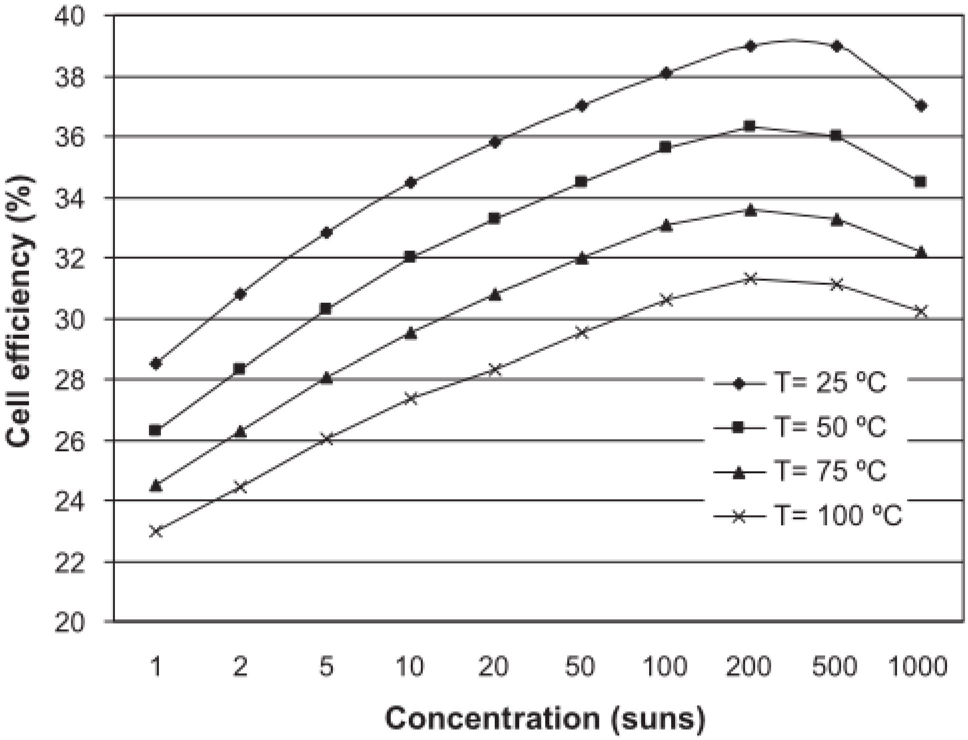

Figure 2. Photovoltaic cell efficiency trend in different temperature.

HCPV plant uses a large quantity of water for cooling the system to keep HCPV running in a moderate efficiency. However, the cooling system maintains the HCPV in operational condition. And the water from the cooling system can still be used as a source of energy. At present, this water is wasted. The cooling system water can be utilized in a biogas plant as a source of energy to maintain the anaerobic tank at a 35 Celsius degree temperature. The objective is to create a co-location environment that includes the hybridization of HCPV, biogas and desalination plants. The hybridization can reuse waste heat from HCPV and still maintain the efficiency of HCPV at a desirable level. The hot water from desalination can still be used as a heat source in biogas production. A model will be built to demonstrate the performance of hybridization and co-location environment. The co-location environment saves energy by utilizing the hot water produced from HCPV and desalination plant for producing biogas. Furthermore, the co-location environment keeps the cost of land, material, maintenance and transportation.

HCPV types

HCPV's concentrator geometries conclude three types: single cells, linear geometry, and densely packed module. In the single cell, solar radiation focus onto each cell, single cell concentrator uses passive cooling to maintain temperature and efficiency [1, 4]. Linear geometry and densely packed module are usually used in large scale plants or to achieve a higher electricity outlet. The cell temperature of an HCPV module impacts its electrical output [5, 6]. Thus, HCPV needs a cooling system to maintain the temperature of the solar module. The cooling system can keep the temperature between 50°C and 80°C [7, 8], many different kinds of cooling system have been shown in literature in the past[9-11]. Passive and active cooling systems are two types of general cooling method for HCPV cooling.

The passive cooling system uses a metal heat sink to cool down the panel. Many types of research show the ability to use passive heat sink to keep panel efficiently (especially in 500suns) [12-19], the passive cooling fin structure can be shown in Figure 3 [19].

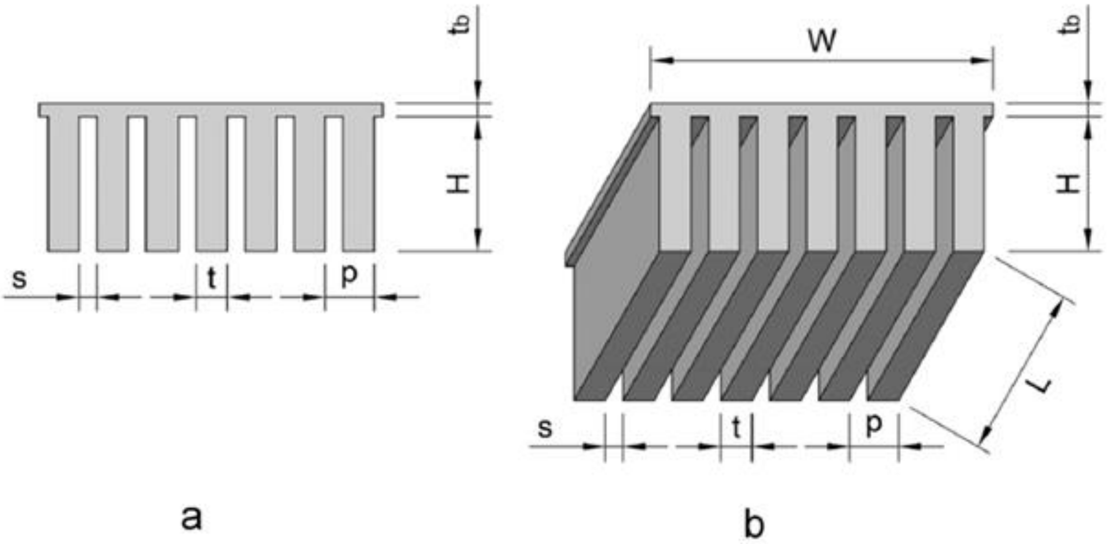

Figure 3. Schematic of a finned heat sink: (a) front view and (b) 3D rendering.

The nomenclature used (Figure 3) in the present work is: spacing (s), pitch (p), height (H), thickness (t), length (L), base width (W), and base thickness (tb) [19]. However, compared to active cooling systems, passive cooling system have lower heat dissipation rates, and environment conditions such as air temperature and wind speed will affect the heat dissipation rates [20]. Active cooling system concludes micro-channels, spray cooling and jet impingement, Abdolzadeh showed spray cooling could reduce cell temperature from 58°C to 37°C [21], however, spray cooling require water usage and the heat from the cell is wasted. The active cooling system is more efficient and more technically feasible if the waste heat from cooling system can be reused in other application [22]. Royne claimed passive cooling system can be used to single cell geometries in 1000 suns. However, more study shows that passive cooling is not efficient enough to cool down the cell especially in high environment temperature [23-26]. Aldossary concluded that active cooling can maintain PV operation efficiency under operating temperature limit and avoid solar cell lifetime degradation [26]. Sun found that the cell temperature can be controlled in 20°C to 31°C when using dimethyl silicon oil [27]. In the active cooling method, Water active cooling can be considered as a cost effective method when the heat from coolant can be reused. Haitham indicated the cell temperature can maintain between 36.6°C and 31.1°C when using active cooling [28]. Zhu found that module temperature can be cooled to 45°C when using water immersion cooling [29]. And Du also showed the water cooling can reduce the cell temperature under 60°C [30]. Aldossary shows the outlet temperature of water cooling can be reached 90°C when it is accessed to a large scales HCPV plant. The heat can be used for heat pump or other thermal application [26]. The active cooling varies from many different types, the paper will discuss them in the following section.

Water cooling

Lasich designed an active cooling system for densely array CPV with 200 suns, which is operating by water [31]. The system can keep a cell's temperature at 40°C with 500 kW/m2 dissipating heat flux capability from cells. Kolhe found that the increasing of water flow rate will increase the electrical efficiency and thermal efficiency rapidly [32], the water cooling increases the CPV electrical output 4.7 to 5.2 times higher than original PV without concentration and cooling. Chong built an automotive radiator cooling system with CPV operating in 377 suns. They observed the efficiency increased from 22.38% to 26.85% in six hours. And the temperature of CPV cell decreased from 59.4°C to 37.1°C [33].

Jet impingement cooling

Jet impingement cooling is an active cooling method which is usually used in industry. It injects a small amount of water into air jets and strikes the grinding wheel at certain speed [34]. Roney designed a jet impingement cooling for densely packed PV cells. In their system, water flows through plenum chamber to the heated surface, which decrease the temperature of PV cells from 60°C to 30°C (200 suns) and 110°C to 40°C (500suns) [35].

Liquid immersion cooling

Russel patented a liquid immersion cooling system. In the system, the photovoltaic cells are placed in a long pipe which is immersed in liquid coolant [36]. Abrahamyan showed dielectric liquid can be used as coolant, in their research, they uses glycerin, butanol, acetone, dioxane, toluol, isopropyl alcohol and deionized water as experimental coolant, their experiment results showed dielectric liquid with 1 to 4 mm thickness can increase cell's efficiency from 40% to 60%. Zhu also designed a liquid immersion cooling system for densely packed PV cells. They found the module was cooled to 35- 45°C under 2.0-2.7 m/s water flow rate and 16°C inlet temperature of silicon oil [37].

Desalination

The desalination is a method to remove mineral salts from saline water and purify the saline water for domestic consumption, industrial usage, and irrigation. Desalination is an important fresh water income particularly in dry countries such as Saudi Arabia, and Australia. Desalination has following conventional methods:

Multi-stage flash distillation

Multi-stage flash distillation (MSF) is a desalination technology which distils salt water by flashing salt water into steam in multiple stages. Multi-stage flash distillation plants produce about 60% of all desalinated water in the world [38], the process can be shown in Figure 4 [39].

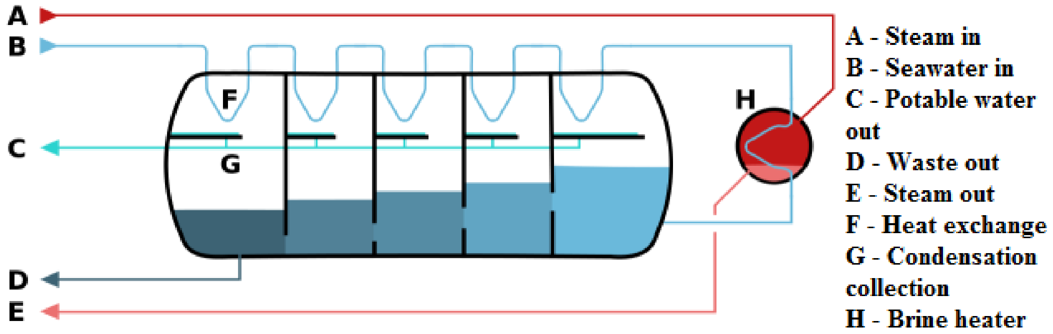

Figure 4. Schematic of a 'once-through' multi-stage flash desalination.

Multiple-effect distillation

Multiple-effect distillation (MED) consists of multiple stages in different condition. Salt water is heated by steam in tubes, some of the salt water is evaporated and collected as fresh water. The heated steam goes into next stage with different condition (temperature and pressure) and evaporates more water. The process of multiple-effect distillation is shown in Figure 5 [40].

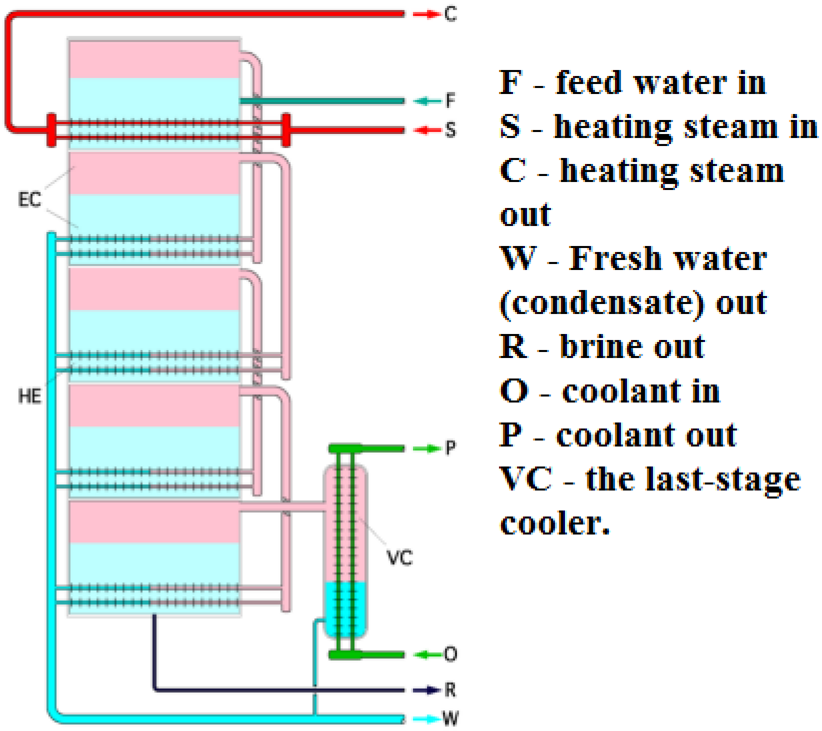

Figure 5. Schematic of a multiple effect desalination plant.

Vapor-compression desalination

Vapor compression desalination is a distillation process which salt water is heated and evaporate by compress vapor. Since the pressure and temperature of the vapor increases, it is possible to use the latent heat rejected during condensation to generate additional vapor. However, desalinated water is more costly than fresh water from natural resource because of its energy consumption. Pre-heat and heat consumption is the most energy usage in distillation technology desalination. A stable and cheap heat resource input can decrease the cost of distillation desalination relevantly.

Anaerobic digestion

Anaerobic digestion uses microorganisms break down biodegradable material in the absence of oxygen [41]. The digestion process can produce bio-fuel for domestic purpose or manage waste for industrial purpose. Digestion process can be described as organic material digest and decompose into methane (CH4) and carbon dioxide (CO2).

$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$

Due to the difference in temperature, there are two types of anaerobic digestion: mesophilic digestion and thermophilic digestion. Mesophilic digestion happens around 30 to 38°C or under 20 to 45°C‘s ambient temperature. Mesophiles are the primary microorganism in digestion. Thermophilic digestion occurs around 49 to 57°C or under 70°C‘s ambient temperature. Thermophiles are the primary microorganism in digestion. Compare to thermophiles, mesophiles has more species and more tolerant to changes of environment. Mesophiles can be considered as a more stable method. However, thermophiles have a faster reaction rate and more rapid gas production because of higher operation temperature.

The production of anaerobic digestion can be divided into two types: biogas, digestate. Biogas is the production of organic waste being decomposed by bacteria, it consists mostly methane and carbon dioxide, and with a small amount of hydrogen, hydrogen sulfide and vapor. Biogas can be graded and purified. The methane can be burned to produce heat and electricity, compare to coal, it has a less environment pollution. Therefore, methane is considered as an ideal resource for fuel-based electricity power plant.

Digestate is a remnant of organic waste after anaerobic digestion, as digestate is produced by acidogenesis and methanogenesis, acidogenesis digestate is fibrous and consists of lignin and cellulose, it can be considered as a soil conditioner [42]. Methanogenesis digestate is a sludge or liquid form. It contains high component such as ammoniums and phosphates, it can be used as fertilizer for plant growth.

Hybridization

Many types of research have shown the availability of solar panel and desalination plant. Srithar designed a triple basin solar desalination system with PV, which can distil basin water 16.94kg/m2/day [43]. Omara presented hybrid of solar dish concentrator with a boiler can distillate 6.7l/m2/day for brackish water [44]. Riffat evaluated v-trough collector solar concentrator’s performance when with desalination plants, it shows the thermal efficiency up to 38% at 100°C operating temperature [45]. Meanwhile, Zhang and Li designed a hybrid system of concentrated solar power (CSP) and biogas power plant. It simulates the performance of CSP and biogas plant in different temperature [46]. Due to the high temperature (more than80°C) of cooling system outlet from HCPV, it can provide a desirable heat resource for distillation desalination plant. And the outlet heat of desalination can be used for anaerobic tank operating in mesophilic digestion (37°C).

System design

The paper will use TRNSYS to simulate the hybridization of HCPV, desalination plant and anaerobic tank. The Schematic diagram is shown in Figure 6.

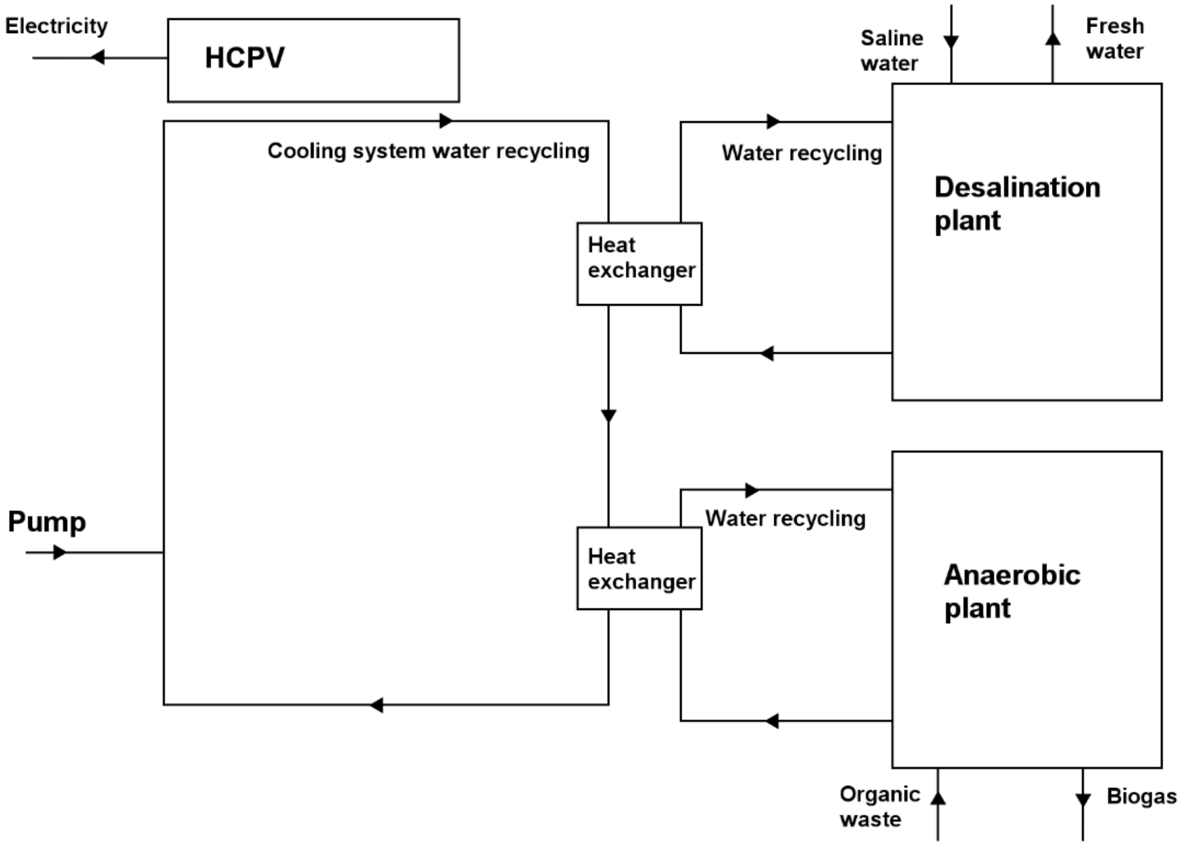

Figure 6. The schematic diagram of hybridization system.

And all the nomenclature used in the paper is shown in Table 1.

Table 1. The nomenclature of designed system.

Nomenclature			
A	The area of HCPV module(m^2)	T_{b1}	The temperature of saline water in first effect(K)
c_p	Specific heat, J/(kg°C)	T_{bN}	The temperature of saline water in the last effect(K)
G_t	Solar radiation (W/m^2)	L_v	The mean latent heat of vaporization(kJ/kg)
d	Thickness of HCPV module(m)	M_d	Mass rate of distillate(kg/h)
η_{cell}	Efficiency of HCPV cell	M_s	Mass rate of feed saline water(kg/h)
η_{power}	Efficiency of power plant cycle	N	Total number of stage or effects
T_{NOCT}	cell temperature at (NOCT) conditions	Q_{loss}	Heat loss from the digestion tank(W)
$T_{a,NOCT}$	ambient temperature at (NOCT) conditions	$T_{a,t}$	Ambient temperature of digestion tank
T_a	ambient temperature	T_t	Temperature of digestion tank
T_c	Temperature of HCPV cell (K)	A_t	The area of digestion tank(m^2)
k	The thermal conductivity of HCPV module(W/mK)	U	overall heat transfer coefficient
T_{c1}	Temperature of cooling system water after cooling the HCPV cell(K)	h_a	The heat transfer coefficient of ambient air (W/m^2 K)
T_{c2}	Temperature of cooling system water after heat exchange for desalination(K)	d_i	Thickness of thermal insulation material(m)
q_2	Pump flow rate of desalination pump	k_i	The corresponding thermal conductivity(W/m^2 K)

The electricity power generated by HCPV is calculated by following equation:

$$E_{HCPV} = A \cdot n \cdot G_t \cdot \eta_{cell} \cdot \eta_{power}$$

Where E_{HCPV} is the electricity power production, A is the area of HCPV module, n is concentration number of HCPV, G_t is solar radiation, η_{cell} is the efficiency of HCPV cell, and η_{power} is the efficiency of power plant cycle.

The temperature of HCPV cell is calculated by following equation:

$$T_C = (T_{NOCT} - T_{a,NOCT})\left[\frac{G_t}{G_{t,NOCT}}\right]\left[1 - \frac{\eta_{cell}}{(\tau\alpha)}\right] + T_a$$

Where T_{NOCT} is the cell temperature at nominal operating cell temperature (NOCT) conditions, $T_{a,NOCT}$ is the ambient temperature at NOCT conditions, $G_{t,NOCT}$ is solar radiation at NOCT conditions (800W/m^2). T_a is ambient temperature. ($\tau\alpha$) is a coefficient which is determined by the type of HCPV.

After cooling HCPV the temperature of cooling system water can be calculated by following equation:

$$T_{c1} = T_c - \frac{c_p q_1 d}{kA}$$

Where c_p is specific heat of water, q_1 is the rate pump of cooling system, which can be changed in parameter, d is the thickness of HPCV module, k is the thermal conductivity of HCPV module, and A is the area of HCPV module.

The heat exchaner between desalination and HCPV can be calculated as:

$$(T_{c1} - T_{c2})q_1 = (T_{b1} - T_{bN})q_2$$

Assuming the heat of water after heat exchange is to maintain anaerobic tank, T_{b1} is determined by MSF desalination, when the pump of desalination is designed, T_{c2} can be calculated.

The system choose multi-stage flash system for desalination simulation.

The distillation production is calculated in following equation:

$$\frac{M_f}{M_d} = \frac{L_v}{c_p \Delta F} + \frac{N-1}{2N}$$

Where M_d is Mass rate of distillate, M_f is mass rate of feed, L_v is average latent heat of vaporization and N is total number of stages or effects.

The flashing temperature range ΔF is given by:

$$\Delta F = (T_{b1} - T_{bN})\frac{N}{N-1}$$

T_{b1} is temperature of saline water in first effect and T_{bN} is temperature of saline water in the last effect.

After heat exchange for desalination, the water will flow through next heat exchanger which will transfer the rest heat for anaerobic digestion plant in a lower temperature (35°C). The heat loss of digestion tank can be calculated as:

The heat which anaerobic tank received from heat exchanger is:

$$Q_c = c_p q_1 (T_{c2} - T_t)$$

$$Q_{loss} = UA_t (T_t - T_{a,t})$$

$$Q_{net} = Q_c - Q_{loss}$$

Where Q_{loss} is heat loss from digestion tank, U is the overall heat transfer coefficient, A_t is the area of digestion tank, $T_{a,t}$ and T_t is the temperature of digestion tank and ambient temperature of digestion tank.

The overall heat transfer coefficient can be calculated:

$$\frac{1}{U} = \frac{1}{h_a} + \sum_{i=1}^{n} \frac{d_i}{k_i}$$

h_a is heat transfer coefficient of ambient air, it can consider as 10 W/m^2 K. d_i is thickness of thermal insulation material and k_i is the corresponding thermal conductivity.

With a designed anaerobic tank, the volume of methane per day is calculated as:

$$V = \frac{24 \times 3600 \times Q_{net}}{LHV_{CH_4}}$$

Where LHV_{CH4} is lower heating value of methane, which is 35.9 MJ/m^3 [47].
The paper uses 4 cm rock wool as thermal insulation material, the overall heat transfer coefficient U is 1 W/ (m^2K). The parameter of hybridization is shown in Table 2.
Some system can have a higher efficiency with a thermal tank attached [48].

Table 2. The parameter of hybrid system.

A(m^2)	0.001	d(m)	0.001
c_p(J/kg°C)	4186	k(m/K)	130
q_1(m^3/s)	0.05	L_v(kJ/kg)	2257
N	50	T_{b1}(°C)	75
U(W/m^2K)	1	T_{bN}(°C)	35
η_{cell}	0.45	η_{power}	0.35
n	500	At(m^2)	9
T_{aNOCT}(°C)	25	LHV_{CH4}	35.9
T_{NOCT}(°C)	100		

The ambient temperature and solar radiation are determined by weather data, the system uses tmy2 weather data, the location is in Key West and time length is 1year (8760hr).
The design of TRNSYS is shown in Figure 7.

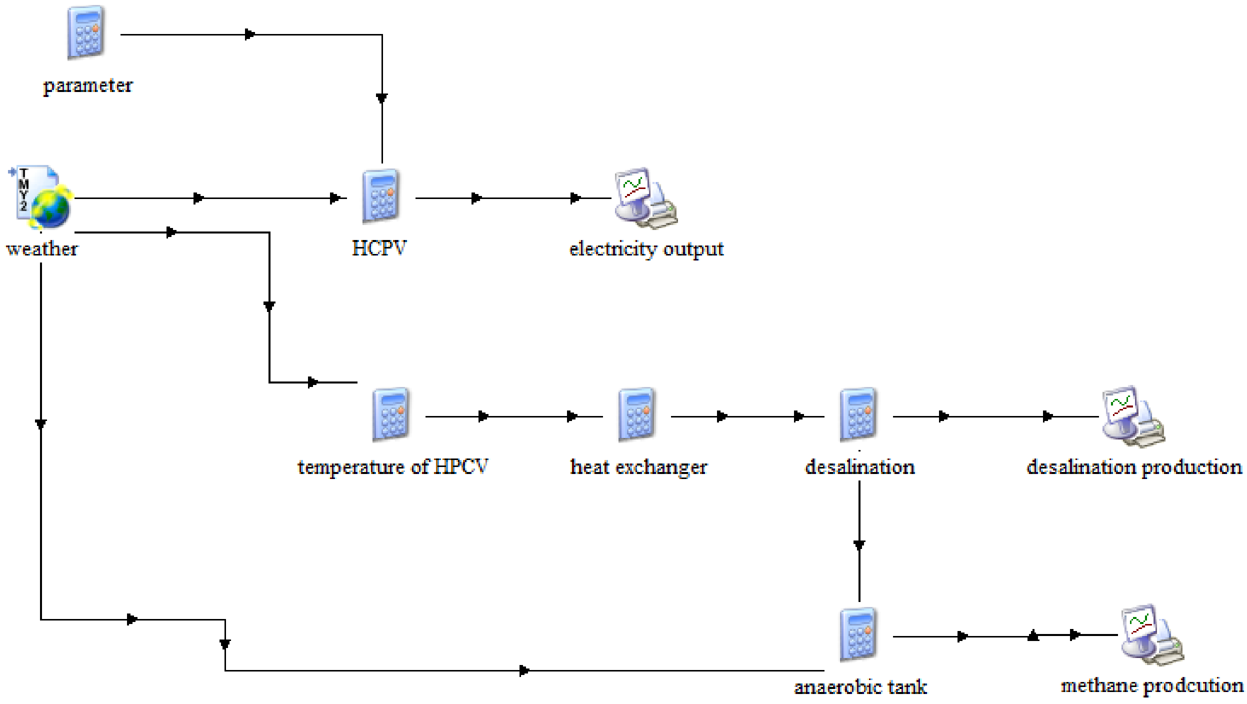

Figure 7. The design of TRNSYS.

In the Simulation, the production of electricity, methane and distillation is shown below.

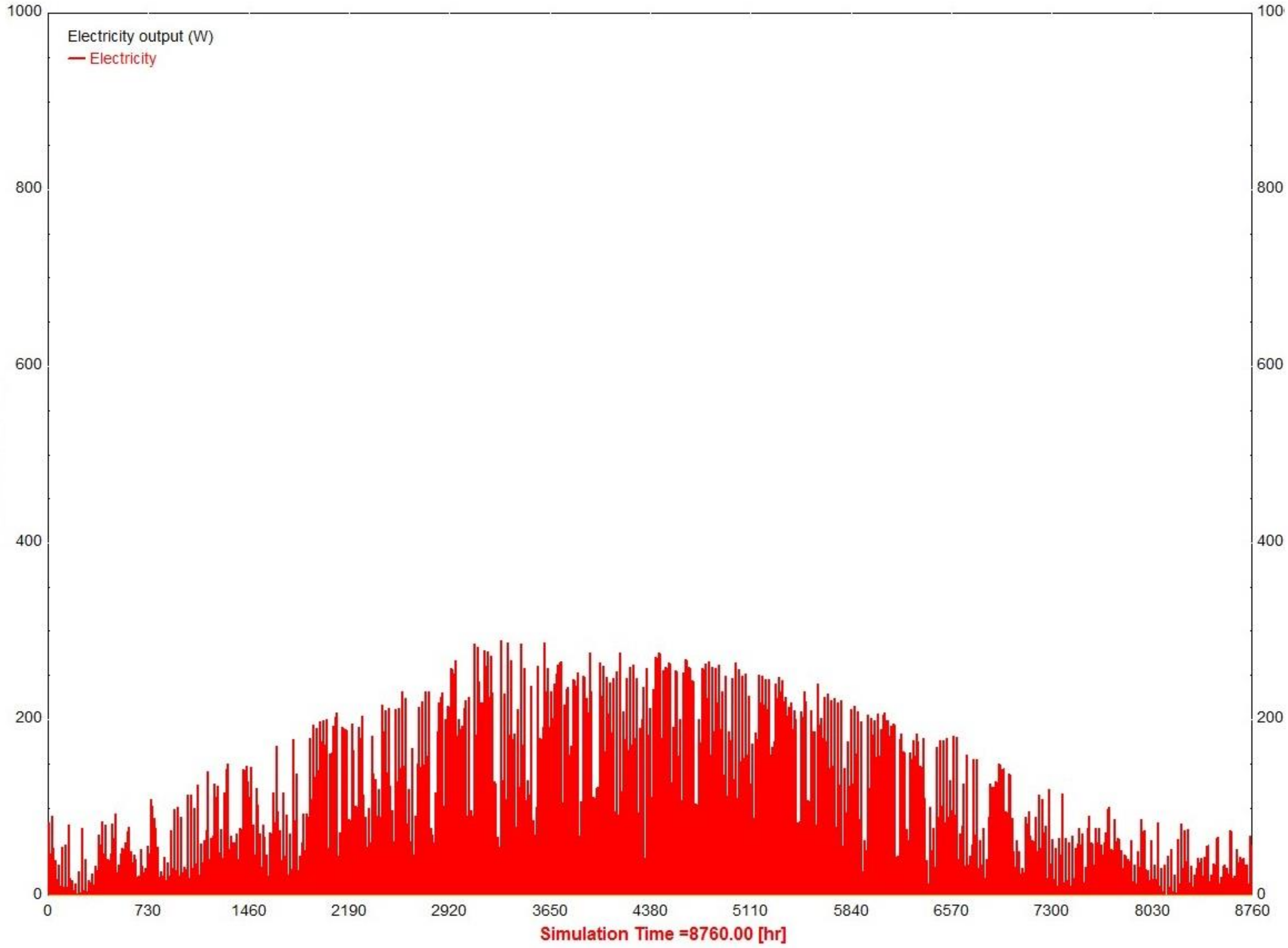

Figure 8. Simulation of HCPV electricity production

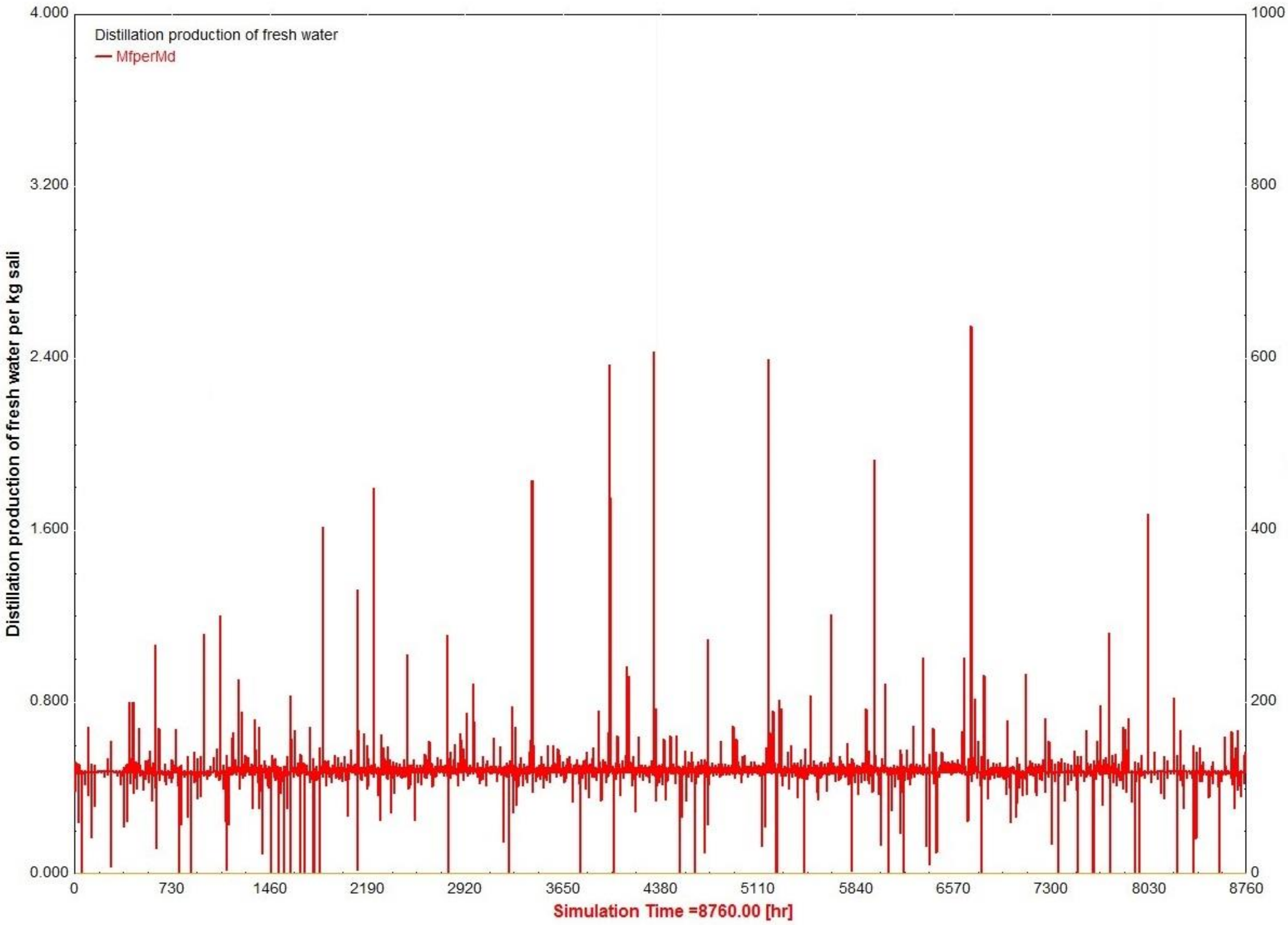

Figure 9. Simulation of desalination fresh water production

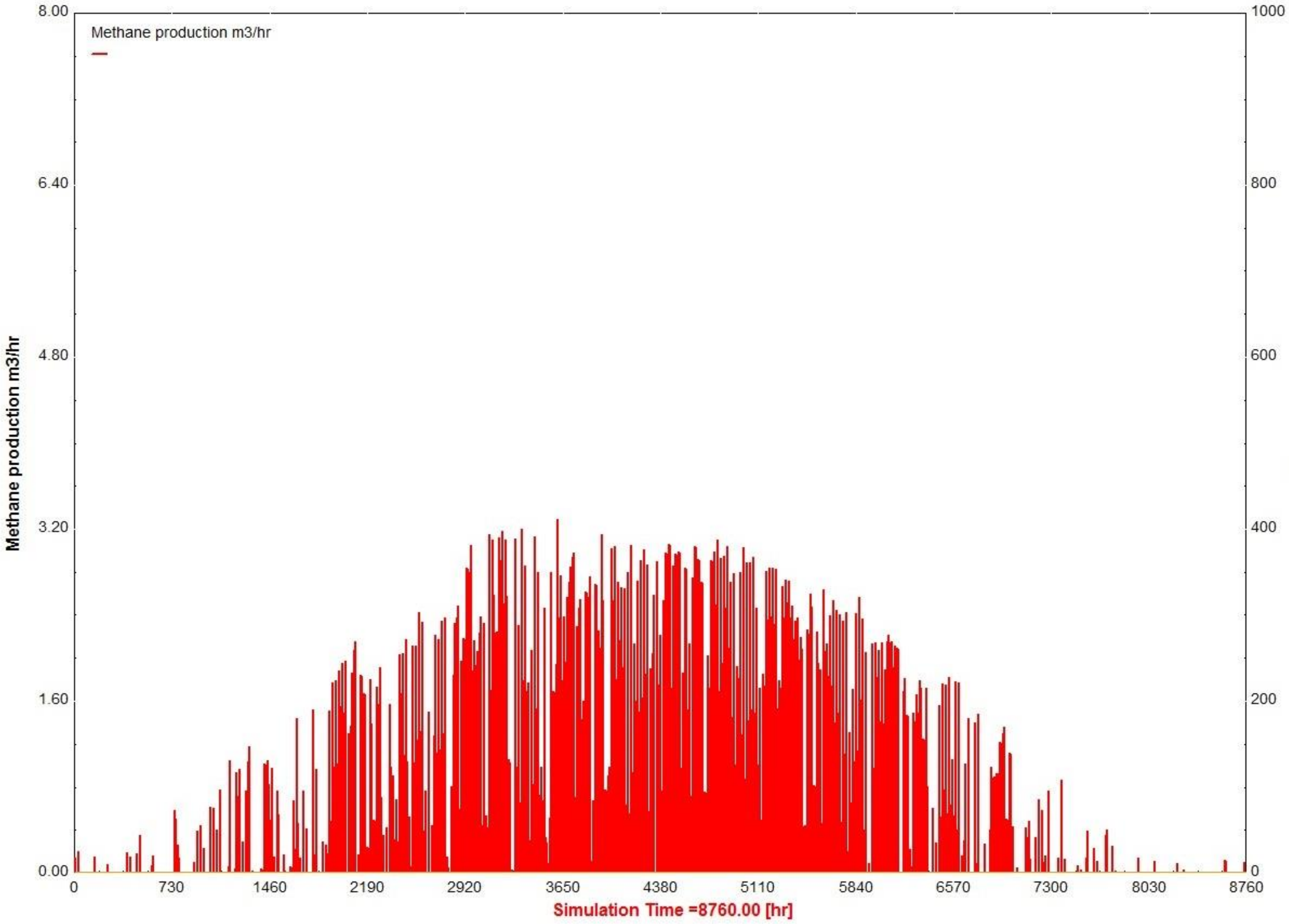

Figure 10. Simulation of methane production

Conclusion

From the simulation, the production of hybridization is related to weather (solar radiation and ambient temperature). The hybridization can achieve its optimal output in summer days. The paper chooses one day in summer (July 16th) for specify.

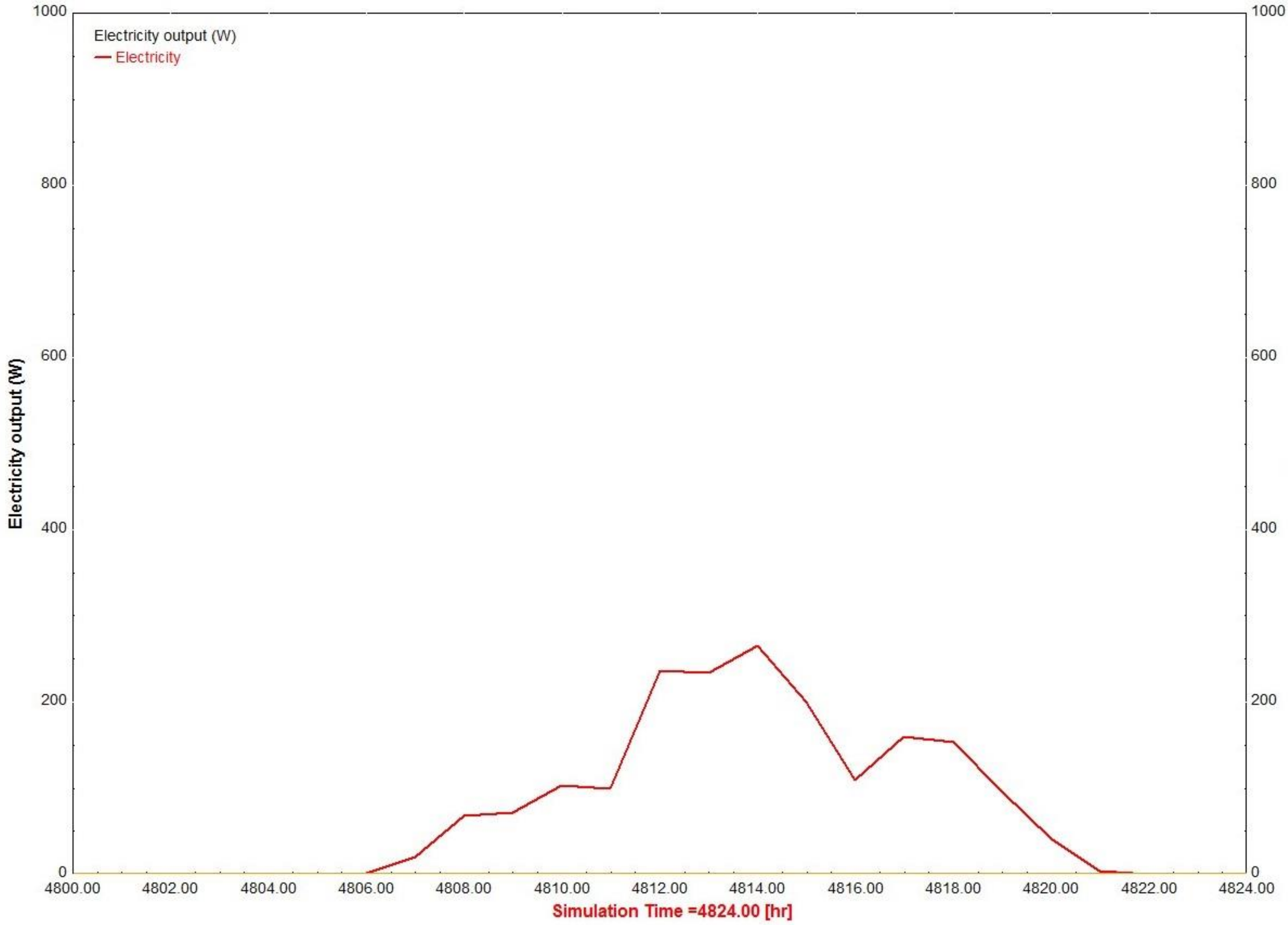

Figure 11. Simulation of HCPV electricity production in July 16th

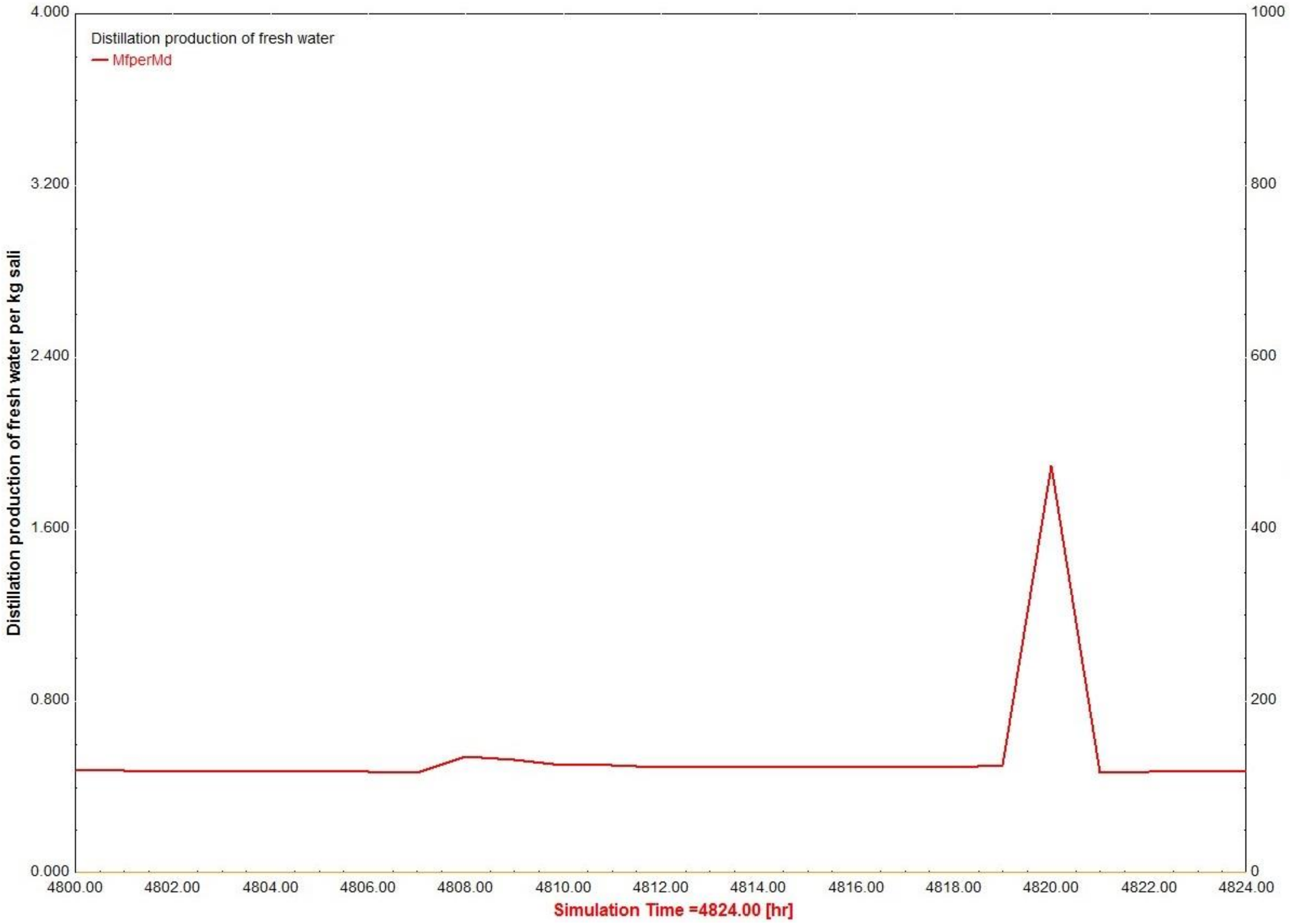

Figure 12. Simulation of desalination fresh water production in July 16th

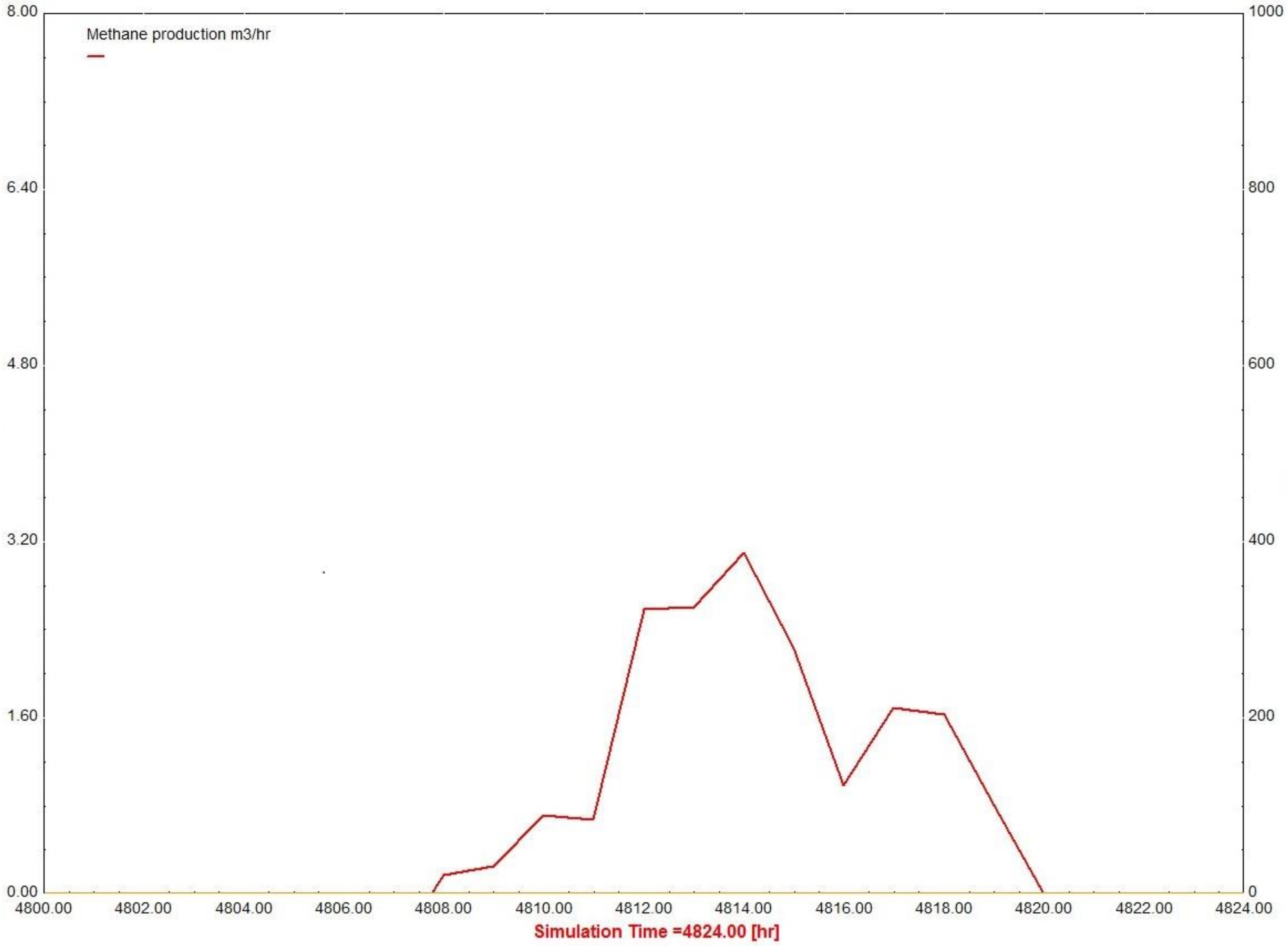

Figure 13. Simulation of methane production in July 16th

In the specified time, the electricity production of HCPV is related to solar radiation, when the solar radiation decreases, it results a decreasing in electricity output. Meanwhile, the cooling system has a less heat input, which results a deficiency in desalination plant and anaerobic tank. In the future research, the methane can be used for the biogas-based power plant. It can increase the production of electricity and remedy the imbalance of electricity output. In future research, the project will focus on optimizing the performance of hybridization and the subsequent consumption of biogas.

Reference

[1] Pérez-Higueras, P., High Concentrator Photovoltaics: Fundamentals, Engineering and Power Plants (Green Energy and Technology) 1st ed. Springer, Inc, New York, 2015 Edition.
[2] Pérez-Higueras, P., Munoz. E., High Concentrator PhotoVoltaics efficiencies: Present status and forecast, Renewable and Sustainable Energy Reviews, 2011, Vol. 15, pp. 1810–1815.
[3] Royne, A., Dey, C., Mills, D., 2005. Cooling of photovoltaic cells under concentrated illumination: a critical review. Sol. Energy Mater. Sol. Cells, Vol. 86, pp. 451–483.
[4] Kinsey, G., Bagienski, W., Advancing Efficiency and Scale in CPV Arrays. IEEE Journal of Photovoltaics. April 2013, Vol. 3, Issue. 2, pp. 873–878.

[5] Peharz, G., Ferrer Rodríguez, J., Investigations on the temperature dependence of CPV modules equipped with triple-junction solar cells, Prog. Photovolt. Res. Appl. 2011, Vol. 19, Issue. 1, pp. 54–60.
[6] Fernández, E., Pérez-Higueras, P., Quantifying the effect of air temperature in CPV modules under outdoor conditions, AIP Conf. Proc., 2012, Vol. 1477, pp. 194–197.
[7] Kinsey G., Edmondson, K., Spectral response and energy output of concentrator multi-junction solar cells, Prog. Photovolt. Res. Appl. 2009, Vol.17, pp. 279–288.
[8] Fernández, E., Almonacid, F., Rodrigo, P., Pérez-Higueras, P., Calculation of the cell temperature of a high concentrator photovoltaic (HCPV) module: a study and comparison of different methods, Sol. Energy Mater. Sol. Cells, 2014, Vol. 121, pp. 144–151.
[9] Martinelli, G., Stefancich, M., 7 Solar Cell Cooling, in: A.L. Luque, A. Viacheslav (Eds.), Concentrator photovoltaics, Springer, Berlin, Germany, 2007, pp. 133–149.
[10] Micheli, L., Sarmah, N., Luo, X., Opportunities and challenges in micro- and nano-technologies for concentrating photovoltaic cooling: a review, Renew. Sustain. Energy Rev. 2013, Vol. 20, pp. 595–610.
[11] Jakhar, S., Soni, M.S., Gakkhar, N., Historical and recent development of concentrating photovoltaic cooling technologies, Renew. Sustain. Energy Rev. 2016, Vol. 60, pp. 41–59.
[12] Araki, K., Uozumi, H., Yamaguchi, M., A simple passive cooling structure and its heat analysis for 500 x concentrator PV module, in: Proceedings of the Twenty-Ninth IEEE Photovoltaic Specialists Conference, 2002, 2nd, pp. 1568– 1571.
[13] Min, C., Nuofu, C., Xiaoli, Y., Thermal analysis and test for single concentrator solar cells, J.Semicond. 2009, Vol 30, pp. 4-11,
[14] Renzi, M., Egidi, L., Performance analysis of two 3.5k Wp CPV systems under real operating conditions, Appl.Energy, 2015, Vol. 160, pp. 687–696.
[15] Gualdi, F., Arenas, O., Determining passive cooling limits CPV using analytical thermal model, AIP Conf. Proc.1556, 2013, 10,http://dx.doi.org/10.1063/1.4822187. Accessed Jan, 2017.
[16] Incropera, F.P., DeWitt, D.P., Bergman, T.L., Fundamentals of Heat and Mass Transfer, Wiley, Hoboken, NJ, 2007.
[17] Nagarani, N., Mayilsamy, K., Review of utilization of extended surfaces in heat transfer problems, Renew.Sustain.Energy Rev, 2014, Vol. 29, pp. 604–613.
[18] Natarajan, S.K., Mallick, T.K., Numerical investigations of solar cell temperature for photovoltaic concentrator system with and without passive cooling arrangements, Int.J.Therm.Sci, 2011, Vol. 50, pp. 2514–2521.
[19] Micheli, L., Fernández, E., Performance limits and economic perspectives for passive cooling of High Concentrator Photovoltaics, Solar Energy Materials & Solar Cells, 2016.
[20] Tan, L., Passive Cooling of Concentrated Solar Cells Using Phase Change Material Thermal Storage, RMIT, 2013.
[21] Abdolzadeh, M., Ameri, M., Improving the effectiveness of a photovoltaic water pumping system by spraying water over the front of photovoltaic cells. Renew Energy, 2009, Vol 34, pp. 91–96.
[22] Royne, A., Dey, C., Mills, D., Cooling of photovoltaic cells under concentrated illumination: a critical review, Sol. Energy Mat. Sol. Cells. 2005, Vol. 86, Issue 4, pp. 451–483.

[23] Theristis, M., et al., Design and numerical analysis of enhanced cooling techniques for a high concentration photovoltaic (HCPV) system. 27th European Photovoltaic Solar Energy Conference and Exhibition, 2012, pp.260–265.
[24] Edenburn, M.W., 1980. Active and passive cooling for concentrating photovoltaic arrays. In 14th Photovoltaic Specialists Conference, pp. 771–776.
[25] Eveloy, V., Rodgers, P., Bojanampati, S., 2012. Enhancement of photovoltaic solar module performance for power generation in the Middle East. 28th Annual IEEE Semiconductor Thermal Measurement and Management Symposium (SEMI-THERM), 2012, pp.87–97.
[26] Aldossary, A., Mahmoud, S., Technical feasibility study of passive and active cooling for concentrator PV in harsh environment, Applied Thermal Engineering, 2016, Vol. 100, pp. 490–500.
[27] Yong, S., Yiping, W., Direct liquid-immersion cooling of concentrator silicon solar cells in a linear concentrating photovoltaic receiver, February, 2014, Vol. 65, pp. 264–271.
[28] Haitham M.S., Experimental performance evaluation and modeling of jet impingement cooling for thermal management of photovoltaics, Solar Energy, 2016, Vol. 135, pp. 605–617.
[29] Zhu, L., Boehm, R., Water immersion cooling of PV cells in a high concentration syste, Solar Energy Materials and Solar Cells, February 2011, Vol. 95, Issue 2, pp 538–545.
[30] Bin, D., Eric, H., Performance analysis of water cooled concentrated photovoltaic (CPV) system, Renewable and Sustainable Energy Reviews, 2012, Vol. 16, pp. 6732–6736.
[31] Lasich, J.B., Cooling circuit for receiver of solar radiation. US patent, 7076965; 2006.
[32] Kolhe, M., Bin D., Hu E., Water cooled concentrated photovoltaic system. Int J Smart Grid Clean Energy, 2012, pp. 2–6.
[33] Chong, K-K., Tan, W-C., Study of automotive radiator cooling system for dense- array concentration photovoltaic system. Sol Energy, 2012, Vol. 86, pp. 2632–2643.
[34] Babic, D., Murray, D B., Torrance A. Mist jet cooling of grinding processes. Int J Mach Tools Manuf, 2005, Vol. 45, pp. 1171–1177.
[35] Royne, A., Dey, C., Design of a jet impingement cooling device for densely packed PV cells under high concentration. Sol Energy, 2007, Vol. 81, pp. 1014–1024.
[36] Russell C. R. Optical concentrator and cooling system for photovoltaic cells. US patent, RE30584, 1981.
[37] Zhu L., Wang, Y., Fang, Z., Sun, Y., Huang, Q., An effective heat dissipation method for densely packed solar cells under high concentrations. Sol Energy Mater Sol Cells, 2010, Vol. 94, pp. 133–140.
[38] IAEA. Introduction of Nuclear Desalination. IAEA Technical Report Series No. 400. 2000.
[39] By Multiflash.png: Ruben Castelnuovo derivative work: NJR_ZA (talk) - Multiflash.png, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=9109184. Accessed Jan, 2017
[40] By Ub - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=5099064. Accessed Jan, 2017
[41] National Non-Food Crops Centre. "NNFCC Renewable Fuels and Energy Factsheet: Anaerobic Digestion", Retrieved on 2011-11-22
[42] Evaluation of Opportunities for Converting Indigenous UK Wastes to Fuels and Energy (Report), NNFCC 09-012

[43] Srithar, K., Rajaseenivasan, T., Stand-alone triple basin solar desalination system with cover cooling and parabolic dish concentrator. Renewable Energy, 2016, Vol. 90, pp. 157-165.
[44] Omara, Z.M., Eltawil, A., Hybrid of solar dish concentrator, new boiler and simple solar collector for brackish water desalination. Desalination, 2013, Vol. 326, pp. 62–68.
[45] Riffat, S., Mayere, A., Performance evaluation of v-trough solar concentrator for water desalination applications. Applied Thermal Engineering, 2013, Vol. 50, pp. 234-244.
[46] Zhang, G., Li, Y., Design and analysis of a biogas production system utilizing residual energy for a hybrid CSP and biogas power plant. Applied Thermal Engineering. 2016, Vol. 109, pp. 423–431.
[47] Yang, S., Tao, W., Heat Transfer, Higher Education Press, 2006 (in Chinese).
[48] Julian, D., Hovsapian, R., Effect of multi-tank thermal energy storage, recuperator effectiveness, and solar receiver conductance on the performance of a concentrated solar supercritical CO2-based power plant operating under different seasonal conditions. Energy. Energy, 2016, Vol. 115, pp 353–368.