Conference Proceedings

Solar World Congress 2015
Daegu, Korea, 08 – 12 November 2015

Concentrating or non-concentrating solar collectors for Solar Aided Power Generation?

Jiyun Qin, Eric Hu and Shengcao Yuan

School of Mechanical Engineering, the University of Adelaide, Adelaide (Australia)

Abstract

A hypothesis has been put forward that using non-concentrating solar collectors in a Solar Aided Power Generation (SAPG) plant might be a more efficient and economical option than using concentrating solar collectors. Few previous works on this topic have been carried out due to the perception that concentrating collectors produce higher temperature (solar) heat, thus higher solar thermal to power efficiency of the SAPG plant. However, other factors related to concentrating collectors, such as collecting only direct solar radiation, taking up more land area to install them, and higher capital and operation costs, have been overlooked. In this paper, a detailed comparison study between using concentrating or non-concentrating solar collectors in an SAPG plant have been undertaken. The results show that using non-concentrating solar collectors in an SAPG plant is superior in some cases.

Keywords: *Solar Aided Power Generation, Net solar efficiency, Concentrating solar collectors, non-concentrating solar collectors.*

1. Introduction

Due to the high capital costs of stand-alone solar power plants, integrating the solar thermal energy into a conventional fossil fired power plant attracts great interest nowadays. Solar Aided Power Generation (SAPG) is a method of integrating solar thermal energy carried by heat transfer fluid (HTF) into a conventional fossil fired power plant. In an SAPG plant, the HTF could be used to displace the extraction steam by preheating the feedwater to boiler at various temperature (and pressure) levels (Hu et al., 2010). The saved/displaced extraction steam by solar heat can expand further to generate power.

Generally, both concentrating solar collectors and non-concentrating solar collectors can be used in an SAPG plant. Since concentrating solar collectors can produce HTF at higher temperatures (200ºC - 450ºC), and non-concentrating solar collectors can produce HTF at lower temperatures (50ºC - 200ºC), concentrating solar collectors and non-concentrating solar collectors can be used to displace the extraction steam at different temperature levels. Yan et al. (2010) and Yang et al. (2011) found that displacing the extraction steam at higher temperature levels can produce more power output. Therefore, the previous works of Hou et al. (2013, 2015), Wu et al. (2015) and Peng (2013, 2014a, 2014b) evaluated the SAPG plant using concentrating solar collectors to displace the extraction steam at high temperature levels. However, the advantages of non-concentrating solar collectors could not be ignored. Concentrating solar collectors can only collect direct solar radiation (I_N). Nevertheless, non-concentrating solar collectors can absorb both direct solar radiation and diffuse solar radiation (I_D). Therefore, on a given piece of land, non-concentrating solar collectors may collect more solar heat than concentrating solar collectors. Zhou et al. (2015) compared using concentrating solar collectors and non-concentrating solar collectors in an SAPG plant by using the concept of Net Solar Efficiency. The net solar efficiency of an SAPG plant is defined as the power output from solar thermal energy in the SAPG plant divided by the total solar energy radiation falling on the land of the solar field. It was found that using non-

doi:10.18086/swc.2015.04.18 Available at http://proceedings.ises.org

concentrating solar collectors has advantages above using concentrating solar collectors from the net solar thermal point view. However, previous work of Zhou et al. (2015) has not considered the differences of capital and installation costs between concentrating and non-concentrating solar collectors. An economic comparison of using concentrating and non-concentrating solar collectors in an SAPG plant is needed.

2. Methodology

On a given piece of land, solar collectors with different layouts lead to different thermal outputs of the solar field. In this study, a solar field model has been developed that can calculate the solar annual useful heat output (from concentrating and non-concentrating fields) at different temperature levels under local weather conditions (for a given location). In the model, the annual output is the sum of annual hourly yields of the field and the layout of the solar fields including the shading factor between rows of the collectors has been considered. The outputs of the solar field model are fed into an SAPG plant simulation model developed in-house to calculate the solar power generation. In the study, a parabolic trough (PT) solar collector is used as the representative of concentrating solar collectors and the evacuated tube (ET) solar collector is used as the representative of non-concentrating solar collectors.

2.1. Parabolic trough solar collectors

The useful thermal energy produced by the PT solar collectors ($\dot{Q}_{useful,PT}$, kW) is calculated as:

$$\dot{Q}_{useful,PT} = \dot{Q}_{absorb,PT} - \dot{Q}_{loss,PT} \quad \text{(eq. 1)}$$

where $\dot{Q}_{absorb,PT}$ (W) is the solar energy absorbed by PT solar collectors and $\dot{Q}_{loss,PT}$ (W) is the heat loss of the solar field.

In Eq.1, the $\dot{Q}_{absorb,PT}$ is given as:

$$\dot{Q}_{absorb,PT} = \eta_{op,PT} I_N \cos\theta_{i,PT} K_{\theta,PT} \eta_{Row\ shading,PT} \eta_{end,loss} F_e A_{PT} \quad \text{(eq. 2)}$$

where $\eta_{op,PT}$ is the optical efficiency of the solar collector, I_N (W/m^2) is the Direct Normal Irradiance (DNI), $\theta_{i,PT}$ is the local solar radiation incidence angle, $K_{\theta,PT}$ is the incidence angle modifier of the solar collector, $\eta_{Row\ shading,PT}$ is the row shading of the solar collector, and $\eta_{end,loss}$ is the aperture area of the solar field. In Eq.2, each factor is calculated from previous work of Zhou et al. (2015).

The heat loss of the solar field in Eq. 1 can be divided into two parts. One is the heat loss of heat pipes $\dot{Q}_{loss,pipe,PT}$ (W) and the other is the heat loss of the PT solar collectors $\dot{Q}_{loss,collector,PT}$ (W). The heat loss is dependent on the solar collectors. In this study, LS-2 PT solar collectors are used as a case study. The $\dot{Q}_{loss,collector,PT}$ and $\dot{Q}_{loss,pipe,PT}$ of an LS-2 solar collector are given as:

$$\dot{Q}_{loss,collector,PT} = b_1 K_{\theta,PT} \dot{Q}_{absorb,PT} + (b_2 + b_3 \Delta T)\Delta T A_{PT}, \text{ (Dudley et al., 1994)} \quad \text{(eq. 3)}$$

where b_1 is 0.00007276, b_2 is 0.00496 (W/m^{2}K), b_3 is 0.00691 (W/m^{2}K^2) and ΔT is the temperature difference between the mean loop temperature of the solar collector and the ambient temperature.

$$\dot{Q}_{loss,pipe,PT} = (0.01693\Delta T - 0.0001683\Delta T^2 + 6.78 \times 10^{-7}\Delta T^3) A_{PT}. \text{ (Patnode, 2006)} \quad \text{(eq. 4)}$$

2.2. Evacuated tube solar collectors

The useful thermal energy produced by ET solar collectors is the product of the thermal efficiency of the ET solar collector and the solar radiation absorbed by the ET solar collector, which is given as:

$$\dot{Q}_{useful,ET} = \eta_{ET}\dot{Q}_{absorb,ET}, \quad \text{(eq. 5)}$$

where $\dot{Q}_{absorb,ET}$ (W) is the solar energy collected by the ET collectors and η_{ET} is the thermal efficiency of the ET solar collector.

Based on the experimental data, Budihardjo and Morrison (2009) found that the thermal efficiency of the ET solar collectors can be given as:

$$\eta_{ET} = 0.536 - 0.824\frac{\Delta T}{I_G} - 0.0069\frac{\Delta T^2}{I_G}, \quad \text{(eq. 6)}$$

where ΔT is the temperature difference between mean loop temperature and ambient temperature, and I_G (W/m2) is the global solar radiation.

In Eq. 5, the $\dot{Q}_{absorb,ET}$ is given as (Du et al., 2013):

$$\dot{Q}_{absorb,ET} = I_G\eta_{Row\ shading,ET}A_{ET}, \quad \text{(eq. 7)}$$

where $\eta_{Row\ shading,ET}$ is the row shading factor of the parallel row and A_{ET} is the area of the ET solar collectors.

For the ET solar collectors, global solar radiation falling on the collectors can be given as (Duffie et al., 2006),

$$I_G = I_D\frac{(1+\cos\beta)}{2} + I_N\cos\theta_{i,ET}, \quad \text{(eq. 8)}$$

where β is the tilt angle (the angle between the collector plane surface and the horizontal), $\theta_{i,ET}$ is the local solar radiation incidence angle, and I_D (W/m^2) and I_N (W/m^2) are solar diffuse radiation and direct radiation, respectively.

In Eq.8, the incidence angle of the ET solar collectors is given as (Duffie et al., 2006):

$$\cos\theta_{i,ET} = (\cos L\cos\beta + \sin L\sin\beta\cos A_{ZS})\cos\delta\cos\omega + \cos\delta\sin\omega\sin\beta\sin A_{ZS} + \sin\delta\,(\sin L\cos\beta - \cos L\sin\beta\cos A_{ZS}), \quad \text{(eq. 9)}$$

where Azs is Azimuth angle, L is the Latitude, ω is hour angle and σ is the solar declination angle.

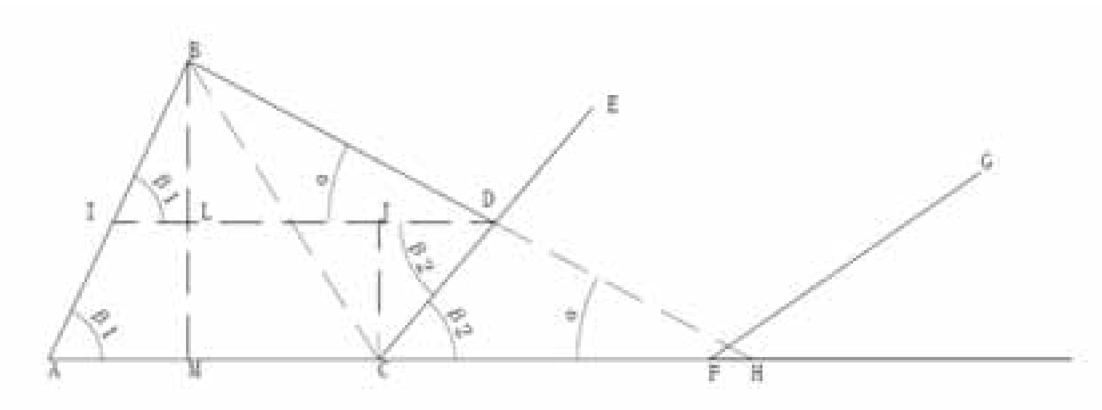

Fig. 1: Two dimensional drawing of the three rows' ET solar collectors.

In Eq.7, the row shading factor should be considered if ET solar collectors are installed in rows. Figure 1 presents a row shading analysis for three rows of ET collectors. For the first row of ET solar collectors, there is no shading on the collectors. As a result, the shading factor for the first row of ET collectors can be ignored. For the second row of ET solar collectors, the shading factor can be given as:

$$\eta_{Row\ shading,ET,2} = 1 - \frac{CD}{CE}. \quad \text{(eq. 10)}$$

The CD can be given as:

$$CD = \frac{CJ}{\sin\beta_2} = \frac{ML}{\sin\beta_2} = \frac{BM-BL}{\sin\beta_2}. \quad \text{(eq. 11)}$$

In Eq.11,

$$BM = l\sin\beta_1. \quad \text{(eq. 12)}$$

$$BL = BD\sin\alpha. \quad \text{(eq. 13)}$$

where the length of the collector is *l* (m) and the altitude angle is *α*.

By using the trigonometric functions, Eq. 10 can be given as:

$$\eta_{Row\ shading,ET,2} = 1 - \frac{\dfrac{l\sin\beta_1 - \dfrac{\sqrt{l^2+d^2-2ld\cos\beta_1}.\sin\left(180^o - \cos^{-1}\dfrac{\left(\sqrt{l^2+d^2-2ld\cos\beta_1}\right)^2+d^2-l^2}{2d\sqrt{l^2+d^2-2ld\cos\beta_1}} - \beta_2\right)}{\sin(\beta_2+\alpha)}\sin\alpha}{\sin\beta_2}}{l}$$

(eq. 14)

where the distance between two rows is *d* (m)

In the second row, for the N[th] row of ET solar collectors the shading factor can be given as:

$$\eta_{Row\ shading,ET,N} = 1 - \frac{\dfrac{l\sin\beta_{N-1} - \dfrac{\sqrt{l^2+d^2-2ld\cos\beta_{N-1}}.\sin\left(180^o - \cos^{-1}\dfrac{\left(\sqrt{l^2+d^2-2ld\cos\beta_{N-1}}\right)^2+d^2-l^2}{2d\sqrt{l^2+d^2-2ld\cos\beta_{N-1}}} - \beta_N\right)}{\sin(\beta_N+\alpha)}\sin\alpha}{\sin\beta_N}}{l}$$

. (eq. 15)

As shown in Eq.14 and 15, the different tilt angle (β) of each row of ET solar collectors have different shading factors. By adjusting the tilt angel (β) of each row in Eq. 15, a minimum shading factor can be calculated. Then, by using the minimum shading factor of each row, the $\dot{Q}_{absorb,ET}$ is calculated by using the Eq. 7.

2.2. Net solar efficiency

On a given piece of land, solar collectors with different layouts lead to different thermal outputs of the solar field. Integration of different amounts of solar thermal energy with different temperature levels into an SAPG plant can also produce different power outputs. The net solar efficiency of an SAPG plant is defined as the power output produced by the solar energy divided by the total solar radiation falling on the given piece of land, which is given as (Zhou et al., 2015):

$$\eta_{Net} = \frac{W_{Solar}}{\dot{Q}_{Total,land}}. \quad \text{(eq. 16)}$$

where W_{Solar} (W) is the power output from the solar thermal energy in the SAPG plant and $\dot{Q}_{Total,land}$ (W) is the total solar radiation falling on the given piece of land.

3. Case study

In the present paper, both the ET and PT solar collectors were installed at three cities Quito (Ecuador, 0°N, 78°W), Reykjavik (Iceland, 64°N, 22°W) and Adelaide (Australia, 34°S, 138°E), respectively. On the given piece of land with same area, the solar thermal energy produced by the ET solar collectors are used to displace extraction steam with lower temperature levels (extraction steam to low pressure feedwater heater) and solar thermal energy produced by the PT solar collectors are used to displace extraction steam with higher temperature levels (extraction steam to high pressure feedwater heater), as shown in Fig.2 and Fig. 3.

In this study, it is assumed that the land area of 1,000 m^2 (length of 40 m, width of 25 m) is used to install the ET and PT solar collectors, respectively. For the ET solar collectors, the distance between each row of solar collectors is 8 m. For the PT solar collectors, the distance between each row of solar collectors is 10 m. Therefore, there are 8 rows ET solar collectors and 3 rows PT solar collectors installed in the land area. It is assumed that the size of each set of the ET solar collector is 10m×25m and the size of each set of the PT solar collector is 5m×40m (the width of the LS-2 PT solar collector is 5m). Therefore, on the given 1,000m^2 land, the area of the ET solar collector is 1,250 m^2 for the ET solar collector and 600m^2 for the PT solar collector. The parameters of ET and PT solar collectors on the given land are shown in Table 1.

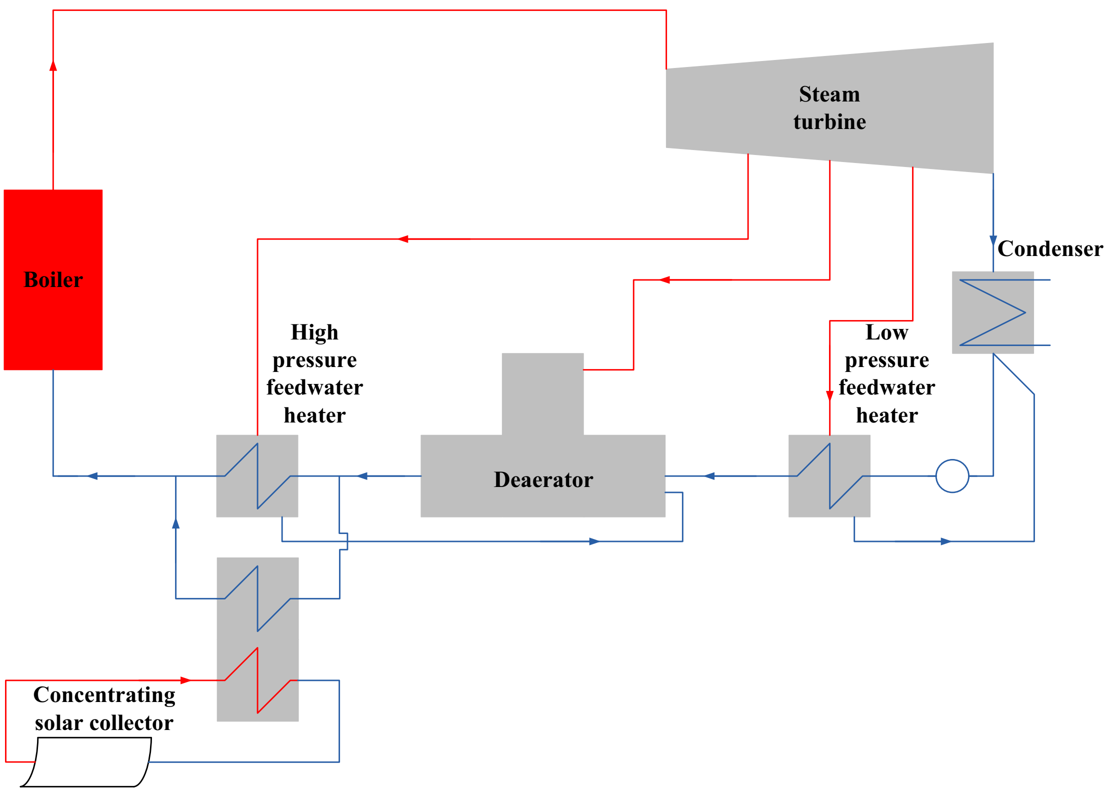

Fig. 2: Case studies of the concentrating solar collector (i.e. PT solar collector) integrated into an SAPG plant to displace the extraction steam to high pressure feedwater heater.

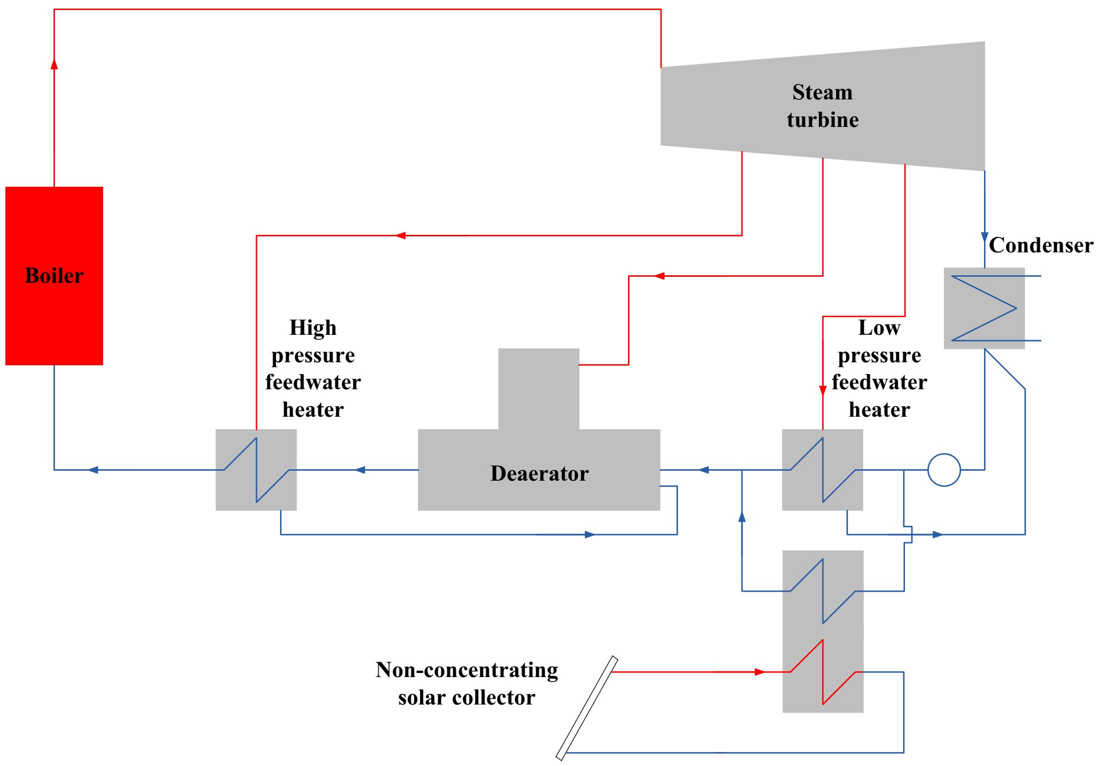

Fig. 2: Case studies of the non-concentrating solar collector (i.e. ET solar collector) integrated into an SAPG plant to displace the extraction steam to low pressure feedwater heater.

Tab. 1: Parameters of ET and PT solar collectors

Solar collector	Model	Total area (m^2)	Cost (AU$/$m^2$)
ET	VHP 30	1,250	255
PT	LS-2	600	651

It is also assumed that the solar thermal energy is integrated into 300 MW and 600 MW subcritical power plants based on the simulation results of Yan et al. (2011). Yan et al. (2011) pointed that the solar thermal to power efficiencies of displacement of high pressure extraction steam (Fig. 1) and low pressure extaction steam (Fig. 2) are 36% and 23% for a 300MW power plant and 41% and 24% for a 600 MW power plant. After the calculation of the useful thermal energy produced by the solar collectors, the solar power output can be calcualted by using the solar thermal to power efficiencies of the SAPG plant.

4. Results

Tab. 2: Annual useful thermal energy produced by evacuated tube (ET) and parabolic trough (PT) solar collectors

	Quito (Ecuador, 0°N, 78°W)	Adelaide (Australia, 34°S, 138°E)	Reykjavik (Iceland, 64°N, 22°W)
$Q_{Total,land}$ (MJ)	9,976,994	8,257,336	4,787,782
$Q_{useful,ET}$ (MJ)	4,963,798	4,012,944	2,530,093
$Q_{useful,PT}$ (MJ)	2,678,270	1,924,509	671,999

Table 2 presents the annual useful thermal energy produced by ET and PT solar collectors. $Q_{useful,ET}$ and

$Q_{useful,PT}$ are then can be integrated into the power plant for power generation purpose. The solar radiation is calculated based on the Bird Clean Sky Model (Bird et al., 1981).It was found that Quito has the highest annual solar radiation in three locations, and Reykjavik has the lowest annual solar radiation in three locations. It is also shown that annual useful thermal energy produced by the ET solar collectors is higher than that produced by the PT solar collectors in three locations. The reason is thought caused by the higher total solar collector area (Table 1) in the given land.

Tab. 3: Annual solar radiation in different locations calculated by the Bird Clean Sky Model

	Quito (Ecuador, 0°N, 78°W)	Adelaide (Australia, 34°S, 138°E)	Reykjavik (Iceland, 64°N, 22°W)
Annual DNI (kWh/m^2)	3451.4	3235.8	2520.2
Annual direct radiation (kWh/m^2)	2369.1	1921.7	1055.2
Annual diffuse radiation (kWh/m^2)	402.6	372.0	277.5

The results of Table 2 also show that for the ET solar collectors, the annual useful thermal energy produced in Quito is 1.24 times higher than in Adelaide and 1.96 times higher than in Reykjavik. However, for the PT solar collectors, the annual useful thermal energy produced in Quito is 1.39 times higher than in Adelaide and 3.98 times higher than in Reykjavik, which is higher than the ET solar collectors. The reason for this is thought to be that ET solar collectors can absorb both direct solar radiation and diffuse solar radiation, while PT solar collectors can only absorb direct solar radiation. The proportion of diffuse solar radiation in global solar radiation in Reykjavik and Adelaide are higher than Quito, which is shown in Table 3. Another reason is that the working area of ET solar collectors is higher than PT solar collectors on a given piece of land.

Tab. 4: Net solar efficiencies of evacuated tube (ET) and parabolic trough (PT) solar collectors

		Quito (Ecuador, 0°N, 78°W)	Adelaide (Australia, 34°S, 138°E)	Reykjavik (Iceland, 64°N, 22°W)
300MW	$\eta_{Net,ET}$	11.4%	11.2%	12.2%
	$\eta_{Net,PT}$	9.7%	8.4%	5.1%
600MW	$\eta_{Net,ET}$	11.9%	11.7%	12.7%
	$\eta_{Net,PT}$	11.0%	9.6%	5.8%

Table 4 shows the net solar efficiencies of ET and PT solar collectors in three locations. It is shown that the ET solar collector has higher net solar efficiencies than the PT solar collector. The reason for this is thought to be that on a given piece of land, the number of ET solar collectors can be arranged more than PT solar collectors. This means that the collector area of the ET solar collectors is higher than that of the PT solar collectors. It is also shown that the net solar efficiency of ET solar collector is highest in Reykjavik and the net solar efficiency of PT solar collector is highest in Quito. The reason is thought to be that Reykjavik is furthest from the equator in three locations and have highest proportion of diffuse radiation and Quito is closest to the equator in three locations and have highest proportion of direct radiation.

Tables 5 and 6 present the annual electricity production and cost of electricity (COE) of ET and PT solar collectors used in SAPG plants with 300MW and 600MW subcritical power plants, respectively. In present paper, the calculation of the COE only includes the cost of the solar collectors. The capital cost of the solar collectors is calculated by using the collector's cost in Table 1. From Tables 5 and 6, for both types of solar collectors, the COE increases with increasing the latitude of installed locations. When ET and PT solar collectors are installed on the same land area, the COE of ET solar collectors is lower than the COE of PT solar collectors, especially in places with higher latitude. Moreover, the advantage of ET solar collectors in cost is more obvious when the latitude is increasing. In other words, if the installed location of the solar collectors is further from the equator, the COE of ET solar collectors is cheaper than the COE of PT solar collectors. The reason for this is thought to be that when the latitude is increasing, the proportion of direct solar radiation is decreasing and the proportion of diffuse solar radiation is increasing.

Tab. 5: Annual electricity production ($Q_{electricity}$) and cost of electricity (COE) of evacuated tube (ET) and parabolic trough (PT) solar collectors used in an SAPG plant with a 300 MW subcritical power plant

	Quito (Ecuador, 0°N, 78°W)	Adelaide (Australia, 34°S, 138°E)	Reykjavik (Iceland, 64°N, 22°W)
$Q_{electricity,ET}$ (kWh)	317,312	256,383	161,645
COE_{ET} (AUD/kWh)	0.05	0.08	0.10
$Q_{electricity,PT}$ (kWh)	267,827	192,450	67,200
COE_{PT} (AUD/kWh)	0.09	0.25	0.34

Tab. 6: Annual electricity production ($Q_{electricity}$) and cost of electricity (COE) of evacuated tube (ET) and parabolic trough (PT) solar collectors used in an SAPG plant with a 600 MW subcritical power plant

	Quito (Ecuador, 0°N, 78°W)	Adelaide (Australia, 34°S, 138°E)	Reykjavik (Iceland, 64°N, 22°W)
$Q_{electricity,ET}$ (kWh)	330,920	267,530	168,673
COE_{ET} (AUD/kWh)	0.05	0.08	0.10
$Q_{electricity,PT}$ (kWh)	305,025	219,180	76,533
COE_{PT} (AUD/kWh)	0.08	0.22	0.30

5. Conclusions

The net solar efficiencies and cost-performance of using concentrating (e.g. Parabolic trough) and non-concentrating (e.g. Evacuated tube) solar collectors into an SAPG plant have been compared by using the solar radiation data in three cities Quito (Ecuador, 0°N, 78°W), Reykjavik (Iceland, 64°N, 22°W) and Adelaide (Australia, 34°S, 138°E), respectively. It is found that,

- Although the thermal efficiency of parabolic trough (PT) solar collectors is higher than the thermal efficiency of evacuated tube (ET) solar collectors, the net solar efficiency of ET solar collectors is higher than the net solar efficiency of PT solar collectors.
- The net solar efficiency of ET solar collectors in Reykjavik is hightest, and the net solar efficiency of PT solar collectors in Quito is hightest.
- The cost of electricity (COE) of using ET solar collectors is lower than the COE of using PT solar collectors.

In conclusion, on a given land with the same area, non-concentrating solar collectors (e.g. ET solar collectors) are superior to concentrating solar collectors (e.g. PT solar collectors) in both technical and economical terms.

6. References

Bird, R. E., and R. L. Hulstrom, 1981, Simplified Clear Sky Model for Direct and Diffuse Insolation on Horizontal Surfaces, Technical Report No. SERI/TR-642-761, Solar Energy Research Institute.

Budihardjo, I., Morrison, G., 2009. Performance of water-in-glass evacuated tube solar water heaters, Solar Energy. 83, 49-56.

Dudley, V.E., Kolb, G.J., Mahoney, A.R., Mancini, T.R., 1994. Test result: SEGS LS-2 solar collector, National Laboratories.

Duffie, J. A., Beckman, W.A., 2006. Solar Engineering of Thermal Processes, Forth ed. Wiley, New Jersey.

Du, B., Hu, E., Kolhe, M., 2013. An experimental platform for heat pipe solar collector testing, Renewable and Sustainable Energy Reviews, 17, 199-125.

Hu, E., Yang, Y.P., Nishimura, A., Yilmaz, F., Kouzani, A., 2010. Solar thermal aided power generation. Applied Energy. 87, 2881-2885.

Hou, H.J., Yu, Z.Y, Yang, Y.P., Chen, S., Luo, N., Wu, J.J., 2013. Performance evaluation of solar aided feedwater heating of coal-fired power generation (SAFHCPG) system under different operating conditions. 112, 710-718.

Hou, H.J., Wu, J.J., Yang, Y.P., Hu, E., Chen, S., 2015. Performance of a solar aided power plant in fuel saving mode. Applied Energy.

Patnode, A. M., 2006. Simulation and performance Evaluation of Parabolic trough solar power plant. University of Wisconsin-Madison.

Peng, S., Hong, H., Jin, H.G., Zhang, Z.N., 2013. A new rotatable-axis tracking solar parabolic-trough collector for solar-hybrid coal-fired power plants. Solar Energy. 98, 492-502.

Peng, S., Hong, H., Wang, Y.J., Wang, Z.G., Jin, H.G., 2014. Off-design thermodynamic performances on typical days of a 330 MW solar aided coal-fired power plant in China. Applied Energy. 130, 500-509.

Peng, S., Wang, Z.G., Hong, H., Xu, X., Jin, H.G., 2014. Exergy evaluation of a typical 330 MW solar-hybrid coal-fired power plant in China. Energy Conversion and Management. 85, 848-855.

Wu, J.J., Hou, H.J., Yang, Y.P., Hu, E., 2015. Annual performance of a solar aided coal-fired power generation system (SACPG) with various solar field areas and thermal energy storage capacity. Applied Energy. 157, 123-133.

Yan, Q., Yang, Y.P., Nishimura, A., Kouzani, A., Hu, E., 2010. Multi-point and Multi-level Solar Integration into a Conventional Coal-Fired Power Plant. Energy & Fuels. 24, 3733-3738.

Yan, Q., Hu, E., Yang, Y.P., Zhai, R.R, 2011. Evaluation of solar aided thermal power generation with various power plants. Int. J. Energy. 35, 909-922.

Yang, Y.P., Yan, Q., Zhai, R.R., Kouzani, A., Hu, E., 2011. An efficient way to use medium-or-low temperature solar heat for power generation-integration into conventional power plant. Applied Thermal

Engineering. 31, 157-162.

Zhou, L.Y., Li, Y.Y., Hu, E., Qin, J.Y., Yang, Y.P., 2015, Comparison in net solar efficiency between the use of concentrating and non-concentrating solar collectors in solar aided power generation systems. Applied Thermal Engineering. 75, 685-691.