CHEMICAL ENGINEERING TRANSACTIONS
VOL. 70, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Timothy G. Walmsley, Petar S. Varbanov, Rongxin Su, Jiří J. Klemeš

ISBN 978-88-95608-67-9; **ISSN** 2283-9216
DOI: 10.3303/CET1870174

A Pilot PTC System Installed in an Industrial factory of Cyprus: Feasibility for the Wider Use in the Cyprus Industry

Panayiotis K. Ktistis, Rafaela A. Agathokleous*, Soteris A. Kalogirou

Cyprus Univ. of Tech., Dep. Mechanical Engineering and Materials Science 36 Kitiou Kyprianou, 3041, Limassol, Cyprus
rafaela.agathokleous@cut.ac.cy

A total of 94 % of the energy demand in Cyprus is covered by consuming fossil fuels. Sectors such as transportation and industry are the biggest consumers, corresponding to a consumption of 57 % and 20 % respectively. Apart from the environmental impact from the use of fossil fuels, fuel cost has a direct impact on the country's economy as well. Based on these facts and having as a goal to reach the EU 2020 energy efficiency target, an effective way to reduce the use of fossil fuels and energy consumption, is the use of renewable energy systems. Moreover, it was revealed that the biggest energy consumer from the industrial sector is the food and beverage industry. Solar energy systems that could support the thermal energy needs of these industries are small-scaled middle temperature parabolic trough collectors (PTC) with thermal storage and auxiliary systems. The purpose of this study is to present the first pilot PTC system installed to serve 40 kW_{th} of the thermal needs of a soft drink factory named 'KEAN', located in Limassol, Cyprus. A dynamic simulation modelling is also developed to predict the performance of the system and study its potential to be further utilized in a higher thermal load. For the dynamic modelling of the system, TRNSYS software is used, with weather data from typical meteorological year (TMY) files for Cyprus. It was concluded that KEAN solar system could produce 125 kW_{th} heat from which the 40 kW_{th} are utilized by the industry whereas the rest are stored and used when needed. For a bigger application, for a dairy factory, a year period, and a thermal load of 190 kW_{th} the system with 42 collectors could cover 68 % of the load and the auxiliary covers the rest. To examine the potential of this system a life cycle cost analysis (LCCA) has been done. It was concluded that the total investment would have a payback period of 5 y.

1. Introduction

Cyprus is the third biggest island in Mediterranean having a population of 1.17 M people. The island is located at 35 ° latitude and 33 ° longitude with an area of 9,254 km^2. The climate is Mediterranean with warm and dry conditions from May until October and mild from November to April. In addition, Cyprus is well known as an island with high solar abundance throughout the year. The total annual sunshine is 75 % corresponding to 11.5 h/d of sunshine. It is significant to note that the cloud period does not exceed three continuous days. The average global radiation exceeds the value of 2,000 kWh/m^2 (Department of Metereology Cyprus, 2018). Moreover, the country has a small and isolate energy system highly dependent on imported fuels (94 %) (European Council, 2017). The main consumers are the transport and industrial sector with a fuel consumption of 57 % and 20 % (IEA, 2018). Cyprus, as a European Union (EU) member since 2004, has adopted the directives of EU energy efficiency target 2020. The energy savings target on the final consumption had been achieved up to 2016. However, Cyprus needs to upgrade its primary energy consumption strategies, as it is one of the eight countries who are lagging behind the primary energy saving target 2020. Until 2016, 32.5 % of the target has been achieved. After new measures established in 2017, it is believed that it will be a kick-start to fully cover the target by 101.6 %, corresponding to an overall saving value of 380,815 ktoe. It is also revealed that the objective criterion is the increase of primary energy savings when the economy is also rising. The replacement of the existing energy systems with new higher energy efficiency ones is equally important, although more effective measures have to be performed immediately (European Commision, 2017). Comparing the fuel consumption after 2011, the manufacturing sector is the most intensive category with an average consumption of 60 % of the whole consumption (IDAE, 2015). Additionally, the food and beverage category is

Please cite this article as: Ktistis P.K., Agathokleous R.A., Kalogirou S.A., 2018, A pilot ptc system installed in an industrial factory of cyprus: feasibility for the wider use in the cyprus industry , Chemical Engineering Transactions, 70, 1039-1044 DOI:10.3303/CET1870174

the main consumer with a fuel consumption of 40 % of the total consumption (171,597.2 kW_{th}/y) (National Statistical Organisation, 2015). Therefore, an effective measure to achieve the primary energy saving target 2020 to reduce the fuel consumption of foods and beverages industries without affecting their overall production. To achieve that, a solar thermal system, which can provide heat at temperatures below 250 ºC to be suitable. In that case, due to the higher temperature range, the flat plate collectors could not satisfy the demand. Concentrated collectors and more specific the parabolic trough collector is the perfect system, as they can exploit the solar potential of Cyprus to produce steam at the required medium temperature range. In fact, 60 % of the industrial sectors worldwide are using this type of collectors, where the heat demand is under 250 ºC (Vannoni et al., 2008)**.** The potential of this technology is confirmed on the predictions for a solar thermal production of 32,000 GWh up to 2050 (Rawlins and Ashcroft, 2013).
Additionally, it is proven that Cyprus can exploit effectively the solar abundance, as a worldwide leader country for the use of solar water heating system per capita, with an overall thermal production being 3.079 TJ (National Statistical Organisation, 2015) and the rapid progress (75 % from 2010-2013) in the production of electricity by using solar photovoltaic systems (French et al., 2016). Until now, none of Cypriot industries is using PTC systems for industrial process heat, although in other countries this technology has been accepted as a high promising technology. Up to now 90 industrial process heat (IPH) systems are operating worldwide with an overall capacity of 27 MW_{th} corresponding to 35,000 m^2 (Günther et al., 2015). However, compared to the total production by solar thermal systems this equals to 0.02 %, which is very low. From the total production of solar thermal energy, India is the leader country accounting for 10 % of the global solar thermal production followed by Brazil (7 %) and Israel (6 %). The PTC system is applied after 1980 and can support different industrial process, such as pasteurization, cooking, drying, sterilization etc. (Kalogirou, 2003). A system of 950 m^2 area had been designed to produce steam for dry conditions with an annual oil saving of 90 m^3 (Sundaram and Eldridge, 1981). In a manufacturing factory in Texas, PTC system is used for heating pressurized water to a steam boiler at a temperature of 174 ºC (Brink and Youngblood, 1982). In 2008 in California, 5,068 m^2 PTCs have been installed for cooking and in 2011, 70 kW_{th} were installed in a dairy factory in Bever, Switzerland. Additionally, NEP SOLAR installed 627 m^2 PTCs for heating water at 130 ºC with a capacity of 400 kW_{th}. A high capacity plant of 1 MW_{th} was installed in dairy factory in Castrogonzalo – Zamora in Spain of 2,040 m^2 to produce steam at 185 ºC. Finally, in Germany, a system of 50 kW_{th} was installed to produce steam at 140 ºC and in Cairo, Egypt, a pharmacy factory have installed 36 PTCs for steam production at 173 ºC (Kumar et al., 2014).
In Cyprus, an innovative pilot PTC system is under construction in a beverage factory in Limassol. The system consists of eight PTCs (CF100) with an aperture area of 3 m and a length of 12 m per module. The nominal thermal power is 125 kW_{th}.The storage system C-TES is concrete type and it has a capacity of 640 kW_{th}.
In this study, initially the PTC system installation is presented. In order to simulate the operation TRNSYS software is used to estimate thermal power produced by the PTC system and the thermal energy stored and utilized by the industry are calculated. Finally, a second TRNSYS model has also been developed to simulate the performance of a bigger system in a factory with a higher thermal load in order to examine the feasibility of using this type of system.

2. The PTC system in a beverage industry

The first step was to define the most suitable industry for installing the PTC system. The basic criterion was that the thermal production of the system could satisfy the thermal needs of the industry. The system was installed in KEAN factory, which is located east of Limassol near the sea front. KEAN is one of the largest soft drink industries in Cyprus and the production of the system could support the thermal load. The existing process is cleaning / disinfecting of the glass bottles and juicing fruits in a middle temperature and there is available area for installing the collectors.
The CF100 PTCs used are constructed by Protarget AG in cooperation with German Aerospace Center DLR and industrial partners (Figure 1a) (Protaget, 2012). These PTCs are operating with high efficient receiver tube in temperatures up to 425 ºC. The heat transfer fluid (HTF) circulated is a new environmental friendly silicone based thermal oil named HELISOL®5A. The fluid is a linear, non-reactive polydimethylsiloxane, clear, odorless and colorless. It has long life, no hazard classification and is also a non-corrosive fluid (Wacker, 2016). Details about the absorber tube and HTF are presented in (Table 1).
CADE Soluciones de Ingeniería, S.L., constructed the concrete storage system, which has high performance at temperatures up to 400 ºC and will supply heat during the night or a cloudy day. It is important to note that with the new composition of the concrete, higher storage capacity and thermal conductivity is achieved, and the performance of concrete volume, density, conductivity and specific heat is improved. The storage system is closed in two container modules with a total mass of 28,157 kg and is surrounded by a thermal insulation. The steam is produced in a steam generator (SG) located in the control room (white container Figure 1b) which also

includes valves and expansion tanks for the HTF. Finally, there is a computer system in order to control all the operation strategy (Figure 1b).

Table 1: Properties of absorber tube.

Receiver tube parameters	Value	HELIOSOL®5A parameters	Value
Mirror reflectivity	0.94	Recommended use temperature	-40 °C up to 425 °C
Outer radius of absorber pipe	19 mm	Boiling point	375 °C
Outer radius of glass envelope	50 mm	Density @ 25 °C	0.93 g/cm^3
Absorption coefficient for absorber tube	0.95	Specific heat	2.3 kJ/kg K @ 400 °C
Transmissivity of the glass envelope	0.91		

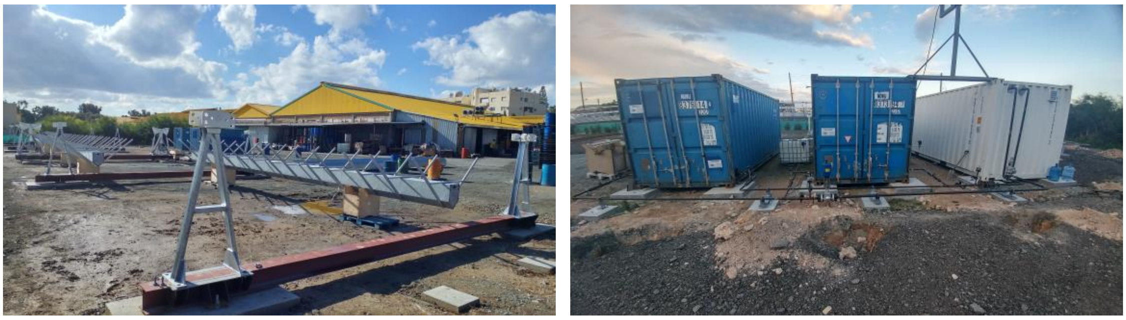

Figure 1: (a) PTC CF100 (b) Concrete storage system and control room

The plant as it is now, is presented in Figure 2a. Furthermore, a weather station has been installed, provided by SIJ to take several weather measurements (Figure 2b). The main target was the protection of the PTCs operation in case of severe weather and to record the available solar radiation in order to estimate the efficiency of the system. The station consists of a wind mast where an anemometer and a wind direction vane replaced, facing the north and measures the wind velocity and direction. On the control box, constructed by CSP Technology, a rotating shadowband irradiometer is placed measuring the direct, ground and diffused solar irradiation. In order to measure the rainfall, the temperature and relative humidity, a rain gauge, a temperature and RH probe are also installed on the control box structure. All the data are sent to the PC400 software and then transferred directly to the computer installed in the control room by an Ethernet cable. Finally, the control box is fed by a battery, which is charged by a 50W PV-panel.

Figure 2: (a) Solar PTC system (b) Weather station (i) anemometer (ii) Wind direction vane (iii) Irradiometer (iv) PV-panel (v) rain gauge (vi) Temperature & RH probe

3. Operation of the system

Initially, the solar system is designed to produced 125 kW_{th} and utilized only the 40 kW_{th} from 7 am to 3 pm. The flow is determined by a variable speed pump, depended on the differential between the inlet and outlet temperatures (DT) in the SG. This DT has to be 50 °C. For instance, if the solar irradiation drops down, the mass flow has to decrease in order to keep the DT below 50 ºC. In general, the main configuration of the PTC solar system consists of two series of four PTCs each. The HTF is heated at the temperature of 425 ºC and is stored to the high performance concrete storage or is directly forwarded to the SG. In the SG, the heat is transferred from the hot HTF to the fresh water entering by a storage tank. Finally, the steam is produced and is delivered to the process. There are four different operation modes and each one is determined according to the needs.

3.1 System configuration and operation modes

The first mode (A) occurs when the HTF exits the PTC array and is delivered to the SG and is circulated back to the PTC array in a lower temperature. Therefore, V_2, V_5, V_6 have to be opened and V_3, V_4, have to be closed (Figure 3A). In mode B, the heat is fed to the concrete storage system for charging it and to the SG. The maximum DT between the temperatures of the HTF and the concrete has to be kept below 50 ºC otherwise the concrete will crack. For this mode, all valves are opened (Figure 3B).

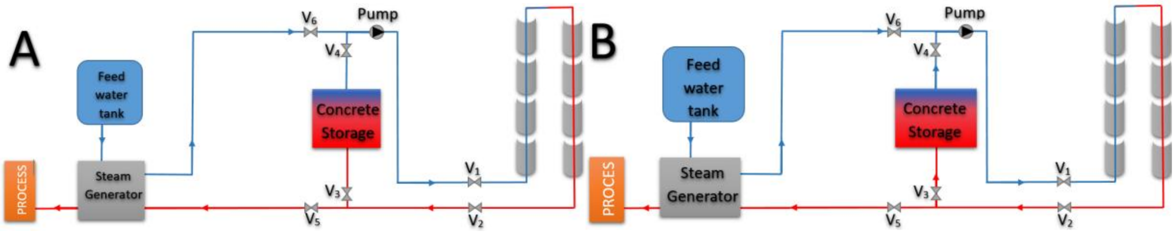

Figure 3: (A) Fed heat directly to the process (B) Fed heat to the storage system and to the process.

Mode C occurs in the case of a cloudy day and during the night. In that case, the concrete storage system is employed to supply heat to the SG. So, V_3, V_4, V_5, V_6 are opened and V_1 and V_2 are closed (Figure 4C). Finally, mode D occurs in early morning hours when the receiver tubes have to be preheated. As a result, V_1 and V_2 are opened slightly so the HTF is circulated through them and V_3, V_4, V_5, V_6 remain open as the concrete storage system supply heat to the SG (Figure 4D).

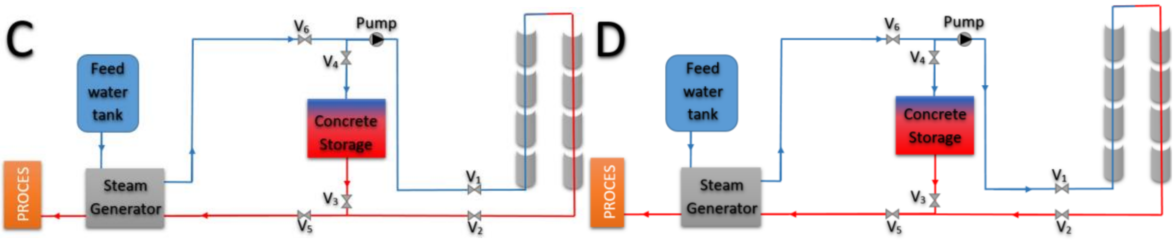

Figure 4: (C) Discharging mode (D) Discharging and preheating mode.

4. TRNSYS simulation model of the PTC system

As the KEAN PTC system is under construction, the four modes have not been simulated in detail yet. However, a TRNSYS simulation model has been developed in order to investigate the amount of the heat collected by the PTC system. Essentially, the HTF is heated in the PTC array and to the storage system. In a lower temperature, the HTF is circulated back by a variable speed solar pump. The hot HTF feeds the SG where the steam is produced and is directed in the required temperature (180 °C) and pressure (10 bars) to the process. The HTF is circulated back to the storage when valve is open (from 7 am to 3 pm). Figure 5, presents the monthly thermal energy production. As can be seen, 40 kW_{th} are utilized by the process and the rest are stored. It is concluded that this type of system can exploit the solar abundance of Cyprus and covers the thermal demands throughout the year.

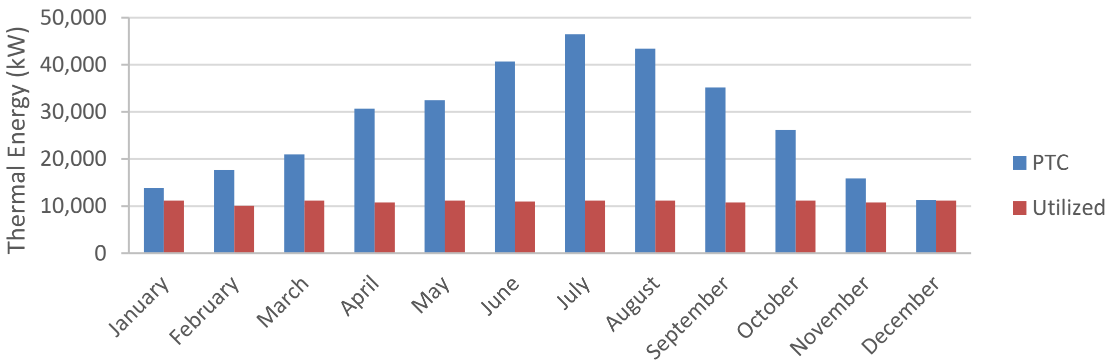

Figure 5: TRNSYS simulation results

5. Scale-up of the system – Application for a dairy industry

The food and beverage sector is the main consumer of fossil fuel in Cyprus accounting an annual average cost of 20.2 MEUR. A simulation model (Figure 6a) has also been developed in order to prove the feasibility of using this system for a dairy factory in Cyprus that uses steam for sterilization and drying in an average daily thermal load of 190 kW_{th} (from 7 am to 5 pm). This system consist of 42 CF100 collectors, a storage system, a solar pump, control valve, a SG and an auxiliary boiler. As can be seen in Figure 6b, the average daily thermal load is always covered, and the auxiliary is enabled if the solar system could not cover the thermal load. The solar contribution to the thermal needs for a year period is 68 %.

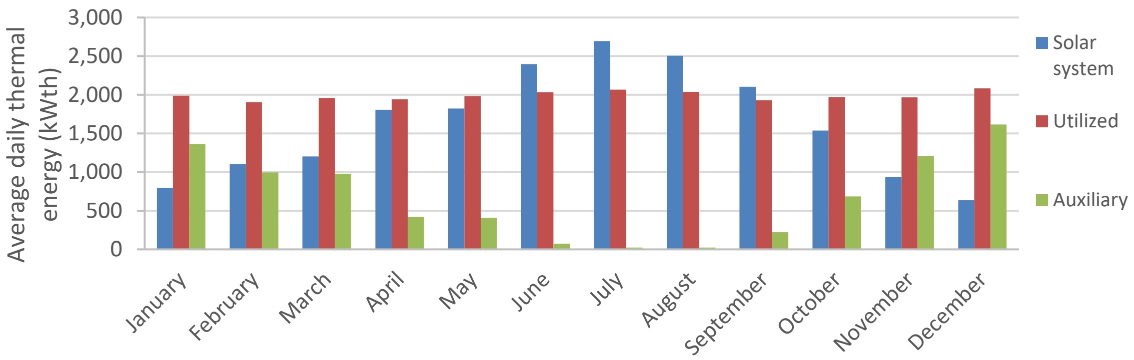

Figure 6: (a) TRNSYS model for various dairy industry (b) simulation results

By using LCCA, the payback period for that possible scenario is estimated for 20 y operation. It is concluded that the payback period will be around 5 - 6 y. The total cost will be €452,240 whereas the cumulative solar saving and the CO_2 emissions saving are estimated to be €161,702 and 394,102 $kgCO_2$.

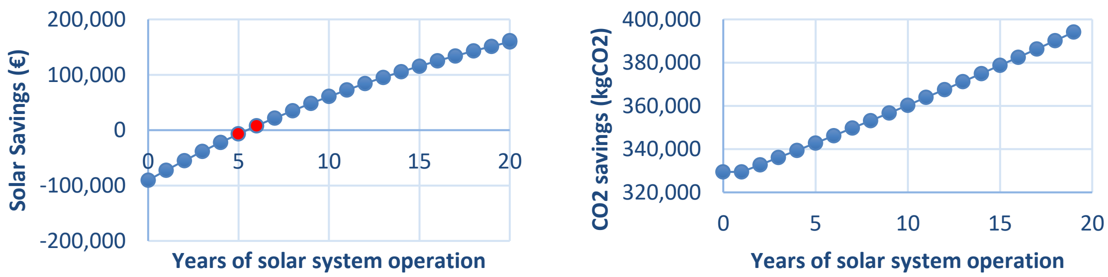

Figure 7: Payback time and solar savings.

6. Conclusions

- Cyprus industry is the second highest consumer of fossil fuels on the island (20 % of the total consumption).
- Food and beverage sector is the highest consumer of fossil fuels paying an annual average cost 20.2 million euros in fuel.
- The first pilot PTC system can produce 125 kW_{th} which can be utilized at 180 $^{\circ}C$ and 10 bars.
- This type of system can exploit the solar abundance of Cyprus and covers the thermal demands all over the year.
- Installing this type of system in a dairy factory with thermal needs of 190 kW_{th} is proved feasible. The production can follow the demand with a solar contribution of 68 %. The investment will have a payback period of 5 y, solar savings of €161,702 and 394,102 $kgCO_2$ savings.

Acknowledgements

The work is supported by the project ‘Evaluation of the Dispatchability of a Parabolic Trough Collector System with Concrete Storage’ with acronym ‘EDITOR’ from technological development and innovation 2009-2010, KOINA/SOLAR-ERA.NET/0114, which is co-financed by the European Development Fund, and the Research Promotion Foundation of the Republic of Cyprus.

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