Parabolic Trough Collector(PTC) system for combined cooling and heating supply for a factory building in Turkey

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Abstract

In 2021, the construction of the solar thermal plant for the combined cooling and heating supply of a factory building in Turkey started. The use of an absorption chiller enables the support of the air conditioning of the factory building during the summer months. In the winter months, the generated heat is used to heat the hall. This combination allows the solar gains to be optimally utilized. The collector field is the largest in Europe built for the use of solar thermal cooling. The plant was commissioned at the end of 2021 and formally inaugurated in June 2022.

In a Mediterranean country like Turkey or any other sunny country, almost all hotels, hospitals, and other public facilities must be air-conditioned during the summer months. This requires a very high amount of energy, as most modern air conditioning systems are driven by refrigerant through electrically powered compression chillers. Since solar radiation occurs simultaneously with the air conditioning demand, it can be assumed that cooling systems with double-acting absorption chillers in combination with parabolic trough collectors can be operated more suitably and intelligently than conventional systems.

Keywords: sustainable energy, parabolic trough collector, solar cooling, high temperature solar thermal systems, solar air conditioning

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1. Introduction

Nowadays, our society faces many energy problems because of fossil fuel depletion, the increasing rate of CO2 emissions, the increasing rate of electricity price, and the new lifestyle trend which are fully connected with high energy consumption. These problems can be easily faced by using renewable and sustainable energy sources. Solar energy utilization is the most widespread method for covering a part of the thermal or electrical needs of buildings. An application that can use Solar energy to reduce electricity consumption is solar cooling technology, a combination of solar thermal energy and absorption cooling chillers.

The sun is the ultimate source of energy. Its energy exceeds the world's primary energy demand by a factor of ten thousand. SOLITERM's ultimate goal is to optimize the use of this enormous energy potential, as it will account for the largest share of the future energy mix.

The SOLITERM Group as an innovative company develops and sets up an absorption chiller-based solar thermal cooling system operated with its own developed and patented parabolic trough collectors (SOLITERM PTC), which not only reduces the high electricity demand and costs for air conditioning, cooling, and warm water generation but also supply a CO2 emission-free energy for the buildings.

Using an Absorption chiller in combination with concentrated collectors is an interesting idea that is investigated over the last few years. Especially for countries with high irradiation levels, the use of solar technologies can be an attractive investment that is also environmentally friendly.

The SOLITERM Group under the direction of Dr. Ahmet Lokurlu planned and installed Europe's largest industrial solar thermal cooling plant at the Mayr-Melnhof Graphia Group in Turkey in 2021. Since then, the cooling system has been operating successfully. At present we are installing some other systems in different

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countries intending to supply air conditioning and steam for summer applications, as well as warm water for winter applications in hotels, hospitals, and industrial facilities.

The presented paper will show and describe the example application of the installed SOLITERM Systems at the Meyr-Melnhof Graphia in Turkey.

2. Selection of technology

An interesting application is to use solar thermal in combination with absorption chiller technology to provide cooling thereby reducing the conventional energy required for cooling. Absorption chillers consist of four main parts: Generators, condensers, evaporators, and absorbers.

A double-effect absorption chiller has the same basic components as a single-effect but also includes an additional generator, heat exchanger, and pump. In this cooling system heat input from the collector is used at the generator to separate the refrigerant vapor from the solution. Li-Br and H2O solutions are used as refrigerant solutions in the absorption system.

The quality of energy transformation from heat to chilling energy for an absorption chiller is given by the coefficient of performance, COP=Chilling capacity/heating capacity.

Mostly single effect absorption chillers are available with a limited operating temperature of the heat (< 100 °C) along with low COP values (annualized) (< 0,6). Double effect absorption chillers offer higher COPs by converting the solar heat more efficiently into chilling energy. Therefore, high-temperature heat should be used in double effect absorption chillers which require a temperature of approximately 140 °C. The elevated temperatures lead to higher thermal losses in the collector – the conversion efficiency overcompensates this effect by far though [1][2]. As is seen in Table 1, double effect absorption chillers are mostly steam-powered.

Table 1: Properties of single effect and double effect absorption chillers

	Single effect	Double effect
Heating Temperature	max 110°	Min 140°
Fluid	water	Steam
COP (annual Value)	0,4...0,7	1,2...1,5

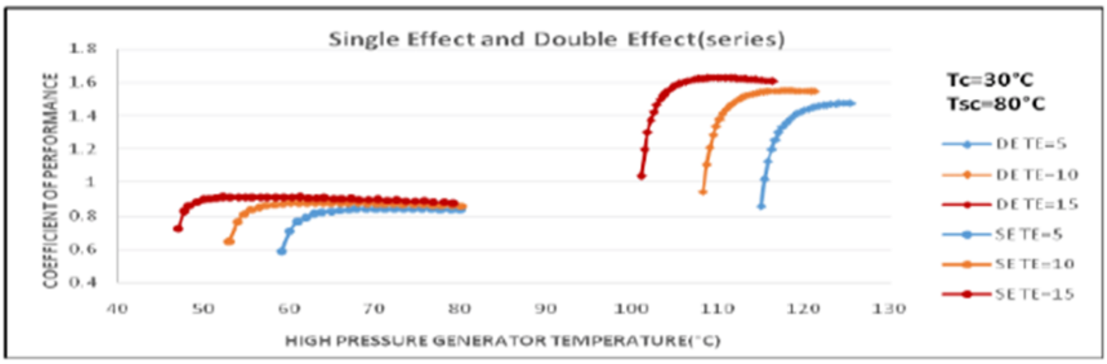

Fig. 1: Variations in COP of single effect and double effect flow cycles with generator temperature at different values of temperatures in the evaporator and the condensers at various pressure levels [3]

The use of solar cooling technologies can be an attractive investment, which is environmentally friendly, especially for countries with high irradiation levels. The combination of double effect absorption chillers and solar thermal technologies has proven its efficiency. Solar thermal is categorized into two groups: concentrating and non-concentrating.

Flat plate and evacuated tube collectors belong to the non-concentrating category. The biggest problem of flat plate and evacuated tube collectors is their low outlet temperature and their low efficiency at high temperatures which prevents them from being efficiently used for air conditioning due to a COP (Coefficient of Performance) of approx. (0.4 to 0.6) for small-sized applications. To satisfy a certain demand, a larger collector area is needed. But at many locations, like hotels, especially on roofs of buildings, space is limited. As a result, the application range of conventional solar systems is limited.

Comparison between PV and PTC:

To compare the two technologies the following calculations, refer to the specifications of a cooling demand of 500kW and a DNI (Direct Normal Irradiance) of 2000 kWh/m² annum. According to the calculations stated above, we would need an available surface of around 1400 m², because the process efficiency of the PV technology is less than 15%. In the case of a PTC Application, 66 PTC modules and therefore only a surface of 540 m² and a process efficiency is around 70% is needed in this case. Considering these drawbacks of PV technology, solar thermal concentrating technology combined with a double effect absorption chiller is much more effective and efficient for cooling applications.

3. PTC system by SOLITERM

The application potential of the solar thermal PTC system by SOLITERM is nearly endless, as it can be installed in any location worldwide. Energy consumers with various energy demands and various boundary conditions can benefit from this technology worldwide, but also in regions with low radiation this represents a highly feasible solution, as the system can be integrated into any infrastructure and reduce the usage of conventional energy supply and the use of fossil fuels. There is no particular target group or industry since the PTC system can be custom-tailored to meet any temperature level (6 °C – 350 °C), pressure level (0-25bar) and provide any form of energy (steam, cooling, heating, warm water, process cooling, sea-water desalination, and electricity). The PTC system by the SOLITERM Group can be combined with any conventional or renewable energy source, making it a highly compatible, flexible, and outstanding solution for any kind of industrial, Commercial, or individual application.

The PTC model used is specially manufactured by SOLITERM in a robot-controlled, automated production line and has an optical efficiency of 99 %. If there is enough space the PTC system can even cover up to 100 % of the energy demand of the end consumer whoever that might be, such as the food and beverage industry, the textile and chemical industry, hotels, shopping malls, airports, public buildings, private buildings, data centers, and many other potential clients.

The use of SOLITERM solar energy systems in combination with highly efficient 2-stage absorption chillers allows the use of solar energy in areas where – during the summer months – cooling requires such a great amount of electricity that tariffs are sky-high and power grids are used to their utmost capacity or even beyond. The connection to steam generators and to the hot water cycle allows supplying even more kinds of energy consumers with solar-powered clean energy. So, the SOLITERM systems are applicable all over the world in a wide range of possible applications, both industrial and commercial. The system at hand represents a universal and at the same time highly customized, as well as a flexible solution towards lowering emissions, becoming independent from fossil fuels, saving money, re-investing in more important aspects, and ultimately building a socially responsible, environmentally friendly, and sustainable economy and world.

To widen the application range for solar energy, SOLITERM developed different-sized Parabolic Trough Collectors (PTC): The SOLITEM PTC 1800 for large applications as well as the small-sized PTC 1100 for residential buildings. Both collectors can supply temperatures about 300 °C to 350 °C and are suitable for roof mounting. As well as the PTC 3000, 4000 and 5000 which are used for solar thermal power plants.

4. Parabolic Trough Collectors

To deliver high temperatures with good efficiency a high-performance solar collector is required. PTCs can effectively produce heat at temperatures between 50°C and 400°C. Parabolic trough collectors are made by bending a sheet of reflective material into a parabolic shape. A black metal tube, covered with a glass tube to reduce heat losses, is placed along the focal line of the receiver. When the parabola is pointed toward the sun, parallel rays incident on the reflector are reflected onto the receiver tube. The concentrated radiation reaching the receiver tube heats the fluid that circulates through it, thus transforming the solar radiation into useful heat. The collector can be oriented in an east-west direction, tracking the sun from north to south, or in a north-south direction, tracking the sun from east to west.

For applications up to 180 °C, the use of pressurized water is established. Higher temperatures can be achieved by using thermal oils. To achieve the required temperature, individual collectors are combined in groups that have their circuits for the heat transfer fluid.

The surface of the receiver is typically plated with a selective coating that has a high absorptance for solar radiation but a low emittance for thermal radiation loss.

A tracking mechanism must be reliable and able to follow the sun with a certain degree of accuracy, return the collector to its original position at the end of the day or during the night, and track during periods of intermittent cloud cover. Additionally, tracking mechanisms are used for the protection of collectors, i.e., they turn the collector out of focus to protect it from hazardous environmental and working conditions, such as wind gusts, overheating, and failure of the thermal fluid flow mechanism.

The sun tracking system with a precision of 0.1° in every row ensures maximizing the energy yield, making it more efficient compared to other solar thermal technologies, such as a flat plate or other collectors.

5. A Model Application for an Integrated Energy Supply System for combined cooling and heating supply of a factory building in Turkey

The production site MM Graphia in, which belongs to Mayr-Melnhof Karton AG, was confronted with increasing energy consumption, which led to high energy costs and greenhouse gas emissions. Therefore, the management decided to find a solution, to improve the environmental and economic situation of the production facilities in Turkey, and potentially all the company's other facilities worldwide. The company turned to SOLITERM Group GmbH, which, based on technical data on-site implemented a solar thermal system to substitute fossil fuels, reduce electricity fossil fuels, reduce electricity consumption, and cover the energy demand as economically and economically, and environmentally friendly.

5.1 Weather Analysis

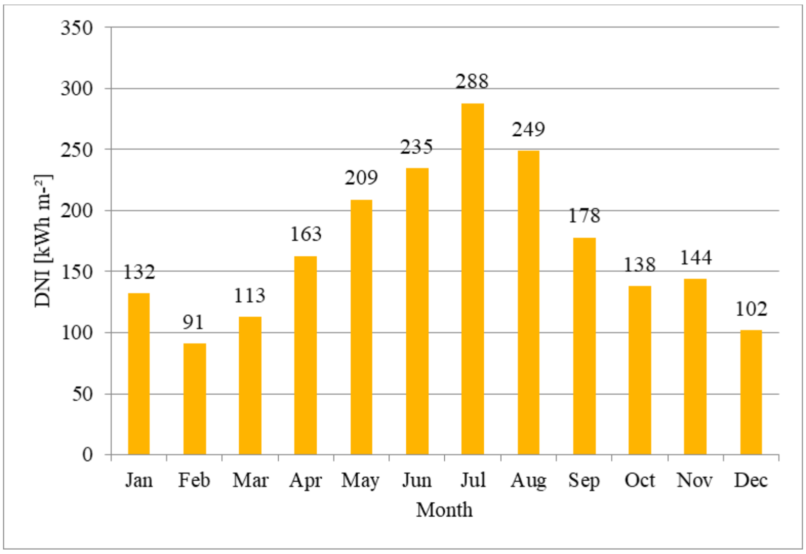

Fig 2: Monthly Direct Normal Irradiance (DNI) data for the project location in Turkey

The conditions for the construction of a solar thermal plant are above average here. Solar data, determined with the database of Meteonorm, show a value of 2049 kWh m^{-2} per year for the direct normal irradiation (DNI). The annual distribution is illustrated by the monthly values, which are shown in Figure 2.

As expected, solar irradiation is higher in summer than in winter. This is due to the long sunshine duration caused by the inclination of the globe in summer. This graph shows essential direct radiation for the parabolic trough. In contrast to many non-concentrating systems, the diffuse part of the global radiation cannot be used. A difference of 197 kW m-² can be observed between the worst month (February) and the month with the highest solar radiation (July). This significant difference represents a major challenge for the design of the system to the process of operation. To use the high gains from the summer on the one hand and to have used for the solar energy in the winter, on the other hand, a combined cooling and heating system was developed.

5.2 Process demands

For the design of the plant, the various process requirements of the plant operator were taken into account. The project aimed to intercept the region's power outages and ensure 24-hour operation. Four halls are available for production, which have different requirements for temperature, air exchange, and humidity. These can be classified as follows:

- The production process for paper requires a steady room temperature of 30 °C.
- For the printing area, a steady temperature of 28 °C is required. In addition, an air exchange of 2 air changes per hour and an air discharge of 1.5 air changes per hour is required.
- For the paper cutting room, a steady humidity of 35% and a temperature range of 28°C - 30°C are required.
- For the board cutting and packaging area, a temperature range of 26°C - 32°C is sufficient to provide suitable working conditions.

As the temperatures at the site show very high seasonal fluctuations, the integration of a combined cooling and heating system was necessary to cool the hall in summer and heat it in winter. Before the integration of solar thermal energy, electric compression chillers with a total capacity of 2050 kW (1150 kW, 550 kW, 350 kW) were used for cooling. For heating, a gas burner with a capacity of 1 MW was used.

5.3 Solar Plant

The solar field consists of a 5.000 m² collector surface area and extends over the roof surfaces of the factory building. Due to the local conditions, it was necessary to realize the field in two stages.

The collectors have an aperture area of 9 m² (5m x 1.8m) and are combined in modules. A module is composed of 6 collectors, which have a common drive and solar tracking systems. The tracking Motor has a precision of 0.1° in every row which ensures maximizing the energy yield, making it more efficient compared to other solar thermal technologies, such as a flat plate or other collectors. The nominal thermal output of a collector is 4.97 kW at an irradiance of 850 W m^{-2} (Direct Normal Irradiance). This results in a specific output of 552 W m^{-2}.

5.4 System Operations

We use our solar field to provide air conditioning for the factory buildings. These factory buildings have different demands in summer and winter.

Summer mode:

The solar field is operated from April to October in summer mode reaching a maximum temperature of 180°C in the absorber tube and providing chilled water for cooling. Fan coils (15kN) and air Handling Units are used to condition and distribute the air in the building to a temperature of 8°C.

Winter mode:

In winter the system generates hot water using fewer collectors compare with cooling for heating. Since the required temperatures are lower in winter, lower temperatures can also be used in the solar field.

The total thermal capacity of the collector array is approximately 2.5 MW. This results in a cooling capacity of a two-stage absorption chiller of 3.5 MW. The absorption chillers used are each matched to the size of the associated collector field so 2 chillers with 1.4 MW and 2.1 MW were used. The double effect absorption chiller has a coefficient of performance value that can achieve up to 1,40. The system was integrated into the heating and cooling supply lines of the facilities, using the existing conventional components as backup systems for safety and emergency cases. The entire plant has an integrated SCADA system that is fed with meteorological data and controls the collectors accordingly, ensuring fully automatic energy optimization, and supply and thus a reduction in unnecessary energy consumption in production and offices.

Fig. 3: SOLITEM PTC 1800 Parabolic Trough Collectors in the project location in Turkey

The implementation of the system described led to numerous benefits, not only for the business but also for the people in and around the company. Firstly, it led to energy savings in form of fuel savings of 1.780 MWh annually and electricity savings of 3.500 MWh annually, while more than 90 % of the annual process cooling, air conditioning, and warm water supply will be provided by the PTC plant. A reduction of 2.000 tons of CO2 emissions is achieved every year, as conventional sources are being used much less.

6. Conclusion

SOLITERM Parabolic Trough Collectors can deliver high-temperature heat. These systems offer a wide range of opportunities to reduce the costs of energy supply. Combined with double effect steam or hot water powered absorption chillers, Parabolic Trough Collectors make highly efficient solar thermal cooling possible.

SOLITERM supplied, installed, and commissioned Europe's largest industrial solar thermal cooling system at Mayr-Melnhof Graphia Group in Turkey. The project paves the way for an economical, renewable energy supply and enables potential and flexibility to adapt to different energy demands as well as the decarbonization of industry.

Besides the ecological and economic aspects, the social impact of the project was great. New jobs for technical management, monitoring, and maintenance have been created, giving young and ambitious people the chance to be part of a revolutionary, innovative, and highly sustainable project. The existing employees were educated and trained with regards to the PTC system and also regarding innovative, as well as renewable technologies. This in turn created awareness among people in and around the client company, leading to an awareness of renewable energy, sustainability, and more careful use of energy in general. Further details of the concept will be presented at the conference.

7. References

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