THE POTENTIAL OF SOLAR ENERGY IN FOOD-INDUSTRY PROCESS HEAT APPLICATIONS

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ABSTRACT: - In this paper an overview of the potential of solar industrial process heat, with emphasis on the food industry, is presented. The temperature requirements of food industry applications range from 60°C to 180°C. The characteristics of low to medium temperature solar collectors that can be employed are given and an analysis of the efficiency and cost of the solar systems is presented. Based on TRNSYS simulations, an estimation of the solar contribution of solar process heat plants operating in Cyprus are given for different collector technologies. The annual energy gains of such systems are from 610 to 910 kWh/m^2-a and the resulting energy costs obtained for solar heat are from 0.028 to 0.05 Euro/kWh depending on the collector type applied. The costs will even be more favourable if the solar collectors become cheaper and subsidisation of the fuel is removed.

Keywords: Food industry, process heat, stationary collectors, economic analysis

1. INTRODUCTION

Beyond the low temperature applications there are several potential fields of application for solar thermal energy both at low to medium temperature level (60°C – 180°C). The most important of them are: heat production for industrial processes, solar cooling and air conditioning, solar drying and seawater desalination. Large amounts of energy are spent for industrial heat generation in many countries. For example industrial process heat demand in the southern European countries is about 15% of the overall demand of final energy requirements.

Stationary collectors have been developed with a good relation of cost and performance at low to medium temperature. Recent developments in the field of medium and high temperature solar collectors are summarised and an overview of efficiency and cost of existing technologies is given.

The objective of this work is to investigate, based on TRNSYS simulations, the system energy yield of solar process heat plants for different collector technologies. For this purpose the climatic conditions of Cyprus will be employed by using the typical meteorological year (TMY) for Nicosia, Cyprus. Finally by using the obtained simulated performance data, an economic feasibility study is carried out in order to examine the viability of the systems considered.

2. THE INDUSTRIAL PROCESS HEAT DEMAND

From a number of studies on industrial heat demand, several industrial sectors have been identified with favourable conditions for the application of solar energy. The most important industrial processes using heat at a medium temperature level are: sterilising, pasteurising, drying, hydrolysing, distillation, evaporation, washing and cleaning. Some of the most important processes related to food industry are given in Table 1.

Large scale solar applications for process heat benefit from the effect of scale. Therefore the investment costs should be comparatively low, even if the costs for the collector are higher. One way to cause economically easy terms is to design systems without heat storage, i.e., the solar heat is fed directly into suitable processes (fuel saver). In this case the maximum rate at which the solar energy system delivers energy must not be appreciably larger than the rate at which the process uses energy. This system however cannot be cost effective in cases where heat is needed at the early or late hours of the day or at nighttimes when the industry operates on a double shift basis.

Particular types of food industries, which can employ solar process heat, are the milk and cooked pork meats (sausage, salami etc.) industries and breweries. The temperatures required in these industries range from 60 to 180°C. Favourable conditions exist in food industry, because food treatment and storage are processes with high energy consumption and high running time.

Table 1. Temperature ranges for different food industrial processes

Industry	Process	Temperature (°C) 80	100	120	140	160	
DAIRY	PRESSURISATION	▨					
	STERILISATION			▨			
	DRYING				▨	▨	▨
	CONCENTRATES	▨					
	BOILER FEED WATER	▨	▨				
TINNED FOOD	STERILIZATION			▨			
	PASTEURISATION	▨					
	COOKING	▨	▨				
	BLEACHING						
MEAT	WASHING, STERILISATION	▨	▨				
	COOKING		▨				
BEVERAGES	WASHING, STERILISATION	▨					
	PASTEURISATION	▨					
FLOURS & BY-PRODUCTS	STERILISATION	▨					

In a solar process heat system, interfacing of the collectors with conventional energy supplies must be done in a way compatible with the process. The easiest way to accomplish this is by using heat storage, which can also allow the system to work in periods of low irradiation and/or nighttime. Where feasible, collectors can be mounted on the roof of a factory especially when no land area is available. In this case shading between adjacent collector rows should be avoided and considered. Some of the most important food processes are:

2.1 Brewing and Malting

In the brewing process thermal energy accounts for about 80% of the total final energy demand. The principal consumers are the wort boiling (25-50%), the bottle washers (25-40%), and pasteurisation. Solar thermal energy can be used for low-pressure steam generation at 100–110ºC and for refrigeration of the wort, which can be accomplished with absorption cooling.

In the malting process the principal energy consumption is for drying of the barley before malting, and of the grains after germination to stop germination, for conservation where hot air at 60 to 80ºC is used, and for cooling of air in the germination process required during the summer months.

2.2 Milk industry

Dairies are very interesting applications for solar energy, because they often work seven days a week, thus fully utilise the solar system compared to other industries, which allow the system to be idle for two days per week.

In the milk industry thermal energy is used for pasteurisation (60-85ºC) and for sterilisation (130-150ºC) processes. Drying of milk powder, due to the high constant energy demand, is another important consumer. In the production, milk and whey are spray-dried in huge towers with air, which is heated from 60°C to 180°C. The drying process can have a running time up to about 8000 hours per annum [1].

2.3 Food preservation

Several processes were identified, where solar thermal energy could be used: scalding of vegetables, sterilization (vegetables, fish, meat, baby food) with hot water or direct steam, scalding, cleaning and pre-cooking of fish, sealing and cleaning of cans, cooking. In addition cold demand can be covered by solar cooling and refrigeration.

3. CHARACTERISTICS OF SOLAR COLLECTORS

There are many types of collectors that can be applied for industrial process heat. The most common and industrially matured systems are the flat-plate, compound parabolic and evacuated tube collectors.

Due to the introduction of highly selective coatings, standard flat-plate collectors can reach stagnation temperatures of more than 200°C. With these collectors good efficiency can be obtained up to temperatures of 100°C.

Additional improvements in efficiency of flat-plate collectors and an extension of the range of possible working temperatures up to 150ºC can be obtained by suppression of convection heat transfer by evacuation (evacuated tubes, evacuated flat plate collector), gas fillings with inert gases, convection barrier by an additional plastic foil or by honeycomb-type transparent insulation (TI) materials [2].

Lately some modern manufacturing techniques have been introduced in the industry like the use of ultrasonic welding machines, which improve both the speed and the quality of welds. This is used for the welding of risers on fins in order to improve heat conduction. The greatest advantage of this method is that the welding is performed at room temperature therefore deformation of the welded parts is avoided.

Compound parabolic collectors (CPC) are non-imaging concentrators and when a low concentration ratio (up to about 2, corresponding to an acceptance half angle of 30º) is used these collectors can be stationary. A CPC concentrator can be orientated with its long axis along either the north-south or the east-west direction and its aperture is tilted directly towards the equator. When orientated along the north-south direction the collector must track the sun by turning its axis so as to face the sun continuously. As the acceptance angle of the concentrator along its long axis is wide, seasonal tilt adjustment is not necessary. It can also be stationary but radiation will only be received the hours when the sun is within the collector acceptance angle.

A large number of evacuated tube collectors are on the market. Evacuated tubes with CPC-reflectors are also commercialised by several manufacturers. One manufacturer recently presented an all-glass evacuated tube collector, which may be an important step to cost reduction and increase of lifetime. Evacuated tube collectors have demonstrated that the combination of a selective surface and an effective convection suppressor can result in good performance at high temperatures. The vacuum envelope reduces convection and conduction losses, so the cylinders can operate at higher temperatures than flat-plate collectors. Like flat-plate collectors, they collect both direct and diffuse radiation. However, their efficiency is higher at low incidence angles. This effect tends to give evacuated tube collectors an advantage over flat-plate collectors in day-long performance.

4. COMBINATION OF SOLAR SYSTEM WITH CONVENTIONAL HEAT SUPPLY

The central system for heat supply in most factories uses steam at a pressure corresponding to the highest temperature needed in the different processes. Typical maximum temperatures are about 160–180ºC. Hot water or low pressure steam at medium temperatures (<150ºC) can be used either for preheating of water (or other fluids) used for processes (washing, dyeing, etc.) or for steam generation or by direct coupling of the solar system to an individual process working at temperatures lower than that of the central steam supply. In the case of water preheating higher efficiencies are obtained due to the low input temperature to the solar system, thus low-technology collectors can work effectively and the required load supply temperature has no or little effect on the performance of the solar system. The system may be pressurised in order to allow storage at temperatures higher than 100°C.

The system shown schematically in Fig. 1 consists of an array of collectors, a circulating pump and a storage tank. It includes also the necessary controls and thermal relief valve, which relieves energy when storage tank temperature is above a preset value. The system is once through, i.e., there is no hot water return to storage, which is what usually happens in food industry applications. The used hot water is replaced by mains water. Mean monthly ground temperature values are used for the mains water temperature in simulations. When the temperature of the stored water is above the required process temperature, this is mixed with mains water to obtain the required temperature.

If no water of adequate temperature is available in the storage tank its temperature is topped-up with an auxiliary heater before use. For the modelling and simulation of the system the well-known program TRNSYS is employed [3].

5. ANNUAL ENERGY GAINS

To estimate the solar energy gains TRNSYS-simulations were carried out using the typical meteorological year (TMY) for Nicosia, Cyprus [4]. Cyprus is located at the Eastern Mediterranean at 35° north latitude. The climatic conditions of Cyprus are predominantly very sunny with daily average solar radiation of about 5.4 kWh/m^2 on a horizontal surface. In the lowlands the daily sunshine duration varies from 5.5 hours in winter to about 12.5 hours in summer. Mean daily global solar radiation varies from about 2.3 kWh/m^2 in the cloudiest months of the year, December and January, to about 7.2 kWh/m^2 in July. The amount of global radiation falling on a horizontal surface with average weather conditions is 1727 kWh/m^2 per year.

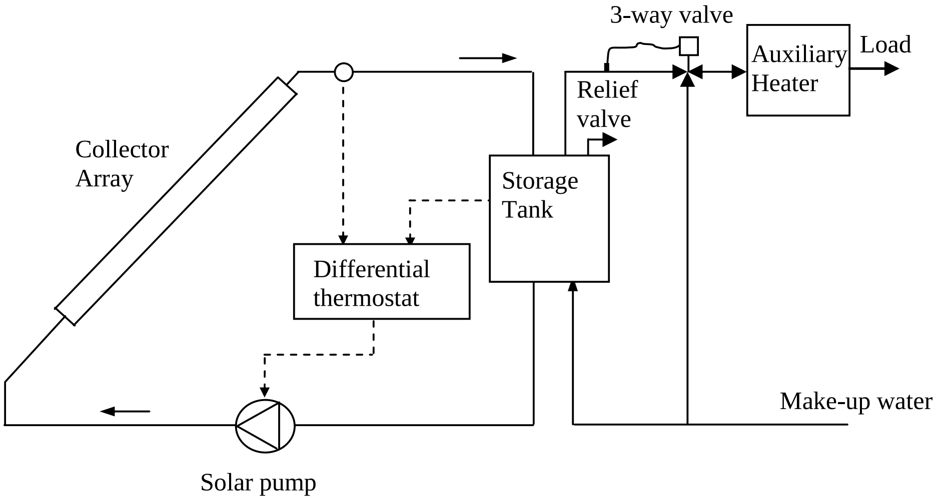

Fig. 1: Possibilities of the combining the solar system with the existing heat supply.

Four representative collector types were considered in this study:

- Flat-plate collector (FP).
- Advanced flat-plate collector (AFP). In this collector the risers are ultrasonically welded to the absorbing plate, which is also electroplated with chromium selective coating.
- Compound parabolic collector (CPC) orientated with its long axis in the east-west direction and tilted at local latitude (35°).
- Evacuated tube collector (ETC).

The collector characteristics are given in Table 2.

Table 2. Collector characteristics for the four collectors considered in this study.

Collector type	Optical efficiency (n_o)	Overall heat loss coefficient (U_L) [W/m^{2}K]
FP	0.79	6.67
AFP	0.80	4.78
CPC	0.72	1.51
ETC	0.82	2.19

The basic process considered is one where 2000 kg/hr of hot water are used at temperatures between 60 to 180°C (load). The load is required for the first three quarters of each hour. The industry is assumed to work on a single shift basis from 8.00 to 16.00. For the estimation of the annual energy supply to the above process, the following assumptions were made:

- The collector field has a gross area of 400 m² and the inclination of FP, AFP and ETC collectors is equal to the local latitude plus 5° (i.e., 40°), whereas the inclination of CPC collectors is equal to 35°. Mutual shading of collectors is considered.
- Heat losses of the piping are considered. It is assumed that the collector field is connected to the process with pipes 30 m long.
- The storage tank capacity is $25 m^3$.
- Collector circuit flow rate is 6 kg/s.

The annual energy yield of the various collectors is shown in Fig. 2. As can be seen the performance of the systems is insensitive to the load supply temperature. At low load temperatures the water in the storage tank can satisfy most of the demand and as less water is replaced in the storage tank by make-up water the storage tank remains at increased temperature and thus the collectors are operating at higher temperature hence the collector is less effective which is reflected as lower energy yield. The solar contribution F [i.e., $(Q_{load}-Q_{auxiliary})/Q_{load}$] is also shown in Fig. 2. As can be seen the lower the load temperature the higher is the contribution of the system and vice versa. This is because at higher load temperatures more energy from the auxiliary is required to cover the load.

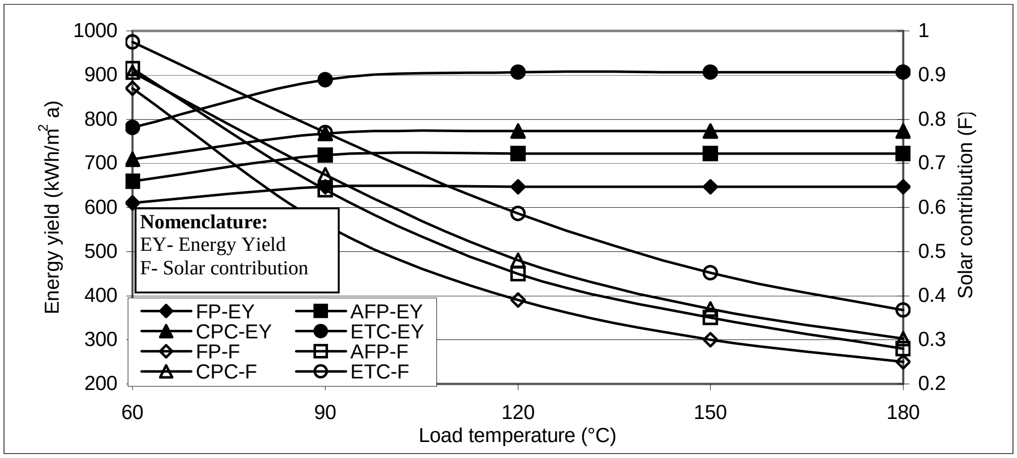

Fig. 2: Annual energy yield delivered to the process and solar contribution (F) of systems.

The collector with the higher energy yield and the higher contribution is the evacuated tube and the lower is the typical flat plate collector. This result is in agreement with the performance characteristics of the collectors shown in Table 2, i.e., a collector with better characteristics gives more energy and thus has a higher contribution and vice versa. It should be noted that the load is constant (same process) for all systems. This finding however has to be compared with the economics of the system in order to select the best collector for this application. The critical parameter for such an analysis is the cost of the collector.

6. ECONOMIC ANALYSIS

A life cycle analysis is performed in order to obtain the total cost (or life cycle cost) and the life cycle savings of the systems. Table 3 shows the estimated costs per square meter of the collectors considered. The economic scenario used in this project is that 30% of the initial cost of the solar system is paid at the beginning and the rest is paid in equal instalments in 10 years. The period of economic analysis is taken as 20 years (life of the system), whereas the inflation rates of fuel and electricity, used for pumps, are mean values of the last 10 years. Maintenance and parasitic costs are also considered. Light fuel oil (LFO) is assumed to be used for a fuel-only system. From the addition of fuel savings incurred because of the use of the system and the tax savings the mortgage, maintenance and parasitic costs are subtracted and thus the annual solar savings of the system are estimated which are converted into present worth values of the system. These are added up to obtain the life cycle savings. A detailed description of the method is given in [5].

It should be noted that in Cyprus the petrol subsidises LFO, and its normal price should be 60% more than the current market price. Both the current and the non-subsidised fuel price are considered in the analysis.

The total system cost is estimated by adding up the initial payment the maintenance and parasitic costs and the mortgage payments. From this figure the tax savings are subtracted and the result is divided by the number of years the system is operational (life of the system) and the total kWh produced by the system during its life, in order to obtain the heat price in Euros per kWh for each collector technology considered, for comparison purposes.

Table 3. Investment cost parameters for collectors considered in this study.

Collector type	Collector price (Euro/m^2)
FP	190
AFP	220
CPC	310
ETC	430
Prices include collector mountings and field piping.	

The heat price obtained from the economic analysis for all the collectors considered here are presented in Fig. 3 together with the current price of LFO and its non-subsidised value. As can be seen the cheaper the collector the better is its economic viability, i.e., a lower heat price value and bigger life cycle savings are obtained. As can be seen from Fig. 3 for the present application and for the current price of LFO only the simple flat plate collector is viable. When a non-subsidised value of LFO is considered however, all the collectors are viable.

The life cycle savings of the different systems considered by using both the normal and the non-subsidised fuel prices are shown in Fig. 4. Life cycle savings represent the money saved by installing the solar system instead of buying the fuel. As can be seen for the normal fuel price, only the relatively cheap, FP and AFP collectors, are viable giving positive life cycle savings. The other two types considered, i.e., CPC and ETC give negative life cycle savings, which means that at the current fuel price it is more economic to use a conventional fuel system instead of investing for a solar system.

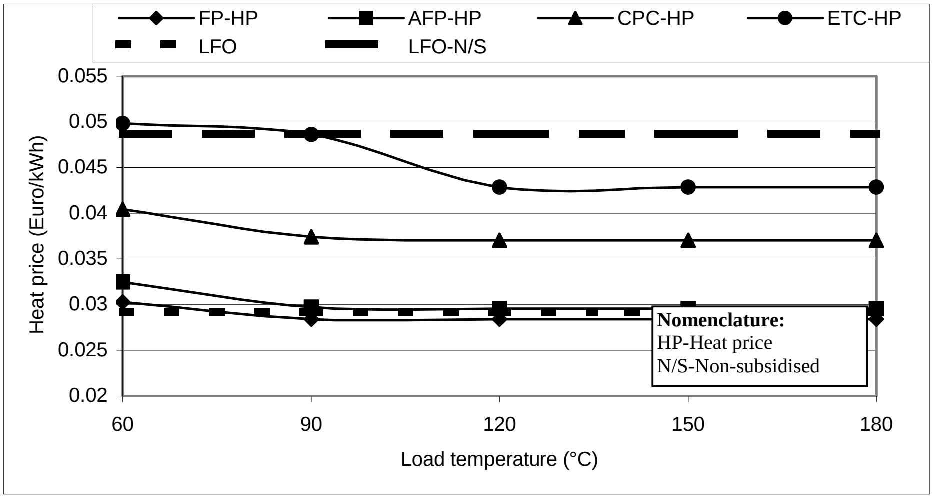

Fig. 3: Heat prices as a function of load temperature

It should be noted however that the situation is completely different for the case where the non-subsidised fuel price is considered. The LCS of all cases examined are positive which means that all systems are viable. The best collector giving the higher life cycle savings is the AFP, which presents a good energy yield, compared to its cost. Much higher LCS are obtained in this case as the solar system is replacing a more expensive fuel. It can also be concluded from the results presented in Fig. 4 that it is more advantageous to apply solar energy to higher temperature processes than to lower temperature ones as the savings incurred are much higher. Additionally the load supply temperature, for values higher than about 100°C, has very little effect on the resulting life cycle savings of the systems.

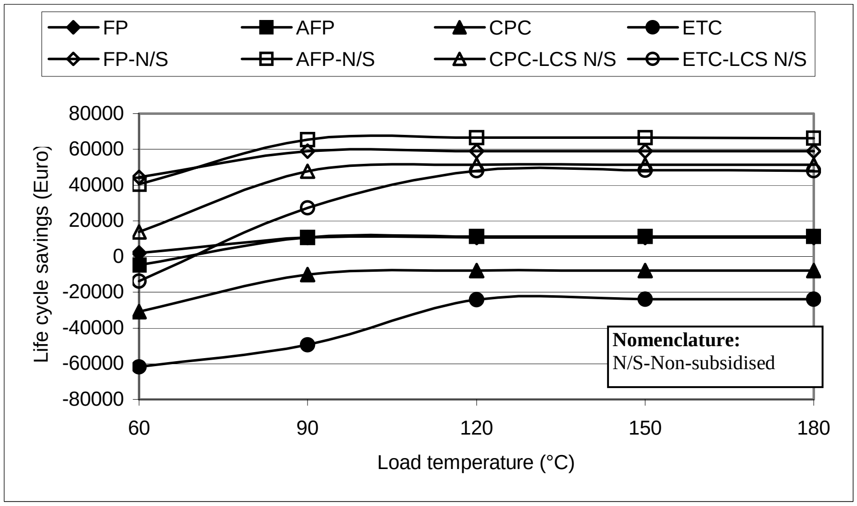

Fig. 4 Life cycle savings as a function of load temperature for the various systems considered

From the above discussion it can be concluded that the viability of the systems depend on their initial cost and the fuel price. None of these costs are stable but are changing continuously depending on international market trends and oil production rates. Finally it should be noted that the systems considered here should be optimised by trying a range of collector areas and storage volumes thus finding the best combination that gives the best life cycle savings.

7. CONCLUSIONS

An industrial process heat system for the food industry is analysed in this paper both with respect to the energy yield and the resulting heat price for a number of collector technologies. The annual energy gains of such systems are from 620 to 915 kWh/m^2-a. The resulting energy costs obtained for solar heat are from 0.028 to 0.05 Euro/kWh depending on the collector type applied. These results are applicable to any country with similar weather conditions as Cyprus. As is proved in the analysis presented in this paper the economic viability of the systems depends on the initial cost of the solar systems and the fuel price. The costs will turn out to be more favourable when the solar collectors become cheaper and subsidisation of the fuel is removed. At the design stage the solar systems to be considered need to be simulated and their economic benefits evaluated as indicated in this paper in order to select the best system for the particular application at the collector cost and fuel price applicable. It is believed by the author that solar energy should be given a chance even if the costs are at present may not be so favourable. As the oil reserves are depleted the oil prices will certainly increase and thus solar systems can provide real economic benefits.

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