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High Efficiency Solar Thermal Collectors Utilization in Process Heat: A Case Study of Textile Finishing Industry

Gökçen A. Çiftçioğlu, M. A. Neşet Kadırgan, Figen Kadırgan

***Abstract*—** Solar energy, since it is available every day, is seen as one of the most valuable renewable energy resources. Thus, the energy of sun should be efficiently used in various applications. The most known applications that use solar energy are heating water and spaces. High efficiency solar collectors need appropriate selective surfaces to absorb the heat. Selective surfaces (Selektif-Sera) used in this study are applied to flat collectors, which are produced by a roll to roll cost effective coating of nano nickel layers, developed in Selektif Teknoloji Co. Inc. Efficiency of flat collectors using Selektif-Sera absorbers are calculated in collaboration with Institute for Solar Technik Rapperswil, Switzerland. The main cause of high energy consumption in industry is mostly caused from low temperature level processes. There is considerable effort in research to minimize the energy use by renewable energy sources such as solar energy. A feasibility study will be presented to obtain the potential of solar thermal energy utilization in the textile industry using these solar collectors. For the feasibility calculations presented in this study, textile dyeing and finishing factory located at Kahramanmaras is selected since the geographic location was an important factor. Kahramanmaras is located in the south east part of Turkey thus has a great potential to have solar illumination much longer. It was observed that, the collector area is limited by the available area in the factory, thus a hybrid heating generating system (lignite/solar thermal) was preferred in the calculations of this study to be more realistic. During the feasibility work, the calculations took into account the preheating process, where well waters heated from 15 °C to 30-40 °C by using the hot waters in heat exchangers. Then the preheated water was heated again by high efficiency solar collectors. Economic comparison between the lignite use and solar thermal collector use was provided to determine the optimal system that can be used efficiently. The optimum design of solar thermal systems was studied depending on the optimum collector area. It was found that the solar thermal system is more economic and efficient than the merely lignite use. Return on investment time is calculated as 5.15 years.

***Keywords*—**Solar energy, heating, solar heating.

I. INTRODUCTION

RENEWABLE energy resources will be always reachable in nature, especially the sun and its potentiality. Solar energy can be used in heating and cooling systems [1].

In industry a range of processes, such as cleaning and washing, heating of baths & vessels, drying, pre-heating for steam networks, raw material production etc., can use solar heat which can technically and economically be accessible [2]. In industry, according to various literature; five sectors use a significant proportion of their process heat at temperatures lower than 400 °C and are therefore strong potential for solar thermal to meet their process heat [3]-[5]. The consumption percentages of the energies used related to the working conditions of different industries are given in Fig. 1.

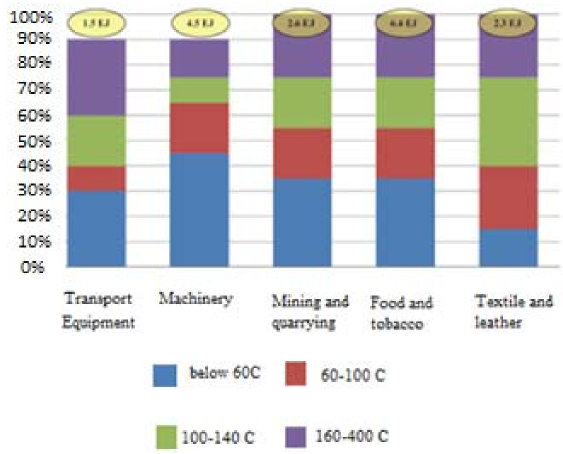

Fig. 1 Low and medium temperature process heat demand by sector [3]

Main resources for a future sustainable energy system will be based on renewable sources via; solar, wind, biomass, etc. In this respect, solar thermal technologies have the potential for a high contribution to the future energy supply [6]. 90 operating solar thermal plants for process heat are reported in literature with a total capacity of about 25 MWth (35,000 m^2) worldwide [7].

Solar thermal systems are well-known and established worldwide having an enormous potential for energy production in the low- to medium temperature range. However, large variety of the produced solar thermal technologies is mostly available for residential applications, which have increasing market shares. In contrast to this, solar heat for industrial applications in the industrial and commercial sectors is insignificant and has no effective share in the market. To improve conditions for the market share of solar heating systems for industrial applications, International Energy Agency (IEA) Solar Heating and Cooling Programme has been established [7]. Predictions of the energy mix, energy

M. A. N. Kadırgan and G. A. Ciftcioglu are with Chemical Engineering Department, Marmara University, Goztepe-Istanbul/Turkey (e-mail: nkadirgan@marmara.edu.tr, gciftcioglu@marmara.edu.tr).

F. Kadırgan is with the Chemistry Department, Istanbul Technical University, Maslak-Istanbul/Turkey and Selektif Teknoloji Co. Inc. Ltd. Ari Tekno City, Istanbul/Turkey (e-mail: kadirgan@ itu.edu.tr).

consumptions and as well as the ratio of the renewable energy in these predictions may be found in literature along with the process heat projections.

In Turkey, industrial use of solar thermal energy is mostly applied in vegetable and fruit drying, and salt productions in ponds. Also, there are many studies related to the drying processes that have found place in literature. However, there are no applications on solar energy in textile industry in Turkey and to the best of our knowledge, there is no systematic study on the potential of solar thermal utilization textile industry in Turkey. In this study, it is aimed to present the potential and economic benefit of the solar heat for industrial process applications. Thus, in this study a Textile Dyeing and Finishing Factory located in Kahramanmaraş, which has more potential for solar radiation being in the south east part of Turkey, was selected for feasibility calculations.

II. Solar Map of Turkey

Application of solar energy is very important for a variety of aspects such as; to provide energy solutions by modifying the energy proportion, improving energy stability, increasing energy sustainability, conversion reduction, and hence enhancing the system efficiency [4]. In this present work, it is aimed to analyze the solar energy systems utilization in industrial applications and economically state if it is compatible to install a solar energy system.

Considering the solar map (Fig. 2), Turkey is located in a relatively advantageous geographical position,

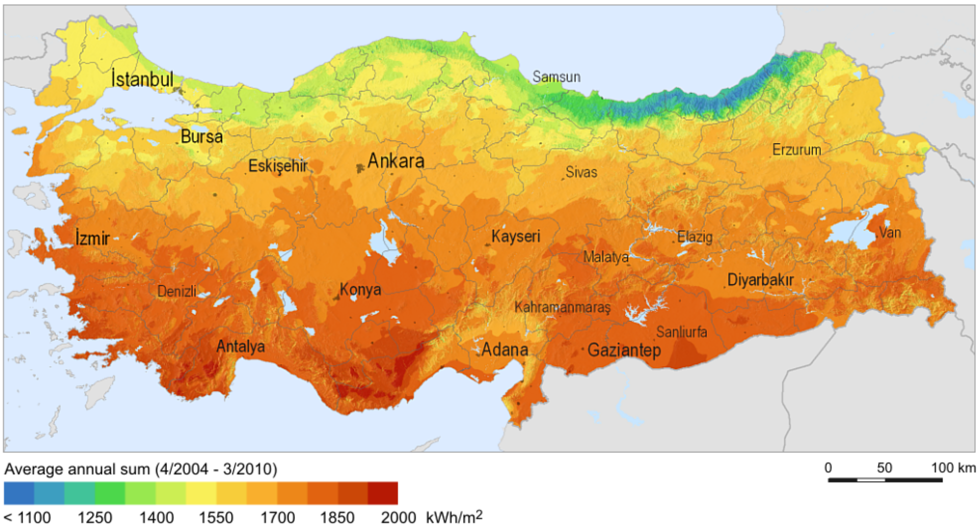

Fig. 2 Solar Map of Turkey [8]

TABLE I
SOLAR ENERGY POTENTIALS FOR HEATING AT LOW AND MEDIUM TEMPERATURE PROCESSES IN TURKEY [8]

Industry	Weighted Production Area	Production Season	Temperature Levels (°C)	Ratio of the energy that can be evaluated from solar energy	Required energy for heating processes (<160°C) (GJ)	Solar Energy Potential (GJ)
Automotive	Marmara	whole year	30-130	40%	4396000	1758400
Paper	50% Marmara 50% south areas	whole year	100-160	30%	14236500	4270950
Textile	50% Marmara 50% south areas	whole year	30-150	45%	83635000	37635750
Dairy	Marmara	spring and summer	30-140	40%	2800000	1120000
Non-Alcohol Beverage	West Areas	mostly summer	<=100	70%	184500	129150
Tomato Paste	West Areas	mostly summer	<=100	80%	3719000	2975200
Vegetable Oil	All Areas	whole year	80-160	45%	3238000	1457100
Distilled Alcohol	West Areas	whole year	<=100	45%	1372000	617400
Total				45%	113581000	49963950

The annual average total solar radiation is calculated as 2640 hours (7.2 hours/day)

Solar energy potentials for heating at low and medium temperature processes in Turkey can be seen in Table I. The data are presented without considering space limitation for collectors.

- Average annual solar radiation as 1311 kWh/m²-year (3.6 kWh/m²-day.
- Yearly required heat energy for low and medium temperature processes to be 113.581 GJ.
- Thus one can calculate the energy demand of the textile industry that requires low and medium heat. This energy

demand value can be calculated as follows: 113.6/324.1*100=35% where 324 PJ/year is the total energy demand of the industry that has process conditions running under 160 °C. This total energy consumption value can be easily calculated. Analyzing the energy distribution in Turkey, it can be seen that 36.7% of the energy is consumed in industry, 34.6% in domestic, and 18.3% in transportation. As can be seen these three sectors hold the 90% of the energy consumption, thus in order to save energy these sectors are the priority ones to be investigated in.

When the industry is examined, it has been seen that 75% of the energy is used for process heating, where more than 60% of this value is used for the process heat under 300 °C, and an average of 25% of the consumption is for the levels under 150 °C.

In 2010 total primary energy consumption is 109.3 MTEP [9]. For the feasibility studies the energy consumption ratio (or the usage percentage) of the processes under 160 °C were needed. The result is calculated as:

$$0.37*0.75*0.25=0.071 \tag{1}$$

where 0.37 is the overall industrial energy consumption ratio, 0.75 is the processes ratio of the industry that consumes energy for heating, and 0.25 is the ratio of the process heating for temperatures under 160 °C. Thus, the yearly energy consumption for the low and medium processes is calculated to be 7.1% for Turkey. With this value, now, the total energy consumption for the industrial processes running under 160 °C can be calculated for one year. This is done by the product of yearly energy consumption and the calculated yearly energy consumption for the low and medium processes (2):

$$109.3 * 0.071 = 7.76 \text{ MTEP} = 324.1 \text{ PJ/year} \tag{2}$$

III. Case Study: Textile Finishing Industry

Textile finishing industry is one of the main steps in production that involves a series of wet and dry processes to manufacture rope, textile, fabric, etc. to have required properties. These processes can be classified as pre-finish, coloring, and finish. In Tables II and III process mapping in textile finishing sector and conventional energy replacement potentials can be seen, respectively.

TABLE II
Process Mapping in Textile Finishing Sector

Process	Energy being used	Temperature required °C	Recommended solar technology
Desizing	Thermal	60-90	ETC,
Scouring	Thermal	90-110	ETC/ Concentrators
Bleaching	Electrical Thermal	-- 90-93	Solar pV ETC
Mercerising	Electrical Thermal	-- 60-70	Solar PV FPC
Dyeing	Thermal	70-90	FPC
Finishing	Thermal	40-100	FPC

TABLE III
Conventional Energy Replacement Potential

Process	Energy replacement (ktoe)	Estimated Monetary savings (Rs Million/annum)
Desizing	65	1306
Scouring	51	1035
Bleaching	65	1306
Mercerising	18	361
Dyeing	108	2166
Finishing	75	1516
Total	383	7692

A feasibility study for solar thermal energy use in a textile finishing company in Kahramanmaraş was carried out in this study. Global radiation values of Kahramanmaraş KWh/m^2 – day can be seen in Fig. 3.

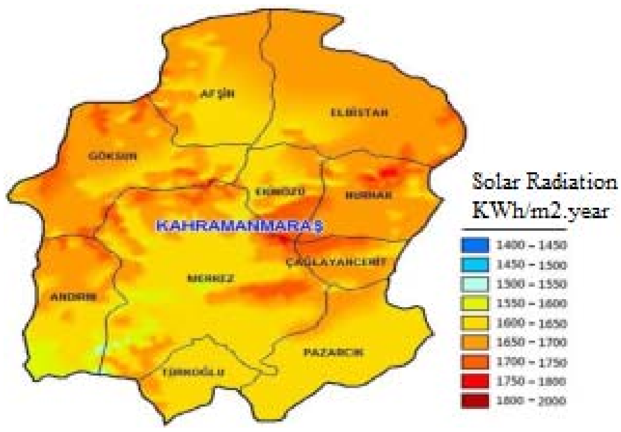

Fig. 3 Yearly global radiation in Kahramanmaraş, Turkey

The meteorological data such as the solar radiation and the ambient temperature, as well as the wind speed, were fitted from the monthly average values. Thus, for feasibility study, solar thermal systems used in this study depended on the collector area.

Using special selective surface high efficiency solar collectors with high absorption and low emission of heat can be obtained [10]. In this study, data of Selektif Teknoloji Co. Inc. collectors are taken into consideration. Efficiency of flat collectors using these absorbers are calculated in collaboration with Institute for Solar Technik (SPF)- Rapperswil, Switzerland. The efficiency of the collectors with selective surface is given in Table IV. These values are calculated under 800W/m^2 solar radiation.

TABLE IV
Efficiency of Collector with Selective Surface

η0 (-) (eff)	0.711
a_1 (W/m^{2}K)	4.27
a_2 (W/m^{2}K^2)	0.0072

The feasibility study carried out in this study uses the cash costs listed in the literature for 2015. The main motivation of this feasibility study was to propose a solution for to decrease conventional energy consumption through demonstrating a positive balance of long-term benefits over long term-costs.

Yearly average outputs provided for system are taken from Textile Company. The sum of 12 month natural gas bill of manufacturing company for textile finishing process between 30-60 °C is given as 2.3 million TL. Taking into consideration unit cost of natural gas 0.33 US$ for 8250 kcal/m^3 of lower heating value and 93% of efficiency:

- Consumed natural gas is 534 000 m^3/month,
- Consumed heat is approx. 171 000 kWh/day,
- Average radiation value for a year is 1883.9 kWh/m^2
- Assuming system and collector efficiency, as 70%, calculated collector area needs is 52000 m^2.
- Collector cost is calculated as 787 740 US$
- Total system cost with auxiliary equipment cost is calculated as 1 097 778 US$.

According to calculations, using 6489 m^2 collector, average 9.3% of natural gas consummation per year is recovered by solar thermal energy (2.75% in December, 16.1 % in July). So, system payback time is 5.15 years.

Economic Benefit Potential for the low and medium temperature processes, when solar energy is used, is shown in Table V in detail.

TABLE V
ECONOMIC BENEFIT

Natural Gas	Natural Gas Consumption (m^3)	Cost of Natural Gas ($)	Cost of importing of Natural Gas	Ratio Cost/Savings to current account deficit
If the required energy is evaluated all using natural gas*	9.38 billion	5.13 billion	3.75 billion	7.7%
If Solar is used economically** Then the saving will be realized***	4.22 billion	3.37 billion	1.69 billion	3.5%

*Only for low and medium heat process
**45%, Table I
*** Saving from the importing of natural gas

IV. CONCLUSION

Solar heat is a backup renewable energy for industrial processes to supply energy for necessary demands and is a solution to decrease our dependence on fossil fuels and to reduce CO_2 emissions [10].

Turkey is importer of energy with an important current account deficit, but the feasibility of industrial use of solar energy depends mostly of crude price and consequently natural gas price.

A specific education and training courses have to be given to decision makers in the industries suitable for solar thermal process heat, e.g. food and textile industry. Participation to demonstration projects will make them gain more experience and increase confidence in this emerging technology.

Research and development funding into green energy production via renewable energies can improve SHIP installation and as well as heat transfer. [10].

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