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Dynamic Modeling and Analysis of Solar Industrial Process Heating (SIPH) for the Food industry

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ABSTRACT

Thermal energy requirements in the industrial sector for different process heating applications consume about 35% of the total global fossil fuels. To mitigate the consumption of fossil fuels, solar industrial process heating (SIPH) can be the best possible option. Therefore, in this paper, dynamic simulation and performance analysis of the SIPH system have been carried out for the food industry. The main objective of this study was to investigate the effect of mass flow rate on the outlet temperature of solar thermal collectors by multi-flat plate collectors (m-FPC) industrial process requirements. The methodology has considered data for the food industry of Pakistan to verify its potential quantitatively for different weather conditions (Summer and winter). The investigation revealed that once the desired temperature (T_{set}) of 60°C was attained at the optimized mass flow rate of 41 kg/s, any additional upsurge in flow rate led to greater energy consumption by the auxiliary heating system. Additionally, the analysis confirmed that the annual thermal energy generated by the solar collector, in conjunction with the supplementary heat provided by the heater, adequately fulfills the process requirements. These findings demonstrate the promising potential of SIPH within the food industry.

Keywords: Solar energy, SIPH, multi-flat plate collectors (m-FPC), TRNSYS, parametric analysis.

NOMENCLATURE

Abbreviations	
m-FPC	Multi-Flat plate collector
IPCC	Intergovernmental Panel on Climate Change
CO_2	Carbon dioxide
GHG	Greenhouse gases
STC	Solar thermal collectors
SIPH	Solar Industrial Process Heating
PV	Photovoltaic
TMY	Typical meteorological year
NASA	National Aeronautics and Space Administration

1. INTRODUCTION

Energy plays a pivotal role in the global industrial sector, serving as a fundamental requirement for its development, economic expansion, and transformation [1]. Evaluating the accessibility of fundamental energy sources is a crucial factor in considering energy sustainability, security, and its impact on the environment [2]. According to an assessment by the International Renewable Energy Agency in order to meet the global warming limit of 1.5°C [3]. Hence, the scientific community is directing its attention towards addressing this issue in order to meet global future energy needs and attain a sustainable and secure energy future.

Energy consumption in the industrial sector globally surpasses that of other sectors, and it fluctuates significantly depending on location, economic conditions, and levels of modernization, among other factors. Statistics indicate that the average energy consumption in the industrial sector across different countries worldwide stands at approximately 35% [4]. The most prevalent equipment used for generating process heat steam and water in the industrial sector are boilers and furnaces, which constitute a substantial portion of energy consumption. A wide range of major industries relies on fossil fuels process heat production, including food and paper processing, petroleum refining, and drying for many applications [5]. Currently, fossil fuels play a significant role in fulfilling the energy demands of various processes, contributing to the global increase in greenhouse gas (GHG) emissions. Hence, when it comes to generating process heat from various renewable sources, solar thermal collectors (STCs) are the preferable option [6]. Direct conversion of solar

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energy into heat is done using STCs, achieving energy efficiency levels 3 to 4 times better than those achieved by photovoltaic (PV) based electric heaters [7]. Additionally, in comparison to batteries, the storage systems designed for solar thermal collectors are both cost-effective and more efficient, rendering them a more favorable choice in the energy market [8]. At present, solar thermal collectors are predominantly used in domestic water heating applications. Nevertheless, these collectors have the capability to provide process heat within the necessary temperature ranges for various industrial processes such as pasteurization, sterilization, drying, dyeing, bleaching, washing, cleaning, pre-heating, and more when installed in industrial applications [9]. Recently, study on the design of a STC system in Pakistan was conducted to produce hot water at a specified temperature. A flow rate of 80 tons per day of hot water was assumed and hot water at 75°C was produced by the system [10].

In this framework, the current study has been conducted for the performance analysis of solar-assisted process heating system with auxiliary source by considering the variation of seasonal based solar radiations and mass flow rate of the working fluid. The methodology adopted in this research has been simulated with a software called TRNSYS. A parametric analysis has been done to optimize the relation between flow rate and outlet temperature of STC. The methodology has considered data for a process in Food industry of Pakistan to verify its potential quantitatively for different weather conditions (Summer and winter).

2. METHODOLOGY

2.1 Key assumptions and Input parameters

To investigate the performance, the dynamic modeling and simulation is applied to one of the low-grade energy-intensive industry in Pakistan as a case study. Weather for the geographical location of Pakistan is taken from NASA weather files. An average ambient temperature ($T_{Average\ Ambient}$) of 25°C is taken on the basis of temperature variations across Pakistan. Selected industry requires hot water for all 365 days having a temperature of 60°C. The plant has conventional boiler based on furnace oil. It requires 1,000 liters (or kg) of hot water per day and the temperature of the inlet water is assumed as equal to the $T_{Average\ Ambient}$.

2.2 Description and Modelling in TRNSYS

In this study, transient System Simulation Program abbreviated as TRNSYS is developed by Solar Energy Laboratory, University of Wisconsin, United States of America [11]. For the location of Pakistan, the described system configuration scheme of the SIPH is modeled in TRNSYS. Typical meteorological year (TMY) weather file for Pakistan, the TRNSYS program (Version 16) is used to model and simulate the system. In this study, basically, a dynamic simulation of the system is carried out to investigate the effect of numerous input parameters on the overall system performance. The representational interpretations of the solar process heating system in TRNSYS for the configuration discussed are illustrated in Figure 1. The description of the several components used in the TRNSYS model is discussed below:

2.2.1 Weather data and weather profile

In the typical TMY2 format Type 109 reads the weather data file and is used by the national solar radiation database (USA) but from many programs TMY2 files can also be generated, such as metronome. At standard interim this part fills the primary need of perusing climate information from an information record, to acquire inclined to appear radiation and point of commonness for a tangled number of surfaces by changing over it to a favoured arrangement of units and treating the sunlight-based radiation information. For this determination Meteonorm 7.2 software was used to simulate meteorological data for Karachi, Pakistan. The weather profile discussed in this section was generated using Meteonorm software. The results were presented in graphical form reflecting essential factor that can affect the performance of the system.

Figure 2. shows the difference of maximum and minimum $T_{ambient}$ temperature for the whole year. April to July is the period that showed maximum ambient temperature. All these months showed maximum temperatures above 42°C. Figure 3 shows the variation of global and diffuse radiation across the year. April to July is the period that showed maximum values for global and diffuse radiation. The global radiations are more than 180 kWh/m^2 for all these months. Figure 4 shows the variation of sunshine duration and astronomical sunshine duration across the year. Longest sunshine duration was observed for the period from April to July.

Based on weather results shown above the period, two seasons i.e. Summer and Winter has been selected to perform the simulation of solar-assisted process heating system. Summer that includes monsoon starts from March to November (1776-7632 h or 5856 hours) and winter starts from November to March (7632-10512 h or 2880 hours).

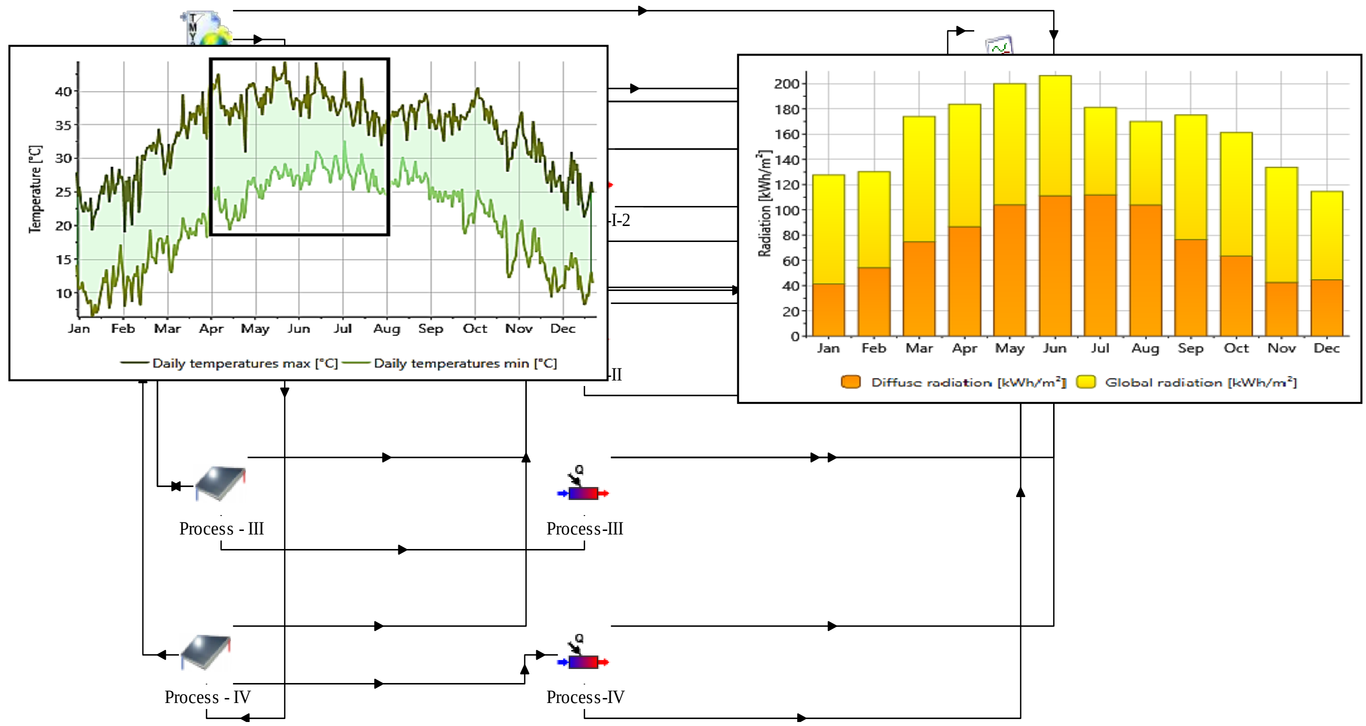

Fig. 1 Schematic of TRNSYS configuration

Fig. 2. Monthly variation of ambient temperature

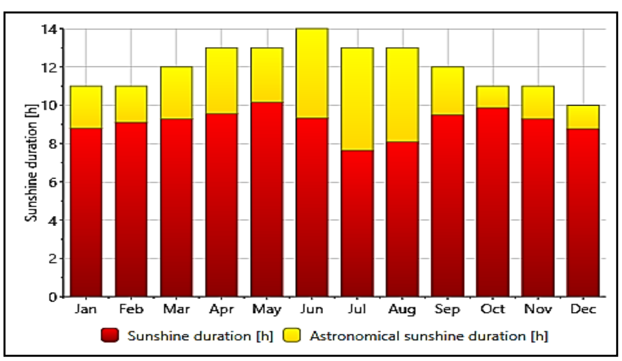

Fig. 3. Monthly variation of diffuse and global radiation

Fig. 4. Monthly variation of sunshine duration

2.2.2 *Solar Collector*

Flat plate solar collector is Type 1b. Solar thermal collectors converts solar radiation energy into internal energy of the fluid. The warm execution of a level plate sun-powered gatherer is demonstrated by this part. The coefficient of the capacities is provided by an ASHRAE or identical test.

2.2.3 Auxiliary Heater

Type 6 is an auxiliary heater. Utilizing either interior control, outer control or a combination of the two sorts of control, an assistant heat exchanger is demonstrated to increase the temperature of a stream. The auxiliary heater is proposed to supply additional heat to the stream at a required rate at whatever point the outside control input is equivalent to one and the outlet temperature is not as much as required Tset. Tset for this simulation and for case study considered is 60°C.

2.2.4 *Online Plotter*

Type 65d is online plotter. The function of online plotter is to show chosen framework factors. This plotter is profoundly prescribed and broadly utilized since it gives required variable data and enables users to instantly follow whether the framework isn't executing as desired or not. The chosen factors will be shown in a different plot window on the screen.

2.2.5 *Printer*

Type 25c is a printer. At determined (even) interims of time the printer part is utilized to yield (or print) chose framework factors. With every segment heading unit descriptors are not printed to the yield document, in this mode. Beginning with respect to the reproduction begin time Output can be imprinted in even time interims or can be imprinted in total time.

3. RESULTS AND DISCUSSION

3.1 Dynamic Analysis

In this section dynamic output of various parameters such as collector outlet temperature, ambient temperature, collector heat gain, auxiliary heat supplied etc. are represented in Figure 5 for the typical day of summer season at an optimized mass flow rate of 41 kg/hour and optimized area of solar thermal collector. From the figure, it can observe that the obtained heat transfer rate from auxiliary device is varying for the required temperature of 60°C. TRNSYS simulation was run for the said data and the designed area of collector for winter season and for summer season approximately becomes 1.4 m^2 for achieving 60°C temperature of water having optimized flow rate of 41 kg per hour

3.2 Parametric Analysis

Performance analysis and the relationship between various parameters such as mass flow rate, inlet and outlet temperature, ambient temperature, rate of heat supplied from auxiliary system and collector heat gain are displayed and discussed in this sub-section.

Effect of mass flow rate of inlet water on outlet temperature of collector is shown in Figure 6 and 7. Figures represent the results for different mass flow rate from 15 kg/hr to 60 kg/hr for summer and winter seasons respectively. Moreover, in this simulation the effect of variation of collector area is also taken into consideration and area of collector is optimized to get the required outlet temperature. Based on the analysis of the above findings, it can be deduced that once the desired temperature (Tset) is reached with an optimized mass flow rate of 41 kg/s, any further increase in the mass flow rate leads to greater energy consumption by auxiliary heat. Consequently, elevating the mass flow rate results in a decrease in outlet temperature and an increase in the auxiliary heat required. This implies that the combined thermal energy generated annually from the solar collector and the auxiliary heat provided by the heater can adequately meet the year-round needs of the process industry, both in summer and winter seasons. Hence, the results attained are comparatively acceptable for the potential of SIPH in Pakistan.

4. CONCLUSIONS

The main objective of this study is to investigate the effect of mass flow rate on the outlet temperature of solar thermal collector for multi flat plate collectors (m-FPC). In this study, a simulation is carried out to estimate the performance parameters of solar thermal collectors for solar assisted process heating. The methodology has considered industrial sector of Pakistan to verify its potential quantitatively for different weather conditions (Summer and winter). It was concluded that after achieving required temperature (Tset) at optimized mass flow rate of 41 kg/s, further increase in the mass flow rate resulted more consumption of energy by auxiliary heat. Moreover, annual thermal energy produced from solar collector and auxiliary heat supplied from the heater meets the requirements of a process in Food industry.

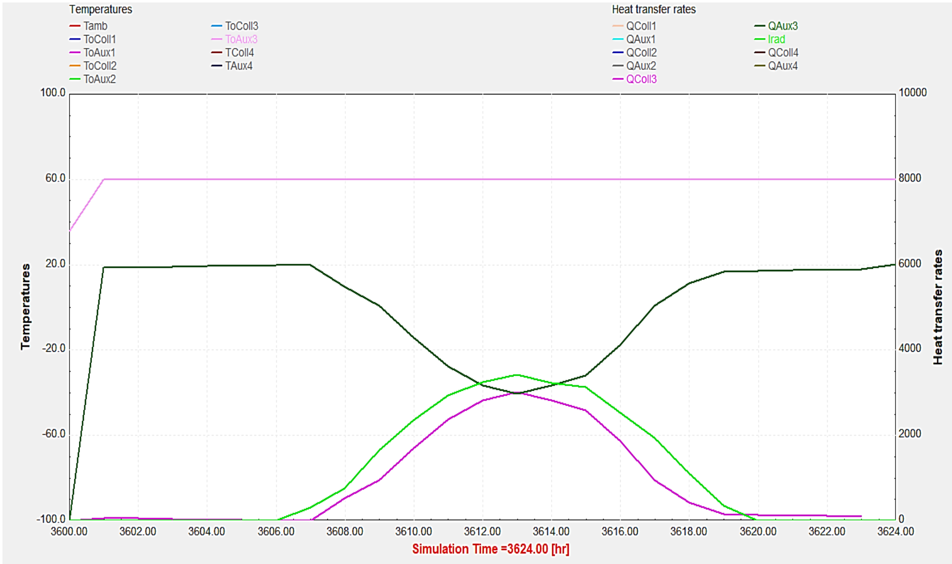

Fig. 5. Dynamic optimized simulation results for a typical day

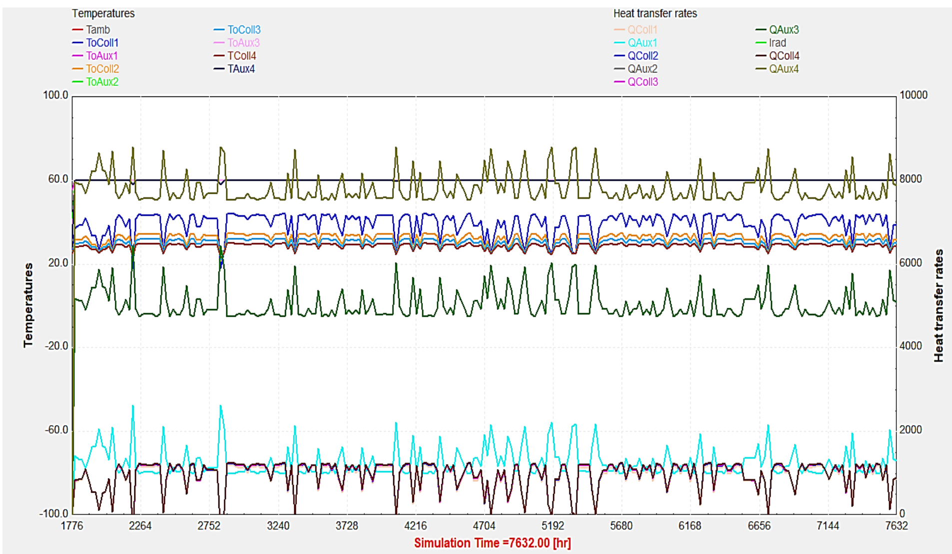

Fig. 6. Effect of mass flow rate on the outlet temperature at 15 kg/hr to 60 kg/hr in the Summer season

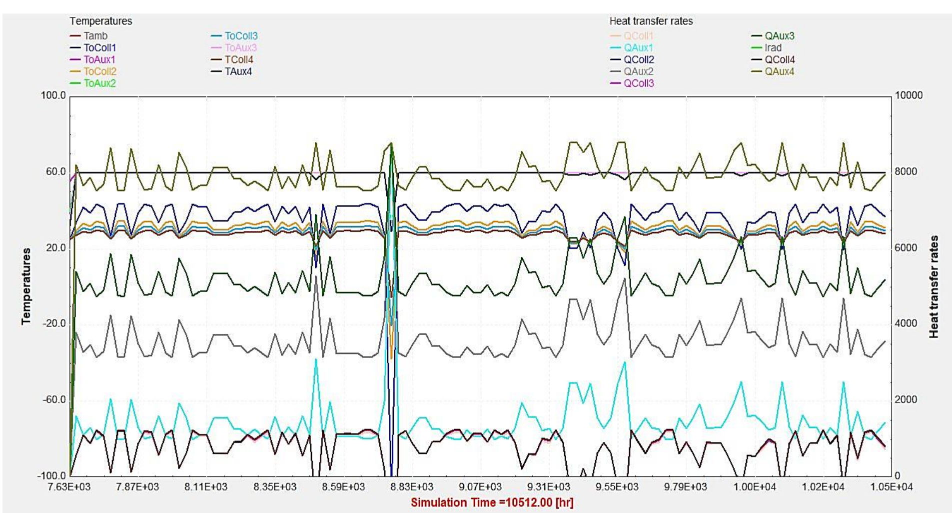

Fig. 7. Effect of mass flow rate on the outlet temperature at 15 kg/hr to 60 kg/hr in Winter season

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