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A new method for optimization of Solar Heat Integration and solar fraction targeting in low temperature process industries

Amir Baniassadi, Mahyar Momen, Majid Amidpour*

Department of Energy System Engineering, Faculty of Mechanical Engineering, KNT, University of Technology, No. 15, Pardis St., Molasadra Ave., Vanak Sq., Tehran, Iran

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ABSTRACT

Today, process industries are responsible for a large portion of world's energy demand. Accordingly, in this section, replacing fossil fuels with renewables can have a great effect on total energy consumption and CO_2 emission of the world. Using Heat Integration concepts, a general procedure for integration of solar heat into processes is generated. This procedure provides a tool for designers to find the best integration scenario and solar fraction targets. Also, it can help economic optimization of Solar Heat Integration by calculating the solar fraction targets for a certain amount of capital investment. Then, a new index for evaluation of existing designs is presented. Finally, the case of an organic distillation plant was investigated for Solar Heat Integration. Using the proposed procedure, the best place for solar heat exchangers on the process heat exchanger network and the solar fraction target was found. Annual simulations suggested that with current collector technologies, a payback period of 7–9 years is reachable. It was predicted that with further developments in collector technologies and more restrictions on CO_2 emission, Solar Heat Integration for this case will eventually be profitable.

1. Introduction

In the past few decades, energy crisis, environmental issues and global warming have motivated researchers and engineers to develop new technologies and methods for exploiting different sources of renewable energies. Most of these researches and developments have focused on residential and power generation sector. The work done regarding the industrial sector were mostly in the field of biofuels. Since technologies for using other forms of renewable energies have improved significantly, one may now consider using them in industrial sector as a more reasonable option. Technological improvements have made energies such as solar heat more reliable and economically viable for using in industrial sector [1].

More than 30% of the total energy demand in industrial sector is due to chemical, petrochemical and food industries. Compared to conventional fuels, the share of solar energy in these industries is nearly zero [2]. Despite some serious efforts, integration of solar energy in process industries is still in research stage. In past few years, several investigations have been made concerning the potential of using solar energy in process industries of different regions. Lauterbach has investigated the potential of using solar heat in process industries of Germany and suggested that processes with temperature ranges below 200 °C are most appropriate for Solar Heat Integration. This includes food, chemicals and beverage industries. Also, it was reported that in Germany, a total annual amount of 16 TWH of energy can be saved by integration of solar heat into processes industries [3]. Fuller has investigated this potential in Australia and suggested that up to 4% of the required industrial heat can be provided by solar systems. Food, textile and beverage were reported as the most promising industries [4]. Kalogirou has categorized process plants of Mediterranean region based on their temperature range and used annual simulations to estimate the efficiency of hypothetical solar integrated plants in these regions for different types of collector technologies [5]. Beath has done a broad analysis of the Australian industry and identified 2498 sites location, energy demand scale and temperature range in order to investigate their potential for Solar Heat Integration. Sites in remote locations which are isolated from energy distribution system were reported as the preferred ones for Solar

* Corresponding author. Tel.: +98 912 1055614.
E-mail address: Amidpour@kntu.ac.ir (M. Amidpour).

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Heat Integration [6]. Also, there are several case studies in which the viability and payback period of Solar Heat Integration are investigated for certain processes. Mauthner have studied the case of a beer production factory located in Spain and reported that 20% of the required heat can be supplied by solar energy [7]. Freina have studied the case of a Tunisian dyeing industry and reported that without governmental subsidies, there will be no payback during the life time of the solar system [8]. Atkins have investigated a dairy process in New Zealand and compared different scenarios for integration of 1000 m^2 of collector area into the process. It was reported that 14.4% of the hot utility demand can be replaced by solar heat [9]. Quijera have studied the case of a canned fish factory in Spain and reported that with 500 m^2 of collector area, a solar fraction of 11.5% is reachable in this region [10]. In an experimental study, Zamen et al. showed that the productivity of a pilot two stage humidification–dehumidification desalination process can be increased by 20% with integration of solar energy [11]. In their next paper, the cost function of the proposed solar integrated desalination process was optimized by mathematical programming. The total cost function was reduced by 28% [12]. Other than the mentioned works, there have been several efforts regarding a systematic approach towards design and evaluation of solar integrated processes. Nemet et al. have proposed using two new tools: The captured solar energy curve and the minimal capture temperature curve. These provide a graphical assessment of the optimization of Solar Heat Integration [13]. In another research, they have suggested a new method for maximizing the use of renewables with variable supplies. Accordingly, the methodology for Heat Integration in batch processes has been extended in order to incorporate variable sources like solar heat [14]. Verbanov et al. have used the concepts of Total Site Heat Integration to develop a method for using renewables sources in total sites. They have extended the concept of heat cascade by including the heat storage in order to minimize the carbon footprint and heat waste in total sites [15]. Wan Alwi et al. have provided an algorithmic targeting method for integration of renewables into total sites. They proposed the use of total site heat storage cascade as the core of their algorithm. In their method, the excess heat from each time slice is transferred to the next via heat storage unit. Their method can also be used for sizing of the heat storage unit [16]. Perry et al. have used the total site Heat Integration techniques in locally integrated energy sectors. In their research, they have also considered the use of variable supplies of energy such as solar heat [17]. In the work of Walmsley et al., incorporation of solar heat in total site heat recovery loops has been investigated. They suggest that combining solar heat and heat recovery loops is a cost effective way to reduce the storage and piping costs. They have also reported that using variable temperature storage is superior to constant temperature storage [18].

The aim of the present paper is to propose a general procedure to help designers find the solar fraction targets for a certain amount of collector area. For this purpose, Heat Integration techniques are used alongside basic solar engineering concepts. This procedure will provide a convenient tool for economic analysis of Solar Heat Integration. Finally, as a method for evaluation of existing designs, a new index is suggested.

2. Solar energy for industrial processes

2.1. The available solar energy

The most challenging aspect of using solar energy is its fluctuating nature. The available radiation from the sun varies by hour and day. Also, the available radiation depends on the sky clearness which has a rather unpredictable nature. Additionally, the thermal loss of collectors depends on the ambient temperature thus adding more uncertainties in predicting the available energy from the sun [19]. There are two ways to overcome this problem: 1-Storing the solar thermal energy when it is abundant in order to meet the demands later [14] 2-Hybrid systems which can switch to conventional energies when solar heat is not available. Although both methods are applicable in process industries, the latter requires far less capital investment and technical efforts [20].

The useful gain of the collector is the heat transferred to the cycling fluid. Although there are several simulation tools available, it may also be calculated using conventional methods in solar engineering. The actual energy received by a process stream is a portion of the useful gain of the collector which is transferred to the process by solar heat exchanger.

2.2. Suitable process characteristics

Despite climatic conditions, thermal characteristics of the process can have a great effect on the performance of the solar system. As seen in Fig. 1, the efficiency of collectors depend on their inlet temperature. This makes the stream temperature range, a key parameter in solar system performance. With current collector technologies, only low temperature (<100 °C) processes such as dairy or beverage may be viable for Solar Heat Integration [2]. Mild temperature processes (100 °C–200 °C) require more advanced collector technologies and for temperatures above 200 °C, solar tracking collectors are required [5]. Fig. 2 shows a list of promising industries regarding their temperature range [3].

Besides temperature range, due to the fluctuating nature of solar energy, the load profile of the process has a great effect in the solar fraction (ratio of solar energy to the total energy demand). For example, in the case of a dairy process, due to the market demand and raw material availability, the factory is shut down in cold seasons [9]. This shifts the annual load profile to towards the available solar heat profile and increases the solar fraction. The same thing may happen in a day if the load varies by hour.

Generally, the most convenient processes for Solar Heat Integration are the ones with lower temperature range and a load profile which matches the available solar energy as much as possible.

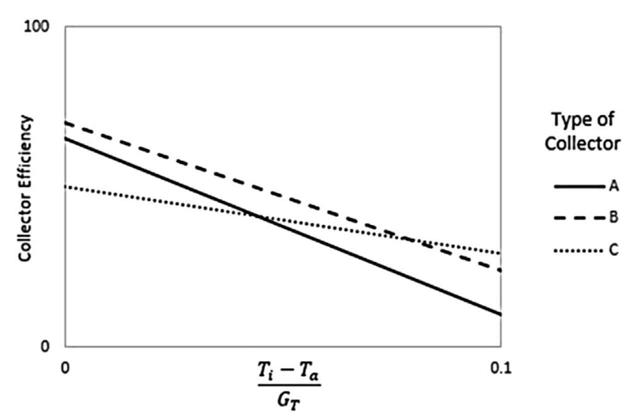

Fig. 1. Efficiency curves for different collector technologies. (A) One-cover liquid heater with moderately selective paint absorber (B) One-cover liquid heater with selective absorber (C) Glass vacuum tube liquid heater with sputtered aluminum nitride absorber [19].

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