Renewable and Sustainable Energy Reviews xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Solar process heat in industrial systems – A global review

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ARTICLE INFO

Keywords:
Solar industrial process heat
Solar thermal processes for industrial applications
Solar collector

ABSTRACT

In developing countries, industries and manufacturing sectors consume a major portion of the total consumption of energy, where most of the energy is used for low, medium or high temperature heat generation to be used for process applications known as process heat. The necessity to commercialize clean, cheap and efficient renewable sources of energy in industrial applications emerges from increasing concerns about greenhouse gas emissions and global warming and decreasing fossil fuel use in commercial sectors. As an abundant source of energy, solar energy technologies have proven potential. Recent research shows currently only a few industries are employing solar energy in industrial processes to generate process heat while replacing fossil fuels. Solar thermal power generation is already very well-known and getting popular in recent years while other potential applications of the concentrated heat from solar radiation are little explored. This review paper presents a detailed overview of the current potential and future aspects of involving solar industrial process heating systems in industrial applications. In order to keep pace with this emerging and fast growing sector for renewable energy applications, it is necessary to get in depth knowledge about the overall potential of industrial processes in individual industrial sector where solar process heat is currently in use and identifying industrial processes are most compatible for solar system integration depending on temperature level and the type of solar collector in use. Furthermore, the promising sectors needs to be identified for the use of solar heat using industrial processes for the integration of solar heat, so that countries with immense solar energy potential can use those technologies in future to reduce fossil fuel consumption and develop sustainable industrial systems. This paper presents a comprehensive review of the potential industrial processes that can adopt solar process heating systems and thus driving towards sustainable production in industries.

1. Introduction

Recent trends of energy production and consumption in manufacturing industries are notably unsustainable due to rapidly increasing greenhouse gas emissions. Developing countries throughout the world are trying to industrialize their own economy to create new opportunities for the young generation to address their own country as a developed one. For mitigating poverty through sustainable development, every developing country is following their own energy policy for employing environmentally friendly energy specifically in the industrial sectors [4,7,12,13,99].

As a renewable and abundant source, solar energy systems are future sustainable solutions for industrial consumers although, some places have inadequate solar energy resource where solar industrial process heating may not be feasible, but many other places receive abundant solar radiation and implementing such systems will drive the industries towards sustainable zero carbon production future. Industrial processes are mainly dependent on either electricity or fossil fuels to supply industrial process heat. As the non-renewable energy sources are going to be finished in future and considering all the drawbacks like GHG emissions, demand for renewable energy sources is imminent. The major drawback which hinders the scope for small and medium scale industries to integrate renewable energy systems in their production processes is the high capital cost while mostly the importance goes for ensuring continued supply of process heat from solar energy systems [7,12,13,71,100].

Industrialized and developed regions in Europe, Asia and North America are successfully using solar thermal systems in industrial processes. Solar thermal energy for electricity generation is also becoming popular in different parts of the world. Feasibility of commissioning and running such systems are heavily dependent on radiation intensity. If the regional and seasonal variation is not

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http://dx.doi.org/10.1016/j.rser.2017.08.065
Received 8 January 2017; Received in revised form 23 June 2017; Accepted 18 August 2017

significant, then a supplementary energy storage system may not be necessary depending on the type of application. Where seasonal variation is quite dominant where reduced radiation available in winter for a few months, energy storage systems may improve the overall performance of the system.

This review paper discussed the fundamentals of solar thermal energy and solar collectors, and the temperature range for industrial applications where process heat is in use. According to solar industrial process heating (SHIP) plants database information, promising industrial sectors are identified and further explained with current literature and plant installation information. The most widely used industrial processes with solar thermal applications are thus identified and reviewed. This review aims to identify the existing potential of solar industrial process heating systems in industrial sectors, where to integrate solar industrial process heating systems, which collectors are suitable for specific processes depending on temperature requirements. The authors systematically analyzes existing solar industrial process heating plants throughout the world, thus identify 11 key industrial sectors, mostly developed 6 processes. In these identified and integrated industrial sectors and processes are categorized through suitable solar collector type and process heating temperature ranges. This paper also discusses the future potential of solar industrial process heating systems.

Section 1 gives an overview of the importance of solar process heat for industrial sectors, and the objectives of this review paper. Section 2 discusses the present literature, trying to identify the potential sectors for solar industrial process heating systems. Section 3 and Section 4 gave an insight into solar thermal energy and solar industrial process heat. Section 5 illustrates the most widely used solar collector types for process heating systems. The process heat requirements by temperature range are discussed in Section 6. Then Section 7 explains the criteria for selecting a suitable solar collector for an integrated solar process heating system. Section 8 worked on temperature range of solar process heat applications, followed by Section 9 where most common solar driven industrial process stages are discussed through current potential, plants in operation and existing literature. Section 10 described a range of industries where solar process heat is in use, how they are employing solar process heat, where they are employing it and how it is performing. Finally Section 11 and Section 12 analyze and compare existing potential research and reviews throughout all industrial sectors to find gaps in the gap of research and also the gap of solar process heating system integration in industries.

2. Methodological approach

There are very few research papers which try to identify potential industrial sectors for integration of solar heat in industrial processes and none of them analyze the potential industrial sectors in respect of existing SHIP plants globally to determine the potentials for others which are feasible and already in practise. This review paper is the first one to do such an analysis in SHIP.

Lauterbach et al. studied and reviewed the potential in the field of solar industrial process heat integrated with suitable industrial processes. The annual specific energy gain is determined using TRNSYS simulation depending on temperature level, location and solar collector type [44]. In another work, Lauterbach et al. methodically analyzed an installed solar process heating system based on simulation and compared it with a validated model [42]. Weiss et al. reviewed the solar industrial process heating potential among countries for medium temperature collectors and sought a solution for SHIP integration problem [94]. Schnitzer et al. applied a newly developed investigation tool to investigate industrial energy systems and heat integration feasibilities through an Austrian dairy industry case study [77]. IEA SHC task 33 and SolarPaces Task IV: Solar Heat for Industrial Processes identifies and discusses potential industrial sectors for SHIP integration [36,92]. Mekhilef et al. reviewed solar energy utilization by industrial applications thus identified potential industries [53]. Norton illustrated the industrial applications of solar heat such as solar water heating system, solar drying system, solar furnaces, green houses, heating and ventilation systems, solar cooking, solar desalination and solar refrigeration [63,64]. Vajen et al. outlined solar heat integration potential at supply level and process level in Europe, Germany and worldwide [91]. Taibi et al. reviewed and discussed renewable energy potential in industrial sectors such as biomass and low temperature solar process heat [89]. Schmitt performed several comprehensive studies to show the utilized process installations in food and beverage industries. He also developed a classification mechanism for SHIP integration [76]. Modi et al. reviewed solar driven heat and power generation systems [54]. Pietruschka et al. reported on the fundamental design, process system layout, operating conditions and industrial processes of three large scale solar process heat installations [69]. Calderoni et al. studied the feasibility analysis of integration of solar process heating systems in industrial processes in Tunisia followed by an economic analysis [9]. Montes et al. presented the parabolic trough solar collector based process heating system and their design results [56]. Frein et al. studies and presents the design procedure and analysis basics required for integrating a solar thermal plant into an industrial system [27]. Schramm et al. presents a new concept of solar process heat integration system based on solar tanks through solar tank volume simulation results [78]. Larcher et al. experimentally investigated the parabolic trough solar collector based integrated solar process heating system [41]. Kalogirou presented simulated results of the parabolic trough collector based solar process heating system performance located on Cyprus [38]. Esen experimentally investigated and presented the thermal performance of vacuum tube collector based solar cooker under varied refrigerant conditions [21,23]. Silva et al. developed an optimization method for parabolic trough solar collector based solar industrial process heating systems. In another research work Silva et al. also conducted uncertainly and sensitivity analysis for parabolic trough collector based steam generation plant [83–85]. Coccia et al. designed and experimentally tested a prototype model of a parabolic trough solar collector for process heating application [11]. Naik et al. reviewed all kinds of medium temperature application areas of concentrated solar thermal technologies in India [62].

This review work analyzes existing solar industrial process heating systems throughout industries over the world. These industries and their respective process systems are analyzed and explained based on their solar collector type, installed thermal capacity and expected temperature range. Existing research and review are also studied by industrial category. Thereby the more common industrial process stages integrated with solar systems are identified and presented in this paper. These industrial process stages are elaborated with their industrial category, country data, solar collector and temperature range specifications. In a later part, potential industrial sectors are identified and discussed to find the integration problems of solar industrial process heating systems and future research scope.

In this review, all industrial sectors are analyzed based on their respective process operations where solar heat is already in use, and also classified based on process operation and temperature range. The dominant industrial sector where solar process heating system is widely in use is food and beverage industries, comprising water heating, washing, pasteurization, cooking, drying etc. Then another sector that is textile industries where cleaning, drying, washing, fixing and pressing are the major operations utilizing solar process heat. The temperature ranges required for these process operations are also identified and reviewed to locate the potential sectors which are currently consuming a significant amount of fossil fuels to run the process operations but where the low range temperature can be easily achieved by using solar process heat. Also, this review paper will be of great help for different countries where solar heat is found in abundance but is not in utilization for industrial operations.