Renewable and Sustainable Energy Reviews 91 (2018) 409–419

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Solar industrial process heating systems in operation – Current SHIP plants and future prospects in Australia

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ARTICLE INFO

Keywords:
Solar industrial process heat
Solar thermal energy
SHIP plants
Australia
Review

ABSTRACT

Solar thermal technology to supply process heat in different industrial sectors has become very promising in recent years. Industries can reduce their consumption of fossil fuels by replacing them with solar process heat with non-conventional system integration and using clean energy. In this paper, a systematic review of 10 countries is presented which demonstrated extensive use of solar industrial process heating systems in their manufacturing sectors. This country-wise analysis is then used to compare with current Australian scenario and identify future prospects of integrating solar process heating in Australian industrial sectors. The choice of countries is based on a database where promising industrial sectors and solar process heating applications are currently using incident solar energy. These are analyzed for their potential of integration to developing solar heat in industrial processes (SHIP) and a number of potential industrial sectors that have the highest potential like Motor vehicles, Textiles, Printing, Wood, Paper, Fabricated metal, Rubber and plastics, chemicals, Food, beverages, electrical equipment, machinery, and equipment are being identified. An overview of available studies is discussed in this paper focused on specific countries and the industrial heat demand of existing operational plants. Future trends due to solar energy potential are also outlined.

1. Introduction

From raw materials extraction to final production processing, process heat is a ubiquitous part of many industries. Over past decades, these have been much interest in buildings, residential areas, and industrial process heat applications. Fossil fuels and natural gas are used in manufacturing industries for process heat generation, which gives rise to greenhouse gas emissions, detrimental to a sustainable world.

Solar industrial process heating systems offer a solution for the sustainability problem through lower carbon emissions. These integrated systems are associated with the high capital cost of solar thermal collectors, which leads very few projects to come to fruition. Recently, solar thermal collectors have gone through significant improvements with the development of advanced modeling tools for solar collectors for solar process heat applications. As a result, the number of concentrating solar power (CSP) plants has increased dramatically, opening new research and development sectors for solar thermal developers using CSP collector technologies. The increase in the market size can help to decrease the cost of CSP collectors for IPH applications. The term “industrial process heat” will be referred to in this paper as solar IPH or “SHIP”.

Solar thermal energy is converted heat from solar irradiation, in other words, the eco-friendliest alternative to fossil fuel energy resources. Typically, thermal energy conversion systems use different combinations of solar collectors and solar concentrators powered by solar radiation for process heating in commercial or industrial plants. The major design specifications that should be considered include, collector type and position of installation, solar collector working fluid, system size, heat exchanger size and the load for specific applications.

The significant drawback of solar energy is unavailability for 24 hour. Supplementary process heating systems should be equipped to store the solar radiance. If the available solar radiation does not vary depending on season, a seasonal storage system is not needed. Seasonal variation is significant in regions with reduced radiation in winter. In areas where low range of solar radiation is available, like central Europe, to support competitive solar thermal technologies require substantial cost reductions.

Of the global final energy demand, electricity accounts for around 17% where low-temperature heat applications stand for 44% whereas high-temperature industrial process heat occupies 10%, and fuel used in

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https://doi.org/10.1016/j.rser.2018.03.105
Received 3 June 2017; Received in revised form 26 February 2018; Accepted 31 March 2018
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transportation accounts for 29% [1]. Several potential studies have been conducted to identify suitable industrial processes, either globally or regionally where solar heat can be used, to demonstrate SHIP integration feasibility. Lauterbach et al. carried out a study to identify potential industrial processes and validated their feasibility based on TRANSYS simulation. Regional data, solar collector types, solar irradiance level data are processed through simulation [2]. Weiss et al. carried out an analysis to mark 10 suitable industries for solar heat integration and sought the solution for integration problems for those countries and institutes involved in the SolarPaces program [3].

Kalogirou et al. outlined a scientific way to choose the most appropriate and economical solar collector for a process heating system through a TRANSYS simulation based on location, on process temperature requirements [4]. Wohlgemuth et al. present an overview of solar energy and biofuel energy potential in industrial applications in developing countries [5]. Vajen et al. outlined the solar heat integration potential at supply level and process level in Europe, Germany and worldwide [6]. Michael et al. reviewed the research trend of solar thermal systems for industrial applications where there is a research gap in the low and medium temperature industrial heat processes [7]. 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 [8]. Sharma et al. reviewed solar industrial process heating systems in respect of utilization potential, present condition, solar collectors, solar industrial process heating systems integration potential, evaluation of system performance, economic assessment and barriers to large-scale system integration. This paper also discussed the current operating solar industrial process heating systems which are only written in existing literature works [9,10].

There is no existing work which makes a global review of solar industrial process heating systems to determine dominating countries based on existing solar industrial process heating systems. Our country-wise analysis is further processed to clarify the immense potential of SHIP in the world's sunniest country- Australia to be utilized by the 5 largest industrial energy consumers. Section 2 describes the methodology followed to conduct this review analysis. Section 3 describes the solar thermal research initiatives taken in the 10 most advanced countries throughout the world. They are India, Austria, Germany, USA, Spain, China, South Africa, Mexico, France, and Greece. 10 countries are selected from the extensive survey conducted among the existing SHIP plants. Section 4 is used to find the potential of the solar industrial process heating system in Australia through analyzing the solar energy potential followed by industrial energy consumption in Australia. Leading manufacturing sectors are also discussed here to identify the potential process stages where solar thermal energy could be in use. An extensive literature survey was done to investigate solar thermal research initiatives in Australia. Finally, the future potential of solar thermal in Australia is examined in comparison with countries that are playing a leading role in solar industrial process heating activities currently.

2. Methodological approach

In this era of industrialization, nations and Governments are working on their own energy policy to make the world sustainable, which would need a drive towards zero carbon emission. The main goal of this review paper is to mark the solar thermal potential in the world's greatest sunny area, Australia. The potential is identified through detailed analysis and comparison among the advanced countries where the highest number of SHIP plants are on the operation. At first, countries with the largest number of solar industrial process heat plants are identified based on industrial sector, installed thermal capacity and installed collector area. Datasets are collected from SHIP plants database source and based on the highest number of SHIP plants in operation, potential countries are chosen. In the current scenario, potential countries are India, Austria, Germany, USA, Spain, China, South Africa, Mexico, France, and Greece. The leading industrial sectors of these potential countries are also discussed in this review paper. In the next stage, the SHIP plants operating in those countries are listed based on their key features like installed thermal capacity and industrial sector. Thus, a comprehensive literature review is conducted at this stage to categorize the country-wise case studies, for the compilation of their results. In a later stage, an extensive analysis is conducted comparing Australia, as the sunniest country in the continent and the identified countries based on their solar resources availability, manufacturing sector usability, and renewable energy policy. After that, Australia is compared with the leading solar industrial process heating plant operating countries based on their key features, solar energy potential, and industrial sector.

The methodology used in this paper is described as below. Steps 1–4 are described in Section 3 while step 5 is illustrated in Section 4. The last step is analyzed in Section 5 of this paper.

1. Solar industrial process heating plants throughout the world are sorted and categorized to identify the top ten potential countries with SHIP plants currently in operation.
2. The SHIP plants operated in the potential countries are analyzed to identify key industrial sectors within those countries.
3. SHIP plants within the identified industrial sectors are listed to identify the highest capacity thermal plant in operation and their key features.
4. An extensive literature survey is conducted related to the potential countries and within their key industrial sectors to categorize their dominant features to flourish their solar industrial process heating potential.
5. Solar industrial process heating potential of Australia is analyzed based on solar energy potential, industrial energy consumption, key industrial sectors and solar thermal activities in Australia. Potential research works related to solar industrial process heating systems are also discussed here.
6. The key features of the 10 potential countries are compared with the Australian one to analyze the drawbacks and barriers towards solar industrial process heating systems to be used in Australia.

3. Existing SHIP-country wise review

Solar industrial process heat plants database information is used for identifying and categorizing countries that are already advanced with SHIP plant integration in their growing manufacturing industries. However, there would be some cases where solar energy for industrial process heat is not convenient due to difficulty in practical implementation. Even for industrial processes consume medium -temperature heat by using steam as a medium of working fluid, lower working temperatures would be sufficient for that purpose. First, the accurate temperature required by the industrial process itself should be accessed to identify the feasibility of the integration, which should not be at the heat carrier temperature in use. This approach should be followed for lowering the process energy consumption.

Table 1 is focused on a country based analysis of solar process heating systems based on the key industrial sectors-where solar heat is in use and where it is not. 10 countries are the focus of consideration, where current solar process heating systems are widely used in several industries. These countries already have SHIP plants in a wide range of manufacturing industries, where other industrial sectors still lack integration. Both are identified through this review work.

3.1. India

India has a popular demand to use renewable energy sources. Indian industrial energy use reached 150 million tonnes of oil equivalent which accounts for 38% of the country's final energy used. The solar

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