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Application of solar energy in water treatment processes: A review

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ABSTRACT

The utilization of solar energy to drive water treatment processes is a potential sustainable solution to the world's water scarcity issue. In recent years, significant efforts have been devoted to developing and testing innovative solar based water treatment technologies, which are comprehensively reviewed in this paper. Recent developments and applications of seven major solar desalination technologies, solar photocatalysis process and solar disinfection are investigated. Potential integration of solar technologies and desalination processes are summarized. By collecting and analysing performance data from recent studies, the status of productivity, energy consumption and water production costs of different technologies is critically reviewed. The real world applicability as well as technical and economic feasibility is also evaluated. Presently, most of the solar water treatment processes are still under development with limited real applications. Economic competitiveness is among the major reasons that affect the scaling up and commercialization. It is revealed that the reported water costs of small to medium scale solar desalination plants are in the range of US$0.2–22/m^3, much higher than conventional fossil fuel based plants. However, the estimated low water costs (US$0.9–2.2/m^3) for large scale solar based plants indicate that solar based alternatives will become potentially viable in the near future.

1. Introduction

Water and energy security are two of the major issues mankind must tackle to achieve the sustainable development of human society. Water scarcity which is already a major challenge faced by many regions is becoming even worse due to the increasing water demand brought by rapid population and economic growth in developing countries. Meanwhile, the discharge of municipal and industrial wastewater effluent without proper treatment that caused serious pollution on fresh water sources has aggravated the problem. According to the United Nations Environmental Programme (UNEP), 1/3 of world population live in water-stressed countries, while by 2025, 2/3 of world population will face water scarcity [1]. The scarcity of water strongly limits the socio-economic development of these countries.

In 2012, 13,371 million tons oil equivalent (MTOE) of total primary energy supply were consumed in the world, with 81.7% from fossil fuels (oil 31.4%, natural gas 21.3%, and coal 29.0%) and only a small amount from biofuel and waste (10%), nuclear (4.8%), hydro (2.4%) and other source (1.1%) [2]. Energy demand will continue to increase over the coming decades to meet the growing population while associated economic development and a 31% increase in global energy consumption is foreseen by 2035 [2]. However, global reserve of crude oil, natural gas and coal are depleting. Many scientists believe that an oil production peak has either occurred already or will be likely to occur in the coming few years [3]. Global oil consumption rate is expected to decline by 75% by 2050 due to the depletion of many oil reserves. It is also forecasted that natural gas and coal production will peak within decades of oil peak [3]. Meanwhile, the emission of large amount of greenhouse gases and other air pollutants such as hydrocarbons, nitrogen oxide, sulphur dioxide, etc. by combustion of fossil fuels has caused serious environmental concerns. Clean, renewable primary energy must be utilized to solve the energy crisis in the near future.

Solar energy is by far the most abundant renewable energy source. It shows the highest technical feasible potential (about 60TW) among all renewable energy sources [4], which surpassed the total world energy consumption (13,371MTOE is equal to 17.75TW) in 2012. Although presently solar energy only accounts for a very small fraction of world energy supply (about 0.5% electricity generation globally) [5], the continuous development of modern solar energy conversion technologies in the past decades is making solar energy systems less expensive and more efficient. According to International Energy Agency, solar energy could become the largest electricity source by 2050 [6].

To address water shortage, a variety of non-traditional water

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sources have been considered for water production for drinking, industrial, agriculture or other usages, such as seawater/brackish water, treated municipal/industrial wastewater, contaminated surface or groundwater, etc. However, sustainable water supply cannot be achieved without considering the energy required in the treatment process. Coincidently, many of the world's arid and semi-arid regions which face severe water shortage are generally blessed with abundant solar radiation. This allows the address of water scarcity with sustainable solar energy. Suitable technologies need to be developed to integrate solar energy into water treatment processes. Solar desalination technologies, solar photocatalysis technologies and solar disinfection are the most widely investigated solar based water treatment technologies, which will be discussed in detail in this paper. Among them, solar desalination technologies have received considerable attention all over the world due to its applicability to arid or remote regions. Various solar desalination technologies have been examined and reviewed [1,7–14]. The global applicability and opportunities of solar desalination have been further demonstrated by researchers [1,8,11]. Specially, Adrian et al. [8] identified 30 nations with high applicability and 28 countries with 'moderate applicability' by a newly proposed method. Detailed reviews of the principles and features of different solar desalination technologies have been provided [9,10,13]. Sharon et al. [10] also discussed briefly the advantage and disadvantages of each technology as well as the problems existing in desalination processes. Special focus of thermodynamic and thermo-economic analysis of solar desalination systems were presented by Iman et al. [9]. However, only limited application cases were shown in these reviews so that the present status and development of specific technologies were not clearly shown. A very comprehensive review in solar assisted seawater desalination was given by Li et al. [13]. Nevertheless, latest research and applications were not included in this review since it was written before 2012. Therefore, in this paper, the current status and progress of different solar water treatment technologies have been extensively reviewed by summarizing research and applications in recent years. The economics and applicability are also discussed.

2. Solar desalination technologies

Desalination of seawater and brackish water is well known to be an alternative solution to provide fresh water for many water-stressed regions. For decades, large commercial desalination plants powered by fossil fuels have been installed in countries that suffer from water shortage, especially oil-rich countries in Middle East. Solar energy can be used directly or indirectly to drive desalination plants. In direct solar desalination systems, solar energy is used directly for the production of distilled water in solar collector, with solar still as the most representative technology; whereas in indirect solar desalination systems, solar energy is harvested either by solar thermal collectors to provide heat or photovoltaic panels to generate electricity for thermal or membrane desalination technologies such as multi-effect desalination (MED), multi-stage flash desalination (MSF), membrane distillation (MD) or reverse osmosis (RO).

In the sections below, brief descriptions of fundamentals of different desalination processes are provided in order to discuss the performance evaluation and operation parameters, as well as recent trends of technologies. Detailed explanations of those processes can be found in books and review papers [9,10,13,15].

2.1. Direct solar desalination—solar still

Solar still is the most common direct solar desalination technology which is mainly suitable for low capacity water supply systems in remote areas where construction of pipelines or water delivery by truck is uneconomical and unreliable [16]. The simplest design of a single basin solar still consists of an airtight, sloping transparent cover which encloses a black painted basin with saline water (see Fig. 1). Water evaporates after being heated up with the absorbed solar energy by the basin. Condensation occurred in the inner surface of the sloping cover

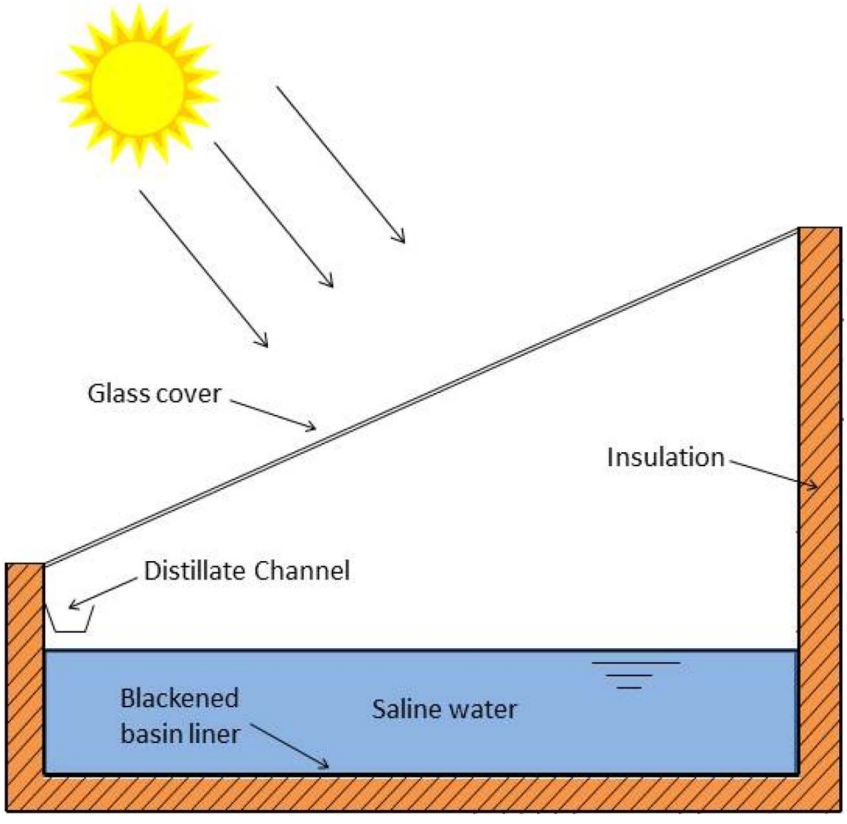

Fig. 1. Schematic diagram of a single slope single basin solar still.