Chapter 1
Introduction

1.1 Overview

This chapter discusses the motivation of the present study on single slope passive solar still. A brief introduction on solar energy, solar still and its types has been incorporated. This chapter also contains a brief discussion on phase change materials for thermal energy storage as well as nanoparticles. In the last part of this chapter, contribution and structure of thesis have been provided.

1.2 Motivation

Solar energy can be considered as a better option for sustainable power generation in India due to its environmental, social, and economic benefits. India is extensively funded with renewable energy sources (solar, wind, biomass, and small hydro) across the country, and can be utilized by commercially viable technologies for generating electricity. However, these renewable energy resources will also be important in meeting environmental objectives, reducing greenhouse gas emissions. India lies between cancer and the equator, receiving massive amounts of radiation from the sun due to its geographical advantage. The average annual temperature in India lies between 24^{o} C and 28^{o} C. This means that the huge solar capacity in India receives more than 5000 trillion kWh of solar power per year, which is much more than its total annual reduction. The Indian Meteorological Department (IMD) preserves a countrywide network of solar radiation stations, which calculates the solar intensity, and the daily sunshine hours. In most parts of India, cloudless weather is experienced 200 to 250 days in a year. The annual global radiation ranges from 1500 to 2100 kWh/m^2 (2001a; 2001b). The world demands for freshwater in order to survive our planet Earth. However, the source of pure water available per capita has been reducing gradually due to speedy growth in pollution and population especially for an economically growing country like India. The world is also facing climate change, which brings uncertainty towards the available freshwater, and due to this uncertainty, the solar distillation can be utilized to obtain drinking water from saline, which is abundantly available in sea. The contaminated water includes bacteria, harmful chemicals, dissolved and undissolved municipal waste, which causes a severe threat to one's health while drinking the same. The UNICEF (United Nations International Children's Fund) and WHO (World Health Organisation) presented a report in 2015 (Fig. 1.1) which stated that nearly 663 million people have no access to safe drinking water and depend upon polluted springs, wells, and surface water (2015).

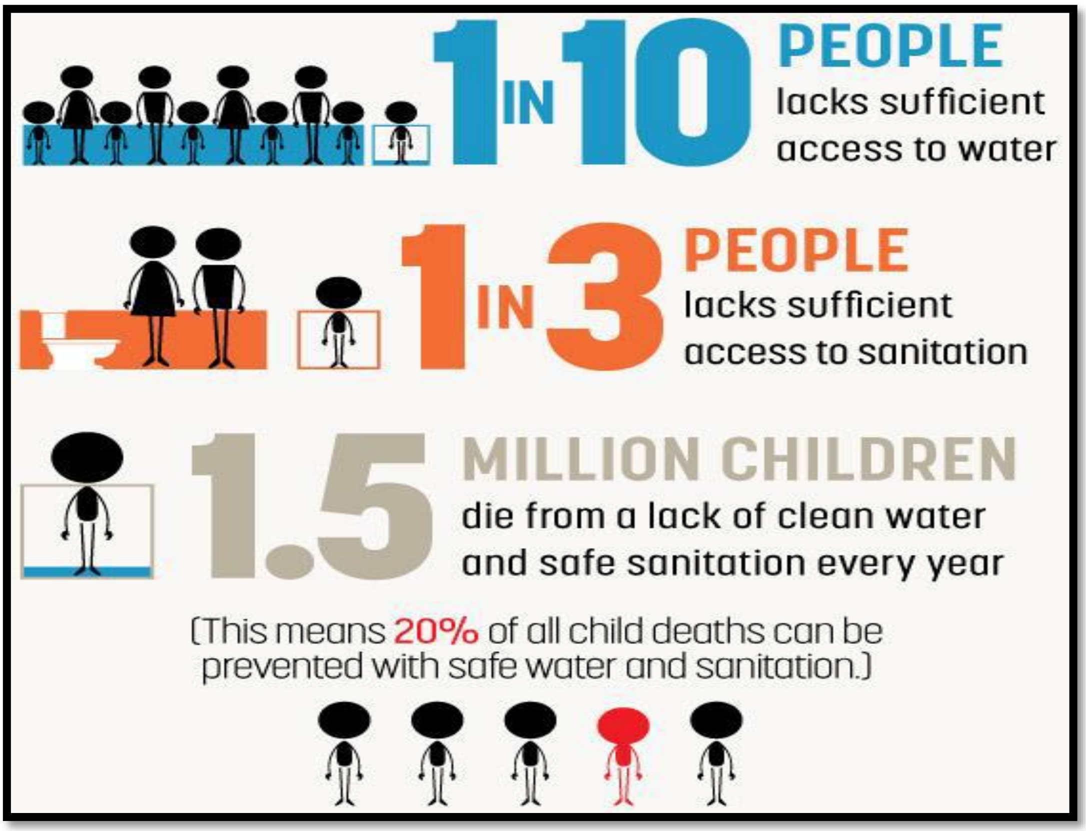

Fig. 1.1 An immediate action need to be taken to find a solution for water shortage globally (www.unwater.org)

Hence, the polluted water obtained from natural resources like lakes, oceans, rivers, rainwater, etc. should be decontaminated. The pollutants present in the contaminated water can be removed by the application of the solar energy which is the most prominent clean and renewable resource by distillation process using solar still (Garg and Mann, 1976). Together with other renewable energy resources, solar energy has a promising future, especially in India, because of its geographical location. Accordingly, regarding water purification, many scientists studied the performance of solar stills experimentally and theoretically. The solar distillation process is one of the available techniques which uses the solar radiation to clean the contaminated water and at the same time can be frugal for developing and underdeveloped nations (Eibling et al., 1971; Malik, 1982). Solar still is a frugal technology which is economically viable and has potential in decontaminating water and thus, it became popular especially in resource limited settings where there is scarcity in drinking water. Distillation of contaminated water utilizing solar energy is admitted as solar distillation and the system used for solar distillation is known as a solar still (Dincer and Rosen, 2010; El-Sebaii and El-Bialy, 2015).

Solar stills are mainly categorized as active and passive solar systems. It has also been found that passive solar stills could be considered as more economical to produce portable water in comparison to the productivity of active solar stills, which depends on climatic conditions and other parameters (Prakash and Velmurugan, 2015). The active solar stills (Fig. 1.2), put up an extra thermal energy which is supply to the solar still basin to increase the basin water temperature using some auxiliary sources such as heat pump, flat plate collectors, waste thermal energy from industries and power plants for faster evaporation and condensation.

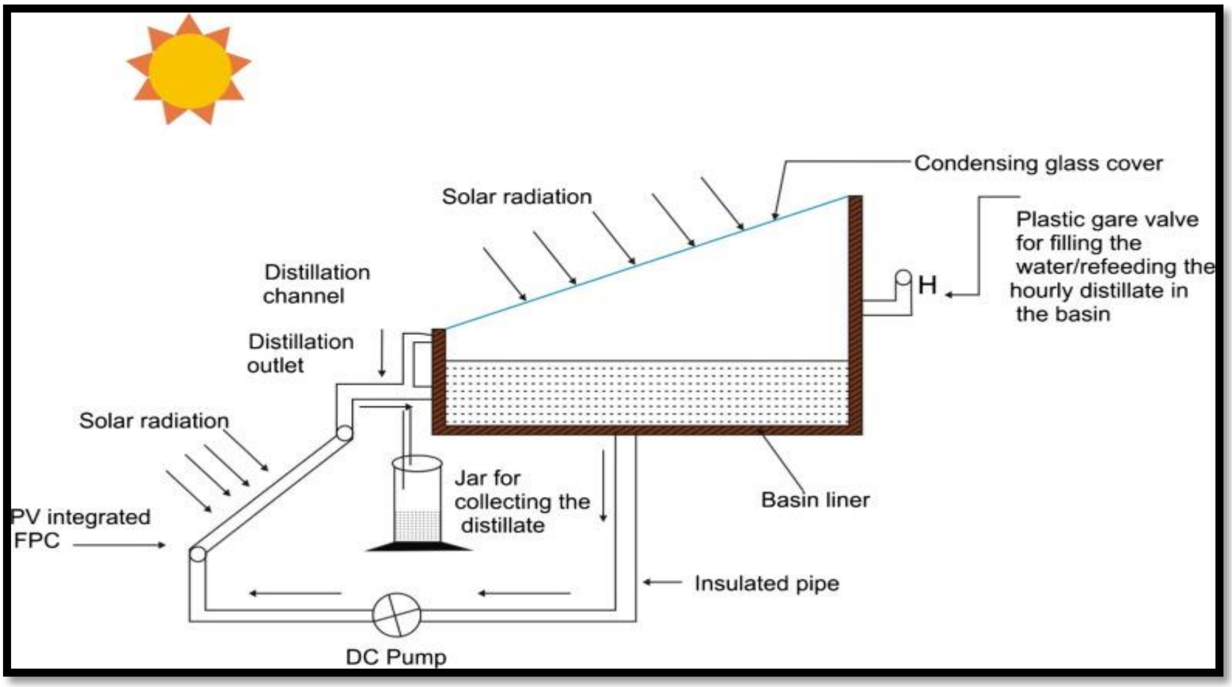

Fig. 1.2 Active solar still (Sampathkumar et al., 2010)

Active solar still incurs higher price as compared with passive solar stills and hence, it is found more acceptable for industrial or large scale applications for more distilled water production.

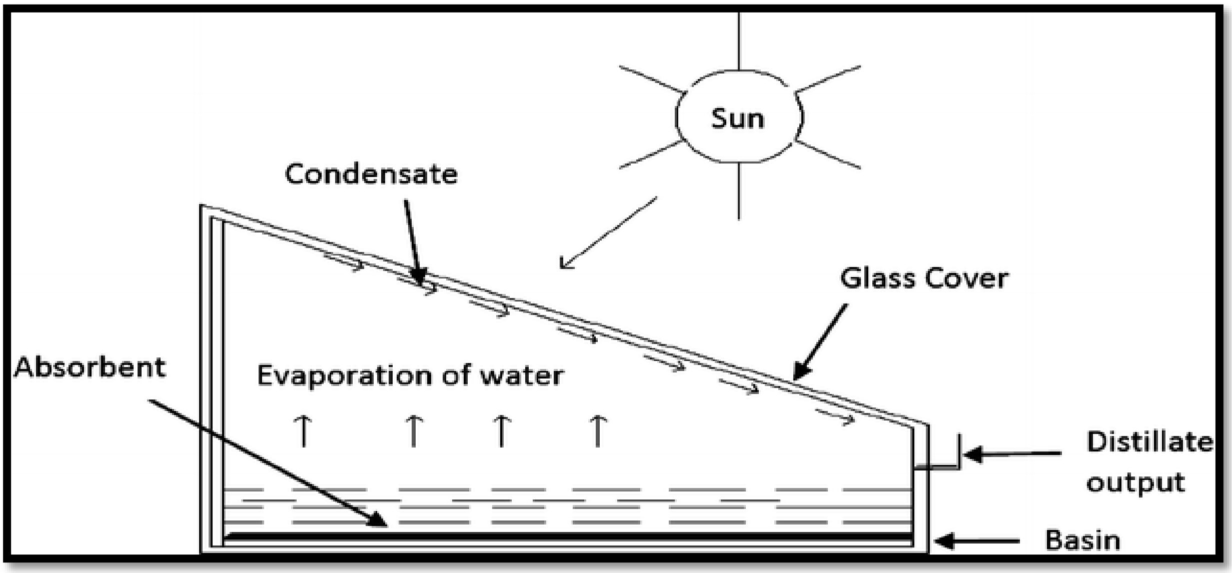

Fig. 1.3 Passive solar still (Singh and Tiwari, 2004)

On the other hand, in passive solar distillation, as depicted in Fig. 1.3, the distillation can be carried out by the principle of natural convection or similar to the hydrological cycle, having evaporation and condensations, where the heat collection and distillation processes occur within the same system (Bloemer et al., 1965; Lawrence and Tiwari, 1990; Rai et al., 1990; Sampathkumar et al., 2010; Tiwari and Garg, 1984). Taghvaei et al. (Taghvaei et al., 2014) concluded that the main drawback of passive solar still was its low productivity. Many researchers worldwide have conducted multiple studies on the improvements of solar still. Most of them found that the performance of solar still highly depends on solar intensity, ambient temperature, absorption area, tilt angle, heat transfer, water depth, evaporation area, heat loss (mainly side and bottom walls) and glass cover temperature (Kalidasa Murugavel et al., 2008; Kalidasa Murugavel et al., 2010; Kalidasa Murugavel and Srithar, 2011). The single slope distillation units with no energy storage system are the basic type of solar distillers that have the minimum productivity in comparison to other advanced solar distillation units. In conventional solar stills, various introducing energy storage materials, and changing mode of operations can increase the distillate output. The solar distillation units may be categorized into passive and active solar stills having some merits and demerits due to their mode of operation and cost (Aybar et al., 2005; Tiwari et al., 1997). Nonetheless, the passive solar distillation units are based on the principle of natural convection which has lower productivity as compared to active solar stills but are economical and user friendly. However, using simple solar still it is not possible to get distilled water beyond sunshine hours in spite of its simplicity. As an advancement of simple passive solar still, phase change materials (PCMs) are still used in solar still to store solar energy. The daily productivity of passive solar still distillation units could be increased dramatically by introducing PCM as a thermal energy storage which releases heat energy during sunset hours and store heat energy during sunshine hours as latent heat or sensible heat or both (Bloemer et al., 1965; Fernández and Chargoy, 1990; Kudish et al., 2003; Lawrence and Tiwari, 1990). The productivity while incorporating PCM depends on the their latent heat capacity, melting and solidifying behaviour, the stability of the storage, etc. (Dashtban and Tabrizi, 2011).

1.3 Contribution

The present research work focuses on solar still using three different phase change materials (PCMs) stored in copper cylinders. The performance of three different phase change materials namely, paraffin wax, lauric acid and stearic acid have been compared in terms of distillation output. The influence of meteorological variables such as solar intensity, ambient temperature and wind speed on the output of solar still have been taken into account. As a design parameter, the optimum depth of water has been estimated for maximising distillate. From this study paraffin wax has been chosen as the appropriate PCM for getting maximum distillate. However, it has also been observed that paraffin wax has low thermal conductivity due to which charging and discharging time becomes very high. In order to eradicate this problem CuO (copper oxide) as nanoparticle has been augmented with paraffin wax to reduce charging and discharging duration drastically and thereby, enabling the system to enhance its distillation output. The experiment has also been conducted during both summer and winter season. Finally, proof of the concept of our novel frugal solar still has been established in laboratory scale. Due to its low price, the technology can easily be deployed in resource constrained settings where drinking water is rarely available. Our proposed distillation unit can also be operated by minimally trained manpower which creates employment opportunities among the underserved population. Considering its socio-economic and technological aspects, an economic model has also been developed for its market entry and further commercialisation from which it has been inferred that beyond a certain threshold our proposed solar still would enjoy better market share than the traditional desalination system. The major objectives of the present thesis can be classified as follows:

- Design and fabrication of passive solar still system using multiple phase change materials
- Thermal modelling of developed system
- Energy balance for solar still (for charging and discharging mode)
- Using copper oxide nanoparticle for enhancement of thermal conductivity of energy storage materials for solar still applications
- Economic analysis and marketing entry (commercialization) of solar still as a frugal technology
- Uncertainty analysis for the designed solar still

1.4 Thesis structure

The present study has been distributed into six chapters, and brief outline of the respective chapters have been covered in this part. The Chapter 1 provides the introduction of solar energy, it also discusses about solar still and its requirement especially due to water scarcity in urban and sub-urban regions.

In the Chapter 2, a detailed literature review has been provided on solar stills and its type with phase change materials and nanoparticles. The Chapter 2 also contains a detailed discussion on the influence of thermal energy storage, design guidelines for phase change materials, operating parameters of phase change materials while using in solar distillation system as well as thermo-physical properties of PCMs used in solar distillation unit.

The Chapter 3 has been divided into two parts. In the first part of the Chapter 3, a detailed discussion on the experimental set-up along with the design and specifications has been provided. In the second part of the Chapter 3, heat transfer and energy balance in solar still with three different phase change materials (lauric acid, stearic acid and paraffin wax) stored in copper cylinders have been covered.

The Chapter 4 covers the influence of PCMs doped with nanoparticles stored in copper cylinders with thermo-physical properties of paraffin wax and nanoparticle during winter season.

The Chapter 5 presents the influence of PCMs doped with nanoparticles stored in copper cylinders with thermo-physical properties of paraffin wax during summer season. The Chapter 5 also includes an economic model for its market entry and further commercialisation.

The Chapter 6 summarizes the conclusions from the thesis and provides recommendations for the future scope of work.