AN EVALUATION ON SOLAR ENERGY STORAGE SYSTEMS: A REVIEW

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Abstract- Solar thermal technologies are promising, given the fact that solar energy is the cheapest and most widely available of all renewable energy technologies. The recent promotion of solar energy for various applications has received considerable attention from researchers, to improve the overall efficiency of various solar thermal systems. Thermal storage systems are essential to overcome the disadvantage of the intermittent nature of solar energy. One of the methods to effectively utilize solar energy is the integration of a highly efficient storage system, which should enhance the storage capacity to make the system suitable for continuous usage. Further, high stratification is required in the storage system in order to increase the efficiency of the solar collector system. Such stratified storage tanks are also vital for the effective storage and retrieval of energy, intended for various solar thermal applications.

Keyword- Solar Energy, Storage System, Evaluation.

1. Introduction Energy is vital for the progress and development of a nation's economy. The domestic, industrial and commercial sectors consume enormous energy. In recent years, these sectors have witnessed manifold growth, and have led to an increased energy demand. Despite the increase in energy production, the burgeoning demands for energy have outstripped the availability. Energy shortages and variable power availability cripple society's advancement. The rise in demand of energy and peak shortages has adversely affected various sectors. Renewable sources of energy have emerged as a crucial option, on account of the greater energy demand, price volatility of fossil fuels, climate mitigation and energy crisis due to the increasing depletion of fossil fuels. However, the unpredictability of the output of renewable energy conversion systems demands robust, reliable and efficient technologies. Such systems can produce savings by reducing the energy use and displacing fossil fuel expenditures. The United Nations general assembly in December 2010 designated 2012 as the international year of sustainable energy for all, aimed at ensuring universal access to modern energy services, doubling the rate of improvement in energy efficiency, and doubling the share of renewable energy in the global energy mix by 2030, thereby achieving economic and environmental goals. Accelerated renewable energy development can contribute significantly to a country's energy security, besides creating new jobs in rural areas and facilitating rural development. The renewable energy share of global energy consumption and the solar water heating capacity in 2010 are shown in Figures 1 and 2 respectively.

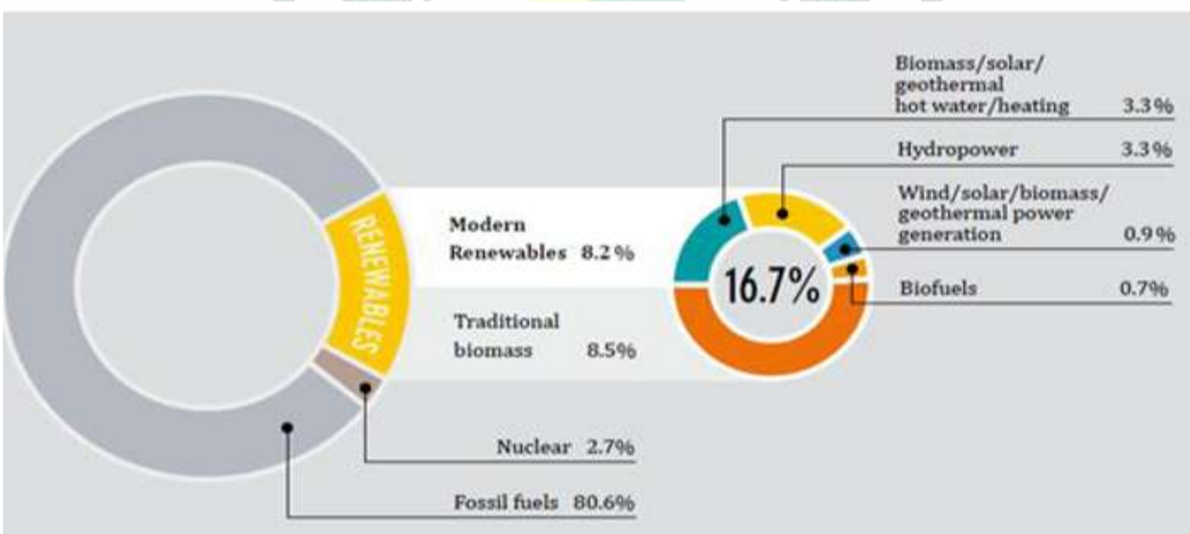

Figure 1 Renewable energy share of global energy consumption Source : REN 21 global status report in 2010

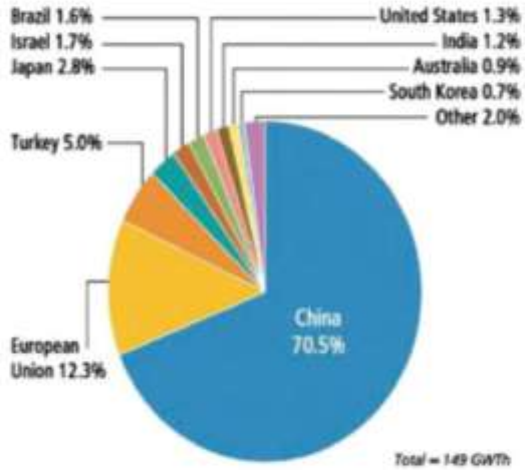

Figure 2 Solar hot water heating: existing capacity, top 10 countries/regions Source : REN 21 global status report in 2010

2. Literature Review

Solar thermal systems are useful in a variety of industrial and domestic applications. Solar thermal systems have been analysed based on energy, environment and economic benefits of its installation by several researchers. Karagiorgas et al. (2001) evaluated the economic and energy equivalent terms for applications of industrial solar thermal systems. Kalogirou (2004) presented several of the most common types of solar collectors and their applications. For low temperature applications, solar water heating is popular. Kalogirou (2009) presented the environmental benefits of thermo siphon solar water heating systems. Researchers have focused on efficiency improvements in solar thermal systems by variation in design and operating variables. Shukla et al (2013) presented a review on the design aspects of SWH systems to improve the thermal efficiency of solar water heating. The review focused on literatures pertaining to issues on refrigerant filled solar collectors in a heat pump system. Raisul Islam et al. (2013) presented an overview of various types, design features, cost effectiveness and market potential of solar assisted water heating systems.

Energy storage is vital when the energy supply and consumption varies independently with time. Energy is supplied to a storage system for retrieval and use at a later time. There are three methods of storing thermal energy: sensible, latent and thermochemical heat or cold storage. Though thermochemical storage offers a larger heat storage capacity compared to sensible heat storage, the storage technology is still in the development stage. At present, latent heat storage is the most promising, due to the high storage density and isothermal phase transition from storage to retrieval. LHS units are particularly useful in solar thermal applications. Apart from solar energy, LHS units are implemented in building applications (Zhang et al (2007), Antony Aroulraj and Velraj (2011), Zhou et al (2012)), cold storage applications (Hasnain (1998), Cheralathan et al (2007)). Velraj et al (2006) explained the concept of using spherical capsules filled with PCM in a water/brine solution tank, that is successfully being adopted in storage based central air conditioning applications. The subsequent section deals in detail with various aspects of the solar thermal system.

In a latent heat storage system used for solar energy storage, energy is stored during melting, and recovered during the freezing of a Phase change material (PCM). Among the various PCMs, paraffins have been widely applied for latent heat energy storage, due to their large latent heat capacity and good thermal characteristics, such as little or no supercooling, low vapour pressure, good thermal and chemical stability, and self-nucleating behavior (Abhat (1983) and Dincer and Rosen (2002)). Hydrated salts are also used as PCM for solar thermal applications. Canbazoglu et al (2005) investigated experimentally by combining SWH with sodium thiosulfate pent hydrate, and theoretically examined the storage performances of other salt hydrates, and compared the enhancement of solar thermal energy storage with the conventional SWH System. Though the energy storage density is higher in the PCM, poor thermal conductivity is its negative feature. Different enhancement techniques such as the inclusion of fins (Abhat (1981), Velraj et al (1997)), graphite Nano fibers (Chintakrinda et al (2011)) are attempted to improve the PCM thermal response. Mettawee and Assassa (2007) investigated experimentally the addition of aluminum-powder to paraffin wax, to improve its thermal conductivity. It was found that the charging time was reduced by approximately 60% by adding aluminum powder in the wax.

hermal stratification is essential for storage to be energy efficient as it improved the overall solar thermal system performance. The studies on stratification to maximize storage performance, and hence, the overall system, have received much attention in recent years. All the research works relevant to the stratification performance and parametric analysis, and the modelling and numerical analysis of sensible and latent heat storage systems suitable for a conventional hot water storage system, are presented under this category. Further, the stratification studies performed on modified storage tank configurations and other applications are also summarized under a separate section.

Several geometrical configurations have been proposed by some of the researchers to minimize mixing and aid thermal stratification. Hugo et al (2010) proposed the use of stratifiers as shown in Figure 2.3 to enhance stratification. Figure 2.4 shows the presence of baffles in the storage tank near the inlet pipe, that lets hot water inside the tank to aid stratification. Mather et al (2002) adopted the use of multi tanks, as shown in Figure 2.5, to improve stratification. They demonstrated the advantageous features of improved stratification and thermal diode effect at the laboratory level, for a multi tank system compared to a single tank system. Multitanks however suffer disadvantage of larger space requirement and higher initial cost. Aiding stratification through fluid inlet design to distribute heat at the correct level, and limiting destratification by the presence of baffle plates, have also been undertaken by researchers. The experimental study of Lavan and Thompson (1977) on stratified hot water storage tanks concluded, that stratification increased on increasing the height-to-diameter ratio of the tank, increased temperature difference between the inlet and the exit water, increased pipe diameters at the inlet and outlet located near the end walls and reduced flow rates.

Mehling et al (2003) conducted experiments by adding a PCM module at the top of the water tank to enhance stratification. The experimental results were used to quantify the stratification in terms of non-dimensional numbers. This resulted in higher storage density, allowing reheating of the transition layer after partial unloading, and compensation of the heat loss in the top layer for a considerable time. Cabeza et al (2006) showed that the energy density of the hot water storage tank with stratification, increased with increasing amounts of the PCM modules at the top of the tank, as shown in Figure 2.9. Castell et al's (2009) experimental comparison revealed a similar stratification between a water tank and a PCM-water tank. It was also stated, that the Richardson number reflected stratification better than the MIX number due to its sensitivity to very small differences in the tank temperature profile. Ordaz-Flores et al (2011) compared a closed two-phase Change System thermosyphon, to heat water with a conventional domestic solar water heating system. The schematic representation of the experimental Phase Change System is shown in Figure 2.10. The stratification profile in the thermo tanks was higher in the Phase Change System than in the domestic solar water heating system. To obtain a high stratification profile it was suggested to place the coil at the lowest part possible of the thermo tank, to transfer heat at a major temperature difference

Theoretical investigations of stratification have been divided into three sections. In the first part, the investigations made, using the mathematical modelling methods are discussed. The second part deals with the stratification performance evaluation by the use of software.Finite difference model and finite volume method were used by various researchers to predict the temperature distribution in forced and natural circulation system of solar water heaters for different operating parameters suitable for domestic applications. A one dimensional explicit finite difference model was developed by Oppel et al (1986) to simulate the behavior of a stratified thermal storage system While some of the models proposed in the literature are simple one-dimensional models (Wildin and Truman (1989), Zurigat et al (1991)) most of the other models are two dimensional turbulence model (Cai et al (1993), Mo and Miyatake (1996), Spall (1998)) with water as the HTF. Zurigat et al (1989) carried out a survey of the stratified thermal storage one-dimensional models available in the literature. They have validated six models with the experimental data, obtained at their laboratory and from the literature, conducted under both constant and varying inlet fluid temperature conditions.

Software has been employed to study the heat transfer phenomenon in solar collection and storage. Selmi et al (2008) simulated the heat transfer phenomena in flat-plate solar collectors, using commercial CFD codes, and their results achieved good agreement with the test data. Alizadeh (1999) numerically investigated the thermal behaviour of a horizontal tank by one dimensional turbulent and displacement mixing models, and validated it with the experimental results. It was reported that the thermal stratification was enhanced using the divergent conical tube as the inlet nozzle. The CFD simulation using parallel computers as a tool for virtually prototyping thermal storage tanks was adopted by Consul et al (2004). The exergy method of stratification evaluation was suggested as an alternative to the MIX number. Altuntop et al (2005) carried out a numerical analysis of the effect of placing various types of obstacles in a solar hot water tank, as shown in Figure 2.12 for thermal stratification. Obstacle numbered 11 provided the best thermal stratification in the tank, followed by obstacle number 7, while the other obstacle types had little effect on improving stratification. Jordan and Furbo (2005) TRNSYS model in a storage tank after draw-offs showed, that the thermal stratification inside the tanks depends differently on the flow rate, the draw-off volume, as well as the initial temperature in the storage tank.

The performance of the stratification is evaluated by various indices such as the mix number and the Richardson number. The recent advancement in the computational analysis that predicts the temperature distribution of the entire storage tank paves the way for a detailed exergy analysis. Hence, the combination of the CFD and exergy analysis has gained importance in recent years. The various studies on the stratification performance available in the literature are presented in the following two subsections

xergy is popularly used for characterizing the stratified store, and it is reported separately in the subsequent section. Rosengarten et al (1999) have developed a performance measure, based on the exergy method for optimizing the design of thermal energy storage systems. Sari and Kaygusuz (2000) have compared the energy and exergy efficiencies of a latent heat energy storage tank. They have reiterated the importance of the exergy analysis in the calculation and comparison of the charge and discharge times for a thermal energy storage system. Rosen (2001) has endorsed the use of the exergy method for rationally assessing, comparing and improving TES, as it reflects the thermodynamic and economic value of the storage operation. Shah and Furbo (2003) conducted experiments to measure the temperature stratification in the tank during the draw-offs with the three inlets, and nine draw-off tests at different inlet flow rates. The results showed the entropy and exergy changes in the storage during the draw offs with the variation in the Richardson number, volume draw-off and the initial tank conditions.

CONCLUSION

From the solar collection and storage aspects, studies are focussed on optimizing the solar collector area and storage volume. Performance studies in a storage system have received the attention of researchers worldwide. The SHS system has reached a maturity stage whereas thermochemical storage is in the developmental phase. In sensible heat storage system, experimental and numerical works have focused on temperature distribution, energy charging and discharging efficiency of storage system at different operating conditions for different configurations of solar hot water storage systems such as conventional hot water system, Integrated collectors storage and mantle tanks. In the stratification enhancement methods, many attempts have been made with various geometrical configurations, such as stratifiers, diffusers and baffles. However, the recent developments with phase change in the storage system, are very promising as the performance enhancement is very high. In phase change systems, though PCM encapsulated spherical capsules were studied by researchers only very few literatures are available on stratification studies of packed bed storage system. In recent years, there is a greater awareness, and hence, there exists several stratification studies in SHS units; however, such studies are scarcely available in LHS units. Stratification evaluation is another important part of thermal storage analysis. Richardson number and stratification number have been used as the stratification evaluation index in majority of research works.

This would be of significance to designers of thermal storage systems to increase the storage system capacity with minimal mixing loss. Various stratification evaluation techniques have been put forth by different researchers. The use of CFD and energy analysis has been adopted by some researchers for reliable and better prediction

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