ABSTRACT

Renewable energy technology presents the best chance of alleviating residential and commercial heating dependence on traditional energy. The thesis comprises numerical and analytical studies on solar thermal energy storage and utilization in house heating and clean ventilation. Thermal energy storage (TES) systems are intended for long-term and short-term house heating. Besides, the term "clean ventilation" refers to the thermal inactivation of airborne viruses after exposure to an elevated temperature for a certain period. Hence, a novel thermal treatment model is developed to decontaminate airborne viruses in the ventilation air. However, the implication of solar energy makes the proposed models self-reliant to suppress the dependence on conventional energy.

In the first objective, a sensible TES system made of mild steel is modelled for house heating in winter. Solar parabolic trough collectors (PTC) charge the TES using compressed CO_2, and the stored energy is later used for house heating in winter. TES's quantitative and qualitative analysis is carried out for two cases: Initial charging and year-round performance. Numerical results reveal the TES charging in 55.2 days with maximum block temperature and stored energy as 324.2 ºC and 2604 MJ, respectively. The year-round performance exhibits a stored energy reduction of 71.6% at the end of January due to increased heating demand. During a cyclic year, TES's average exergy efficiency and exergy effectiveness are noticed as 56.12 % and 0.76. Besides, the rational economic study finds the proposed system 42.5% less expensive than the traditional heaters, which also mitigates the average CO_2 production of 4.54 Tonne/year.

The second objective is to model a PCM-encapsulated thermal energy storage system for Day-round house heating. Contrary to sensible TES, the latent heat TES systems exhibit large energy density, enhanced heat transfer rate, and high thermal efficiency. Solar PTC acts as a heat source for daytime house heating and energy storage in packed-bed (PB-TES) for later uses. The PCM candidates are numerically analysed to optimize the solar PTC and PB-TES sizes in Indian cold provinces. The periodic outcomes reveal the minimum time and temperature to initiate the melting of sodium nitrite ($NaNO_2$) and sodium nitrate ($NaNO_3$) as 1180 sec at 261.19 °C and 1760 sec at 296.86 °C, respectively. In contrast to $NaNO_3$, $NaNO_2$ stores more heat at a specific temperature due to its extensive heat of fusion at 180.12 kJ/kg.

Besides, solar collectors and packed-bed thermal energy storage (PB-TES) are also sized based on the Indian climate conditions and solar potential in a different zone. Despite lower energy storage capacity (kJ/kg), the PB-TES volume is less with $NaNO_3$ PCM than with $NaNO_2$. Since $NaNO_3$ is denser, it can hold a greater mass within a sphere. Therefore, the $NaNO_3$-based PB-TES required a smaller number of PCM capsules.

The third objective introduces modelling and analysis of a novel thermal treatment model to decontaminate airborne in ventilated air. The contaminated air at 0.036 kg/sec passes through a porous domain and the insulated chamber to decontaminate the virus at 105 ^{o}C, ensuring 5 mins exposure period. The treated air is allowed in the residential space at ambient conditions passing through a storage tank and air cooler. All essential components are analytically designed; however, the numerical simulations are performed for the porous pipe model and buffer storage tank. The porosity and L/D ratio of 0.9 and 8.33 seems optimal, owing to the maximum temperature and minimum $\Delta p/L$ of 105.1 ^{o}C and 1.6 kPa/m. Besides, a storage tank (13 m^2) cools the treated air through natural convection and maintains buffer storage. A critical period of 5 hours characterizes the minimum time lag between system initialization and steady-state condition. An air cooler (4.83 m^2) further cools the tank's outlet air from 50.05 ^{o}C to room temperature. Moreover, a solar photovoltaic module of 28 m^2 is proposed to meet the prerequisite energy requirements of all equipped devices.

In the fourth objective, the proposed thermal treatment model incorporates solar PTC and heat exchangers to optimize energy efficiency at large mass flow rates (0.44 kg/sec). A solar PTC offers air heating during the day; however, the porous domain with the electrical heaters acts during the night and intermediate time. A heat exchanger exchanges energy between hot and cold air streams. Numerical outcomes reveal porous domain's optimal porosity is 0.9, owing to maximum exit temperature and a minimum $\Delta p/L$ of 5.16 kPa/m. Inclusive computational analysis of storage tanks (ST-1 and ST-2) aims to find critical time lag for steady-state occurrence and maximum leaving air temperature at the peak (0.44 kg/sec) and partial load (0.22 kg/sec). Two storage tanks are connected in series for enhanced natural cooling, and the ST-2 exit air temperature is firmly stable at 47.8 °C (peak load) and 45.2 °C (partial load). A finned air cooler (6.02 m^2) further cools the ST-2 exit air. The system's energy efficiency is noted at 37.4 and 91.1 % during the day time (x =1) and night-time (x =0) operation, respectively.

Keywords: Solar thermal energy, Thermal energy storage, Sensible heat and latent heat storage materials, House heating, Airborne virus, Thermal inactivation, Clean ventilation.