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Long-term Thermal Energy Storage Using Thermochemical Materials

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Abstract

There are different methods to store thermal energy. The thermochemical heat storage is one of the sufficient thermal energy storage. The energy storage density of the thermo-chemical material (TCM) is higher compared with sensible and latent heat storage method. This paper presents a mathematical simulation of thermochemical energy storage process by using COMSOL Multiphysics modeling Software. The TCM studied is magnesium chloride hexahydrate. The model result is validated with the experimental results, and the temperature distribution in the bed and material are investigated. Two reactor designs are considered; cylinder and truncated cone with different radiuses and heights. The comparison of the performance between them is investigated. The validation shows good agreement between the present work and the literature. The results indicate that the increase in entrance area reduces the charging time and increases the pressure drop at constant volume and height of the bed. Cylinder reactor and truncated cone with small and large diameters of 15.5 cm and 18.4 cm are the best to charge this material with thermal energy.

Keywords: Seasonal storage, Thermochemical; heat storage; Salt hydrates; Magnesium chloride hexahydrate.

1. Introduction

The energy demand for buildings accounts for 25% of the total energy consumption in the world and 51% in Egypt [1]. The domestic sector is considered the highest contribution in energy utilization. Also, space heating and

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hot domestic water account for half of this consumption [2]. Thermochemical Heat Storage (THS) is a quite modern technology promises energy storage field with more efficient and desired results. Thus, selecting thermochemical material process depends on different factors [3]; (1) environmental safety and the toxicity, (2) material cost, (3) energy density, (4) charging and discharging temperature range, (5) corrosiveness, (6) operating pressure, (7) sustainability, and (8) cyclability and stability.

Thermochemical materials storage has distinctive advantages, [3] which they are; (1) THS materials have a high energy storage density, (2) the thermal losses during storage period close to zero when the energy stored in the form of chemical potential, (3) the required volume of material is low and applicable inside houses, (4) variable charging temperature range, and (5) low cost materials. However, the weaknesses of thermochemical materials storage [4] are; (1) heat and mass transfer rate are quite low, (2) recyclability is not available in all materials, and (3) formation of layer like gel during hydration may occur. The storage energy density for the thermochemical material is about 100–500 kW h/m^3.

A reversible reaction occurred for TCM in exceptional conditions, is exo/endothermic reaction. TCM can store thermal energy and release it via hydration/dehydration chemical reaction [5]. In hot summer climate, desorption (dehydration) process occurs as the heated air produced by the solar application passes into adsorbent (porous material). In cold winter climate, adsorption (hydration) process occurs, and the hot outlet air is used in heating requirements. The general equation for the thermochemical reaction is [6]: $C + Heat \leftrightarrow A + B$. Rubino and R. de Boer [5] illustrated a model for the thermo-chemical open reactor to analyze the heat discharge process by using magnesium chloride hexahydrate ($MgCl_2$. $6H_2O$). They showed that the model was useful in studying the effects of reactor design and operating conditions on the heat storage efficiency of the reactor. Michel et al. [7] investigated an open thermochemical storage system experimentally and focused on the design of the bed using $SrBr_2/H_2O$. They concluded that the inlet moist air conditions regulate both moist air outlet temperature and thermal power. In another study [8], during hydration of the magnesium chloride ($MgCl_2.6H_2O$), the layer nearest to the evaporator was over hydrated due to some disturbance in inlet condition. They avoided high-pressure drop by using a suitable carrier material. Marias et al. [9] solved the problem of the formation of a hard layer and examined the pressure drop experimentally when using aluminum potassium sulphate12-hydrate ($KAl(SO_4)_2.12H_2O$).

However, the literature shows different works in seasonal energy storage, but there is no study focused on the design of bed reactor. Furthermore, the studies aiming to improve charging and discharging time are not found. The objective of this work is to investigate theoretically the effect of variation entering and outlet area of thermochemical bed reactor on the temperature range, pressure drop, charging time and hydration time.

2. Mathematical Model

An open atmospheric reactor is applied in the lab-scale systems because of its simplicity and potential low costs. The porous material fills the reactor, and the hot gas passes through it during dehydration processes. The holes inside porous allow the hot and relatively dry airflow through it. A new material ($MgCl_2$-$4H_2O$) appears as a product with H_2O. The cooled air stream transports out the vapor [10]. Magnesium chloride hydrate is selected as the range of operating temperature is suitable for domestic use and applicable to simple solar systems. The following reactions apply for this TCM [5].

$$Mgcl_2.6H_2O \Leftrightarrow MgCl_2.4H_2O + 2H_2O \text{ and } Mgcl_2.4H_2O \Leftrightarrow MgCl_2.2H_2O + 2H_2O \tag{1}$$

The schematic diagram of the reactor model used in the present study is provided in Fig. 1.with one of the studied design (cylinder) The studied model represents a 2D symmetric axis geometry. There are assumptions considered [5]; (1) the side walls are insulated, (2) the air density is constant, (3) the gas and solid phase conductivity is constant, (4) there is no diffusivity between gas and solid, (5) the radiation is negligible, (6) the velocity is constant in the flow direction, (7) the pressure drop via the porous media is related to Darcy’s law, (8) the heat transfer by natural convective is negligible, (9) the friction in the energy balance is equal zero, and (10) the mass transfer resistance is negligible on the air side.

2.1. Mass, Momentum and Energy Balance and Reaction Kinetics

During charging, the completely hydrated sample of a crystalline $MgCl_2$-$6H_2O$ is exposed to the hot and relatively dry air stream. The water vapor mass fraction is varying through the porous bed. The cooled air stream