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Thermoeconomic analysis of a building energy system integrated with energy storage options

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ABSTRACT

This study deals with exergetic and thermoeconomic analyses of thermal energy storage (TES) systems, such as latent, sensible and thermochemical options coupled with different units for building heating applications under varying reference (dead-state) temperatures of 8 °C, 9 °C and 10 °C, respectively. It is found that the variation reference temperature affects the thermoeconomic parameters. The exergetic cost of the system becomes higher at the higher reference conditions, as directly proportional to the varying dead state conditions. It also becomes minimum at 8 °C reference temperature as 196.96 $/h while it is maximum at 10 °C dead-state temperature with 357.60 $/h. Furthermore, the maximum capital cost of the equipment is determined for the thermochemical TES as 4.612 $/h. So, the better optimization of this equipment may be considered.

1. Introduction

Energy storage systems help in successfully meeting the societies' energy demand, for such as building heating and cooling applications. Also, energy storage provides more efficient and environmentally-benign energy utilization. Some general benefits of the energy storage may become reduced energy cost and consumption, better indoor air quality, conservations of fossil fuels, compact equipment size, reduced emissions and higher efficiency [1].

Thermal energy storage (TES) is employed to supply thermal energy in an efficient way where there is a mismatch between energy utilization and production. There are generally three fundamental types of TES as sensible, latent and thermochemical. In the sensible energy storage, mass and temperature changing of the storage medium determine the stored energy quantity. Here, the main effect is the changing of the temperature of a material. In the latent heat storage, phase of the storage material changes like from solid to liquid. The storage capacity is increase via latent heat due to a change in the TES temperature (such as freezing or melting point of the storage material). Generally, phase change material (PCM) is used, which has highly energy density, for the latent heat storage. In the thermochemical energy storage, chemical reactions occur, and components are transferred separately and combined when thermal energy is needed [2].

Thermal systems, such as TES, can be understood better with exergetic approach with respect to its reference (dead state) conditions effects on the systems. In this regard, if thermal systems are assessed from an economic point of view, there is a need to consider exergetic values to obtain more reliable results. At this point, thermoeconomics, which is a branch of thermal engineering, is defined as the combination of exergy analysis and economic principles. Thermoeconomic analysis is also treated as exergy aided cost minimization, so the word of thermoeconomics may interchangeably be used as "exergoeconomics" [1,3].

There are limited studies on "thermoeconomic analysis" of "TES systems" or "energy storage systems" or "TES supported buildings" in the open literature. Domanski and Fellah [4] applied thermoeconomic analysis to the charging and discharging processes of the sensible heat TES systems to find the performance of the systems with minimum cost of maintaining and operating. The effects of the different monetary rates on optimum number of heat transfer units, charging time, and second-law efficiency were investigated. It was found that exergetic based results provided better designing and operating for TES systems. Demirel and Ozturk [5] performed a thermoeconomic analysis of the latent heat TES system for heating the 180 m^2 greenhouse, which included 18 packed-bed solar air heaters and a storage tank filled with PCM. It was found that the feasibility of the system mainly depended on the exergetic cost rate, operating cost, internal interest rate, and rate of taxation. Ba-

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Nomenclature

A	area (m^2)
$[AC]$	annual capital cost ($/year)
c	unit exergy cost ($/kW h)
$\dot{C}$	exergy cost ($/h)
c_p	specific heat capacity (kJ/kg K)
$[CRF]$	capital recovery factor (–)
ex	specific exergy flow (kJ/kg)
$\dot{E}x$	exergy rate (kW)
h	specific enthalpy (kJ/kg)
I	solar radiation (W/m^2)
i	interest rate (%)
$\dot{m}$	mass flow rate (kg/s)
n	lifetime of the system (year)
P	pressure (kPa)
$[PW]$	present factor of the investigated system equipment ($)
$[PWF]$	present worth factor (–)
$\dot{Q}$	heat rate (kW)
R	ideal gas constant (kJ/kg K)
s	specific entropy (kJ/kg K)
$[SV]$	salvage value ($)
T	temperature (°C or K)
$[TCI]$	total capital of investment ($)
Z	capital cost ($/h)

Greek letters

μ	salvage value percentage (%)
ω	humidity ratio (kg_w/kg_{da} or kg_w/kg)
$\bar{\omega}$	mole fraction ratio (–)
Ω	the factor including total operating and maintenance cost (–)
τ	working hour in a year (h/year)
ψ	exergy efficiency (%)

Subscripts

0	dead state (reference) condition
a	air
CI	capital investment
Comp	compressor
Cond	condenser
dest	destruction
Evap	evaporator
fan	fan
flow	flow
glass	glass
heat	heat
HE	heat exchanger
in	input
LTES	latent thermal energy storage
OM	operating and maintenance
out	output
sun	sun
tot	total
TTES	thermochemical thermal energy storage
v	water vapor
valve	valve

Abbreviations

PCM	phase change material
TES	thermal energy storage

kan et al. [6] investigated a glycol cold TES system along with thermoeconomic aspects. Some thermodynamic factors were determined such as coefficient of performance of the chiller, storage temperatures, heat losses and mass flow rates. It was found that exergy efficiency of the system was smaller than the corresponding energy efficiency. Also, thermoeconomic results of the system were determined as 0.00233–0.00225 kW/$ at a 35 °C reference temperature, while they were 0.00235–0.00227 kW/$ at a 25 °C reference temperature. It was reported that the use of thermoeconomics in designing and analyzing TES systems resulted with having a potential to enable more efficient energy use. Ucar and Inalli [7] presented the thermal performance and economic feasibility of the various solar heating systems with seasonal storage (such as storage tank without insulation on ground, storage tank with insulation on ground, and underground storage tank without insulation). It was computed that the higher solar fraction and savings were determined for the system with storage buried into the ground. Also, the solar fraction of the storage tank system with insulation is significantly higher than that of without insulation storage system. The minimum payback period was 19 years for a system with underground storage tank, while it was 34 years for the tank without insulation on ground. Karacavus and Can [8] applied thermal and economic analyses to an underground seasonal storage heating system coupled with building. As a result, it was found that, the utilized and stored energy by storing the solar energy and using the stored energy, in addition to the produced energy, an important benefit was obtained in terms of primary fuel consumption by storing the solar energy and utilizing the stored energy with produced energy. Also, the payback time of the system is calculated as 19–20 years. Hessami and Bowly [9] performed economic analysis and optimization study of an energy storage system for the wind farm. The computer model was prepared to simulate the operation of several energy storage systems. The modeled systems were the pumped seawater hydro storage, the compressed air energy storage, and TES. It was found that the compressed air energy storage was the best storage medium requiring 140 M A$ (million Australian dollar) capital expense and generating 15.4% rate of return. Sanaye et al. [10] applied termoeconomic analysis method to an ice (latent) TES system for the gas turbine inlet cooling application using algorithm optimization technique. The power output was improved of 3.9–25.7% and the efficiency increased 2.1–5.2%, respectively, using a TES system (inlet air cooling) for the gas turbines with the net power output of 25–100 MW. Also, the payback period was improved from about 4 to 7.7 years. Henchoz et al. [11] studied on energy storage applying thermoeconomic analysis. It was based on the heat pump and heat engine cycles using ammonia. The cold surfaces of the cycles were connected with TES, while the hot surface of the heat engine and heat pump cycles were hot water (from solar collector) and environment air, respectively. It was calculated that the solar energy storage represented 56% of the total cost, while cold storage was 22% for the system with 57% round-trip efficiency and 1189 USD/kW costing. Godarzi et al. [12] investigated a PCM storage system for a solar absorption chiller using thermoeconomic analysis method and genetic algorithm. So, the thermoeconomic analysis was performed to the LiBr-water absorption. As a result it was determined that the total investment cost of the system, except storage, was increased 2.0568% compared to the base case (usual operation). Also, the payback period was increased from 0.61 years to 1.13 years with an addition of a storage system.