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Latent heat based high temperature solar thermal energy storage for power generation

Bruno Cárdenas*, Noel León

Centre for Innovation in Design and Technology, Instituto Tecnologico y de Estudios Superiores de Monterrey, Avenida Eugenio Garza Sada 2501, Monterrey 64849, México

Abstract

The design of a phase change material based high temperature solar thermal energy storage device is presented. Said unit will be used as an energy reserve for a 1 kWe domestic CCHP system using a Stirling engine to produce electric power. The thermal energy storage is conducted by means of the exploitation of the latent heat of fusion of the material contained inside the tank. This method was chosen because a great energy density is obtained and, at the same time, it is possible to extract the stored energy with very small variations on the temperature, which is a favorable feature for its intended purpose. The selection of the phase change material is discussed and the design of the different components of the proposed storage model is described. It is analyzed, as well, the insulating solution applied that minimizes heat losses. Finally, a comparison between experimental results of the tests performed on the first built to scale prototype and the data obtained from computer simulations is shown.

"Keywords: Solar thermal energy storage; Phase change material; Latent heat; Stirling engine; PCM; CCHP; TES"

1. Introduction

Numerous organizations estimate that global net electricity generation will increase in an 87 % over the next years, reaching 35000 TWh in 2035 as a result of demographic growth and population's economic development. [1].

Specifically in Mexico, the net domestic power consumption will experience an average annual growth rate of 3.9% [2,3]. This, together with the known fact that the kWh cost in Mexico has increased more than 250% in the last 10 years and the trend is still on the rise [4], will represent a serious outflow in the family economy of consumers.

Rise in the global power consumption is not exclusively an economy-related problem for population, but represents a serious environmental threat. It is important to know that in Mexico, USA and many other countries, more than 75% of electricity is produced by burning fossil fuels in thermoelectric plants, which consume either natural gas, fuel oil or coal [5], thus an increase in power consumption translates directly in an increase in the emission of CO2 and other greenhouse effect gases harmful for the atmosphere and

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the environment. It is estimated that in 2035, 42 billion tons of CO2 will have been emitted to the atmosphere as a residue of global power generation [6].

High cost of electricity and environmental impacts have prompted the search for power supply alternatives that lead to a reduction of the huge environmental impact that current power generation has. Different technologies that allow harvesting of existing renewable resources have been developed in the wake of this. Solar energy has had extensive acceptance because is the most reliable renewable energy source available. There are 2 main approaches in solar energy use for power generation; one is the thermal approach, in which solar radiation is concentrated to heat a work fluid, which is then used to drive a steam turbine or a Stirling engine to produce electricity. The other is the photovoltaic approach, in which sunlight is transformed directly into electricity by means of solar cells; this means that solar panels are only effective during the hours of the day in which solar resource is available because the cost of storing electricity in batteries is considerably high. Thermal energy storage is much less costly, which makes the solar thermal approach very attractive for big scale power generation [7].

In the present article the design of phase change material based high temperature solar thermal energy storage is presented. This unit is currently under development as a key component for a 1 kWe domestic CCHP system using a Stirling engine to produce electric power. The premise of the design of this distributed system is that it is cheaper to store energy as heat and convert it to electricity when needed than to store it directly as electric energy, furthermore; on site production eliminates the cost and losses of the transmission.

Nomenclature

CCHP	Combined cooling, heating and power
h_0	Air convection coefficient (W/m^2 K)
K_n	Thermal conductivity of the n layer of insulation (W/m K)
L	Height of the PCM container (m)
LHS	Latent heat storage
PCM	Phase change material
r_n	Thickness of the n layer of insulation (m)
T_0	Average ambient temperature (°C)
T_1	Melting temperature of the PCM (°C)
T_3	Temperature at the surface of the first insulation layer (°C)
T_4	Desired outermost surface temperature (° C)
TES	Thermal energy storage
W	Lambert-W function, also known as product logarithm

2. Thermal Energy Storage Methods

There are three methods for storing thermal energy storage, being the first 2 the most widely used in TES systems: sensible heat storage, latent heat storage and thermochemical storage

Latent heat storage consists in heating a material until reaching a change of phase, generally from solid to liquid, when the material reaches its fusion temperature it absorbs a very large amount of heat to carry on the phase change, this way energy is stored [9]. Liquid-gas transitions contain enormous amounts of phase change heat, however the huge density changes render the system very complex and unpractical, due to this, the solid to liquid phase change is mostly used [10].