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Investigation of the effect on the efficiency of phase change material placed in solar collector tank

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ABSTRACT

In parallel with the increase in population, natural energy resources on earth started to run out. And this brought along tendency to new energy resources. Therefore, studies on new and renewable energy resources became intensified and especially researches about solar power as the most important renewable energy resource gained intensity. In this study, tank with latent heat storage in combination with hot water collector was designed and tests were held under Elazığ climatic conditions. Thermal efficiencies obtained from collector system were compared to the efficiencies of a standard insulated tank. In accordance with this purpose the results of the tests, held on certain days in July-November, were commented. The highest thermal efficiency value in the study was obtained as 58% in July around hour 13:30 from the tank in which phase change material (PCM) was used.

1. Introduction

In parallel with increasing population, countries need more energy. Within this scope use of renewable energy resources becomes mandatory. Being easily accessible, clean and cheap, renewable energy resources bring advantage when used. Also, it is important to design the systems in a way that they use the energy with maximum efficiency.

It is determined that Turkey's average annual solar radiation period is 2640 h (Daily total 7.2 h), average total radiation power is 1311 kWh/m^2-year (Daily total 3.6 kWh/m^2). It can be utilized in Turkey technically during ten months of a year and economically on 63% of the total country surface area and 17% all over the year. Turkey's most solar energy receiving area is Southeastern Anatolia Region, it is followed by Mediterranean and Eastern Anatolia Region.

Average annual radiation power is 1365 kWh/m^2 in Eastern Anatolia Region including the Elazığ city where the tests were held and average annual solar radiation period is 2664 h [4].

Within this scope energy storage is used as a method for using energy efficiently. For this purpose, especially solar energy can be stored as sensible heat, latent heat and their combinations.

Latent heat storage methods can be used in line with the requirements for heating and cooling purposes. Smaller tank volume is needed compared to sensible heat. Heat storage capacity is higher. Phase change materials (PCM) used for latent heat storage are more advantageous compared to other methods because they provide fluid storage at constant temperature range.

Shukla et al. [13], examined solar water heaters with phase change materials PCM) in heat energy storage. They classified their studies also according to collector type besides natural and latent heat storage. They compared solar water heaters with PCM and without PCM, they concluded that collectors with PCM had better thermal performance [13].

Koca et al. [8], performed energy and exergy analysis of a latent heat storage system with PCM on a flat plate solar collector. They used $CaCl_2 \cdot 6H_2O$ (Calcium chloride hexahydrate) as PCM. For system efficiency in changing periods, using first law equation of thermodynamics for energy analysis and second law equation of thermodynamics for exergy analysis they obtained the efficiencies of energy and exergy respectively as 45% and 2.2%. Finally, they stated that the exergy efficiency of the latent heat storage system with PCM was too low [8].

Da Cunha and Eames [5], examined storage of solar energy for applications at low and intermediate temperatures using PCM. They found out that phase transition temperatures were between 0 and 250 °C. When organic compounds and salt hydrates were under 100 °C, other mixtures varied between 100 and 250 °C. They remarked that mixture of sodium and potassium as PCM with melting temperature at around 170 °C was preferred more because of its cheaper price and moderate latent heat storage capacity [5].

Sharma et al. [12], performed examinations about thermal energy storage and its applications with phase change materials. They remarked that latent heat storage using PCM was the most effective way

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Nomenclature

A_c	surface area of solar collector [m^2]
C_p	specific heat [kJ/kgK]
ρ	specific gravity of water [kg/m^3]
G_T	global solar radiation [W/m^2]
Q_u	rate of useful energy gained [W]
Q_r	radiation energy [W]
T_a	ambient temperature [°C]
T_{ci}	collector inlet temperature [°C]
T_{co}	collector outlet temperature [°C]
T_t	TANK water temperature [°C]
T_o	Outlet fluid temperature of solar collector [K]
T_i	inlet fluid temperature of solar collector [K]
ΔT	temperature difference [K]
$\dot{m}$	mass flow rate [kg/h]
$\dot{V}$	volume flow rate [m^3/h]
η_i	instant collector efficiency
W_r	average error that can be made in radiation measurement [W/m^2]
W_t	total error that can be made in temperature measurement [°C]
W_{te}	Total error value
x_1, x_2…	error value

of storing thermal energy and PCMs had high energy storage density. In their study, they examined PCM usage at heating and cooling applications in buildings for last 10 years and they summarized their analyses on thermal energy storage system [12].

Mehling et al. [10], examined hot water heat storage with PCM (phase change material) module. They explained that the system provided high thermal storage density when PCM was used at the upper side of the water tank and heat loss through the upper side of the tank was prevented. In their studies, they made the numerical simulation of the system using finite difference method and explained the test results. Thus, it was stated that PCM kept the water hot longer by 50–200% and increased average energy density by 20–45% [10].

Mazman et al. [9], examined PCM usage in solar hot water systems. They stated that PCM modules placed on water tank were high storage density systems and heat loss was reduced because of PCM's latent heat. In their studies, they used PCM graphite composed of paraffin and stearic acid PS), paraffin and palmitic acid PP), stearic and myristic acid SM) with optimized thermal properties and 80:20 percentage rates. In their tests, they explained that average tank water temperature dropped under PCM melting point in 6–12 h and when reheating PCM raised the temperature of 14–36 L, of water in the upper side of the tank by 3–4 °C. Also, they concluded that paraffin and stearic acid PS) were the best PCM as they increased the efficiency by 74% [9].

Papadimitratos et al. [11], they worked on phase change materials PCMs) in solar collectors for solar water heaters SWH). In this method, the heat pipe is immersed inside the phase change material that is stored for an extended period of time. Thus, they provide hot water at times when the solar intensity is insufficient. In the solar collector, were utilized two distinct phase change materials PCM), namely Tritriacontane and Erythritol, with melting temperatures of 72 °C and 118 °C respectively. From the results of this study, they have obtained efficiency improvement 26% for normal operation and 66% for stagnation mode, compared with standard solar energy water heaters with that lack phase change material [11].

Fazilati and Alemrajabi [6], examined the effects of PCM usage in a solar water heater. They used paraffin as PCM. They compared energy and exergy efficiencies of the water heater with and without using PCM. They remarked that PCM usage enhanced energy and exergy efficiencies respectively up to 39% and 16%. Also, they found out that from the PCM using solar water heater hot water was provided for 25% longer time [6].

Cardenas and Leon [3], researched on thermal energy storage and observed PCMs commonly used in latent heat storage systems. They stated that thermal energy storage via latent heat was superior than the other thermal storage methods. They explained that salt components used as PCM were generally comprised of chloride, fluoride and nitrate. Also, they saw that in literature there were great differences between the data of PCM melting temperature, thermal conductivity and density and they concluded that this was rooted from lack of international PCM test methods [3].

Zalewski et al. [17], they have studied the phase change material on the small scale Trombe composite solar wall. They placed the phase change material into the wall in the form of a brick- shaped. While this material can store more heat than the same volume of concrete, but under dynamic conditions have seen a very different thermal behavior. They focused on the delay between the absorption of solar radiation and the energy supplied to the room. In their experiments, they determined the energy performance of the wall from heat flux measurements and enthalpy balances [17].

Veeraragavan et al. [14], in their work, they examined the solar thermophotovoltaic (SISTPV) system at night. We have seen that for any given PCM length in the results we have obtained, a combination of small taper ratio and large inlet hole-to-absorber area ratio are essential to increase the operation time and average power produced during the night time. They concluded that there was a balance between running time and the average power produced during the night time. They have stated that this solar thermophotovoltaic SISTPV) system can be a versatile solution that can be applied to work in different climatic conditions, even in space applications [14].

Veeraragavan and Shum [15], they have modeled heat losses from a phase change material PCM) storage tank for solar thermophotovoltaic SISTPV) systems. The heat losses from the side surfaces of the PCM tank are modeled using Newton's law of cooling. From the results they obtained, they determined that low thermal efficiencies would occur at high heat losses. As can be expected when thermal insulation is used on the lateral surfaces, they have found that approximately 40% thermal efficiency can be realized with low heat losses. It is expected that these thermophotovoltaic SISTPV) systems can be designed at steady-state when the PCM can be fully molten in order to maximize the thermal energy storage through latent heat. The analytical model they developed is said to be used to predict the design conditions in which the PCM tank is completely melted [15].

In this study, in terms of using solar energy more efficiently, tank with latent heat storage in combination with hot water collector was designed under Elazığ climatic conditions and the efficiency of the system was investigated experimentally.

2. Material and method

In the study, heat storage via latent heat method in a flat plate solar collector-natural circulation tank system was observed.

The flat plate solar collectors consist of, glass cover, absorber plate, flow tubes, heat insulation and the collector frame (Fig. 1). Open loop systems with natural circulation are the systems that fluid heated in collector circulates by itself because of reduced density of the heated fluid (Fig. 2). Cold water accumulated in the lower level of the tank passes to the collector and becoming lighter by heating it rises to the top level of the tank. This event continues all day long and the water in the tank is heated. The water in the collector of the natural circulation open loop system is same as the water used and these systems are of high efficiency. The pump is not used in our system because the use of the pump causes more cost increase in all systems. This has provided us