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Research Paper

Improved thermal stratification with obstacles placed inside the vertical mantled hot water tanks

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HIGHLIGHTS

- Enhancement of thermal stratification via obstacles in vertical mantled hot water tank has been studied experimentally.
- Four different obstacles have been placed in four different heights from the tank bottom.
- Effect of the obstacle and its position has been investigated.
- At the end of the present study, placing the obstacle inside the inner tank in vertical mantled hot water tanks has improved thermal stratification of the tank.
- This result has been presented by temperature distribution, stored energy amount, Richardson Number, mantle outlet temperature and usage outlet temperature.

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ABSTRACT

Thermal stratification is a significant performance parameter for thermal energy storage tanks. In present study, the thermal stratification of vertical mantled hot water tank was investigated by placing different obstacle inside the tank. Four different obstacles were placed inside the tank in four different distances from the tank bottom. Thus effects of the obstacle types and positions were investigated. At the end of study, it was found that obstacle placed inside the tank enhanced the thermal stratification. Results were presented in the terms of temperature distribution, energy storing capacity, Richardson Number, consumption outlet and mantle outlet temperature. All these values were improved by placing the obstacle inside the tank, according to ordinary tank. The best thermal stratification was obtained between Y = 200 and Y = 300 mm the distance from the tank bottom. A type obstacle supplied the best thermal stratification.

1. Introduction

Thermal energy storage (TES) is an important issue for renewable energy sources for later usage, when the energy sources are non-available. Methods, thermal stratification and thermodynamic performance of the TES systems are investigated in Dincer and Rosen [1]. Hot water tanks are used in solar domestic how water systems (SDHWS) to store hot water for later usage. Although there are many hot water storage tank types, vertical mantled hot water tanks have common usage because of its easy production, supplying better thermal stratification and having large heat transfer area. Thermal stratification is one of the most important parameters for hot water tanks, because better thermal stratification increases system performance and utilization efficiency [1–4]. So thermal stratification is researched and tried to be improved by many researchers.

Altuntop et al. [5] analyzed enhancement of the thermal stratification via obstacles in a vertical hot water tank numerically. They used 12 different obstacles. They found that all obstacles supplied better thermal stratification than empty tank. The best thermal stratification occurred in the tank with the number of 7th and 11th obstacles. Rhee et al. [6] placed some parts called thermal diode inside the tank. They investigated the effect of thermal diodes on thermal stratification experimentally. Thermal diode was a part allowing flow through specific place and direction. At the end of their study, they found that the best thermal stratification was supplied by double express thermal diode. Knudsen and Furbo [7] studied the effect of two different mantle inlet positions on thermal stratification, numerically and experimentally. They emphasized that mantle inlet position was important for heat transfer from mantle to tank. If mantle inlet temperature was higher than inside the tank, mantle inlet position should be placed on the top. However if mantle inlet temperature was lower than inside the tank, mantle inlet position could be placed lower. Kenjo et al. [8] investigated three

Abbreviations: SDHWS, solar domestic hot water system; PIV, particle image velocimetry.

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different mantle inlet position numerically. They used new numerical procedure for numerical analyses. They used 2-D and axisymmetric numerical model. They reported that using boundary layer in the numerical model had important effect on the results. Shah and Furbo [9] performed experimental and theoretical investigations for differently designed mantled tanks. Shah et al. [10] investigated flow characteristic in the mantled hot water tank experimentally and numerically. They used particle image velocimetry (PIV) in an experimental study. A commercial square mantled hot water tank that has common usage in Denmark was chosen for this study. Shah [11] numerically researched heat transfer in vertical mantled hot water tank. Two different heat transfer correlations were presented in this study. Effect of the thermal stratifiers on thermal stratification was researched experimentally and numerically by Shah et al. [12]. Also Knudsen et al. [13] investigated flow characteristics in the tank and mantle gap with PIV. Shin et al. [14] researched physical mechanisms and optimum working conditions of thermal stratification in their study. Also, they used some diffuser types for improving thermal stratification. Too et al. [15] researched the characteristic of mantle gap in vertical hot water tank. The effect of inlet water jet caused forced heat transfer in the mantle gap, so heat transfer ratio increased with the increasing the water velocity. But this relation between mantle inlet velocity and heat transfer ratio wasn't linear. Goppert et al. [16] studied the effect of inlet stratifier on thermal stratification numerically. They used their own numerical procedure for numerical analyses. They developed a new code faster than commercial CFD programs. Altuntop et al. [17] tried 12 different mantle inlet velocities. At the end of study, it was determined that heat transfer increased by increasing inlet velocity. However this increasing wasn't proportional. Barzegar and Dehghan [18] investigated thermal performance of a vertical solar hot water storage tank having a peripheral shell type mantle heat exchanger during charging mode. Furbo and Knudsen [19] carried out side-by-side tests of two small low flow SDHWS based on mantle tanks. Huang et al. [20] experimentally researched thermal performance of the mantled thermosyphon solar water heater. In the end of the study, they found that the average daily efficiency of mantled heat exchanger with 10 mm mantle gap could reach up to 50%. Arslan and Igci [21] studied numerical investigations to predict the influence of the operating parameters during discharging/consumption mode in vertical mantled hot water tank.

It is clear that there are a lot of papers on literature about design and operating conditions of vertical mantled hot water tanks. Also there are some studies about using obstacle inside hot water tanks. However there is no sufficient study about obstacle usage in vertical mantled hot water tanks. Besides, the previous studies were limited to consideration of either the storage tank thermal performance or mantle thermal characteristics without considering their thermal interaction discharging operation modes. In present study, the effect of the obstacle placed inside the inner tank in vertical mantled hot water tank was investigated experimentally during discharging period. Four different obstacles were placed in four different distances from the tank bottom. Thus, effects of the obstacle type and their positions on thermal stratification are researched.

2. Material and methods

2.1. Experimental apparatus

A schematic view of the experimental system is seen in Fig. 1. As seen from Fig. 1, experimental system contains vertical mantled hot water tank, heater, transformer, circulation pump, expansion tank, temperature sensors, data logger, valves and flow meters.

A commercial vertical mantled hot water tank that has common usage in Turkey was selected as the test tank. Mains water system pressure is generally low in country side. Unpressurized mantled tanks are widely used where mains water systems pressure is low, so unpressurized SDHWSs are very common in Turkey. Fig. 2 gives a detail information about the test tank. As seen from Fig. 2a, the tank has two section which are cold water section and hot water section. When hot water is used, cold water comes from cold water section with low velocity because there is no direct inlet to inner tank from the main line. Water level is in the cold water section is controlled by a floater. Also cold water section supplies a small amount of water to users, when the water is cut. There is a 15 mm thick insulation between cold and hot water section. Mantled tank has two inlets and two outlets. These are mantle inlet, main inlet, mantle outlet and consumption outlet. Mantle inlet is hot water coming from collector (heater). Main inlet is cold water coming from main line. Mantle outlet is cold water exit to collector (heater). Consumption outlet is hot water exit to usage. Heat transfer occurs in the interface between mantle and hot water section. Hot water

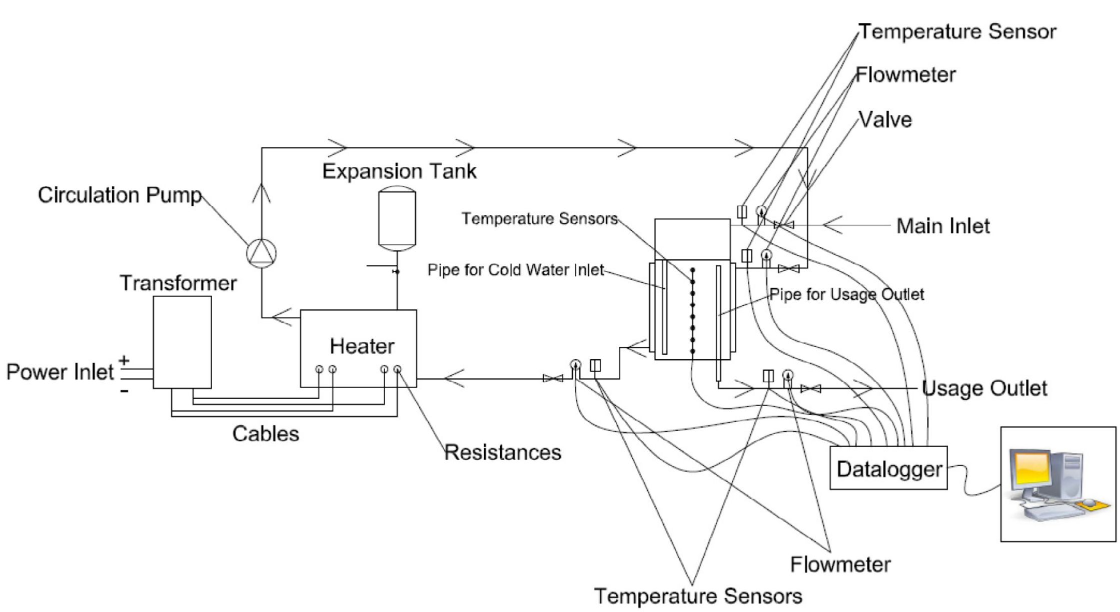

Fig. 1. Schematic view of the experimental system.