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A Water Heater That Regulates Itself for Solar Heating Systems

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Abstract: A method for calculating the water intermediary in a multilayer stratified thermal storage tank used in solar heating and hot water supply systems has been developed. The intermediary has a constant cross-section and uniform perforation throughout its height. The examination of global and domestic practices for improving the performance of self-regulating active water heat accumulators in solar heating systems is ongoing. Innovative solutions for self-regulated stratified thermal storage systems are being developed. Conditions for achieving self-equilibrium in the self-regulatory components of hot water storage tanks are being identified, considering dynamic processes caused by unbalanced solar radiation. A theoretical investigation of water flow in perforated distributors with a constant cross-section under the influence of volume forces is being conducted. Additionally, a theoretical analysis of water collection in perforated collectors with constant cross-sections due to volume forces is taking place. A method for calculating water distribution and designing a self-regulating thermal storage system is currently being developed. An experimental exploration of the perforation in the water distribution system of a self-adjusting hot water storage tank is also underway.

Keywords: Water distribution, heat accumulation, solar heating system, and stratification accumulation are all components.

Introduction

Solar collectors for water heating are the most commonly used and cost-effective method of utilizing solar energy. This is because direct conversion of sunlight into heat has the highest efficiency, and the demand for hot water remains consistent throughout the year.

Knowing the habits of family members makes it easy to calculate their daily intake and that of the entire family. In Europe, typically, one person consumes 50 to 70 liters of hot water each day, assuming an average temperature of 45 ℃ degrees Celsius. Given that many consumers in Ukraine do not save hot water, water consumption could be higher in this country.

Heating such a large volume of sanitary hot water requires a significant amount of thermal energy, considering heat loss in the pipes for recirculation. At least 3.65 kilowatt-hours (kWh) per day per user is required. This would result in more than 109 kilowatt-hours of energy being used per month. For a family of four people, 435 kilowatt-hours per month would be needed.

Relevance

Water heat accumulators (WHA) are an essential part of solar energy systems (SES). They help to align the time of heat production and consumption between the solar collectors (SC) and the consumers: hot water supplies (HWS) and heating systems. The water heat accumulator can operate with significant temperature stratification, where the top of the tank is hotter than the bottom [1].

The principle of layered charging of a heat accumulator with an SC, where water heated in the collector is fed to a layer corresponding to its temperature along the length of the tank, and the mixing of layers is avoided, is widely used in the design of solar HWS and heating systems [2].

At the same time, the potential gain in solar energy coverage for a solar installation with a perfectly stratified tank and a low specific water flow through SC, in the range of 0.002-0.07 kg/(m²·s), compared to a fully mixed tank with a large specific flow through the solar collector, can be about 1/3 of that [1].

Research Methodology

Development of a new self-regulating design of a water heat accumulator with temperature stratification, excluding the mixing of heated water carriers, entering the battery through charging and discharging circuits based on natural stratification in the tank, under the influence of the volumetric (Archimedes) force. The work was carried out in conditions of forced circulation of the coolant by analyzing world experience in developing water thermal accumulators and taking into account stability criteria for the stratified (stratified) flow of coolant within the volume of the battery.

Result and Discussion

The German companies, Viessmann [2] and Buderus [3], have developed special variants of their products using special HWS equipment with automatic temperature control for heating mountain water in the SC. To do this, they use layer-by-layer charging WHA. Therefore, the development of thermal battery designs that ensure a high temperature stratification in storage tanks is a crucial task that needs to be addressed.

When using the principle of layered charging, water heated in the IC is distributed in layers, each with a certain temperature. At the same time, there is no mixing with colder layers (Fig. 1).

a) b)

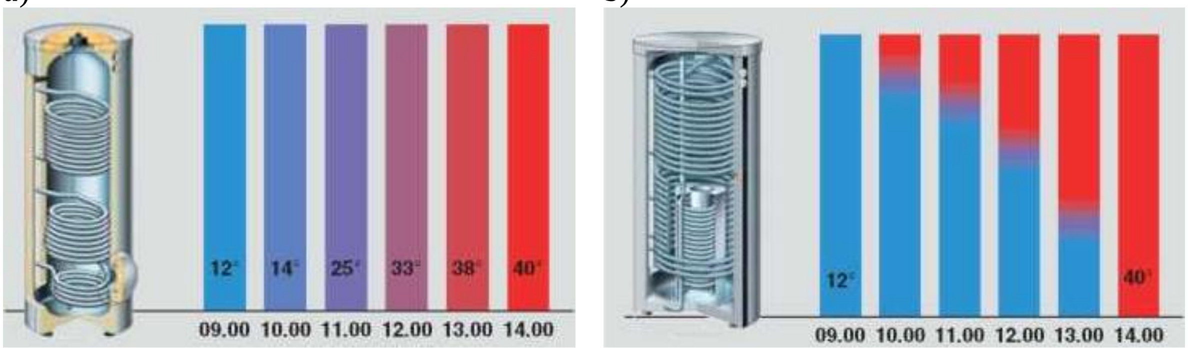


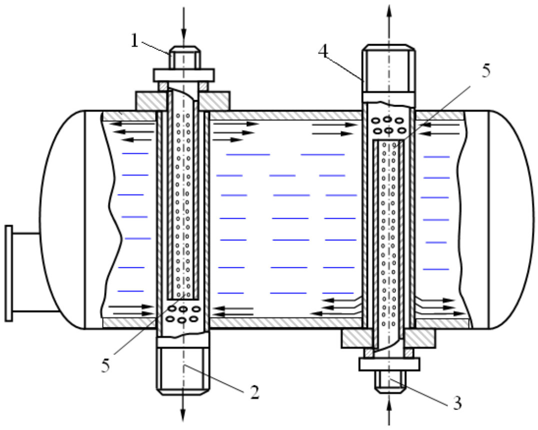
Fig. 1. Conventional (a) and layered (b) WAT charging

When charging a capacitive water heater with an integrated heat exchanger, without using the layered principle, the entire volume of the liquid is simultaneously heated. (Fig. 1a) To achieve the required temperature, the collector must operate for a long period of time. If a need for heat occurs before the required water temperature has been reached, then additional heating will be required using a conventional heat generator.

With layer-by-layer charging, set temperature in the upper part of the capacitive water heater is reached earlier (Fig. 1, b). The entire volume reaches set temperature within the same period of time as a water heater without layer-by layer charging.

The work of many foreign solar engineers, has been devoted to the study of issues related to the phenomenon of stratification of water in battery tanks in relation to solar heat supply systems [4, 5].

The action of the self-regulating WHA developed [6], which prevents mixing of the heated and heating carriers entering the battery from the charging and discharging circuits, is based on the natural stratification of water in the tank due to volumetric (Archimedes) forces in conditions of forced circulation (Figure 2). For this purpose, perforated supply pipes 1 and 3, and discharge pipes 2 and 4, are used, in which the area f of the holes 5 must be calculated according to conditions for ensuring distribution and selection of liquids from corresponding temperature layers, as well as stability of stratification within the volume of the battery.



1. Perforated pipe for the supply of heating coolant. 2. Perforated discharge pipe for heated coolant. 3. Perforation of pipes for the supply and discharge of cooled heat. 4. Perforations in pipes for cooled and heated fluids. 5. Holes in the perforated pipes.

Fig.2. Schematic diagram of a self-regulating stratification heat accumulator

The impact of water stratification on short-term and long-term thermal accumulation can be determined by examining the dynamics of the entire solar system. The effect depends on the type of thermal load that the system covers.

This was evaluated in [7, 8]. It was demonstrated in [7] that the use of stratification in heating can increase the proportion of solar energy use by 2-12%. A study conducted in [8] on hot water supply, heating, and air conditioning systems found that the efficiency of solar systems increased by 5-15% when using water stratification in the storage tank.

In [9], the generalization of test results from experimental solar houses with solar heating and cooling systems showed that the use of stratification in short-term and long-term thermal accumulation led to a 15% increase in the use of solar heat. Experimental data from [10] confirms this conclusion, indicating that stratification increases the amount of radiation that is usefully employed by 20%.

To optimally design stratification heat accumulators and storage systems, it is necessary to understand the conditions under which stable stratification occurs and to assess its level. The stability of the stratified coolant flow within the battery volume is significantly influenced by the Richardson number, a dimensionless quantity that also affects the Reynolds number. [11].

$$Ri = -\frac{g}{\rho}\frac{d\rho}{dx} / \left(\frac{dv}{dx}\right)_{st}^{2}. \quad (1)$$

The case $Ri = 0$ means a homogeneous liquid. The case $Ri > 0$ means a stable bundle. The case of $Ri < 0$ indicates an unstable bundle. In formula (1), the subscript "ct" means the velocity gradient value of the wall. Energy estimates show [11] that turbulence decreases at $Ri > 2$. The stability limit is given as $Ri \geq 1$ in [11].

In the case of a continuous density distribution and with a linear velocity distribution in an infinitely distributed liquid, the value $Ri = 0.25$ is given as the stability limit in [11].

Conclusion

With temperature stratification of the water, a self-regulating water heat accumulator was developed. The battery is not mixed between heated and heating heat carriers when it is charged or discharged, and instead they are separated from each other through charging and discharging circuits based on the natural stratification of water in the tank by volumetric forces (Archimedes' forces) during forced circulation of a coolant.

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