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Assessment of a novel technology for a stratified hot water energy storage – The water snake

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HIGHLIGHTS

- Stratified thermal storage systems can integrate different heat sources.
- This paper presents an assessment of a new technology, 'the water snake'.
- The water snake is a flexible tube that reacts based on water temperature.
- The results show that the suggested technology is successful in providing stratification.
- The water snake reacts to different water temperatures by moving to the right level in the thermal storage.

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ABSTRACT

The increasing demand to enhance sustainability and reduce carbon emission and pollution is attracting the attention for implementing and integrating diverse heating technologies such as heat pumps, solar energy, gas boilers, Combined Heat and Power (CHP), and electric heaters. Integrated technologies for heating include low and high temperature district heating, domestic small-scale applications and commercial large-scale buildings. Energy from flooded coalmines and water from other sources could also play a vital role in improving energy efficiency of heating and cooling applications. Stratified thermal storage are likely to significantly contribute to energy efficient heating, particularly when implementing a mixed-approach of diverse technologies. A stratified hot water tank, and naturally stratified reservoirs, are expected to play a central role in the integration of several heating technologies that operate efficiently at different levels of temperature with reduced cost. This paper presents a new innovative technology to improve stratification, namely 'the water snake', and an automated test rig to evaluate the new stratification method for energy utilisation using energy storage of hot water. An automated system is utilised to evaluate the performance. The results indicate that the test rig has been successful for the automated testing of the technology. Moreover, the results show that the water snake, as a new technology for stratification, is successful in minimising mixing and turbulence inside the thermal energy storage. The results prove that the technology could be implemented for a wide range of applications to enhance the efficiency of heating systems in buildings as well as district heating and cooling applications.

1. Introduction

In recent decades, the world has increasingly become interested in the production of electricity and energy from renewable energy. As a result, the world is facing the problem of storing energy for later use because of the instability and discontinuousness of renewable energy resources due to variations in location, weather and season [1]. Since the energy can be converted to other forms, it would be possible to store it for later use [2]. Several storage methods have been created in research and industry such as magnetic systems, electrochemical systems, hydro systems, pneumatic systems, mechanical systems and thermal systems [3]. Thermal Energy Storage (TES), which could use water, oil and molten salt, is a technology used to store the thermal energy for later time use in buildings and industrial processes [4,5]. Water is considered to be the simplest and most suitable heat transfer and heat storage fluid because of its high volumetric heat capacity, low cost and widespread availability [6,7]. Hot water storage is used in almost every home to provide a reliable source of hot water [8].

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Nomenclature

CHP	combined heat and power
TES	thermal energy storage
CO_2	carbon dioxide
COP	coefficient of performance
MDPE	medium-density polyethylene
UVR1611	universal controllers
PT1000	platinum resistance thermometer sensor
DHW	domestic hot water storage

Technologies that use water are common in heating and cooling applications as well as power generation. TES systems can assist in balancing energy demand and supply; reducing peak demand, energy consumption, CO_2 emissions as well as cost [9]. A thermal energy storage provides a focus point for heating systems, allowing several producers of heat to contribute to the heating system and several consumers to draw from it. This allows adventitious sources such as solar thermal to be used with the greatest flexibility. It also simplifies the control required as the store use need to be kept at a minimum temperature as is required to meet the demand. Where some or all of the heat required for a building is produced by electricity, the thermal energy storage allows heat to be generated at times of high availability, stored and used when required. This has advantages for both the consumer who will see reduced bills and the grid which can reduce peak demand spikes and reduce emissions arising from having to generate inefficiently to cover the requirement.

1.1. Thermal storage systems

Thermal storage systems are already widely used with solar thermal systems so that the heat can be used after sunset. Thermal storage systems are used to reduce the mismatch between the supply and the demand of power [10]. Thermal storage systems such as Domestic Hot Water storage (DHW) is mandatory when solar system is used in heating up water [11]. Thermal storage systems are also used for heat pumps and boilers. Thermal storages are an attractive option to use because of their simplicity and low cost [12]. They can be used to enhance the hot or cold storage buffer tank and also they can be used to enhance the stratification of the water in flooded coalmines to reduce underground water mixing between the water intake and return [13,14]. Hence, there is an increasing market for large stratified thermal storage systems as they allow inputs from different heat sources to be combined and used for heating and hot water inside the property.

1.2. The stratification process

The term ‘Stratification’ refers to the intention to heat, or cool, two or more horizontal layers to different temperatures. In a stratified water storage tanks, the hot water lies above the cold water to form a gradient thin layer called thermocline [15]. Typically, the lower 60% of a thermal store is heated to an appropriate temperature for space heating with the top 40% being at a temperature high enough for the hot water preparation. The less mixing there is between fluids at different temperatures, the more efficient the stratification is.

The stratification is one of the ways utilised to improve the performance of solar water heating systems [16,17]. It is one of the main factors of the performance of the hot water storages. It is the degree of the difference in temperatures between the top and the bottom parts of water inside the collector [18]. Stratification is found to be efficient not only for the water storage tank but also for the whole system linked to it. For example, for a solar collector, it has been found that the thermal stratification decreases the temperature at the collector inlet which increases its efficiency as well as it decreases the operation cycle of the secondary source of energy [19–21]. The stratification is becoming an effective factor for both commercial and environmental reasons. Stratified tank will keep the hot water for longer periods and hence reduces the heating and reheating processes, which are normally costly and wasteful to the environment. Thermal stratification leads to higher operation temperatures, lower auxiliary energy consumption and higher exergy outputs [22].

Several parameters influence thermal stratification such as the tank geometry, inlet, outlet and operating conditions [7,23]. The location of the inlet is one the most important factors that affects the stratification of the tank. The design of the inlet is found to have more impact on the tank stratification [24]. This means that the inlet fluid should be entered to a suitable height [25]. Therefore, the methods that improve the supplying process of the water to the right level inside the thermal storage is vital. Existing systems use different designs of inlet stratifiers such as vertical polymer pipes with openings along their heights and porous tube manifolds [24,26], vertical fabric pipes and vertical polymer film pipes with openings in different levels [27].

The benefits of a stratified store have been appreciated for some time. The advent of heat pumps and solar thermal greatly increases the benefits from stratification. It is now entirely realistic for half the calorific value of gas consumed in a power station to appear as electricity entering a building. Air source heat pumps, properly installed, can operate at COPs in excess of 3 giving an immediate advantage over gas fired heating. The COP of a heat pump is directly related to the temperature at which the heat is generated. A good stratified thermal store can significantly increase the average COP of a heat pump.

1.3. The water snake

One of the novel methods proposed to improve the stratification inside the thermal energy storage is by using a thin flexible tube, named as the water snake [28]. The water snake moves up and down according to the temperature and the density of water entered into the tank placing it in the right layer where temperatures and densities are the same. Furthermore, the technology could also be implemented on a larger scale for open loop geothermal heating and cooling systems using water from flooded coalmines and large water reservoirs as energy storage buffers [13,14]. This means the water snake could be implemented to reduce mixing in temperature between the water inlet and outlet, hence improving the efficiency of the system.

Early hot water storage tanks had a high degree of mixing and therefore they had a uniform temperature, however, in recent years, they are being designed to keep a higher degree of stratification as much as possible [29]. Existing designs for stratified thermal stores rely on fixed baffles, chambers and other features to reduce the turbulence as fluid returns to the store. This means that, inevitably, mixing of fluid at different temperatures will occur and the result is not perfect. The novel Water Snakes of this paper offer the following advantages:

- Because they direct the entire flow to the layer at the same temperature it is hard to conceive of a design that could be more thermodynamically efficient.
- The design is inexpensive, simple, reliable and requires no separate control.
- The method is effective enough to avoid the need to get the fluid in at “approximately” the right level. This reduces the need for zone valves and controls.

The novel approach of the water snake contributes to saving energy by maintaining low level of increase in entropy generation levels. In other word, the efficiency of the heat pumps and solar thermal heat generation will be improved if the entropy generation is kept to a minimum.