Thermal energy storage systems – Review B. Akhmetov¹, A. Georgiev², A. Kaltayev¹ A. A. Dzhomartov⁴, R. Popov³ M. S. Tungatarova¹

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Abstract: There are several thermal energy-consuming appliances in buildings such as heating, ventilation, air conditioning and hot water systems, which are generally responsible for significant proportion of total building energy consumption. One of the effective ways to decrease the amount energy consumption of these appliances from traditional grids, is the application of renewable energy sources, especially solar energy, as the main thermal energy provider. But, because of intermittent and unpredictable nature of solar energy, it is difficult to supply necessary thermal energy to aforementioned appliances without help of effective storage. Therefore, development of a storage that can store thermal energy harvested from renewable energy sources has high importance and one of the active research areas among scientists.

Aim of the current work is to review different types of thermal energy storage systems, their technical characteristics, advantages and disadvantages, and compare them with each other. Particularly, this paper is concentrated in two energy storage technologies. One of the technologies, which allows storing thermal energy in a large-scale, is underground thermal energy storage (UTES) and another one is based on phase change materials named as latent heat storage (LHS).

Keywords: Renewable energy, thermal energy storage, borehole, latent heat storage, phase change material.

INTRODUCTION

Among built environment, buildings are major energy intensive consumers of energy and main contributors of greenhouse gas emissions [1]. Most demanded energy for buildings is thermal energy because of its thermal energy-consuming appliances such as heating, ventilation, air conditioning (HVAC) and domestic hot water (DHW) systems [2, 3]. In order to supply necessary amount of energy to these appliances, most of the time conventional energy sources are used which are not eco-friendly and hazardous. On the other hand, it would be possible to use renewable energy sources, especially, solar energy as the main source of thermal energy for above mentioned energy intensive appliances because technologies for harvesting thermal energy from solar energy are becoming efficient, and cost effective. But solar energy value is periodic and unpredictable [4]. For instance, it is not possible to use abundant summer solar energy during winter for space heating purposes unless there is large-scale thermal energy storage is considered. Therefore, development of effective energy storage techniques is becoming one of the main research topics for scientists along with improvement of performance of energy harvesting technologies [5].

There are number of thermal energy storage technologies are being studied and developed in last decades. Some of them for storing thermal energy at small and medium scales while others for storing thermal energy in a large amount [6].

Aim of the study provided in the current paper is to review different types of thermal energy storage technologies since such review studies help to choose appropriate storage types for developing pilot plant of a hybrid thermal energy storage system at Al-Farabi Kazakh National University based on the experience of the research team of Professor A. Georgiev from Technical University of Sofia, Branch Plovdiv [7]. The hybrid storage system is going to be developed in a way that it will be able to store thermal energy for short term as well as for long term purposes. Therefore, main concentration of this review paper is underground thermal energy storage system (UTES) which is also named as long term storage and latent heat storage (LHS) based on phase change materials (PCM) – short term storage.

UNDERGROUND THERMAL ENERGY STORAGE

General

Thermal energy is abundant and available during warm seasons, but heating demand increases during cold days of the year. Similarly, cold thermal energy is necessary during summer, which is available in the nature during winter. Therefore, the development of large-scale seasonal thermal energy storage is useful in terms of using heat or cold at necessary time [6].

One of the technologies, which allows storing thermal energy in a large-scale, is Underground Thermal Energy Storage (UTES). Such technology gives opportunity to store heat into the ground and groundwater in the summer, and extract it during winter. In a similar way, cold can be stored during winter and extracted in the summer for cooling purposes [8, 9].

According to the measurements the ground temperature at a certain depth remains relatively constant and higher than the surrounding air temperature during the winter and lower during the summer. The temperature fluctuations of the surrounding air influence shallow ground and groundwater temperatures up to a depth of approximately 10 m. With increasing depth the underground temperature increases by an average progression of 3°C per 100m because of the geothermal gradient [10]. Hence, the ground and groundwater are suitable media for heat extraction during winter and cold extraction during summer. This type of thermal energy extraction method can be applied for heating during winter and cooling during summer. If extracted thermal energy recharged during summer or winter back to the ground, the ground is considered as a thermal energy storage system [11, 12].

Several types of large-scale or seasonal thermal energy storages are well established worldwide. The most common systems are Borehole Thermal Energy Storage (BTES), Aquifer Thermal Energy Storage (ATES), Tank Thermal Energy Storage (TTES) and Pit Thermal Energy Storage (PTES) [10–18].

UTES systems are divided into two types [11]: - Systems where working fluid is circulated through heat exchangers in the ground which are also named as "closed loop" systems (BTES).

- Systems where groundwater is pumped out of the ground and after extracting thermal energy from the

water, it charged back into the groundwater layer by means of wells. Such systems are known as open loop systems (ATES).

ATES - Aquifer Thermal Energy Storage

ATES is one of the geothermal technologies which is considered as innovative open-loop seasonal storage based on cold/warm groundwater in an aquifer. Main storage media is underground water together with sand, gravel, sandstone or limestone layers which have high hydraulic conductivities. This technology was developed over 20 years and it is now mostly used in Europe, especially, in Netherlands and Scandinavia. Although, ATES is not famous in United States, with the exception of ATES project at Richard Stockton College in Pomona [14, 15].

Application of ATES system for space heating and cooling is efficient and very green, but it can't be considered as renewable technology. Although, it is usually used together with renewables, for instance, with solar collectors or wind powered devise with the purpose of providing to mechanical components of ATES electrical power [16].

Main components of ATES system are its wells installed into a ground where the ends of the wells reach an aquifer (Figure 1). Number of wells must be at least two, one of them for water discharging from aquifer and another one for pumping the water back to the aquifer. For instance, if cooling is demanded by user, cold water is discharged from the cold well, and applied for cooling purposes. The water is then charged back to the aquifer by the warm well at an elevated temperature. In large scale ATES systems, it requires several cold and warm wells. Besides wells, there are other main components of ATES such as heat exchanges, conveyance piping, and mechanical and control systems for integrating it with heating or cooling systems of buildings.



Fig.1. Aquifer Thermal Energy Storage

Table2. Major criteria for unconsolidated aquifer

Aspect	Lower limit	Typical	Upper limit
Aquifer thickness (m)	2-5	25	None (partial use)
Aquifer depth (mbgs)	5 (injection pressure)	50	150 (economic)
Aquifer permeability (m/s)	3×10^{-5}	3×10^{-4}	1×10^{-3}
Groundwater flow (m/d)	0	0.1	0.3
Static head (mbgs)	50	10	-5

Unfortunately ATES technology is not applicable to any location because it is geologically dependent. There are number of limitations such as water chemistry, permeability of the underground formations, depth and thinness of aquifer, natural groundwater flow and static head (Table 1). In case of large ATES system, much attention is paid to distribution and location of warm and cold wells. If warm and cold wells are located separately, it leads to large changes in hydraulic head which might cause, for instance, land substance. Therefore, well field layout must be set up in a number of pairs where each pair consists of one warm and one cold well. Moreover, distance between warm and cold wells is also very important. In order to avoid shortcircuiting between wells located on both sides of natural temperature, minimum distance between warm and cold wells should be three times the thermal radius of the stored heat or cold. Thermal radius can be estimated using following formula [15]:

$$r_{th} = \sqrt{\frac{c_w Q}{c_a H \pi}} \tag{1}$$

where r_{th} thermal radius of the stored thermal energy, C_w and C_a are heat capacities of water and aquifer material respectively, Q is the amount of pumped water during the season. On the other hand, if warm and cold wells are located on one side of the natural groundwater temperature, shortcircuiting helps to increase the thermal efficiency. Consequently, distance between wells should be 1-2 times the thermal radius.

The extracted energy during cooling or heating period is determined using formula (2) [17]:

$$E_{extracted} = \int_{extraction} c_{w} \cdot Q \cdot \left| T_{extraction} - T_{injection} \right| \cdot dt \quad (2)$$

Here, Q is the total pumping rate, $T_{extraction}$ temperature of the water extracted from production well, $T_{injection}$ temperature of the water entering injection well.

BTES - Borehole Thermal Energy Storage

Borehole thermal energy storage (BTES) is more practical and can be installed anywhere except places where high pressure geysers or large empty caverns exist in underground rocks. BTES uses the underground itself as the storage material which may range from unconsolidated material to rock with or without groundwater. Depending on the water content of the underground, subsurface layers can be saturated or unsaturated [18].

Main component of BTES is a vertical heat exchanger (BHE) or also named as borehole heat exchanger. By circulating heat carrier fluid through BHE, thermal energy can be transferred between BHE and subsurface layers which are usually solid materials where main heat transport state mechanism is heat conduction. There are different types of BHE have been realized due to geological conditions. Open water-filled boreholes became popular in hard rock areas of Scandinavia, because of their excellent heat exchange performance. This technique is not efficient in the areas of unconsolidated rock. Common ones are single and double U-type BHE and coaxial BHE (Fig. 2). While double U-tubes are common in central Europe, most BTES systems today use single Utubes [19]. In case of single and double U-type BHE, polyethylene or polypropylene pipes are used as BHE.



Fig.2. BTES types: a) singe U-type, b) coaxial

BTES may consist of one or several borehole heat exchangers installed into boreholes. BTES construction is relatively simple. Firstly, borehole is drilled with required depth. In a standard borehole, depth of a borehole is usually 20-300 m. After drilling of the borehole, BHE is mounted into the borehole and the space between the pipe and the hole is filled with grouting material to ensure good contact between the BHE and surrounding soil (Fig.3). Moreover, the arrangement of flow channels of the GHE (i.e. distance between inlet and outlet pipes of U-type BHE) and types of grouting material are another important aspect of developing effective BTES system. It was found that when shank spacing was increased, borehole



Fig.3. Side and top view of single U-type BHE installed into the borehole.

thermal resistance R_b was degreased [20]. Moreover, choice of appropriate grouting material helps to effectively transfer necessary thermal energy between rocks and BHE. Detailed study of backfilling materials and their thermal properties can be found from the articles [21].

BTES is considered as sensible heat storage, therefore, high heat capacity of storage medium is important. All type of underground material have volumetric thermal capacity which is about half that of water (4.15 MJ/m³ K). This value depends on the material itself, the bulk density and the water content. Thermal properties of underground materials are discussed in the article by Reuss [22].

High groundwater content of underground porous materials increase the heat capacity, but groundwater flow may reduce the efficiency of BTES because of increasing losses due to convective heat transport. Therefore, the local geology and hydrology are important in selecting of storage type (BTES or other types) [23].

First project of BTES system for storing solar or waste heat from summer to winter for space heating was carried out in Sweden in 1980s. In the following decades, this technology became famous in other countries too. Majority of BTES systems were integrated with heat pumps for extraction of heat from the storage to provide the required supply temperatures for users. Although, early days BTES system was applied to satisfy hearing demands, today it is also used for cooling purposes, and in most cases for combined heating and cooling [22].

In order to develop proper BTES design good knowledge of the heat demand and the heat sources are required. Not only amount of charged

and discharged energy have importance, but also the dynamics of the heat flux due to the limited conductivity thermal of the underground. Knowledge of heat flux dynamics in subsurface lavers may be estimated from geological maps of a location. But, still the accuracy of these data usually is poor and can't give enough information about thermal behaviour of the underground. Therefore, site investigation by test drillings is essential to obtain detailed geological profile and thermophysical evaluate the properties of subsurface layers.

Well known method used to determine subsurface and borehole thermal properties is Thermal Response Test (TRT) which was developed at Oklahoma State University (USA) and Technical University Luleå (Sweden) [22]. Based on this methods, is possible to evaluate effective thermal conductivity over the whole length of the BHE and the borehole resistance [24, 25]. To carry out the test procedure, first test installation must be constructed. The installation consists of the parts such as electrical heater, a water pump, expansion tank, water filter, monometer, air remover and connecting pipes and wrapping insulation materials to ensure no heat loss from connecting pipes. The test procedure is relatively simple. The TRT installation is connected to BHE and constantly heated heat carrier fluid (usually water) is circulated thought the BHE with the help of the pump in the test installation. During the process, temperature of the working fluid at the inlet and outlet sections of BHE pipe is measured and recorded. Furthermore, applying line source model a simplified approximation of the heat transport of an infinite linear heat source in the underground thermal properties of the formation can be determined. Since the model assumes a homogeneous medium and conduction as the only heat transport process, the test delivers an effective thermal conductivity of the underground over the whole length of the BHE and the thermal borehole resistance between the fluid and surrounding formation. Thus, using average of the inlet and outlet temperatures in the formula (3)

where

$$k = \frac{q_0}{1}$$

(3)

$$-4\pi\alpha$$

 $T_{f}(t) \cong m + k \ln t$

and



Fig.4. BTES and description of TRT installation [24].

$$m = T_0 + \frac{q_0}{4\pi\alpha} \left[\ln\left(\frac{4\alpha}{r_b^2}\right) - \gamma \right] + \frac{R_b}{q_0}$$

effective thermal conductivity and overall borehole thermal resistance may be estimated. Correct estimation is achieved when test time satisfies the condition $t \ge \frac{5r_b^2}{\alpha}$ [26]. The duration of the thermal

response test is from 5 up to 10 days.

As mentioned above, size of BTES system depends on the energy demand and type of building. The first BTES systems for seasonal storage were developed in Sweeden and Netherlands in 1980s for solar district heating systems and effective use of waste heat from industrial systems [26]. Moreover, several solar district heating systems were built with different types of seasonal storage under the R&D program 'Solarthermie 2000' and three of them were based on BTES [22].

Solar district heating in Neckarsulm, Germany, is significant and first large project where BTES technology was used for space hearing and domestic hot water of 700 apartments of different sizes and residential buildings. Around 5000 m^2 of solar flat-plate collectors installed on buildings and

two buffer storages of 100 m³ each. They are used to deliver thermal energy to district heating directly or to the seasonal storage. Number of boreholes in the first operational stage (1997) was 36 and was extended in two stages by 2001 to 528 boreholes. Because of the local geological formation where below 30-35 meters highly permeable dolomite layer with groundwater flow starts, the depth of the boreholes was chosen to be 30 meters to avoid high bottom losses. Borehole heat exchanges were double-U pipes made of polybutene which has high life expectancy at temperatures up to 85°C and pressure up to 10 bars.

Other large-scale BTES systems are: Solar district heating at Okotoks, Canada, solar district heating with hybrid storage in Attenkirchen, Germany and so on (table 2).

TTES - Tank Thermal Energy Storages

Most of the small tank storages are connected to solar collectors as a buffer storage for single-family houses. Although, there are some examples tank storages being used as seasonal storage. Seasonal tank storage is made of reinforced concrete and partially buried in the ground. This type of storage can be built almost independently of geological conditions. It is thermally insulated on the top and on the vertical walls. One of the first tank storages were developed in Germany in 1995. The pilot heat

N°=	Location	Country	Type of building	Heated floor	Heating power (kW)	Refrigerating power	Number of	Active length of
_				area (m²)		(kW)	BHE	the BHE (m)
1	Langen	Germany	Office	44500	330	340	154	70
2	Lucerne	Switzerland	Office	20000	450	700	49	160
3	Neckarsulm	Germany	District heating	25000	500		528	30
4	Crailsheim	Germany	District heating	40000	530		80	49
5	Truro	Canada	Prison	3837	211		24	63
6	Lugano	Switzerland	Single family house	250	14	no cooling	3	80
7	Sopot	Poland	Hospital	4223	200 (300 with the boiler)		80	50
8	Münster	Germany	Office	14000	529	379	95	100
9	Ulm	Germany	Office	6911	120		40	99
10	Athens	Greece	Office	6000	526	461	13	90
11	Lincoln	USA	School	6410	694 (1081 with the boiler)		120	73
12	Melle	Belgium	Office	20700	500 (200 with the boiler)	378 (1200 with the refrigerating machine)	90	120
13	Attenkirchen	Germany	District heating	6075			90	30
14	Aachen	Germany	Office	2072	56		28	45
15	Donaueschingen	Germany	Office	3500	90	452	56	95
16	Schöffengrund	Germany	Office	385	22	no cooling	8	50
17	Stuttgart	Germany	Office	2400	67		18	55
18	Markham	Canada	School	16822	1442		360	61
19	Pylaia	Greece	Town Hall	2500	265	168	21	80
20	Wollerau	Switzerland	Office	3000	190	210	32	135
21	Stadl Paura	Austria	Office	1540	43		8	100
22	Onamia	USA	School	7246	679		560	15,2
23	Vestal	USA	Office	743	84,4		16	76,2
24	York County	USA	Office	2480	351,7		96	50
25	Oslo	Norway	Office, hotel	180000	6000	9500	180	200
26	Setubal	Portugal	University	220	15	12	5	80
27	Sabadell	Spain	Office	1546	165	165	14	
28	Montreal	Canada	Store	4180			12	175
29	Lancaster	USA	Restaurant	1394	90		6	153
30	Wysox	USA	Hotel	3623	341,1		30	91,4

Table2. Examples of BTES projects over the world [27].

store of 600 m³ used water as the storage material. Shape of the store is cylindrical and half of it buried into the ground. Stainless still liners and insulaton were used on the top and on the sides. Moreover, 4500 m³ store in Hamburg and the 12.000 m³ store in Friedricshafen are another examples of large scale tank storage. Inside of these storages used stainless-steel liner to ensure water tightness and to reduce heat losses caused by steam diffusion via wall. concrete Moreover, polyethylene or polyvinylchloride film was applied as the thermal insulation to the storage. Inner steel liner can be avoided if high-density concrete (HDC) material with lower vapour permeability and one of such storage were developed in Hannover [28].

Large-scale solar-heated tank seasonal heat storage systems were developed in Sweden. But, some of them were not successful. For instance, solar heating plant at Ingelstad designed to cover 50% of the annual energy demand of 52 houses and volume of the storage was 5000 m³. But, because of the low efficiency of the solar collects and thermal losses from the storage the system covered only 14% of the annual energy. Tank storages in Hoerby and Herlev in Denmark with storage capacity of 500 m³ and 3000 m³ respectively showed leakage problems at the beginning and were not competitive for large storage volumes [11].



Fig.5. Tank thermal energy storage.

Numerical simulations were used to predict performance of central solar heating plants with seasonal storage (CSHPSS) and later validated with the experimental data obtained [29]. For instance, TRNSYS and OmSim were used to simulate the performance of CSHPSS developed at Saro, Sweden. Argiriou compared the results of MINSUN and SOLCHIPS used to simulate the performance of Lukovrissi Solar Village, in Greece. Zhang at al. developed a model to study tank storage performance which included a surface water pond with polystyrene foam as insulating cover, which works as a heat source in winter and heat sink in summer [30].

PTES - Pit Thermal Energy Storages

Pit thermal energy storages (PTES) are constructed without static constructions installing a liner and insulation in a pit. Type of lid depend on a geometry of the PTES as well as on the storage medium. But there are examples where the pit is filled both with gravel along with water. In that case, lid might be constructed similar to the walls. Indeed, construction of a lid of a PTES requires most of the effort and expensive part of the storage. Usually, lid is not supported by the walls of PTES, instead, floats on top of the water [11].



Fig.6. Pit thermal energy storage.

Typically, PTES is entirely buried into the ground and can be installed almost anywhere regardless of the type of geological location. The gravel water PTES has lower specific heat capacity compared to water alone PTES. Therefore, size of gravel water PTES systems are bigger than water alone PTES systems to obtain the same heat storage capacity.

First large scale PTES was developed in the Institute for Thermodynamics and Thermal

Table3. Comparison of hot water and gravel water PTES.

Engineering of Stuttgart University in 1984 [31]. Shape of the pit was similar to truncated cone and storage was filled with pebbles and water, high-density polyethylene liner was used and thermally insulated only on top with porous lava and earth layers. One of the largest PTES constructed in Denmark has a storage volume of 75 000 m³. It was sealed with a HDPE liner and covered by a floating lid made of coated elements of PUR. Other examples of PTES are: 8000 m³ heat storage at Chemnitz (Germany); 1500 m³ storage at Steinfurt–Borghorst (Germany); and gravel–water storage with the capacity of 500 m³ developed at theTechnical University of Denmark, Lyngby [32].

Compared to TTES, PTES requires less constriction cost and upper part of the storage can be used as a part of a residential area, but needs bigger size to achieve the capacity of TTES. Moreover, it is easy to have maintenance or repair TTES than PTES, although former has higher construction costs for the cover (lid). Table 3 summarize the advantages and disadvantages of both tank and pit thermal energy storages [33].

Above mentioned all storages are usually used as large scale thermal energy storage systems. They can be used separately or can be coupled together to achieve better performance depending on the energy demand. One of the hybrid storage which used BTES and TTES is the solar district heating in Attenkirchen, Germany. The concrete TTES with the height of 8.5 m and with the diameter of 9 m (total volume is 500 m^3) is installed in the center of the BTES field. Number of BTES is 90 with the depth of 30 m. Top of the tank storage was covered with 20 cm thick layer of polystyrene. Heat losses of the tank storages from the side walls and the bottom is the partial heat gains of BTES. Therefore, thermal insulation of the walls and steel liner for the tank is no longer necessary. Around 765 m² of solar collectors serve as thermal energy deliverer [34].

Hot water	Gravel / sand / soil water
pit thermal energy storage	pit thermal energy storage
+ thermal capacity	+ low static requirements
+ operation characteristic	+ simple cover
+ thermal stratification	
+ maintenance / repair	
- sophisticated and expensive cover	- thermal capacity
- low static cover load	- charging system
- costs for landfill of excavated soil (if applicable)	 additional buffer storage (if applicable)
	- maintenance / repair
	- gravel costs

Table4.	Comparison	of large-scale	storage systems
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TTES	PTES		BTES	ATES	
storage medium					
water	water*	gravel-water*	soil / rock	sand-water	
heat capacity in kWh/m ³					
60 - 80	60 - 80	30 - 5 0	15 - 30	30 - 40	
storage volume for 1 m ³ water equivalent					
1 m³	1 m³	1.3 - 2 m³	3 - 5 m³	2 - 3 m³	
geological requirements					
 stable ground conditions preferably no groundwater 5 – 15 m deep 	- stable ground conditions - preferably no groundwater - 5 – 15 m deep		- drillable ground - groundwater favourable - high heat capacity - high thermal conductivity - low hydraulic conductivity $(k_f < 10^{-10} \text{ m/s})$ - natural ground-water flow < 1 m/a - 30 - 100 m deep	- natural aquifer layer with high hydraulic conductivity $(k_f > 10^{-5} m/s)$ - confining layers on top and below - no or low natural groundwater flow - suitable water chemistry at high temperatures - aquifer thickness of 20 - 50 m	

The hybrid system is designed to meet the 50% of thermal energy demand of the residential buildings located 40 km north from Munich. Thus, it is possible to combine two or more large-scale thermal energy storage systems to achieve better performance in thermal energy storage techniques, but combination of the storage systems depend on things such as properties of large-scale storages (table 4), geological formations of the location, thermal energy demand, cost recovery and construction risks that might influence on the performance of the system.

LATENT HEAT STORAGE WITH PHASE CHANGE MATERIAL

Among the methods for heat accumulation, thermal storage in the form of latent heat is very attractive and considered as promising candidates for effective heat storage technique [35]. Latent heat storage (LHS) relies on storage materials which absorbs/releases heat while undergoes phase transition. Such phase change materials (PCMs) has higher energy storage density with the range of 150-200kJ/kg and narrower temperature range between storing and releasing heat compared to sensible heat storage. However, LHS systems suffer from the low thermal conductivity of the phase change materials. In turn, this leads to low charging and discharging rates [36].

There are different types of phase change materials and they have various built-in thermal properties. PCMs are divided into three main groups: organic, inorganic and eutectic. For instance, paraffinic and non-paraffinic materials are considered as organic PCMs, while salt hydrated are inorganic materials. About PCMs, their types and thermal characteristics can be found in the papers [PCMs] [37].

As mentioned above, one of the problems related to PCMs is their low thermal conductivity feature. To enhance heat transfer process during charging or discharging of LHS filled with PCMs, different methods are applied based on thermal conductivity improvement techniques. One of the methods is the application of metal foams as a heat transfer intensifier. For instance, Xiao at al. [38] studied paraffin/nickel foam and paraffin/copper foam composite phase change materials. According to the experimental results, it was found that compared with pure paraffin, the thermal conductivities of the composite PCMs were drastically enhanced, especially, the thermal conductivity of the paraffin/nickel foam composite

was about three times higher than that of pure paraffin. There were other experimental and numerical studies have been conducted and results are discussed in papers [39, 40]. Another method which applied to improve thermal efficiency of PCMs is based on extended surfaces. In other words, fins are attached to the surfaces between hear carrier fluid and PCM with the purpose of improving heat transfer between them. Wang at al. [41] studied PCM melting in enclosures with vertically-finned internal surfaces end concluded that fins help to enhance phase change process during charging/discharging of LHS. Heat exchanges mounted into PCM storage were also equipped with extended surfaces and results showed that process of phase transition was improved [42]. Scientists also studied PCMs which included particles with high thermal conductivity [43, 44]. As a result, particles also have some assessment in enhancement of phase transition process. Encapsulation of phase change material within a heat carrier fluid is another effective method which helps to improve heat transfer process [45, 46]. Usually, encapsulated PCM are placed in a latent heat storage and during charging process upper layer of encapsulated PCM gains thermal energy of heat transfer fluid. Layers below can not gain same amount of thermal energy as the upper layers. Therefore, series of PCMs with a decreasing melting temperature along the heat carrier fluid flow direction are used. Moreover, different design of LHS are proposed by researchers. Most considered ones are shell and tube heat exchanger mounted storages, storages which equipped with vertical or horizontal PCM filled containers [4], and LHS with finned tubes designed to intensify heat transfer between heat transfer fluid and PCM.

CONCLUSION

This review paper is focused on thermal energy storage technologies, especially, large-scale thermal storages such as aquifer and borehole thermal storages, tank and pit thermal energy storages. Moreover, construction of such storages, their, advantages and disadvantages, benefits and differences from each other are also discussed. Moreover, small and medium scale thermal energy storages based on phase change materials (PCMs) are considered as well. Particularly, thermal properties of PCMs, methods for improving thermal conductivities of PCMs and latent heat storage types are discussed. Aim of the review was to gather necessary knowledge from last year scientific papers in the area of thermal energy storage and apply the knowledge to develop hybrid thermal energy storage, which is able to store thermal energy for short term as well as long term purposes. The hybrid storage will be developed in Al-Farabi Kazakh National University with the help of Bulgarian research team under the guidance of Professor Georgiev from Technical University of Sofia, Branch Plovdiv.

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