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Thermal energy storage systems – review

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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 the 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 the 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 a 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 a number of thermal energy storage technologies which are being studied and developed during the 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].

The aim of the study 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 a pilot plant of a hybrid thermal energy storage system at Al-Farabi Kazakh National University based on the experience of the research team of Prof. A. Georgiev from Technical University of Sofia, Plovdiv Branch [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

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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. The examples of UTES systems can be found in the papers [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 ºC per 100 meter because of the geothermal gradient [10]. Hence, the ground and groundwater are suitable media for heat extraction during winter and heat rejection 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.

Several types of large-scale or seasonal thermal energy storages are well established worldwide [11, 12]. 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).

UTES systems are divided into two types:

- 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 the Netherlands and Scandinavia. However, ATES is not popular in the 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 electrical power to drive the mechanical components of ATES [16].

The main components of ATES system are its wells installed into a ground where the ends of the wells reach an aquifer (Fig.1). The number of wells must be at least two, one of them for water discharging from the aquifer and another one for pumping water back to the aquifer. For instance, if cooling is demanded by the user, cold water is discharged from the cold well, and applied for cooling purposes. 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 exchangers, conveyance piping, and mechanical and control systems for integrating it with heating or cooling systems of buildings.

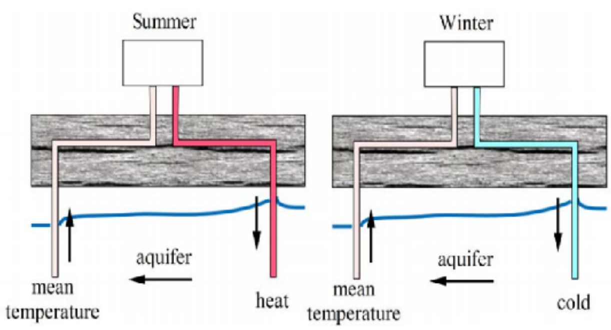

Fig.1. Aquifer Thermal Energy Storage [16]

Table 1. Major criteria for unconsolidated aquifer [15]

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 every location because it is geologically dependent. There are a 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 subsidence. Therefore, the careful design of the field layout must be set up in a number of pairs where each pair consists of one warm and one cold well. Moreover, the distance between warm and cold wells is also very important. In order to avoid short-circuiting 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 the following formula [15]:

$$r_{th} = \sqrt{\frac{c_w Q}{c_a H \pi}} \quad (1)$$

where r_{th} is thermal radius of the stored thermal energy (m), c_w and c_a are heat capacities of water and aquifer material respectively (J/m^{3}K), Q is the amount of pumped water during the season (m^3) and H is the screen length (m).

On the other hand, if warm and cold wells are located on one side of the natural groundwater temperature, short-circuiting 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) [16]:

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

Here, Q is the total pumping rate (m^3/min), $T_{extraction}$ temperature of the water extracted from production well (K), $T_{injection}$ temperature of the water entering injection well (K).

BTES - Borehole Thermal Energy Storage

Borehole thermal energy storage (BTES) is more practical and can be installed anywhere except in 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].

The 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 state materials where the main heat transport mechanism is by conduction. There are different types of BHE 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 U-tubes. In case of single and double U-type BHE, polyethylene or polypropylene pipes are used as BHE. More information about typical BHE can be found in article [9]. These days,

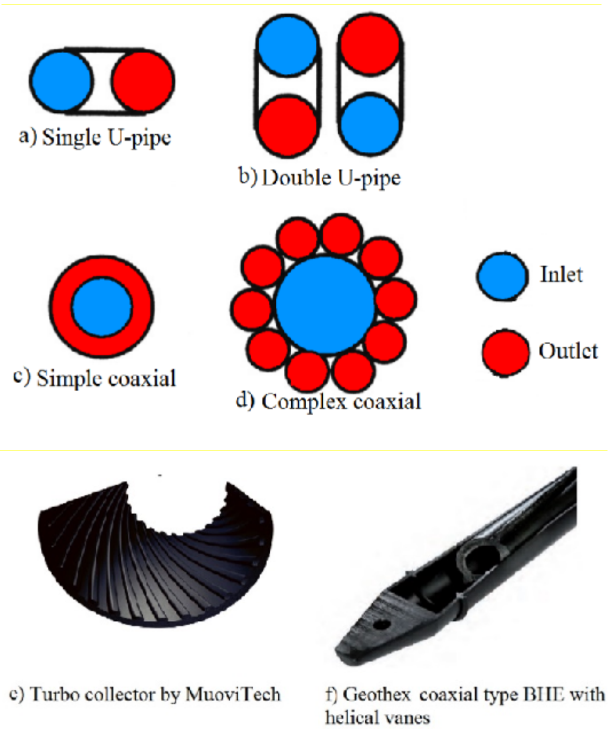

Fig.2. BTES types: a) singe and b) double U-type, c) simple and d) complex coaxial [9]; e) Turbo collector by Muovitech f) coaxial type BHE by Geothex (pictures are from muovitech and geothex websites)

there are other advanced BHE exist in the market. They are: turbo collector developed by Muovitech company. The main advantage of the collector is its fins located inside, which creates turbulent flow thus assists in increasing the heat transfer process.

The collector can be used instead of conventional pipes of single or double U-type BHE. Another recently developed high efficiency ground heat exchanger is the one by Geothex. It has insulated inner pipe and helical vanes between outer and inner pipes. These vanes are designed to increase the heat transfer between heat carrier fluid and the surrounding media.

BTES may consist of one or several borehole heat exchangers installed into boreholes. BTES construction is relatively simple. Firstly, a borehole is drilled up to the required depth. In a standard borehole, depth of a borehole is usually 20-300 m. After drilling of the borehole, the 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 thermal resistance R_b was decreased [20]. Moreover, choice of appropriate grouting material helps to effectively transfer the necessary thermal energy between rocks and BHE. Detailed study of backfilling materials and their thermal properties can be found in the articles [21].

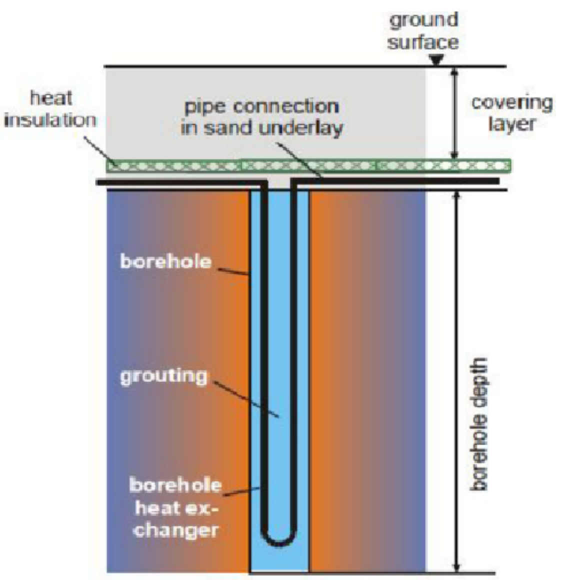

Fig.3. Side and top view of single U-type BHE installed into the borehole [16]

BTES is considered as sensible heat storage, therefore, high heat capacity of storage medium is important. All types of underground material have volumetric thermal capacity which is about half that of water (4,15 MJ/m^3 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 selection of storage type (BTES or other types) [23].

The 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 popular in other countries too. The 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, in early days the BTES system was applied to satisfy heating demands, today it is also used for cooling purposes, and in most cases for combined heating and cooling.

In order to develop proper BTES design good knowledge of the heat demand and the heat sources are required. Not only is the amount of charged and discharged energy has importance, but also the dynamics of the heat flux due to the limited thermal conductivity of the underground plays an important role. Knowledge of heat flux dynamics in subsurface layers 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 the thermal behaviour of the underground. Therefore, site investigation by test drillings is essential to obtain detailed geological profile and evaluate the thermophysical properties of subsurface layers.

A 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) [23]. Based on this methods, it 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, a test installation must be constructed first (Fig.4).

As mentioned above, the size of BTES system depends on the energy demand and type of building. The first BTES systems for seasonal storage were developed in Sweden 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.

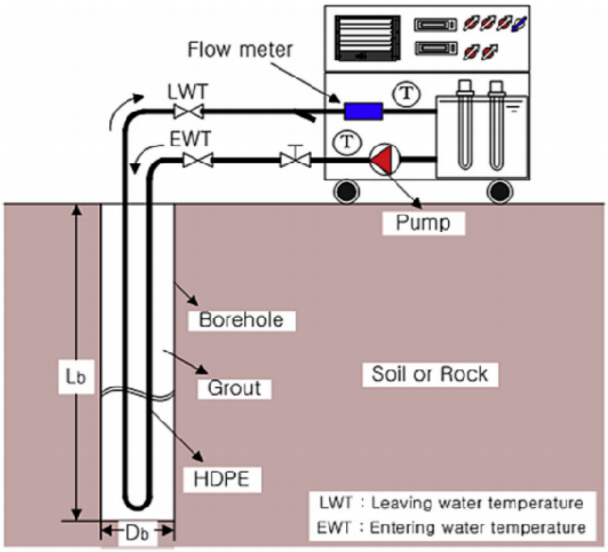

Fig.4. BHE and description of TRT installation [24]

Solar district heating in Neckarsulm, Germany, is significant and has the first large project where BTES technology was used for space heating and domestic hot water of 700 apartments of different sizes and residential buildings [22]. Around 5000 m^2 of solar flat-plate collectors installed on buildings and two buffer storages of 100 m^3 each were used to deliver thermal energy to district heating directly or to the seasonal storage. The number of boreholes in the first operational stage (1997) was 36 and this was extended in two stages in 2001 to 528 boreholes. Because of the local geological formation where highly permeable dolomite layer with groundwater flow starts below 30-35 meters, the depth of the boreholes was chosen to be 30 meters to avoid high bottom losses. Borehole heat exchangers 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 of 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 (Fig.5). One of the first tank storages were developed in Germany in 1995. The pilot heat store of 600 m^3 used water as the storage material. The shape of the store was cylindrical and half of it was buried into the ground. Stainless steel liners and insulation were used on the top and on the sides. Moreover, 4500 m^3 store in Hamburg and the 12000 m^3 store in Friedrichshafen are other examples of large scale tank storage. Inside of these storages, stainless-steel liners are used to ensure water tightness and to reduce heat losses caused by steam diffusion via the concrete wall. In addition, 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 is used. One of such storages was 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, the solar heating plant at Ingelstad designed to cover 50% of the annual energy demand of 52 houses and volume of the storage was 5000 m^3. But, because of the low efficiency of the solar collectors 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 m^3 and 3000 m^3 respectively showed leakage problems at the beginning and were not competitive for large storage volumes [11].

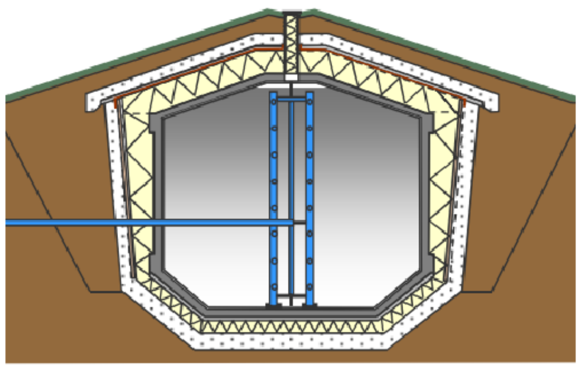

Fig.5. Tank thermal energy storage [33]

Numerical simulations were used to predict performance of central solar heating plants with seasonal storage (CSHPSS) and later validated with

Table 2. Examples of BTES projects over the world [27]

N°=	Location	Country	Type of building	Heated floor area (m²)	Heating power (kW)	Refrigerating power (kW)	Number of BHE	Active length of 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

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. The type of lid depends 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, the lid may be constructed similar to the walls (Fig.6.). Indeed, construction of a lid of a PTES requires most of the effort and expensive part of the storage. Usually, then lid is not supported by the walls of PTES, instead, it floats on top of the water [11].

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, the size of gravel water PTES systems is bigger than water alone PTES systems, for the same heat storage capacity.

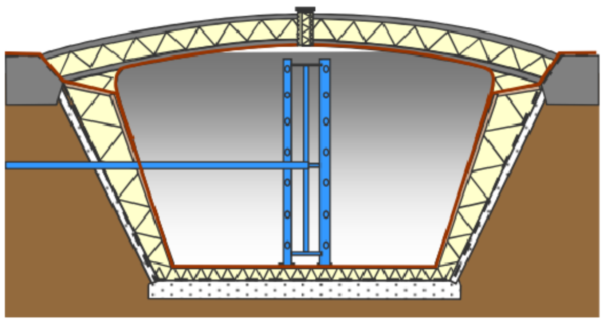

Fig.6. Pit thermal energy storage [33]

First large scale PTES was developed at the Institute for Thermodynamics and Thermal Engineering of Stuttgart University in 1984 [31]. The 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

Table 3. Comparison of hot water and gravel water PTES [33]

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

and earth layers. One of the largest PTES constructed in Denmark has a storage volume of 75000 m^3. 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 m^3 heat storage at Chemnitz (Germany); 1500 m^3 storage at Steinfurt–Borghorst (Germany); and gravel–water storage with the capacity of 500 m^3 developed at the Technical University of Denmark, Lyngby [32].

Compared to TTES, PTES requires less construction cost and the 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 for TTES than PTES, although the former has higher construction costs for the cover (lid). Table 3 summarizes the advantages and disadvantages of both tank and pit thermal energy storages [33].

The above mentioned 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 combined storage which used BTES and TTES is the solar district heating system in Attenkirchen, Germany. The concrete TTES with a height of 8.5 m and a diameter of 9 m (total volume is 500 m^3) is installed in the centre of the BTES field. The number of BTES is 90 with a depth of 30 m. The 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. Around 765 m^2 of solar collectors serve as thermal energy deliverers [34].

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 depends 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) have higher energy storage density with the range of 150-200 kJ/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 [36, 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.

Table 4. Comparison of large-scale storage systems [33]

TTES	PTES		BTES	ATES
storage medium				
water	water*	gravel-water*	soil / rock	sand-water
heat capacity in kWh/m³				
60 - 80	60 - 80	30 - 50	15 - 30	30 - 40
storage volume for 1 m³ 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 ($k_f < 10^{-10}$ 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

There were other experimental and numerical studies, which have been conducted and reported in papers [39, 40]. Another method which was 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 exchangers 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 cannot gain same amount of thermal energy as the upper layers. Therefore, a series of PCMs with a decreasing melting temperature along the heat carrier fluid flow direction are used. Moreover, different designs 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. As it can be concluded from the studies presented in this paper, each storage has its own advantages and disadvantages as well. ATES systems are highly dependent on the geological structure of the subsurface layers, especially on an aquifer type, while BTES systems do not need special geological conditions, except there should not be emptied caverns or high pressure geysers in the subsurface. Moreover, TTES system can be built independently of geological conditions and it is reliable and efficient if it was constructed properly, otherwise leakage problems might arise. Special liners are used in TTES system to hinder thermal energy loses from the storage. Another large scale storage is PTES system. Some PTES systems include gravel with water as the storage media. TTES storage is usually covered by a lid and construction of a lid requires most of the effort and is the most expensive part of the storage. In addition, 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. Is can be concluded that usually PCMs have low conductivity problems, therefore, methods used to increase conduction heat transfer in the PCMs are developed. Some of them are adding high conductive micro or nanoparticles, encapsulation of PCMs in small sizes, application finned heat exchangers or metal foams in PCMs. Moreover, design of the storage tank plays important role in developing efficient storage with PCM.

Additional 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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