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REVIEW OF THERMAL ENERGY STORAGE SYSTEMS AND THEIR APPLICATIONS

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ABSTRACT

Nowadays, the worldwide worry about a global climate change pushes to develop new energetic strategies. And more, after the recent energetic crisis due to the increase of oil price, or the gas crisis arisen between Russia and Ukraine This paper reviews the Thermal energy storage systems which have the potential for increasing the effective use of thermal energy equipment and for facilitating large-scale switching. They are normally useful for correcting the mismatch between the supply and demand of energy. There are different methods in thermal storage systems.

INTRODUCTION

Developing efficient and inexpensive energy storage devices is seen as important as developing new sources of energy. In the energy industry stakeholders and investors are increasingly interested in new technologies or the innovative use of existing technologies in thermal energy storage (TES) to reduce energy wastage. This is a result of growing concerns about environmental and economic conundrums facing industry such as:

- The potential imminent energy shortage through fossil fuel depletion;
- Increasing complexity in extracting less accessible fossil fuels;
- Climate change as a result of greenhouse gas emissions;
- Future price volatility of fuel sources; and
- Daily and seasonal energy demand variations require peaking power plants, usually gas turbines, and load following power plant.

WASTE HEAT SOURCES FOR TES

Incineration

Incineration of waste is becoming a more attractive option to dispose of waste instead of landfill since legislation is making landfill increasingly more uneconomical and difficult. Recovery of energy from incineration plants seems to be the next logical step to make the most of optimizing the usefulness of waste and to reduce carbon emissions.

Power plant

Thermal energy storage has not been developed for electric storage yet. Desrues et al (2009) researched a thermal energy storage process for large scale electric applications, which does not suffer from geographical constraints such as the need for a large altitude difference between two large water reservoirs for pumped hydroelectric storage, or a large cavern for compressed air energy storage (Denham and Holloway, 2005; Denham and Kulcinski, 2004).

Passivhaus

Passivhaus buildings essentially turn a building into a massive TES system. Passivhaus make extensive use of internal waste heat from lighting, electrical appliances (but not confined to heaters alone), body heat from people and other animals within the building. An average human being emits heat equivalent to 100 12 watts each of radiated thermal energy. With the comprehensive energy conservation measures, this means that a conventional central heating system is not necessary, hence why these buildings can be considered as unconventional TES systems.

Passive Solar Heating

Passive solar heating (PSH) distributes solar energy in the form of heat in the winter or at night and rejects solar heat in the summer or during the day. It does not involve the use of mechanical or electrical devices
Industrial sources
Manufacturing industries are very diverse by nature. Industries provide a diverse source of waste heat of differing qualities.

LITERATURE REVIEW

Review of Phase Change Materials For Thermal Energy Storage Applications Prabhu P.A., Shinde N.N*., Prof. Patil P.S*.

The heat storage applications used as a part of solar water-heating systems, solar air heating systems, solar cooking, solar green house, space heating and cooling application for buildings, off-peak electricity storage systems, waste heat recovery systems etc

Thermal energy storage technologies and systems for concentrating solar power plants
Sarada Kuravi 1, Jamie Trahan, D. Yogi Go swami*, Muhammad M. Rahman, Elias K. Stefanakos

This paper presents a review of thermal energy storage system design methodologies and the factors to be considered at different hierarchical levels for concentrating solar power (CSP) plants. Thermal energy storage forms a key component of a power plant for improvement of its dispatch ability. Though there have been many reviews of storage media, there are not many that focus on storage system design along with its integration into the power plant. This paper discusses the thermal energy storage system designs presented in the literature along with thermal and energy efficiency analyses of various thermal energy storage systems integrated into the power plant.

Economic aspects of these systems and the relevant State of the art of high temperature storage in thermo solar Plants. Antoni Gil, Pablo Arce, Ingrid Martorell, Marc Medrano, Luisa F. Cabeza

A review of state of the art of high temperature storage in thermo solar plants has been done, consulting about 95 references, with the aim to study and show the technologies applied until the moment in thermal energy storage in solar power plants. Publications in literature are also summarized in this effort.

High Temperature Heat Storage for Industrial Process Heat and Power Generation Rainer Tamme, Doerte Laing, Hans Müller-Steinhagen, Wolf-Dieter Steinmann

This paper gives an overview of the high temperature thermal energy storage development at the DLR Institute of Technical Thermodynamics. Within this context high temperature is defined to be beyond 100 °C as needed for comfort heating and cooling.

High Temperature Thermal Storage for Solar Gas Turbines Using Encapsulated Phase Change Materials Peter Klein1, Thomas Roos2, and John Sheer3

This paper discusses the development of high temperature thermal storage systems is required to increase the solar share of solar-hybrid gas turbine cycles. This paper proposes a pressurized packed bed of Encapsulated Phase Change Materials (EPCM) as a thermal storage system for a gas micro turbine. Sodium sulphate, with a melting temperature of 884 oC, was identified as a suitable low cost PCM and both macro and micro-encapsulation techniques were analysed. A numerical model of the EPCM concept was developed and used to compare the storage system with sensible heat storage in ceramic media. The results show that the discharge time of EPCM storage is comparable (<10 % improvement) with a packed bed of alumina particles, while the total storage mass is reduced by up to 31 %. The decrease in ceramic material costs must be higher than the encapsulation costs for this storage technology to be viable. A preliminary cost analysis is provided for the maximum allowable encapsulating costs.

TES TECHNOLOGIES

This section identifies technologies suitable for low-grade heat storage and high-grade heat storage. These distinct classifications are required since the obstacles to low-grade heat storage are different from high-grade heat storage, such as potential for certain phase change materials (PCMs) to degrade at higher temperatures. Low-grade heat storage is also thermodynamically more challenging since the temperature difference is smaller than for high-grade heat storage, resulting in much less efficient heat transfer. Low-grade heat is usually defined as effluents having temperatures less than 150ºC. Low-grade heat such as geothermal, waste heat and heat from low- to mid-

temperature solar collector's accounts for 50% or more of the total heat generated worldwide as these sources cannot be converted efficiently to electrical power by conventional power generation methods (Hung et al, 2011). There have been many studies to utilize this low-grade heat efficiently and economically using a wide variety of methods such as TES and organic Rankin cycle with or without supercritical applications (Chen et al, 2011 and 2010). When attempting to choose and/or design TES systems the important attributes to consider are (Ataer, 2011):
The temperature range over which the storage has to operate;
- The capacity of the storage has a significant effect on the operation of the rest of the system, because a smaller storage unit operates at a higher mean temperature. This results in a reduced heat transfer equipment output as compared to a system having a larger storage unit;
- The optimum capacity ("short-term" storage units) is a TES system which can meet fluctuations over a period of two or three days, as it is the most economical for building applications;
- The heat losses from the storage have to be kept to a minimum, especially important for long-term storage;
- The rate of charging and discharging; and 22
- The cost of the storage unit (storage medium, the containers and insulation, and the operating cost).

This section examines the types of TES technologies available and whether the applications are for high-grade or low-grade heat. TES can be in the form of stored cold as well as heat.

The types of TES methods being investigated discussed in detail in this report are:
a) Phase Change Material (PCM)/ latent heat storage;
b) Thermoelectric materials;
c) Magnetic refrigeration;
d) Chemical sorbent/ bond storage; and
e) Sensible heat

APPLICATIONS OF TES

District heating

The problem with distribution of low grade heat traditional heat transfer media such as water is the difficulty in providing constant heating temperature. The end of the heat distribution line where temperature of the water is the lowest will end up providing the least heat. Micro-encapsulation of PCM suspended in water will allow temperature of the liquid heat transfer media, e.g. water or ammonia, to be constant, so long as PCM has not completely released all its latent heat content. This will allow for more or less uniform heating throughout the heat distribution line. Cost could also potentially be saved via reduced requirement for insulation for the distribution pipeline, by reducing the heating temperature, since higher temperature might not be necessary in making sure that the end of the distribution pipeline provides sufficient heat (hence reducing the rate of heat loss). The size of the heat exchangers can also potentially be reduced if the low-grade heat can be maintained at a sufficiently high temperature. A slightly more technologically complicated approach will be using meta-stable surfactant to encapsulate hydroscopic PCMs such as calcium chloride hex hydrate. These PCMs will first solidify when releasing latent heat. Once PCM solidifies, surfactant will gradually allow adsorb ate, in this case, water, to enter into the PCM. The exothermic hydration of calcium chloride hex hydrate further releases heat for district heating. Theoretically speaking, this method should incur even less heat loss due to the fact less sensible heat storage and latent heat storage media being used and pumped.

Power plants

Metal hydride could potentially be used to store energy from renewable power plants (or nuclear) such as wind power and wave power. The energy produced during period of low demand could be converted to chemical energy by electrolyzing water into hydrogen and oxygen. Hydrogen and oxygen can then be combusted together in gas turbine to generate electricity during times of peak demand. Hydrogen can be stored in metal complexes in the form of hydrides as previously mentioned. Although, metals have the ability to store a lot of hydrogen, they are pretty bulky and heavy to handle or transport. However, power plants are stationary hence the storage of 52 hydrogen in the form of metal hydrides is preferable over gas, compressed gas and liquid storage, as metal hydrides have higher energy density. The advantage of metal hydrides is that they also have the ability to function as chemical heat pumps as mentioned earlier, i.e. the metal hydride heating and cooling systems operate similar to conventional solid sorption systems. The metal complexes are also cheap to obtain. The combine benefits of chemical sorption and combustion of hydrogen should increase the overall efficiency and reliability of these power plants.

Manufacturing industries

Industries generally produce a lot of waste heat. Certain industries such as steel and glass production do not have infrastructure to distribute its waste process heat for district heating. It does not have the economies of scale and in direction competition with energy industries, hence making it difficult for non-energy industries to make a profitable investment in district heating infrastructures. A good alternative will be to upgrade its waste process heat to be return into their processes again. The exothermic hydrogenation of ketone and/or aldehyde to alcohol at high temperature serves as a mechanism for heat upgrade. Regeneration occurs when alcohol is subjected to lower temperatures where it experiences endothermic dehydrogenation. The medium can be reused and regenerated without incurring loss. Some authors propose using mechanical heat pump although Ajah et al, (2008) show that it is not as efficient.

Automobiles

For automobiles, a good solution will be the application of PCM with thermoelectric materials. Thermoelectric materials need to run at large temperature difference to produce electricity. The charging up phase occurs when the internal engine is running, where PCM melts as it meets the hot exhaust gas. The discharging phase occurs when the internal combustion engine is shut off. The temperature difference between the liquid PCM and lower ambient air drives electricity production. The electricity produced from waste heat can be used to operate electrical and electronic equipments within the automobiles instead of using mechanical energy directly from combustion that was meant for locomotion. A good area of research will be using chemical sorption pumps to cool down automobiles for comfort of passengers especially in warm countries. The current chemical heat pumps are too heavy and bulky to be used efficiently and properly as an air conditioner. Most automobile air-conditioners run on mechanical vapor compression heat pumps that divert part of the mechanical energy away from locomotion.

Localized heating

The ground is used a sensible heat storage. Heat charging occurs in warmer weather (e.g. summer). The heat stored will then be discharged during winter to maintain warmth within the buildings. The ground does also act as ‘cold’ storage (i.e. heat is discharged during winter, storing ‘cold’ in the process). This ‘cold’ storage can be use to cool the buildings at times of warm weather (e.g. summer). To maintain, rather constant cooling or heating rate in the buildings (i.e. rather constant ground temperature), PCMs can be used. This energy stored in the ground is used as ground sourced heat pumps (GSHP). They are more efficient than conventional heating and air-conditioning technologies and typically have lower maintenance costs. Energy consumption is reduced by 30–70% in the heating mode and 20–50% in the cooling mode can be obtained (Benli and Durmuş, 2009). GSHP used in conjunction with PCM could potentially yield even higher savings. Using the ground as sensible heat 53 storage in certain countries where permafrost is significant may not go down well environmentally, as many climate scientists are worried that the melting of permafrost as a result of global warming could raise sea level. 6.

CONCLUSIONS

This report identifies the various technologies available for thermal energy storage. The most promising routes are usually a combination of different technologies and vary by their intended applications. When considering thermal storage technologies, All these factors determine the feasibility and the appropriate applications of certain thermal storage technologies. Although there are applications where thermal energy storages are in the form of stored ‘cold’, for example using excess electricity to make and store ice to be used in cooling applications later on, this report does not attempt to cover the ‘cold’ storage as this review is based on high temperature applications.
A few technologies have been identified to be of great potential:

- Phase change materials (latent heat storage);
- Sensible heat storage;
- Chemical/ bond storage; and
- Metal hydride storage.

Applications of these TES technologies largely depend on type of heat source, for example:

(i) Industrial heat source has better economy of scale than smaller more localized heat sources such as vehicle engines. The weight of the heat storage medium is of less importance in industry since the burden of transportation is less than in, for example, vehicle engines.

(ii) Chemical/bond storage and metal hydride storage are particularly interesting because they have the potential to upgrade widely available low grade heat source to high grade heat as high grade heat source has more practical applications, especially in heavy industries. a. Chemical/ bond storage also works as an adsorption heat pump with same function as mechanical vapor compression heat pump.

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