Phase Change Materials for Thermal Energy Storage in Greenhouse: A Review

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Abstract. Latent heat storage in a Phase Change Material (PCM) is very attractive because of its high storage density with small temperature swing. It has been demonstrated that, for the development of a latent heat storage system, the choice of the PCM plays an important role in addition to heat transfer mechanism in the PCM. The information on the latent heat storage materials and systems is enormous and published widely in the literatures. In this paper, we make an effort to gather the information from the previous works on PCMs used in greenhouses. Each of the literature cited was represented here with a "dry matter" approach, in other words the most useful parts to the scientists working on the subject were summarized. Such an investigation revealed that the types of heat exchangers, stores and the amounts of phase change materials per square meter of greenhouse ground area were dissimilar in all of the studies.

Keywords: Thermal energy storage, Latent heat storage, Phase change material, Greenhouse.

1 Introduction

The continuous increase in the level of greenhouse gas emissions and the climb in fuel prices are the main driving forces behind efforts to more effectively utilize various sources of renewable energy. In many parts of the world, direct solar radiation is considered to be one of the most prospective sources of energy. The scientists all over the world are in search of new and renewable energy sources. One of the options is to develop energy storage devices, which are as important as developing new sources of energy. The storage of energy in suitable forms, which can conventionally be converted into the required form, is a present day challenge to the technologists [1].

Energy storage not only reduces the mismatch between supply and demand but also improves the performance and reliability of energy systems and plays an important role in conserving the energy. It leads to saving of premium fuels and makes the system more cost effective by reducing the wastage of energy and capital cost [2]. For example, storage would improve the performance of a power generation plant by load levelling and higher efficiency would lead to energy conservation and lesser generation cost. One of prospective techniques of storing thermal energy is the application of phase change materials (PCMs). Unfortunately, prior to the large-scale practical application of this technology, it is necessary to resolve numerous problems at the research and development stage [3].

Types of energy storage methods are given below [4].

1.1 Mechanical energy storage

Mechanical energy storage systems include gravitational energy storage or pumped hydropower storage (PHPS), compressed air energy storage (CAES) and flywheels. The PHPS and CAES technologies can be used for large-scale utility energy storage while flywheels are more suitable for intermediate storage. Storage is carried out when inexpensive off-peak power is available, e.g., at night or weekends. The storage is discharged when power is needed because of insufficient supply from the base-load plant.

1.2 Electrical storage

Energy storage through batteries is an option for storing the electrical energy. A battery is charged, by connecting it to a source of direct electric current and when it is discharged, the stored chemical energy is converted into electrical energy. Potential applications of batteries are utilization of off-peak power, load leveling, and storage of electrical energy generated by wind turbine or photovoltaic plants. The most common type of storage batteries is the lead acid and Ni –& Cd.

1.3 Thermal energy storage

Thermal energy storage (TES) systems can store heat or cold to be used later under varying conditions such as temperature, place or power. The main use of TES is to overcome the mismatch between energy generation and energy use. In TES systems energy is supplied to a storage system to be used at a later time, involving three steps: charge, storage and discharge, giving a complete storage cycle (Fig. 1).

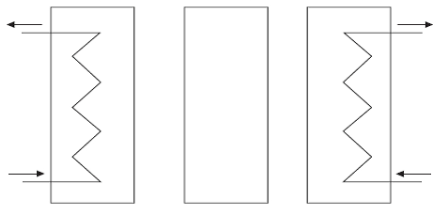

Fig. 1. TES complete storage cycle

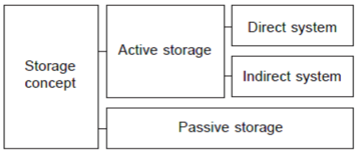

Fig. 2. Scheme of classification of different storage systems according to the storage

Storage concepts are active or passive systems (Fig. 2). An active storage system is characterized by forced convection heat transfer into the storage material. The storage material circulates through a heat exchanger, a solar receiver or a steam generator. Active storage systems can be direct, the heat transfer fluid (HTF) serving also as storage medium, or indirect systems, where a second medium is used for storing the heat. Passive storage systems are generally dual –& medium storage systems, where the HTF passes through the storage only for charging and discharging a solid material [5].

2 TYPES OF TES TECHNOLOGIES

Thermal energy available in the form of heat or cold can be stored by virtue of change in internal energy of a material through sensible heat, latent heat, and thermochemical means [6][7]. Thermal energy can be either stored in the aforementioned means independently or in combination with these storage means. The three major physical principles by which the heat or cold energy can be stored is explained in forthcoming sections.

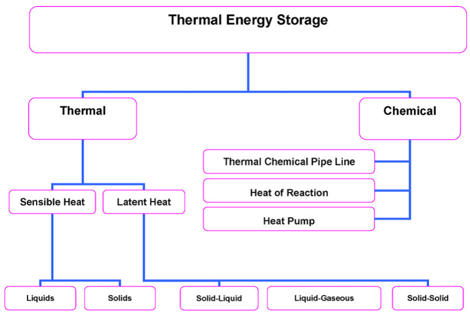

Fig. 3. Different types of thermal storage

2.1 Sensible heat storage

In sensible heat storage (SHS), thermal energy is stored by raising the temperature of a solid or liquid. SHS system utilizes the heat capacity and the change in temperature of the material during the process of charging and discharging. The amount of heat stored depends on the specific heat of the medium, the temperature change and the amount of storage material [3][8].

$$Q = \int_{T_i}^{T_f} mC_p dT = mC_{ap}(T_f - T_i)$$

SHS systems can be classified on the basis of storage material as liquid media sensible storage (such as water, oil, molten salt, etc.) or solid media sensible storage (such as rocks, and metals).

2.2 Latent heat storage

Latent heat thermal energy storage (LHS) involves heating a material until it experiences a phase change, which can be from solid to liquid or from liquid to gas; when the material reaches its phase change temperature it absorbs a large amount of heat in order to carry out the transformation, known as the latent heat of fusion or vaporization depending on the case, and in this manner the energy is stored.

The following graph further explains the storage mechanism; as a solid material is heated its temperature begins to increase in direct proportion to the received energy until it reaches the melting temperature. Beyond this point, the energy delivered to the material ceases to raise the temperature, and is used instead to perform the transition from solid to liquid (latent heat), that is, the material stores isothermally the thermal energy received; once the transformation is complete and the material is wholly in the liquid state, the temperature begins to increase again as it receives a heat input until it reaches the vaporization point where the occurred in the first phase change is repeated. The heating process works the same way for cooling, which means that it is possible to extract the stored energy as latent heat at a constant temperature (Fig. 4).

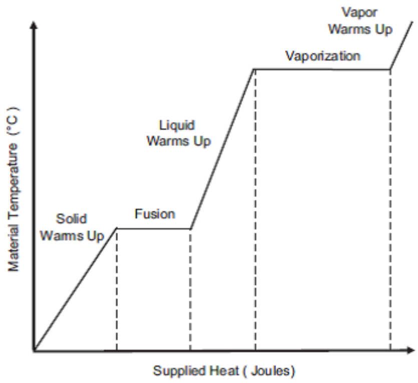

Fig. 4. Temperature increase profile in respect of supplied heat

As can be seen it is impossible to exclusively store latent heat, as to reach the phase change point the material had to undergo a temperature increase which represents storage of sensible heat. The storage capacity of an LHS system can be represented by the following expression [3][8]:

$$Q = \int_{T_i}^{T_m} mC_p dT + ma_m \Delta h_m + \int_{T_m}^{T_f} mC_p dT$$

$$Q = m\left[C_{sp}(T_m - T_i) + a_m \Delta h_m + C_{lp}(T_f - T_m)\right]$$

The first term of the equation represents the sensible heat stored by the material temperature increase from its initial temperature to the phase change temperature, the second term represents the energy stored by the latent heat of the material during the phase change, the amount of energy stored depends on the amount of material, the specific latent heat and the fraction of the material that has experienced a transformation. If the material is further heated after the phase change a third term appears in the equation to account again for sensible heat storage.

Materials used for latent heat thermal energy storage are known as phase change materials (PCMs). The PCM may undergo solid –& solid, solid –& liquid and liquid –& gas phase transformations.

i. Solid –& solid latent heat storage

Generally, LHS systems use the latent heat between solid and liquid phases of the storage medium, whereby the PCM is required to be contained or encapsulated within a container to prevent the liquid from leaking; however, the capsules decrease the energy density of the system and increase the cost of production. To overcome these problems the use of the solidsolid phase change of certain materials has been proposed as an alternative (SSPCM). Relatively few SSPCM with suitable transition temperatures and latent heats for thermal storage applications have been identified.

Solid –& solid phase change is quite simple and provides advantages such as easy handling and cost effectiveness, because as it has been said, the lack of liquid material eliminates the risk of leakage and hence there is no need for encapsulation. There has been work focused on developing steel alloy based SSPCM for high temperature waste heat recovery [9].

Despite the advantages that SSPCM offer, their latent heat of transition is about one order of magnitude smaller than that of the solid –& liquid PCM, which is a major drawback that has to be addressed in order to achieve a greater introduction of this technology. SSPCM metal alloys are expected to be used in the future in stationary systems, as structural materials with a heat storage function, because they have a small latent heat per mass unit, but a rather large per volume unit. This means that they are suitable for energy storage on site but unsuitable for energy transport.

ii. Liquid –& gas latent heat storage

Transformations from liquid to gas have the highest latent heat of phase change; however, the enormous changes in the volume of the storage material associated with the evaporation make the storage complex and highly impractical; thus the possible use for TES systems is discarded, the reason why the gaseous state information of many materials is quite limited.

iii. Solid –& liquid latent heat storage

The change from solid to liquid phase is the transformation that has been most widely studied and used in LHS applications; despite having a smaller latent heat compared with the liquid –& gas phase change it does not present such a serious problem regarding volumetric expansion, which is generally in the order of an increase of 10% or less relative to the original volume [3].

During fusion, the heat is transferred to the PCM in the first instance by conduction and by natural convection afterwards; this is because the solid region moves away from the heat transfer surface and the liquid region thickness increases near the heat transfer surface. Since the liquid PCM thermal conductivity is lower than that of the solid PCM, the conductive heat transfer becomes almost negligible as the melting process continues due to the density gradient that exists in the liquid PCM.

Contrary to the melt, solidification is dominated by conduction; during solidification natural convection exists only in the beginning of the process and as time passes the effect is negligible compared to the conduction effect [9].

Using solid –& liquid transition PCMs has a number of technical complications; one of the biggest problems that has contributed to the widespread use of LHS remains unsatisfactory so far is the unacceptably low thermal conductivity of the PCMs; besides that, there are other problems such as the complexity of the container, phase segregation and subcooling, which can be very severe and completely impede the extraction of the stored energy [9].

The distinctive feature and main advantage of LHS systems is the isothermal operation at the phase change temperature of the material, i.e. it is able to deliver the stored energy at a nearly constant temperature. Another advantage offered by this type of storage is its compactness; due to that in most materials the latent heat of fusion is much greater than the specific heat. For example, 80 times more energy is required to melt 1 g of ice (latent heat) than to raise the temperature of 1 g of water 1°C (sensible heat).

Given its characteristics, the phase change materials are chosen over sensible heat materials primarily for applications where volume and weight are restrictions and therefore a high energy density is required or when there is a load whose power input must be at constant temperature.

Typically, PCMs are placed in long slender tubes tightly packed within a container. During a storage cycle in a solar application, for example, the heat collected by the unit is transported by a heat transfer fluid (HTF) through the narrow spaces between the tubes, melting the PCM. During the extraction cycle or heat recovery, the circulation of low temperature HTF collects the energy stored in the PCM and transports it to the thermal load.

Any LHS system must possess at least the three following basic components:

- a substance or energy storage medium, which undergoes a solid to liquid phase change at the required temperature range where most of the added heat is stored as latent heat;
- a container for containing the storage medium;
- a heat exchange surface to transfer the energy from the heat source to the PCM and from the PCM to the load [9].

2.3 Thermochemical energy storage

Thermochemical systems rely on the energy absorbed and released in breaking and reforming molecular bonds in a completely reversible chemical reaction. In this case, the heat stored depends on the amount of storage material, the endothermic heat of reaction, and the extent of conversion [3].

$$Q = a_r m \triangle h_r \tag{1}$$

3 LATENT HEAT STORAGE MATERIALS

Phase change materials (PCM) are "Latent" heat storage materials. The thermal energy transfer occurs when a material changes from solid to liquid, or liquid to solid. This is called a change in state, or "Phase". Initially, these solid –& liquid PCMs perform like conventional storage materials, their temperature rises as they absorb heat. Unlike conventional (sensible) storage materials, PCM absorbs and release heat at a nearly constant temperature. The effect of latent heat storage has two main advantages:

1. It is possible to store large amounts of heat with only small temperature changes and therefore to have a high storage density. 2. Because the change

of phase at a constant temperature takes some time to complete, it becomes possible to smooth temperature variations.

They store 5 –& 14 times more heat per unit volume than sensible storage materials such as water, masonry, or rock. A large number of PCMs are known to melt with a heat of fusion in any required range. However, for their employment as latent heat storage materials these materials must exhibit certain desirable thermodynamic, kinetic and chemical properties. Moreover, economic considerations and easy availability of these materials has to be kept in mind.

The PCM to be used in the design of thermal-storage systems should passes desirable thermophysical, kinetics and chemical properties which are as follows [3][10]:

3.1 Properties of PCMs

Thermal properties

1. Suitable phase-transition temperature.
2. High latent heat of transition.
3. Good heat transfer.

Selecting a PCM for a particular application, the operating temperature of the heating or cooling should be matched to the transition temperature of the PCM. The latent heat should be as high as possible, especially on a volumetric basis, to minimize the physical size of the heat store. High thermal conductivity would assist the charging and discharging of the energy storage.

Physical properties

1. Favorable phase equilibrium.
2. High density.
3. Small volume change.
4. Low vapor pressure.

Phase stability during freezing melting would help towards setting heat storage and high density is desirable to allow a smaller size of storage container. Small volume changes on phase transformation and small vapor pressure at operating temperatures to reduce the containment problem.

Kinetic properties

1. No supercooling.
2. Sufficient crystallization rate.

Supercooling has been a troublesome aspect of PCM development, particularly for salt hydrates. Supercooling of more than a few degrees will interfere with proper heat extraction from the store, and 5 –& 10 °C supercooling can prevent it entirely.

Chemical properties

1. Long-term chemical stability.
2. Compatibility with materials of construction.
3. No toxicity.
4. No fire hazard.

PCM can suffer from degradation by loss of water of hydration, chemical decomposition or incompatibility with materials of construction. PCMs should be non –& toxic, nonflammable and non-explosive for safety.

Economics

1. Abundant.
2. Available.
3. Cost effective.

Low cost and large-scale availability of the phase change materials is also very important.

3.2 Classification of PCMs

A large number of phase change materials (organic, inorganic and eutectic) are available in any required temperature range. A classification of PCMs is given in Fig. 5.

There are a large number of organic and inorganic materials, which can be identified as PCM from the point of view melting temperature and latent heat of fusion. As no single material can have all the required properties for an ideal thermal storage media, one has to use the available materials and tries to make up for the poor physical property by an adequate system design. For example metallic fins can be used to increase the thermal conductivity of PCMs, super cooling may be suppressed by introducing a nucleating agent in the storage material and incongruent melting can be inhibited by use of suitable thickness.

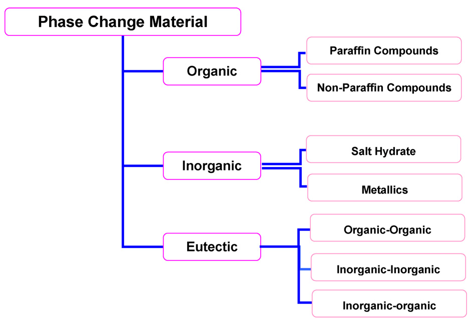

Fig. 5. Classification of PCMs [3]

4 THERMAL ENERGY STORAGE (TES) TECHNOLOGIES FOR GREENHOUSE SYSTEMS WITH PHASE CHANGE MATERIAL (PCM)

Since the 1970s TES systems have proven to be significant tools to increase energy efficiency in contrast to conventional energy systems. TES systems provide alternative heating and cooling solutions to decrease consumption of electricity and fossil fuels and also replace mechanical cooling devices. Greenhouses need a lot of thermal energy, and a significant portion of its costs is heating. Therefore they can get major benefits from TES [11].

Phase change materials with high latent heat storage capacities and isothermal application opportunities can be used in active or passive greenhouse systems for storing the solar energy for curing and drying process and plant production. The alternatives for using PCMs in greenhouses are as follows:

- Active systems
  - diurnal storage in combination with heat pumps
  - diurnal storage with solar collectors
  - peak shaving with seasonal storage systems

- Passive systems
  - passive storage with the greenhouse covering material
  - passive storage to control temperature of the plants and to protect from frost.

Depending on the way PCMs are used, different materials with different phase change temperatures and encapsulation techniques may be needed [11].

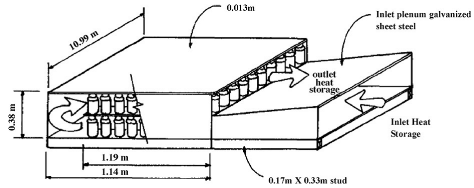

Fig. 6. Energy storage unit inside the greenhouse [12]

Kern and Aldrich [12] employed 1650 kg of CaCl2·6H2O in aerosol cans each weighing 0.74 kg was used to investigate energy storage possibilities both inside and outside a 36 m2 ground area greenhouse covered with tedlar-coated fibreglass. PCM cans were placed in a store with 22.86 mm spacing and two stores containing different amounts of PCM was used, one inside and the other outside the greenhouse. While the energy storage unit inside the greenhouse collected warm air from the ridge of the greenhouse during the daytime, the direction of air flow was reversed for the energy releasing process at night (Fig. 6).

Hung and Toksoy[13] had designed and constructed a latent heat storage system with two different stacking configurations and air baffling as an integrated part of the greenhouse solar system. Commercial cylindrical storage rods were used as the primary storage elements. The results showed that the designed latent storage systems demonstrated significantly higher compact storage capacity than the rock or water storage. It is also revealed that the ring-baffled storage unit performed better than the cross –& baffled storage unit. Using phase change material, experiments were conducted in a 500 m2 single glazed greenhouse for the production of rose in France (Fig. 7). The solar heat available inside the greenhouse was transferred and stored by recycling the air through an underground of flat heat exchangers filled with a PCM. The performance of solar greenhouse compartment with PCM storage was compared with a traditional greenhouse of identical geometry having the same plantation. The PCM green house achieved 80% savings in propane gas as compared with the traditional green house to have the same temperature. Latent heat storage material can also be stacked in racks placed in a greenhouse which will be directly heated by the solar radiation [14]. In this system the hot air was circulated in the greenhouse through the storage to increase the rate of charging/discharging of PCM. The stored heat was utilized during off sunshine hours to maintain the desired temperature of the green house. Na2SO4·10H2O was used as PCM storage material in the green house.

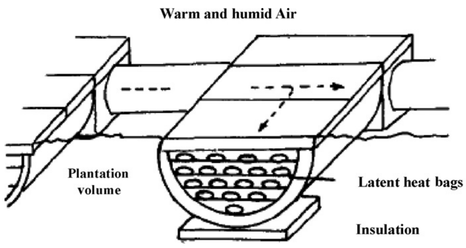

Fig. 7. Underground tunnel with PCM Storage [15]

Nishina and Takakura[16] used Na2SO4·10H2O with some additives to prevent phase separation and degradation for heating a greenhouse in Japan. Fig. 8 shows the general view of the experimental set –& up. They concluded that 40 –& 60% of the latent heat potential of the PCM was realized, which indicated that almost half of the PCM was not used efficiently during the energy exchange processes. Takakura and Nishina[17] tested polyethylene glycol and CaCl2·6H2O as PCMs in greenhouse heating for 7.2 m2 ground area. They compared conventional greenhouses with PCM storage type greenhouses. The efficiency of the greenhouse with PCM storage integrated with solar collector was 59% and able to maintain 8°C inside the greenhouse at night, when the outside temperature dropped to -0.6°C. A microcomputer control system has been developed in order to establish more accurate and more sophisticated control for solar greenhouse systems.

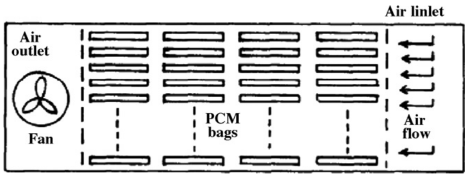

Fig. 8. General view of the phase change energy storage system in green house [16]

In a design and experimentation study by Baille and Boulard[18] and Boulard et al. [19] CaC12·6H2O melting at 21°C was utilized in a greenhouse with 176 m2 ground area, double polycarbonate-cover and forced ventilation (Fig. 9). Thermostat settings for night and day in February and March were, respectively, 12 and 14, and 22 and 26°C. Air velocity in the greenhouse had an order of magnitude 1 m/s. It was calculated that while 0.260 kW h/m2 energy was stored during the daytime, 0.360 kW h/m2 was released at night in the greenhouse. When the outside air temperatures were 3.8 and 6.6 °C, respectively, in February and March, inside air temperatures for the same periods of 10.9 and 13.5 8C were obtained. With this method, instead of what would be 7.2 1/m2 fuel requirement, 40% of heating load was supplied and an overall 30% in energy saving was achieved.

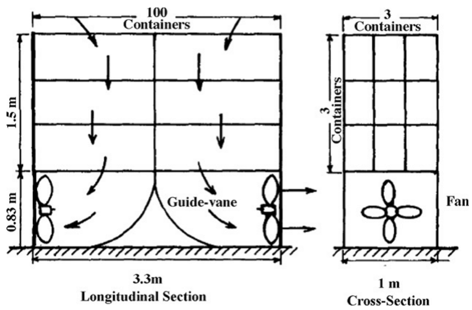

Fig. 9. General view and dimensions of the energy storage unit [15]

Ozturk[20] presented a seasonal thermal energy storage using paraffin wax as a PCM with the latent heat storage technique was attempted to heat the greenhouse of 180 m2 floor area. The schematic arrangement of the LHS system for greenhouse heating is given in Fig. 10. The system consists mainly of five units: (1) flat plate solar air collectors (as heat collection unit), (2) latent heat storage (LHS) unit, (3) experimental greenhouse, (4) heat transfer unit and (5) data acquisition unit. The external heat collection unit consisted of 27 m2 of south facing solar air heaters mounted at a 558 tilt angle. The diameter and the total volume of the steel tank used as the latent heat storage unit were 1.7 m and 11.6 m3, respectively. The LHS unit was filled with 6000 kg of paraffin, equivalent to 33.33 kg of PCM per square meter of the greenhouse ground surface area. Energy and exergy analyses were applied in order to evaluate the system efficiency. The rate of heat transferred in the LHS unit ranged from 1.22 to 2.63 kW, whereas the rate of heat stored in the LHS unit was in the range of 0.652.1 kW. The average daily rate of thermal exergy transferred and stored in the LHS unit were 111.2 W and 79.9 W, respectively. During the experimental period, it was found that the average net energy and exergy efficiencies were 40.4% and 4.2%, respectively. The effect of the temperature difference of the heat transfer fluid at the inlet and outlet of the LHS unit on the computed values of the energy and exergy efficiency is evaluated during the charging period.

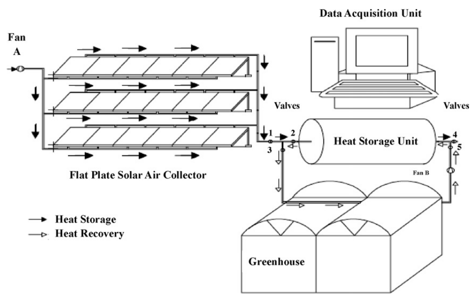

Fig. 10. The arrangement of the heat storage and greenhouse heating system [20]

5 SUMMARY

Energy storage studies for heating greenhouses dates back to the 1980s. Early studies started with CaC12·6H2O; later on this was followed by Na2SO2·10H2O, PEG and paraffins. Amounts of PCMs per square meter of greenhouse ground area and melting temperatures varied from application to application with minimum and maximum amounts of 4.84 kg/m2 and 83.3 kg/m2. Most applications were carried out in either double-covered greenhouses or greenhouses with one or more layers of thermal screens. However, all studies imply that PCMs could be used for both energy storage and humidity control in greenhouses, in a way for energy management, effectively given the right choice and design of the whole system [15].

PCM applications in greenhouses as summarized in Table 1 were in the pilot stage for greenhouses with areas between 20 and 500 m2. Energy savings in the range of 20 –& 51% were achieved in these studies. CaCl2·6H2O was the PCM preferred for short-term heat storage in the majority of the studies [11].

Many greenhouses around the world can benefit considerably from TES systems. These benefits are: more manageable interior temperatures, increased yields, extended harvests, improved working conditions inside the greenhouse, energy savings, less reliance on fossil fuels, and CO2 emissions reduction.

6 CONCLUSION

This review paper is focused on the available thermal energy storage technology in greenhouses with PCMs. Those technologies is very beneficial for the humans and as well as for the energy conservation.

The achieved sustainable benefits could result in more profitable greenhouse growing, and increased food production capacities would result in their spreading. Especially in developing countries, greenhouses would relieve the undernourished population with crops produced in an economic and more sustainable manner.

More demonstration greenhouses with TES would help determine better management strategies. Such examples would also reinforce the benefits observed in earlier studies. Various locations would necessitate the adaptation of this technology for different climate conditions. The result would be a proliferation of greenhouse TES technologies on a wider scale.

The trend in greenhouse development is from self-sufficient greenhouses to energy-producing greenhouses. With TES systems properly integrated into greenhouses, it will be possible to use greenhouses as energy sources for heating buildings near them. This concept is already under development in Denmark, Netherlands and Sweden.

In future greenhouses, TES solutions can combine heating-cooling-dehumidification functions and provide poly-generation possibilities. Further research on the possibility of thermochemical energy storage and better development of phase change materials is needed for this option to be widely adopted in a more cost-effective manner.

References

1. Garg HP, Mullick SC, Bhargava AK., Solar thermal energy storage, D. Reidel Publishing Co., 1985.
2. Johan HeierProject Report, Energy conservation through thermal energy storage, KTH School of Industrial Engineering and Management, Stockholm, 2013.
3. A. Sharma, V. Tyagi, C. Chen and D. Buddhi, "Review on thermal energy storage with phase change materials and applications," Renewable and Sustainable Energy Reviews, vol. 13, pp. 318-345, 2009.
4. Khartchenko NV, Advanced energy systems, Berlin: Institute of Energy Engineering & Technology University, 1997.
5. I. M. L. M. A. I. F. C. B. L. F. Cabeza, "Introduction to thermal energy storage (TES) systems," in Advances in Thermal Energy Storage Systems, Spain, Elsevier, 2015, pp. 1-28.

6. ASHRAE, ASHRAE handbookHVAC systems and equipment, Atlanta GA-30329: ASHRAE, 2008.
7. B. Silvetti, "Thermal energy storage," in Encyclopedia of energy engineering and technology, Boca Raton, FL: CRC press, 2007, pp. 1412-1421.
8. L. GA, Solar heat storage: latent heat material, Florida: CRC press Boca Raton, 1983.
9. N. Bruno Crdenas, "High temperature latent heat thermal energy storage: Phase change materials, design considerations and performance enhancement techniques," Renewable and Sustainable Energy Reviews, vol. 27, pp. 724-737, 2013.
10. A. ABHAT, "Low temperature latent heat thermal energy storage: heat storage materials," Solar Energy, vol. 983, pp. 313-332., 1983.
11. B. B. H. . Paksoy, "Thermal energy storage (TES) systems for greenhouse technology," in Advances in Thermal Energy Storage Systems, Turkey, Elsevier, 2015, pp. 533-548.
12. K. M and A. RA, Phase change energy storage in a greenhouse solar heating system, St. Joseph, MI, 1979.
13. H. K and T. M, "Design and analysis of greenhouse solar system in agricultural production," Energy Agric, vol. 2, no. 2, pp. 115-136, 1983.
14. H. . K. Song, "Utilization of latent heat storage materials for the high concentrated thermal energy storage," 1988.
15. A. Kurklu, "Energy storage applications in greenhouses by means of phase change materials (PCMs): a review," Renewable Energy, vol. 13, no. 1, pp. 89-103, 1998.
16. N. H and T. T, "Greenhouse heating by means of latent heat storage units," ActaHort (Energy in Protected Cultivation Ill, vol. 148, pp. 751-754, 1984.
17. T. T and N. H, "A solar greenhouse with phase change energy storage and a microcomputer control system," ActaHort (Energy in Protected Cultivation), vol. 115, pp. 583-590, 1981.
18. B. A and B. T, Phase change material for heat storage in greenhouse, R. t. s. l, Ed., von Zabeltitz C, 1987, pp. 139-142.
19. B. T, R. E, B. A, J. A and F. B, "Performance of a greenhouse heating system with a phase change material," Agric Forest Meteorol, vol. 52, pp. 303-318, 1990.
20. H. H. Ozturk, "Experimental evaluation of energy and exergy efficiency of a seasonal latent heat storage system for greenhouse heating," Energy Conversion and Management, vol. 46, pp. 1523-1542, 2005.

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