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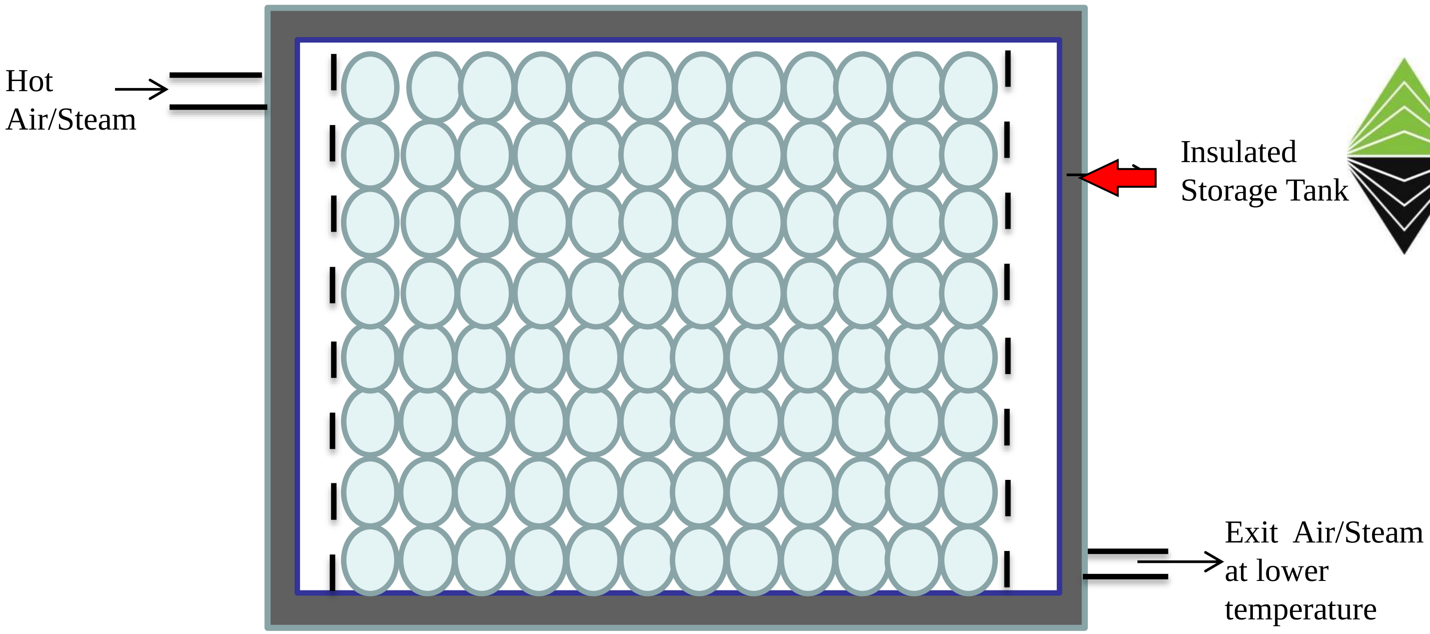

Keilir Atlantic Center of Excellence

Development of Encapsulated Phase Change Material

for

Thermal Energy Storage and Transport

Feasibility Study

by

Nordic Engineering, Keilir Research Center and University of South Florida

JHM, August 2013

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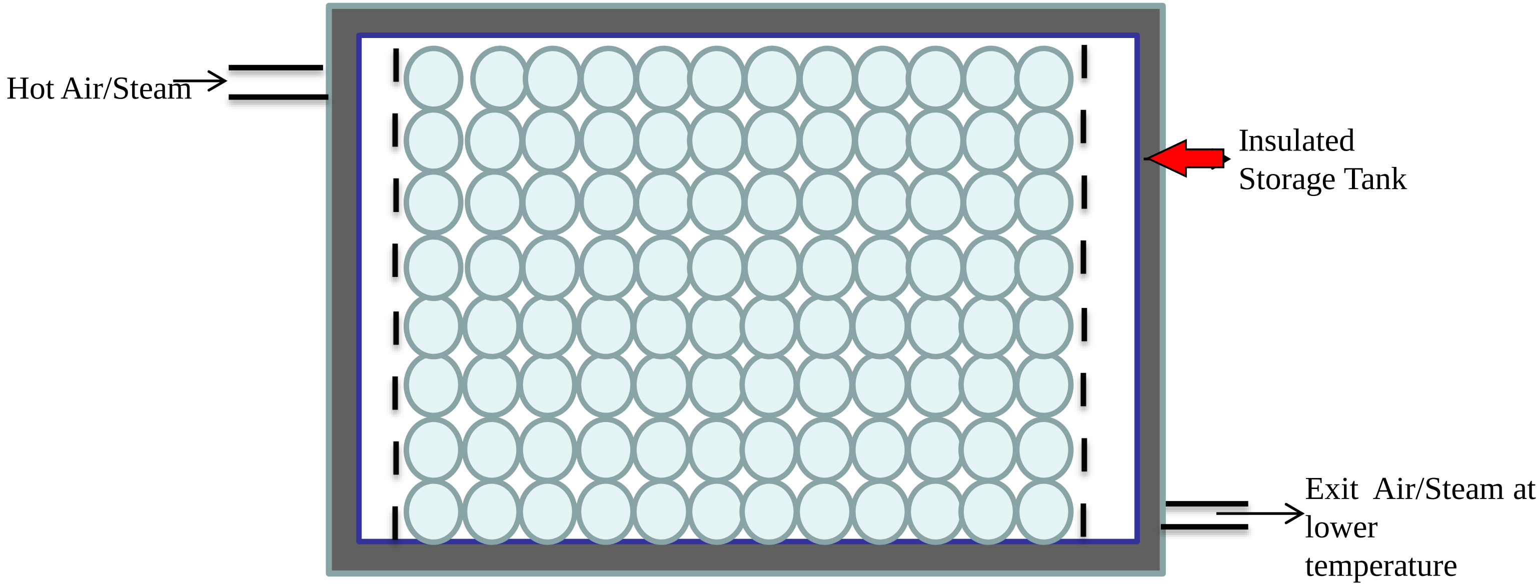

A simplified schematic of the thermal energy storage test set-up.

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Table 1. Comparison of heat storage between water and the PCMS per m^3 volume.

Water	PCM [100°C]	PCM[150°C]	PCM[200°C]	PCM[250°C]
52.25 kWH/m^3	145.2 kWh/m^3	214.30 kWh/m^3	268.26 kWh/m^3	340.26 kWh/m^3
PCM/Water	2.8	4.1	5.1	6.5

Table 2. Comparison between water and PCMs* for a 63 m^3 (40ft container)

Water	PCM [100°C]**	PCM [150°C]*	PCM [200°C]*	PCM [250°C]*
3292 kWh	7977 kWh	10801 kWh	13520 kWh	17150 kWh
PCM/Water	2.42	3.2	4.1	5.2

* Assuming 20% void fraction PCM in the container.

** Void fraction is filled with water

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Task 1- Characterization of PCMs

UoSF will measure the thermophysical properties of salt or salt eutectic in the laboratory. These properties include melting point, heat of fusion, specific heat and thermal conductivity. Simultaneously, a thermal analyzer SDT-600, TA instrument, will be used to measure melting point, heat of fusion and specific heat of the PCMs. A Linseis XFA 500 will be used to measure the thermal diffusivity of PCMs. From the data obtained, the energy storage density will be calculated.

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Task 2- Encapsulation of PCM pellets

UoSF has developed a cost effective PCM storage system that involves the encapsulation of high temperature, 300 to 450^{o}C, PCMs. The encapsulating material is stable in a wide temperature range and is inert to most of the known salts and their eutectics. In addition, it is also able to accommodate the change in volume of the PCM on melting without the need of void space. In our present development the PCM capsules have undergone more than 1700 thermal cycles using air as a heat transfer fluid which corresponds to about 5 years of life. This developed encapsulating technique may be used with selected PCMs which melt in the proposed temperature range (100-250^{o}C). In addition, simpler and more cost effective encapsulating methods will be pursued (depending on the heat transfer fluid, HTF). Even though our present method has been applied to spherical capsules, other shapes may be found to be easier to implement and cheaper.

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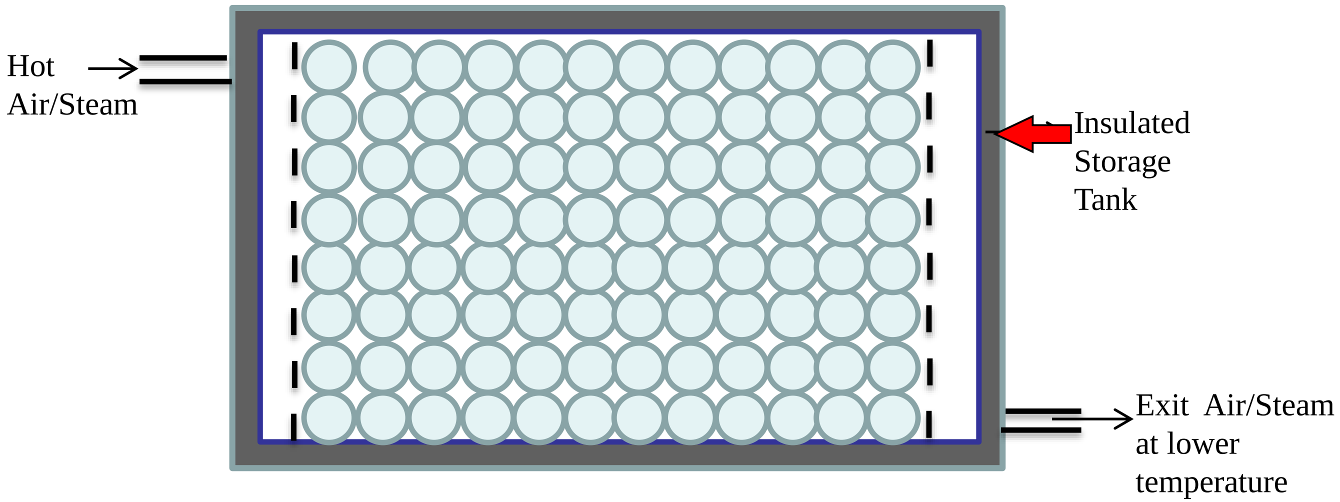
Task 3- Testing of Prototype TEST System.

Task 3 of the proposed R&D will focus on testing a prototype laboratory scale TEST system in order to measure the properties of the system and assess the behavior of the capsules under continuous cycling. The tank material will be made of carbon steel and will be insulated to minimize heat losses during the experiment. Figure 1 shows the simplified schematic of the thermal energy storage test set-up.



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Task 3 cont.- Testing of Prototype TEST System.

The heat transfer fluid (hot air or steam) will be passed through the PCM capsules at the charging temperature. While passing through the tank, it will supply heat to the PCM capsules and will exit through the tank outlet. During this procedure, the thermal performance in terms of the charging and discharging rate and energy storage density of the TEST system will be measured. Thermal performance will be measured by calculating the efficiency, η (= $Q_{stored}/Q_{theoretical}$) of the TES unit. $Q_{theoretical}$ is the theoretical heat storage capacity, which is the sum of sensible heat and latent heat of the PCM within the operating range of the experiments. Q_{stored} is the heat stored during the experiments and is estimated using the flow rate of the heat transfer fluid, its specific heat and the measured fluid temperatures at the inlet and outlet of the TES storage unit.

We have successfully tested the developed PCM capsules with air as a heat transfer fluid and it is proposed to test the same with steam (as an alternative HTF).

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At the end of the project period detailed and complete information will be available on the following:

1. PCM material to be used for application at 100, 150, 200 and 250 °C.
2. Encapsulation material and the most durable and cost effective encapsulation method.
3. Ability of encapsulated material to withstand the HTF (air or steam). Air will be especially studied as the preferred HTF.
4. 40'container storage capacity with specific PCMs and operating temperatures.
5. Percent of container space that will be void of PCM material. Typically one would expect a void fraction of 0.3 to 0.4.

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KERC´s Task 4 - Feasibility Study for the TEST System.
KERC in cooperation with its Icelandic partners will study the feasibility of utilization of geothermal heat from Geothermal Power Plants for storage and transport of thermal energy to cold areas in Iceland as well as for export to the Faroe Islands, Greenland, Europe, New Foundland, etc.

KERC´s Task 5 – Design of Full Scale Plant for Encapsulation of PCM Pellets
KERC will develop a full scale plant for encapsulation of the PCM for high temperature thermal storage in the range of 100-250°C based on CERC´s recommendations and laboratory tests.

KERC´s Task 6 - Design of a Full Scale TEST System.
KERC in cooperation with its Icelandic partners will develop and design a full scale energy loading and unloading system for the PCMs developed by CERC as well as for different transport systems based on CERC´s recommendations and laboratory scale tests.
Unloading systems will be studied and developed for different applications like individual farms and houses, district heating systems, etc.
Prototypes will be built for actual testing of energy loading and unloading of the PCM in a suitable container. A transport system of the thermal energy stored in PCMs will be studied for 40ft containers, truck tank transport and double hull product tankers.

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Timeline and Milestones for Detailed Specific Tasks by CERC

Specific Research Activities	YEAR 1 - 2014			
	Q1	Q2	Q3	Q4
Task 1 Characterization of PCM's	X	X		
Task 2 Encapsulation of PCM pellets	X	X		
Task 3 Testing of prototype TES system			X	X
Reporting:		X		X

Timeline and Milestones for Detailed Specific Tasks by KERC

Specific Research Activities	YEAR 1 - 2014			
	Q1	Q2	Q3	Q4
Task 4 Feasibility Study of TEST	X	X		
Task 5 Design of Plant for Encapsulation of PCM pellets			X	X
Task 6 Design of Full Scale TEST system			X	X
Reporting:		X		X