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Experimental Studies For The Thermal Storage Tank Used In Elec-Tro-Solar Hybrid Station

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Abstract— The experimental and design work of the developed thermal storage tank is revealed by the geometric form of the designed thermal storage pattern, and presentation of design methodology of this pattern, through existence of thermal isolator of (mineral wool) on the long of nitrates salts pot, this stored energy is used for covering the different loads at decreasing of normal solar radiation intensity in electro-solar station during the day. In this research,we concentrated on the study of the experimental results of the Latent Heat Storage which uses a mixture of phase change materials(PCM:phase change material), the selected (PCM) in this research is a mixture of sodium nitrates salt and potassium nitrates salt (NaNO3: KNO3) in ratio (60:40%), where we tested this salty mixture using the special apparatus called (Differential Scanning Calorimetry ,DSC) for recognition the physical and chemical specifications of the salty mixture , it became clear that the melting temperature of this mixture is (228.521℃) and the latent heat of phase change from solid to liquid is(114.321 KJ/Kg),the results were identical for the temperature and latent heat according to many of the references in addition that the heat storage tank pattern possesses energy efficiency reaches to percentage (0.96) while the other types of thermal tanks working on (PCM) reach to energy efficiency(0.66-0.70),consequently, the heat storage tank has high latent energy suitable for the work of electro-solar stations during different period in a day.

Keywords— Thermal storage , solar radiation , hybrid stations , phase change materials (PCM), nitrates salts, thermal efficiency.

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1 Introduction

The developed system of the heat storage prototype is a heat storage prototype contains materials with high thermal characteristics , which are materials with phase changing composed of mixture of nitrate salts(sodium & potassium nitrates) for obtaining the necessary energy source for heating the thermal transfer liquid(thermal oil) in the solar field, this field is composed of several longitudinal rows and parallel of concentrated solar panels which concentrate the solar radiation and heating this liquid for helping melting these salts and generation of the suitable thermal energy for operating the energy cycle and generating of solar steam and obtaining the electrical energy at constant rate conform this station power, the operating principle of the station depends of heating the thermal transfer liquid which is thermal oil (thermonil) in the solar field system during solar radiation fall from hour(0) till hour (24) during the day, and watching the daily operating behavior of the station in each working hour of the system. The station system is composed of two main parts which are: first part is the solar field prototype which is the source of thermal energy of the station, the second part is energy cycle prototype composed of a number of heat exchangers for steam generation and a number of heaters working on natural gas for station operating at low solar radiation called non-solar hours system, a special prototype of heat energy storage is developed [1], [2].

2 Research Scope

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The aim of this research is to show the experimental and numerical results of the designed heat storage prototype in electro-solar station, where the heat energy resulted from melting operation of the used mixer of nitrates in the prototype for obtaining a suitable high level of energy for operating the developed heat storage prototype in the electro- solar station conform the following steps:

1. Principle equations used in the designed heat storage prototype for calculation of stored energy capacity.

2. Explication the working mechanism of heat storage prototype during starting of melting operation of nitrates salts mixture.

The developed thermal storage tank has thermal isolator of mineral wool on the geometric external body of the thermal tank designed for the surrounding ambient with existence of a mixture of melted nitrates salts, this design conserves the heat energy from losing and infiltration at the work of this tank in electro- solar station.

This prototype with cylindrical shape with following dimensions:volume 0.345(m^3) height 1(m), and external diameter 31(cm), it contains nitrates salts, salts mixture works in the determined temperature range from (260-550℃) [3], [4].

The experimental operation has three main aims in sake of development of the developed heat storage which are:

1.Showing the working mechanism of this pattern for understanding the mechanism of thermal transfer during each single phase of charging and discharging of melted mixture of nitrates salts.

2.Showing the heat transfer mechanism during melting and solidification period of the mixture inside the thermal tank.

3.Showing and indication the experimental and designed statements of charging and discharging operations of the thermal tank model. The heat exchangers existing in the thermal tank contain a set of chrome pipes, the heat storage cylindrical body is made of stainless steel with diameter 31(cm) with determined dimensions according to the volume change during charging phase, the thermal hot oil enters from the top and exit from the heat storage bottom, returning to oil reservoir within a close cycle , where the phase change material (nitrates salts) is melted, it will be a constant charging period of this material during melting operation. The main problem in operating of phase change materials (PCM) is the low heat conduction of (PCM), during the discharging of the heat storage the (PCM) becomes hard on the internal surface of pipes, the thermal flux will decrease as result of heat isolation of the(PCM) thick layer , as there are two layers: First layer is the solid phase of nitrates salts (sodium & potassium nitrates) as result of these salts solidification after a period of time .

Second layer: is the exterior pipe wall of heat exchangers pipes inside of the designed heat storage .

It is important to calculated the necessary solidification time of the mixture of nitrates salts in the thermal tank pattern during solidification phase firstly, secondly determination the thermal flow of solidification phase at temperature difference between the internal surface touching the solidified material and the external surface of heat storage, the phase change of nitrates salts depend on temperature inside heat storage in relation with temperature of exterior surface of designed heat storage prototype

The main reason for selecting nitrates salts is that they have high latent energy comparing with other types of (PCM), they have high temperature enabling them to work in high thermal efficiency, as these salts work in the temperature range (260-550C°) ,and a rate(4.6%) of volume increasing at the beginning of melting operation of nitrates salts in the designed heat storage, consequently, selection of nitrates salts as main material in the designed heat storage enable us to obtain a high rate of necessary heat energy for the operation of rankine traditional energy cycle when using heat storage prototype at hybrid electro-solar, gaseous station [5].

The principle equation for energy calculation necessary for solidification and melting phase of (PCM) is determined by the following equation:

$$[Q] \cong \rho * \nu * \Delta H \qquad (1)$$

In addition to the equation of phase change of(PCM) in form of latent energy which is :

$$(Q) \cong (M) * \Delta H \qquad (2)$$

Where:

ρ :The density of the nitrates salts mixture at the beginning of phase change of the mixture.

ν : Volume of nitrates salts mixture in heat storage prototype.

ΔH : Enthalpy change in nitrates salts mixture at starting of phase change and melting happening .

M:Mmass of (PCM) existing within the heat storage (kg).

3 OPERATION WAY OF LATENT THERMAL TANK PATTERN

The thermal storage tank is composed of the main following parts:

1. Apot of stainless steel and type of (High Chrome 304).
2. A pot designed for thermal oil .
3. A pot with a cover designed for pressure conserving, which contains a mixture of melted nitrates salts in addition to electrical and mechanical valves.
4. A pump special for thermal oil transport from oil tank to thermal oil pot in addition to an electrical coil and an external cover of stainless steel which has thickness of 0.8(mm), the thermal tanks works as follows:

The thermal oil tank situated inside the internal pot of the developed pattern is filled by an internal pump which bears high temperature at the starting of apparatus operation and raising of oil temperature.

The nitrates salts material is put inside the developed thermal tank.

The nitrates salts is heated to constant temperature (221°C) and solidification temperature is(238°C) for assuring disconnecting the bond of the mixture entering the heat storage pattern, consequently obtaining of the high complete latent heat at mixture melting [6], [7], [8].

The thermal oil is evacuated from the heat storage prototype to prevent any heat exchange between the material and the thermal oil at charging ending.

The water of is entered around the heat storage body from inside , then we measure the influence of heat exchange between water and melted nitrates mixture, then we draw the change curve on the control screen according to different work conditions of hybrid electro-solar, gaseous station in case of high solar corresponding the start of thermal oil heating to high temperature by an electrical coil to a high temperature, then passing the heated thermal oil coming from the concentrated solar panels to thermal tank pattern to start the charging operation and storing of thermal energy carried by the thermal oil , and starting of phase change by melting the salty mixture of nitrates and to use this thermal energy in water heating in the economizer, and generating of steam, then roasting it , then leading it to a steam turbine for electricity generation, the figure(1) shows the designed thermal tank, the figure(2) shows the digital control circuit (PLC:propertional linear controller) of the thermal tank, the figure(3) shows the compared thermal tank which works on two separate materials , and comparing the graphic results of the two pattern from the point of view of thermal efficiency conform the figures(4)and (5) and the figures(7) and (9).

Fig 1. Thermal tank with control circuit(PLC)

Fig.2. Designed thermal tank

4 EXPERIMENTAL RESULTS OF LATENT THERMAL LATENT TANK PROTOTYPE

Showing the experimental results of heat storage prototype include display of temperature change of thermal oil, temperature of PCM during melting and solidification phases ,entering and exit temperatures of cooling water to inside of heat storage,this presentation is done conform the following main points:

1. Showing the temperature changes curves of thermal oil inside the oil tank.
2. Showing the melting graphic of nitrates salts as main material with high latent temperature, storing of heat energy is result of melting operation.
3. Realization of discharging of extra pressure inside thermal storage tank.
4. Determination of melting and solidification temperatures of nitrates salt mixture inside the tank, and determination the corresponding melting operation time of nitrates salts, We present the graphics results extracted from the apparatus at starting of operation which show the changes of thermal indexes which regulate the operation of heat storage during the operations of charging and discharging ,these two operations are shown according to video file designed according to (LITE WAVE) program, where this video presents operations of charging and discharging of melted mixture of nitrates salts during two phases of melting and solidification, the figure(1) shows the designed heat storage prototype, and the figure(2) represents digital control circuit(PLC:proportional linear controller) of heat storage prototype, and the figure(3) represents the compared heat storage. It is done three experiments, first one was preliminary each experiment has two stages, first stage represents charging stage, heating of thermal oil, and nitrates salts mixture, the second stage is cooling stage of designed tank pattern at the end of melting operation, with the remark that all experiments were done at the same essential working conditions of the designed thermal tank as from the quantity used in the experiment at thebeginning of apparatus operation and temperature(350°C) ,and starting of phase change of materials, the graphic result were compared with that of other compared heat storage which use phase change materials with single salt during operating it in this prototype , at the starting of operations of charging and discharging for obtaining the latent heat energy. An optional sample of salty mixture composed of Sodium & Potassium nitrates is tested by Differential Scanner Calorimetry produced by (SETARAM) company and the type (LABSYS) used for determination of melting point of the salty mixture composed of (60%) Sodium nitrates and (40%) Potassium nitrates, the graphic analysis of the results of experimental sample test on this apparatus reveals that the melting point of salty mixture starts at (129.667°C) at certain conditions which are ten degrees for each one minute,and maximum heating range till (250°C) in nitrogen atmosphere.

The testing sample for nitrates salts inside the thermal tank pattern is a sample composed of (60%) potassium nitrates and (40%) sodium nitrates operated on the same apparatu , the graphic analysis results of this experimental sample of salty mixture reveals that the melting point of the salty mixture starts at the temperature (228.521°C) at certain conditions which are ten degrees for each one minute in nitrogen atmosphere, the amount of latent energy is 114.328 (kj/kg) as it is clear in the figure(6) of the testing result of the sample, where it became clear the coincidence between the test results of nitrates salts sample with tests results of the sample of nitrate conform the designed program (framework dotnet) during operating of thermal tank and melting of the full quantity of nitrates salts during a period of (12) hours.

The offered quantity of thermal energy presented by (PCM) represented in Sodium & Potassium nitrates salts mixture is determined by the main equation(1) and equation(2) [9], [10], [11].

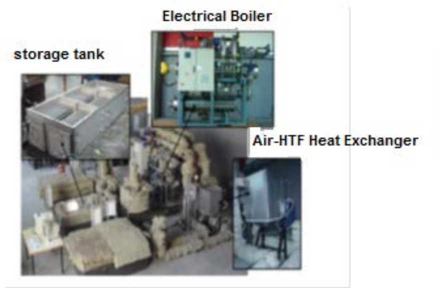

Fig 3. Thermal tank with control circuit(PLC)

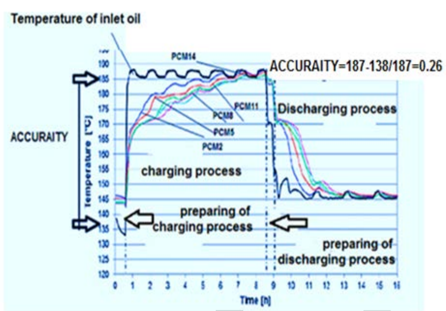

Fig .4. temperatures change in compared heat storage at using (Hydroquinone) as PCM

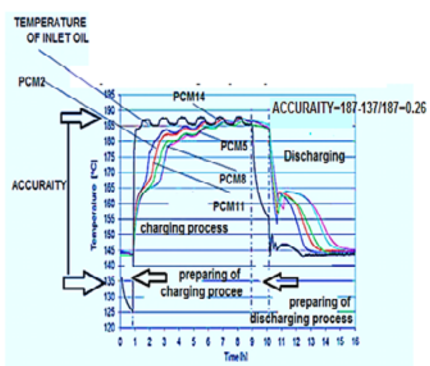

Fig. 5. temperatures change in the compared heat storage when using (d-mannitol) as (PCM)

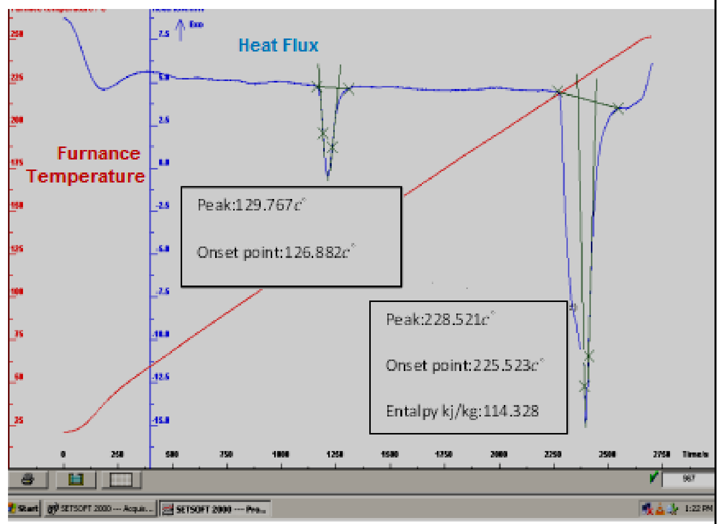

Fig.6. test of a sample composed of sodium nitrates in percentage 60% and potassium nitrate 40% on (DSC) apparatus

5.1 Experimental Results of Latent Thermal Tank Pattern

1. Results of first experiment :

It is used a limited quantity of nitrates salts mixture (1.3)Kg , at apparatus operation we obtained identical results to that at doing operations of heating and cooling of designed heat storage pattern.

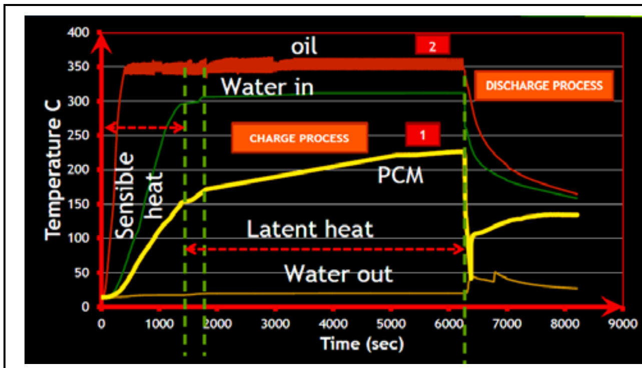

Fig. 7. results of the first stage of heating and cooling of(PCM) and the thermal oil inside the thermal tank pattern designed for the first experiment.

4.1 Results of the second experiment

It is used a limited quantity of nitrates salts mixture (1.3)Kg, at apparatus operation identical results for thermal tank pattern.

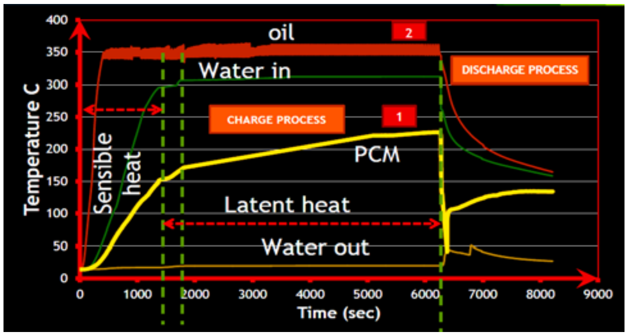

Fig 8. results of the first stage of heating and cooling of(PCM) and the thermal oil inside the thermal tank pattern designed for the second experiment.

4.2 Results of the Third experiment

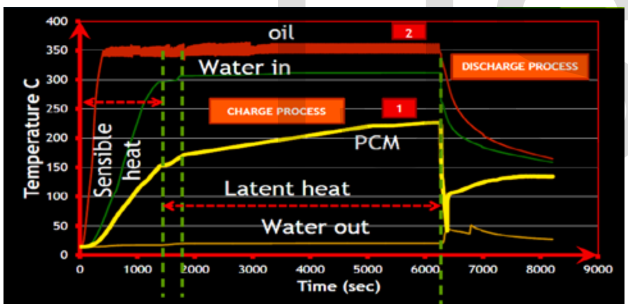

Fig 9. results of the first stage of heating and cooling of(PCM) and the thermal oil inside the thermal tank pattern designed for the first experiment.

Discussion of the graphic results of the designed thermal tank pattern and comparing them with types of thermal tanks working on one phase (PCM). From the results shown previously, which are the first, second and third experiments of the thermal tank. The figures(7) till figure(9) shows the graphic results of heat storage pattern design conform dimensions design calculations of heat storage , as it is shown in these figures, the change of thermal oil temperature inside the oil tank existed in this pattern design, where all readings are taken from the design program called frame work dotnet in interval of five seconds from starting of heat storage operating, according to the resulted graphics , we found that the (PCM) (mixture of Sodium & Potassium nitrates) temperature change as explained in the curve (1) in the figure(8), and in the curve(1) in the figure(7),the temperature is gradually increasing with operating time of heat storage tank (solid-solid: phase change), from the graphics in figure(8) it is clear that thermal oil temperature explained in curve(2)and in curve(2)in figure(9) begins to increase starting from operating moment reaching to the suitable design conditions of heat storage pattern limited by the melting temperatue (221°C)and prevention it reaching to freezing temperature (238°C), as result it happened obviously a thermal gradient increasing descending graduation during heating period of thermal oil at charging stage of this pattern ,the thermal oil curve(2) increases its slope in figure(7),and increasing of salty mixture begins to increase and the melting phase begins as explained in curve(1) in figure(7), then the mixture of salt will has a high latent energy comparing with compared heat storage pattern.

As result of the comparison between heat storage pattern with another pattern in which are used two single materials which are hydroquinone and d-mannitol as(PCM), we found that these materials, at the beginning of melting operation (solid-liquid change) have high latent heat but not as high as that of salty mixture used in operating phase of heat storage tank pattern, it reveals also that during the discharging phase of these used materials in these two patterns, we found that the heat efficiency of salty mixture used in heat storage pattern reaches the thermal efficiency factor of nitrates salts at discharging phase (0.965), and at charging(0.965) this means that the thermal efficiency of heat storage tank is bigger than that of the two previous materials when are used separately in the compared heat storage pattern at the start of melting operation, the heat efficiency factor for the compared pattern at charging and discharging are determined by the values: $\varepsilon(charge) \cong [0.70]$ and $\varepsilon(discharge) \cong [0.68]$ for the two (PCM) used in the compared heat storage pattern.

There is numerical approach and coincidence between the experimental and computer of the designed heat storage tank as explained in the figures(7) till (9), this coincidence appears in the temperature of salty mixture (nitrates salts) and thermal oil as thermal transfer liquid as explained in the curve(1) and curve(2) in the figures (7) till (9) in addition to the internal energy of the (PCM) during computer modeling period with light change in thermal oil temperature at the beginning working of the designed heat storage conform the curve(2) as explained in figure(8), then to keep a low pressure of the melted nitrates salts .

Consequently there is a numerical approach and coincidence between the experimental value measured at the test and the executed calculations at digital control circuit, by comparing the two figures (4) and (5) which explain the graphic results of the compared pattern of the designed heat storage, it reveals to us that rate of heat energy resulted by melting of the two separate materials is less than that in the designed heat storage pattern,also the accuracy measurement of the designed heat storage is limited with the value(0.96) while for the compared tank is(0.26) as explained in the two figures (4) & (5) ,the thermal energy offered by this pattern which uses mixture of nitrates salts bigger than that in the compared pattern which uses two single (PCM), consequently the thermal variables represented in change in latent energy and change in internal energy also the temperature of thermal transport liquid (thermal oil) in heat storage tank pattern will be higher and numerically approaching to that in the compared thermal tank as from accuracy of measuring results as explained in the two figures(4) & (5), then the solution of the problem belonging to the (PCM) that have no high thermal characteristics suitable for thermal storing, by using the melted nitrates salts and remaining this mixture for a long period in the liquid state, keeping its physical and chemical characteristics during melting and solidification phases in thermal tank pattern, and assuring obtaining a high rate of latent heat energy during operation of the designed heat tank pattern after ending of heating and melting operation of salty mixture and ending of cooling operation as explained in the figures(7) till (9) of the graphic results of the designed thermal tank pattern comparing with that of the compared tank.

By comparing between the designed thermal tank pattern and the compared thermal tank explained in figure(3), we found the followings:

1. The designed heat storage tank pattern has higher energy efficiency than that of the compared pattern and has bigger heat energy storing , the cause is the use of salty mixture with high thermal characteristics not as in the compared heat storage tank where was used single material, this made the latent energy rate bigger in the thermal tank pattern at using less quantity of salty mixture than that used in the compared pattern where are used two separate materials one at the front of the thermal tank and the another at its end.Way of (PCM) location in the thermal storage tank participates in decreasing of freezing time at the beginning of melting operation, consequently the designed thermal storage tank has lesser solidification time , this contributes in keeping the material in its liquid phase much more than in the compared thermal tank , this permits repeating the melting mechanism and mixture conservation which has thermal characteristics at melting process and decreasing the solidification time and preventing the melted mixture of reaching to solid crystal state, this is following by keeping the latent thermal energy, this is not available in the compared pattern of the thermal tank which uses two separate materials at melting operation.

By comparing the energy efficiency of the types of thermal storage tanks existing in the world , which work on (PCM) comparing with the designed heat storage tank, we found that the energy efficiency of these types varies between (0.66) and (0.70) , the energy efficiency of the designed heat storage tank reaches (0.956),this means that the designed heat storage tank surpasses the compared pattern in percentage of (26%) according to what it is explained in figures(4) and (5) consequently there is increase in the thermal graduation and high energy level in the thermal energy offered by the thermal oil, the thermal energy offered by the nitrates salts mixture, as nitrates salts is distinguished by high rate of thermal energy in spite of using them in limited low quantities comparing with the compared pattern where were used two single materials with big quantities in addition to the long path of the melted mixture of these two materials according what it is explained in the figures(4) & (5),as result the mixture of nitrates salts in its chemical composition possesses the characteristic of keeping the physical characteristics at liquid phase and remaining in it for long period comparing with actual types of thermal storage systems which use (PCM) but do not possess high energy level and do not realize the suitable thermal and physical characteristics for work conditions of thermal storage systems, as the (PCM) contain old bonds, so at the beginning of melting operation, the bindings bonds begin to disconnect, they need energy that is taken from completion of melting operation in the tank pattern,consequently, its organic structure which contains old bonds that make them keeping their phase change when they are in liquid or in solid state, completion of melting operation and quickly approaching to solid crystalline state comparing with the melted nitrates salts which realizes that the reality of the physical and chemical characteristics as a mixture used in the developed thermal tank pattern, then the melting operation needs less energy for disconnecting the melted mixture bonds, and keeping it in the liquid state for longer period comparing with rest (PCM) which differ in their organic characteristics and composition, this decreases the thermal energy during melting operation, it will be loss in latent energy, this gives us the ideal possibility for linking the thermal storage tank pattern with electro-solar station system and obtaining the electrical energy .

The thermal oil can keep the main operation conditions represented in melting the salty mixture at determined design conditions, at remaining the salty mixture in liquid state and preventing it from reaching to crystalline solid state. Consequently. we found in the curves that this mixture remains keeping the melting sill without reaching to crystalline solid state. Consequently , the increase of latent energy as result of melting operation at thermal oil temperature, these curves explain that the thermal oil keeps the temperature (250°C) suitable for keeping the salty mixture in liquid state at main operating conditions determined by the melting temperature (228°C) and certain freezing temperature (238°C) [12], [13],[14].

5 Conclusions

1. Realization of a design for thermal storage tank pattern which is different of different types of thermal storage tanks.

2. This designed thermal storage tank pattern is characteristic with existence of thermal isolator called metallic wool, and using of suitable quantities of nitrate salts mixture which gives bigger thermal efficiency with keeping the resulted thermal energy by melting and preventing the solidification of nitrates salts inside the thermal tank pattern.

3. Through the figures from (7) to (9) and as result of comparison between the designed heat storage tank with the compared one , we found that the change rate energy

efficiency of designed thermal tank pattern and the compared thermal tank pattern at using mixture for nitrate salts is: $\Delta\varepsilon \cong {0.95-0.70}/{0.95} \cong (0.26)$. From the equation it results that the designed heat storage tank surpasses the compared pattern as from measuring accuracy which reaches(0.96) while for the compared pattern it takes the value (0.26),the thermal energy offered by designed pattern comparing with that of the compared pattern is bigger, mentioning that in the designed heat storage tank it is used mixture of nitrates salts while in the compared pattern it is used two separate (PCM) during determined time of charging and discharging during operation of melting and solidification.

4. The developed tank pattern solves a major problem in thermal storage systems that do not contain the same high thermal properties of materials, and this problem concerns the period of thermal energy storage for long-term periods of time without change in the thermal characteristics through the conservation of thermal energy and prevent them from being lost as a result of containment of this model to the mix of salts of melted nitrates salts ,which achieve thermal storage properties due to chemical installation to the mix and remaining in this liquid state for a long time in this case by reducing the melting time of the used mixture,this is experimentally proved at testing of the latent thermal tank pattern in comparison with the rest of the phase change materials used in thermal storage which possess this property when working during phases fusion and solidification.

5. It was determined the melting point of a mixture of Sodium nitrate and Potassium nitrate which is (228.521°C) and latent heat associated with the process of the phase change from solid to liquid (114.328 ${kj}/{kg}$).

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