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# INVESTIGATION OF COMBINATION BETWEEN LATENT AND SENSIBLE HEAT STORAGE MATERIALS ON THE PERFORMANCE OF FLAT PLATE SOLAR AIR HEATER

**Akram H. Abed** **Abdulmunem R. Abdulmunem**
akraaam82@yahoo.com, abdulmunemraad@yahoo.com
**Electro-mechanical Engineering Department, University of Technology, Baghdad-Iraq**

## ABSTRACT

In this work, a combination between latent heat storage materials (LHSm) and sensible heat storage materials (SHSm) as new storage heat material in flat plate solar air heater was tested experimentally. PCM (paraffin wax) at a certain ratios (10%) and (20%) were used as LHSm with a pure cement (base material) as SHSm. The experimental tests was done indoor at irradiance of (1000W/m$^2$) with forced convection, the mass flow rate of air are (0.5kg/min) and (1.13kg/min). The results indicated that the enhancing thermo-physical properties of adding pure cement by a certain ratios of paraffin wax led to enhancement in thermal energy stored. The percentage increasing in storage heat duration time was (29%) for compound cement with (10%PCM), (38.4%) for compound cement with (20%PCM), compared with pure cement at (0.5kg/min) air mass flow rate. And at (1.13kg/min) air mass flow rate, it was (33.3%) for compound cement with (10%PCM) and (52.6%) for compound cement with (20%PCM) compared with pure cement.
**KEYWORDS : Solar air heater; storage heat material; PCM; LHSm; SHSm;**

# دراسة التاثير المشترك لمادة الخزن الحراري الكامن والمحسوس كمادة خزن حراري جديدة على اداء سخان الهواء الشمسي المستوي

**اكرم حمزة عبد عبد المنعم رعد عبدالمنعم**

**الخلاصة**

في هذا العمل، الجمع بين مادة الخزن الحراري الكامن و مادة الخزن الحراري المحسوس كمادة خزن حراري جديدة في سخان الهواء الشمسي مستوي الصفيحة حضرت وفحصت عملياً. استخدمت مادة متغيرة الطور(شمع البارافين) بنسب محددة (10%) و (20%) استخدمت كمادة خزن حراري كامن مع السمنت النقي (مادة اساسية) كمادة خزن حراري محسوس. الفحوصات العملية تمت مختبرياً تحت تعرض اشعاع ( 1000واط\متر مربع) مع حمل قسري (0.5 كغ\دقيقة) و (1.131 كغ\دقيقة). بينت النتائج ان التحسين بالخصائص الفيزيائية-الحرارية للسمنت النقي بإضافة نسب محددة من شمع البارافين ادى الى تحسين بالطاقة الحرارية المخزونة. كانت النسبة المئوية للزيادة بزمن التخزين الحراري (29%) لمركب السمنت مع (10% مادة متغيرة الطور)، ( 38.4 %) لمركب السمنت مع (20% مادة متغيرة الطور) مقارنة مع السمن النقي عند معدل تدفق هواء كتلي (0.5كغ\دقيقة). و عند معدل تدفق هواء كتلي (1.13 كغ\دقيقة)، كانت (33.3%) لمركب السمنت مع (10% مادة متغيرة الطور) و (52.6%) لمركب السمنت مع (20% مادة متغيرة الطور) مقارنة مع السمن النقي.
**كلمات مفتاحية : سخان شمسي هوائي; مواد خزن حراري; مادة متغيرة الطور; مادة خزن حراري كامن; مادة خزن حراري محسوس.**

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## NOMENCLATURE

$A_{as}$ = area of collector ($m^2$).
$T_{fin}$= air inlet temperature (oC).
$T_{fout}$ = air outlet temperature (oC).
$T_g$ = Flat plate surface temperature (oC).
$\eta_{storage}$ = thermal storage efficiency %.
$\rho_f$ = are density ($kg/m^3$)
$A_d$ = Duct area ($m^2$).
$Cp_f$ = specific heat of air at constant pressure.
LHSm= latent heat storage materials.
$m^{\cdot}{}_f$ = air mass flow rate (kg/s).
$P_{atm}$ = air pressure (101325 Pa).
PCM = phase change material
$Q_{loss}$ = heat loss (W).
$Q_{ug}$ = useful heat gain (W).
R= gas constant for dry air (287.05 J/kg.K).
SAH= solar air heater.
SHSm= sensible heat storage materials.
$T_{fin}$ = air inlet temperature ($^oC$).
$T_{fout}$ = air outlet temperature ($^oC$).
Ub = bottom collector heat loss coefficient (W/m2.k).
$U_e$ = heat loss coefficient from the collector edge (W/m2.k).
$U_{loss}$ = Overall heat transfer coefficient ($W/m^2$. °C).
Ut = top collector loss coefficient
$v$ = air speed in (m/s).

## INTRODUCTION

Heat energy can be stored as a change in material internal energy such as (sensible and latent) heat or thermo chemical or combination of them. Solar air heaters (SAH) are one of more applications that integrated with these materials and extensively used in industrial, residential and agricultural fields. Common sensible storage heat materials such as (water, gravel bed, sand, clay, concrete, etc.) and latent storage heat (phase change) material such as (Glauber's salt, paraffin wax, etc.) are used to store heat in large domain. The specific heat, the amount of storage material and temperature difference is dominated on the amount of heat stored in sensible storage heat materials. In latent heat storage materials, charging and discharging process occur when the storage material undergoes phase change either from solid to liquid, liquid to gaseous**. Chauhan et al.[1996]**, gives a theoretical investigation of solar air heater with a rock bed storage unit, a simulation was built by using the energy and mass balance equations for different components of the dryer, and by adopting a finite difference approach. The results indicated that the reducing of the (coriander in a stationary 0.5 ton/batch capacity) moisture content from (28.2%) (db) to (11.4%) (db) the solar air heater takes about 3 sunshine days, while the solar air heater with rock bed storage material take about 2 days and 2 nights at the same air flow velocity. A forced convection solar dryer which consist of double pass solar air heater integrated with 56 kg of sand as sensible heat storage material, are studied by **Shalaby[2012]**, under climate condition of Tanta city. The result indicated that the drying time of 1 kilogram of grapes is dropped by about 3 hrs or more when using a storage material (sand).

**Walid Aissa et al [2012]** were discussed the variation of solar radiation, air heater efficiency, Nusselt number, and temperature distribution along the forced convection flat plate solar air heater with granite stone storage material bed, the test was done under the climatic conditions of Egypt-Aswan . A forced convection solar collector integrated with (sand, concrete, pure cement) as sensible heat storage materials, under meteorological conditions of Baghdad, Iraq are given by **Abdulmunem R. et al [2016]**. The experimental results showed that the pure cement gave the best thermal storage by (240 min) after (6:30 PM), but the duration was (170 min) and (65 min) for concrete and sand respectively. Practical comparison between Pebbles (sensible stored heat medium) and paraffin wax(latent stored heat medium) were stuffed in ten copper pipes, are used to improve heat storage inside water tank was done by **Miqdam Chaichan et al.[2014]** in Baghdad-Iraq wintertime. The results show that latent heat storage is more efficient than sensible heat storage.
A numerical and experimental investigation of PCM based on epoxy resin paraffin wax was done by **Moussa Aadmi et al.[2014]**. The experimental results of (thermal conductivity, the heat storage capacity and the latent heat of fusion) have been simulated numerically and serve to validate the numerical approach. **Akram Abed[2016],** was presented experimentally the enhancing of thermal storage efficiency for solar air heater by using cylindrical capsules integrated with storage heat materials, a latent storage heat material (paraffin wax) are mixed with sensible heat storage materials (pure sand) to increase the ability of storage heat. The results shows that the compound (sand+20%PCM) gives the best thermal storage time duration (380 min, 355 min) compared with pure sand that gives (240 min, 220 min) in forced convection at (0.5 kg/min, 1.132 kg/min) respectively.
This work aimed to combine between LHSm (paraffin wax) based on SHSm (pure cement) as storage heat materials in flat plate solar air heater that were designed and fabricated for this reason, to eliminate the changes in the environment such as wind speed, the changes in solar incident irradiation with time, etc. the test was done indoor under constant radiation of $1000Wm^{-2}$.

## EXPERIMENTAL PART

### System configuration

To investigate the effect of addition LHSm to SHSm on performance of SAH, indoor tests were done under forced convection operating conditions. In this work, a solar air heater system was designed and fabricated as shown in figures (1,2). The experimental system of the solar air heater consists of halogen lamps, glass cover, insulated thermal storage material container [area $(0.6\times1)\ m^2$], aluminum absorber plate, rigid support frame, convergent duct, flexible pipe, centrifugal air blower and data acquisition system. The bottom and lateral walls of the thermal storage material container made from a wood and coated with silicon paint to avoid drainage of the LHSm (PCM) during the melting process. The distance between the aluminum absorber plate and bottom side of the TSM container designed with 0.04m, filled with only pure cement and compound (Cement, PCM). The thermo-physical properties of (PCM- paraffin wax) showed in (Table 1). The outlet airflow of the collector is opened with cross sectional area (540 mm×75mm) and connected to aluminum convergent duct with front sectional area of $[(0.11\times0.12)m^2]$, end sectional area $[(0.54\times0.075)m^2]$ connected with 0.076m diameter flexible pipe. To control the air mass flow rate, an electrical air blower with variac voltage transformer was used and seated to give (0.5 kg/min, 1.132 kg/min) air speed through the flexible pipe. The aluminum absorber side facing on solar radiation source painted with matte black coat and top side of (SAH) was covered with 0.004m thickness single transparent glass. The aluminum absorber plate and transparent cover glass was designed to maintain a gap of 0.1 m. Table (2) shows the thermo-physical properties (thermal conductivity, specific heat) for two samples of compound (cement +10%PCM), (cement +20%PCM) using thermo analyzer (Hot Disk) type (TPS 500) as shown in fig(3). The experimental tests were done in three cases: the first case (SAH) with SHSm (pure cement) as thermal storage material, second case (SAH) with compound (cement+10%PCM) as thermal storage material, and third case (SAH) compound (cement+20%PCM) as thermal storage material

## Experimental Measurements

Six calibrated thermocouples (Type K)were installed in five positions for measuring the inlet and outlet air temperatures, glass cover, absorber plate and tow thermocouples inserted inside the thermal storage materials at the distance (10mm) and (25mm) from the absorber plate. All thermocouples are connected to selector switch and digital thermometer temperature recorder type (Lurton TM-964) with accuracy (±0.01%). To measure the air velocity, an anemometer type (Kaindl/wind master) was used with accuracy (±4%). The solar irradiation was measured using solar irradiation meter type (ProTek – DM301) with accuracy (±0.7%).

## Experimental Procedure

Thermal behavior and thermal storage efficiency of the charging and discharging process of solar air heater (SAH) is studied using natural and forced convection. Experimental tests were conducted in three cases, in the first case cylindrical capsules packed with pure sand, second case cylindrical capsules packed with (sand + 10% PCM) and third case cylindrical capsules packed with (sand + 20% PCM). Firstly, the gained thermal energy from the solar radiation, stored interior the cylindrical capsules as sensible heat until the paraffin wax reach its melting point temperature. The thermal energy accumulates inside the cylindrical capsules as a result of the charging process finally, the paraffin wax reaches its melting point temperature and the energy storage achieved. Thermo-physical properties of paraffin wax are given in (table 1). The measurement tests conducted at varying air mass flow rate to show the effect of mass flow rate on solar air heater performance. The charging process is continued 45 minutes until the temperature reaches ≈78C. The temperatures of the combined (sand, PCM) are recorded at an interval of 5 minutes.

## DATA REDUCTION

The rate of useful simulated solar energy gained by a solar air heater (SAH) can be measured by following relation [9].

$$Q_{ug} = \dot{m}_f \times C_{pf} \times \Delta T_f = \dot{m}_f \times C_{pf} \times \left(T_{fout} - T_{fin}\right) \qquad (1)$$

The mass flow rate of air can be calculated as follow [10].

$$\dot{m}_f = \rho_f \times A_d \times V \qquad \textbf{(2)}$$

The density of air can be estimated by ideal gas law:

$$\rho_f = \frac{P_{atm}}{R \times T_f} \quad (3)$$

The heat loss from solar air heater collector can be calculated by [11].

$$Q_{loss} = U_{loss} \times A_{as} \times \Delta T_{sf} = U_{loss} \times A_{as} \times (T_s - T_f) \quad (4)$$

$$U_{Loss} = U_t + U_b + U_e \quad (5)$$

Where;

$$U_t = \frac{1}{\dfrac{N_{glass}}{\dfrac{C}{T_{plate}}\left[\dfrac{T_{plate} - T_{air}}{N_{glass} + f}\right]^{0.33} + \dfrac{1}{h_w}} + \dfrac{\sigma(T_{plate} + T_{air})(T_{plate}^2 + T_{air}^2)}{\dfrac{1}{\varepsilon_{plate+0.05N_{glass}}(1-\varepsilon_{plate})} + \dfrac{2N_{glass} + f - 1}{\varepsilon_{glass}} - N_{glass}}}$$

$$U_b = \frac{1}{\dfrac{t_b}{k_b} + \dfrac{1}{h_{c,b-a}}} \quad , \quad U_e = \frac{1}{\dfrac{t_e}{k_e} + \dfrac{1}{h_{c,e-a}}}$$

and

$$f = (1 - 0.04h_{c,g-a} + 0.0005h_{c,g-a}^2)(1 + 0.091N_{glass})$$

$$C = 365.9(1 - 0.00883\beta + 0.0001298\beta^2)$$

$$h_w = h_{c,g-a} = \frac{8.6V^{0.6}}{L^{0.4}},$$

The thermal storage efficiency of the solar air heater (SAH) defined as the ratio of retrievable heat to the summation of retrievable heat and lost heat [11].

$$\eta_{storage} = \frac{Retrievable\ heat}{Retrievable\ heat + Lost\ heat} = \frac{Q_{ug}}{Q_{ug} + Q_{loss}} \quad (6)$$

## RESULTS AND DISCUSSION

Figures (4 and 5) show the outlet air temperature of SAH for three type of heat storage materials (Pure cement as SHSm, and compound of SHSm with (10 and 20)% of PCM (paraffin wax) as LHSm) in forced convection at air flow (0.5, 1.132) kg/min respectively, outlet air temperature period time decreased when the air mass flow rate increased due to increased the heat exchange process between the flat plate surface and air layers. In charge process, the compound of heat storage materials with (20%) PCM gives the maximum outlet air temperature (65°C and 70°C) respectively, while the compound of heat storage materials with (10%) PCM gives (60°C and 67°C) respectively, compared with pure cement that gives (56°C and 61°C) at the end of the charging time of 45 min. In discharge proceeds, compound heat storage materials with (20%) PCM gives higher outlet air temperature and longer time duration (587min and 545min) respectively, and the heat storage materials with (10%) PCM gives (547 min and 476 min) respectively. While the pure cement gives (424 min, 357 min). That is caused by decreases in thermal conductivity and enhanced in specific heat for the compound heat storage materials as shown in table(2). The influence of the mass flow rate of air on the outlet air temperature for three types of heat storage material showed in Figures (6, 7, and 8).The experimental results show that, the duration time for three types of heat storage material reduced when the air mass flow rate increased. Figure(9) shows the heat gained by SAH in forced convection with mass flow rate (0.5 kg/min); the compound cement with (20%)PCM gives the best results in charge and discharge process compared with others. When the mass flow rate increases, the useful heat gain time duration dwindled as shown in figure (10) for the same sensible and compound heat storage materials. Figure (11) represents the thermocouple reading at a distance (2.5 cm) from absorber plate. In charge process with forced convection (1.13 kg/min), pure cement gives high temperature than compound cement with (10, 20)% PCM. That is caused due to the heat energy are stored as latent heat energy in the compound cement with (10, 20)% PCM compared with pure cement. Figure (12) shows the thermal storage efficiency (TSE) in forced convection with (0.5 kg/min). In discharge process, firstly after (45 min) pure cement gives the best performance compared with others, but dropped quickly and gave the final value at (424 min). Compound cement with (20%) PCM gives the best storage performance with longer time duration (587 min) compared with cement with (10%) PCM gives (547 min). As the air mass flow rate increases, the thermal storage efficiency time decreases as shown in figure (13). It seen that from figure (14) the percentage increasing in storage heat duration time of combine (cement & PCM) with respect to the base material (pure cement), depending on air mass flow rate. It was (29%) for compound cement with (10%PCM), (38.4%) for Compound cement with (20%PCM) at (0.5kg/min) air mass flow rate. And at (1.13kg/min) it was (33.33%) for compound cement with (10%PCM) and (52.6%) for compound cement with (20%PCM) .

## CONCLUSIONS

1-Enhancing thermo-physical properties of SHSm by addition a certain ratios (10%) and (20%) of PCM (paraffin wax) as a LHSm led to enhancing in thermal energy stored; The percentage increasing in storage heat duration time was (29%) for compound cement with (10%PCM), (38.4%) for Compound cement with (20%PCM), compared with pure cement at (0.5kg/min) air mass flow rate. And at (1.13kg/min) air mass flow rate, it was (33.3%) for compound cement with (10%PCM) and (52.6%) for compound cement with (20%PCM) compared with pure cement.

2-In this work, the new thermal storage material (combine between SHSm & LHSm) gives best storage duration time depending on the LHSm ratios based on SHSm, Compound cement with (20%) PCM gives the best storage performance with longer time duration (585 min) compared with cement with (10%) PCM that gives (547 min), but pure cement gives (419 min) storage duration time.

3- Air mass flow rate are dominated on thermal energy stored, outlet air temperature period time decreased when the air mass flow rate increased due to increased the heat exchange process between the flat plate surface and air layers..

**Table 1:** The thermo-physical properties of paraffin wax [12]

| **Property** | **Values** |
|---|---|
| Melting temperature ($T_m$) [°C] | 53.7 |
| Specific heat ($Cp_s$) [kJ/kg.K] | 2.0 |
| Specific heat ($Cp_l$) [kJ/kg.K] | 2.15 |
| Thermal conductivity ($k_s$) [W/m.K] | 0.24 |
| Thermal conductivity ($k_l$) [W/m.K] | 0.22 |
| Density ($\rho_s$) [kg/m$^3$] | 910 |
| Density ($\rho_l$) [kg/m$^3$] | 790 |
| Latent heat of fusion [kJ/kg] | 190 |

**Table (2)** Measured Thermo-physical properties

| **Material** | **Specific heat** (kJ/kg.K) | **Thermal Conductivity (W/m.K)** |
|---|---|---|
| Cement-dry | 1.55 | 0.290 |
| Compound (Cement +10%PCM) | 1.692 | 0.260 |
| Compound (Cement +20%PCM) | 1.872 | 0.235 |

**Fig. (1)** Experimental setup

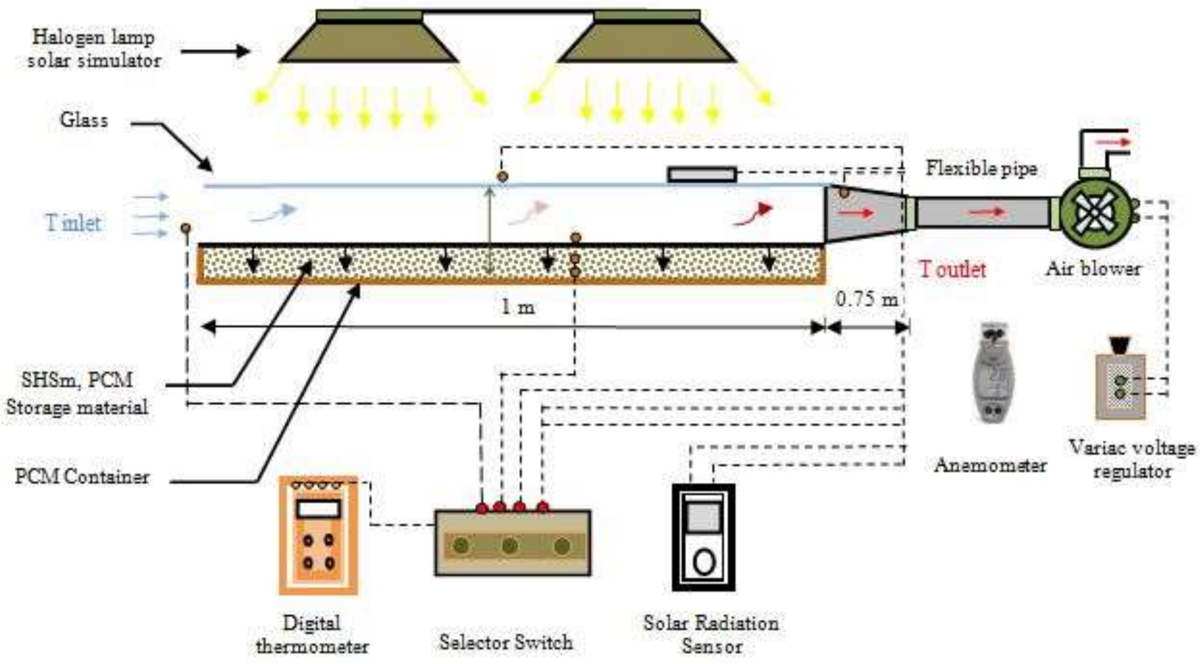


**Fig. (2)** Schematic diagram of the SAH

**Fig. (3)** Thermal constant analyzer (Hot Disk) with samples

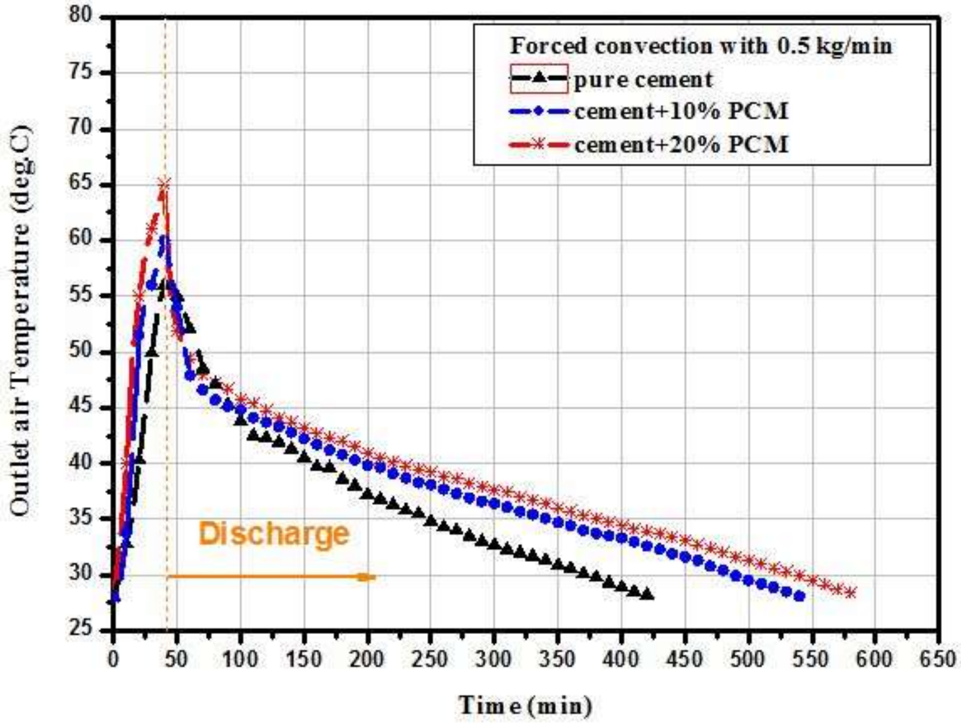


**Fig.(4)** Outlet air temperature versus time in forced convection (0.5 kg/min) with three types of heat storage materials.

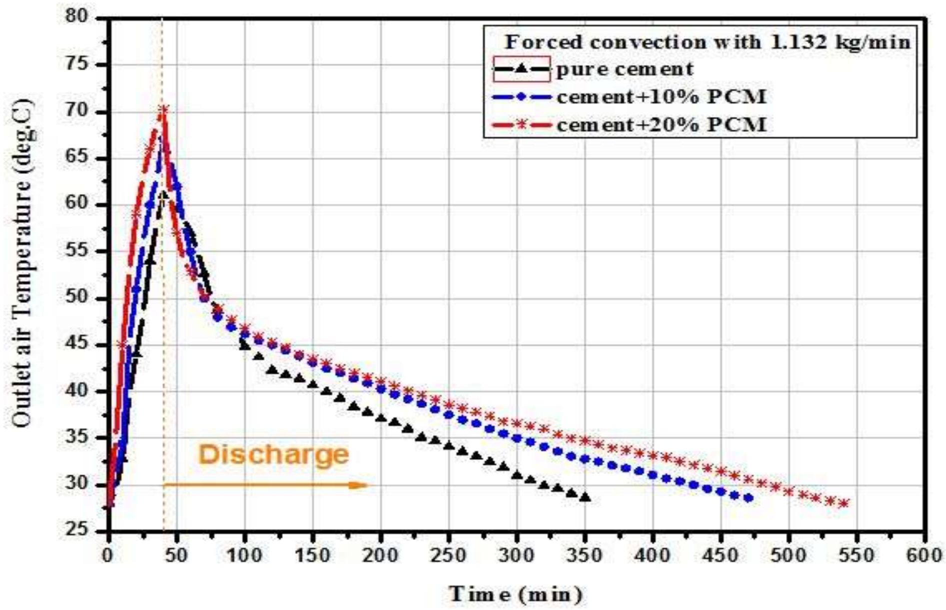


**Fig.(5)** Outlet air temperature versus time in forced convection (1.132 kg/min) with three types of heat storage materials.

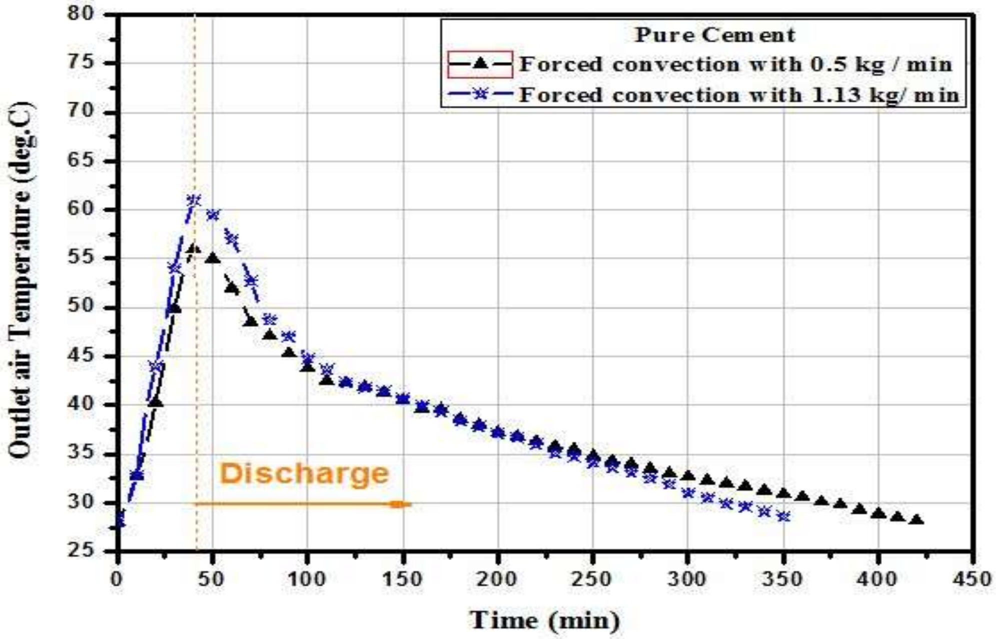


**Fig.(6)** Effect of air mass flow rate on outlet air temperature for pure cement

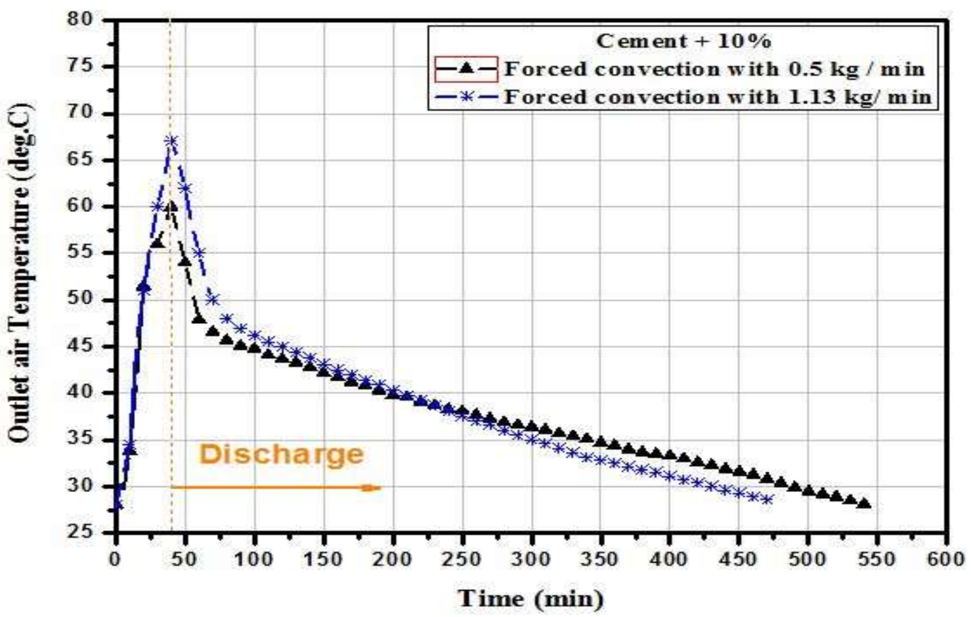


**Fig.(7)** Effect of mass flow rate on outlet air temperature for (Cement +10%PCM)

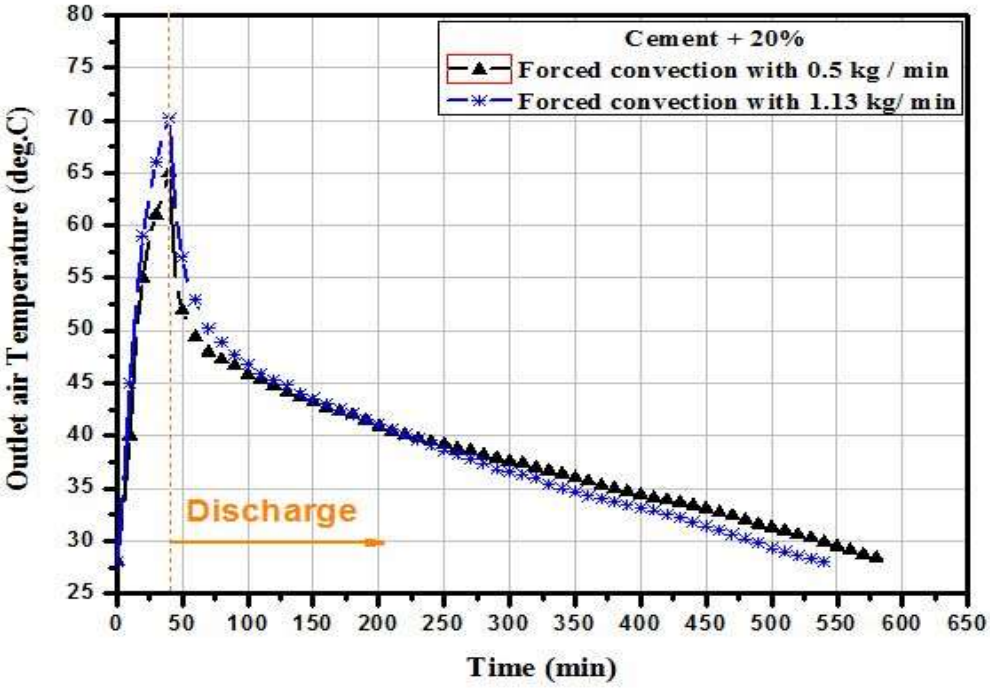


**Fig.(8)** Effect of mass flow rate on outlet air temperature for (Cement +20%PCM)

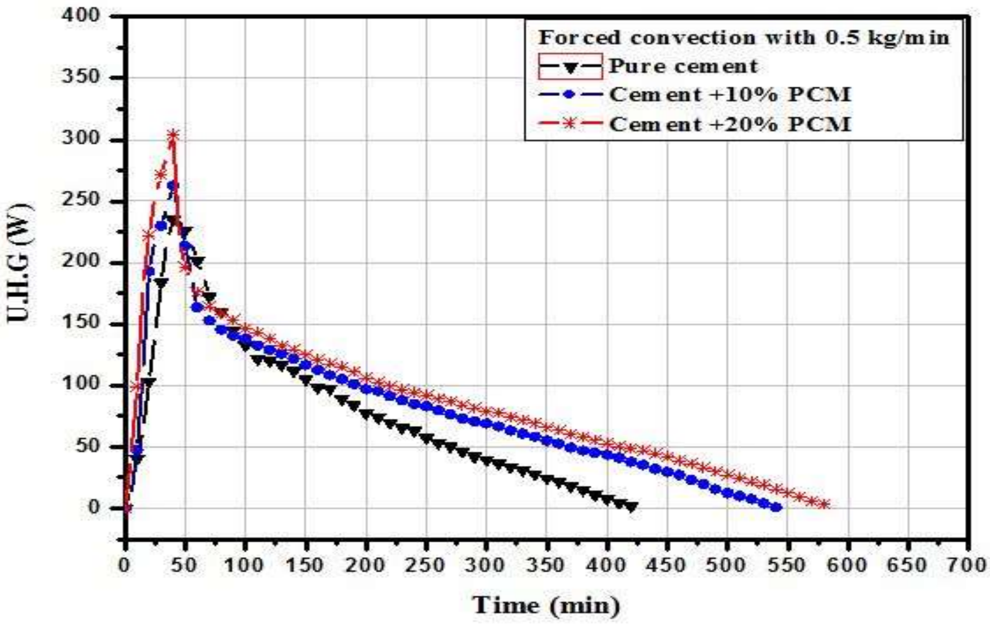


**Fig.(9)** Useful heat gain versus time in forced convection (0.5 kg/min) with three types of heat storage materials.

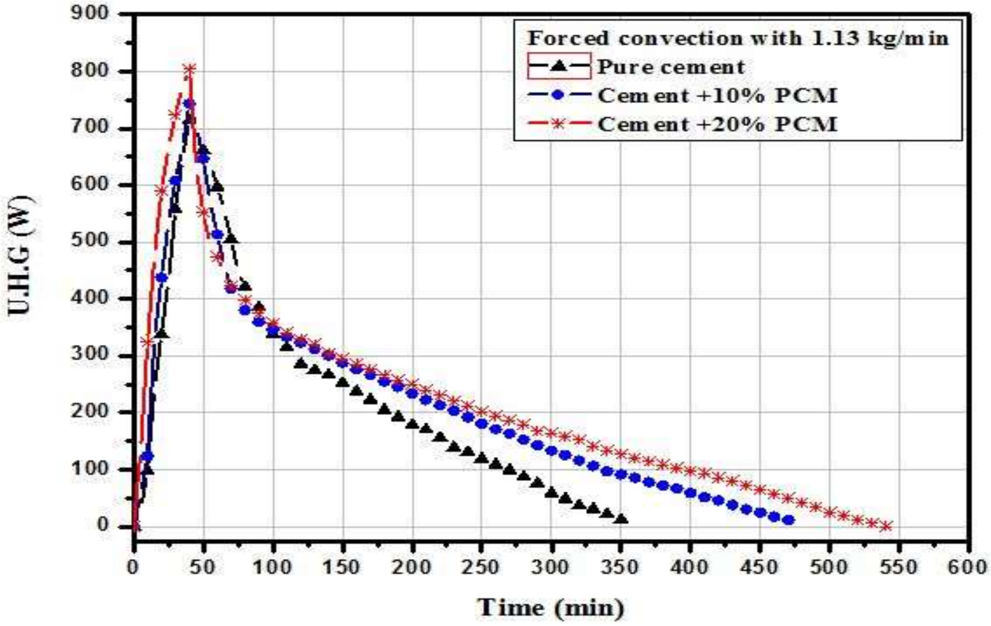


**Fig.(10)** Useful heat gain versus time in forced convection (1.132kg/min) with three types of heat storage materials.

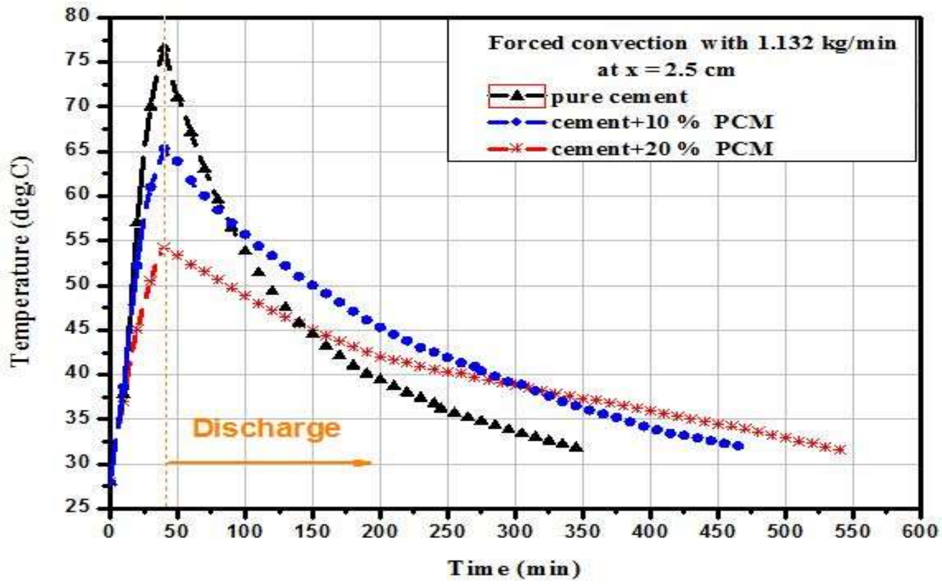


**Fig.(11)** Thermocouples reading fixed at distance 2.5 cm (charge and discharge process) in forced convection

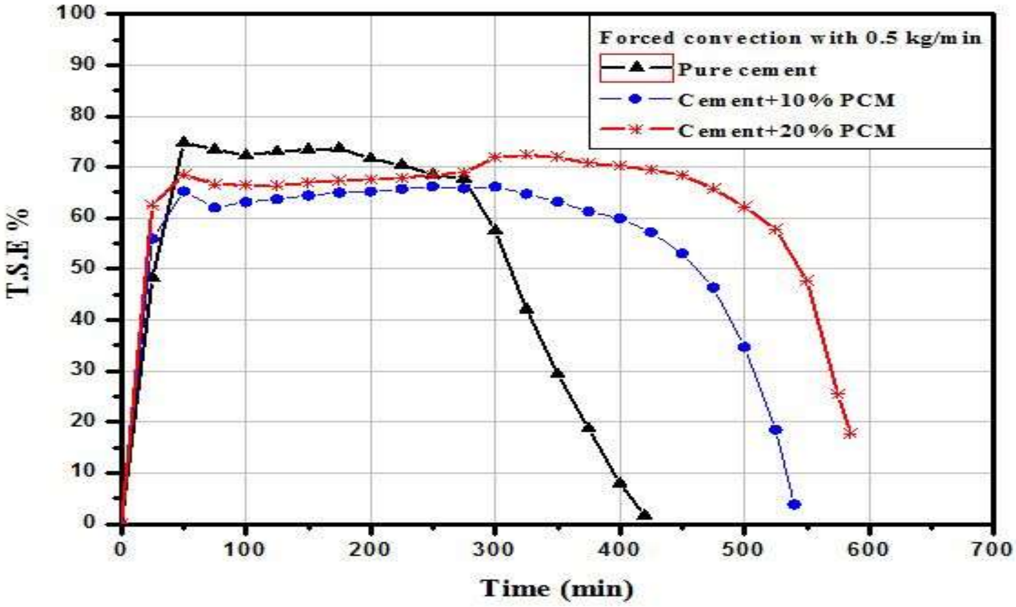


**Fig.(12)** System thermal storage efficiency versus time in forced convection (0.5 kg/min) with three types of heat storage materials.

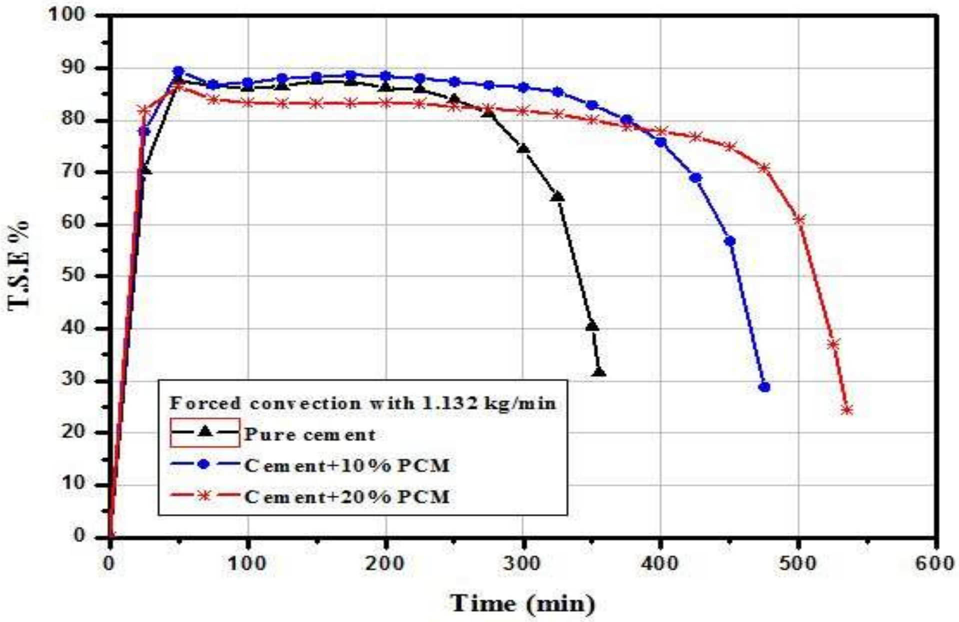


**Fig.(13)** System thermal storage efficiency versus time in forced convection (1.132 kg/min) with three types of heat storage materials.

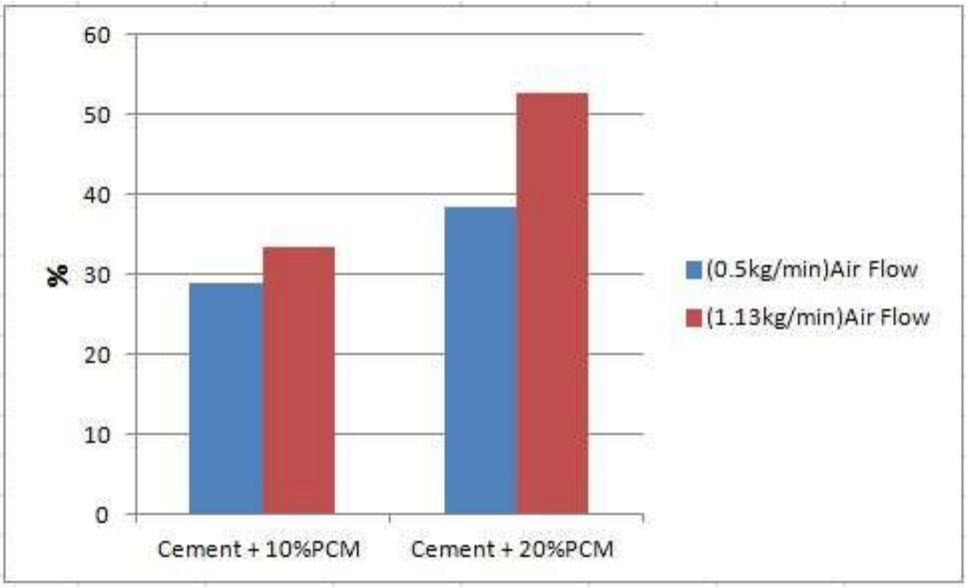


**Fig.(14)** percentage of increasing in storage heat duration time of combine (cement & PCM) depending on air mass flow rate

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