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USE OF SOME INDUSTRIAL WASTF AS ENERGY STORAGE MEDIA

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Abstract- Solar energy is stored using different solid storage materials, both chemical and metallic industrial wastes. The materials tested in the prsent study are paraffin wax, copper slag, aluminium slag, iron slag, cast iron slag and copper chips. Solar energy is stored in these materials and the energy is then recovered with water stream at different flow rates and the storage capacity and period for different materials were compared. The same set of experiments is run on solid metallic materials mixed with wax. The results indicated that iron slag has the highest storage capacity followed by cast iron slag then aluminium slag and copper chips and copper slag. It is also noted that addition of paraffin wax to the solid metallic material improves its storage capacity and duration greatly. The storage efficiency of different units is calculated and compared.

Energy Storage   Solid storage materials (SSM)   Mixed systems
Phase change material (PCM)   Heat transfer fluid (HTF)

1. INTRODUCTION

The seasonal as well as diurnal changes in the amount of insolation received at a particular place necessiate the use of storage techniques for the optimum use of solar energy. In other words, the storage of solar energy is essential to match the gap between solar energy supply and its demands because thermal storage permits the intermittent solar energy to be used later upon demand (1-2). Besides, energy storage can reduce the primary thermal energy production thus reducing oil and electricity consumption and contributing to a better environment (3).

Thermal energy storage in various materials can be categorized by systems which either depend on sensible heat accumulation or materials which undergo a reversible chemical or physico-chemical reaction accompanied by a change in phase within the temperature range of operation as the dehydration of salt hydrates or the vaporization of water.

Each energy storage technology has some advantages as well as some limitations. The task of system designer is to select the appropriate storage system to meet a given situatuion and more than one storage technology may make sense in a given situation (4).

For practical applications, only solid-liquid phase change materials are useful because they store a relatively large quantity of heat over a narrow temperature range, without a large volume change (5). The thermal conductivity values of solid PCM_s are low. Thus, while the material stores thermal energy well, it takes a long time and/or large temperature difference to get the heat transfered through the PCM (6). Paraffin wax is in common use as an energgy storage PCM and it has a melting point of 44°C, thermal conductivity of 0.16 W/m°C, specific heat 2.51 KJ/kg°C and latent heat of fusion 226 KJ/kg (7). Thus, the primary efforts were directed to improving overall thermal storage characteristics of the solid-state PCM_S by controlling thermal conductivity and heat capacity. Therefore, the use of mixed systems represents not a pure latent heat but a latent/sensible hybrid storage concept (8).

Most of the materuials proposed for high temperature (120-1400°C) energy storage are either inorganic salts or metals. Among the metals,, aluminium, magnesium and zinc have been mentioned as suitable examples.The use of metal media may be advantageous where high heat conductivity is required and where cost is of secondary importance.

In a trial to reduce the environmental pollution problems, the new trend is now towards the use of solar energy as a clean energy source. Being intermittent in nature, solar energy should be stored some way to spread the time range of its use to satisfy the most important requirement of a storage sytem for being inexpensive.Thus, in the present work trials are made to use solid industrial wastes as energy storage materials. These materials are known to store energy through increasing its sensible heat which is somewhat limited. On the other hand, phase change energy storage materials ,like paraffin wax, store a bigger amount of energy as latent heat of transformation but it has the problem of low thermal conductivity. Taking all these points into consideration, the objectives of the present study were put such that it covers the following aspects: storing solar energy in some solid industrial wastes like copper slag, iron slag, cast iron slag, aluminium slag and copper chips. Secondary, storing solar energy in pareaffin wax as a PCM and thirdly, storing solar energy in paraffin wax mixed with metallic industrial wastes as matrices to improve the thermal conductivity of the system.

2. EXPERIMENTAL WORK

Experiments were run on the solid materials selected for storing solar energy, namely on iron slag, aluminium slag, copper slag, cast iron slag and copper chips (the remainings from the ternary processes of copper). These slags are brought from the factory in the form of large lumbs and it is crushed before use to improve its performance. Equal quantities of the materials (each 20kg) are placed in solar collectors of the same area, each collector is laid on an iron support and connected to an input tank and output tank for feeding the HTF and discharging it. The tanks are put such that the input tank is higher than the collector while the output tank is lower than it. The tanks are thermally insulated to insure constant feed temperature and constant storage temperature, and the collectors are insulated at the bottom and sides to reduce heat losses. Besides, the top of the collectors is insulated with a 3 mm glass cover to reduce convection and radiation losses. Thermocouple terminals are fixed on the input and output of HTF and on the energy storage materials in the collector for determination of temperature. The collectors are subjected to the solar inscolation (charging period), while the valves between the feed tanks and the collectors are kept closed, and when it reaches maximum temperature the valves are opened and energy is withdrawn by a stream of water , of controlled flow rate, as a heat transfer fluid (HTF), passing through copper pipes imbeded in the material (discharging period). The same tests were run on commercial- grade paraffin wax and energy extraction begins when the wax reaches constant temperature, i.e., complete melting of the wax. Another test was run on wax mixed with different materials for the object of improving its thermal conductivity which is known to be low and which delays the transfer of heat from wax to HTF and for having the combined action of latent heat storage and sensible heat storage. The flow of HTF is continued till its outlet temperature is the same as its inlet temperature, a state which means that all the energy previously stored in the SSM is extracted (discharge period). Heat ransfer operating parameters such as atmospheric temperature, material temperature, inlet and outlet temperature of the HTF, solar intensity and HTF flow rate are recorded periodically. The cycle is repeated by allowing collectors to be charged again from solar energy The quantity of energy that could be extracted from each unit is calculated from the simple relation, $Q = m_{water} * C_p * \wedge T$, and the storage efficiency of each unit is calculated from the relation: Storage efficiency = Solar heat recovered/ Total solar heat received during experiment

3. RESULTS AND DISCUSSION

The following parameters were studuied for the differenrt storage materials:

Storage Capacity of Different Metallic Materials:

The collectors containing the materials are exposed to sunrays and when the materials reach maximum temperature (at 2 p.m.) valves are opened and HTF is allowed to pass thgrough the materials bed to extract energy. The energy stored by each material, Q, is calculated. Results are given in Fig. 1 ($T_{fluid\ out}$ versus time) and in Fig. 2 (Q versus time). Fig. 1 shows that copper slag gives the highest outlet fluid temperature at the begining of experiment which means bigger amount of energy stored in the material but it cools rapidly. This may be due to its relatively high specific heat and high thermal conductivity. The same attitude of temperature declination is followed by the quantity of energy extracted which shows a large amount of energy at the begining followed by a rapid decrease (Fig. 2). The same trend is almost shown by copper chips but to a less extent i.e. lower temperature at the begining followed by lower decrease for the rest of the experiment. Examination of Fig. 1 shows that iron slag cools less rapidly than copper slag and copper chips and this is confirmed by Fig. 2. Aluminium slag does not give high outlet HTF temperature at the begining and meanwhile does not cool rapidly and this is due to its low specific heat and low thermal conductivity, respectively. Besides, it gives the longest time of energy storage. Lastely, cast iron slag gives the lowest temperature at the begining and the lowest declination in temperature versus time. This results in a less severe declination in energy versus time curve as is given in Fig. 2.

The amount of energy stored by and extracted from each material in the period 2p.m. till sunset is calculated and was found to be: iron slag 319, copper chips 272.5, cast iron slag 123.8, copper slag 225.5 and aluminium slag 294.3 all in joules and the time of energy extraction (half a cycle) ranges between 3.25 hour for cast iron slag and 4.25 hour for copper chips and aluminium slag.

Storing Energy in Paraffin Wax:

The results of experimental work on paraffin wax are presented in Fig. 3. Examination of the results shows that the HTF outlet temperature never approaches the wax temperature (at least six degrees difference along the test). This is due to the low thermal conductivity of wax which is considered a characteristic property foi it. Wax continued giving energy for 6.5 hours from the time of complete melting at 3.45 p.m. to the state of nearly equal material and fluid temperature at

10:15 p.m.. This is a relatively longer period than that recorded previously for metallic materials. It is clear that energy extraction continued after sun set for about three hours. An amount of energy equals to 921 joules is given by wax for a storage period of 6.5 hours. This amount seems greatly higher than its corresponding for e..g. copper chips and cast iron slag (272.5 and 123.8 joules, respectively). This marked increase in energy given by wax is attributed to the type of mechanism it gives energy through and which is known to be latent heat of transformation while in metallic materials it is sensible heat, but that advantage for paraffin wax is faced by its drawback of low thermal conductivity thus, longer cycle time.

Studying Mixed Storage Materials:

To overcome the problem of low thermal conductivity of wax and in a trial to reduce the cycle time of wax melting and solidification, it is mixed with metallic materials in the ratio of one part wax to three parts material and tests were run as before. Sample results for copper chips and cast iron slag mixed with wax are given. Fig. 4 gives the variation of $T_{mat, out}$ versus time for: wax, copper chips and cast iron slag, and for these last two materials when mixed with wax. Examination of the results shows that a system composed of wax mixed with a solid metallic material has a relatively shorter cycle time than a system composed of wax alone (a decrease of about two hours was recorded) . Meanwhile, a system of mixed storage materials showed a great improvement in performance regarding the amount of energy stored. Specifically speaking, a system of cast iron stored jouleslory and when mixed with wax it stored 843 joules for the same period, i.e. an increase of 161.8%. As for the system of copper chips, it stored joules and when mixed with wax it stored 638.8 joules, i.e. an increase of 108.4%. This is because the wax added to the system participated with its latent heat of transformation with the sensible heat of the metallic material and this led to a sensible/latent heat system.

Studying of the Effect of HTF Flow Rates on Energy Extraction:

Two test runs, with different HTF flow rates, were carried out simultaneously on a system of copper chips and another of cast iron slag. The results are given in Table 1. Examination of the results shows that, for a specified period of time, e.g. 2-6 p.m. on 21 June 1993, copper chips gave 271.5 joules at a HTF flow rate of 2.75 kg/period and it gave 183 joules at HTF flow rate of 2.5 kg/period, and the same trend is shown by cast iron slag. This means that increasing HTF flow rate increases the amount of energy that could be extracted in a specified period of time. Meanewhile, it decreases the cycle time as a whole.

Effect of Solar Intensity on Storage Efficiency of a System:

The storage efficiency of a system is calculated from the relation :

$$\eta = M.S \Delta T/HS\ A\ N\ t$$

and sample results of two systems namely, copper chips system and cast iron slag system, are represented in Fig. 5. In the calculations the following parameters were used:
M = mass of water per reading period = 2.5 (kg), S = specific heat of water = 4.1868 (KJ/kgK), Δ T = temperature difference in water stream (°C), HS = solar radiation (W/m^2), A = absorbing

area of collector = 0.56 (m^2), n = number of solar collectors = 1, t = charging period = 900 (seconds).

Fig. 5 shows that for cast iron slag system a higher storage efficiency is obtained at the vicinity of solar noon. As we move further along the day, till 4 p.m., the ambient temperature is reduced and a driving force for thermal losses is developed. Because these thermal losses is not

Table 1: Effect of HTF flow rate (in kg/period) on energy extraction (Q)

	Copper Chips				Cast Iron slag			
	M=2.75kg		M=2.5 kg		M= 2.75 kg		M= 2.5 kg	
Local time	T_O	Q	T_O	Q	T_O	Q	T_O	Q
2:00	51	57.75	48	37.5	40	27.5	50	42.5
2:15	45	41.25	44	27.5	36	16.5	45	30
2 :30	40	27.5	41	20	35	13.75	43	25
2:45	38	22	38	12.5	35	13.75	41	20
3:00	37	19.25	37	10	34	11	41	20
3:15	36	16.5	37	10	34	11	40	17.5
3:30	36	16.5	37	10	33	8.25	40	17.5
3:45	35	13.75	37	10	32	5.5	39	15
4:00	34	11	37	10	32	5.5	39	15
4:15	34	11	36	7.5	31	2.75	39	15
4:30	33	8.25	36	7.5	31	2.75	38	12.5
4:45	33	8.25	36	7.5	31	2.75	38	12.5
5:00	32	5.5	35	5	31	2.75	38	12.5
5:15	32	5.5	35	5	30	0	37	10
5:30	31	2.75	35	5	30	0	37	10
5:45	31	2.75	34	2.5			37	10
6:00	31	2.75	34	2.5			36	7.5
6:15	30	0	34	2.5			36	7.5
6:30			34	2.5			36	7.5
6:45			33	0			36	7.5
7:00							35	5
7:15							35	5
							34	2.5
							34	2.5

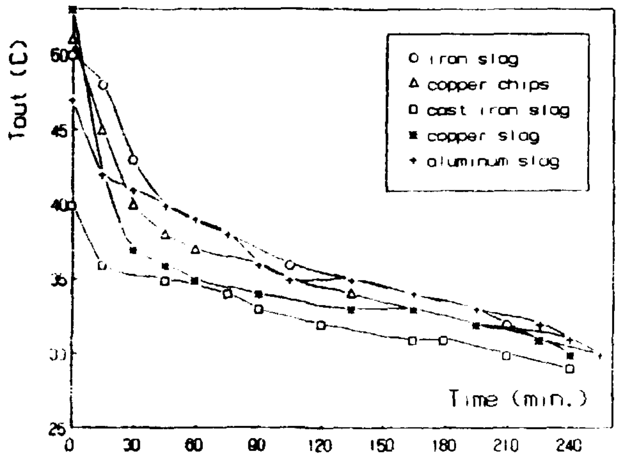

Fig.1: Tout Vs. time for different materials

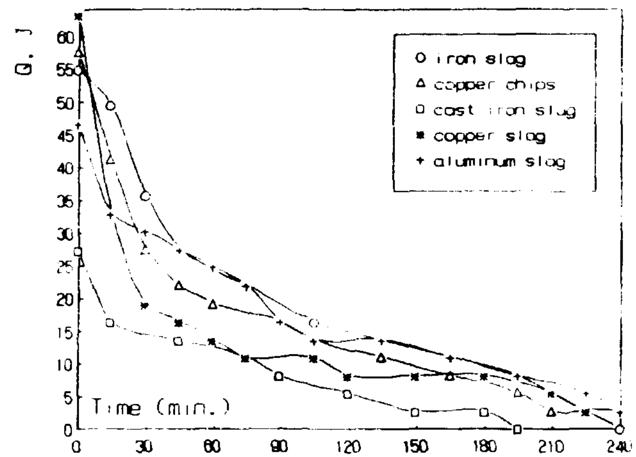

Fig. 2 : Q Vs. time for different materials

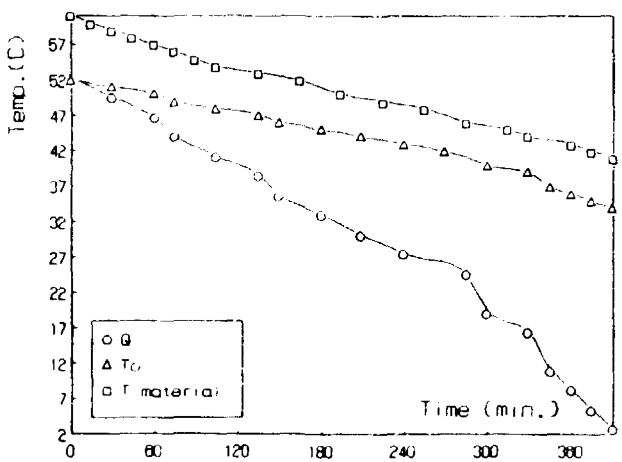

Fig. 3 : Tout Tmat. and Q Vs. Time for wax

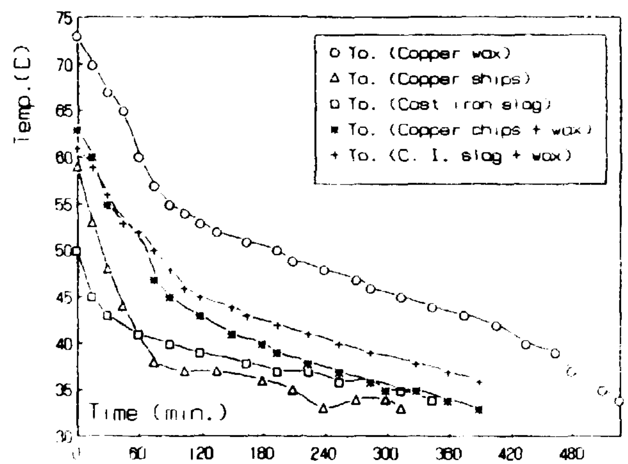

Fig. 4: Performance of mixed storage materials

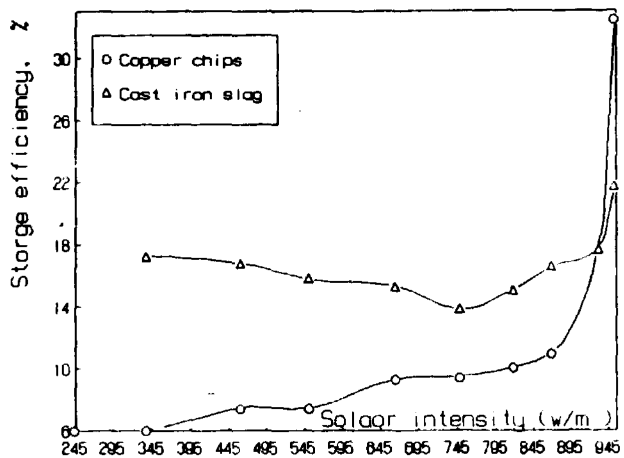

Fig. 5: Effect of solaor intensity on storage efficiency

compensated by enough solar energy received, the storage efficiency decreases. A point is reached after 4 p.m.) when the system cools and thermal losses is reduced thus, the storage efficiency increases again till sunset.
For copper chips system, a higher solar intensity , at noon period, is associated with higher efficiency because of higher ambient temperature and lower thermal losses. As the solar intensity decreases and while the system is storing energy in it, the system temperature is much higher than ambient temperature and the thermal losses increases and this is associated with a decrease in storage efficiency. This effect continues till the end of the experiment. The high thermal conductivity of copper chips led to a rapid decrease in its temperature thus the driving force for thermal losses is not pronounced near the end of the experiment and the upward conversion of the curve is not noticed here.
It could be concluded that maximum storage efficiency is obtained from a cast iron slag system in the vicinity of solar noon and prior to sunset while for copper chips it is obtained only at the vicinity of solar noon. So, it is suggested that the last period of very low efficiency is neglected and instead the system is subjected for a charging period.

4. CONCLUSION

The following conclusions were obtained from experimental work on energy storage systems of some industrial wastes:

1. Some industrial wastes (or by- products) can be used efficiently for storing solar energy. For the same charging period, iron slag stored 319 joules, copper chips 272.5, cast iron slag 123.8, copper slag 225.5 and aluminium slag 294.3, all in joules and the time of energy extraction ranges between 3:15 to 4:15 hours.

2. Paraffin wax stores energy for a longer period (6.5 hours) during which it stored 921 joules.

3. Systems composed of paraffin wax mixed with solid metallic materials in the ratio 1:3 stored much higher amounts of energy, e.g. 843 joules for wax-cast iron slag system and 306.5 joules for wax-copper chips system with a corresponding increase of 161.8% and 108.4%, respectively.

4. Increasing HTF flow rate increases the amount of energy that can be extracted in a specified period of time, but it decreases the time of energy extraction (half a cycle).

5. The maximum storage efficiency is obtained near solar noon and it decreases with the decrease in solar intensity, and rises again slightly prior to sunset (except for copper chips).

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