

# Experimental Analysis of a Thermal Energy Storage System-Waste Heat Recovery

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**ABSTRACT:** The generator exhaust waste heat and environmental pollution has more emphasized recently. Out of the total heat supplied to the engine in form of fuel, approximately 30 to 40% is converted into useful mechanical work. In this present work thermal energy storage tank is integrated with an I.C. engine setup to extract heat from the exhaust gas using two types of phase change materials (Paraffin wax type-2 And Stearic acid).The performance parameters pertaining to the storage tank such as amount of charging time, discharging time, water flow rate, heat recovered, heat lost, and % of energy saved are evaluated in this work.

**KEYWORDS:** Diesel engine exhaust, Thermal Energy Storage Tank, Phase Change Material, (PCM).

## I. INTRODUCTION

High capacity diesel engines are one of the most widely used power generation units. Nearly two-third of input energy is wasted through exhaust gases, cooling water of engines and other losses. It is imperative that a serious and concrete effort should be launched for conserving this energy through waste heat recovery techniques. Such a waste heat recovery would ultimately reduce the overall energy requirement and also the impact on global warming. Waste heat is generated in a process by the way of fuel combustion or chemical reaction and then dumped into the environment even through it could still be reused for some useful and economic purpose. Thermal energy store system (TES) in general and phase change materials (PCMS) in particular, have been an area of interest of researchers for the last two decades. Three types of TES systems are common in practice. The selection of TES is generally dependent on storage period required, economic vial ability and operating conditions. Ibrahim dincer (2000) evaluated both energy and energy analysis under taken, energy analysis often produces more meaningful and useful information than energy analysis regarding efficiencies and losses for TES systems. R.Velraj et al. (2010) reviewed the energy storage system, phase change materials indicates that improving the performance of engine is more importance than the recovery of low grade energy loss. AliH. Abedin and Marc A.Rosen (2011) reviewed various types of TES systems, highlighting thermo chemical TES, has been presented. R. Saidur et al. (2012) have done experiment on waste heat recovery of exhaust gas from I.C engines. Mali sanjay D, et al. (2012) observed energy efficiency is lower than energy. And also found the 47.43% energy loss occur in combustor which shows combustor is not fully adiabatic and combustion. Vimal chaudari et al. (2013) described the change in metting temperature<sup>1</sup> and latent heat of fussion was accepted for SA have reasonable good thermal reliability as PCM used for latent heat storage system. (SA = stearic acid). J.S. Jadhao and D.G thombare (2013) identified waste heat recovery from exhaust gas and conversion into mechanical power is possible with the help of Rankine, stirling & Brayton thermodynamic cycle. For waste heat recovery thermoelectric generator is use low heat which has low efficiency. It is helpful to reduction in emission.

## II. OBJECTIVE OF THE WORK

Objective of the work is to extract heat from the exhaust gas and store in TES tank. In TES tank PCM is filled. Because of higher energy storage density, the gas flow pipe is inserted in the cylindrical tank and is fixed at both the ends. The PCM is poured into the gap between the outer cylindrical tank and exhaust gas flow pipe. To increase the heat transfer

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(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

rate from gas flow pipe surface and PCM, the fins are arranged on the gas flow pipe surface. The water flow tube is arranged such that, it passes through the PCM and winding like coil around the gas flow pipe at some distance. Two valves are fixed at inlet and outlet of the water tube to control the water flow rate. The outer cylinder is well insulated to prevent the heat losses, thereby increases the energy storage capacity. The thermocouples are used to measure the temperatures at various locations in the entire setup.

### III. COMPONENTS OF TES SYSTEM

#### 3.1 Exhaust gas flow pipe:

The exhaust gas flow pipe is to absorb the heat energy in outgoing exhaust gases of generator. Mild steel is selected as a material to fabricate gas flow pipe based on various parameters like thermal conductivity, cost, and easiness in fabrication. No of fins are arranged to increase the heat transfer rate. Fins are made up of copper for effective heat transfer. The fabricated picture of exhaust gas flow pipe is shown in fig.1 below.



Fig.1 Exhaust gas flow pipe with copper fins

#### 3.2 Cylinder:

The cylinder acts as a container to store PCM. This cylinder tank is made up of stainless steel due to its corrosive resistance nature when it is in contact with PCM. To prevent the heat losses the outer portion of the cylinder is insulated with glass wool. Aluminium sheet is used to cover the glass wool. The fabricated cylinder is shown in fig.2 below.



Fig.2 Cylinder

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

### 3.3 Water flow tube:

The water flow is made up of through Copper tube. The tube is arranged such that most of PCM is in contact with it. The tube is in shape of coil and is around the gas flow pipe. The fabricated copper tube is inserted in cylinder as shown in fig.3 below



*Fig.3 Copper tube inserted in cylinder*

### 3.4 Thermo couples:

To note the temperature of water, PCM, exhaust gas, the thermocouples are arranged. Two rod type thermocouples are inserted into the PCM at two locations. For measuring water, temperature two pin type thermocouples are inserted at inlet and outlet of water tube. And two thermocouples are used to indicate exhaust gas temperature at inlet and outlet. All thermocouples are connected to digital indicator, which gives values simultaneously. Paraffin wax type – 2 and stearic acid are selected as PCM for present work. The function of PCM is to absorb the energy from surface of exhaust gas flow type

TABLE I  
THERMO PHYSICAL PROPERTIES OF PCM PARAFFIN – II

Property	value
Latent heat of fusion	213 [KJ/Kg]
Specific heat capacity solid	861[KJ/Kg K]
Specific heat capacity liquid	778[KJ/Kg K]
Density solid	1850[Kg/M]
Density liquid	2384[Kg/M3]
Thermal conductivity solid	0.40[W/M K]
Thermal conductivity liquid	0.15[W/M K]
Phase transformation temperature	61[°C]

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

TABLE II  
THERMO PHYSICAL PROPERTIES OF STEARIC ACID

Property	value
Melting temperature	57 [ <sup>0</sup> C]
Latent heat of fusion	198.91 [KJ/Kg]
Density solid	960 [Kg/M3]
Density liquid	840 [Kg/M3]
Specific heat Solid	1600 [KJ/kg0c]
Specific heat liquid	2300 [KJ/kg0c]
Thermal conductivity solid	0.3 [W/MK]
Thermal conductivity liquid	0.172 [W/MK]

## IV. SYSTEM DESCRIPTION

The line diagram of entire system is shown in below. The experimentation unit consists of diesel engine. The TES system is as shown in below fig.4.

After arranging the entire setup on stand such that the inlet of gas flow pipe is coincide with the exhaust pipe of generator, pour the PCM into tank through hole provided. The entire surface is covered with all sheets. First we take the charging of PCM by regular time intervals after we take the discharging values of PCM by using regular time.

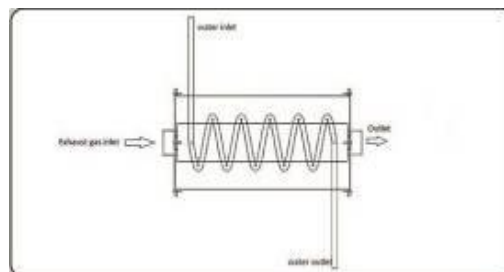


Fig.4 Line diagram of system

## V. RESULTS AND DISCUSSION

The results obtained from the experimental investigation for engine at various temperature levels are studied. In present work, attempts have been made to recover the maximum possible heat from exhaust gas through TES tank filled with PCM.

### 5.1 Charging of PCM:

Comparison of both charge and discharge of PCM

The fig.5 shows that the charging of PCM upto the temperature of 93<sup>0</sup>c is done in 70 minutes. As the time increases, the temperature of PCM also increases upto the range of 60<sup>0</sup>c to 70<sup>0</sup>c and then the temperature remains constant though the exhaust gas is flowing through the system. In the range of 60<sup>0</sup>c, the PCM changes its phase from solid to liquid and then the temperature rises up to 93<sup>0</sup>c.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

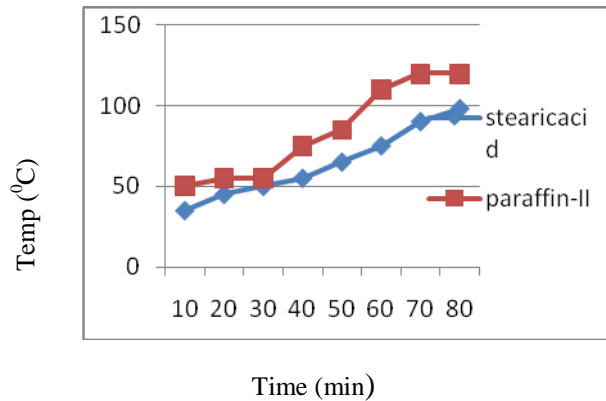


Fig.5 Comparison of both charge and discharge of PCM

Graph shows that the charging of PCM (i.e Stearic acid) up to the temperature of 98<sup>0</sup>c is done in 60 minutes. As the time increases, the temperature of PCM also increases up to the range of 55 to 57<sup>0</sup> and then the temperature remains constant through the exhaust gas is flowing through the system. In the range of 57<sup>0</sup>, the PCM changes its phase from solid to liquid and then temperature raises up to 98<sup>0</sup>.

## 5.2 Discharging Of PCM:

From the below graph, we conclude that PCM takes nearly one day to reach the atmospheric temperature. From the maximum temperature 90<sup>0</sup>c, the paraffin wax temperature reduces to 65<sup>0</sup>c linearly with time and it changes its phase from liquid to solid phase releasing the latent heat and slowly it gets reduced to atmospheric temperature.

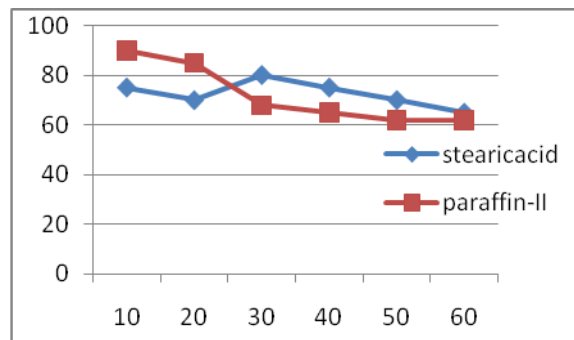


Fig.6 Discharging of PCM

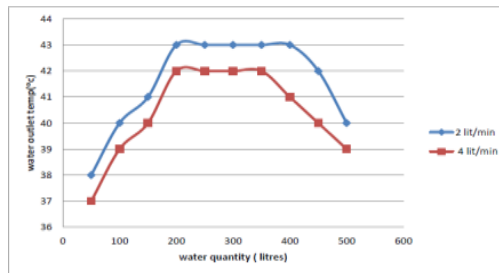
In above discharging graph a lot of heat and this energy can be removed efficiency using TES system. In present work PCM based TES From the above graph, we conclude that PCM takes nearly one day to reach the atmospheric temperature. From the maximum temperature 78<sup>0</sup>c, Stearic Acid temperature reduces to 57<sup>0</sup>c linearly with time and it changes its phase from liquid to solid phase releasing the latent heat and slowly it gets reduced to atmospheric temperature.

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(An ISO 3297: 2007 Certified Organization)

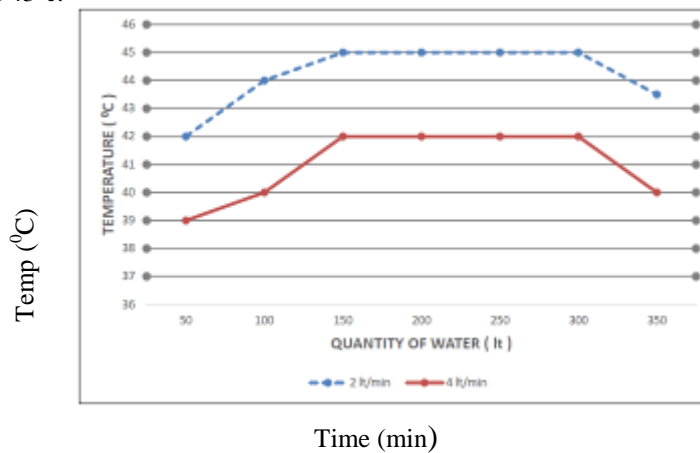
Vol. 4, Issue 8, August 2015

### 5.3 Water Flow Rate:



**Fig.7 Flow rate 2lt/min and Flow rate 4lt/min by using Paraffin wax (Type-II)**

The above graph shows that the maximum temperature attained by water is 43<sup>0</sup>c when the experiment is carried out at 36<sup>0</sup>c as atmospheric temperature. It reveals that the water outlet temperature decreases as the flow rate of water increases. Because when the flow rate increases, the time to exchange the heat from PCM to water decreases. So to increase the water outlet temperature less flow rate is to be adjusted. And nearly 250 liters of water is obtained at targeted temperature of 43<sup>0</sup>c.



**Fig.8 Flow rate 2lt/min and Flow rate 4lt/min by using Stearic Acid**

The temperature of outlet water from the system will vary on flow rate. Lower flow rate gives the higher temperature compared to the high flow rates. The obtained temperature of water outlet is 45<sup>0</sup>C at flow rate of 2 lt/min and 42<sup>0</sup>C at flow rate of 4 lt/min

Heat recovered

Heat recovered by exhaust gas using SA as PC M is – 57<sup>0</sup>c and paraffin wax type –<sup>2</sup> as 61<sup>0</sup>c.

Heat lost by exhaust gas

$$\begin{aligned}
 Q_c &= m c_p \Delta t \\
 &= 46.53 \times 10^{-3} \times 1.1 \times (310 - 30) \\
 &= 14.33 \text{ kJ/s}
 \end{aligned}$$

Percentage Energy Saved

$$\begin{aligned}
 \frac{\text{Required energy}}{\text{loss by diesel generator}} &= \frac{M c_{\text{solid}} \Delta t + m_l + M c_{\text{liquid}} \Delta t}{M f c v \Delta t} \\
 &= 16155 / 46.53 \times 10^{-3} \times (43) \times (145 - 35) = 73.40\% \text{ (Stearic Acid)}
 \end{aligned}$$

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 8, August 2015

$$\frac{\text{Required energy}}{\text{loss by diesel generator}} = \frac{M_{\text{solid}} \Delta t + m_l + M_{\text{liquid}} \Delta t}{M_{\text{fuel}} \Delta t}$$

$$= 16155 / 46.53 * 10^{-3} (43) * (150 - 30) = 67.29\% \text{ (Paraffin Wax Type-II)}$$

## VI. CONCLUSION

The exhaust gas of diesel engine carries tank capacity were designed and fabricated and test by integrating a diesel engine of capacity is 50 kW. The investigation has shown the following conclusions:

1. By using paraffin wax type-II, the charging of PCM upto the temperature of 93°C is done in 70. minutes. In the range of 60°C , the PCM changes its phase from solid to liquid and then temperature raises upto 93°C. By discharging of PCM the maximum temperature 90°C, the paraffin wax temperature reduces to 65°C linearly with time and it changes its phase from liquid to solid phase releasing the latent heat and slowly it gets reduced to atmospheric temperature. By the flow rate of paraffin the maximum temperature attained by water is 43°C when the experiment is carried out at 36°C as atmospheric temperature And nearly 250 litres of water is obtained at targeted temperature of 4 °c.
2. By using Stearic Acid the charging of PCM upto the temperature of 98°C is done in 60 minutes. In the range of 57°C, the PCM changes its phase from solid to liquid and then temperature raises upto 98°C By the discharging of PCM takes nearly one day to reach temperature 78°C, Stearic Acid temperature reduces to 57°C linearly with time and it changes its phase from liquid to solid phase releasing the latent heat. The temperature of outlet water from the system will vary on flow rate. Lower flow rate gives the higher temperature compared to the high flow rates.
3. Energy saved through Paraffin wax is less when compared to energy saved through Stearic acid as a PCM.

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