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Waste Heat Recovery Management using Thermoelectric Generator System

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ABSTRACT

A substantial amount of energy is wasted by several industries in the form of thermal energy as heat with exhaust gases from engine. Waste heat utilization would also serve to mitigate Green House *gas (GHG) emissions. Although, it is not technically and economically feasible to recover all waste heat; can be used in preheating combustion air, boiler feed water and process loads. However, waste heat utilization from lower temperature sources, is generally more problematic. Thermal Energy Storage would serve the purpose of utilizing the waste heat from lower temperature sources. For that, various Thermal Storage methods compared, with preference to Phase change Material as Latent Heat Storage over Sensible Heat. Paraffin wax is preferred over other Phase Change material as it is cheaper and has moderate thermal energy storage density but low thermal conductivity. Four different materials, as, Air, Water, Paraffin wax and Petroleum jelly with wax is compared experimentally. For utilization purpose, Thermo-electric effect is used for direct conversion of Thermal energy into electrical output, thus providing an alternative for power generation. The Petroleum jelly combination with wax as storage material is preferred over other mediums and chosen because a great energy density is obtained, and at the same time, it is possible to extract the stored energy with very small variations in temperature, which is a favorable feature for the intended purpose. The Charging and discharging rates is also calculated and compared for different cases analyzed. An experimental setup was built to analyze all the effects with different material used.*

I. INTRODUCTION

In the present developing scenario, the impact on the fossil fuels is increasing day by day and hence necessities on the search for other source of energy having lesser burden on the environment. On the search, Renewable sources of energy tops the list with many useful qualities, apart from acting as a source of fuel. But, it brings other hindrances in the path of installing it for the general or multipurpose, like time-frame, area used in the installation, problem in utilizing it from their naturally occurring passive modes, etc. So, we need to go for some other alternate sources of energy which would be utilizing the energy going in the environment as a waste heat.

These days we can easily witness the harmful effects of exhaust gases in the environment, mainly in some-what developed places like Delhi, Patna and other parts of India. The various efforts, like Odd-Even Rule by Delhi Government, also introduced Bharat Stage IV for the reduced emission from the heavy duty diesel engines.

Emissions are reduced also through changes in engine design, combustion conditions and by using catalytic or thermal converters.

Also, we know that the emissions from the engine largely depends on the exhaust temperature; larger the temperature, greater will be the emission of Carbon monoxide, Hydrocarbons and Carbon dioxide. Therefore, if the temperature of exhaust gets lowered, then the emission will also get reduced. We can also consider the rising environmental temperature every year from previous one, like the current year.

Now, if the thermal energy contained in the exhaust gases gets utilized, then it will lower down the temperature of the exhaust gases, apart from utilizing it for required purpose. In the run, we can utilize exhaust, but we need to go for utilizing it even it's not in use, i.e. to store the energy for future purpose. The quest for the imminent shortage of energy and increasing energy cost need to be reason for scientific research for past several years. Also, the waste energy from several sources need to be stored for later use. In this case, we have to go for Thermal Energy Storage Systems (TESS).

II. LITERATURE REVIEW

Literature review for project consist the study of different journals paper relating dissertation work and gives idea about the project work.

D.Cano, et.al. [1] have performed experiments on four different PCMs for dissimilar process (parallel as well as counter current arrangement) with varying water (taken as Heat Transfer Fluid (HTF)) flow rates. PCM counter current arrangement over performed other setup for thermal transfer by about 71% higher than parallel system.l system. Lower HTF flow rates lead toward greater value of heat transfer.

Bruno Cardenas, Noel Leon [2] designed a Stirling engine using high temperature PCM for solar energy using TES device. TES uses the latent heat of fusion of PCM, stored in tank. The output results as the almost constant temperature heat source obtained from the heat of fusion stored in the PCM, good for planned use. The insulation apply minimize the temperature loss. In this work, it also showed that among PCMs, the solid-liquid PCMs are far better than that of Liquid-gas PCMs.

Mathew Aneke, Meihong Wang [3] reviewed the various ways of Energy storage and their real time applications. They also predicted and forecast the energy storage sector and summarized the challenges facing energy storage industries. They concluded for a new and lesser influenced TES as Thermo chemical, such as,supercapacitors, and gravity need a greater attention for future research work.

LaiaMiro, et.al. [4] taken water, Erythritol and Zeolite as TES materials for Industrial Waste Heat (IWH) Recovery. In this paper, more than 35 IWH case studies of on-site and off-site TES systems reviewed. They also showed that industrial activities have great potential for IWH recovery. They also showed that electricity production is the most recurrent application for IWH recovery.

Xiao Zhang, Li-Dong Zhao [5] emphasized on thermoelectricity with respect to different materials, and hence compared them on the basis of their dimensionless figure of merit (ZT) leading to different values of power generation efficiency with comparison to their Carnot efficiency. They are supporting thermoelectricity by stating that it is environmental friendly for power generation and refrigeration, thus a better solution to energy crisis and pollution. However, they also concluded that thermoelectric conversion efficiency is low and mainly limited by performance of thermoelectric materials. There require an intensive research on improving the performance of thermoelectric materials.

Mohammed M. Farid, et.al. [6] reviewed on PCM storage, based on used materials and their applications. They focused mainly on the encapsulation of different PCMs to get optimum results. They used different PCMs, such as paraffin wax, hydrated salts, etc for the study. Paraffin wax is cheap and has reasonable energy storage. However, they have small thermal conductivity and therefore need larger heat transfer region. PCM classifies as the best material for storage applications, as it has has flexible melting temperatures.

Atul Sharma, et.al. [7] classified PCMs on their basis of their characteristics and preferred Latent heat storage for the TES with PCMs according to their applications available. Different properties like physical, thermal, kinetic, thermal discussed along with their economics. Thermo-physical property of PCMs is independent on temp., but dissimilar for different phase. PCM melts to liquid phase. Conduction predominates the other way of heat transfer. PCMs are classified as organic, inorganic and Eutectics. Emphasis was laid on solar applications, such as, solar cooker, air heating, water-heating, green house and on buildings.

III. OBJECTIVE

To gather the heat wasted in a tank to utilize them in heating the PCMs used. The same heat is utilized to be stored in tank in the form of latent heat, which will be utilized during discharging phase.

The heat generated is to be used as hot source for the thermoelectric module used, and hence obtaining power output and comparing with the calculated one for different cases used.

IV. METHODOLOGY

With the aim of utilizing dissipated heat through thermoelectric effect using PCM, heat is stored in a tank, to get greater temperature for the hotter side of the thermoelectric module. The exhaust is passed through the tank in a spiral coiled tube in two pipes. The digital thermometer is use on the way to measure temperature at inlet and exit of tank. The similar arrangement to measure hot temperature at the two points where modules are placed is also done. For colder side of module, two sources, one as air and other water is used which is passed through the heat sink which has finned internal structure is made; a digital thermometer is again placed for measuring the cold side temperature. Thus, temperature is recorded at a total of 5points. A digital multimeterbeuse on the way to assess open circuit electrical energy, and hence power is measured, which is compared with the theoretically calculated power. Different readings are taken for different arrangements, such as, at different time intervals at all points mentioned above for different loads applied on engine, such that temperature increase can be noted at different places and steady nature can be obtained. Once, got steady state, for some time, it’s called charging. The similar procedure is repeated during discharging phase, when engine is stopped, and the measurements are taken at all points till it becomes steady with environment. The total time for charging and discharging in all the different cases is measured and compared.

V. SCHEMATIC DIAGRAM

The schematic diagram of the project work is as shown below.

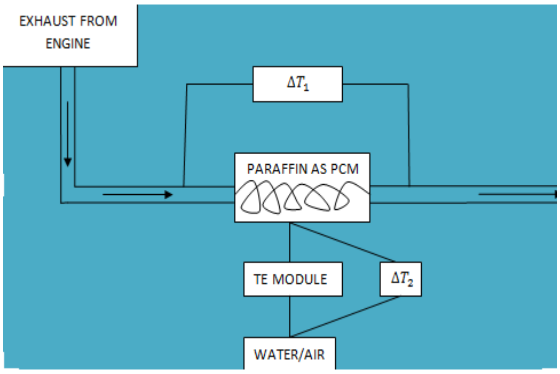

Fig - 1

In this system, we are required to take the heat input from the automotive engine exhaust which is to be stored in the LHSS using Paraffin as our PCM. Then we will install a Thermo-Electric (TE) Module to use the stored energy in the paraffin

Here, ΔT_1 represents the steadiness of the paraffin to be in a single liquid phase, which will indicate the beginning of the experiment, however, ΔT_2 represents the temperature difference between the stored heat energy in the Paraffin & reference temperature of water/ice (taken for observing effects having better temperature difference).

VI. EXPERIMENT SET-UP AND PROCEDURES

System is built according the objective of the project work which is to store the waste heat of the engine for utilizing it by thermoelectric effect. In our proposed model, we are going to utilize the thermal energy of the exhaust of the "10HP diesel engine" present in our lab, for storing it and being utilized in the Thermoelectric generator using Seebeck effect. Firstly, we will pass the exhaust gases through the spiral copper tube in doublet, joining at the inlet and exposing individually to the atmosphere, special care is taken so that, minimal effort is laid on the engine, while doing the diversion in the area of the flow of exhaust gases through the pipe. 0.5mm diameter Copper wires is meshed through the coiled tube, so that, the heat transfer gets increased through the coil to the PCM stored in the tank, and we can get faster temperature rise in the material. Once the exhaust gases is passed through the spiral tube, thermal energy is laid off to heat the pipe, and hence the container inscribing the paraffin as PCM. The heat is absorbed by the paraffin, making able to charge it by converting to the liquid phase at its fusion temperature; once it is fully charged, it can be now act as thermal energy source, for the thermoelectric generator. The PCM is taken in a container of thickness less than 1 cm. The conducted heat from the exhaust pipe heats the PCM container. Heat is conducted to other surface of container. From the heat gained through the tube surface, PCM converts to its liquid phase. Thus, the PCM is charged during the process. This phase continues till all paraffin wax is transformed in the liquid; thus steady state arrives. Comparative study can be done between the PCM used and others, like water or air in place of the PCM, also petroleum jelly is mixed with paraffin wax used as PCM to lower down the melting point of wax used, and hence used for better heat recovery in the charging phase. The DT380D digital multimeter is used to measure the electrical output of thermoelectric module, such as, current and voltage and hence the actual power output. Once the steady state arrives, the engine is stopped, the pattern of temperature is noted down for different time interval with the help of digital thermometers, till it comes in equilibrium with the surroundings. The electrical output is also noted for the module from the multimeter at different instant. The whole setup is insulated by Glass wool batt thermal insulation well covered by self adhesivetapes, so that Glass wool gets attached to the tank always.

While the setup is constructed in order to utilize the exhaust gas coming out of the "10HP Diesel engine", shown in Fig.7 as the detailed exhaust pipe arrangement shown in Fig. 5 with the help of a spiral copper tube with mean coil diameter of 20cm having double pipe of 1cm having 1mm thickness, as shown in Fig.5(a) which is connected to main exhaust using connector shown in Fig.5(b) with the exhaust pipe of the engine, in Fig.5(c). The exhaust from the engine is shown in Fig.6. The exhaust from the engine is firstly passed through the spiral copper tube, so that it can take maximum amount of thermal energy to be used for increasing the temperature of the Heat Transfer Fluid taken in each case in the experiment.

Fig.2 Spiral copper tube

This tube is to be fitted with the exhaust pipe of the engine with the help of a reducer. This is put in a tank as shown in Fig.11. To increase the heat transfer further, copper wire of 1mm diameter is meshed around the copper spiral tube, as shown in Fig.12. The whole tube along with meshed copper wire is now put inside tank with two copper plate of dimension 164mm×42mm×1mm is installed, shown in Fig.13, to be used to install 4 thermo-electric modules,TEC12706, as shown in Fig.9. The thermo-electric module is installed on the copper tube using thermal paste to reduce thermal resistance. The other side of TEC12706 is cooled by Heat sink, as shown in Fig.10. Fig.10 (a) represents the water heat sink, while it's inner finned surface is shown by Fig.10 (b). The whole experimental setup is shown in Fig.14. Front portion is shown by Fig.14 (a), while the rear one by Fig.14 (b).

Fig.3 Main (Exhaust pipe)

Earlier research has let us know about the percentage of exhaust of fuel combustion with up to a maximum of 40% [14]. These results lead us to go for the utilization process of the exhaust energy wasted. The overall energy flow can be well illustrated in the Fig.8. In the setup, the exhaust gases are first passed through the spiral coil, the gases leaves the spiral tube through the vent left in the tube. The thermal energy thus stored, is transferred to the material used in different cases, for charging purpose used to store it for discharging time, when engine is shut down.

The energy flow path in an engine can be traced as

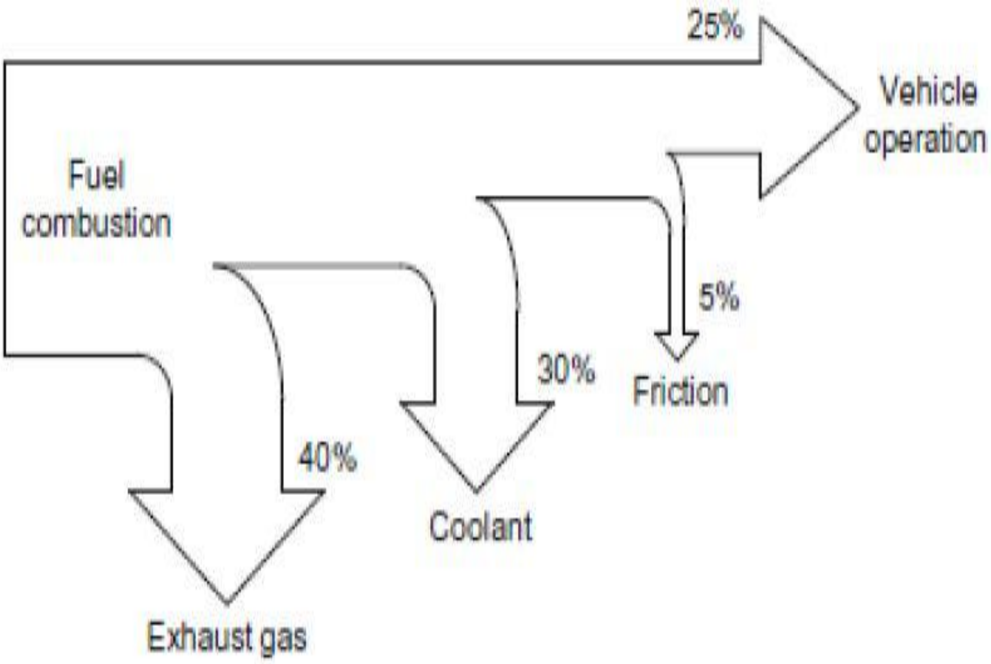

Fig.4 Energy Flow Path [14]

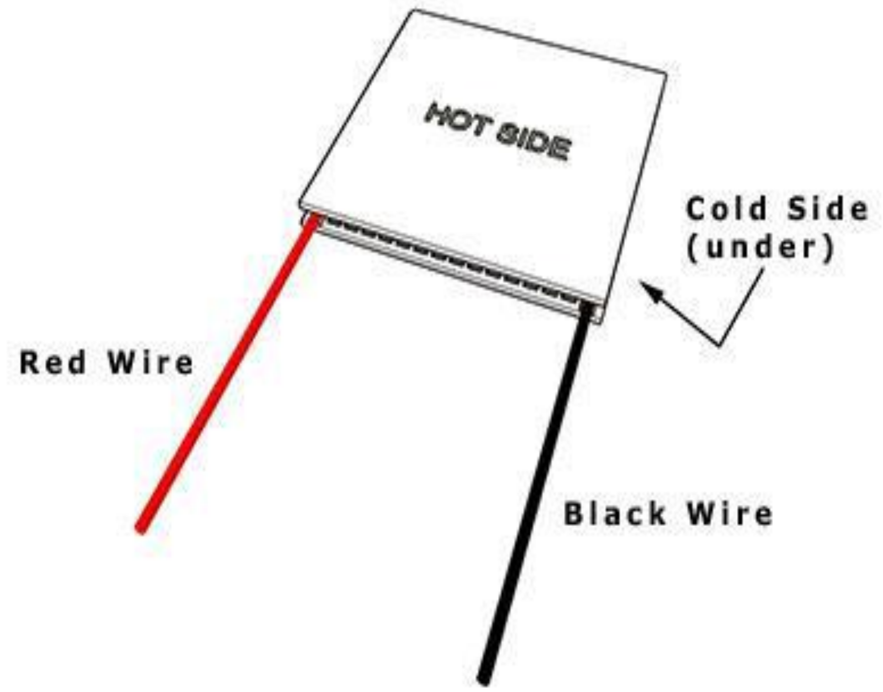

Fig.5 Thermoelectric Module showing different sides

The stored thermal energy is utilized through thermo-electric module for electricity generation, in which the temperature difference is directly used to be converted into potential difference. The temperature difference is created through the temperature of hot copper plate (obtained from thermal energy storage) and normal water temperature (obtained through the heat sink), placed in the opposite surface of the module.

Fig.6 Overview of Heat Sink

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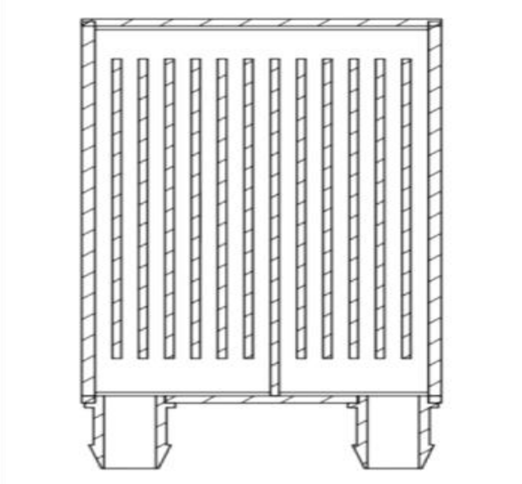

Fig 7 Heat Sink (internal structure)

This heat sink used for the water medium cooling of cold side of TE module.

Fig.8 installing coiled tube in tank

Fig.9 Copper plate installed for Thermoelectric Module

The whole tank is well insulated with the help of glass-wool and then from black insulating tape, so that minimal heat loss would occur and temperature would be retained for the longer period of time. This can be seen in the figure shown below.

For measurement purpose, digital multimeter and thermometer is used. Digital Thermometer is installed at four points, one at entry to tank, other at exit from tank and rest two at the two points where the module is installed, so that the mean temperature of these two point would lead to the average temperature of the storage material used in the tank. The electrical output is measured using the digital multimeter. The whole arrangement can be seen in the Fig.15.

Air, Water, Paraffin wax and petroleum jelly along with paraffin wax is used as the heat storage material in each of the four different cases used.

Fig.10 DT830D small Digital Multimeter (yellow) and ST-1A Digital Thermometer

Fig.11 Paraffin Wax   Fig. 12 Petroleum Jelly

VII. CALCULATION

Here, in this report, we are going to compare the maximum thermoelectric conversion efficiency for the different cases, such as when storage in taking place in empty tank, water in the tank, paraffin wax in the tank or when having mixture of paraffin wax and petroleum jelly in 10:1 ratio respectively. We will also conclude with the result that which one combination out of above stated four cases suits for which conditions, or environment.

Now, we are going to observe the outputs of the experimental setup established for each of the four cases.

Case I:-When tank is empty

Time(minutes)	T_{in} (°C)	T_{out} (°C)	T_{avg} (°C)	T_{module} (°C)	V_{oc}(in Volt)
0	32	32	32	32	0
10	90	86	88	85	1.05
20	129	109	119	115	1.28
25	139	120	129.5	124	1.45
30	152	131	141.5	140	1.63

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Table – 1 Case II:- When tank is filled with water

Time(minutes)	T_{in} (°C)	T_{out} (°C)	T_{avg} (°C)	T_{module} (°C)	V_{oc}(in Volt)
0	32	32	32	32	0
5	87	61.6	74.3	47	0.32
10	99	79.9	89.45	62.4	0.62
15	101	92.3	96.65	75.8	0.84
20	128	114.7	121.35	79.8	1.05
25	140	120.5	130.25	94.6	1.32
30	155	127.5	141.25	103.7	1.53

Table – 2 Case III :- When tank is filled with Parrafin Wax and Petroleum jelly

Time(minutes)	T_{in} (°C)	T_{out} (°C)	T_{avg} (°C)	T_{module} (°C)	V_{oc}(in Volt)
0	32	32	32	32	0
5	73	59.3	66.15	49.3	0.53
10	87	65.4	76.2	69.0	0.62
15	94	67.9	81.95	82.6	0.71
20	101	70.8	85.75	85.5	0.83
25	108	81.4	94.7	91.1	0.92
30	114	92.2	103.1	96.8	1.01
35	121	101.3	111.15	98.9	1.21
40	132	111.4	121.7	102.3	1.32
45	141	120.2	130.6	106.4	1.43
50	149	125.5	137.25	111.3	1.56

VIII. CONCLUSION

The analysis for the thermal energy storage is done for the different cases. Four different material such as air, water, paraffin wax and a combination of petroleum jelly with wax is used as the medium for thermal energy storage. Following points are concluded during the experiment:-

1) Air gets maximum temperature rise in comparison to all other material used as medium of thermal energy storage, however it also gets discharged quickly in comparison to other medium.

2) Water acts as a better sensible heat storage medium, however, not outperform latent heat storage, as the maximum temperature in our experimental cases is lower than boiling temperature of water, whereas, in latent heat storage cases, fusion temperature for paraffin wax used is much lower than that of water.

3) Paraffin wax melts at a temperature of 40°C, and hence has heat transfer of about 1239 KJ with greatest heat transfer rate of 413 W.

4) The combination of petroleum jelly with wax at a ratio of 1:10 further lowers the melting point of petroleum wax to 39°C, thus having greatest heat transfer rate of about 1346 KJ with heat transfer rate of about 320 W.

5) The discharging rate in each case found to be greater than the charging rate.

6) The maximum output voltage of thermo-electric module comes out to be of around 0.4 V for air medium, but the fluctuation is found to be least for the combination of wax and petroleum jelly used.

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