ANALYSIS ON TECHNIQUE TO RECOVER THE WASTE HEAT FROM THE AUTOMOTIVE EXHAUST WITH THERMAL ENERGY STORAGE USING PHASE CHANGE MATERIAL

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Abstract: This research will conduct a comparative examination of several methods to recover waste heat from automobile exhaust using thermal energy storage. Thermal energy storage (TES) is a technology for storing waste heat so that it can be used whenever it is needed. Waste heat recovery systems (WHRS) lower the temperature of gas that is released into the environment. We will use phase change material as the storing unit in this experiment, and we will learn about its performance and efficiency during the process, as well as how it will be useful for the waste heat recovery system. So, in this analysis we perform an investigation into waste heat produced by a diesel engine's exhaust with the help of a phase change material called acetamide (CH3CONH2). Which operates in the temperature range of 298k to 400k. We prepared an equipment (cuboid shape) with proper sealings and a removable top. There are two valves: one on the connecting side, which connects to the exhaust pipe end, and the other on the opposite side, which allows the exhaust gases to exit the system. Inside this cuboid there are 5 open mugs which are filled with the phase change material & every mug also contain a temperature sensor dipped inside the pcm which is in salt form; the sensors' wiring is connected to the RTD machine outside the cuboid by passing the wire through the top for the measurements of temperature at different loading conditions to study the heat storing capacity and efficiency of the PCM. As the results of our little experiment, we got some promising values as our system provides us with the efficiency of 21% at the load of 500W, 20.95% at the load of 1000W, 20.9% at the load of 1500W, 20.8% at the load of 2000W, 20.7% at the load of 2500W.

I. INTRODUCTION

A phase change material (PCM) is a substance that absorbs and releases energy to generate useful heat/cooling at phase transition. The transition will usually be between solid and liquid. The phase transition may also occur between non-classical states of matter, such as crystal conformance, in which the material transitions from one crystalline structure to another, which may have a lower or higher energy state. The heat of fusion, or the energy released/absorbed as a result of a phase transition from solid to liquid or vice versa. Thermal energy storage (TES) is a heat storage technology that allows it to be used whenever it is needed, even if it is hours, days, or months after it was produced. Since the TES approach is applicable in a wide range of fields, it is commonly used in a variety of industries. Seasonal storage, in which summer heat is stored for use in the winter, and ice production during off-peak times and used for cooling later are two examples of TES applications. It may also be waste heat from manufacturing processes that is collected and used for district heating. Acetic acid or Ethanamide is also known as acetamide. The most straightforward amide is derived from acetic acid. The plasticiser is widely used. Ethanamide is achieved as a colourless and mouse smelling hygroscopic solid. It dissolves in water, chloroform, hot benzene, glycerol, and is mildly soluble in ether. It is an acetamide formed by the condensation of formal acetic acid (CH3COOH) with ammonia (NH3). Naturally, it can be found in red beetroot.

II. LITERATURE REVIEW

This chapter is about a survey of previous work on waste heat recovery systems done by various researchers in the past. The following are the specifics of the literature review:

1. SS Prabu et al [2015]

A phase change material was used to examine heat recovery from diesel engine exhaust. Paraffin phase change material (PPCM) was merged with a diesel engine system to capture heat from exhaust gas in Thermal Energy Storage System (TESS) and in shell & tube heat exchanger. At maximum load, the heat exchanger extracts 86.45 kJ/kg of heat energy and 0.54 kW of heat energy is conserved; this amounts to roughly 7% of the fuel power stored as heat in the storage system.

2. S. Subramanian et al. [2005]

A heat recovery heat exchanger with an I.C. engine, as well as a combined sensible and latent heat storage system using spherical PCM (phase change material) capsules as the latent heat material, are designed, built, and tested. The performance aspects of the system are also thoroughly evaluated. The combination storage system stores about 15% of the fuel power and makes it available at a higher temperature for applications that require it.

3. Dr M. Rajagopal et al [2015]

The experimental work uses a PCM-based combination sensible and latent heat storage device to recover heat from IC engine exhaust gas. In the storage tank, about 0.2 percent of the energy in the fuel is collected and stored (or 6 to 7 percent of energy in exhaust waste heat). Increase surface area of contact of the heat recovery exchanger and properly insulate the thermal storage tank to improve the percentage of heat recovered and charging efficiency.

4. Karthikeyan et al [2020]

The steel inner and outer shells of the LHTES system were designed for holding PCM and water circulation for unloading, respectively. The heat transfer fluid is circulated for loading purposes through the spiral copper tube, which is inserted inside the inner shell. The temperature variations inside LHTES systems for D-sorbitol Phase Change Material (PCM) without Nano material and Nano PCM with Graphite are investigated. When comparing PCM with Nano material to PCM without Nano material, the heat transfer rate during is raised by 23 percent. It has also been increased by roughly 8% for the finned LHTES system.

5. Hassan et al [2016]

Three different classes are proposed in this research. The first classification is based on the temperature of the gas. High temperature systems, medium temperature systems, and low temperature systems are all considered depending on the temperature range. The second categorization denotes a classification based on the heat recovery equipment used. Several gadgets were demonstrated, with each one's functioning mode outlined. The third group is based on heat recovery applications, and the systems are divided into three categories: heating, power generation, and cooling.

6. Atul Sharma et al [2009]

This study summarises current research in this topic, with a special focus on evaluating the thermal properties of various PCMs. Heat storage applications include solar cooking, solar green homes, solar water heating systems, solar air heating systems, building space heating and cooling applications, off-peak power storage systems, and waste heat recovery systems. In that study, the melt fraction examinations of the few discovered PCMs used in various applications for storage systems with various heat exchanger container materials are also reported.

III. Research Gap

In this study, we investigated waste heat recovery from the exhaust of a Kirloskar diesel IC engine using phase change material as a crucial component of our heat recovery. Acetamide was employed as the phase change substance (CH_3CONH_2). Which functions in the 298k to 400k temperature range. We will use phase change material as the storing unit in this experiment, and we will learn about its performance and efficiency during the process, as well as how it will be useful for the waste heat recovery system.

IV. OBJECTIVES OF THIS STUDY

To design and fabricate the system for recover the waste heat from engine exhaust with thermal energy storage at different load conditions on engine. The heat is recovered from the exhaust is directly transfer to the energy storing material without using any working fluid.

So, the objectives of our work are:

1. An experimental examination of the performance characteristics of a waste heat recovery system on a diesel engine under various load conditions.
2. Study the energy storing behaviour of phase change material (acetamide) at different load conditions from exhaust gas.
3. Calculation the parameters like total heat stored, heat loss and the efficiency of the system.

V. Research Methodology

Experiment methodology for recovering waste heat from an IC engine's exhaust utilising the phase change substance acetamide.

Step 1-we put the PCM acetamide into the containers of the equipment as shown in given figure (no.6)

Step 2-we put the containers back in the equipment's housing

Step 3- then we insert the temperature sensor inside the cans which are filled with the pcm acetamide so that we can measure the temperature reading during the phase transition of the PCM

Step 4- now we will seal the housing from the top

Step 5- and then connect the exit wire clips of the sensor to the RTD equipment serial wise. Accordingly like we placed the sensors inside the can naming them T1 T2 T3 T4 T5 resp.

Step 6- now we connect the whole equipment to the engine's exhaust pipe and open the equipment's inlet and exit valves.

Step 7- now we will start the engine

Step 8- the engine is power source for the system connected to it with different loading condition

Step 9- now as the engine is running and all of our equipment and system is in position, we will start giving out load on the engine

Step 10- first we will put a load of 500W on the engine & keep it running for 10 sec & note down the amount of fuel consumed & air consumed (orifice meter) ; & also note down the temperature readings for all T1 to T5 through the RTD meter gradually.

Step 11- now will repeat the same process gradually for 1000W 1500W 2000W 2500W.

VI. EXPERIMENTAL SET-UP

This chapter discusses the experimental work done to investigate waste heat recovery from engine's exhaust using a thermal energy storage device. The experiments have been performed at Lovely Professional University (LPU), Jalandhar, India at 58 Block.

1. Experimental set-up components

A single cylinder diesel engine with electric loading and a waste heat recovery system with energy storage unit make up the experimental setup. The key elements have been designed. To transport and store waste heat, A waste heat recovery system is utilised in conjunction with a thermal energy storage unit. Acetamide is a phase transition substance that can be used to store latent heat energy. While performing the experiment we need to use the PCM which is place in different carry mugs that's hold the PCM at same time shown in the figure 6. This is the PCM we use in the experiment it's known as ACETAMIDE this PCM is use to recover or to store the waste heat that is coming out by the exhaust pipe.

Fig. 5 Experimental set-up

Fig. 6 - PCM

2. ACETAMIDE (CH3CONH2) - Acetic acid or Ethanamide is also known as acetamide. The most straightforward amide is derived from acetic acid. The plasticiser is widely used. Ethanamide is achieved as a colourless and mouse smelling hygroscopic solid. It dissolves in water, chloroform, hot benzene, glycerol, and is mildly soluble in ether. It is an acetamide formed by the condensation of formal acetic acid (CH3COOH) with ammonia (NH3). Naturally, it can be found in red beetroot.

Table 2: Specification of PCM Acetamide

Property of PCM	**PCM**
Latent heat of fusion	.263 KJ/KG
Capacity for specific heat	1.94 KJ/KG°C
Thermal conductivity	0.5 W/M°C
Density (solid form)	1159 KG/M^3
Density (liquid form)	998 KG/M^3
Temperature range	25-127 °C

Fig. 7 ACETAMIDE (PCM)

3. Engine use to perform the experiment

we have used a water-cooled single cylinder four stroke diesel engine by Kirloskar group. All specification shown below in table

Table 3: Engine specifications

Sr. No	Specification and Dimension of engine	
1	**Manufacturers**	Kirloskar Group
2	Model	TVI
3	Type	Water cooled single cylinder four stroke Diesel Engine
4	Stroke and bore	87.05mm*110mm
5	Cubic Capacity	661
6	Compression Ratio	18.1
7	Onfice Diameter	20mm
8	Rated power	5.2KW@1500rpm
9	Drum Break Diameter	185mm

Fig.8 Kirloskar diesel engine

4 Measuring Devices and Instrumentation

The RTD-PT 150 thermocouple is used to measure various parameters such as exhaust gas inlet and outlet temperatures, PCM temperature at various loading circumstances on the engine. As we can see in the below picture first one is the display screen that shows the temperature readings when we change the channel for different sensors which shows different temperatures with different engine loading conditions. And the second one shows the sensor's wiring attached the input socket of the RTD meter to feed the input coming from temperature sensors which are placed inside the equipment for measurement of heat of the exhaust gas.

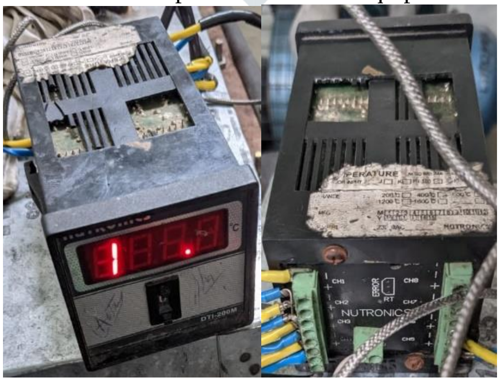

Fig. 9 RTD-PT 150 Thermocouple

VII. PERFORMANCE ANALYSIS OF EXPERIMENTAL DATA

The total heat stored, total heat loss, heat extraction rate, and energy saved were all considered in the performance study of the waste heat recovery system.

1. Fuel consumption

Fuel consumption is the rate at which an engine uses fuel to produce power per unit time. This equation is defined as a fuel consumption of engine at different loading conditions.

Wf=x×fuel density×60/t×1000 kg/min………………………………………………. eq1

- **x** - volume of fuel consumed
- **t** - Time taken in second

2. Heat supplied to Engine

The total amount of heat sent to the engine by the combustion of the fuel. Total heat is generated inside the engine at different loading conditions are given by the following equation:

Hf = Wf×C.V kJ/min………………………………………………………………. eq2

- **Wf -** fuel consumption.
- **C. V -** Calorific value of diesel.

3. Air Consumption by Engine

Air consumption refers to the input air's mass flow rate as measured by a U tube manometer.

Qa = Cd ×ao× √2gh m3/sec………………………………………………...……eq3

- **Cd** - Coefficient of discharge
- **ao -** Cross section area of orifice
- **g -** Acceleration due to gravity
- **h –** Head difference of manometer

4. Exhaust gas carries heat away in waste heat recovery system

At different loading situations, total waste heat carried by the engine's exhaust tail pipe linked to the waste heat recovery system with thermal energy storage.

Hg = meg×cp×(Tg-Tr) kJ………………………………………………………..……eq4

- **Hg -** total heat supplied
- **meg -** p×v×t
- **meg** - mass of exhaust
- **p -** Density of exhaust gas
- **v -** Volume of waste heat recovery system with thermal energy storage
- **t -** Operating time of engine
- **cp -** specific heat capacity
- **Tg -** the temperature of the system's exhaust gas inlet
- **Tr** - temperature of the system's exhaust gas exit

5. Heat stored in PCM

The heat stored by the PCM is a combination of latent and sensible heat as a result of the change in phase of the PCM from solid to liquid. The following equation is used to compute total stored heat energy:

Hpcm = mpcm×Cppcm×(Tg-Tr) +mpcm×L kJ………………………………………eq5

- **Hpcm -** Heat stored in PCM
- **mpcm -** Mass of PCM
- **cppcm -** PCM's specific heat capacity
- **L –** PCM's latent heat

6. Heat loss in PCM

There is no system which is 100% efficient in this universe similarly for the waste heat recovery system there will be some losses. These losses are calculated using this equation.

Hloss = Hg – Hpcm……..………………………………………………………. eq6

- **Hloss =** Heat loss
- **Hg =** Total heat supplied
- **Hpcm =** Heat stored in PCM

7. Waste heat recovery system efficiency

The waste heat recovery system stores a percentage of the total heat delivered to the system. The efficiency of a system is defined as the amount of heat stored in relation to the amount of heat delivered to the system. The efficiency is calculated using the equation:

EFF (%) = (Hpcm/ Hg) ×100…………………………………………………….……eq7

- **EFF (%) -** Efficiency of waste heat recovery system
- **Hpcm** - Heat stored in PCM
- **Hg** - total heat supplied

EFF (%) = (Hpcm/ Hg) ×100

Hloss = Hg – Hpcm

VIII. RESULTS AND DISCUSSION

This chapter presents the outcomes of the experiments. The tests are conducted on a diesel engine under a variety of load circumstances. Calculating heat recovery and heat loss from the engine exhaust carrying waste heat is used to assess the system's performance. The goal of this experiment is to recover as much heat as possible from waste exhaust heat. This experiment focused on acetamide CH3 CONH2, an organic phase change material. Under various engine loading conditions, the temperature change of the exhaust gas at entrance and exit of a waste heat recovery system with thermal energy storage is investigated. In this experiment, a waste heat recovery system with thermal energy storage serves as a heat exchanger and a thermal energy storage system in various situations. The container acts as a heat exchanger, with both inlet and exhaust valves being opened. When the container's input and outlet valves are closed, it acts as a thermal energy storage device.

The experiments are carried under these cases to evaluate the performance of the system

Case 1. Variation of temperature of exhaust gas vs load

This below given graph depicts variation of the exhaust temperature with the variation of the engine load. The min. temperature recorded was 37.1 degree Celsius at the load of 500W, the max. temp. recorded was 96.8 degree Celsius at the load of 2000W.

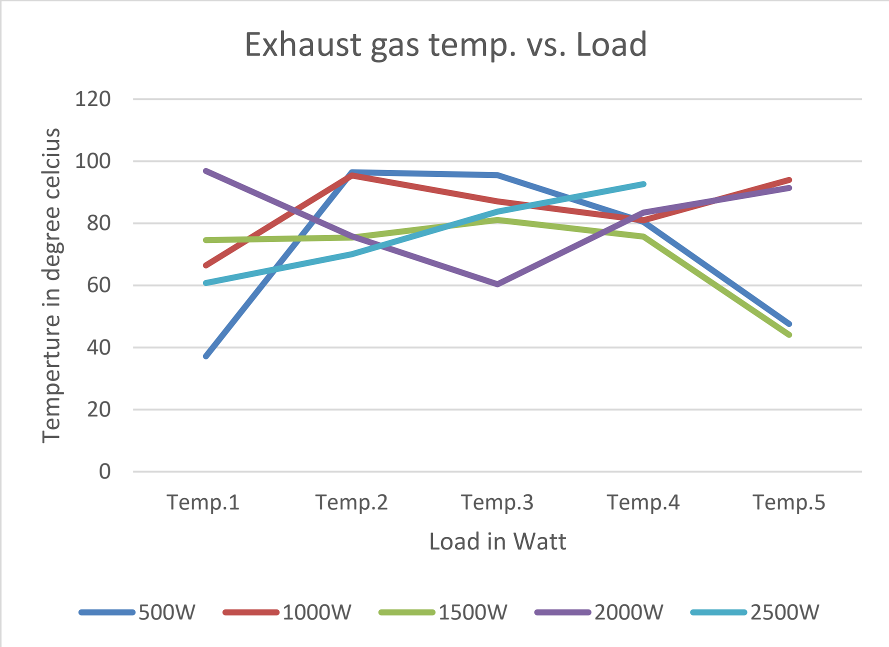

Fig. 10 temperature variation of exhaust gas with change in load

Case 2. Fuel consumption vs Load

Case 3. Air consumption vs Load

In these cases, the below given graph depicts the amount of fuel consumed and amount of air consumed by the engine when it goes through different loading conditions. The consumption of air was almost constant throughout the process which was about 0.0013qubic meter/sec. the consumption of fuel was min.0.00765Wf for 500W & max. 0.01632Wf for 2500W.

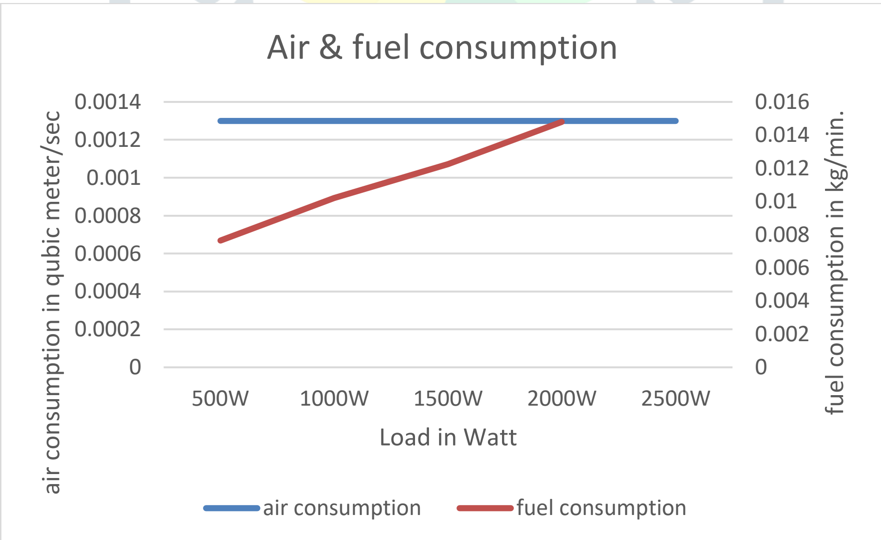

Fig. 11 air & fuel consumption

Case 4. Load vs total heat supplied

In this case the below given graph depicts the amount of heat supplied to the engine under various loading conditions. The min. amount of heat supplied was 348.075KJ/min. for the load of 500W and the max. heat supplied was 742.56KJ/min. for the load of 2500W.

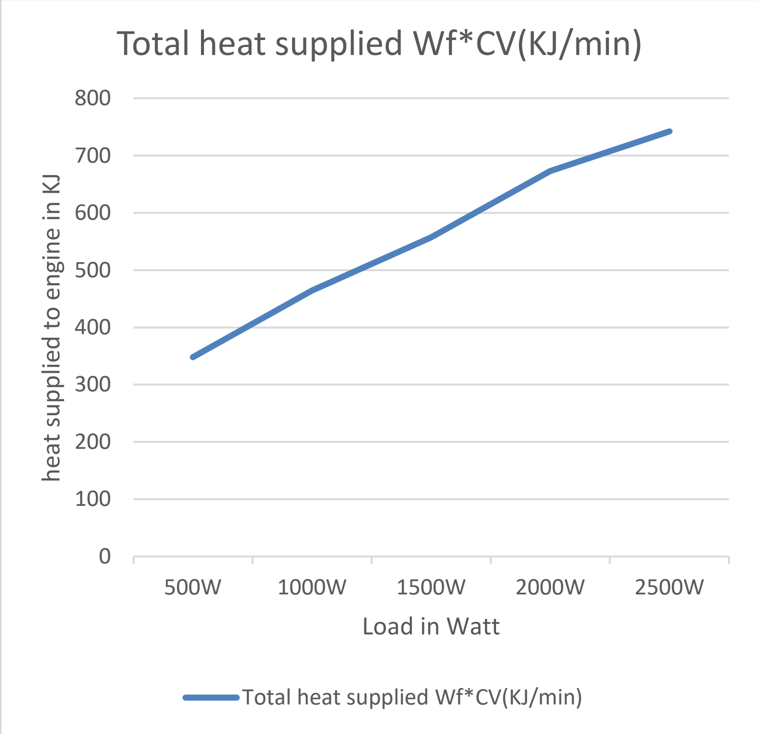

Fig. 12 Heat supplied to engine

Case 5. Heat transported by exhaust gases

The graph given below depicts the amount of waste heat energy coming from the exhaust which were transported away by the waste heat recovery system's exhaust gases. The min. heat carried away was 1.488384KJ at the load of 500W. and the max. heat carried away was 2.017152KJ at the load of 2500W.

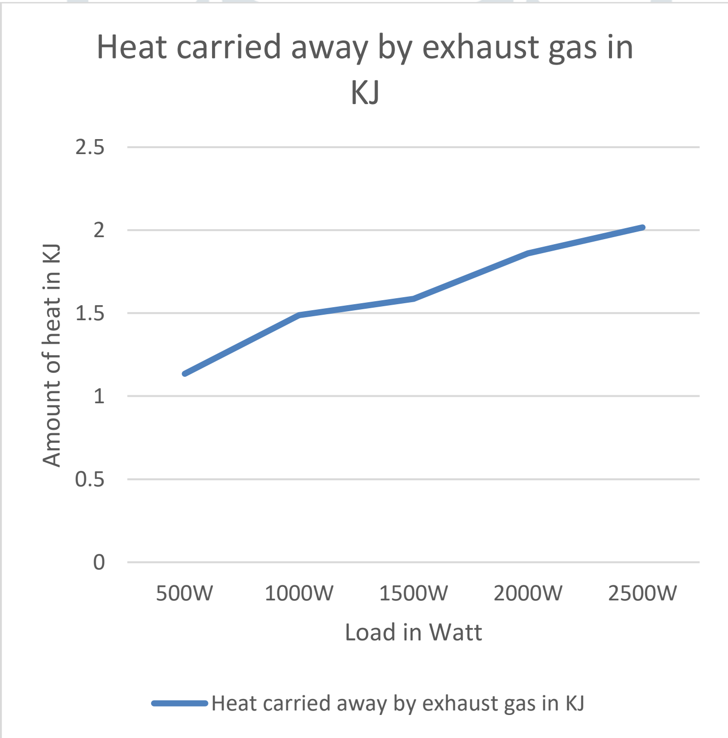

Fig. 13 heat carried by exhaust gases

Case 6. Heat stored in PCM

Case 7. Heat loss in PCM

This graph shows the amount of energy which is stored by the pcm and the amount of energy which the pcm was unable to store from the exhaust waste heat energy at different loading conditions. The min. heat stored was 0.24178KJ at 500W & max. heat stored was 0.4182295KJ at the load of 2500W. Whereas the min. heat loss 0.89409KJ & max. 1.5989225KJ at the loading of 500W and 2500W respectively.

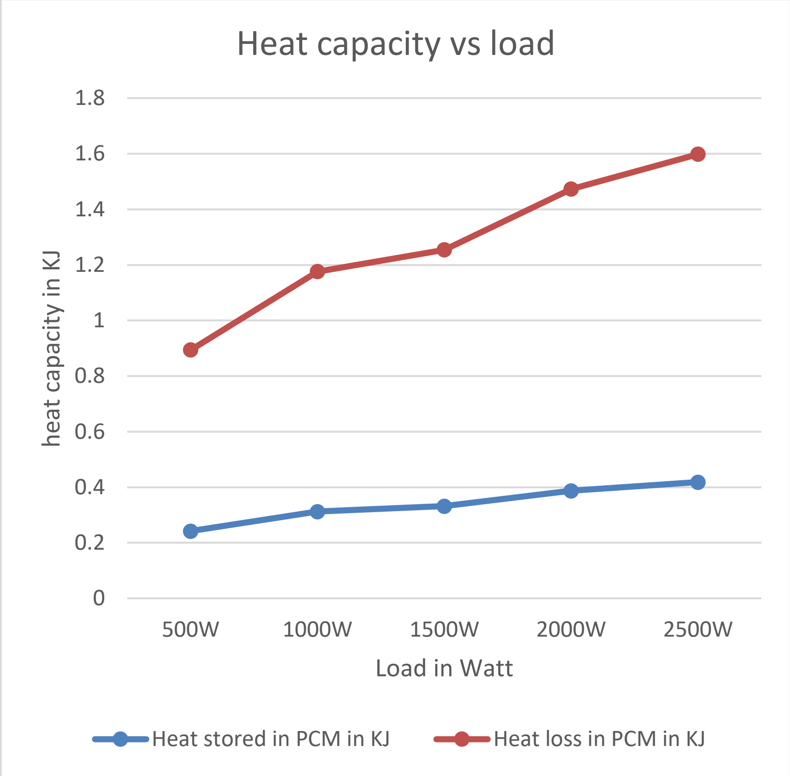

Fig. 14 heat stored & heat loss in PCM

Case 8. Efficiency

This case describes the final result of our experiment.

The graph given below shows the efficiency of system we developed by the use phase change material(acetamide). We got a min. efficiency of 20.7% at the max. loading of 2500W & the max. efficiency of 21% at the min. loading of 500W.

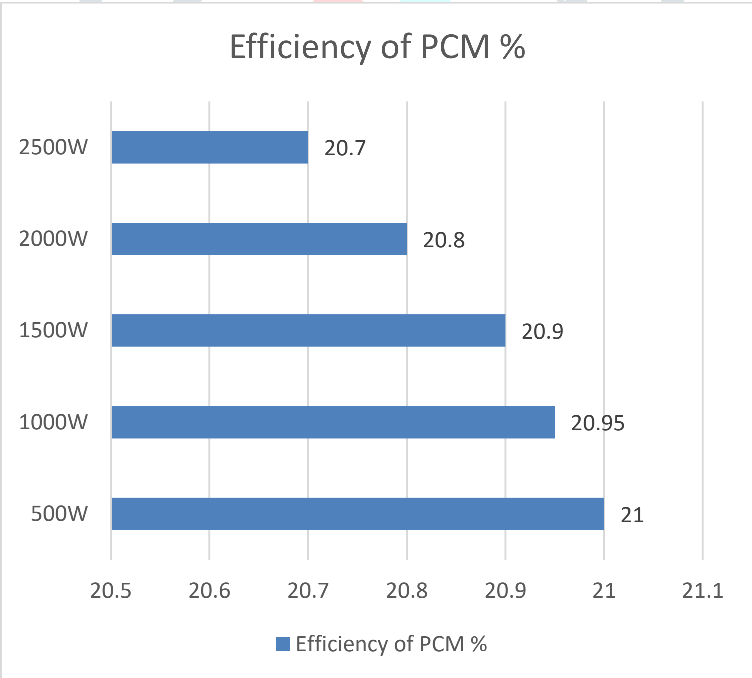

Fig. 15 Efficiency of PCM

IX. CONCLUSION

We can conclude that by using the method of providing a chamber in the line of exhaust pipe that is filled with phase change material, we can recover some of the waste heat coming from the exhaust gases of the engine after performing the experiment for the recovery of waste heat from a diesel IC engine's exhaust. As we completed our experiment in limited resources in our college laboratory and we were able to get an efficiency of around 21% from a phase change material which performs at temperatures of up to 120 degrees Celsius.

So, if the same can be done on a large scale in automotive industries it can be big leap in the energy sector & which also improves the efficiency of the vehicle and also the pollution released in the environment will be less.

- The consumption of air was almost constant throughout the process which was about 0.0013qubic meter/sec.
- The consumption of fuel was min.0.00765Wf for 500W & max. 0.01632Wf for 2500W.
- The min. amount of heat supplied to the engine for process was 348.075KJ/min. for the load of 500W and the max. heat supplied was 742.56KJ/min.for the load of 2500W.
- The exhaust gas waste heat recovery system's minimum heat transported away by exhaust gases was 1.488384KJ at the load of 500W. and the max. heat carried away was 2.017152KJ at the load of 2500W.
- The min. heat stored in the pcm was 0.24178KJ at 500W & max. heat stored was 0.4182295KJ at the load of 2500W.
- The min. heat loss in the pcm was 0.89409KJ & max. was 1.5989225KJ at the loading of 500W and 2500W respectively.
- We got a min. efficiency of 20.7% for the pcm at the max. loading of 2500W & the max. efficiency of 21% at the min. loading of 500W.

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