INVESTIGATION OF WASTE HEAT RECOVERY SYSTEMS USING THERMO-ELECTRIC GENERATORS AND SIMULATIONS FOR USED AUTOMOBILE RADIATORS

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Abstract - Providing good and best solutions to everyday problems varies day by day with the evolving technologies. The solution pertaining to the problems associated with the exhaust gases from the automobile or other such equipments revolves around only on the ways of reducing the pollution. Many designs and developments are also made in terms of alternative energies at low cost. One such ideology is to recover and reuse the energy that is exhibited out in the form of liquid or heat. Waste heat recovery will be a new energy source. Thermal fluid flow heat recovery system from Automobile radiator with internal and external tubes is one such option .While most of the state of art papers considers only the waste heat as energy source, this thesis discusses the usage of phase changing materials in the external fluid flow tubes in heating and cooling paths. Both the static and dynamic nature of the energy is used in the work. Design and development of heat energy recovery system from the air cooled radiator is made. The system is very challenging and it plays a major role in the works where the heat energy is recovered as electrical energy which paves way for an additional usage of TEG.

Key Words: Thermoelectric generator,radiator,phase change material, energy conservation

1.INTRODUCTION

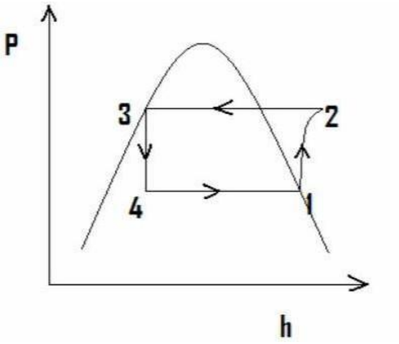
The amount of energy consumed increases every year with the growth in the domains of the various industries. The burden of this demand falls on the environment and it should be reduced. According to(Lebduska 1978). The "Law Concerning the Rational Use-Of Energy" (Energy Conservation Law), as amended in 2008, obligated business and Indian operators participating in various business activities ranging from small to large scale should publish the reports about their energy consumption. This mainly applies to the automobile sectors(Houlihan 1998). Management methods for energy consumption by company operators are consequently becoming an issue for the retail industry, as well as energy conservation strategies at individual outlets. The Indian authorities promised a 7.1% reduction in greenhouse gasses from 2017 pertaining to the recommendations by the "Prathama green yochana system" which proves to be succeeded in Gujarat(NakazawaAsami *et al.* 1973). All the necessary steps are made in order to achieve the target specified above. This also satisfies the Energy conservation law.

The amended Energy Conservation Law was put into effect from April 2017(JeongMumma *et al.* 2003). This legislation demands certain actions such as submission of energy consumption reports by the industries with the duties executed by the respective company operators and franchise operators who involved in the activities done for managing the energy consumption. Roughly 115.5 billion India Rupees spent on consumption of electrical power. Various energy conservation strategies are implemented by the business owners in order to cut down the prices and abide by the actions suggested by the Government,(Maizza &Maizza 2001). In spite of these efforts, the concentration was made on to enhance the performance of the individual facilities but there is a lack in the total management of energy consumption. In reality, proper measures as directed are not followed in many of the industries. This includes inappropriate maintenance of temperature in the locations where centre equipment is installed. Human error also exaggerates the issue(Kalina 1983). From the distribution socket industry, particularly, which includes convenience shops and which frequently involves the establishment of numerous socket, the capability to comprehend the energy intake status is lacking at individual outlets (Hasnain 1998, Yu &Chau 2009,Quoilin, Aumann *et al.* 2011). The methods employed for managing energy consumption by business operators are becoming a significant problem for the distribution business, along with energy conservation approaches for implementation at different outlets(Kalina 1983, SahaAkisawa *et al.* 2001). It's against the "Energy Conservation Controller" for attaining energy conservation in individual outlets and the "Energy Management Service", which offers energy management services for distribution outlet systems.

2. WASTE HEAT RECOVERY FROM AUTOMOBILE RECOVERY SYSTEM

In western countries the energy from condenser of Automobile recovery systems are used for heating the room but this system can be used to produce hot water in tropical countries like India. An Automobile catalytic converter is essentially a vapour compression catalytic converter machine which takes heat from a low temperature source such as air or water and upgrades it to be used at a higher temperature. Unlike a conventional catalytic converter machine, the heat produced at the Catalytic converter is utilized and not wasted to the atmosphere.a simple vapour compression Rankine cycle, together with the relevant pressure and temperature diagram.

. This illustrates the layout of a normal Rankine cycle with air cooled and heated. In the cycle shown, the low pressure and low temperature vapour refrigerant from the evaporator is drawn into the compressor through the suction valve.



1. Where it is compressed to a high pressure and high temperature. This high pressure and high temperature vapour automobile is discharged into the condenser through the delivery valve

2. The condenser (here it is water cooled condenser where the coolant is water) consists of coils of pipe lines where high pressure and high temperature vapour automobile is cooled and condensed. The refrigerant, while passing through the condenser, gives up its latent heat to the coolant (water) thereby hot water is being generated. After condensation the refrigerant is sent to expansion valve.

3. Here the pressure and temperature are decreased. The automobile is finally sent to evaporator

4. The liquid-vapour refrigerant at low pressure and low temperature is evaporated and changed into vapour refrigerant at low pressure and temperature. While evaporating, the liquid vapor refrigerant absorbs its latent heat of vaporization from the room which is to be cooled. Thus the heat pump cum air conditioner cycle repeats and generates hot water from the air conditioner through waste heat recovery process.

3. CLASSIFICATION OF AUTOMOBILE WASTE RECOVERY SYSTEM

Jadhao &Thombare (2013), a reduction in energy intake is possible by enhancing the performance of heat exchange systems and introducing different heat transfer enhancement techniques. From the middle of the 1950s, some efforts have been done on the variation in geometry of heat exchanger apparatus using different fin forms or various tube inserts or surface and the similar a number of the published investigations have concentrated on electrical or magnetic field application or vibration technique although an improvement in energy efficiency is possible from the topological and configuration points of perspective, much more is needed in the standpoint of the heat transfer fluid (Aghaali &Ångström (2015) in this paper enhancement in heat transfer is always in demand, since the operational rate of these devices is based on the cooling rate (MengWang *et al.* 2016). New technology and innovative fluids with greater potential to enhance the flow and thermal characteristics ($3.5 < Re < 280$) along with a brand new convective heat transfer correlation for nanofluids in microchannels was also suggested(Matsubara 2002, LaGrandeurCrane *et al.* 2006)implemented 9.15 vol. % $Al2O$ in water at a horizontal tube geometry and reasoned that in Pe amount of 2700 and 5700 around 37% promotion in heat transport coefficient in comparison to pure water may be occurred (KimPark *et al.* 2011) conducted a test for heating in flat tube at laminar flow of $Al2O3$ E water in 1 and 2 vol. % concentrations and concluded the interesting enhancement of 51 percent in heat transfer coefficient. Nguyen *et al.*, Smith &Thornton (2009) performed their experiments at the radiator type heat exchanger and at 6.8 vol.. In the paper, driven convection heat transport coefficients are noted for pure water and water/alumina Nano powder mixtures under fully turbulent conditions (Park Teng *et al.* 2011) The test section is made up of a normal automobile radiator, and the effects of the working requirements on its heat transport performance are examined. Additives to liquids are more noticeable. Recent advances in nanotechnology have allowed development of a new group of fluids termed nanofluids. Such fluids are liquid suspensions comprising particles that are significantly bigger than 100 nm, and possess a bulk solids thermal conductivity greater than the base liquids (Yaeger &Keller 1980). Nanofluids are shaped by suspending metallic or non-metallic oxide nanoparticles in conventional heat transport fluids. These so called Nano fluids display good thermal properties compared with Percent of nanoparticle for Reynolds number varying between 700 and 2050 (Armstead & Miers 2014). The Nusselt number for the nanofluid was discovered to be higher than that of the base fluid; and the heat transport coefficient increased with the increase in particle concentration. The ratio of the measured heat transfer coefficients increases with the Peclet number as well as nanoparticle concentrations.

4. RADIATOR

Engine produces high amount of heat while running. This can raise the engine temperature to very high level and can damage or seize the engine components. (HatamiGanji *et al.* 2014, Wankhede &Krispin 2016).

Hence for the safety of engine components, it must be running at lower temperature, which is called engine working temperature. Engine cooling system keeps the engine running at its working temperature by removing excess heat. Coolant used here is the mixture of water and antifreeze which flows through the engine cooling system to absorb the excess heat and dissipate it through radiator. Engine coolant is a mixture of Antifreeze and Water(GoldmanBaker *et al.* 1987, VerdeCortés *et al.* 2010, RoweSmith *et al.* 2011). It is generally mixed in 30:70 to 50:50 ratios depending on the weather conditions in which the vehicle is used. 50% of Antifreeze is used in conditions where the temperature falls below -15 o Centigrade. 30% of Antifreeze is used in conditions where the temperature does not fall below -15Centigrade. Antifreeze is mixture of Glycol and Additives. It has anti rust properties to avoid rusting of engine passages. It has very low freezing temperature to avoid freezing in extreme cold conditions.

4.1 COMPONENTS OF RADIATOR

Radiator is also known as heat exchanger, the purpose of which is to take out the heat from the engine. Here heat is transmitting through coolant from liquid medium to atmosphere. It consists of core, top and bottom tank. Core is designed with two sets of passageway, one set of tube as well as fin. Liquid coolant flows inside the fins as soon as air gets flow its outer surfaces. The heat presents in the engine is absorbed by the coolant and carried via the radiator then transferred to the atmosphere.

4.2 RADIATOR CAP

Tsopelas (1982), Bhogare &Kothawale (2013)radiator cap maintains a constant high pressure in the cooling system, which increases the boiling temperature of engine coolant. The increased temperature helps in easy dissipation of heat to atmosphere because of higher difference in radiator temperature and ambient temperature. It contains two valves. High pressure valve maintains the pressure in the system. It opens to release the coolant to coolant reservoir if pressure increases more than a limit. Low pressure valve or vacuum valve opens to allow the flow of coolant back to radiator when engine cools down

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4.3 COOLANT RESERVOIR

Coolant reservoir stores the coolant which flows out from radiator cap when engine temperature and coolant pressure rises. It also allows the flow of coolant back to the radiator when engine cools down. This avoids the loss of coolant and frequent top ups.

4.4. RADIATOR COOLING FAN

Cooling fan maintains the flow of air through the radiator to dissipate the excess heat of engine to atmosphere. There are two types of cooling fans, mechanical fan and electrical fan. Mechanical fan is generally connected to engine crankshaft through a belt and set of pulleys. Electrical fan has an electric motor which is controlled either by a fan switch installed on radiator tank or by ECM which turns it ON or OFF with the help of coolant temperature sensor.

4.5. RADIATOR HOSE

Hoses connect the components of cooling system that is top and bottom radiator tanks to the engine coolant passages. They also connect the heater coil to the system.

4.6. WATER PUMP

Water pump circulates the coolant by pushing it through engine passages and radiator. It is usually mounted on cylinder block and powered by engine through a belt.

4.7. THERMOSTAT VALVE

Thermostat valve allows the flow of coolant to radiator only when the working temperature is attained after starting the engine. This helps engine to attain the working temperature quickly. It also avoids overcooling of engine and fuel wastage.

4.8. RADIATOR COOLING

Radiator cooling fins increases the total surface area of the metal body which provides cooling effect and hence, improves the efficiency to attain the maximum cooling effect. It also speeds up the transfer of heat energy.

4.8.1. Heat Conservation of Air Cooled Radiator

Automobile energy is totally free, non-polluting and abundant on Earth. It may provide approximately 10W/m2 of Automobile energy on a Dynamic and Static conditions. Air Cooling radiator with and Thermoelectric Generating (TEG) cells are radiator outlet tube/inlet tube-based power generating cells which could convert auto energy to electric energy. In spite of the fact that the solar energy being cost free, these solar cells feature expensive semi-conducting materials and pose problems of low energy conversion efficiency (Scott 2010). By concentrating the incoming radiation by using an Automobile concentrator, the Automobile energy intensity could be increased many times determined by the Automobile concentration ratio. The use of immersion in solar power generating systems may either increase the electrical power output or lower the required amount of solar cells for any given output energy. Automobile immersion is cost-cutting methods for solar-electricity production as smaller quantities of expensive Automobile cells are combined with an inexpensive solar concentrator to get a similar degree of power production.

5. THERMAL STORAGE AND PHASE CHANGE MATERIAL

In Automobile air cooling industry that are equipped with RWHTEG systems, the heat transfer fluids flow to control and discharge the renewable energy to and from the PCM respectively. On the other hand, the heat transfer speeds between the heat transfer and the PCM are restricted by the low thermal conductivity of the PCM. Inorder to reduce the thermal resistance of the PCMs, Shabgard *et al.* (2010) indicated to stud the HTF tubes using bare HPs. The advantages that could be gained by using HPs along with fins (finned HPs) in high-temperature LHTES systems have not been studied. The combo of both HPs and fins has got the potential to enhance the operation and decrease the capital cost, this is stated depending on the fact that the HPs outperform fins in terms of heat transfer (Robak *et al.* 2011b), however fins are predicted to be cost-competitive especially contrasting with high-temperature HPs.

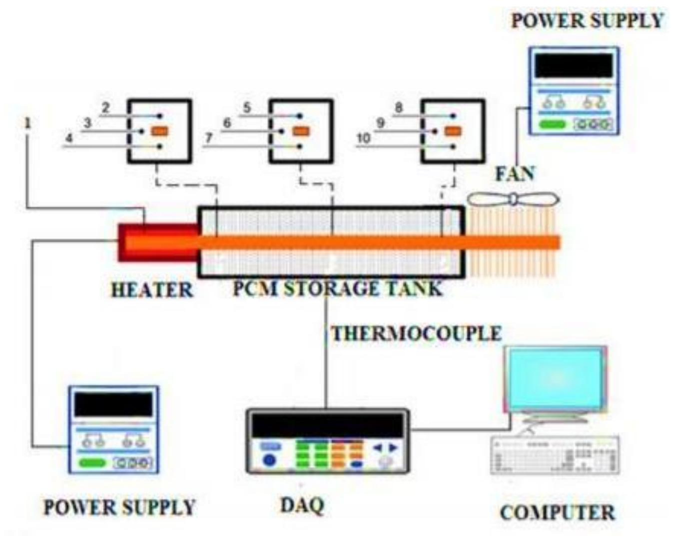

Fig. PCM storage system in heat transfer fluids

These pipes were surrounded by heat transport fluid.

Bajnoczy *et al.*studied the two-grade heat storage system (60-30 8C and 30-20 8C) based on calcium chloride hexahydrate and calcium chloride tetra hydrate. Authors also studied the phenomenon with the various storage capacities during the cycles and possible utilization of a solar energy storage platform for national water-heating system. CaClH2O was utilized as phase change material. A comparison is also made with different storage systems made with PCM, Water and stone. Whenever solar energy is available, it is collected and transferred into the power storage tank that is full of 1500 kg encapsulated Phase Change Material (PCM). It consists of a boat packed from the horizontal direction with cylindrical tubes. The power storage material (CaCl26H2O) is within the tubes (the tube container is made up of PVC plastic) and heats transfer fluid (water) flow parallel to them. A solar collector with storage for water heating having salt hydrate as a phase change material is also studied. The results of parametric studies on the impact of this transition temperature and of the depth coating of the salt hydrate PCM on the thermal performance of the charging procedure has also been presented. Sharma *et al.*(2004) designed, developed and evaluated the performance of a latent heating device during the day and morning hours, employing a box type solar collector. Paraffin wax (m.p. 54 8C) was used as a latent heating material and also found that the functioning of the latent heating unit in the machine was quite great to find the warm water at the desirable temperature range. Inside this collector, the absorber plate--container unit plays the role of absorbing the solar energy and saving PCM. The solar energy was saved in paraffin wax, which was used as a PCM, and was discharged to cold water flowing in pipes situated within the wax. The collector's effective area was assumed to be 1 m2 and its total volume was divided into five businesses. The experimental device was developed to simulate among the collector's industries, with an apparatus-absorber effective place of 0.2 m2 . Outdoor experiments were carried out to demonstrate the applicability of utilizing a streamlined solar collector for water heatingsystem. The time-wise temperatures of this PCM were recorded through the procedures of charging and discharging. The solar intensity was recorded throughout the charging process. Experiments were conducted for various water flow rates of 8.3-- 21.7 kg/h. The impact of this water flow speed on the helpful heat gain was analyzed. The heat transfer coefficients were computed for the charging process. The propagation of this melting and freezing front was also studied during the charging and discharging procedures. The experimental results showed that during the charging process, the average heat transfer coefficient increases sharply with the increase in the molten layer thickness. During the discharge process, the useful heat gain was found to rise with the increase in the water mass flow rate.Cabeza *et al.*(2006) assembled solar pilot plant at the University of Lleida to test the PCM behavior in actual conditions, which could work continuously with a solar system, or could also work with an electric heater.

The PCM module geometry adopted uses several cylinders at the top of the water tank. Several experiments with two, four and six PCM modules were carried out in the real installation. A granular PCM graphite chemical of roughly 90 vol. % of sodium acetate trihydrate and 10 vol. Percent graphite was selected as the PCM for the experiments presented here. Writer concluded that the addition of a PCM module in water tanks is a really promising technology. It might allow to have warm water for longer periods of time even without outside energy supply, or to utilize smaller tanks for the identical function.

Suat *et al.*(2007) introduced a traditional open-loop passive solar water-heating system with sodium thiosulfate pentahydrate as phase change material (PCM). Experimental investigations were made. A comparative study in terms of enhancement in solar thermal energy functioning is made with the conventional system with no PCM. Heat storage functions of the exact same solar water-heating system with other salt hydrates PCMs like zinc nitrate hexahydrate, disodium hydrogen phosphate dodecahydrate, calcium chloride hexahydrate and sodium sulfate decahydrate (Glauber's salt) were analyzed theoretically using meteorological data and thermo physical properties of PCMs with few assumptions. It was observed that the storage period of hot water, the generated hot water mass and complete heat accumulated in the solar waterheating system with the heating storage tank blended with PCM were roughly 2.59 to 3.45 days of that at the traditional solar water-heating system. It was also revealed that the hydrated salts of the highest solar thermal energy storage functionality in PCMs used in theoretical evaluation were disodium hydrogen phosphate dodecahydrate and sodium sulfate decahydrate.

6. CONCLUSION

This research study investigates a new way of recovering waste heat out of car radiator and power utilizing an internal combustion unit blend of radiator heating pipes and thermoelectric generators (RHP-TEG). The RHP- TEG system is made up of Bismuth Telluride (Bi2Te3) based thermoelectric generators (TEGs), which can be sandwiched between 2 air cooled radiator heating pipes to accomplish a temperature gradient throughout the TEG to get thermoelectricity generation. This system is unique as it may simultaneously recover waste heat and create electricity utilizing a completely passive method with no moving components in auto systems. A detail manufacturing model was created to offer a preliminary performance quote for this system before beginning more thorough laboratory work. The analytic model was derived with the energy balance equation along with the thermal resistance procedure. It was discovered from the experiment that the thermal resistance of this TEG diverse with all the heat input. The TEG thermal resistance revealed a little change (standard deviation of 0.03°C/W) using the rising heat input on the heating ion assortment95 of 120 W. As an average, a normal value of 0.8 °C/W has been considered in this study. It was also discovered that the TEG thermal-to-electric energy conversion efficiency increased with increasing temperature gradient throughout the TEG. The parameters gathered for this experiment were used from the theoretical design to ascertain the optimum configurations of this potential full- scale RHPTEG system. The simulation results of this theoretical model have revealed that the electrical and thermal operation of the RHP-TEG system diminished with increasing mass flow. The simulation results indicated that the optimal mass flow rate should be roughly 0.03 kg/s (or air face velocity of 0.9 m/s) for generating the most electrical and thermal operation of the system. It was noticed in the simulation effect that decreasing the mass flow rate less than 0.03 kg/s can create the temperature of the RHP-TEG to rise within the TEG temperature limit of 125°C. Additionally, a rise in the amount of radiator leak heating pipe row installed into the machine could raise the quantity of heat transfer speed and the electric power output. Based on these outcomes, it had been proposed that the potential full-scale RHP-TEG system ought to be set up with concurrent flows of their RHP-TEG modules. Under those thermal conditions, the theoretical model predicted that the RHP-TEG method could possibly create approximately 10 W of electric power and the speed of heat recovery could be 1.6 kW utilizing 2 kW of heating energy input. The experimental information obtained from this testing has been utilized to confirm the theoretical model. The simple notion of the experimental rig consisted of a TEG connection between two heating pipes that they functionas an evaporator (heating pipe 1-outlet) and a condenser (heat pipe two inlet). These procedures made a temperature gradient throughout the TEG and create power. The system configuration has been anticipated to grow the recovery ratio of waste heating since the warmth discharged from the condenser preheats the incoming air and thus raises the warmth of air flow within the evaporator. In the true experimentation, eight rows of those HP-TEG modules were set up between those ducts. The modules were organized in series to the management of air flow. A 120 millimeter gap split each module. On account of this high temperature increase across the TEG temperature limitation, the cheapest air face velocity was confined to 1.1 m/s. The temperature limitation of the TEG was put from the producer at 125°C. During this limitation, the solder substance of this TEG could be ruined with potential loss of functionality. It was discovered from the experimental results that the heat transfer speed of this RHP-TEG system decreased with a rise of air flow speed. The decrease in the heat transport rate happened due to the fall of the temperature gradient between the warm and the cold ducts. This deviation was imputed to the heat reduction though the machine wall in the real experiments. For the theoretical design, heat reduction didn't happen because the walls have been considered adiabatic. The heat recovery operation of the RHP- TEG system has been evaluated by the radiator efficacy. It has been revealed that the potency of the system rose from 28 percent to 37 percent when the air flow has been diminished to the minimum speed moderate driving conditions. In a minimal air face velocity, the temperature difference between the warm and the cold atmosphere improved, leading to the gain of the system efficacy. Like the speed of heat transport instance, the energy output rose when the air flow speed was decreased to the bottom air mill atmosphere.The maximum electric power generated was roughly 7 W.

Experiments on the projected system have shown the use of entirely passive devices (heat pipes and TEGs) for heat recovery and electricity production is an efficient way of reusing waste energy. This is only because it provides many benefits when compared to the concurrent flow heat settings. A counter flow setup of a RHP-TEG was also designed to replicate the functional situation of this heat exchanger in business. The counter flow heat exchanger of this RHP-TEG has two different air ducts. Both of these ducts were thermally linked utilizing the RHPTEG modules. The condenser part of these RHP-TEG modules was set up in the cold duct that transported cold air in the environment. The evaporator part of this RHP-TEG was put from the hot duct that carried hot atmosphere. Air example supplied fresh air to the duct and has been installed in the entry of every duct. The ambient air entering the hot duct was warmed with a 2 kW electric heater prior to flowing through the evaporator part of this RHP-TEG.

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