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Recovery of exhaust heat in automotive to enhance its efficiency using TEGs and heat pipes

Jayaram V[a], Arun S Lal[b], Joseph Thomas[b], Naveen S Babu[b], Sreenath VR[b] .

a. Asst Prof- Department of Mechanical Engineering, Lourdes Matha College of Science and Technology

b. UG Student, Department of Mechanical Engineering, Lourdes Matha College of Science and Technology

Abstract—The majority of chemical energy is dissipated as heat in exhaust and coolant in internal combustion engine(ICE). Efforts are being made to recover this waste heat and convert it into some usable form. This paper propose a novel method of waste heat recovery utilising thermoelectric generators(TEGs) and heat pipes. TEGs directly convert the temperature difference into electrical energy. Heat pipes reduce the pressure loss and thermal resistance in the system and also increase the design flexibility.

Index Terms—Waste heat recovery, Exhaust gas, Thermoelectric Generators (TEGs), Heat pipes.

I. INTRODUCTION

The CO_2 emissions regulations in any country is getting more stringent day by day. Vehicle manufacturers are trying to improve the fuel efficiency and thereby reduce the CO_2 emissions. Current ICEs, on average, are approximately 25% efficient [1] under typical driving conditions (i.e.: European driving cycle). The remaining will be wasted as heat in the exhaust gases as well as the engine coolant. A waste heat recovery system has the potential to convert some of this waste heat into electricity and thus reduce the fuel consumption. Heat pipes and TEGs could be used for waste heat recovery. Being compact in size and solid state, they are ideal for automotive applications.

TEGs work in the principle of Seebeck effect. TEGs have semiconductor materials which are connected electrically in series and thermally in parallel. A voltage is generated when one side of the TEG is heated and the other side cooled. Their efficiency is typically around 5% [2].Their efficiency is limited by the Carnot efficiency. The higher the temperature difference, the more the voltage generated. TEGs operate at about 20% of the Carnot efficiency over a wide temperature range [3]. Thermoelectric figure of merit (ZT) is used to compare the efficiencies of different TEGs operating at same temperature. The higher the ZT, the better the TEG.The advantages of using TEGs are that they silent, scalable and durable.Bismuth Telluride is the most popular thermoelectric material. Lead telluride and calcium manganese are also as they can handle higher temperatures.

Heat pipes have a very high effective thermal conductivity and thus they are used to transfer heat over long distances.Water is mostly used as the working fluid but other fluids like Naphthalene, liquid metals such as potassium and sodium can also be used for different operating temperatures [4].Heat pipes consist of three section: an evaporator section, an adiabatic section and a condenser section. When heat is supplied at the evaporator section the working fluid evaporates at temperature much lower than the boiling point, as the pressure inside the heat pipe is vacuum. At the condenser section the vapour it condenses back to liquid, and release heat. The liquid then returns to the evaporator through the wick using capillary action and the cycle repeats itself.

Heat pipes have a limitation that they have a limited rate of heat transfer. Another limitation is that if the temperature is too high, the high pressure inside the heat pipe may lead to its rupture. Water heat pipes typically have a working temperature range from room temperature to about 300 °C [4]. The working temperature of Naphthalene ranges from 250°C to 450 °C [5] and potassium and sodium have even higher working temperature ranges.

II. LITERATURE SURVEY

Companies like BMW [6], Ford [7], Renault [8] and Honda [9] have expressed their interest in exhaust heat recovery. Their designs are relatively similar, with the hot side of TEGs placed on rectangular (or hexagonal) exhaust pipe surface and the cold side is cooled using engine coolant [10].

Kim et al. and Baatar et al. have developed a waste heat recovery system that replaced a traditional car radiator [1,11]. Their system used only existing moving components like the water pump and fan.72 TEGs of 40 mm by 40 mm size and 128 small diameter heat pipes were used. In idle conditions 28 W were produced, with the hot side temperature of 90 °C and the cold side of 70 °C. In the driving mode of 80 km/h 75 W were produced. The hot side temperature was approximately 90 °C and the cold side was about 45 °C in the driving mode.

Kim et al. [12] has designed an exhaust heat recovery system utilising both TEGs and heat pipes. In this system, the protruding heat pipes in the exhaust pipe absorb some of the heat from the exhaust gases and spread it through the aluminium block in which they are inserted into. On the surface of the aluminium block the hot side of the TEGs are placed. The heat rejected from the TEGs is removed by a water cooled heat sink. This system with 112 40 mm × 40 mm TEGs generated a maximum of 350 W.

Goncalves et al., Brito et al. and Martins et al. [13–16] developed a system using the variable conductance heat pipe (VCHP) to extract the heat from the exhaust gases to the hot side of the TEGs and using a water heat sink to cool the other side of the TEGs.

Orr et al. [17] developed a system that used heat pipes on both sides of the TEG, for transferring heat both to and from the TEG. The system is air cooled using a fan (to simulate air flow in a moving car). To maximise the rate of heat transfer, a counter flow heat exchanger arrangement was used. The system with 8 40 mm × 40 mm TEGs generated approximately 6W of power when the exhaust gases from a small 50 cc gasoline engine were supplied. Remeli et al. [18] also demonstrated a similar design, but in this case, for industrial waste heat recovery.

Orr et al. [19,20] further improved the design to handle higher exhaust gas temperatures. The newer design used thick walled copper water heat pipes, higher temperature rated TEGs and higher temperature rated thermal paste. Naphthalene heat pipes, with working temperature range between 250 °C and 450 °C, do not transfer heat when the exhaust gas temperature is low but removed heat when the exhaust gas temperature is high.The system with 8 75 mm × 75 mm TEGs is predicted to produce 54 W of electricity.

III. PROPOSED METHOD

A simplified diagram showing the proposed concept for the exhaust heat recovery system is shown in Fig. 1. CPU coolers will be used to transfer heat to and from the TEGs. CPU coolers (without fan) placed inside the exhaust gas duct will transfer the heat to the hot side of the TEGs, whereas the cold side of the TEGs are cooled by the CPU coolers with fan blowing the ambient cold air.

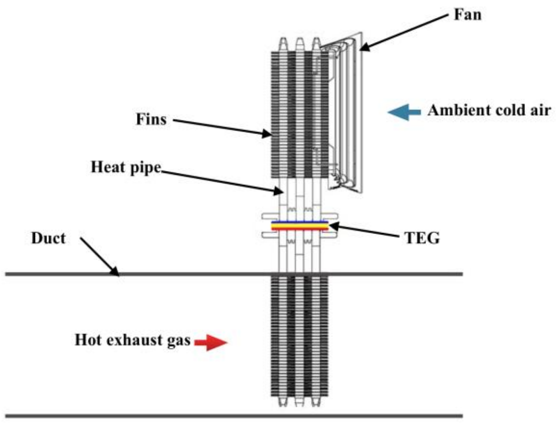

Fig.1 . Proposed concept for the exhaust heat recovery system.

The basic design of exhaust duct inside which the CPU coolers are to be placed is shown in Fig.2 . CFD analysis of the exhaust duct will be performed to determine the optimum method of placing the TEGs on the exhaust duct.

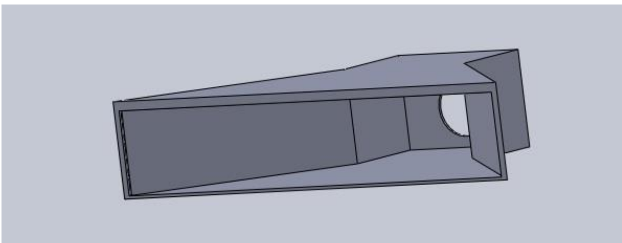

Fig.2 . Proposed design of the exhaust gas duct.

An example of placing the TEGs in exhaust duct is shown in Fig.3.

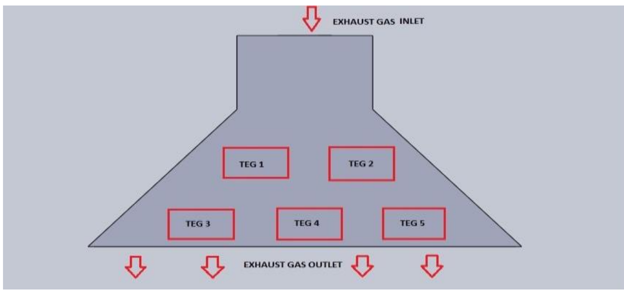

Fig.3 . A method of placing TEGs.

The single cylinder diesel engine on which the test will be performed is shown in Fig. 4. The exhaust duct of the system after fabrication will be connected to the exhaust pipe of the engine.

Fig.4 . Single cylinder diesel engine

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REFERENCES

[1] S. Kim, S. Park, S. Kim, S.H. Rhi, A thermoelectric generator using engine coolant for light-duty internal combustion Engine-Powered Vehicles, J. Electron. Mater. 40 (2011) 812–816.
[2] M.A. Karri, E.F. Thacher, B.T. Helenbrook, Exhaust energy conversion by thermoelectric generator: two case studies, Energy Convers. Manag. 52 (2011) 1596–1611.
[3] H. Goldsmid, Bismuth telluride and its alloys as materials for thermoelectric generation, Materials 7 (2014) 2577–2592.
[4] X. Yang, Y.Y. Yan, D. Mullen, Recent developments of lightweight, high performance heat pipes, Appl. Therm. Eng. 33–34 (2012) 1–14.
[5]C.T.Kniess,M.B.H.Mantelli,A.Cunha,G.J.M.Martins,G.V.Nuernberg,W.Angelo, et al., Experimental study of mercury and naphthalene thermosyphons, presented at the 14th International Heat pipe Conference, Florianopolis, Brazil, 2007.
[6] J. LaGrandeur, D. Crane, S. Hung, B. Mazar, A. Eder, Automotive waste heat conversion to electric power using skutterudite, TAGS, PbTe and BiTe, International Conference on Thermoelectrics (2006) 343–348.
[7] Q.E. Hussain, D.R. Brigham, C.W. Maranville, Thermoelectric exhaust heat recovery for hybrid vehicles, SAE Int. J. Engines 2 (2009) 1132–1142.
[8] N. Espinosa, M. Lazard, L. Aixala, H. Scherrer, Modeling a thermoelectric generator applied to diesel automotive heat recovery, J. Electron. Mater. 39 (2010) 1446–1455.
[9] M. Mori, T. Yamagami, M. Sorazawa, T. Miyabe, S. Takahashi, T. Haraguchi, Simulation of fuel economy effectiveness of exhaust heat recovery system using thermoelectric generator in a series hybrid, SAE Int. J. Mater. Manuf. 4 (2011) 1268–1276.
[10] K.M. Saqr, M.K. Mansour, M.N. Musa, Thermal design of automobile exhaust based thermoelectric generators: objectives and challenges, Int. J. Automot. Technol. 9 (2008) 155–160.
[11] N. Baatar, S. Kim, A thermoelectric generator replacing radiator for internal combustion engine vehicles, TELKOMNIKA 9 (2011) 523–530.
[12] S.K. Kim, B.C. Won, S.H. Rhi, S.H. Kim, J.H. Yoo, J.C. Jang, Thermoelectric power generation system for future hybrid vehicles using hot exhaust gas, J. Electron. Mater. 40 (2011) 778–783.
[13] L.M. Goncalves, J. Martins, J. Antunes, R. Rocha, F.P. Brito, Heat-pipe assisted thermoelectric generators for exhaust gas applications, ASME 2010 International Mechanical Engineering Congress & Exposition, 2010, 1387–1396.
[14] F.P. Brito, L.M. Goncalves, J. Martins, N. Antunes, D. Sousa, Influence of heat pipe operating temperature on exhaust heat thermoelectric generation, SAE Int. J. Passeng. Cars – Mech. Syst. 6 (2013).
[15] F.P. Brito, J. Martins, E. Hançer, N. Antunes, L.M. Gonçalves, Thermoelectric exhaust heat recovery with heat pipe-based thermal control, J. Electron. Mater. 44 (2015) 1984–1997.
[16] J. Martins, L.M. Goncalves, J. Antunes, F.P. Brito, Thermoelectric exhaust energy recovery with temperature control through heat pipes, SAE Technical Papers, 2011, doi:10.4271/2011-01-0315.
[17] B. Orr, B. Singh, L. Tan, A. Akbarzadeh, Electricity generation from an exhaust heat recovery system utilising thermoelectric cells and heat pipes, Appl. Therm. Eng. 73 (2014) 586–595.
[18] M.F. Remeli, L. Tan, A. Date, B. Singh, A. Akbarzadeh, Simultaneous power generation and heat recovery using a heat pipe assisted thermoelectric generator system, Energy Convers. Manag. 91 (2015) 110–119, 2.
[19] B. Orr, A. Akbarzadeh, P. Lappas, Predicting the performance of a car exhaust heat recovery system that utilises thermoelectric generators and heat pipes, in: SOLAR2014, Melbourne, Australia, 2014.
[20] B.G. Orr, A. Akbarzadeh, P. Lappas, Reducing Automobile CO2 emissions with an exhaust heat recovery system utilising thermoelectric generators and heat pipes, presented at the APAC18, Melbourne, Australia, 2015.
[21] J. Ringler, M. Seifert, V. Guyotot, W. Hübner, Rankine cycle for waste heat recovery of IC engines, SAE Int. J. Engines 2 (2009) 67–76.
[22] R.Stobart,D.Milner,The potential for thermoelectric regeneration of energy in vehicles, SAE Technical Papers (2009) doi:10.4271/2009-01-1333.
[23] B. Orr, A. Akbarzadeh, P. Lappas, Predicting the performance of a car exhaust heat recovery system that utilises thermoelectric generators and heat pipes, in: SOLAR2014, Melbourne, Australia, 2014.
[24] B.G. Orr, A. Akbarzadeh, P. Lappas, Reducing Automobile CO2 emissions with an exhaust heat recovery system utilising thermoelectric generators and heat pipes, presented at the APAC18, Melbourne, Australia, 2015.