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ORIGINAL ARTICLE

Energy Recovery from Exhaust Gas of Diesel and Petrol Engine by Turbo-electric Generator

Atanu Mazumder, Asif Hasan, Arafat Hossain Ayon and Dewan Hasan Ahmed*

Department of Mechanical and Production Engineering, Ahsanullah University of Science and Technology, 141-142 Love Road, Tejgaon Industrial Area, Dhaka, Bangladesh

ABSTRACT – A turbo-electric generator has been placed on the exhaust port of the petrol and diesel engines to investigate the possibility of recovering energy from the exhaust gas. Turbo-electric generator is a combination of a turbocharger and a generator. The aim of the study is to find the possibility and effectiveness of the turbo-electric generator for recovering the energy from the exhaust gas of an engine. The test has been conducted on the two engines, i.e. first one is TD 202 small test engine bed (diesel engine) and another one is Honda CG125 cc (petrol engine) motorcycle. Two types of motor i.e. DC motor and AC motor have been used as generators by altering the way a motor works. Firstly, a DC motor is used as a generator in the turbo-electric generator for both test engines. The results show that turbo-electric generator recover less than 1% energy of the exhaust gas for both engines when a DC motor is used as a generator (TD 202 and Honda CG125 cc motorcycle). But in case of Honda CG125 cc motorcycle, the percentage of recovering energy is comparatively higher than the TD 202 test engine. The experiment is further extended by using an AC motor as a generator only for the Honda CG125 cc motorcycle. The results show better energy recovering from exhaust gas through turbo-electric generator, which is more than 1% of exhaust gas. The results reveal that the engine speed and the mass flow rate of the exhaust gas play a major role in harvesting the energy from the exhaust gas. Moreover, it is found that the turbo-electric generator module provides good efficiency when an AC motor is used as a generator in the module. The experimental results have been compared with available literature.

INTRODUCTION

Since efficiency is the first concern of every engine running nowadays, researchers all around the world put their efforts in increasing the efficiency of an IC engine in both conventional and unconventional ways. In addition to this, there are several methods followed by the researchers to harvest or recover the exhaust gas to produce electricity and to increase the efficiency of IC engines through electric turbo compounding, thermoelectric generators, thermoelectric materials, turbines and heat exchangers. To be specific one-third of the energy of combustion that escapes through the exhaust. However, there are different types of exhaust gases combination coming out based on sources (i.e. fuel). In general, the exhaust gas contains a substantial amount of heat and oxides of carbon & nitrogen. Therefore, exhaust gas coming out from IC engines is a potential energy source as it contains higher heat energy and has a moderate velocity. Using this energy potential can pave the way to recover or harvest energy and use it for the IC engine's purpose, which in turn increases the efficiency of the IC engine. One of the main challenges is capturing the waste and later the effective utilization of that waste heat of the internal combustion engine. Successful accomplishment of these two important tasks could enhance engine performance and also reduce the emission level, and definitely attracts the automotive manufacturers [1]. Waste heat recovery technology has huge potential for energy savings from different industrial applications. Other than the internal combustion engine, many researchers have given much efforts on the exhaust gas from external combustion engines like thermal power plants [2-5]. There are lots studies could be found in the literature where waste heat from the exhaust gas has been considered to recover in various ways like thermoelectric generator, organic Rankine cycle (ORC), Brayton cycle, and turbocharge compound.

Meng et al. [6] investigated the thermoelectric generator (TEG) to recover the waste heat from the exhaust gas. They optimized the thermoelectric generator and successfully recovered the waste heat from the exhaust gas. They used the exhaust gas and cold water as a heat source and heat sink, respectively; however, they put different mechanisms to enhance the power generation but couldn't get any remarkable increment of the output power. However, they claimed that the optimum or better system performance is much influenced by the number of units iJaf the thermoelectric and the consumption of the thermoelectric materials. Meisner [7] also worked on the thermoelectric generator for waste heat recovery of automotive engines and computed the related heat transfer and electrical output based on the inlet conditions of the exhaust gas.

Aranguren et al. [8] claimed that the waste heat could be recovered and converted to electric power. They constructed a prototype thermoelectric generator and placed it at the exhaust port of the combustion chamber, which included 48 thermoelectric modules and two different kinds of heat exchangers, finned heat sinks and heat pipes. They obtained 21.56W of Net power from exhaust gases of a combustion chamber. In addition, they reported that exhaust gas temperature and mass flow are the key parameters for recovering the electrical energy from the waste heat. Suryawanshi et al. [9] worked on the exhaust gas of a two-wheeler and implemented seebeck effect to generate power. They also showed that a battery could be charged successfully with electrical energy which can be obtained from waste heat by using the thermoelectric generator. Rajpoot et al. [10] had analyzed power generation by using Morse test from the exhaust gas of a 4-stroke 4-cylinder petrol with the inclusion of a thermoelectric generator where only surface heat of the silencer was used. Thus, they claimed that it is possible for power generation by the thermoelectric generator at an affordable cost. Rahman et al. [11] claimed that recovering the waste heat of exhaust gas eventually improves the fuel consumption of IC engines. They studied several methods like supercharger, turbocharger or combined to recover thermal energy which is wasted from the exhaust gas of an internal combustion engine and reported that the brake power could be enhanced by 7% and 15% with the effective waste heat recovery.

Bari et al. [12] recommended the Rankine cycle can be used to generate power from the exhaust gas of a diesel engine. In fact, they used a diesel engine where ammonia was used as fuel and they successfully captured the exhaust heat to generate additional power. They successfully recovered 9.85kW additional power at a pressure of 30 bar for water and 4.5kW at a pressure of 50 bar ammonia respectively. Shameer et al. [13] showed the feasibility of power generation by thermoelectric generator where the exhaust heat is recovered from the surface of the silencer. They reported their results from the experiments of a two stroke engine with output of less than 1 W power; however, they recommended that the number of turbo-electric generators placed in series could enhance the power generation. Surwase et al. [14] carried out the experiments to harvest the energy from the exhaust gas by using the parallel flow shell and tube heat exchanger. They showed that around 30% of the total energy of the diesel engine is wasted to the environment and possibly a good option to harvest energy from the exhaust gas. Pandiyarajan et al. [15] also investigated waste heat recovery system by integrating the shell and finned tube heat exchanger with a latent heat storage system (i.e. phase change material) to recover the heat energy from a diesel engine, and reported that 10-15% thermal power could be stored in thermal storage. Orido et al. [16] used an Eddy current dynamometer for loading and recovered waste heat from the exhaust gas energy of IC engine for useful applications and recovered a maximum of 3.513% fuel energy and 19.3% of heat entering the exhaust. Yasa [17] showed that an Organic Rankine Cycle (ORC) based system could be a good option to recover the energy of a diesel engine cooling system. Similar types of works have been reported by Cipollone et al. [18]. Jianqin et al. [19] approached a system named steam assisted turbocharging and found it as effective for waste heat recovery. However, they reported that the lower engine speed was not viable to improve the engine performance as the exhaust gas contained much lower energy for the lower engine speed. Talib et al. [20] conducted experiments with the waste heat recovery mechanism (WHRM) from the SI engine where water was used as the heat absorption medium. Kennedy et al. [21] confirmed that the output power is strongly affected by the turbine inlet temperature and system pressure drop through the Inverted Brayton Cycle for exhaust gas energy recovery.

Kumaravel et al. [22] had done different studies according to their practical inputs. For example, they found that for the different engine speeds (rpm) the accompanied turbine produced different outputs. They concluded that increasing the engine speed resulted in a higher mass flow rate which could increase the power from the turbo-electric generator. Guduru et al. [23] studied to recover the waste heat from an internal combustion engine and showed that the waste heat can be used for heating or converting to mechanical or electrical work. They conducted experiments on the kinetic energy of exhaust gas to run the turbine blades and hence produced electricity. In addition, they reported that recovering the waste heat could improve the performance of internal combustion engines and also help to reduce the emission of exhaust gases. Shaikh et al. [24] had identified that fuel economy could be saved up to a greater extent, and they identified the potential of the technologies with the inclusion of other devices and is possible to maximize the potential energy efficiency of the vehicles. They used the kinetic energy of the exhaust gas to rotate the runner of a turbine to generate the electricity, however, they could produce 1 W power which ultimately depended on the runner speed of the turbine. Mamat et al. [25] worked on how to recover the energy of exhaust gas by electric turbo compounding. They developed a low-pressure turbine for turbo compounding applications in order to recover the waste heat in downsized gasoline engines. The low-pressure turbine reduced the back pressure on engine performance and to recover energy from exhaust gas. It showed that maximum 2.5% reduction of brake specific fuel consumption (bsfc) is possible. Venkatesh et al. [26] generated electricity by turbine from exhaust gas where the turbine used waste exhaust gas and produced electricity. Risse et al. [27] showed that closed couple thermoelectric exhaust gas energy recovery in a gasoline engine with exhaust gas turbocharger and asynchronously variable exhaust valve control was possible without any serious adverse effect on the engine's performance.

There are very few studies on internal combustion engines to recover the waste heat energy by a turbocharger. In most cases, the researchers tried to highlight the demonstration process to harness the energy from the exhaust gas either from internal or external combustion engines. In addition to this, it is mainly focused by giving emphasis on the method of energy harvest like TEG, ORC, and turbocompound, for particular types of engine. In the current study, an experimental investigation has been carried out to find the possibility of recovering the exhaust gases energy through a turbo-electric generator and the effectiveness of this approach for the gasoline engine (SI engine) and diesel engine (CI engine) for the certain range of engine speed. There are two variations added by implementing a DC motor as a generator for both test engines (TD 202 small engine test bed and Honda CG125) and an AC motor as a generator for the Honda CG125

motorcycle engine. The variations have been done to see the acceptability of the turbo-electric generator module for recovering the exhaust gas energy and also to see the influential parameters for the overall performance.

EXPERIMENTAL SETUP

Two test engines are used in the study. The first engine is a small engine test bed of Model TD 202 of TecQuipment. The test set is a single-cylinder diesel engine, and it includes a robust, precision-machined, trunnion-mounted hydraulic dynamometer. The dynamometer applies load according to the flow rate and level of water in the casing, and an electronic load cell measures the torque. The engine is included with an exhaust thermocouple, dynamometer coupling, hoses and fittings. Along with these, the engine has a digital display unit from where necessary data are collected.

The second engine is Honda CG125 (petrol engine), a commuter motorcycle that was made by Honda of Japan. The CG125 is powered by a 124 cc (7.6 cu in) four-stroke, single-cylinder engine. The detailed specification of the tested engines is shown in Table 1.

Table 1. Specifications of the test engines.

Specification	Model	
	TecQuipment TD202 (Small engine test bed)	Honda CG125 (Motorcycle)
Type	Four stroke diesel engine	Four stroke petrol engine
Cylinder No.	Single Cylinder	Single Cylinder
Volume	232 cc	125 cc
Cooling capacity	Water cooled	Air cooled
Weight	300 kg	114 kg

The turbo-electric generator consists of a turbocharger; a generator used for the experiments. At first a DC motor was used as a generator for both the cases of the small engine test set and for motorcycle and then an AC motor used as a generator only for the motorcycle. Both types of motors were selected based on the voltage and speed range. Detailed specifications of the motors used in the study are shown in Table 2.

Table 2. Specifications of the DC and AC motors.

Specification	Model	
	ROB-00011	ATO57STH82-5004 (Nema 23)
Type	DC Motor	AC Motor (Stepper)
Voltage	12V	12V
Phase	N/A	2
Speed Range	100 rpm and above	180 rpm and above

A turbocharger has two basic sections, the 1st section was a compressor wheel and the 2nd one was a turbine wheel. A schematic diagram of the constructed experimental setup with the turbocharger is shown in Figure 1(a) and 1(b). Here the casing of the turbine wheel is separated from the main casing then the turbine wheel meshes with a generator through two gears. One gear is attached to the turbine wheel, and another one is attached to the generator. Then the two gears are meshed with each other and when the exhaust gas is coming out from the engine it is rotating the gear of the turbine wheel's part. Therefore, as the gear of the turbine wheel's part is rotating, it is also rotating the gear of the generator part because the two gears are meshed with each other and ultimately the electricity is generated from the exhaust gas of the engine. The gears are selected on the basis of availability in the local market and are made of plastic material. The gear ratio between the two gears is 1:1. Therefore, the output gear (connected with turbo-electric generator) has the same rotating speed as the input gear (connected with a turbine wheel). The photographic view of the experimental setup is shown in Figure 1(c) and 1(d). When the AC motor was used as a generator, there was a regulator rectifier used to convert the AC current to DC current output, and no other change was made rather than that. There was a digital multimeter used to measure voltage and current, from where power was calculated and how much energy was recovered through the producing electricity. The digital multimeter "VICTOR 86B" was used which had a good accuracy where the error limit was less than 1% for measuring the voltage and current. A laser tachometer, VA8030 of aTEL electronics, is used to measure the engine speed with 0.02% accuracy.
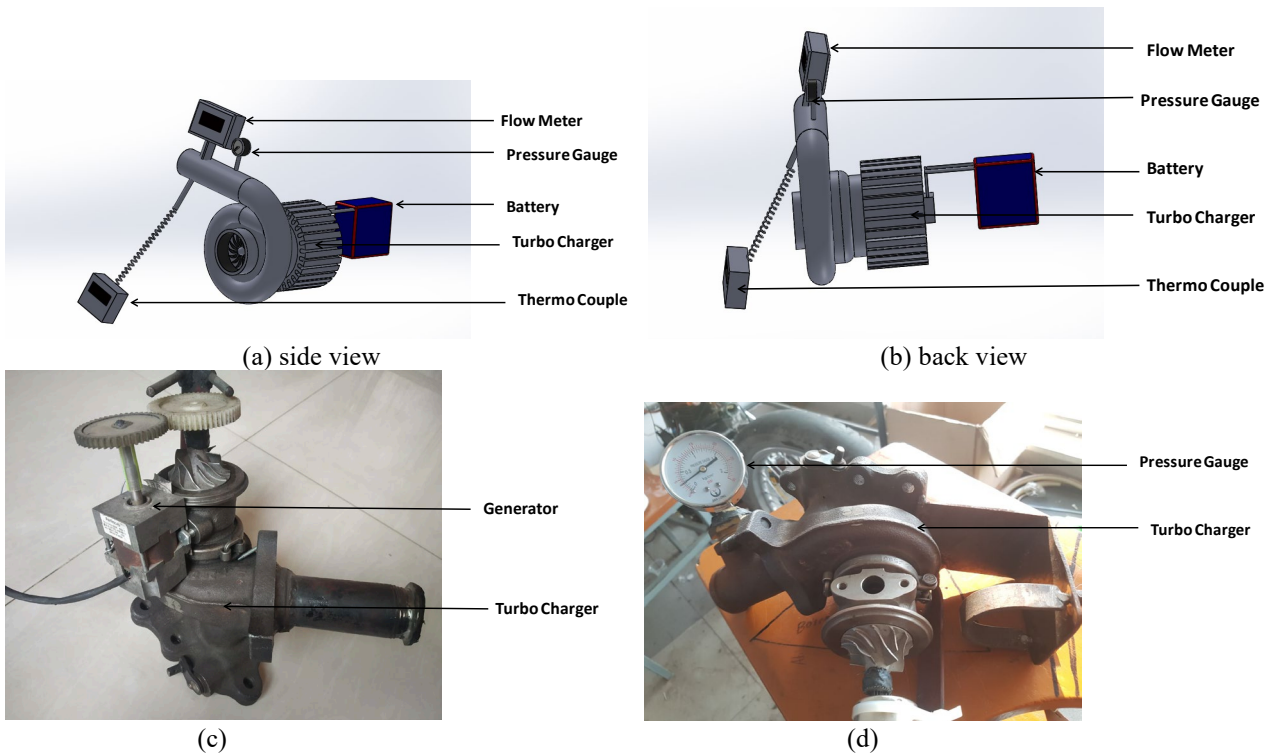
(a) side view

(b) back view

(c)

(d)

Figure 1. (a), (b) Schematic view and (c), (d) experimental setup of the turbocharger.

Once the exhaust gas flows through the exhaust manifold and passes through the turbocharger, it helps to rotate the gear which is coupled with the motor generator. Therefore, the harvested power has been calculated from the following equation; the product of the harvested voltage and current.

$$P_h = V_h \times I, \text{ watt} \tag{1}$$

where, V_h = Harvested voltage (V) and I = current (A). The percentage of energy harvest is mainly the ratio of harvested power and the heat taken by the exhaust which is obtained from the following equation.

$$\eta_{hav} = \frac{P_{hav}}{Q} \times 100 \tag{2}$$

The heat taken by the exhaust is:

$$Q = (m_a + m_f)\, C_{pg}\, \Delta T \tag{3}$$

This equation was used for the TD 202 small engine test bed, where m_a = air flow rate (kg/s), $m_{f=}$ fuel flow rate (kg/s), C_{pg} = specific heat of fuel (kJ/kg K), ΔT = temperature difference (K).

From the data acquisition system of TD 202, the temperature of the exhaust gas, the mass flow rate of air and fuel can be taken. However, the mass flow rate of fuel was not considered for the Honda CG125 because of the experimental limitations in the experimental test engine. There is another equation was used to calculate heat taken by exhaust (Q) for Honda CG125;

$$Q = ms\Delta T \tag{4}$$

here, m = mass of air (kg/s), s = specific heat of fuel (kJ/kg K), and ΔT = temperature difference (K).

The experiments on energy harvest from exhaust gas were carried out first in the small test engine bed (TD 202), varying different throttle positions, as shown in Figure 3(a). The experiments were carried out for various engine speeds with the variation of the throttle position. All the necessary data were collected from the digital display unit of the small engine test bed (TD 202). The second set of experiments were carried out on Honda CG125. The rpm meter (Assy Speedometer) was attached to the Honda CG125 to know the speed of the engine; however, there was no option to vary the throttle positions like the small engine test bed (TD 202). Figure 3(b) shows the turbo-electric generator mounted on the exhaust of the Honda CG125. An infrared ray thermometer was used to know the temperature of the exhaust gas. The engine speed was varied manually and then the necessary data were taken to calculate the results.
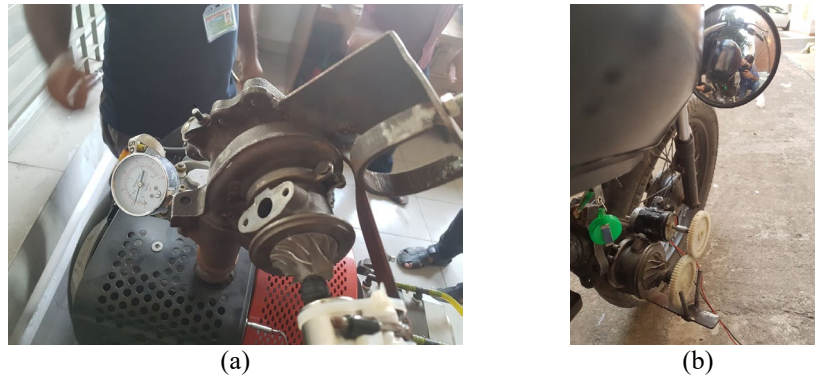
(a)   (b)

Figure 3. Turbo electric generator mounted on (a) exhaust manifold of TD 202, and (b) Honda CG125.

RESULTS AND DISCUSSION

The possibility of electricity generation from the exhaust gas of both diesel and petrol engines by using turbo-electric generator is the main purpose of this study. So, the inclusion of the turbocharger in an IC engine is tested for the analysis. Before conducting the experiments, it is needed to find out the reliability of the data and do some uncertainty analysis. Therefore, for taking the data for each case, time average values are considered and observed the fluctuation of the results for about 2 minutes and the average values are considered. However, the process is repeated at least six times and the data taken in a similar way. Figure 4 shows the experimental data i.e. exhaust gas temperature for five different throttle positions where the time average values are taken six times for each throttle position. Minimum and maximum variations of the exhaust gas temperatures are observed as less than 0.03% and 1.5% respectively. Similar procedures are ensured for all the experiments and it is believed that the results obtained from the experiments are acceptable with minimum error.
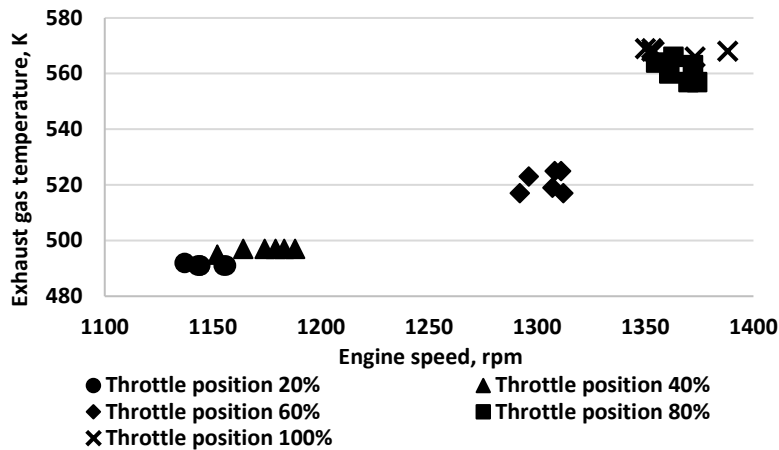

Figure 4. Repeatability check of the measured data during the experiments for different throttle positions on TD 202 small engine test bed.

Testing on Small Engine Test Bed - Model: TD 202

The experimental setup was tested at different throttle positions at the small engine test bed (TD 202), while a DC motor was used as a generator. The speed of the engine varied during the experiments with the change of the throttle position. The variation of engine speed had a range of 1100 rpm to 1500 rpm during the experiment for testing in the small engine test bed (TD 202). Figure 5 shows the variation of exhaust energy power with respect to engine speeds for different throttle positions. Equation (3) is used to calculate the exhaust energy power and plotted against engine speeds for different throttle positions. Exhaust energy power increases with the higher engine speeds because higher engine speeds provide more air and fuel to release more energy. It should be noted here that the engine speed for the 100% throttle position is slightly decreased as compared with the 80% throttle position even though the mass flow rate of the exhaust gas is higher. This may be due to engine frictional losses which become the dominant factor, ultimately slowing down the engine speed.
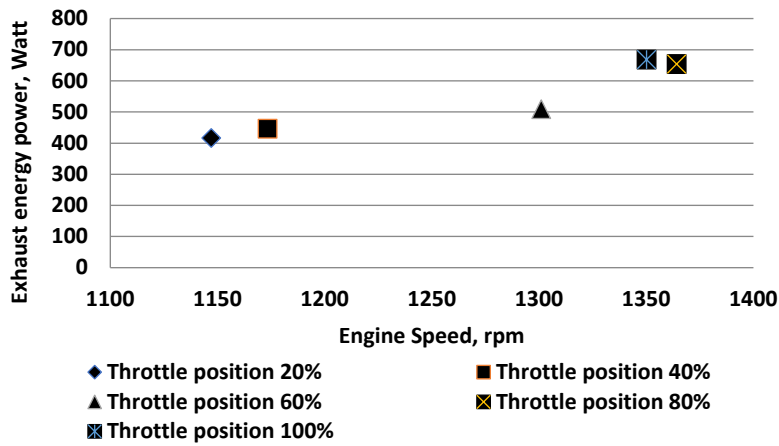
Figure 5. Variation of exhaust energy power for different engine speeds at different throttle positions of TD 202 diesel engine.

Figure 6 shows the variation of the harvested power with respect to the engine speed for different throttle positions. It was obvious that once the throttle is wide open, more air-fuel mixture entrapped in the cylinder and produces much power leading to higher engine speed, and as a consequence, the amount of exhaust gas increases with higher temperature. Therefore, the results shown in Figure 6 depict the usual finding for the harvested power. From the figure, it is shown the harvested power increases with the increase of the engine speed. Therefore, it's a good sign that it is possible to harvest power and the power is much influenced by engine speed though the amount of harvested power was not that much significant i.e. few Watts. Eventually, with the more amount of exhaust gas with higher momentum and pressure caused to rotate the turbocharger more rapidly where two gears are meshed between the turbine wheel of the turbocharge and the generator. Recently, Madaro et al. [28] explained clearly the three forms of energy available in the engine exhaust gas i.e. thermal, pressure and kinetic. Comparing these three energies kinetic energy in the range of 10 Watt, pressure energy in the range of 100 Watt and the thermal energy in the range of 10000 Watt while the total energy they calculated (internal power or mechanical power) in the range of 100000 Watt and these values slightly varied with the engine speed which was in the range of 1500 to 3000 rpm for the 4 stroke 2000 cc AUDI A4 diesel engine. The kinetic and pressure energy also depend on the position of the measurements as these two energies significantly influenced the friction with the exhaust manifold, silencer, muffler etc. Therefore, the results obtained from the TD 202 engine can be taken positively to harvest the energy from the exhaust gas.
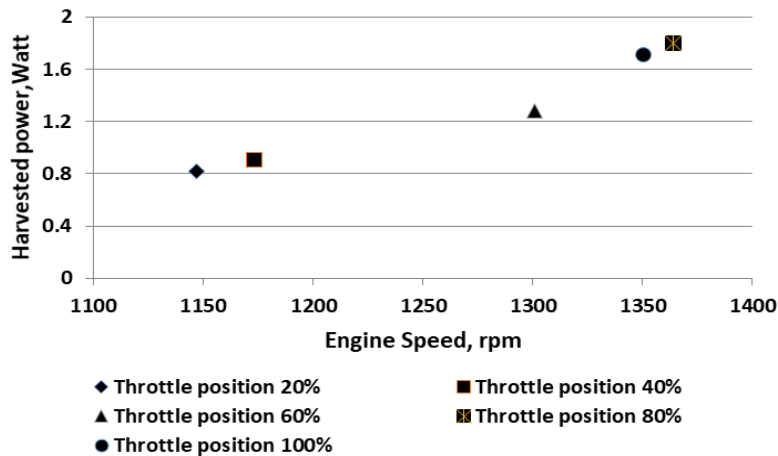

Figure 6. Variation of harvested power for different engine speeds at different throttle positions on TD 202 diesel engine.

Using Eq. (1) to (3), the percentage of the harvested power is calculated and plotted against the engine speed for the different throttle positions and shown in Figure 7. The maximum percentage of harvested energy is not so significant. In fact, harvested energy is less than 0.30% of exhaust energy in that case. The reasons may be the pressure in the exhaust gas to rotate the turbocharger is too low, the amount of exhaust gas is comparatively insufficient to utilize the exhaust gas power etc. The pressure in the exhaust gas depends on the heat energy from the exhaust gas. More exhaust gas provides more exhaust gas pressure and the momentum to rotate the meshed gears.
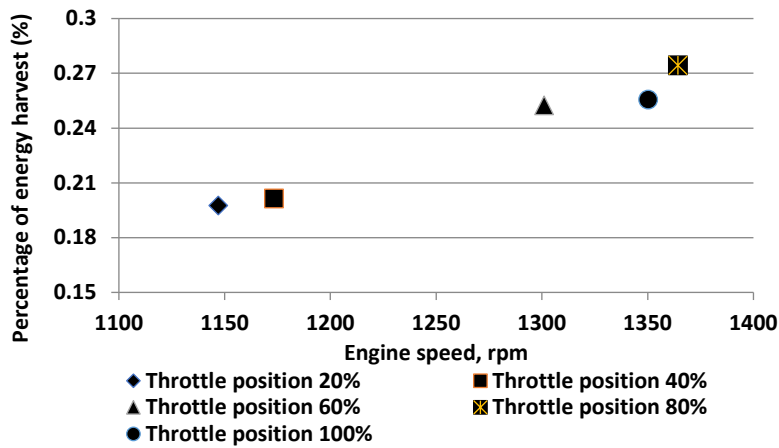
Figure 7. Variation of percentage of energy harvest for different engine speeds at different throttle positions.

Testing on Honda CG125

After testing in an engine test bed at the laboratory, the study is continued to test the motorcycle engine to see the possibility of recovering exhaust gas energy in a practical life engine. The Honda CG125 (motorcycle) is used in this study and conducted experiments in two different ways i.e. using DC motor and AC motor as a generator. A regulator rectifier has been used to convert the AC current to DC current when the AC motor is used as a generator. However, in these experimental studies, the throttle positions are not considered because of some complexity of the experimental setup.

DC motor as a generator

When pressing the accelerator of the motorcycle engine, the speed increases, which means the engine rotates rapidly and results in higher exhaust temperature, producing more exhaust energy. The experiments were carried out for a wide range of engine speeds ranging from 3000 rpm to 7000 rpm, which was much higher than the first case. Figure 8 shows the variation of exhaust energy power for different engine speeds. Equation (4) was used to calculate the exhaust energy power in this case. It should be mentioned here that the mass flow rate was calculated from the engine volume and the engine speed with a simple calculation by considering the properties of air. Engine exhaust energy power increases with the engine speed because more engine speed provides more air and fuel to mix to release more exhaust energy. Talib et al. [20] reported a similar trend of the exhaust gas energy for variation of the engine speed. However, their engine was a 1.6 liter in-line 4-cylinder gasoline engine. As the engine speeds are comparatively higher than in the previous case, the exhaust energy power also shows a similar kind of increment as engine speeds.
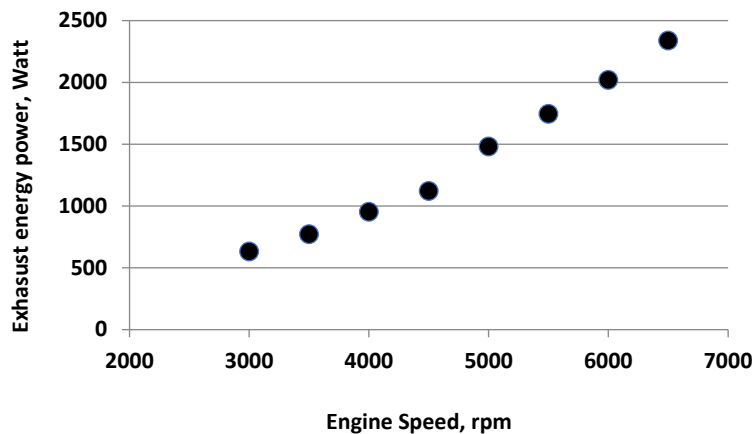

Figure 8. Variation of exhaust energy power for different engine speeds of CG125 petrol engine.

More exhaust energy gives more opportunity to produce more harvested power, as it is getting more pressure for the rotation of gears and to recover the exhaust energy. When the engine speed is more, a higher amount of the exhaust gas flows through the exhaust manifold and eventually helps to rotate the turbocharger with a higher speed (rpm) which is meshed with a generator. Figure 9 showed the harvested power increased exponentially with increasing engine speed. The highest harvested power obtained here is 10 W for 6500 rpm.
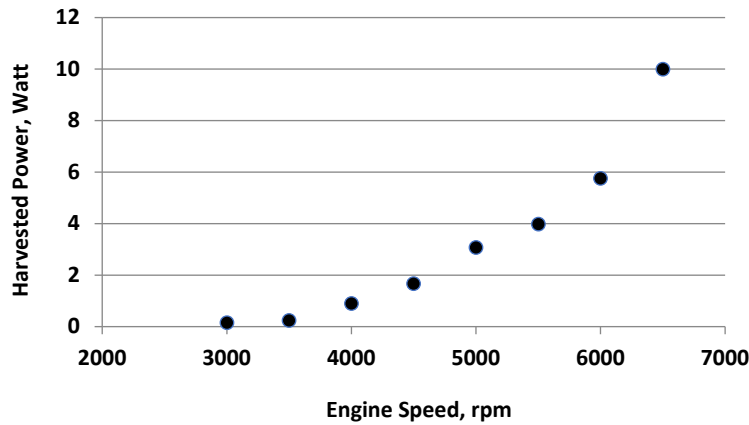
Figure 9. Variation of harvested power for different engine speeds of CG125 petrol engine.

Figure 10 showed the percentage of energy harvest for different engine speeds when the experimental setup was tested on Honda CG125. In fact, less than 0.5% of exhaust energy was harvested by using a turbocharger with a DC motor used as a generator. It is clear from the above figures that, increasing the engine speed is one of the main criteria for increasing the harvested power by using the turbocharger. And definitely, there is a maximum limit of the engine speed of a particular engine. In the present study, it was not possible to obtain the maximum engine speed for both engine test bed and also the motorcycle engine due to some experimental limitations. Now, increasing the engine speed depends on many issues; however, the volume of the exhaust gas and its pressure in the exhaust manifold should play a vital role in harvesting the energy. In addition, the exhaust gas temperature directly influences the characteristics of the exhaust gas. Therefore, the compression ratio of the engine along with the combustion within the cylinder can be a major influential parameter to harvest energy. However, the above experimental results show that the energy can be harvested from the petrol engine even though the amount is not that much significant, but the effort has been continued to increase the harvested energy.
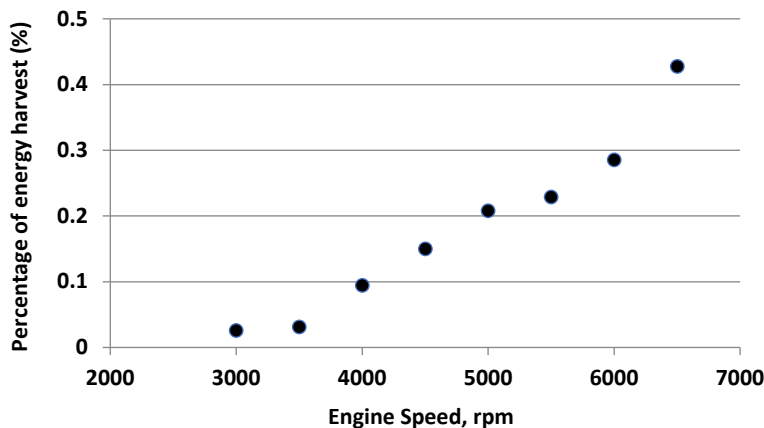

Figure 10. Variation of percentage of energy harvest for different engine speeds of CG125 petrol engine.

AC motor as a generator

As the DC motor didn't give the expected results, an AC motor was used as a generator to see whether it can improve the power output or not. Usually, the energy losses in a DC motor generator is much more as compared with the AC motor generator. The experimental setup was similar to the previous case. Only an AC motor substituted the DC motor and a regulator rectifier was connected to the AC motor to give the output in DC by converting the AC output to DC.

Figure 11 describes the harvested power against the engine speed and shows that the harvested power increased with the increment of engine speed. The highest power obtained here is 26 W which is comparatively more than the previous cases. Using an AC motor as a generator gives more power output compared to the DC motor used as a generator and the AC motor rotates more smoothly than the DC motor. Similarly, Figure 12 shows the variation in percentage of energy harvest with the increment of engine speed while using the AC motor as a generator. The significant fact here is that more than 1% exhausts energy harvested, which was less than 0.5% in the previous case. Aktas and Dogu [29] reported a similar range of energy recovery for the gasoline engine with a single stage small gas turbine.
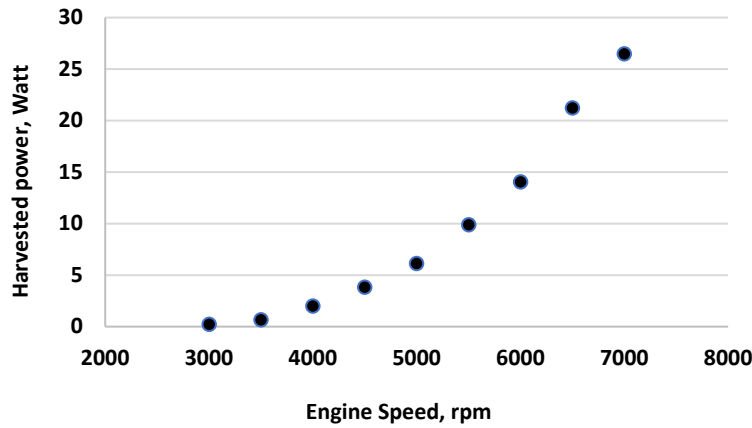
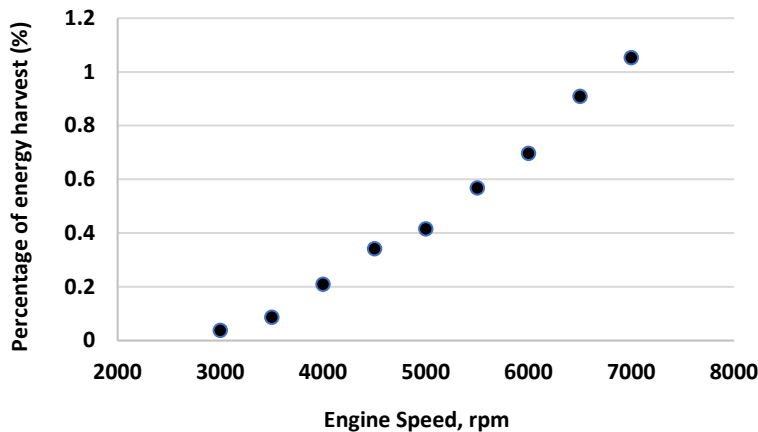**Figure 11.** Variation of harvested power for different engine speeds

Figure 12. Variation of percentage of energy harvest for different engine speeds

It is clearly seen that the percentage of the energy harvested by using turbo-electric generators is not significant even though the harvested energy increases with the inclusion of AC generator. Table 3 shows some output data during the experiments. It is obvious that the power harvested from the turbo-electric generator is mainly dependent on the flow rate of the exhaust gas and the exhaust gas pressure, which contributes to rotating the turbo generator. Indeed, the minimum engine speed is obtained once the exhaust gas flow rate was sufficient to rotate the turbo-electric generator. Comparing the harvested power from the TD 202 small engine test bed and Honda CG125, the harvested power was around 1.9 W and 10 W respectively, which is evident that exhaust flow rate played a major role in power generation. It should be mentioned here that engine speed (rpm) plays a vital role in the exhaust flow rate even though the engine size of the Honda CG125 is smaller than the TD 202 engine. The increase of the mass flow rate ultimately contains higher momentum, which helps to rotate the turbo-electric generator. Therefore, the rotational speed of the turbo-electric generator ultimately guides the power generation in the present study. It is observed that the rotational speed of the turbo-electric generator goes up to 100 rpm for the TD 202 for the maximum throttle position and this speed was around two-fold higher for the Honda CG 125 experiments, which are because of the higher mass flow rate.

Table 3: Experimental data during the experiments.

Output parameters	TD 202	Honda CG125
Minimum flow rate of exhaust gas, kg/s	2.20×10^{-3}	3.69×10^{-3}
Maximum flow rate of exhaust gas, kg/s	2.26×10^{-3}	7.99×10^{-3}
Minimum exhaust gas temperature just after the exhaust port, K	495	467
Maximum exhaust gas temperature just after the exhaust port, K	497	578
Engine speed range, rpm	1130-1400	3000-7000

Therefore, it is expected that the use of the turbo-electric generator can be suitable for the higher engine speed with the higher exhaust flow rate. Diesel engines with higher engine speed might give better output as the diesel engine has a higher compression ratio along with the larger cylinder volume as compared with the petrol engine. As the kinetic energy and the pressure energy are the major contributors to harvest energy from the exhaust gas by using the turbo-electric generator, special consideration is needed on the above two energies for maximum utilization. Moreover, some design aspects can be considered in the exhaust port to increase the pressure of the exhaust gas, which also may have detrimental effects on the engine performance. Therefore, the proper or better design of the exhaust manifold along with the

turbocharger by ensuring the smooth rotary motion could bring some positive outcomes on energy harvest from the exhaust gas of IC engine.

CONCLUSION

Experimental studies are carried out by using turbo-electric generator modules on two types of test engines (diesel and petrol) to investigate the possibility of energy recovering from the exhaust gas and the effectiveness of the procedure. From the experimental results, the major findings of the study are:

i. It is possible to recover the energy of exhaust gas through turbo-electric generators by placing it in the exhaust port of the engines.
ii. The amount of recovering energy from the exhaust gas is comparatively less when a DC motor is used as a generator.
iii. Using AC motor as a generator gives a significant rise in recovering energy from exhaust energy which is two times of energy recovered as compared with the use of DC motor as a generator in the turbo-electric generator module.
iv. So far maximum of 1% energy has been recovered with the turbo-electric generator.
v. The harvested energy from the exhaust gas is mainly influenced by the engine speed and exhaust gas flow rate. However, as every engine has a maximum engine speed limit, the harvested energy is maximum at that limit.

Proper designing of the exhaust port to increase the pressure and kinetic energy of the exhaust gas along with the frictionless rotation of the turbo-electric generator will enhance the energy recovery system from the exhaust. Therefore, significant research and study are needed to make it viable for practical applications.

ACKNOWLEDGEMENT

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