The Effect of Exhaust Gas Recirculation on the Performance of Single Cylinder Spark Ignition Engine

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ABSTRACT.

A single cylinder variable compression ratio spark ignition engine type (PRODIT GR306/0001) was used in this study. The experiments were conducted with gasoline fuel (80 octane No.), at equivalence ratio (Ø =1). The study examines the effects of exhaust gas recirculation on engine performance. The study was conducted at wide range of engine speeds (1500, 1900, 2300 and 2700 r.p.m.).

The exhaust gases were recirculated in volumetric ratios of 10 and 20% of the entering air/fuel charge. The results show that the EGR addition decreases to the brake power, brake thermal efficiency, volumetric efficiency and exhaust gas temperatures. Also, it increases the brake specific fuel consumption.

Keywords: EGR (Exhaust Gas Recirculation), EGR Rate, EGR Temperature, Break Power, brake specific fuel consumption (bsfc), Volumetric efficiency, Brake thermal efficiency

1. INTRODACTION.

EGR has been one of the key technologies due to its ability to reduce exhaust emission. EGR acts as an additional diluent to the unburned gas mixture, thereby reducing the peak burned gas [1 & 2]. In addition to the benefit of emission reduction, EGR also brings out the benefit of fuel economy because of the increase of intake pressure corresponding to the EGR amount especially in part load [3& 4]. However, excessive amount of EGR would result in the deterioration of combustion stability due to the thorough mixing of inert gas and air-fuel mixture [5].

The effects of EGR on the reduction of thermal loading at exhaust manifold were also investigated because the reduced gas temperature is desirable for the reliability of an engine in light of both thermal efficiency and material issue of exhaust manifold [6]. The steady-state tests by Ref. [7] show that decreasing EGR temperature by 180°C enabled the reduction of exhaust gas temperature by 15°C in cooled EGR tests at 1600 rpm / 370 kPa BMEP operation, and consequently the reduction of thermal load at exhaust.

Exhaust gas recirculation (EGR) and lean burn utilize the diluents into the engine cylinder to control combustion leading to enhanced fuel economy and reduced emission where proper stratification of mixture and diluents could improve the combustion stability under high diluent environment [8]. EGR stratification within the cylinder was made by adopting a fast-response solenoid valve in the midst of EGR line and controlling its timing and duty by Ref. [9]. With EGR in both homogeneous mode and stratified mode, in-cylinder pressure and emissions were measured [10]. The thermodynamic heat release analysis showed that the burning duration was decreased in case of stratified EGR [11]. It was found that the stratification of EGR hardly affected the emissions. Almost same amount of nitrogen oxides (NOx) reduction was attained with and without the EGR stratification process [12].

Planar laser induced fluorescence (PLIF) technique was applied to investigate the stratification of the in-cylinder charge. Acetone as a tracer was seeded into the EGR to get the EGR distribution within cylinder. It was found that EGR occupied the low part of cylinder through the stratification process and this could help reducing the burning duration [13].

The overall performance of a gasoline engine when employing EGR technique that reduces NOx emissions will be reduced. To minimize this reduction studies suggested increase engine compression ratio and using turbocharging as a mean to recover the original performance.

The formation of pollutants and the engine performance were verified at full and partial loads. The results show that the combination of exhaust gas recirculation with turbocharger or by increasing compression ratio the relation between the engine performance and the emission of NOx will be enhanced. However, the turbocharger seemed to be more sensitive to the negative effects of the EGR technology [14].

The present work investigates the benefit from recirculating engine exhaust gas with different ratios and its effects on the performance of a single cylinder spark ignition engine.

2. EXPRAMANTAL SETUP.

Experimental apparatuses.

Experiments were performed using petrol engine, type (PRODIT GR306/0001). The engine is a single cylinder, water cooled, four strokes and variable compression ratio engine. It is designed to be a spark ignition. The general arrangement of the experimental rig is shown in **Fig.(1)**, while **table(1)** illustrates engine specifications. The engine rig is coupled to the following equipments:

- The air providing system consists of air drawing tube, damping room and power converter of pressure. This set was calibrated in the labrotary, by using a calibrated set and compared the readings of the two sets. Engine provided air was measured by using whole measurement device.
- A hydraulic dynameters was used to measure the torque of the output engine. This dynamometer was calibrated in the laboratory using calibrated weights.
- Exhaust gas temperaturee were measured by using thermo- couples type K (Ni-Cr/Ni-AL) at the beginning of the exhaust tube. These thrmocouples were calibrated in the laburatory by comparing its readings with that of a set of calibrated thermocouples.
- A set of heat exchanger was cupper designed and manufactured to recirculation and controls the ratios of the recirculate exhaust gases.
- Using an orifice plate flow meter, through which, the volumatric ratio of the recirculated exhaust gas can be determined.
- The fundamental equations [15] describing the performance of spark ignition engine, with EGR and without EGR are:
- The brake power:

$$bp=W_b*N/348.067 \quad (1)$$

Where:

W_b= the load in (N)

N= speed engine (r.p.m.)

- The brake specific fuel consumption:

$$bsfc= m^o{}_f*3600/bp \quad (2)$$

Where:

$m^o{}_f$= mean fuel mass flow consumption (kg/kw.hr)

- The volumetric efficiency:

η_{vol}= $(m_a)_{act}/(m_a)_{theo}$ (3)

- The brake thermal efficiency:

η_{bth}= pb/ $m^o{}_f$*(L.C.V) (4)

Where:

L.C.V.= 43700 (kJ/kg) for gasoline

- The equivalent ratio:

Ø= $(A/F)_{stoichiometric}/(A/F)_{actual}$ (5)

3. TEST PROCEDERE.

He first set of tests: the experiments were conducted on the engine without exhaust gas recirculation, i.e., (0% EGR) and engine performance was evaluated:

1- When the torque is constant at (10 N.m) and engine speed was varied (1100, 1500, 1900, 2300 and 2700 r.p.m.).
2- When engine speed was fixed at (1900r.p.m.) and engine torque was changed (10, 15, 20 and 25 N.m.).

The second set of tests: the experiments were conducted on the engine with recirculating exhaust gas by (10, 20% EGR volumetric percentage). and engine performance was evaluated and compared with the first case.

4. RESULTS and DISCTION.

Fig.(2) shows the effect of the EGR with different ratios (10 & 20%) on brake power for variable engine speed at constant torque. It is clear that brake power increases with speed increasing in the case of (0% EGR). While with (10% EGR) the brake power reduces about (10.8%) compared with case 1. When (20% EGR) was used the brake power reduced more in comparison with gasoline fuel of (0% EGR). This reduction in brake power with increasing EGR for the studied speeds resulted from the fact that the test was conducted with gasoline engine where the fuel enters the engine with the air through the carburetor. Adding the recalculated exhaust gas, will take a part of the combustion chamber volume, and hence affecting the entering air/fuel charge. This reduces the resulted brake power. Also, the recirculated exhaust gas will absorb a part of the combustion heat inside the combustion chamber.

Fig.(3) shows the effect of torque on brake power at constant speed (1900 rpm). The brake power increases with increasing the torque. Increasing subjected torque on the engine increases the inlet fuel which means releasing higher thermal energy. Entering recirculated exhaust gas will cause a reduction in break power. However, this reduction will increase by increasing EGR percentage. The reduction of the break power was about (4.0%) in the case of (10% EGR), and about (6.0%) in the case (20% EGR) compared with (0% E GR) case.

The effect of EGR clearly appears on the volumetric efficiency of the engine as shown in **Fig.(4),**which indicates the relation between the volumetric and engine speed at constant torque. The efficiency of the engine enhances when transferring from low speeds (1000 rpm) to mid speeds (1500 to 1900 rpm). After that the volumetric efficiency reduces at higher speeds more than (2200 rpm), because at miduim speeds engine section enhances.

By adding the recirculated exhaust gas, the volumetric efficiency reduced clearly for all the studied speeds as shown in **Fig.(4)**. EGR takes a part from the combustion chamber volume on the expence of the drawing air/fuel charge. The volumetric efficiency of the studied speeds reduced by (3%) for (10% EGR), and about (6%) for (20% EGR) compared with (0% EGR) state.

Fig.(5) shows the same previous effect of EGR on volumetric efficiency, when engine speed fixed at (1900 rpm) with variable torques. Increasing subjected torque cause reduction in engine speed, to return to the required engine speed more fuel must be consumed which reduces air percentageinside the combustion chamber, causing a decremant in volumetric efficiency. The reduction in volumetric efficiency was about (8.0%) in the case of (10% EGR), and about (25%) in the case of (20% EGR) in compareson with (0% EGR).

The effect of adding EGR on brake specific fuel consumption (bsfc) at variable engine speeds and constant torque is shown in **Fig.(6)**. EGR takes a space from the charge which reduces speed and torque. In order to reach the required speed and torque, the entering fuel in the charge must be increased, which means increasing the bsfc. BSFC increased by (13.0%) in case of (10% EGR), and (34.0%) at (20% EGR) case in comparison with (0% EGR).

EGR effect on bsfc at constant speed and variable engine torque is shown in **Fig.(7)**. Increasing torque increased bsfc. In order to reach the required speed and torque, the fuel in the entering change must be increased which means increasing fuel consumpsion. BSFC increased about (27.0%) in case of (10% EGR), and about (46.0%) in case of (20% EGR) in comparison with (0% EGR) case.

Fig.(8) and **Fig.(9)** reveals the variation of the brake thermal efficiency with the engine speed and torque respectively. Brake thermal efficiency increased with engine speed and engine torque increase. Adding exhaust gas to the entering charge reduced the brake thermal efficiency by (5.0, 12%) in cases of (10, 20% EGR) with speed variation, (10,15 %) in cases of (10, 20% EGR) with torque variation case. The results indicate that EGR effect is clearer in torque variation. The lower values of resulted thermal efficiency are due to the low octane number of the used gasoline. Also the engine needs overall maintenance.

Fig.(10) shows the effect of adding EGR on exhaust gas temperatures when the engine runs at constant torque and variable speeds. Adding EGR means adding a completely combusted gases with high temperature which increase the change temperature before combustion. After combustion, the EGR takes a part of combustion heat reducing the generated energy causing a reduction in the resulted exhaust gas temperatures. **Fig.(11)** shows the effect of EGR on the exhaust temperature as a function of engine torque for gasoline 0%EGR, 10%EGRand 20%EGR, the exhaust temperature increased with increasing engine torque while it decreased with increasing EGR ratio.

5. CONCLUSION.

1- Brake power increases with speed and torque increase, while it decreased with increasing EGR ratio.
2- bsfc increase with increase EGR percentage at variable engine speeds and constant torque. Also, it increases when the engine run at constant speed and variable engine torque.
3- Volumetric efficiency increases at medium speeds and reduces for high speeds. Also it reduces with increasing torque.
4- EGR addition reduces the volumetric efficiency for all addition rates.
5- Brake thermal efficiencies reduce with EGR addition at variable speeds and torques.

6- The exhaust temperature increases with increasing of engine speed and torque, and it decreases with increasing of EGR ratio.

6. REFERANCE.

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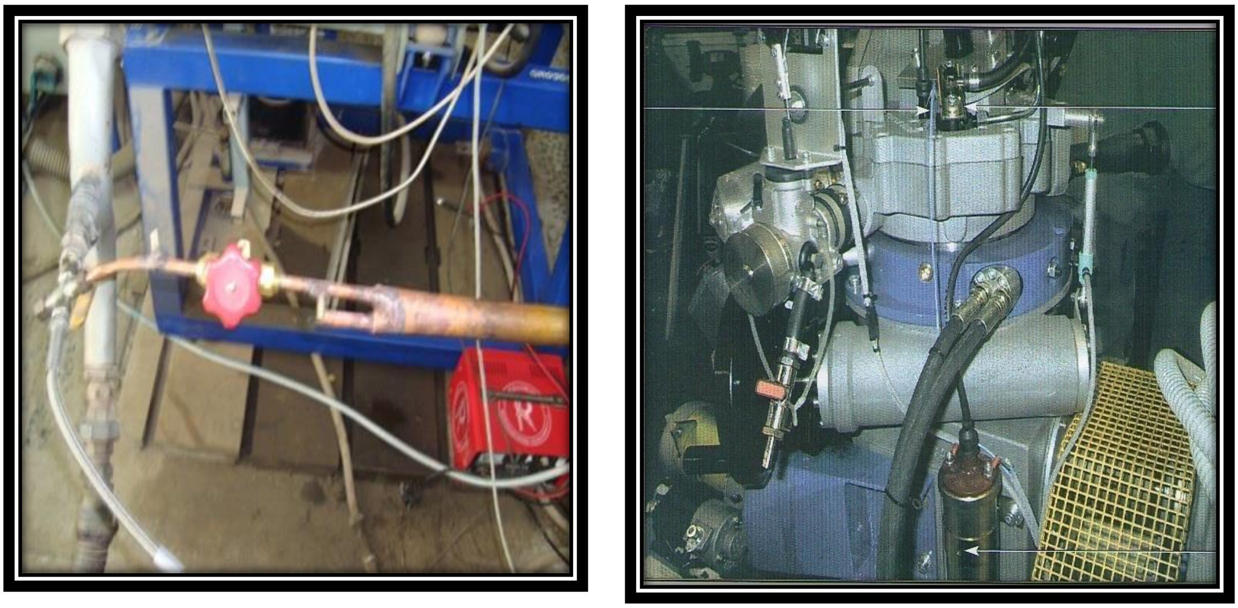

Fig.(1), The rig.

Table (1) Engine specifications [16]

1	Manufacturer	PRODIT	9	No load speed range	500÷3600 rpm (Otto cycle)
2	Cycle	OTTO or DIESEL, four strokes	10	Load speed range	1200÷3600 rpm (Otto cycle)
3	Number of cylinder	1 vertical	11	Intake star	54^0 before T.D.C
4	Diameter	90mm	12	Intake end	22^0 after T.D.C
5	Stroke	85mm	13	Exhaust start	22^0 before T.D.C
6	Compression ratio	4÷17.5	14	Exhaust end	54^0 after T.D.C
7	Max .power	4kWat 2800 rpm	15	Fixed spark advance	10^0 (spark ignition)
8	Max .torque	28 Nm at 1600 rpm	16	Swept volume	541cm^3

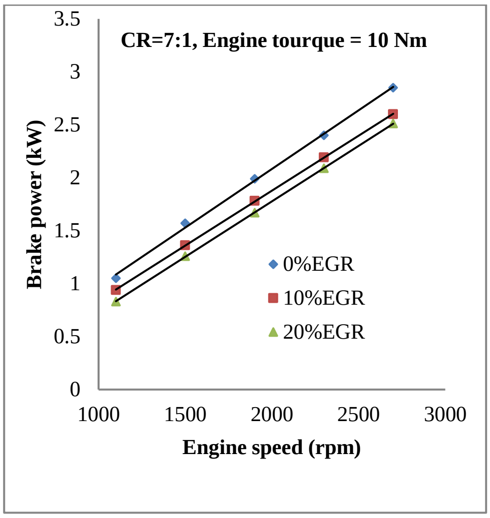

Fig.(2), EGR effect on brake power for variable engine speed at constant load

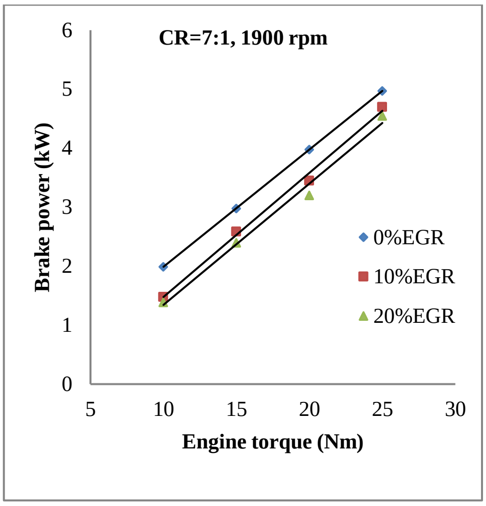

Fig.(3), EGR effect on brake power for variable engine load at constant speed

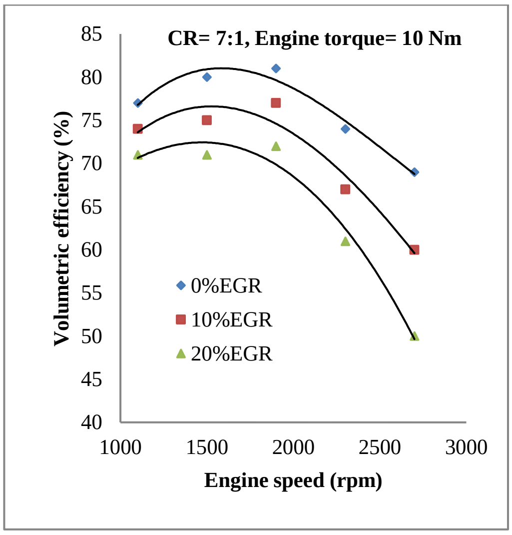

Fig.(4), EGR effect on volumetric efficiency for variable engine speed at constant load

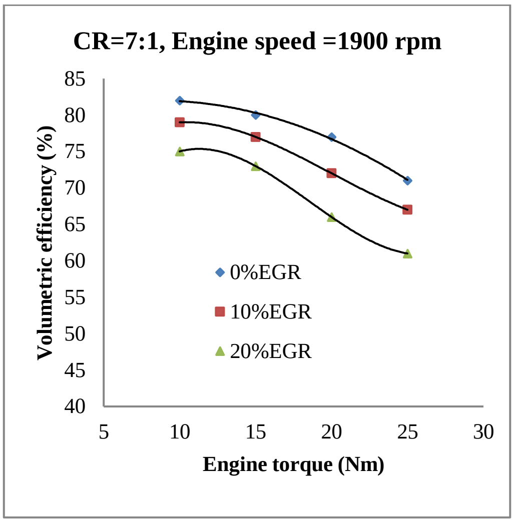

Fig.(5), EGR effect on volumetric efficiency for variable engine load at constant speed

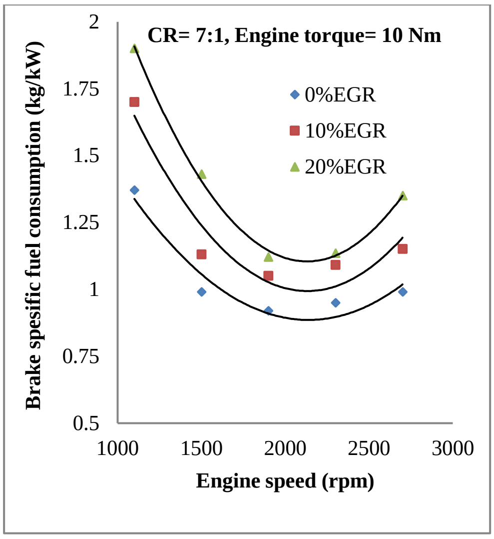

Fig.(6), EGR effect on brake specific fuel consumption for variable engine speed at constant load

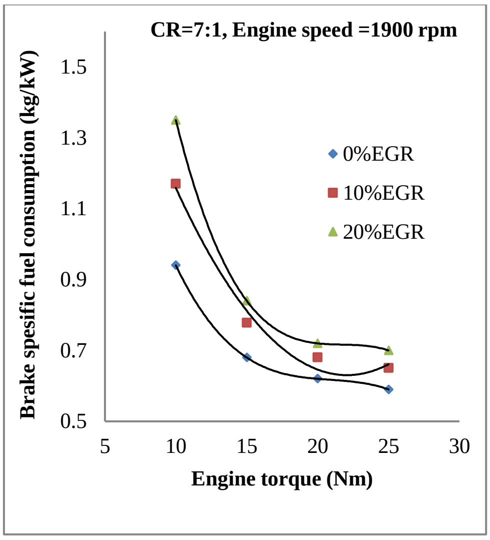

Fig.(7), EGR effect on brake specific fuel consumption for variable engine load at constant speed

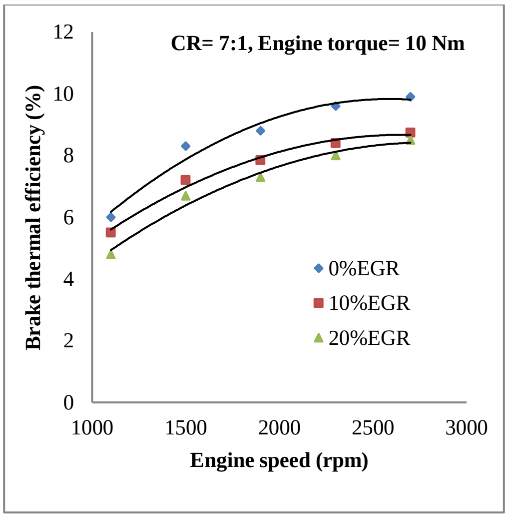

Fig.(8), EGR effect on brake thermal efficiency for variable engine speed at constant load

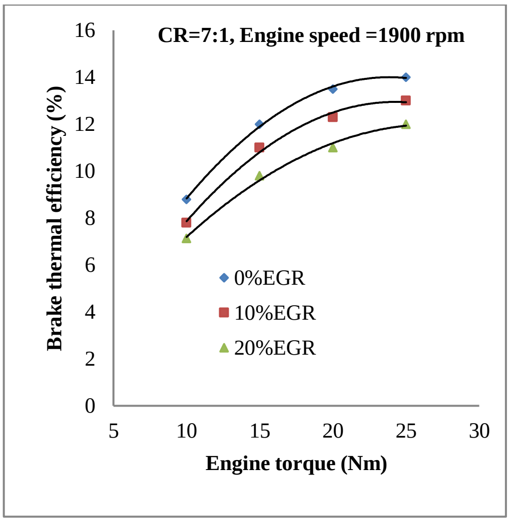

Fig.(9), EGR effect on brake thermal efficiency for variable engine load at constant speed

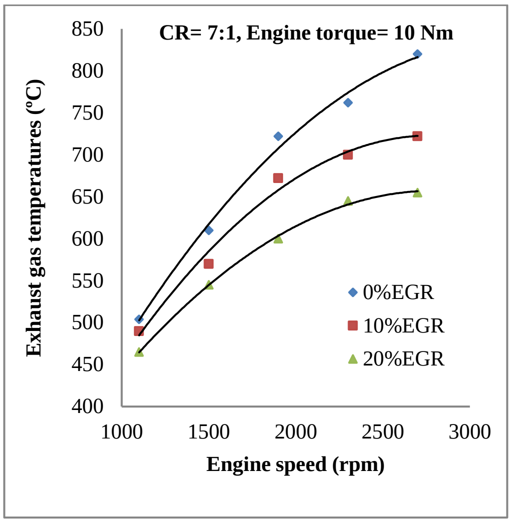

Fig.(10), EGR effect on exhaust gas temperatures for variable engine speed at constant load

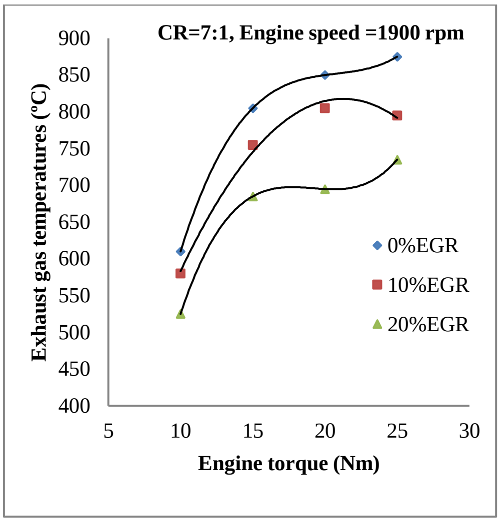

Fig.(11), EGR effect on exhaust gas temperatures for variable engine load at constant speed

دراسة تأثير تدويرغاز العادم على اداء محرك احتراق داخلي احادي الاسطوانة يعمل بالشرارة

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الخلاصة:

تم استخدام محرك اشتعال بالشرارة احادي الاسطوانة يعمل بنسبة انضغاط مختلفة نوع (PRODIT) في هذا البحث، اجريت التجارب باستخدام وقود كازولين ذو العدد الاوكتاني (80) ولنسبة مكافئة (Ø=1)، و تمت الدراسة لبيان مدى تأثير اعادة تدوير العادم على اداء المحرك، لمدى واسع من سرع المحرك (1500, 1900, 2300, 2700 r.p.m.) .

وقد تم تدوير غازات العادم بنسب 10%, 20% كنسبة حجمية من نسبة شحنة الهواء/الوقود الداخلة، بينت النتائج ان تدوير غاز العادم يؤدي الى انخفاض كل من القدرة المكبحية والكفاءة الحرارية المكبحية والكفاءة الحجمية ودرجة حرارة غاز العادم , بينما يزداد الاستهلاك النوعي المكبحي.

الكلمات الرئيسية: اعادة تدوير غاز العادم, درجة حرارة غاز العادم, القدرة المكبحية, استهلاك الوقود النوعي المكبحي, الكفاءة الحجمية, الكفاءة الحرارية .