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The Effect of Exhaust Gas Recirculation in Direct Injection Spark Ignition Engine Using Ethanol Blended Fuel

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Abstract

This research is explain about the investigation on DISI(Direct Injection Spark Ignition) engine using ethanol blends as fuel and EGR(Exhaust Gas Recirculation) system. With a huge number of transportation nowadays, there are global crisis with the fossil fuel usage and the limitation of fossil fuel in the world, Although, CO, HC, NOx and PM are the emission made from the fossil fuel used in the internal combustion engine. This problem is something we have to solve and make it better for human life in the present and also in the future. The combination of ethanol alternative fuel and EGR technique on part load can be directly effect to internal combustion, it improve Brake Specific Fuel Consumption (BSFC) and emission while power and torque remain constant.

This research is experiment on the adaptation of EGR system, mostly use in diesel engine to DISI engine. EGR is dilute air intake in engine part load operations. The result of EGR system is an improvement of Brake Specific Fuel Consumption(BSFC), anti-knocking limit and decrease combustion temperature which lead to NOx emission with lean burn mixture in DISI engine using ethanol blends as fuel.

Keywords: Ethanol, Exhaust Gas Recirculation, Emission.

1. Introduction

The combustion engine is the most using engine in the world which use fossil fuel as the main energy. Human have a serious problem due to the amount of fossil fuel usage for the transportation all around the world. Since the rate of decreasing of fossil fuel is a huge number. Moreover, other serious problem that effect on environment is the emission release from the internal combustion engine using fossil fuel. Internal combustion engine produce emissions called, "CO, CO2, HC, NOx and PM (particulate matter). Most of the regulations have their standard to control the amount of emission for manufacturing vehicle. Therefore, It is our responsibility to find a way to reduce this problem as much as possible.

Ethanol alternative fuel is one of the way to reduce the amount of fossil fuel usage, Also reduction of emission. Many countries try to use ethanol fuel for the vehicle as much because they can produce it themselves such as Brazil where can produce and use ethanol fuel most in the world [1]. So they can reduce the import of fossil fuel and get a better economic in their country.

This research is focusing on ethanol fuel using in DISI (Direct Injection Spark Ignition) engine with an adaptive of EGR (exhaust gas recirculation) system. Ethanol fuel has a good characteristic compare to Diesel and Gasoline with high heating value nearby to gasoline fuel.

The usage and development of SI (spark ignition) engine has been for a long time. In Thailand, people use gasoline port fuel injection spark ignition as commonly and this is an old technology now. DISI engine is a new technology engine which has better thermal efficiency. This engine can avoid self-ignition as causing in SI engine because of the direct injection technology. DISI engine can have higher compression ratio and the combustion efficiency will rise up relate to compression ratio. Furthermore with new technology DISI engine can be combustion under lean burn mixture by avoiding knocking with 'Stratified charge combustion'[2]. It can produce power with less fuel required and it can prevent knocking that cause serious damage to engine. Disadvantage of the stratified charge is, it inject fuel lately when the piston move up in compression stroke. Fuel and air mixture is not mixing well in small period of time, the combustion will not complete and will release the emissions, also lean burn combustion produce NOx emission[3]. Although factory will use after treatment method for their vehicle to reduce emission but this research use ethanol fuel which can reduce the emission because it is bio-oxygenated fuel.

2. Experiment Setup and Method

2.1 Fuel Properties

This research is about EGR System in DISI engine. E20 ethanol blended fuel is used. The study with ethanol blended fuel and DISI engine combustion character can gives further knowledge in agriculture which can produce high number of ethanol alternative fuel. Ethanol blended fuel also has some advantage such as flame speed that cause by oxygen inside the molecule of ethanol blended fuel[4]. Ethanol is made from wasted plant, the combustion can give carbon neutral to an environment. The properties of E20 ethanol blended fuel is shown in Table. 1

Table.1 shown E20 ethanol blended fuel properties.[5]

Fuel Properties	E20
Formula	$CH_{1.63}O_{0.065}$
Mw[g/mol]	88.12
Carbon[mass%]	79.85
Hydrogen[mass%]	12.88
Oxygen[mass%]	7.54
Density, kg/l at 15°C	0.7645
RVP at 37.8°C,kPa	58.3
LHV, MkJ/kg	40.6
RON	98.3
MON	84.6
Stoichiometric AF ratio	13.51
Initial boiling point ,IBP	42.1
End boiling point	182.8

2.2 Method

A DISI engine will test at 45Nm. engine torque and 2000 rpm which is mentioned in section **2.8.** This condition is engine partial load which match to vehicle cruising speed 90kph whereas the maximum speed for Thailand local road. The testing engine will work with E20 ethanol blended fuel. Stratified mode will work in this engine operation. The optimization of DISI engine injection and ignition timing relate to E20 ethanol blended fuel will interested in 80-110 CAD(crank angle degree) which is stratified charge mode. The ignition timing will adjust from 18 to 32 CAD. Dilution of EGR rate by 0 to 25 percent will be operate at the optimized point of injection timing and ignition timing To get an improvement in BSFC and emission. Air fuel mixture is controlled by using Innovate Lm-2 oxygen wide band sensor. Brake Specific Fuel Consumption (BSFC) and gas emission will be collected and analyze. Emissions are examined from exhaust pipe directly and evaluated by gas analyzer MRU SWG 200-1 illustrated in section **2.5**. The schematic diagram of experiment setup is shown in "Fig.1"

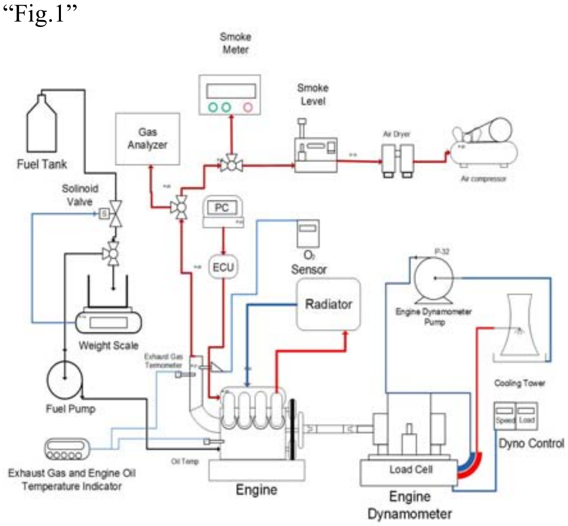

Fig.1 shown schematic diagram of experiment setup.

2.3 DISI Engine

DISI (direct injection spark ignition) engine is a variant of fuel injection employed in modern four-stroke gasoline engines. The gasoline is highly pressurized, and injected directly into the combustion chamber of each cylinder, as opposed to conventional multi-port fuel injection which fuel is injected in the intake manifolds, or cylinder port. In some applications, gasoline direct injection enables to work in stratified charged combustion mode for improving fuel efficiency, and reducing emission levels at low load. The main advantage is the increasing of engine compression ratio coped with cooling effect from the fuel direct inject to piston dome. DISI engine can operate with stratified charge combustion which can combust by lean burn mixture operation.

The in-line 4 cylinder DISI engine is operated in this research which shown in table. 2

Table 2 shown DISI engine specification.

Model	Mitsubishi 4G93 GDI
Type	In-Line, DOHC 16V.
Number of cylinder	4
Displacement(cc)	1,834
Compression Ratio	12.0:1
Bore x Stroke(mm)	81.0x89.0
Maximum Output	96kW @6000RPM
Maximum Torque	177Nm @3750RPM
Vehicle	Mitsubishi Lancer/2003
Dimension	
Width (mm)	1,695
Height (mm)	1,430
Curb Weight (kg)	1,200
Drag Co-efficient	0.3
Tire	185/65/R14
Wheel Diameter (mm)	596
Transmission Specification	
1st	2.319
2nd	1.62
3rd	1.26
4th	1.00
5th	0.7
6th	0.445
Final Drive	5.219

2.4 Engine Dynamometer

The "Tokyo Plant 150 PS@3000RPM Model" engine dynamometer interfaced with in-house program has measured the results of this experiment: power, torque, Brake Specific Fuel Consumption as shown in "Fig. 2"

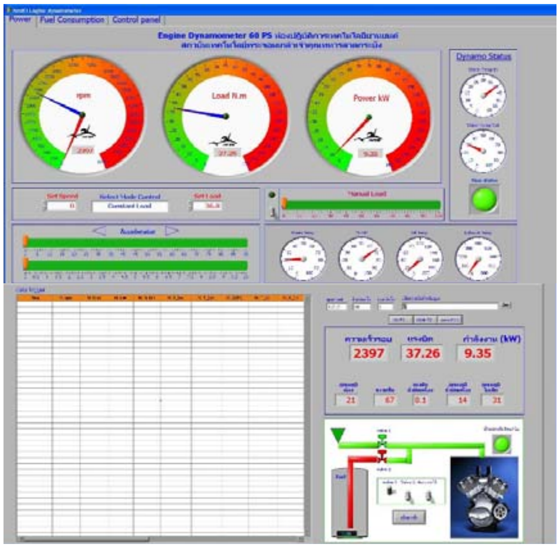

Fig.2 shown in-house program of engine dynamometer

2.5 Emission Analyzer

The gas emissions such as CO, HC and NOx are collected by Gas Analyzer: (MRU SWG 200-1). The gas analyzer measuring emission gas from exhaust pipe when engine operate at the testing condition. It can measure 0-4,000 ppm CO, 0-5,000ppm CxHy, and 0-2,500 NOx accurately.

2.6 Electronic Control Unit

The DTA fast S60 Pro is standalone electronic control unit for DISI testing engine which is able to controls Fuel injection timing, Fuel injection duration and spark ignition timing which can control testing engine conditions.

2.7 EGR Device

EGR (Exhaust Gas Recirculation) Valve is controlled by National Instrument and Labview program "Fig.3". It is design to control percentage of EGR gas into intake pipe. The program analyzes data from intake and exhaust oxygen sensor. The software is automatically control EGR valve.

The percentage of EGR gas is determined by "eq.1"[6]

$$\%EGR = \frac{[O_{2,amb}]-[O_{2,man}]}{[O_{2,amb}]-[O_{2,exh}]} \quad (1)$$

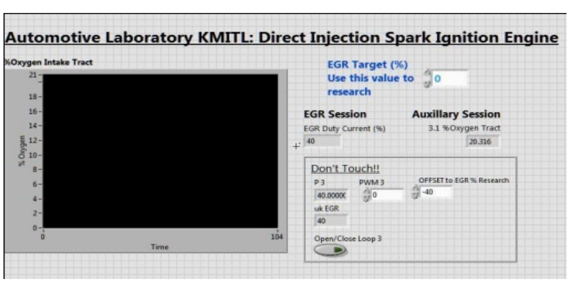

Fig.3 shown EGR controlled software

2.8 Test Conditions

DISI engine is operate on dynamometer with E20 ethanol blended fuel, 2000RPM engine speed and 45kN of brake torque which is cruising speed. testing sequence is shown in "Fig. 4".

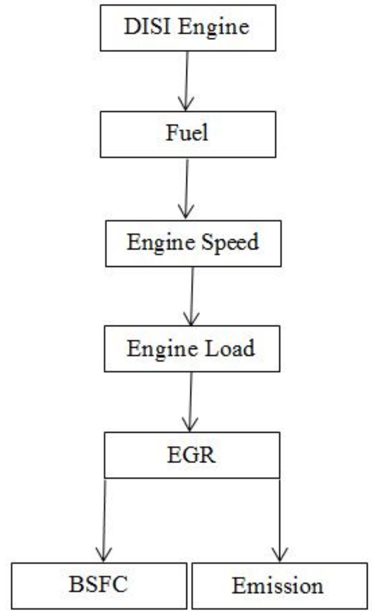

Fig.4 shown the testing sequence diagram.

Then investigate on DISI engine stratified mode characteristic by adjust fuel injection timing and ignition timing. After the optimization of fuel injection timing and ignition timing, The EGR system is operate by 0 to 25 percentage of intake air dilution as shown in Table. 3. After engine is operated in each condition, BSFC is calculated by in-house software cooperates with engine dynamometer and emission is collected by gas analyzer.

Table.3 Shown EGR testing condition

Engine Speed(RPM)	2,000
Fuel Type(%Ethanol)	20
Ambient Temperature(°C)	30
Coolant Temperature(°C)	87
Engine Torque(Nm)	45
Engine Operation	Stratified charge
Lamda(λ)	1
Injection Timing(CAD, BTDC)	80°-110°
Ignition Timing(CAD, BTDC)	17°-32°
EGR rate(%)	0-25

After vehicle specification is purposed, the surroundings condition such as vehicle speed, pavement conditions were based on Thailand regulations which shown in table.4.

Table.4 Surroundings condition

Speed (km/h),	90
Engine Efficiency (%)	90
Road: Fair Pavement = Kr	0.019
Road Gradient (%),	4
Air Density (kg/m^3)	1.2

From table.4 and table. 5, total resistance consist of air resistance, rolling resistance and gradient resistance. With the calculation of Resistance and the following results showed in table.5 and table.6 respectively.

Table.5 Air Resistance calculated value,

1. Air Resistance (Ra)	
Cross-Section Area (m2)	1.94
So, Air resistance (N)	218.15
2. Rolling Resistance (Rr)	
From Curb Weight (N)	11,772
So, Rolling Resistance	223.67
3. Gradient Resistance (Rg)	47.09
Hence, Total Resistance (Rt,N)	488.90

Table.6 Engine calculated power and torque

Engine Power (kW)	13.58
Engine Torque (Nm)	
1. Torque at wheel	145.69
2. Torque at engine	44.31

The following table.6 shows that calculated engine torque for cruising speed of 90kph. is 44.31Nm.

3. Result and Discussion

3.1 DISI engine

An investigation of DISI engine with stratified mode made by adjust fuel injection timing and ignition timing. “Fig.5” shows BSFC of each engine condition. The best BSFC is locate at 100 CAD, BTDC, it can also shows that injection timing is really effect to engine.

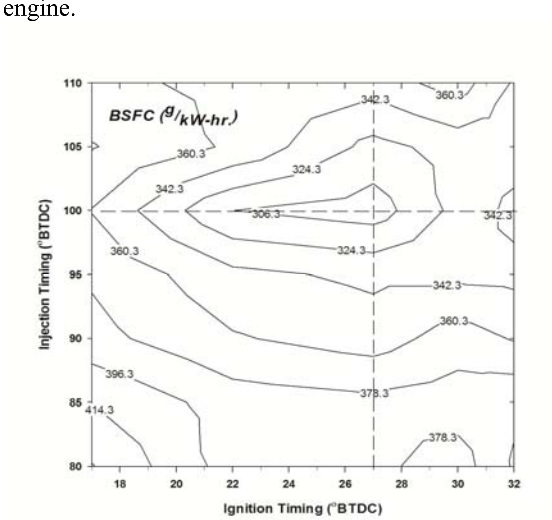

Fig.5 Effect of injection and ignition timing on BSFC

At 100CAD, BTDC injection timing and 27CAD, BTDC ignition timing can produce the highest thermal efficiency relate to BSFC. So the combustion temperature is also high which means high temperature produce NOx emission[7] as shown in “Fig.6” NOx emission is collected from exhaust gas.

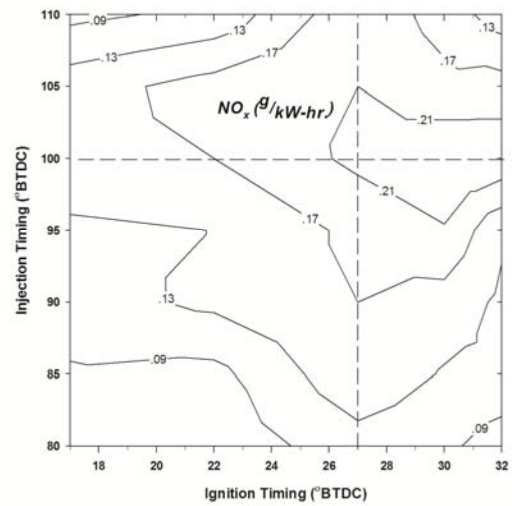

Fig.6 Effect of injection and ignition timing on NOx emission

Both “Fig.7”,”Fig.8” show that CO and THC reduce if inject fuel lately near TDC and will increase when inject fuel earlier. When inject fuel lately, the combustion is a late phase that will get low cylinder pressure but it can be well after burned with late phase causing low CO and THC emissions.

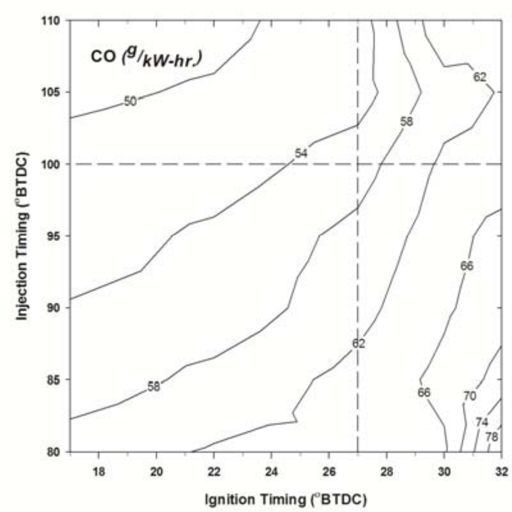

Fig.7 Effect of injection and ignition timing on CO emission

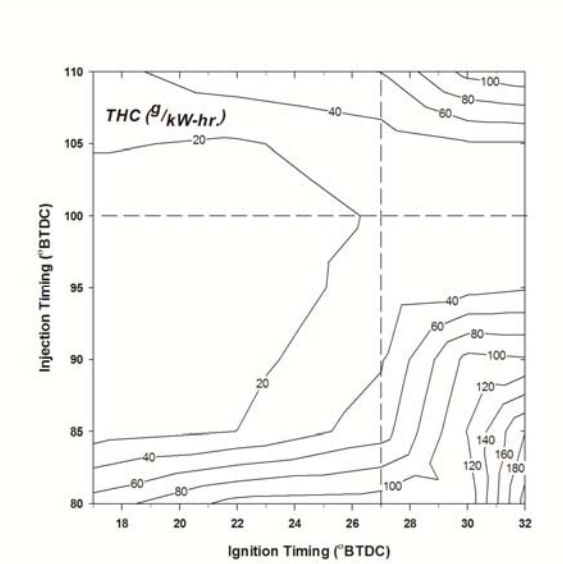

Fig.8 Effect of injection and ignition timing on THC emission

After the investigation of DISI engine with stratified mode and E20 ethanol blended fuel. It is found that at 100CAD, BTDC injection timing and 27CAD, BTDC ignition timing is the lowest number of BSFC. Furthermore, emission increase at 100CAD, BTDC injection timing and 27CAD, BTDC. This is an optimum point for Injection and Ignition timing in DISI engine using ethanol blended fuel. Some number of emission can be reduced by using EGR technic after found this optimum point.

3.2 EGR System

When the engine operate on partial load the movement of the piston suction the air make intake manifold become vacuum. EGR can reduce intake manifold vacuum which causing to reduce the pumping work[8]. It cause an improvement in BSFC. "Fig.9" shows manifold absolute pressure inside intake manifold when EGR is operate

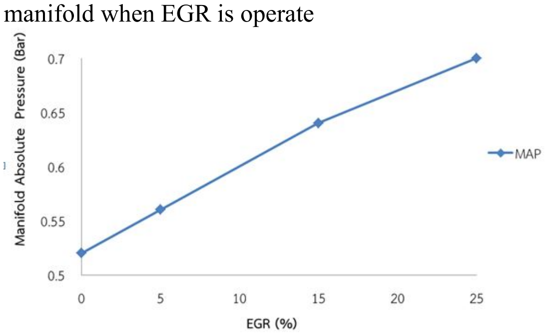

Fig.9 Effect of manifold absolute pressure on EGR rate

EGR can reduce pumping work that can improve BSFC but Exhaust gas actually harmful to combustion reaction. EGR is classified as inert gas which cause low speed flame[9]. "Fig.10" shown that EGR optimum point is at 5% EGR rate. It can improve BSFC at 5 percent of the EGR.

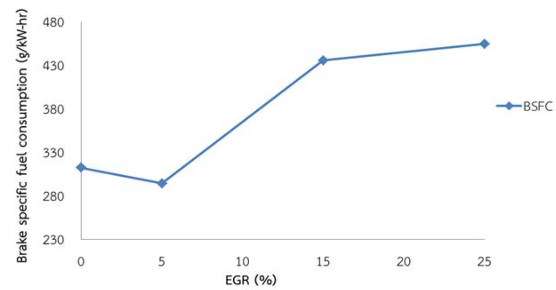

Fig.10 Effect of BSFC on EGR rate

NOx emission can reduce relate to adiabatic flame temperature as shown in "Fig.11". EGR dilution is a wall between fuel mixture molecules. It effect to exhaust temperature.

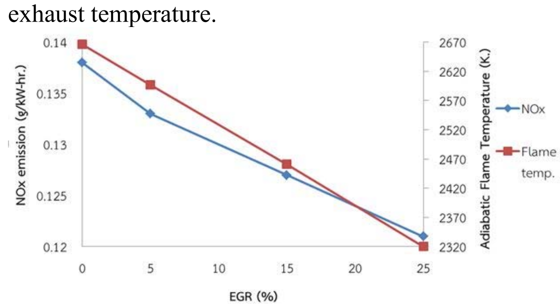

Fig.11 Effect of NOx emission on EGR rate

Although, EGR can reduce NOx emission, it increase CO and HC because too much percentage of EGR dilute to intake manifold as shown in "fig.12","fig.13"[9].

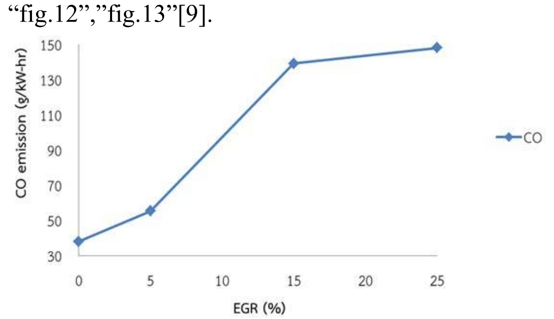

Fig.12 Effect of CO emission on EGR rate

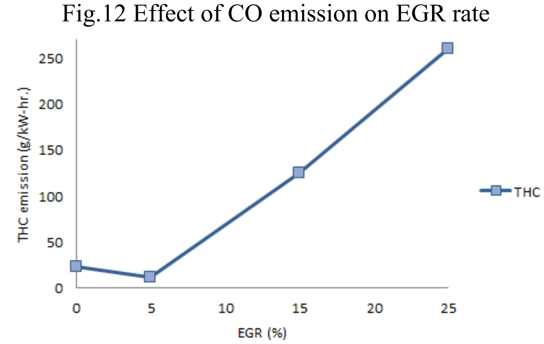

Fig.13 Effect of THC emission on EGR rate

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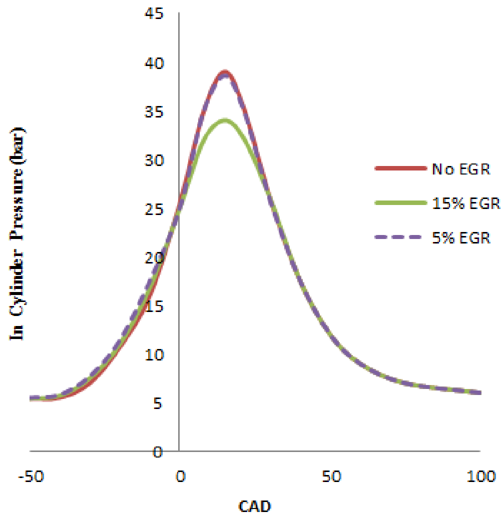

Fig.14 Effect of in cylinder pressure and CAD on EGR rate

The optimum EGR rate for DISI engine with stratified charge combustion is 5% EGR. 5% EGR can reduce pumping work and has less effect to in cylinder pressure as shown in "Fig.14". 15% EGR is highly effect to cylinder pressure which engine require more fuel to maintain engine torque. The BSFC is reduce when increasing EGR rate to engine more than 5%

4. Conclusion

4.1 DISI Engine

DISI engine operate in stratified mode with E20 ethanol blended fuel is optimized at 100CAD, BTDC injection timing and 27CAD, BTDC ignition timing.

Early injection and late ignition timing, mixture stratification is reduced by increasing duration of air fuel mixture. So, partial burns in for combustion is increase. Early injection and early ignition timing, too early of combustion phase. An over lean mixture occur rapidly in combustion phase. Late injection and late ignition timing, in-cylinder pressure is decrease[10]. This causes retarding for air fuel mixture and causing later combustion phase. Late injection and early ignition timing, In sufficient duration between the end of injection and start of spark causing over rich mixture and liquid droplet effect.

The engine can operate well at optimum point. It effect to BSFC, CO, NOx and HC emission

4.1 EGR

The optimum EGR rate for DISI engine which has the least BSFC is at 5 percent. It reduces vacuum inside intake manifold which also reduce pumping work. NOx emissions also decrease due to low flame temperature. AT optimum point 5% EGR rate HC and CO increase slightly but it increase extremely high if dilute 10 to 25 percent of EGR because of low flame temperature and highly effect to combustion pressure.

5. Acknowledge

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