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Investigation of the effects of exhaust and power loss in dual-fuel six-stroke engine with EGR technology

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ABSTRACT

In today's world, the usage of internal combustion engines is inevitable. Particularly the diesel engines find their importance more than the petrol engines due to their operating cost. But diesel engines have their demerits in the area of exhaust and power loss. Necessary steps have to be taken in order to effectively use the fuel available. In this technical presentation, we have discussed about the utilisation of six-stroke engines which run on dual fuel. The six-stroke engine's principle resembles a double-stage compressor. By this way, effective compression is done and the need for turbocharger is completely neglected. We have also considered cylinder's position in a six-stroke engine. As the lubrication and cooling system needs special attention in the case of opposing-type cylinders, we have formulated a better and simple arrangement in which same power is produced, eradicating the lubrication problems. Also, the pollution (NOx) emitted by the diesel engines is also taken into account. We found the solution in the form of dual-fuel and exhaust gas recirculation system. The combusting temperature of the diesel engine is above 2000°F and this is the prime reason for NOx emission. So an alternative fuel which can be combusted below the level of diesel should be used. Moreover, the availability and production cost must be taken into consideration. We found ethanol as a better alternative for diesel. The cold starting of the engine is made easier using a glow plug, which is used to preheat the charge coming inside the combustion chamber.

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KEYWORDS
Internal combustion engines; dual fuel; exhaust gas recirculation system and glow plug

1. Introduction

Considering the importance of a cleaner, powerful and economical engine, we have come up with this new idea for practical implementation of a six-stroke engine (Devaraj, Yuvarajan, and Vinoth Kanna 2018), which will be nearly 40% more fuel efficient than the existing four-stroke engines. The engine is also more efficient and powerful than the existing six-stroke and four-stroke engines. The engine is also having the scope of using heavy fuels and bio-fuels (Vinoth Kanna and Paturu 2018).

The engine with the varied thermodynamic cycle of operation has better thermodynamic efficiency, reduced fuel consumption, and reduced pollution. The usage of heavy fuels/kerosene in an engine with increased efficiency can dramatically reduce the cost of running (Agrell and Dehlin 1989).

The engine is a Double cylindered with V-type piston arrangement. The increased efficiency is achieved by using the energy of the exhaust gases to power an additional power stroke in the cylinder, which is used for supplying compressed air to the main cylinder (Vinoth kanna and Pinky 2018). Thus, unlike any other former six-stroke engine design, the engine has two power strokes during the entire six-stroke cycle.

The scavenging system can also be effectively designed with better valve timing arrangement. The engine can achieve a high compression ratio (25–27), which cannot be easily achieved in normal combustion engines. The engine also has better turbulence due to which the combustion is smooth and effective. The engine has better air pollution control than the existing four-stroke engine (Vinoth Kanna, Vasudevan, and Subramani 2018). The engine may be smokier with heavy fuels, but the pollution level when compared to the existing heavy fuel engines will be within limit. With the use of conditioned heavy fuels, this sulphur smoke can be dramatically reduced and pollution can be reduced considerably (Vinoth Kanna, Devaraj, and Subramani 2018) (Figure 1).

2. Basic engine parts

- **Inlet valve**: When open, it supplies fresh air into the engine
- **Exhaust valve**: When open, it removes the burned gases from the engine
- **Connecting valve**: This valve connects the two compression chamber with the combustion chamber. When open, it permits the flow of compressed air from the compression chamber to the combustion chamber and also permits the flow of exhaust gases from the combustion chamber to the compression chamber to drive the second power stroke.
- **Scavenging valve**: The combustion chamber has been provided with a scavenging valve, to remove the burned gases formed during the combustion. The valve makes scavenging much more effective than what is found in the existing six-stroke or four-stroke engines.

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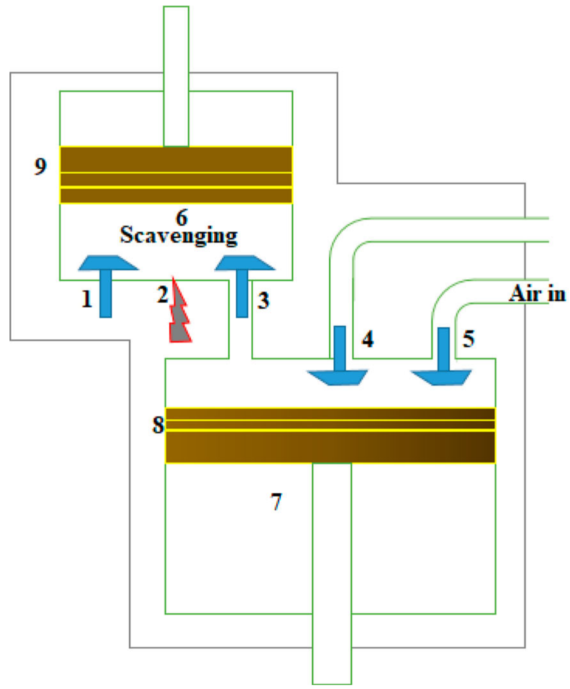

Figure 1. General alignment of cylinders in a six-stroke engine.

- **Fuel injector**: It injects highly pressurised fuel into the combustion chamber.
- **Compression chamber**: It supplies compressed air to the combustion chamber. It also aids in providing better turbulence in the combustion chamber, making combustion smooth and effective.
- Combustion chamber: The combustion of the compressed fuel occurs with the aid of the fuel pumped into the cylinder.
- **Piston 1**: moving in the combustion cylinder, gets work output during every power stroke.
- **Piston 2**: moving in the compression chamber, gets power from the exhaust of the combustion chamber.

3. The six strokes

3.1. First stroke

During the first stroke, the inlet valve is opened and the air is sucked into the compression chamber. The scavenging valve is also opened to push out the remaining exhaust gases in the combustion chamber.

3.2. Second stroke

The connecting valve is opened and the air sucked in by the compression chamber is compressed and sent to the combustion chamber.

3.3. Third stroke

All valves remain closed, air is compressed in the compression chamber.

3.4. Fourth stroke

During the fourth stroke, the fuel is injected into the combustion chamber and the combustion of fuel takes place, giving out power, which is obtained from the first piston.

3.5. Fifth stroke

The connecting valve is opened, driving out the exhaust gases from the combustion chamber into the compression chamber. The high pressure with which the exhaust gases are pushed out aids to obtain an additional power stroke, using the second piston.

3.6. Sixth stroke

The exhaust valve is opened and the exhaust gases are pushed out from the cylinder. The scavenging valve is opened and the air is sucked into the combustion chamber, which is pushed out during the first stroke. The scavenging valve helps make the combustion chamber much cleaner, as this engine burns heavy fuels.

3.7. Advantages

- 30% reduction in fuel consumption
- Two Power strokes
- Heavy fuel Usage
- Dramatic reduction in pollution
- Better Scavenging
- More powerful than the existing conventional engines (Figure 2).

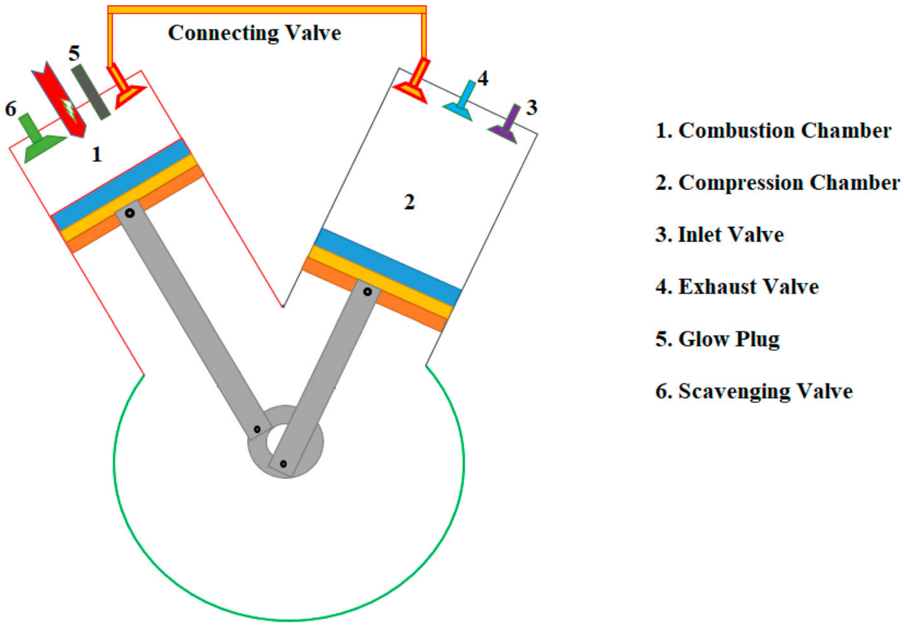

Figure 2. Modified design of a six-stroke engine.

4. Modified design

4.1. Design changes considered in the engine

- The opposing cylinder type is being replaced by a V-type cylinder.
- Three separate valves are employed in the compression cylinder (inlet, exhaust, connecting valve).
- The angle of the V-type cylinder arrangement is 60 or 90 degrees.
- Application of glow plug in the combustion chamber.

4.2. Benefits

- The area occupied by the engine is considerably reduced.
- The lubrication system is much simple and effective as the cooling system.
- Construction is much simpler.

5. Dual-fuel technology

Dual-fuel engine is one which operates with two different fuels (Paturu and Vinoth kanna 2018). One is the igniting fuel (diesel) and the other is the running fuel. We can find a huge variety of running fuels from the present research. One such fuel is alcohol.

Under alcohol, many types are found to satisfy the budding problem such as Methanol, ethanol, and Butyl alcohol (Vinoth Kanna and Pinky 2018). We Prefer Ethanol as the suitable running fuel because of the following properties listed.

Moreover, some additional advantages related to ethanol are:

- It is not a fossil fuel; that is, combusting it does not cause any green house effect.
- It is biodegradable, which does not affect the environment.
- Higher oxygen content ultimately reduces the NOx emission and other harmful pollution
- The fuel is very much economical for the long run.
- The compression ratio is high of the order 25–27.

Since the alcohols have a very high self-ignition temperature, so the design of the engine using ethanol as the primary fuel will be robust and expensive (Okamoto et al. 1998). So a general idea of using ethanol in dual-fuel operation is practised.

5.1. Principle of operation

In a dual-fuel engine, the alcohol is generally carburetted or injected into the combustion chamber. Due to a high self-ignition temperature of alcohols, there will be no combustion with usual diesel compression ratios of 16–18. So a little before the end of compression stroke, a small quantity of diesel oil is injected into the combustion chamber through normal pumping techniques. The diesel oil readily ignites and this initiates combustion in the alcohol–air mixture also.

5.2. Methods of injecting ethanol

Several methods are adopted for injection of alcohol into the intake manifold. Some of the techniques used are pneumatic spray nozzle, vaporiser, carburettor and fuel injector.

Another method that can be implemented is the direct injection of ethanol into the combustion chamber after the diesel fuel injection. By this way, alcohol cooling of the charge is avoided to a degree which will jeopardise the ignition of the diesel fuel (Arabaci et al. 2015).

This system requires two complete and separate fuel systems with their necessary fuel feed systems (Figure 3).

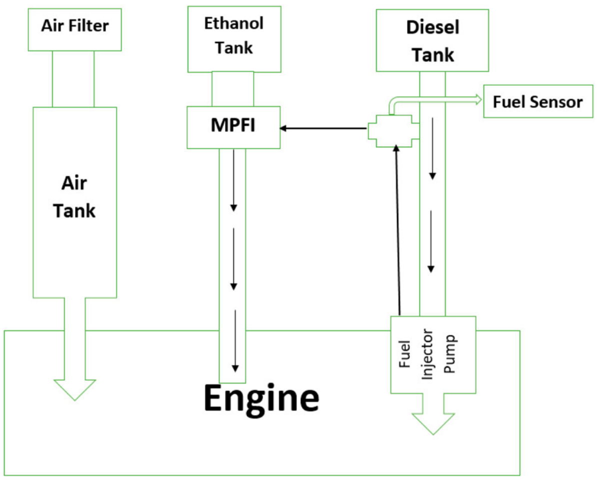

Figure 3. Schematic layout of system.

In the dual-fuel engines, major portion of the heat release is by the alcohol supplied and this alcohol is ignited by a spray of diesel oil injection.

6. Exhaust gas recirculation

6.1. Need for EGR

During acceleration and normal running condition, the combustion temperature inside the cylinder is around 2000 Fahrenheit. This condition is favourable for the NOx formation. The nitrogen and oxygen in the combustion chamber can chemically combine to form nitrous oxides, which, when combined with hydrocarbons (HCs), produce harmful effects (Conklin and Szybist 2010).

6.2. Evolution of EGR

The EGR technique was first implemented in 1970s by General Motors. The general principle is that the exhaust from the combustion chamber is being circulated back to intake manifold by a simple piping mechanism. By this way, the fuel charge is diluted and temperature is reduced so as to reduce harmful emission (Devaraj, Vinoth kanna, and Manikandan 2017).

The amount of exhaust circulated is determined by the Electronic control unit (ECU). Depending upon the engine loading condition, the flow is allowed by the EGR valve, which is actuated by ECU.

Conditions, when EGR should not respond, are:

- Higher accelerating conditions.
- During idling and cold start conditions.

EGR has to work for a normal loading and running condition. This phenomenon is not really understood by the people early and they started to disconnect the EGR system from the Engine. To overcome the above-listed problems, a closed loop system was invented in the early 1980s. The working of such an EGR system is explained below (Figure 4).

The purpose of the Exhaust Gas Recirculation (EGR) system is to reduce engine exhaust gas emissions in accordance with EPA regulations (Sughosh Belur 2014).

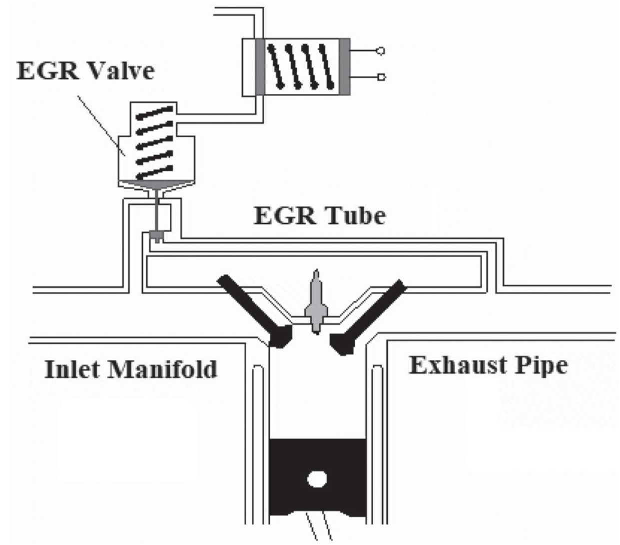

Figure 4. Position of EGR.

6.3. The EGR system consists of:

- EGR cooler
- EGR control valves
- Reed valves
- EGR charge air mixer

Part of the exhaust gasses from the cylinders are routed from the exhaust manifold through the EGR cooler, past control and reed valves, and are mixed with the intake manifold charge air (Koksharov 2015). The addition of cooled exhaust gasses back into the combustion airflow reduces the peak in cylinder combustion temperature. Less oxides of nitrogen (NOx) are produced at lower combustion temperatures. The recycled exhaust gasses are cooled before engine consumption in a tube (radiator) and circulated.

7. Components

7.1. EGR cooler

The EGR Cooler is equipped with a single-pass cooler. Part of the exhaust gasses from the cylinders are directed through the EGR shutoff valve and through the cooler and reed valves, past the EGR-modulated control valve and the mixer and then back to the cylinder (Siswanto et al. 2017) (Figure 5).

7.2. EGR control valves

The EGR shutoff valve and the EGR-modulated control valve are control valves. The EGR shutoff valve is a pneumatically driven butterfly valve, located at the inlet of the EGR cooler (Karmalkar 2014). It closes when the exhaust flap or turbo-brake actuates, avoiding exhaust gas flow and excessive pressure in the EGR cooler and reed valves. The EGR-modulated control valve is an electronically actuated butterfly valve located after the EGR cooler and reed valves, controlled by the ECU. This valve controls the exhaust gas flow for the intake manifold.

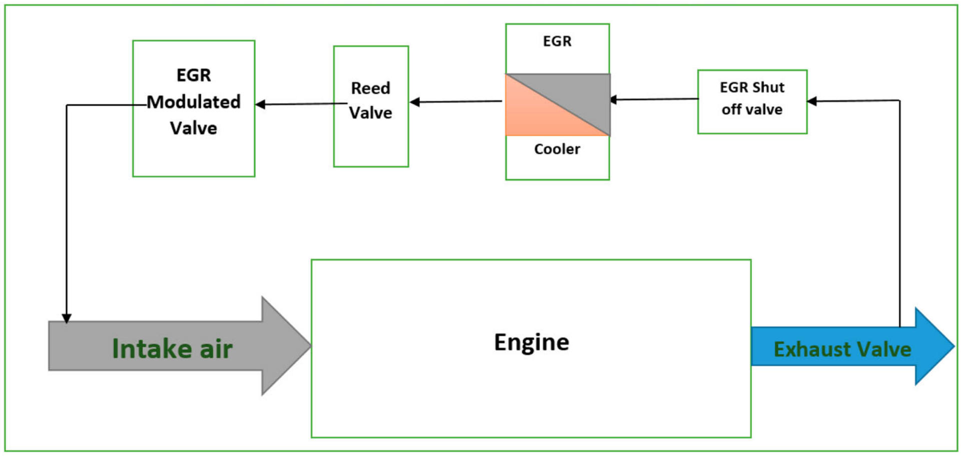

Figure 5. Flow diagram of exhaust gas in EGR technology.

7.3. *Reed valves*

The reed valves work like a check valve, allowing the flow of gas only in one direction, avoiding gas back flow when the intake pressure is higher than exhaust gas pressure (Gohil, Dave, and Gawande 2015). As the average exhaust pressure is lower than the intake pressure, the gas flow through the reed valves is possible due to exhaust gas pressure peaks – peaks slightly higher than the intake air pressure, which occurs as the engine exhaust valves open. During this peak of pressure, the reed valves open and allow gas flow to the EGR-modulated valve and mixer.

7.4. *EGR mixer*

The purpose of the mixer is to ensure good mixing of the cooled EGR gasses with filtered charge air. Once the exhaust gasses are cooled and have completed their cycle through the EGR system, they are released into the EGR mixer. The recycled exhaust gasses are combined with the charged air and directed to the cylinders.

8. Conclusion

A good engine needs high efficiency, high performance characteristics, and low emission standards. It seems that the above-mentioned solution meets all these specified standards. For the practical implementation, changes in the design of Compression Ignition engines are not of a greater magnitude. The only change that has to be implemented is that the metering system should be able to meet 9:1 air fuel ratio. Indian economy can be considerably saved because the fuel usage does not involve any foreign exchange. Further cold starting is performed efficiently using glow plugs. It is very much essential to implement the dual-fuel technique ASAP in order to save the ozone layer and to live in a green world.

Disclosure statement

No potential conflict of interest was reported by the authors.

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