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# CURRENT MARKET TECHNIQUES USED TO REDUCE $CO_2$ EMISSIONS FROM DIESEL ENGINES

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**ABSTRACT:** The I.C. engine plays a major role in our mobility and it will continue to do so in the distant future as well. But it will also have to contribute to the protection of the world's climate and the conservation of our limited reserves of fossil fuel. Controlling vehicle emissions is one of the most important aspects of modern environment management. Over 99.5% of the exhaust gases from diesel engine are a combination of nitrogen, oxygen, carbon dioxide, and water. Alone $CO_2$ contributes for about 5% of the total volume of exhaust. Thus the engine performance, combustion efficiency and emissions are all related to the engine design, running parameters and fuel properties. These parameters are important for optimization of the engine performance and for reducing emissions. The objective of this paper is to review the various engine technologies available in the market which contributes in $CO_2$ emission reduction as per the standard norms. The paper ends with future scope chalked out based on this study.

***Keywords:*** *$CO_2$ emissions; diesel engine; frictional losses; emission control.*

## 1. INTRODUCTION

Air pollution is an important public health problem in most cities of the developing world. Motorized road vehicles are a major source of air pollution and they tremendously dominate the market of transport throughout the world because of their versatility, flexibility, and low initial cost. Transport is the worst performing sector under 'Kyoto' and seriously endangers the achievement of the Kyoto targets. About 56.6 % of the total $CO_2$ emissions results from the burning of fossil fuels; much of which is due to the transportation sector [1]. Out of the total amount of energy consumed in this sector major part is required for the road transport which includes passenger vehicles, light duty trucks, heavy duty trucks, buses and two or three-wheelers. The passenger cars and light duty trucks are held account for about 65% of road transport greenhouse emissions and for about 45% of the total transport activity emissions.

So now, the automotive industry is focusing on diesel engines as the best way to achieve the $CO_2$ reduction goal. Improvements in diesel technology have been important for the rise in diesel sales. Diesel engine performance, combustion efficiency and emissions are simply related to the engine design and running parameters and fuel properties. These parameters are important for optimization of the engine performance and for reducing emissions. One of the reasons for forming exhaust pollutants is insufficient combustion in the engine cylinder. Burning one liter of diesel will produce approximately 2.67 kg of $CO_2$. When compared with gasoline engine, emissions from diesel engine prove to be more hazardous to humans. Thus, controlling diesel engine emissions has become one of the most important aspects of modern air quality management.

## 2. LITERATURE SURVEY

The automobile field is very active with collection of numerous papers and presentations annually on the health effects of diesel exhaust, new fuels, engine technologies and emission control technologies [2]. Some of these studies have been summarized in this section.

Thipse [3] focuses his recent research on fuel economy in order to minimize the $CO_2$ emissions. He states that, fuel economy of a vehicle can be improved by various strategies, among which engine combustion plays a very vital role.

Palmer et.al. [4] enlists a few techniques for $CO_2$ reduction that are center of attention in current market. They focus on the potential of these techniques to reduce $CO_2$ emissions, their incremental costs in existing technology, applicability and the possible barriers for their use.

Fontaras and Samaras [5] from their experiment on three gasoline and three diesel engines of different weight and engine capacity characteristics concluded that there is a huge potential in today's vehicle to reduce $CO_2$ emissions, if parameters such as reduction in vehicle weight, reduction in aerodynamic resistance through optimization of the design characteristics, using low rolling resistance tires and an increase of the overall powertrain efficiency, are correctly controlled.

Leonhard [6] concludes that developing pioneering powertrain technologies may give us the confidence to say that the $CO_2$ targets of 70 grams per kilometer, in discussion for 2025, are achievable.

Johnson [2] has reviewed in his paper about the regulatory targets for the then upcoming 10 years and projected advancements in the diesel engine technology that are used to estimate future emission control needs. He focuses on the tightening of the emissions norms in consecutive years, particularly for PM and $NO_x$. Thus, he summarizes that for environmental safety though all the nations are striving hard to control their emissions, they are attaining the same values at different time periods.

Bakar et. al. [7] experimented upon the injection system of a direct injection diesel engine. They have varied the injection pressures for two conditions, i.e. constant load-varying speed and constant speed-varying load. From the results obtained they conclude that increasing injection pressure is in line with increasing power. But also increasing injection pressure leads to increased fuel consumption.

Douglass et.al. [8] from the available statistics predict that if it is possible to increase the average fuel economy from 30 miles per gallon in 2006 to 60 miles per gallon in 2056; 25 billion tons less $CO_2$ may be emitted in those 50 years. They conclude that there may be numerous solutions to increase fuel economy but unless they are scientifically, economically and politically feasible, none of them will be easy because the global climate change is an important problem to risk anything but a positive outcome.

Kaleemuddin et.al. [9] in their industrial project have made improvements in a 395cc single cylinder naturally aspirated air cooled HSDI engine to meet proposed BS III emission norms. Modifications such as valve protrusion in cylinder head, re-oriented higher velocity injection cam with higher aspect ratio, combustion bowl and added features in fuel injection system have been incorporated in the upgraded version of engine.

## 3. $CO_2$ REDUCTION TECHNIQUES

Until now many techniques have been suggested and adopted for reducing the ever increasing greenhouse gas emissions. Thus it is important for engineers to develop such techniques by keeping regulatory norms in mind, as these norms are the primary driver for technical advancements. Rather than being major innovations, many of these technologies have been in existence for several years and have been advanced, refined and adjusted to optimize diesel technologies.

### *3.1 Piezo Injectors*

Piezo injector allows the fuel to be injected in very fine spray and also meter the fuel so that lower fuel consumption and emission levels are ensured. Nowadays piezo injection is gradually replacing the solenoid injection. Earlier injectors were using electromagnetic solenoids to move injector needle but piezo injector uses piezo crystal plates. These plates expand when electric current is supplied & causes needle to move. This expansion is more precise thus enabling exact fuel metering, lower fuel consumption and emissions.

Delphi Corp. is one of the earliest companies that have incorporated the diesel fuel injection technology, called DFI3, with piezo injectors, as shown in **Fig. 1**.

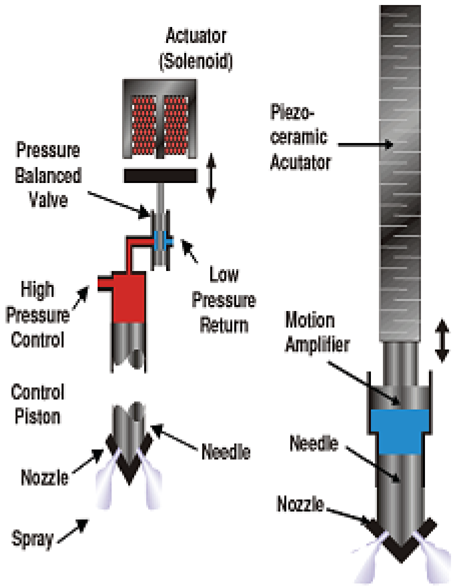


**Figure 1** Delphi's DFI3 Piezo Injector [10]

This approach allows the injector to spray fuel into a diesel engine combustion chamber faster, with greater accuracy and at higher pressures upto 2,000 bar. This provides an advantage equivalent to raising the system pressure by about 200 bars. In other words, the 2000 bar of a Direct Acting Piezo injector has a performance comparable to a 2200 bar servo injector. This system has ensured around 30% fewer $NO_x$ emissions, 55-60% lower HC, 25-40% lower CO, ~8% more fuel efficiency and approximately 10% more torque and power.

### *3.2 Cylinder Deactivation*

By deactivating half of the number of cylinders in a multi-cylinder engine under varied demands, the other cylinders would operate at twice the normal load. This reduces overall pumping loss and improves fuel efficiency. This technique has proven successful for Mitsubishi 4 cylinder engine and Mercedes V8 and V12 engines. It is also known commercially as Active Fuel Management (AFM) or Multiple Displacement System (MDS) and many other names by different manufacturers.

General Motors was the first automobile company to introduce the concept of Cylinder Deactivation in its 1981 model of Cadillac. In that a microprocessor determined which cylinders could be deactivated with at a given moment. Then, the microprocessor signaled a solenoid-actuated blocker plate, which shifted position to permit each unwanted cylinder's valve rocker arms to pivot at a different point than usual. Therefore, rather than operate normally, certain cylinders' intake and exhaust valves would remain closed. Valve lifters and their related pushrods moved up and down within the engine as usual, but those unneeded valve pairs remained idle. But in practice, some problems developed in this system, many of which were related to the somewhat primitive fuel-injection system. Rather than cut off fuel to the unused cylinders, the engine's injectors continued to keep them supplied, causing gasoline to accumulate.

More than two decades after the V8-6-4 misfortune, GM was back with a far more sophisticated and dependable form of cylinder deactivation. First installed on the 2005 Chevrolet Trail Blazer and GMC Envoy SUV with a 5.3 liter V-8 engine, the Displacement on Demand (DoD) system could cut off half the cylinders when the vehicle was under light load conditions and restore them when the driver pushed on the gas pedal to accelerate or the need for additional power was detected. Special collapsible valve lifters installed in four specific cylinders assisted in this. These lifters had a spring-loaded locking pin actuated by oil pressure. Solenoids could increase the oil pressure, dislodging the pins for the affected valves and causing the top of each lifter to collapse-no longer contacting its pushrod. When more power was needed, oil pressure was removed and the lifters locked back into their full-length configuration. GM claimed an 8% boost in fuel economy for the DoD equipped SUVs. Displacement on Demand soon went into selected GM V-6 engines, in such models as the Pontiac G6.

Like other variable-displacement engines, Chrysler's Multi-Displacement System (MDS) was designed for the car and other heavy vehicles that started off with all 8 cylinders functioning. Above 18 mph or so, if the engine was cruising lightly at moderate rpm, half the cylinders could shut down until they were needed again to accelerate or whenever the load increased. Special lifters were forced by oil pressure to collapse. As a result, the engine's camshaft was disengaged from the pushrods that acted upon selected valves in this overhead-valve design. Switching between 8- and 4-cylinder operations could take place in 40 milliseconds, according to Chrysler, and no fuel entered the unused cylinders. Chrysler claimed a fuel economy improvement of 10% to 20% for this Hemi V-8 engine.

The latest and the most efficient application of cylinder deactivation is the Cylinder Deactivation System (CDS) incorporated in the V-12 engine of Lamborghini Aventador LP 700-4. Under low load and at speeds of less than 135 kmph; the CDS deactivates one cylinder bank, allowing the power unit to run as an inline six. But with just the slightest movement of the gas pedal, the extreme performance of the V12 engine with its 700 HP is back online. The CDS system works incredibly quickly, is barely detectable to the driver and has absolutely no negative impact on the amazing driving experience. The average fuel consumption drops by 7% to 16 liters per 100 km when in CDS mode. At highway speeds of around 130 kmph the reduction in consumption and emissions is as much as 20%. In total the $CO_2$ emissions of the Aventador have been reduced from 398 g/km to 370 g/km.

### *3.3 Reducing Engine Friction*

The reduction of engine friction is an on-going effort. The level of friction in an engine is measured in normalized terms as Friction Mean Effective Pressure (FMEP). FMEP may constitute about 18% to 20% of the brake mean effective pressure at wide-open throttle. Major components that contribute to friction are (in order of importance); pistons and piston rings, valve train components, crankshaft and crankshaft seals, and the oil pump [3]. Considerable work has been done into the design of these components to reduce friction and significant friction reduction technology is usually incorporated into modern engine designs. Various technologies are available to reduce engine friction. Major among these are:

- Low mass pistons and valves
- Reduced piston ring and valve spring tension
- Surface coatings on the cylinder wall and piston skirt
- Improved bore/piston diameter tolerances in manufacturing
- Higher efficiency gear drive oil pumps.

Friction losses may be minimized by the use of advanced components (ceramics, rollers) and lubricants reduced/enhanced throttling (electronic throttle control) and load control by valve timing [3].

Federal-Mogul Corporation; a leading global supplier of power train components and other advanced vehicle solutions, has experimented widely on the engine components for the reduction of friction losses [11]. According to their report; the piston and piston rings account for approximately 40% of the total friction losses. By coating the piston skirt and improving its ovality, Federal-Mogul has achieved 35% reduction in friction losses. This has lead to 2.5 g/km reduction in $CO_2$ emissions of a diesel vehicle with 150g/km $CO_2$. With reference to the friction losses associated with cylinder bore distortion; Federal-Mogul has highlighted the optimization of cylinder head gasket design, reduction of mass in cylinder head and cylinder block, reduction in piston ring tension and use of lower friction dynamic sealing component. These changes tend to reduce $CO_2$ emissions by 2 g/km from a diesel vehicle with 170 g/km $CO_2$.

### *3.4 Homogeneous Charge Compression Ignition (HCCI)*

In HCCI diesel engines the fuel air mixture is ignited simultaneously throughout the cylinder rather than only compression ignition like in conventional diesel engine. This results in high peak pressure but relatively lower peak temperature. The low temperature reduces NOx emission and high pressure allows us to lean air-fuel mixture to obtain high fuel efficiency **(Fig. 2)**. The amount of CO and UBHC remains quit same and can be tackled by existing after-treatment devices. The $CO_2$ emission from HCCI engine is about 18% to 21% lower than conventional diesel engine. HCCI engine are currently available only as prototype at general Motors, Volkswagen, Honda and Mercedes-Benz. It is estimated that HCCI will be employed commercially until 2015 [12].

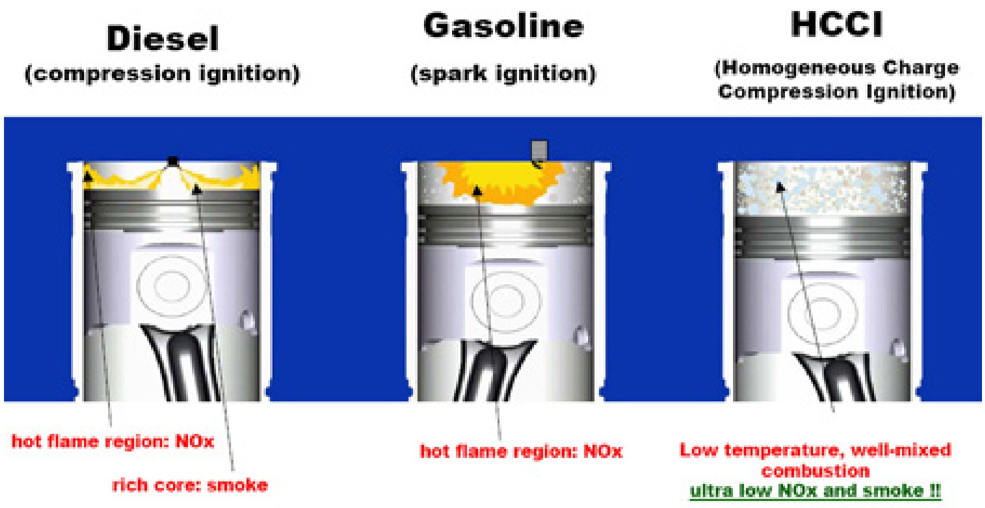


**Figure 2** Working Principle of HCCI Engine [13]

During HCCI operation, engine control is very difficult as the ignition timing is not directly under control. This is different to conventional gasoline or diesel engines where the ignition is controlled directly by sparks or injectors. In order to maintain good operation in HCCI mode, very fast and precise control is required, making advanced engine control units, sensors and actuators necessary. As a consequence, further development is needed to ensure robust operation of HCCI in all conditions before it becomes available to consumers [4,14].

### *3.5 Improving Powertrain Efficiency*

The key challenge with the development of new powertrains is to provide specific solutions for different markets and vehicle categories within cost effective modular powertrain systems. For most competitive powertrain solutions, the IC engine must not be developed separately, but in close interaction with the other powertrain elements including the control strategies. Both the trend towards downsizing and new transmission concepts enhancing IC engine operation in the fuel efficient high load regime will have significant impact on the combustion systems. With best matching of engine, transmission and vehicle characteristics, attractive $CO_2$ emissions can be achieved within moderate cost [15].

While some of the improvements to reduce $CO_2$ can be achieved by reducing weight, rolling resistance and improving aerodynamic properties; powertrain has been identified as the system that can provide the greatest improvement with a 10% fuel consumption reduction and from 10 to 15g/km of $CO_2$ reduction [16].

Valeo Corporation; a French automotive components manufacturer, has pioneered in the production of dual clutch in order to improve the powertrain efficiency. As seen from **Fig. 3**; the Valeo Dry Double Clutch has two clutches and three clutch plates whose rotation is linked to the engine's flywheel. The clutch on the plate's motor side engages both when starting and when shifting to odd gears. The clutch on the plate's gearbox side engages only when shifting to even gears and reverse. Each of the two parts alternately transmits torque to one of the two axial transmission input shafts.

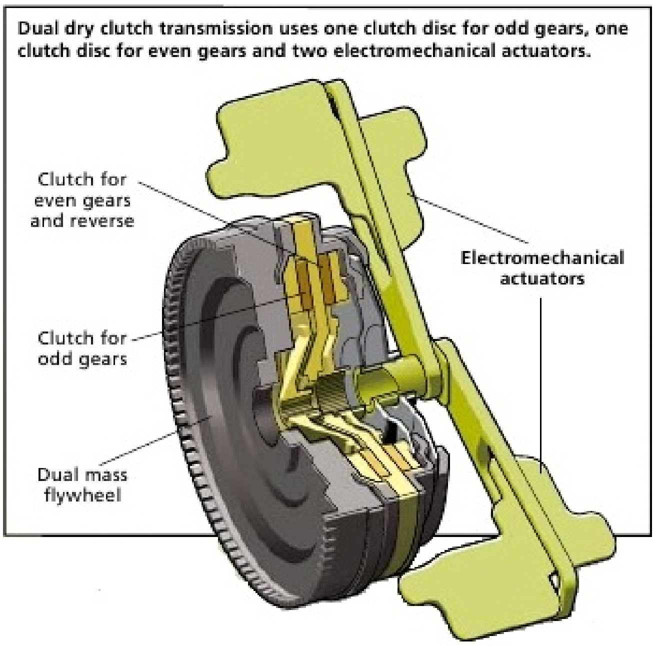


**Figure 3** Valeo's Dry Double Clutch [17]

The Valeo dual clutch model is associated with energy-efficient electro-mechanical actuators, resulting in a reduction of fuel consumption and $CO_2$ emissions of 6% to 10% compared to an automatic transmission with the same number of gears. The electro-mechanical actuators also enable the sliding of the two clutch plates to be controlled in a precise, synchronized manner. They include an assisting spring which reduces electrical consumption. The smooth acceleration when changing gears, without torque interruption, offers improved comfort and performance compared to an automated manual transmission. In addition, when stationary, the clutches are disengaged for enhanced safety. Valeo's Dry Double Clutch is extremely compact, and can be easily fitted to a large number of transmissions.

***3.6 Exhaust Heat Recovery***

Exhaust heat recovery is very old technique used to improve engine performance. It uses the recovered heat for either warming up of the engine or for electric generation to be utilized in the vehicle itself. This reduces the friction losses and amount of fuel needed for cold starting; thereby improving fuel efficiency. Despite improvements in engine efficiency with technologies such as direct fuel injection, variable valve timing, exhaust-driven turbochargers, brake energy regeneration and Auto Start/Stop function; about 60% of the generated energy is still lost, half of it being exhaust heat with the remaining half as heat absorbed by the engine cooling system.

BMW Group is the one involved in several projects, each with different approaches to recovering dissipated heat energy. The company's most promising projects are the Thermo Electric generator (TEG) and the Turbosteamer.

The TEG works on the principle that there is great potential for considerable fuel savings if the electrical energy required by all of the systems in an automobile can be produced using waste heat rather than relying solely on the vehicle's generator. The engineers of the BMW Group basically refined a technology that has been used to power space probes for more than four decades by NASA. The principle behind this technology is known as the Seebeck Effect i.e. that an electrical voltage can be generated between two thermoelectric semiconductors if they have different temperatures. Since the percentage degree of efficiency of TEGs was rather low, this technology was considered unsuited for automotive applications. However, in recent years progress in the area of material research has led to discoveries that have improved the performance of TEG modules.

The first step taken by engineers was to integrate a thermoelectric generator in the exhaust system to generate electrical current. The first such system was shown to the public in 2008 and delivered a maximum of 200 watts, which was relatively low in terms of power efficiency. But the use of new materials and improvements in the weight and size of the TEGs led to rapid new developments, so that the latest generation of TEG installed in the exhaust is capable of generating 600 watts of electrical power.

Then in 2009, the BMW Group unveiled an alternative development in this project. Rather than installing the TEG as a separate module in the exhaust system underneath the vehicle, engineers decided to integrate the TEG in the radiator of the exhaust gas recirculation system. In this configuration, customer testing has shown that 250 watts can be generated while $CO_2$ emissions and fuel consumption are reduced by 2% at the same time.

This energy recovery system also offers some interesting added benefits, such as supplying the engine or passenger compartment heating with additional warmth during cold starts. Researchers forecast that the TEG will lead to fuel consumption savings of up to 5% under real everyday driving conditions in the future.

On the other hand; the Turbosteamer is based on the principle of a waste heat recovery process already practiced on a large scale in modern power generation plants. Large gas and steam power stations combine the principles of a gas turbine and a steam circuit to achieve a significantly higher level of efficiency. The gas turbine process is the first phase of the energy conversion and serves as the source of heat for the downstream steam cycle in the second phase.

The BMW turbosteamer is based on this two-stage stationary power generation method, but reduced in scale and design to form a component that can be used in modern automobile engines. Researchers proved the feasibility of this technology in December 2005 with the unveiling of the first-generation turbosteamer, which was based on a maximalist approach: they designed a dual-cycle system. The primary element was a high-temperature circuit that employed a heat exchanger to recover energy from the engine exhaust gases. This was connected with a secondary circuit that collected heat from the engine cooling system and combined this heat with the high-temperature heat from the primary circuit to create lower temperature heat. When this design was laboratory tested on the four-cylinder gasoline engines of BMW itself, the dual system boosted the performance of these engines by 15%.

In order to further develop the system for use in series production; BMW focused on reducing the size of the components and making the system simpler to improve its dynamics and achieve an optimized cost-benefit ratio. Thus, researchers focused on designing a component having only one high-temperature circuit wherein a heat exchanger recovers heat from the engine exhaust and this energy is used to heat a fluid which is under high pressure. This heated fluid then turns into steam, which powers an expansion turbine that generates electrical energy from the recovered heat.

For the latest generation of the Turbosteamer, engineers developed an innovative expansion turbine based on the principle of the impulse turbine, which offered many advantages in terms of cost, weight and size when compared to earlier concepts. Under these conditions the developers are sure that the average driver will be able to reduce fuel consumption by up to 10% on long-distance journeys.

## 4. CONCLUSION AND FUTURE SCOPE

In all developing countries, economic growth has triggered an increase in the number and use of motor vehicles. Without timely and effective measures to lessen the adverse impacts of motor vehicle use, the living environment in the cities of the developing countries will continue to deteriorate and become increasingly unbearable. A single technological solution to further reducing $CO_2$ emissions from the vehicles does not exist. Most likely, the future will see a number of technological combinations entering the market. But for now in order to reduce $CO_2$ emissions; the I.C. engine should be explored further more for new combustion techniques such as HCCI, downsizing and reducing friction.

With continued research, gaps in our current knowledge will diminish permitting improvement in future predictions of vehicle emissions, its consequences and the role of technological improvements in emission control. Improvement in specific power and thermal efficiency will reduce $CO_2$ further. Innovations should focus on refining conventional engine technologies, improving aerodynamics of vehicles, reducing rolling resistance and decreasing the mass (weight) of cars.

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