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| Logo_MEC  **LECTURE HANDOUTS**  **Year/Sem : IV / VII**  **MECH** | **MUTHAYAMMAL ENGINEERING COLLEGE**  **(An Autonomous Institution)**  **(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)**  **Rasipuram - 637 408, Namakkal Dist., Tamil Nadu** | **L - 1** |

Course Name : Advanced IC Engine

**Unit : I – Spark Ignition Engines**

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| **Topic of Lecture:** Introduction |
| **Introduction :**  A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work. |
| **Prerequisite knowledge for Complete understanding and learning of Topic** Gear terminology   1. Classification of Engine 2. Working Principle of SI Engine |
| **Detailed content of the Lecture:**  A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work. It is classified into two types-   1. External combustion engine 2. Internal combustion engine   **External combustion engine:**  In this engine, the products of combustion of air and fuel transfer heat to a second fluid which is the working fluid of the cycle.  Examples:  \*In the steam engine or a steam turbine plant, the heat of combustion is employed to generate steam which is used in a piston engine (reciprocating type engine) or a turbine (rotary type engine) for useful work.  \*In a closed cycle gas turbine, the heat of combustion in an external furnace is transferred to gas, usually air which the working fluid of the cycle.  **Internal combustion engine:**  In this engine, the combustion of air and fuels take place inside the cylinder and are used as the direct motive force. It can be classified into the following types:   1. According to the basic engine design- (a) Reciprocating engine (Use of cylinder piston arrangement), (b) Rotary engine (Use of turbine) 2. According to the type of fuel used- (a) Petrol engine, (b) diesel engine, (c) gas engine (CNG, LPG), (d) Alcohol engine (ethanol, methanol etc) 3. According to the number of strokes per cycle- (a) Four stroke and (b) Two stroke engine 4. According to the method of igniting the fuel- (a) Spark ignition engine, (b) compression ignition engine and (c) hot spot ignition engine 5. According to the working cycle- (a) Otto cycle (constant volume cycle) engine, (b) diesel cycle (constant pressure cycle) engine, (c) dual combustion cycle (semi diesel cycle) engine.      1. According to the fuel supply and mixture preparation- (a) Carburetted type (fuel supplied through the carburettor), (b) Injection type (fuel injected into inlet ports or inlet manifold, fuel injected into the cylinder just before ignition). 2. According to the number of cylinder- (a) Single cylinder and (b) multi-cylinder engine 3. Method of cooling- water cooled or air cooled 4. Speed of the engine- Slow speed, medium speed and high speed engine 5. Cylinder arrangement-Vertical, horizontal, inline, V-type, radial, opposed cylinder or piston engines. 6. Valve or port design and location- Overhead (I head), side valve (L head); in two stroke engines: cross scavenging, loop scavenging, uniflow scavenging. 7. Method governing- Hit and miss governed engines, quantitatively governed engines and qualitatively governed engine   14. Application- Automotive engines for land transport, marine engines for propulsion of ships, aircraft engines for aircraft propulsion, industrial engines, prime movers for electrical generators. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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Course Name : Advanced IC Engine

**Unit : I – Spark Ignition Engines**

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| **Topic of Lecture:** Mixture requirements |
| **Introduction :**  A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work. |
| **Prerequisite knowledge for Complete understanding and learning of Topic** Gear terminology   1. Classification of Engine 2. Working Principle of SI Engine |
| **Detailed content of the Lecture:**  **Mixture requirements for steady state operation:**  Three main areas of steady state operation of automotive engine which require different air fuel ratio are discussed below,  12.png    ***(a) Idling and low load:***   * From no load to about 20% of rated power * No load running mode is called idling condition * Very low suction pressure give rise to back flow of exhaust gases and air leakage Increases the amount of residual gases and hence increase the dilution effects * Rich mixture i.e. F/A ratio 0.08 or A/F ratio 12.5:1 provide smooth operation of the engine  1. ***Normal power range or cruising range:***  * From about 20% to 75% of rated power * Dilution by residual gases as well as leakage decreases, hence fuel economy is important Consideration in this case * Maximum fuel economy occurs at A/F ratio of 17:1 to 16.7:1 * Mixture ratios for best economy are very near to the mixture ratios for minimum emissions  1. ***Maximum power range:***  * From about 75% to 100% of rated power * Mixture requirements for the maximum power is a rich mixture, of A/F about 14:1 or F/A 0.07. * Rich mixture also prevents the overheating of exhaust valve at high load and inhibits detonation * In multi-cylinder engine the A/F ratio are slightly lower   **Mixture requirements for transient operation:**   * Carburetor has to provide mixture for transient conditions under which speed, load, temperature, or pressure change rapidly * Evaporation of fuel may be incomplete in the transient condition, quantity of fuel may be increasing and decreasing   ***(a) Starting and warm up requirements:***   * Engine speed and temperature are low during the starting of the engine from cold * During starting very rich mixture about 5 to 10 times the normal amount of petrol is sulpplied i.e. F/A ratio 0.3 to 0.7 or A/F ratio 3:1 to 1.5:1 * Mixture ratio is progressively made leaner to avoid too rich evaporated fuel-air ratio during warm up condition * Too high volatility may form vapour bubbles in the carburettor and fuel lines particularly when engine temperatures are high * Too low volatility may cause the petrol to condense on the cylinder walls, diluting and removing the lubricating oil film   ***(b) Acceleration requirements:***   * Acceleration refer to an increase in engine speed resulting from the opening of the throttle acceleration pump is used to provide additional fuel |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=ngXfCeGeeBg |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 357- 366. |

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Course Name : Advanced IC Engine

**Unit : I – Spark Ignition Engines**

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| **Topic of Lecture:** Fuel injection systems |
| **Introduction :**  A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work. |
| **Prerequisite knowledge for Complete understanding and learning of Topic** Gear terminology   1. Classification of Engine 2. Working Principle of SI Engine   **Detailed content of the Lecture:**  **Petrol injection:**   * To avoid above problem of modern carburettor, petrol injection is used like in diesel engine -petrol injected during the suction stroke in the intake manifold at low pressure * Injection timing is not much critical as like in diesel engine Continuous injection and timed injection methods are used   **1.12.1. Continuous injection:**   * The fuel is sprayed at low pressure continuously into the air supply -amount of fuel is governed by air throttle opening * In supercharged engine, fuel injected in the form of multiple spray into the suction side of the centrifugal compressor * It provide efficient atomisation of fuel and uniform mixture strength to all cylinder. higher volumetric efficiency.one fuel injection pump and one injector   **1.12.2. Timed injection system:**   * It is similar to high speed diesel engine * The components are fuel feed or lift pump, fuel pump and distributor unit, fuel injection nozzles and mixture controls * mixture controls are automatic for all engine operating conditions   ***(i) Multiple plunger jerk pump system:***   * Pump with separate plunger and high injection nozzle pressure for each cylinder pressure is between 100 to 300 bar * measured quantity of fuel for definite time and over definite period is delivered   ***(ii) Low pressure single pump and distributor system:***   * Single plunger or gear pump supply fuel at low pressure to a rotating distributor -pressure about 3.5 to 7 bar  1. **Lucas petrol injection system**  * Firstly used in racing car * Single distributor system with novel metering device Line pressure is maintained at 7 bar * Metering distributor and control unit distributes the required amount of fuel at correct time and interval * Has shuttle arrangements for metering unit * In aircraft engine two injectors and spark plug provided for direct injection of fuel in combustion chamber   **(B)Electronic fuel injection**    **Fuel delivery system**   * Electrically driven fuel pump draws fuel from tanks to distribute Fuel and manifold pressure kept constant by pressure regulator   **Air induction system:**   * Air flow meter generate voltage signal according to air flow * Cold start magnetic injection valve give good fuel atomisation and also provide extra fuel during warm up condition   **Electronic control unit (ECU):**   * Sensors for manifold pressure, engine speed and temperature at intake manifold -sensor measures operating data from locations and transmitted electrically to ECU   **Injection timing:**   * Injected twice for every revolution of crank shaft triggering of injectors   **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=qId3Th6\_a4U  **Important Books/Journals for further learning including the page nos.:** R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 391- 393. |

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Course Name : Advanced IC Engine

**Unit : I – Spark Ignition Engines**

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| **Topic of Lecture:** Mono point, Multipoint & Direct injection |
| **Introduction :**  Fuel injection is the introduction of [fuel](https://en.wikipedia.org/wiki/Fuel) in an [internal combustion engine](https://en.wikipedia.org/wiki/Internal_combustion_engine), most commonly [automotive engines](https://en.wikipedia.org/wiki/Automotive_engine), by the means of an [injector](https://en.wikipedia.org/wiki/Injector). |
| **Prerequisite knowledge for Complete understanding and learning of Topic** Gear terminology   1. Classification of Engine 2. Working Principle of SI Engine |
| **Detailed content of the Lecture:** Single-point injection  * Single-point injection uses one injector in a [throttle body](https://en.wikipedia.org/wiki/Throttle_body) mounted similarly to a [carburetor](https://en.wikipedia.org/wiki/Carburetor) on an [intake manifold](https://en.wikipedia.org/wiki/Intake_manifold). As in a carbureted induction system, the fuel is mixed with the air before the inlet of the intake manifold. * Single-point injection was a relatively low-cost way for automakers to reduce [exhaust emissions](https://en.wikipedia.org/wiki/Vehicle_emissions_control) to comply with tightening regulations while providing better "driveability" (easy starting, smooth running, freedom from hesitation) than could be obtained with a carburetor. Many of the carburetor's supporting components - such as the air cleaner, intake manifold, and fuel line routing - could be used with few or no changes. This postponed the redesign and tooling costs of these components.  Multi-point injection  * Multi-point injection injects fuel into the intake ports just upstream of each cylinder's intake valve, rather than at a central point within an intake manifold * Typically, multi-point injected systems use multiple fuel injectors, but some systems such as the GM central port injection use tubes with poppet valves fed by a central injector instead of multiple injectors.  Injection schemes  * Manifold injected engines can use several injection schemes: continuous and intermittent (simultaneous, batched, sequential, and cylinder-individual). * In a continuous injection system, fuel flows at all times from the fuel injectors, but at a variable flow rate. The most common automotive continuous injection system is the Bosch [K-Jetronic](https://en.wikipedia.org/wiki/Jetronic#K), introduced in 1974, and used until the mid-1990s by various car manufacturers. * Intermittent injection systems can be sequential, in which injection is timed to coincide with each cylinder's intake stroke; batched, in which fuel is injected to the cylinders in groups, without precise synchronization to any particular cylinder's intake stroke; simultaneous, in which fuel is injected at the same time to all the cylinders; or cylinder-individual, in which the engine control unit can adjust the injection for each cylinder individually.  Internal mixture formation In an engine with an internal mixture formation system, air and fuel are mixed only inside the combustion chamber. Therefore, only air is sucked into the engine during the intake stroke. The injection scheme is always intermittent (either sequential or cylinder-individual). There are two different types of internal mixture formation systems: indirect injection, and direct injection. Indirect injection [https://upload.wikimedia.org/wikipedia/commons/thumb/8/87/Acro-Luftspeicher.jpg/220px-Acro-Luftspeicher.jpg](https://en.wikipedia.org/wiki/File:Acro-Luftspeicher.jpg)   * [Air-cell chamber injection](https://en.wikipedia.org/wiki/Indirect_injection#Air_cell_chamber) – the fuel injector (on the right) injects the fuel through the main combustion chamber into the air-cell chamber on the left. This is a special type of indirect injection and was very common in early American diesel engines. * Indirect injection as an internal mixture formation system (typical of Akroyd and Diesel engines); for the external mixture formation system that is sometimes called indirect injection (typical of Otto and Wankel engines), * In an indirect injected engine, there are two combustion chambers: a main combustion chamber, and a pre-chamber, that is connected to the main one. The fuel is injected only into the pre-chamber (where it begins to combust), and not directly into the main combustion chamber. Therefore, this principle is called indirect injection. There exist several slightly different indirect injection systems that have similar characteristics. All [Akroyd](https://en.wikipedia.org/wiki/Hot-bulb_engine) (hot-bulb) engines, and some [Diesel](https://en.wikipedia.org/wiki/Diesel_engine) (compression ignition) engines use indirect injection.  Direct injection  * Direct injection means that an engine only has a single combustion chamber, and that the fuel is injected directly into this chamber. This can be done either with a blast of air ([air-blast injection](https://en.wikipedia.org/wiki/Air-blast_injection)), or hydraulically. The latter method is far more common in automotive engines. * Typically, hydraulic direct injection systems spray the fuel into the air inside the cylinder or combustion chamber, but some systems spray the fuel against the combustion chamber walls ([M-System](https://en.wikipedia.org/wiki/M-System)). Hydraulic direct injection can be achieved with a conventional, helix-controlled injection pump, [unit injectors](https://en.wikipedia.org/wiki/Unit_injector), or a sophisticated [common-rail injection](https://en.wikipedia.org/wiki/Common-rail_injection) system. * The latter is the most common system in modern automotive engines. Direct injection is well-suited for a huge variety of fuels, including petrol (see [petrol direct injection](https://en.wikipedia.org/wiki/Petrol_direct_injection)), and [diesel fuel](https://en.wikipedia.org/wiki/Diesel_fuel). * In a [common rail](https://en.wikipedia.org/wiki/Common_rail) system, the fuel from the fuel tank is supplied to the common header (called the accumulator). This fuel is then sent through tubing to the injectors, which inject it into the combustion chamber. The header has a high pressure relief valve to maintain the pressure in the header and return the excess fuel to the fuel tank. * The fuel is sprayed with the help of a nozzle that is opened and closed with a needle valve, operated with a solenoid. When the solenoid is not activated, the spring forces the needle valve into the nozzle passage and prevents the injection of fuel into the cylinder. The solenoid lifts the needle valve from the valve seat, and fuel under pressure is sent in the engine cylinder. * Third-generation common rail diesels use [piezoelectric](https://en.wikipedia.org/wiki/Piezoelectric) injectors for increased precision, with fuel pressures up to 300 [MPa](https://en.wikipedia.org/wiki/Pascal_(unit)) or 44,000 [lbf/in2](https://en.wikipedia.org/wiki/Pounds-force_per_square_inch) |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=GlM9MHOX6iY |
| **Important Books/Journals for further learning including the page nos.:** R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 425- 428. |

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Course Name : Advanced IC Engine

**Unit : I – Spark Ignition Engines**

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| **Topic of Lecture:** Stages of combustion |
| **Introduction :**  Combustion may be defined as a relatively rapid chemical combination of hydrogen and carbon in fuel with oxygen in air resulting in liberation of energy in the form of heat |
| **Prerequisite knowledge for Complete understanding and learning of Topic** Gear terminology   1. Classification of Engine 2. Working Principle of SI Engine |
| **Detailed content of the Lecture:**  Combustion may be defined as a relatively rapid chemical combination of hydrogen and carbon in fuel with oxygen in air resulting in liberation of energy in the form of heat. Following conditions are necessary for combustion to take place: 1. The presence of combustible mixture 2. Some means to initiate mixture 3. Stabilization and propagation of flame in Combustion Chamber In S I Engines, carburetor supplies a combustible mixture of petrol and air and spark plug initiates combustion  **Ignition Limits**  Ignition of charge is only possible within certain limits of fuel-air ratio. Ignition limits correspond approximately to those mixture ratios, at lean and rich ends of scale, where heat released by spark is no longer sufficient to initiate combustion in neighboring unburnt mixture. For hydrocarbons fuel the stoichiometric fuel air ratio is 1:15 and hence the fuel air ratio must be about 1:30 and 1:7.  **Theories of Combustion in SI Engine**  Combustion in SI engine may roughly is divided into two general types: Normal and Abnormal (knock free or knocking). Theoretical diagram of pressure crank angle diagram is shown in figure below. (a → b) is compression process, (b → c) is combustion process and (c → → d) is an expansion process. In an ideal cycle it can be seen from the diagram, the entire pressure rise during combustion takes place at constant volume i.e., at TDC. However, in actual cycle this does not happen.  12.png  **Richard Theory of Combustion**:  Sir Ricardo, known as father of engine research describes the combustion process can be imagined as if it is developing in two stages: 1. Growth and development of a self-propagating nucleus flame. (Ignition lag) 2. Spread of flame through the combustion chamber |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=Y8l6AEquy94 |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 226- 234. |

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Course Name : Advanced IC Engine

**Unit : I – Spark Ignition Engines**

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| **Topic of Lecture:** Normal and Abnormal combustion |
| **Introduction :**  Combustion may be defined as a relatively rapid chemical combination of hydrogen and carbon in fuel with oxygen in air resulting in liberation of energy in the form of heat. |
| **Prerequisite knowledge for Complete understanding and learning of Topic** Gear terminology   1. Classification of Engine 2. Working Principle of SI Engine |
| **Detailed content of the Lecture:**  **Normal combustion**   * Spark-ignited  flame  moves  steadily  across  the  combustion  chamber  until  the  charge   is  fully  consumed.   * A  combustion  process  which  is  initiated  solely  by  a  timed  spark   and  in  which  the  flame  front  moves  completely  across  the  combustion  chamber  in  a  uniform  manner  at  a  normal  velocity.  **Three Stage of Combustion:**   * According to Ricardo, There are three stages of combustion in SI Engine as shown * Ignition lag stage * Flame propagation stage * After burning stage  1. **Ignition lag stage**:  * There is a certain time interval between instant of spark and instant where there is a noticeable rise in pressure due to combustion. This time lag is called IGNITION LAG. Ignition lag is the time interval in the process of chemical reaction during which molecules get heated up to self ignition temperature , get ignited and produce a self propagating nucleus of flame. The ignition lag is generally expressed in terms of crank angle ( 1θ ). * The period of ignition lag is shown by path (a-b). Ignition lag is very small and lies between 0.00015 to 0.0002 seconds. An ignition lag of 0.002 seconds corresponds to 35 deg crank rotation when the engine is running at 3000 RPM. Angle of advance increase with the speed. This is a chemical process depending upon the nature of fuel, temperature and pressure, proportions of exhaust gas and rate of oxidation or burning. 125  1. **Flame propagation stage:**  * Once the flame is formed at “b”, it should be self sustained and must be able to propagate through the mixture. This is possible when the rate of heat generation by burning is greater than heat lost by flame to surrounding. After the point “b”, the flame propagation is abnormally low at the beginning as heat lost is more than heat generated. Therefore pressure rise is also slow as mass of mixture burned is small. * Therefore, it is necessary to provide angle of advance (30-35) degrees, if the peak pressure to be attained (5-10) degrees after TDC. The time required for crank to rotate through an angle (θ2) is known as combustion period during which propagation of flame takes place.  1. **After burning:**   Combustion will not stop at point “c” but continue after attaining peak pressure and this combustion is known as after burning. This generally happens when the rich mixture is supplied to engine  **Abnormal combustion**   * Fuel  composition,  engine  design  and  operating  parameters,  combustion  chamber   deposits  may  prevent  occurring  of  the  normal  combustion  process.A  combustion  process  in  which  a  flame  front  may  be  started  by  hot  combustion-chamber  surfaces  either  prior  to  or  after  spark  ignition,  or  a  process  in  which  some  part  or  all  of  the  charge  may  be  consumed  at  extremely  high  rates  There  are  two  types  of  abnormal  combustion:   * Knock * Surface  ignition |
| **Video Content / Details of website for further learning (if any): H**ttps://www.youtube.com/watch?v=Vtvy4NODK08 |
| **Important Books/Journals for further learning including the page nos.:** R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 201- 208. |

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Course Name : Advanced IC Engine

**Unit : I – Spark Ignition Engines**

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| **Topic of Lecture:** Knock |
| **Introduction :**   * Knock  is  the  auto  ignition  of  the  portion  of  fuel,  air  and  residual  gas  mixture   ahead  of  the  advancing  flame  that  produces  a  noise. |
| **Prerequisite knowledge for Complete understanding and learning of Topic** Gear terminology   1. Classification of Engine 2. Working Principle of SI Engine |
| **Detailed content of the Lecture:**  **PHENOMENON OF KNOCKING IN SI ENGINE:**   * Knocking is due to auto ignition of end portion of unburned charge in combustion chamber. As the normal flame proceeds across the chamber, pressure and temperature of unburned charge increase due to compression by burned portion of charge. * This unburned compressed charge may auto ignite under certain temperature condition and release the energy at a very rapid rate compared to normal combustion process in cylinder. * This rapid release of energy during auto ignition causes a high-pressure differential in combustion chamber and a high-pressure wave is released from auto ignition region. * The motion of high-pressure compression waves inside the cylinder causes vibration of engine parts and pinging noise and it is known as knocking or detonation. This pressure frequency or vibration frequency in SI engine can be up to 5000 Cycles per second. * Denotation is undesirable as it affects the engine performance and life, as it abruptly increases sudden large amount of heat energy. It also put a limit on compression ratio at which engine can be operated which directly affects the engine efficiency and output.   **34.png**  **Auto ignition**  A mixture of fuel and air can react spontaneously and produce heat by chemical reaction in the absence of flame to initiate the combustion or self-ignition. This type of self-ignition in the absence of flame is known as Auto-Ignition. The temperature at which the self-ignition takes place is known as self-igniting temperature. The pressure and temperature abruptly increase due to auto-ignition because of sudden release of chemical energy. This auto-ignition leads to abnormal combustion known as detonation which is undesirable because its bad effect on the engine performance and life as it abruptly increases sudden large amount of heat energy. In addition to this knocking puts a limit on the compression ratio at which an engine can be operated which directly affects the engine efficiency and output.  **Pre-ignition**  Pre-ignition is the ignition of the homogeneous mixture of charge as it comes in contact with hot surfaces, in the absence of spark. Auto ignition may overheat the spark plug and exhaust valve and it remains so hot that its temperature is sufficient to ignite the charge in next cycle during the compression stroke before spark occurs and this causes the pre-ignition of the charge. Pre-ignition is initiated by some overheated projecting part such as the sparking plug electrodes, exhaust valve head, metal corners in the combustion chamber, carbon deposits or protruding cylinder head gasket rim etc. pre-ignition is also caused by persistent detonating pressure shockwaves scoring away the stagnant gases which normally protect the combustion chamber walls. The resulting increased heat flow through the walls, raises the surface temperature of any protruding poorly cooled part of the chamber, and this therefore provides a focal point for pre-ignition. |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=uWx1cXR7x\_M |
| **Important Books/Journals for further learning including the page nos.:** R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 208- 210. |

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Course Name : Advanced IC Engine

**Unit : I – Spark Ignition Engines**

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| **Topic of Lecture:** Factors affecting knock |
| **Introduction :**  A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work. |
| **Prerequisite knowledge for Complete understanding and learning of Topic** Gear terminology   1. Classification of Engine 2. Working Principle of SI Engine |
| **Detailed content of the Lecture:**  **Effects of Detonation**  The harmful effects of detonation are as follows:  **1. Noise and Roughness:** Knocking produces a loud pulsating noise and pressure waves. These waves which vibrates back and forth across the cylinder. The presence of vibratory motion causes crankshaft vibrations and the engine runs rough.  **2. Mechanical Damage:**  **(a)** High pressure waves generated during knocking can increase rate of wear of parts of combustion chamber. Sever erosion of piston crown( in a manner similar to that of 133 marine propeller blades by capitation), cylinder head and pitting of inlet and outlet valves may result in complete wreckage of the engine.  **(b)** Detonation is very dangerous in engines having high noise level. In small engines the knocking noise is easily detected and the corrective measures can be taken but in aero-engines it is difficult to detect knocking noise and hence corrective measures cannot be taken. Hence severe detonation may persist for a long time which may ultimately result in complete wreckage of the piston.  3. **Carbon deposits:**  Detonation results in increased carbon deposits.  4**. Increase in heat transfer:** Knocking is accompanied by an increase in the rate of heat transfer to the combustion chamber walls. The increase in heat transfer is due to two reasons: • The minor reason is that the maximum temperature in a detonating engine is about 150°C higher than in a non-detonating engine, due to rapid completion of combustion • The major reason for increased heat transfer is the scouring away of protective layer of inactive stagnant gas on the cylinder walls due to pressure waves. The inactive layer of gas normally reduces the heat transfer by protecting the combustion and piston crown from direct contact with flame.  **5. Decrease in power output and efficiency.**  Due to increase in the rate of a detonating engine decreases.  **6. Pre-ignition:**  The increase in the rate of heat transfer to the walls has yet another effect. It may cause local overheating, especially of the sparking plug, which may reach a temperature high enough to ignite the charge before the passage of spark, thus causing pre-ignition. An engine detonating for a long period would most probably lead to pre ignition and this is the real danger of detonation  **EFFECT OF ENGINE OPERATING VARIABLES ON THE ENGINE KNOCKING DETONATION**  The various engine variables affecting knocking can be classified as:   * Temperature factors * Density factors * Time factors * Composition factors  1. TEMPERATURE FACTORS Increasing the temperature of the unburned mixture increase the possibility of knock in the SI engine We shall now discuss the effect of following engine parameters on the temperature of the unburned mixture: 2. RAISING THE COMPRESSION RATIO: Increasing the compression ratio increases both the temperature and pressure (density of the unburned mixture). Increase in temperature reduces the delay period of the end gas, which in turn increases the tendency to knock. 3. SUPERCHARGING: It also increases both temperature and density, which⎬ increase the knocking tendency of engine 4. COOLANT TEMPERATURE: Delay period decreases with increase of coolant temperature , decreased delay period increase the tendency to knock 5. TEMPERATURE OF THE CYLINDER AND COMBUSTION CHAMBER⎬ WALLS: The temperature of the end gas depends on the design of combustion chamber. Sparking plug and exhaust valve are two hottest parts in the combustion chamber and uneven temperature leads to pre-ignition and hence the knocking. 6. DENSITY FACTORS increasing the density of un burnt mixture will increase the possibility of knock in the engine. The engine parameters that affect the density are as follows: Increased compression ratio increase the density increasing the load opens the throttle valve more and thus the density Supercharging increase the density of the mixture increasing the inlet pressure increases the overall pressure during the cycle. The high-pressure end gas decreases the delay period, which increase the tendency of knocking. 135 Advanced spark timing: quantity of fuel burnt per cycle before and after TDC, position depends on spark timing. The temperature of charge increases by increasing the spark advance and it increases with rate of burning and does not allow sufficient time to the end mixture to dissipate the heat and increase the knocking tendency. 7. TIME FACTORS Increasing the time of exposure of the unburned mixture to auto-ignition conditions increase the possibility of knock in SI engines. Flame travel distance: If the distance of flame travel is more, then possibility of knocking is also more. This problem can be solved by combustion chamber design, spark plug location and engine size. Compact combustion chamber will have better anti-knock characteristics, since the flame travel and combustion time will be shorter. Further, if the combustion chamber is highly turbulent, the combustion rate is high and consequently combustion time is further reduced; this further reduces the tendency to knock. Location of sparkplug: A spark plug that is centrally located in the combustion chamber has minimum tendency to knock, as the flame travel is minimum. The flame travel can be reduced by using two or more spark plugs. Location of exhaust valve: The exhaust valve should be located close to the spark⎬ plug so that it is not in the end gas region; otherwise, there will be a tendency to knock. Engine size: Large engines have a greater knocking tendency because flame requires a longer time to travel across the combustion chamber. In SI engine therefore , generally limited to 100mm Turbulence of mixture decreasing the turbulence of the mixture decreases the flame speed and hence increases the tendency to knock. Turbulence depends on the design of combustion chamber and one engine speed. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=w2TWPDdHYVo |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 209 - 210. |

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Course Name : Advanced IC Engine

**Unit : I – Spark Ignition Engines**

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| **Topic of Lecture:** Combustion chambers |
| **Introduction :**  A heat engine is a device which transforms the chemical energy of a fuel into thermal energy and uses this energy to produce mechanical work. |
| **Prerequisite knowledge for Complete understanding and learning of Topic** Gear terminology   1. Classification of Engine 2. Working Principle of SI Engine |
| **Detailed content of the Lecture:**  **Design of Combustion Chambers**  It involves   * Shape of combustion chamber * Location of spark plug. * Position of inlet and exhaust valves.   **COMBUSTION CHAMBERS DESIGN PRINCIPLES.**  **1. High volumetric efficiency –** largest possible inlet valve.  **2. To prevent knock**  \* Minimum flame travel.  \* Bore limited up to 100 mm in SIE. In CIE there is no limit.  \* Proper location of spark plug, valves, shape of CC.  **3. To reduce knock**  \* No hot surface in end gas portion.  \* Exhaust valve should not be in end gas region and it should be near spark plug.  **4. Small exhaust valve** – high lift can be used.  **5**. **Short combustion duration**   * High flame velocity. * Optimum turbulence. * Suitable position of inlet valve. * Streamlined passages.   **6. Shape of combustion chambers -**  largest mass of charge burns as soon as possible after ignition.  **7**. **To get high BTE**   * Minimum heat loss. * Minimum S/V ratio in combustion zone. * Hemispherical shape gives minimum S/V ratio and minimum air pollution.   **8. In end gas region S/V ratio should be large**  \* Good cooling in knock zone.  \* Quench space in end gas region.  **9. Cooled exhaust valve head**  \* Hottest region in combustion chambers.  \* High velocity water stream.  **DIFFERENT TYPES OF COMBUSTION CHAMBERS IN SI ENGINE**   * T-head  combustion  chamber * L-head  combustion  chamber * I-head  (or  overhead  valve)  combustion  chamber * F-head  combustion  chamber   It  may  be  noted  that  these  chambers  are  designed  to  obtain  the  objectives  namely:   * A  high  combustion  rate  at  the  start. * A  high  surface-to-volume  ratio  near  the  end  of  burning. * A  rather  centrally  located  spark  plug.   **i.T Head Type Combustion chambers**  This  was  first  introduced  by  Ford  Motor  Corporation  in  1908.  This  design  has  following  disadvantages.   * Requires  two  cam  shafts  (for  actuating  the  in-let  valve  and  exhaust  valve   separately)  by  two  cams  mounted  on  the  two  cam  shafts.   * Very  prone  to  detonation.  There  was  violent  detonation  even  at  a   compression  ratio  of  4.  This  is  because  the  average  octane  number  in  1908  was  about  40  -50.  **ii.L Head Type Combustion chambers**  It  is  a  modification  of  the  T-head  type  of  combustion  chamber.  It  provides  the  two  values  on  the  same  side  of  the  cylinder,  and  the  valves  are  operated  through  tappet  by  a  single  camshaft.  This  was  first  introduced  by  Ford  motor  in  1910-30  and  was  quite  popular  for  some  time.  This  design  has  an  advantage  both  from  manufacturing  and  maintenance  point  of  view.  **iii.Overhead valve or I head combustion chamber**  The  disappearance  of  the  side  valve  or  L-head  design  was  inevitable  at  high  compression  ratio  of  8:1  because  of  the  lack  of  space  in  the  combustion  chamber  to  accommodate  the  valves.  Diesel  engines,  with  high  compression  ratios,  invariably  used  overhead  valve  design.  Since  1950  or  so  mostly  overhead  valve  combustion  chambers  are  used.  This  type  of  combustion  chamber  has  both  the  inlet  valve  and  the  exhaust  valve  located  in  the  cylinder  head.  An  overhead  engine  is  superior  to  side  valve  engine  at  high  compression  ratios.  The  overhead  valve  engine  is  superior  to  side  valve  or  L  head  engine  at  high  compression  ratios,  for  the  following  reasons:  **Fig.. Different Combustion Chambers**  **F- Head combustion chamber**  In  such  a  combustion  chamber  one  valve  is  in  head  and  other  in  the  block.  This  design  is  a  compromise  between  L-head  and  I-head  combustion  chambers.  One  of  the  most  F  head  engines  (wedge  type)  is  the  one  used  by  the  Rover  Company  for  several  years.  Another  successful  design  of  this  type  of  chamber  is  that  used  in  Willeys  jeeps. |
| **Video Content / Details of website for further learning (if any):**  https://unacademy.com/lesson/ic-engine-combustion-chambers-in-c-i-engine/4JQYJCLJ |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 238 - 240. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : 2 - COMPRESSION IGNITION ENGINES**

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| **Topic of Lecture :** Diesel Fuel Injection Systems |
| **Introduction:**  The fuel is supplied through camshaft driven fuel pump. Fuel valve is also connected with high pressure airline to inject into cylinder. In multi-stage compressor which supply air at a pressure of about 60 to 70 bar |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Air injection system, Solid injection system***,*** Individual pump and injector or jerk pump system, Common rail system |
| **Detailed content of the Lecture:**  **DIESEL INJECTION SYSTEM:**  **Requirements of diesel injection system:**   * The fuel must introduce precisely defined period of cycle * Amounts metered very accurately * Rate of injection meet desired heat release pattern * Quantities of fuel meet changing speed and load condition * Good atomization of fuel * Good spray pattern for rapid mixing of fuel and air * No dribbling and after injection of fuel i.e. sharp injection * Injection timing suits the speed and load requirements * Distribution of fuel in multi * Cylinder should uniform * Weight, size and cost of fuel injection system should be less   **Types of diesel injection system:**  ***(a)* Air injection system:**  The fuel is supplied through camshaft driven fuel pump. Fuel valve is also connected with high pressure airline to inject into cylinder. In multi-stage compressor which supply air at a pressure of about 60 to 70 bar.    **Fig. Air injection system**  The blast air sweeps the fuel along with it. Good atomization results in good mixture formation and hence high mean effective pressure. Here heavy and viscous fuels are used. The fuel pump require small pressure. But it is complicated due to compressor arrangement and expensive.  ***(b) Solid injection system:***  The fuel is directly injected to combustion chamber without primary atomization termed as solid injection. It is also known as airless mechanical injection. 2 units are there, 1.Pressurise and 2.Atomising unit  3 different types which are described below,  (i) Individual pump and injector or jerk pump system:  The separate metering and compression pump is used for each cylinder. The reciprocating fuel pump is used to meter and set the injection pressure of the fuel. The heavy gear arrangements which gives jerking noise, hence name is given is jerk pump. The jerk pump is used for medium and high speed diesel engines  **Fig. . Individual pump and injector or jerk pump system**    **Fig. Unit injector**  (ii) Common rail system:  The high pressure fuel pump delivers fuel to an accumulator whose pressure is constant. Here plunger type of pump is used. The driving mechanism is not stressed with high pressure hence noise is reduced. The common rail or pipe is connected in between accumulator and distributing elements. It is separate metering and timing elements connected to automatic injector.  **Fig. Common rail system**  (iii) Distributor system:  The fuel pump pressurizes, meters and times the fuel supply to rotating distributor. The number of injection strokes per cycle for the pump equals to the number of cylinder. One metering element which ensure uniform distribution  **Fig.. Distributor system** |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=H28bE6gf5qQ |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 226-228. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : COMPRESSION IGNITION ENGINES**

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| **Topic of Lecture :** Stages of combustion |
| **Introduction:**  Stages of combustion consists of our stages likeIgnition delay period, Rapid or uncontrolled or pre-mixed combustion phase, Controlled or diffusion combustion phase, After burning or late combustion phase. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Ignition delay period, Rapid or uncontrolled or pre-mixed combustion phase, Controlled or diffusion combustion phase, After burning or late combustion phase |
| **Detailed content of the Lecture:**  **Stages of combustion in CI engine**  ***1*. Ignition delay period*:***  The period between the start of fuel injection into the combustion chamber and the start of combustion is termed as ignition delay period. The start of combustion is determined from the change in slope on p-θ diagram or from heat release analysis of the p-θ data, or from luminosity detector in experimental conditions. Start of injection can be determined by a needle-lift indicator to record the time when injector needle lifts off its seat. Start of combustion is more difficult to determine precisely. It is best identified from the change in slope of heat release rate, determined from cylinder pressure data. In DI engines ignition is well defined, in IDI engines ignition point is harder to identify  Both physical and chemical processes must take place before a significant fraction of the chemical energy of the injected liquid is released.  **Physical processes**are fuel spray atomization, evaporation and mixing of fuel vapour withcylinder air. Good atomization requires high fuel-injection pressure, small injector hole, optimum fuel viscosity, high cylinder pressure (large divergence angle).  Rate of vaporization of the fuel droplets depends on droplet diameter, velocity, fuel volatility, pressure and temperature of the air.    **Fig.7. Stages of combustion in CI engine**  **Chemical processes**similar to that described for auto ignition phenomenon in premixed fuel-air, only more complex since heterogeneous reactions (reactions occurring on the liquid fuel drop surface) also occur.  Chemical delay is more effective for the duration of the ignition delay period. Ignition delay period is in the range of  0.6 to 3 ms for low-compression ratio DI diesel engines,  0.4 to 1 ms for high-compression ratio, turbocharged DI diesel engines, 0.6 to 1.5 ms for IDI diesel engines  ***2. Rapid or uncontrolled or pre-mixed combustion phase:***  Combustion of the fuel which has mixed with air within flammability limits during ignition delay period occurs rapidly in a few crank angle degrees - high heat release characteristics in this phase. If the amount of fuel collected in the combustion chamber during the ignition delay is much - high heat release rate results in a rapid pressure rise which causes the diesel knock.  For fuels with low cetane number, with long ignition delay, ignition occurs late in the expansion stroke - incomplete combustion, reduced power output, poor fuel conversion efficiency. If the pressure gradient is in the range 0.4 - 0.5 MPa/oCA, engine operation is not smooth and diesels knock starts. This value should be in the range 0.2 to 0.3 MPa/oCA for smooth operation (max allowable value is 1.0 MPa/oCA) of the engine.  ***3. Controlled or diffusion combustion phase:***  Once the fuel and air which is pre-mixed during the ignition delay is consumed, the burning rate (heat release rate) is controlled by the rate at which mixture becomes available for burning. The rate of burning in this phase is mainly controlled by the mixing process of fuel vapour and air. Liquid fuel atomization, vaporization, pre flame chemical reactions also affect the rate of heat release.  Heat release rate sometimes reaches a second peak (which is lower in magnitude) and then decreases as the phase progresses. Generally it is desirable to have the combustion process near the TDC for low particulate (soot) emissions and high performance (and efficiency).  ***4. After burning or late combustion phase:***  Heat release rate continues at a lower rate into the expansion stroke -there are several reasons for this: a small fraction of the fuel may not yet burn, a fraction of the energy is present in soot and fuel-rich combustion products and can be released. The cylinder charge is non-uniform and mixing during this phase promotes more complete combustion and less dissociated product gases. Kinetics is slower. |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=H28bE6gf5qQ |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : COMPRESSION IGNITION ENGINES**

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| **Topic of Lecture :** Knocking |
| **Introduction:**  CI engine detonation occurs in the beginning of combustion. In CI engine the fuel and air are imperfectly mixed and hence the rate of pressure rise is normally cause audible knock. Rate of pressure rise may reach as high as 10 bar/ᵒCA-High engine vibration is the symptoms of knocking -no pre-ignition or premature ignition as like SI engine. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Factors affecting knocking in SI engines, Methods Of Controling Diesel Knock |
| **Detailed content of the Lecture:**  **knocking**  Knocking is due to auto ignition of end portion of unburned charge in combustion chamber. As the normal flame proceeds across the chamber, pressure and temperature of unburned charge increase due to compression by burned portion of charge. This unburned compressed charge may auto ignite under certain temperature condition and release the energy at a very rapid rate compared to normal combustion process in cylinder. This rapid release of energy during auto ignition causes a high pressure differential in combustion chamber and a high pressure wave is released from auto ignition region. The motion of high pressure compression waves inside the cylinder causes vibration of engine parts and pinging noise and it is known as knocking or detonation. This pressure frequency or vibration frequency in SI engine can be up to 5000 Cycles per second. Denotation is undesirable as it affects the engine performance and life, as it abruptly increases sudden large amount of heat energy. It also put a limit on compression ratio at which engine can be operated which directly affects the engine efficiency and output.    **Detonation in CI engine**  **Auto ignition**  A mixture of fuel and air can react spontaneously and produce heat by chemical reaction in the absence of flame to initiate the combustion or self-ignition. This type of self-ignition in the absence of flame is known as Auto-Ignition. The temperature at which the self-ignition takes place is known as self-igniting temperature. The pressure and temperature abruptly increase due to auto-ignition because of sudden release of chemical energy. This auto-ignition leads to abnormal combustion known as detonation which is undesirable because its bad effect on the engine performance and life as it abruptly increases sudden large amount of heat energy. In addition to this knocking puts a limit on the compression ratio at which an engine can be operated which directly affects the engine efficiency and output.  **Pre-ignition**  Pre-ignition is the ignition of the homogeneous mixture of charge as it comes in contact with hot surfaces, in the absence of spark. Auto ignition may overheat the spark plug and exhaust valve and it remains so hot that its temperature is sufficient to ignite the charge in next cycle during the compression stroke before spark occurs and this causes the pre-ignition of the charge. Pre-ignition is initiated by some overheated projecting part such as the sparking plug electrodes, exhaust valve head, metal corners in the combustion chamber, carbon deposits or protruding cylinder head gasket rim etc. pre-ignition is also caused by persistent detonating pressure shockwaves scoring away the stagnant gases which normally protect the combustion chamber walls. The resulting increased heat flow through the walls, raises the surface temperature of any protruding poorly cooled part of the chamber, and this therefore provides a focal point for pre-ignition.  ***Effects of Pre-ignition***  -It increase the tendency of denotation in the engine  -It increases heat transfer to cylinder walls because high temperature gas remains in contact with for a longer time  -Pre-ignition in a single cylinder will reduce the speed and power output  -Pre-ignition may cause seizer in the multi-cylinder engines, only if only cylinders have pre-ignition |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=H28bE6gf5qQ |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 228-230. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : COMPRESSION IGNITION ENGINES**

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| **Topic of Lecture :** Factors affecting knock |
| **Introduction:**  CI engine detonation occurs in the beginning of combustion. In CI engine the fuel and air are imperfectly mixed and hence the rate of pressure rise is normally cause audible knock. Rate of pressure rise may reach as high as 10 bar/ᵒCA-High engine vibration is the symptoms of knocking -no pre-ignition or premature ignition as like SI engine. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Factors affecting knocking in SI engines,  Methods Of Controling Diesel Knock |
| **Detailed content of the Lecture:**  **FACTORS AFFECTING KNOCKING IN SI ENGINES**  CI engine detonation occurs in the beginning of combustion. In CI engine the fuel and air are imperfectly mixed and hence the rate of pressure rise is normally cause audible knock. Rate of pressure rise may reach as high as 10 bar/ᵒCA-High engine vibration is the symptoms of knocking -no pre-ignition or premature ignition as like SI engine.  Knocking  is  violet  gas  vibration  and  audible  sound  produced  by  extreme  pressure is going through differentials  leading  to  the  very  rapid  rise  during  the  early  part  of  uncontrolled to the  second  phase  of  combustion.  In  C.I.  engines  the  injection  process  takes  place  over  a  definite  interval  of  time. Consequently,  as  the  first  few  droplets  injected  are  passing  through  the  ignition  lag  period,  additional  droplets  are  being  injected  into  the  chamber.  If  the  ignition  delay  is  longer,  the  actual  burning  of  the  first  few  droplets  is  delayed  and  a  greater  quantity  of  fuel  droplets  gets  accumulated  in  the  chamber.  When  the  actual  burning  commences,  the  additional  fuel  can  cause  too  rapid  a  rate  of  pressure  rise,  as  shown  on  pressure  crank  angle  diagram  above,  resulting  in  Jamming  of  forces  against  the  piston  (as  if  struck  by  a  hammer)  and  rough  engine  operation.  If  the  ignition  delay  is  quite  long,  so  much  fuel  can  accumulate  that  the  rate  of  pressure  rise  is  almost  instantaneous.  Such,  a  situation  produces  extreme  pressure  differentials  and  violent  gas  vibration  known  as  knocking  (diesel  knock),  and  is  evidenced  by  audible  knock.  The  phenomenon  is  similar  to  that  in  the  SI  engine.  However,  in  SI  Engine  knocking  occurs  near  the  end  of  combustion  whereas  in  CI  engine,  knocking  the  occurs  near  the  beginning  of  combustion.  **Delay period is directly related to Knocking in CI engine. An extensive delay period can**  **be due to following factors:**  A  low  compression  ratio  permitting  only  a  marginal  self-ignition  temperature  to  be  reached.   * A  low  combustion  pressure  due  to  worn  out  piston,  rings  and  bad  valves * Low  cetane  number  of  fuel * Poorly  atomized  fuel  spray  preventing  early  combustion * Coarse  droplet  formation  due  to  malfunctioning  of  injector  parts  like  spring * Low  intake  temperature  and  pressure  of  air   **METHODS OF CONTROLING DIESEL KNOCK**  We  have  discussed  the  factors  which  are  responsible  for  the  detonation  in  the  previous  sections.  If  these  factors  are  controlled,  then  the  detonation  can  be  avoided.  **Using a better fuel:**  Higher  Cetene number  fuel  has  lower  delay  period  and  reduces  knocking  tendency.  **Controlling the Rate of Fuel Supply:**  By  injecting  less  fuel  in  the  beginning  and  then  more  fuel  amount  in  the  combustion  chamber  detonation  can  be  controlled  to  a  certain  extent.  Cam  shape  of  suitable  profile  can  be  designed  for  this  purpose.  **Knock reducing fuel injector:**  This  type  of  injector  avoids  the  sudden  increase  in  pressure  inside  the  combustion  chamber  because  of  accumulated  fuel.  This  can  be  done  by  arranging  the  injector  so  that  only  small  amount  of  fuel  is  injected  first.  This  can  be  achieved  by  using  two  or  more  injectors  arranging  in  out  of  phase.  **By using Ignition accelerators:**  C  N  number  can  be  increased  by  adding  chemical  called  dopes.  The  two  chemical  dopes  are  used  are  ethyl-nitrate  and  amyle  ”nitrate  in  concentration  of  8.8  gm/Litre  and  7.7  gm/Litre.  But  these  two  increase  the  NOx  emissions. |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=H28bE6gf5qQ |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 236-238. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : COMPRESSION IGNITION ENGINES**

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| **Topic of Lecture :** Direct and Indirect injection systems |
| **Introduction:**  An  indirect  injection  diesel  engine  delivers  fuel  into  a  chamber  of  the  combustion  chamber,  called  a  pre-chamber  or  ante-chamber,  where  combustion  begins  and  then  spreads  into  the  main  combustion  chamber,  assisted  by  turbulence  created  in  the  chamber. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Direct and Indirect Injection Systems |
| **Detailed content of the Lecture:**  **DIRECT AND INDIRECT INJECTION SYSTEMS**  1.   Direct  injection  diesel  engines  have  injectors  mounted  at  the  top  of  the combustion  chamber.  2.  The  injectors  are  activated  using  one  of  two  methods  -  hydraulic  pressure from  the  fuel  pump,  or  an  electronic  signal  from  an  engine  controller.  3.  Hydraulic  pressure  activated  injectors  can  produce  harsh  engine  noise.  4.  Fuel  consumption  is  about  15  to  20%  lower  than  indirect  injection  diesels.  5.  The  extra  noise  is  generally  not  a  problem  for  industrial  uses  of  the  engine,  but  for  automotive  usage,  buyers  have  to  decide  whether  or  not  the  increased  fuel  efficiency  would  compensate  for  the  extra  noise.  6.Electronic  control  of  the  fuel  injection  transformed  the  direct  injection  engine  by  allowing  much  greater  control  over  the  combustion.    Fig.Direct and Indirect Injection Systems  **INDIRECT INJECTION DIESEL ENGINE**  1.   An  indirect  injection  diesel  engine  delivers  fuel  into  a  chamber  off  the  combustion  chamber,  called  a  pre-chamber  or  ante-chamber,  where  combustion  begins  and  then  spreads  into  the  main  combustion  chamber,  assisted  by  turbulence  created  in  the  chamber.  2.  This  system  allows  for  a  smoother,  quieter  running  engine,  and  because  combustion  is  assisted  by  turbulence,  injector  pressures  can  be  lower,  about  100  bar  (10  MPa;  1,500  psi),  using  a  single  orifice  tapered  jet  injector.  3.  Mechanical  injection  systems  allowed  high-speed  running  suitable  for  road  vehicles  (typically  up  to  speeds  of  around  4,000  rpm).  4.  The  pre-chamber  had  the  disadvantage  of  increasing  heat  loss  to  the  engine's  cooling  system,  and  restricting  the  combustion  burn,  which  reduced  the  efficiency  by  5”10%.[35]  Indirect  injection  engines  are  cheaper  to  build  and  it  is  easier  to  produce  smooth,  quiet-running  vehicles  with  a  simple  mechanical  system.  5.In  road-going  vehicles  most  prefer  the  greater  efficiency  and  better  controlled  emission  levels  of  direct  injection.  6.  Indirect  injection  diesels  can  still  be  found  in  the  many  ATV  diesel applications. |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=H28bE6gf5qQ |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 236-238. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : COMPRESSION IGNITION ENGINES**

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| **Topic of Lecture :** Combustion chambers |
| **Introduction:**  An  indirect  injection  diesel  engine  delivers  fuel  into  a  chamber  of  the  combustion  chamber,  called  a  pre-chamber  or  ante-chamber,  where  combustion  begins  and  then  spreads  into  the  main  combustion  chamber,  assisted  by  turbulence  created  in  the  chamber. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Direct Injection Chambers,  Indirect Injection Combustion Chambers, |
| **Detailed content of the Lecture:**  **TYPES OF COMBUSTION CHAMBERS- CI Engines**  CI  engine  combustion  chambers  are  classified  into  two  categories:  **1. OPEN INJECTION (DI) TYPE:**  This  type  of  combustion  chamber  is  also  called  an  Open  combustion  chamber.  In  this  type  the  entire  volume  of  combustion  chamber  is  located  in  the  main  cylinder  and  the  fuel  is  injected  into  this  volume.  **2. INDIRECT INJECTION (IDI) TYPE:**  in  this  type  of  combustion  chambers,  the  combustion  space  is  divided  into  two  parts,  one  part  in  the  main  cylinder  and  the  other  part  in  the  cylinder  head.  The  fuel  ”injection  is  effected  usually  into  the  part  of  chamber  located  in  the  cylinder  head.  These  chambers  are  classified  **1.DIRECT INJECTION CHAMBERS – OPEN COMBUSTION CHAMBERS**  **Shallow Depth Chamber:**  In  shallow  depth  chamber  the  depth  of  the  cavity  provided  in  the  piston  is  quite  small.  This  chamber  is  usually  adopted  for  large  engines  running  at  low  speeds.  Since  the  cavity  diameter  is  very  large,  the  squish  is  negligible.  **Hemispherical Chamber:**  This  chamber  also  gives  small  squish.  However,  the  depth  to  diameter  ratio  for  a  cylindrical  chamber  can  be  varied  to  give  any  desired  squish  to  give  better  performance.    **Fig.9 Different combustion chambers**  **Cylindrical Chamber:**  This  design  was  attempted  in  recent  diesel  engines.  This  is  a  modification  of  the  cylindrical  chamber  in  the  form  of  a  truncated  cone  with  base  angle  of  30°.  The  swirl  was  produced  by  masking  the  valve  for  nearly  1800  of  circumference.  Squish  can  also  be  varied  by  varying  the  depth.  **Toroidal Chamber:**  The  idea  behind  this  shape  is  to  provide  a  powerful  squish  along  with  the  air  movement,  similar  to  that  of  the  familiar  smoke  ring,  within  the  toroidalchamber.  Due  to  powerful  squish  the  mask  needed  on  inlet  valve  is  small  and  there  is  better  utilisation  of  oxygen.  The  cone  angle  of  spray  for  this  type  of  chamber  is  150°  to  160°.  **2. INDIRECT INJECTION COMBUSTION CHAMBERS**   1. **Ricardo’s Swirl Chamber:**   Swirl  chamber  consists  of  a  spherical  shaped  chamber  separated  from  the  engine  cylinder  and  located  in  the  cylinder  head.  In  to  this  chamber,  about  50%  of  the  air  is  transferred  during  the  compressionstroke.  A  throat  connects  the  chamber  to  the  cylinder  which  enters  the  chamber  in  a  tangential  direction  so  that  the  air  coming  into  this  chamber  is  given  a  strong  rotary  movement  inside  the  swirl  chamber  and  after  combustion,  the  products  rush  back  into  the  cylinder  through  same  throat  at  much  higher  velocity. The  use  of  single  hole  of  larger  diameter  for  the  fuel  spray  nozzle  is  often  important  consideration  for  the  choice  of  swirl  chamber  engine.    **Fig . Ricardo’s Swirl Chamber:**   1. **Pre Combustion Chamber**   Typical  pre-combustion  chamber  consists  of  an  anti-chamber  connected  to  the  main  chamber  through  a  number  of  small  holes  (compared  to  a  relatively  large  passage  in  the  swirl  chamber).  The  pre-combustion  chamber  is  located  in  the  cylinder  head  and  its  volume  accounts  for  about  40%  of  the  total  combustion,  space.  During  the  compression  stroke  the  piston  forces  the  air  into  the  pre-combustion  chamber.  The  fuel  is  injected  into  the  pre-chamber  and  the  combustion  is  initiated.  The  resulting  pressure  rise  forces  the  flaming  droplets  together  with  some  air  and  their  combustion  products  to  rush  out  into  the  main  cylinder  at  high  velocity  through  the  small  holes.  **Fig.** **Pre Combustion Chamber**   1. **Energy cell:**   The  ‘energy  cell’  is  more  complex  than  the  precombustion  chamber.  As  the  piston  moves  up  on  the  compression  stroke,  some  of  the  air  is  forced  into  the  major  and  minor  chambers  of  the  energy  cell.  When  the  fuel  is  injected  through  the  pintle  type  nozzle,  part  of  the  fuel  passes  across  the  main  combustion  chamber  and  enters  the  minor  cell,  where  it  is  mixed  with  the  entering  air.  Combustion  first  commences  in  the  main  combustion  chamber  where  the  temperatures  higher,  but  the  rate  of  burning  is  slower  in  this  location,  due  to  insufficient  mixing  of  the  fuel  and  air.  The  burning  in  the  minor  cell  is  slower  at  the  start,  but  due  to  better  mixing,  progresses  at  a  more  rapid  rate.  The  pressure  built  up  in  the  minor  cell  ,  therefore  ,  force  the  burning  gases  out  into  the  main  chamber,  thereby  creating  added  turbulence  and  producing  better  combustion  in  the  this  chamber.    **Fig. Energy cell:** |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=H28bE6gf5qQ |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 239-240. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : COMPRESSION IGNITION ENGINES**

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| **Topic of Lecture :** Fuel Spray behavior |
| **Introduction:**   * Depending on the mechanism to characterize, diesel spray can be analyzed in a macroscopic or   microscopic point of view.   * With the purpose of understanding in detail this process, the various physical parameters involved * during the transition of a pulsed diesel spray will be expressed in this chapter, * however it is essential to know the systems that make possible for an injection process to take   place |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Diesel spray characteristics, Atomization |
| **Detailed content of the Lecture:**  **Diesel spray characteristics**   * Depending on the mechanism to characterize, diesel spray can be analyzed in a macroscopic or microscopic point of view. With the purpose of understanding in detail this process, the various physical parameters involved during the transition of a pulsed diesel spray will be expressed in this chapter. * however it is essential to know the systems that make possible for an injection process to take place. These are the injection nozzle, active fluid to inject (liquid), and the working fluid on which the liquid is injected, as seen in figure 1.   **Fig. Meaningful variables of the injection process**  Reynolds Number: Density and kinematic viscosity must be particularized for liquid or gas, furthermore these properties can be evaluated for intermediate conditions between both fluid film conditions. These parameters can be divided into two groups:   * 1. External flow parameters (relation of densities, Weber number, Taylor parameter), these parameters control the interaction between the liquid spray and the surrounding atmosphere.   2. Internal flow parameters (Reynolds number, cavitation parameter, length/diameter relation, nozzle radius entrance/diameter relation, discharge coefficient): these parameters control the interaction between the liquid and the nozzle.   **ATOMIZATION**   * Disintegration of fuel stream issuing from the injector nozzle into droplets of different sizes. Disintegration presents large surface and quicker heating and vaporization of droplets. Caused by friction between stream of fuel and air in Combustion chamber. Previous studies have shown that a spray penetration overcomes that of a single droplet, due to the momentum that the droplets. * Located in the front of the spray experiment, accelerating the surrounding working fluid, causing the next droplets that make it to the front of the spray an instant of time later to have less aerodynamic resistance. We must emphasize that diesel fuel sprays tend to be of the compact type, which causes them to have large penetrations. * Several researchers have studied the front penetration and have found a series of correlations that allow us to establish the main variables that affect or favour the penetration of a pulsed diesel spray. The following are some of the most relevant. From the theory of gaseous sprays, was one of the pioneers in the study of spray phenomena. * The author proposed an experimentally adjusted correlation which is applicable to pulsed diesel sprays; this correlation was the compared by with other correlations, finding certain discrepancies between them. However, this correlation is considered to be applicable in a general form to diesel sprays |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=H28bE6gf5qQ |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 287-290. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : COMPRESSION IGNITION ENGINES**

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| **Topic of Lecture :** Spray structure and spray penetration and Air Motion |
| **Introduction:**   * The injection front penetration (S) is defined as the total distance covered by the spray in a control volume, and it’s determined by the equilibrium of two factors, * first the momentum quantity with which the fluid is injected and * second, the resistance that the idle fluid presents in the control volume, normally a gas |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**   1. Spray tip penetration, 2. Spray angle, 3. Break up length |
| **Detailed content of the Lecture:**   1. Spray tip penetration 2. Spray angle 3. Air Motion   **Physical parameter of a diesel spray**   1. **Front Penetration**    * The injection front penetration (S) is defined as the total distance covered by the spray in a control volume, and it’s determined by the equilibrium of two factors, first the momentum quantity with which the fluid is injected and second, the resistance that the idle fluid presents in the control volume, normally a gas.  * Due to friction effects, the liquids kinetic energy is transferred progressively to the working fluid. This energy will decrease continuously until the movement of the droplets depends solely on the movement of the working fluid inside the control volume. * Previous studies have shown that a spray penetration overcomes that of a single droplet, due to the momentum that the droplets. * located in the front of the spray experiment, accelerating the surrounding working fluid, causing the next droplets that make it to the front of the spray an instant of time later to have less aerodynamic resistance. * We must emphasise that diesel fuel sprays tend to be of the compact type, which causes them to have large penetrations.Several researchers have studied the front penetration and have found a series of correlations that allow us to establish the main variables that affect or favour the penetration of a pulsed diesel spray. * The following are some of the most relevant. From the theory of gaseous sprays, was one of the pioneers in the study of spray phenomena. The author proposed an experimentally adjusted correlation which is applicable to pulsed diesel sprays; this correlation was the compared by with other correlations, finding certain discrepancies between them. * However, this correlation is considered to be applicable in a general form to diesel sprays      1. **Cone angle**  * The cone angle is defined as the angle formed by two straight lines that stat from the exit orifice of the nozzle and tangent to the spray outline (sprays morphology) in a determined distance. * The angle in a diesel spray is formed by two straight lines that are in contact with the spray’s outline and at a distance equivalent to 60 times de exit diameter of the nozzles orifice. * This angle usually is between 5 and 30 degrees. This determines greatly the fuels macroscopic distribution in the combustion chamber. In one hand, the increase in angle decreases the penetration and can cause interference between sprays (when sprays are injected using multi -orifice nozzles) in the same chamber favouring the merging of droplets. * On the other hand, an excessive penetration is favoured when the angle decreases lower than certain values, causing the spray to collide with the piston bowl or the combustion chamber. * In previous studies there have been a series of proposals to determine the cone angle, some of the most important are as follows:      1. **Air Motion**  * The liquid length of the spray is a very important characteristic to define the behaviour of the spray in the combustion chamber. This zone of the spray is also called continuous or stationary and it is understood as being from the nozzle exit to the point were the separation of the first droplets occur. * To define this zone the use of diverse measurements methods and techniques is of vital importance. In the literature we find some of the most useful measurement methods and techniques in the analysis of the liquid length * To analyze the internal structure of the spray, identified two zones inside the atomizing regime, the zone of the incomplete spray and the zone of the complete spray. Figure shows structure in a general way. * The difference between them is due to the fact that with the incomplete sprays the disintegration of the surface of the spray begins at a certain distance from the point of the nozzle of the injector, indicating a distance Lc, while in the case of the incomplete sprays distance Lc is nearly cero and Lb is maintained virtually constant on increasing speed. * Furthermore show that cavitation greatly favours the atomization process in the complete spray regime. * To define liquid length a series of expressions have been proposed which have been suggested in specific conditions according to each case and among the most relevant the following can be cited:   **Fig. Internal structure of complete and incomplete spray** |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=H28bE6gf5qQ |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 241-243. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : COMPRESSION IGNITION ENGINES**

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| **Topic of Lecture:** Introduction to Turbo charging. |
| **Introduction:**  A  turbocharger  or  turbo  is  a  forced  induction  device  used  to  allow  more  power  to be  produced  for  an  engine  of  a  given  size.  A  turbocharged  engine  can  be  more powerful  and  efficient  than  a  naturally  aspirated  engine  because  the  turbine  forces  more  air,  and  proportionately  more  fuel,  into  the  combustion  chamber  than  atmospheric  pressure  alone. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**   1. Turbo Charger 2. Working Principle 3. Component |
| **Detailed content of the Lecture:**  **Turbocharger**  A  turbocharger  or  turbo  is  a  forced  induction  device  used  to  allow  more  power  to be  produced  for  an  engine  of  a  given  size.  A  turbocharged  engine  can  be  more  powerful  and  efficient  than  a  naturally  aspirated  engine  because  the  turbine  forces  more  air,  and  proportionately  more  fuel,  into  the  combustion  chamber  than  atmospheric  pressure  alone.      **Fig. Turbocharger**  **Working principle**   * aturbocharger  is  a  small  radial  fan  pump  driven  by  the  energy  of  the  exhaust   gases  of  an  engine.  Aturbocharger  consists  of  a  turbine  and  a  compressor  on  a  shared  shaft.  The  turbine  section  of  a  turbocharger  is  a  heat  engine  in  itself.   * It converts  the  heat  energy  from  the  exhaust  to  power,  which  then  drives  the   compressor,  compressing  ambient  air  and  delivering  it  to  the  air  intake  manifold  of   * the  engine  at  higher  pressure,  resulting  in  a  greater  mass  of  air  entering  each   cylinder.   * In  some  instances,  compressed  air  is  routed  through  an  intercooler  before   introduction  to  the  intake  manifold.  Because  a  turbocharger  is  a  heat  engine,  and  is  converting  otherwise  wasted  exhaust  heat  to  power,  it  compresses  the  inlet  air  to  the  engine  more  efficiently  than  a  supercharger.  **Components**   * The  turbocharger  has  four  main  components. * Theturbine  (almost  always  a  radial turbine)  and  impeller/compressor  wheels  are  each  contained  within  their  own  folded   conical  housing  on  opposite  sides  of  the  third  component,  the  centre  housing/hub  rotating  assembly  (CHRA).   * The  housings  fitted  around  thecompressor impeller  and  turbine  collect  and  direct   the  gas  flow  through  the  wheels  as  they  spin.  The  size  and  shape  can  dictate  some  performance  characteristics  of  the  overall  turbocharger.   * turbocharger  assembly  will  be  available  from  the  manufacturer  with  multiple  housing   choices  for  the  turbine  and  sometimes  the  compressor  cover  as  well.   * the  designer  of  the  engine  system  to  tailor  the  compromises  between  performance,   response,  and  efficiency  to  application  or  preference.   * valve-operated  exhaust  gas  inlets,  a  smaller  sharper  angled  one  for  quick  response   and  a  larger  less  angled  one  for  peak  performance.   * Theturbine and impeller wheel  sizes  also  dictate  the  amount  of  air  or  exhaust  that   can  be  flowed  through  the  system,  and  the  relative  efficiency  at  which  they  operate.   * Generally,  the  larger  the  turbine  wheel  and  compressor  wheel,  the  larger   the  flow  capacity.  Measurements  and  shapes  can  vary,  as  well  as  curvature  and  number  of  blades  on  the  wheels.  Variable  geometry  turbochargers  are  further  developments  of  these  ideas.   * Thecentre hub  rotating  assembly  (CHRA)  houses  the  shaft  which  connects  the   compressor  impeller  and  turbine.  It  also  must  contain  a  bearing  system  to  suspend  the  shaft,  allowing  it  to  rotate  at  very  high  speed  with  minimal  friction.   * instance,  in  automotive  applications  the  CHRA  typically  uses  a  thrust  bearing  or  ball   bearing  lubricated  by  a  constant  supply  of  pressurized  engine  oil.   * also  be  considered  "water  cooled"  by  having  an  entry  and  exit  point  for  engine   coolant  to  be  cycled.   * Water  cooled  models  allow  engine  coolant  to  be  used  to   keep  the  lubricating  oil  cooler,  avoiding  possible  oil  coking  from  the  extreme  heat  found  in  the  turbine.  The  development  of  air-foil  bearings  has  removed  this  risk. |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=H28bE6gf5qQ |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 520-526. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : 3- POLLUTANT FORMATION AND CONTROL**

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| **Topic of Lecture :** Pollutant Sources |
| **Introduction:**  Internal combustion engines (ICE) operate by burning fossil fuel derivatives. Exhaust  Emissions are their major contribution to environmental pollution. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Typical emissions  contain primary greenhouse gases – carbon dioxide (CO2), methane (CH4) and nitrous  oxide (N2O). All criteria pollutants – carbon monoxide (CO), total nitrogen oxides (NO  x), sulfur dioxide (SO2), non-methane volatile organic compounds (NMVOC) and  particulate matter (PM) are the other major components |
| **Detailed content of the Lecture:**  **Internal Combustion Engines.**   * ICE may be classified by different criteria. For instance, - according to fuel type, to power, to ignition type and so on. An appropriate classification from the point of view of combustion chemistry and air pollution will divide them into two major groups. * The first group includes engines in which combustion is performed periodically in a chamber of changing volume (i. e. reciprocating piston engines). * In the second group combustion takes place continuously (steady flow) in a chamber of constant volume. * The first group may be further divided into spark ignition (SI) and compression ignition (CI) engines, although there are engines combining both principles. * SI engines may be classified as two stroke and four stroke engines, CI engines – as direct and indirect injection engines. * The second group includes the jet engines, which may use a gas turbine, liquid fuel, air   as oxidation agent and a turbo compressor (aircraft jet engines), and the rocket jet engines, which have chemical agents as fuels and oxidizers.   * Details of combustion systems, combustion processes, efficiencies, Another useful distinction between internal combustion engines is the fact that only in SI engines the fuel is evaporated and mixed with the oxidizing agent before the ignition takes place. In other designs, the fuel is sprayed in the combustion chamber, in the form of drops of different size. * It is not the purpose of this chapter to describe the organization of the combustion   Processes in the different engines. Its main task is rather to compare the main groups  etc. can be found in Pollution Control through Efficient Combustion Technology. Have the important advantages of lower weight and cost per unit of power output.   * They are widely used in small motorcycles, as outboard motors and other small power equipment. * The main pollutants from four-stroke gasoline engines are hydrocarbons, CO and nitrogen oxides. They are contained in exhaust emissions, but hydrocarbons are contributed both with the exhaust, and with the evaporative emissions. * Particulate matter is usually negligible and is produced mainly from oil components brought in the combustion chamber by the piston. Sulfur oxides are typically low and for some time were not considered a problem. New regulations restrict drastically sulfur in gasoline, because of reconsidering its influence on catalysts.   **SI/CI ENGINE EMISSIONS**  1.  Unburned  Hydro  Carbons  2.  Carbon  monoxide  3.  Oxides  of  nitrogen  4.  Oxides  of  sulphur  and  5.  Particulates  including  smoke |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=AVBjNCtqe4M&list=PL215741C530D11AFB&index=5&t=0s |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 612-614. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : 3 - POLLUTANT FORMATION AND CONTROL**

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| **Topic of Lecture :** Formation of Carbon Monoxide |
| **Introduction:**  The  nitric  oxide  formation  during  the  combustion  process  is  the  result  of group  of  elementary  reaction  involving  the  nitrogen  and  oxygen  molecules.  Different  mechanism  proposed  is  discussed  below. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**   * Mechanism of NO formation * Simple reaction between N2 and O2 * Zeldovich Chai Reaction mechanism |
| **Detailed content of the Lecture:**  **Formation of NOX, HC/CO mechanism**  **Mechanism of NO formation:**  The  nitric  oxide  formation  during  the  combustion  process  is  the  result  of  group  of  elementary  reaction  involving  the  nitrogen  and  oxygen  molecules.  Different  mechanism  proposed  is  discussed  below.  **a. Simple reaction between N2 and O2**  N2 + O2     2  NO  This  mechanism  proposed  by  Eyzat  and  Guibet  predicts  NO  concentrations  much  lower  that  those  measured  in  I.C  engines.  According  to  this  mechanism,  the  formation  process  is  too  slow  for  NO  to  reach  equilibrium  at  peak  temperatures  and  pressures  in  the  cylinders.  **b. Zeldovich Chai Reaction mechanism:**  O2  2  O-------------  (1)  O  +  N2   NO  +  N  ------(2)  N  +  O2 NO  +  O  ------(3)  The  chain  reactions  are  initiated  by  the  equation  (2)  by  the  atomic  oxygen,  formed  in  equation  (1)  from  the  dissociation  of  oxygen  molecules  at  the  high  temperatures  reached  in  the  combustion  process.  Oxygen  atoms  react  with  nitrogen  molecules  and  produces  NO  and  nitrogen  atoms.  In  the  equation  (3)  the  nitrogen  atoms  react  with  oxygen  molecule  to  form  nitric  oxide  and  atomic  oxygen.  According  to  this  mechanism  nitrogen  atoms  do  not  start  the  chain  reaction  because  their  equilibrium  concentration  during  the  combustion  process  is  relatively  low  compared  to  that  of  atomic  oxygen.  Experiments  have  shown  that  equilibrium  concentrations  of  both  oxygen  atoms  and  nitric  oxide  molecules  increase  with  temperature  and  with  leaning  of  mixtures.  It  has  also  been  observed  that  NO  formed  at  the  maximum  cycle  temperature  does  not  decompose  even  during  the  expansion  stroke  when  the  gas  temperature  decreases.  In  general  it  can  be  expected  that  higher  temperature  would  promote  the  formation  of  NO  by  speeding  the  formation  reactions.  Ample  O2  supplies  would  also  increase  the  formation  of  NO.  The  NO  levels  would  be  low  in  fuel  rich  operations,  i.e.  A/F  15,  since  there  is  little  O2  left  to  react  with  N2  after  the  hydrocarbons  had  reacted.  The  maximum  NO  levels  are  formed  with  AFR  about  10  percent  above  stoichiometric.  More  air  than  this  reduces  the  peak  temperature,  since  excess  air  must  be  heated  from  energy  released  during  combustion  and  the  NO  concentration  fall  off  even  with  additional  oxygen. |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=AVBjNCtqe4M&list=PL215741C530D11AFB&index=5&t=0s |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 615-617. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : 3 - POLLUTANT FORMATION AND CONTROL**

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| **Topic of Lecture :** Unburned hydrocarbon (HC) |
| **Introduction:**  Hydrocarbon  exhaust  emission  may  arise  from  three  sources  as,  a.  Wall  quenching  b.  Incomplete  combustion  of  charge  c.  Exhaust  scavenging  in  2-stroke  engines |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Because  of  the  cooling,  there  is  a  cold  zone  next  to  the  cooled  combustion  chamber  walls.  This  region  is  called  the  quench  zone.  Because  of  the  low  temperature,  the  fuel-air  mixture  fails  to  burn  and  remains  unburned. |
| **Detailed content of the Lecture:**  Unburned hydrocarbon (HC) exhaust  emission  may  arise  from  three  sources  as,  a.  Wall  quenching  b.  Incomplete  combustion  of  charge  c.  Exhaust  scavenging  in  2-stroke  engines  In  an  automotive  type  4-stroke  cycle  engine,  wall  quenching  is  the  predominant  source  of  exhaust  hydrocarbon  under  most  operating  conditions.  The  quenching  of  flame  near  the  combustion  chamber  walls  is  known  as  wall  quenching.  This  is  a  combustion  phenomenon  which  arises  when  the  flame  tries  to  propagate  in  the  vicinity  of  a  wall.  Normally  the  effect  of  the  wall  is  a  slowing  down  or  stopping  of  the  reaction.  Because  of  the  cooling,  there  is  a  cold  zone  next  to  the  cooled  combustion  chamber  walls.  This  region  is  called  the  quench  zone.  Because  of  the  low  temperature,  the  fuel-air  mixture  fails  to  burn  and  remains  unburned.  Due  to  this,  the  exhaust  gas  shows  a  marked  variation  in  HC  emission.  The  first  gas  that  exits  is  from  near  the  valve  and  is  relatively  cool.  Due  to  this  it  is  rich  in  HC.  The  next  part  of  gas  that  comes  is  from  the  hot  combustion  chamber  and  hence  a  low  HC  concentration.  The  last  part  of  the  gas  that  exits  is  scrapped  off  the  cool  cylinder  wall  and  is  relatively  cool.  Therefore  it  is  also  rich  in  HC  emission. |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=AVBjNCtqe4M&list=PL215741C530D11AFB&index=5&t=0s |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 618-620. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : 3- POLLUTANT FORMATION AND CONTROL**

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| **Topic of Lecture :** Oxides of Nitrogen (NO) |
| **Introduction:**  The  nitric  oxide  formation  during  the  combustion  process  is  the  result  of group  of  elementary  reaction  involving  the  nitrogen  and  oxygen  molecules.   Different mechanism  proposed  is  discussed  below |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  N2 + O2     2  NO  This  mechanism  proposed  by  Eyzat  and  Guibet  predicts  NO  concentrations  much  lower  that  those  measured  in  I.C  engines.  According  to  this  mechanism,  the  formation  process  is  too  slow  for  NO  to  reach  equilibrium  at  peak  temperatures  and  pressures  in  the  cylinders. |
| **Detailed content of the Lecture:**  **Mechanism of NO formation:**  The  nitric  oxide  formation  during  the  combustion  process  is  the  result  of  group  of  elementary  reaction  involving  the  nitrogen  and  oxygen  molecules.  Different  mechanism  proposed  is  discussed  below.  **a. Simple reaction between N2 and O2**  N2 + O2     2  NO  This  mechanism  proposed  by  Eyzat  and  Guibet  predicts  NO  concentrations  much  lower  that  those  measured  in  I.C  engines.  According  to  this  mechanism,  the  formation  process  is  too  slow  for  NO  to  reach  equilibrium  at  peak  temperatures  and  pressures  in  the  cylinders.  **b. Zeldovich Chai Reaction mechanism:**  O2  2  O-------------  (1)  O  +  N2   NO  +  N  ------(2)  N  +  O2 NO  +  O  ------(3)  The  chain  reactions  are  initiated  by  the  equation  (2)  by  the  atomic  oxygen,  formed  in  equation  (1)  from  the  dissociation  of  oxygen  molecules  at  the  high  temperatures  reached  in  the  combustion  process.  Oxygen  atoms  react  with  nitrogen  molecules  and  produces  NO  and  nitrogen  atoms.  In  the  equation  (3)  the  nitrogen  atoms  react  with  oxygen  molecule  to  form  nitric  oxide  and  atomic  oxygen.  According  to  this  mechanism  nitrogen  atoms  do  not  start  the  chain  reaction  because  their  equilibrium  concentration  during  the  combustion  process  is  relatively  low  compared  to  that  of  atomic  oxygen.  Experiments  have  shown  that  equilibrium  concentrations  of  both  oxygen  atoms  and  nitric  oxide  molecules  increase  with  temperature  and  with  leaning  of  mixtures.  It  has  also  been  observed  that  NO  formed  at  the  maximum  cycle  temperature  does  not  decompose  even  during  the  expansion  stroke  when  the  gas  temperature  decreases.  In  general  it  can  be  expected  that  higher  temperature  would  promote  the  formation  of  NO  by  speeding  the  formation  reactions.  Ample  O2  supplies  would  also  increase  the  formation  of  NO.  The  NO  levels  would  be  low  in  fuel  rich  operations,  i.e.  A/F  15,  since  there  is  little  O2  left  to  react  with  N2  after  the  hydrocarbons  had  reacted.  The  maximum  NO  levels  are  formed  with  AFR  about  10  percent  above  stoichiometric.  More  air  than  this  reduces  the  peak  temperature,  since  excess  air  must  be  heated  from  energy  released  during  combustion  and  the  NO  concentration  fall  off  even  with  additional  oxygen. |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=AVBjNCtqe4M&list=PL215741C530D11AFB&index=5&t=0s |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 621-626. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : 3- POLLUTANT FORMATION AND CONTROL**

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| **Topic of Lecture :** Smoke and Particulate matter |
| **Introduction:**  Engine  exhaust  smoke  is  a  visible  indicator  of  the  combustion  process  in  the  engine.  Smoke  is  due  to  incomplete  combustion.  Smoke  in  diesel  engine  can  be  divided  into  three  categories:  blue,  white  and  black. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:** Large  amounts  of  carbons  will  be  formed, during  the  early  stage  of  combustion.  This  carbon  appears  as  smoke  if  there  isinsufficient  air,  if  there  is  insufficient  mixing  or  if  local  temperatures  fall  below  thecarbon  reaction  temperatures  (approximately  1000C)  before   the  mixing  occurs. |
| **Detailed content of the Lecture:**  **Blue smoke:**  It  results  from  the  burning  of  engine  lubricating  oil  that  reaches  combustion  chamber  due  to  worn  piston  rings,  cylinder  liners  and  valve  guides.  **White or cold smoke:**  It  is  made  up  of  droplets  of  unburnt  or  partially  burnt  fuel  droplets  and  is  usually  associated  with  the  engine  running  at  less  than  normal  operating  temperature  after  starting,  long  period  of  idling,  operating  under  very  light  load,  operating  with  leaking  injectors  and  water  leakage  in  combustion  chamber.  This  smoke  normally  fades  away  as  engine  is  warmed  up  and  brought  to  normal  stage.  **Black or hot smoke:**  It  consists  of  unburnt  carbon  particles  (0.5  ”  1  microns  in  diameter)  and  other  solid  products  of  combustion.  This  smoke  appears  after  engine  is  warmed  up  and  is  accelerating  or  pulling  under  load.  **Formation of smoke in Diesel engines:**  The  main  cause  of  smoke  formation  is  known  to  be  inadequate  mixing  of  fuel  and  air.  Smoke  is  formed  when  the  local  temperature  is  high  enough  to  decompose  fuel  in  a  region  where  there  is  insufficient  oxygen  to  burn  the  carbon  that  is  formed.  The  formation  of  over-rich  fuel  air  mixtures  either  generally  or  in  localized  regions  will  result  in  smoke.  Large  amounts  of  carbons  will  be  formed  during  the  early  stage  of  combustion.  This  carbon  appears  as  smoke  if  there  is  insufficient  air,  if  there  is  insufficient  mixing  or  if  local  temperatures  fall  below  the  carbon  reaction  temperatures  (approximately  1000C)  before  the  mixing  occurs.  Acceptable  performance  of  diesel  engine  is  critically  influenced  by  exhaust  some  emissions.  Failure  of  engine  to  meet  smoke  legislation  requirement  prevents  sale  and  particularly  for  military  use,  possible  visibility  by  smoke  is  useful  to  enemy  force.  Diesel  emissions  give  information  on  effectiveness  of  combustion,  general  performance  and  condition  of  engine. |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=AVBjNCtqe4M&list=PL215741C530D11AFB&index=5&t=0s |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 629-631. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : POLLUTANT FORMATION AND CONTROL**

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| **Topic of Lecture :** Methods of controlling Emissions |
| **Introduction:**  The  combustion  chamber  temperature  can  be  decreased  by  1.  Decreasing  compression  ratio  2.  Retarding  spark  timing  3.  Decreasing  charge  temperature  4.  Decreasing  engine  speed  5.  Decreasing  inlet  charge  pressure  6.  Exhaust  gas  recirculation  7.  Increasing  humidity |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Emissions from large ships were not restricted for many years, even after strict laws were  enforced on other engines. It was reasoned that ships operated away from land masses most  of the time and the exhaust gases could be absorbed by the atmosphere without affecting  human habitat. However, most seaports are in large cities, where emission problems are most  critical, and polluting from all engines is now restricted, incl.Mdingship engines. |
| **Detailed content of the Lecture:**  **Methods of controlling emissions**  **1.NOx is decreased by,**  **A. Decreasing the combustion chamber temperature**  The  combustion  chamber  temperature  can  be  decreased  by  1.  Decreasing  compression  ratio  2.  Retarding  spark  timing  3.  Decreasing  charge  temperature  4.  Decreasing  engine  speed  5.  Decreasing  inlet  charge  pressure  6.  Exhaust  gas  recirculation  7.  Increasing  humidity  **B. By decreasing oxygen available in the flame front**  The  amount  of  oxygen  available  in  the  chamber  can  be  controlled  by  1.  Rich  mixture  2.  Stratified  charge  engine  3.  Divided  combustion  chamber  **2. Hydrocarbon emission can be decreased by**  1.  Decreasing  the  compression  ratio  2.  Retarding  the  spark  3.  Increasing  charge  temperature  4.  Increasing  coolant  temperature  5.  Insulating  exhaust  manifold  6.  Increasing  engine  speed  7.  Lean  mixture  **3. CO can be decreased by**  1.  Lean  air  fuel  ratio  2.  Adding  oxygen  in  the  exhaust  3.  Increasing  coolant  temperature.  **Chemical methods to reduce emissions**  Development work has been done on large stationary engines using cyanuric acid to  reduce NOx emissions. Cyanuric acid is a low-cost solid material that sublimes in the exhaust  flow. The gas dissociates, producing isocyanide that reacts with NOx to form N2, H20, and  CO2· Operating temperature is about 500°C. Up to 95% NOx reduction has been achieved  with  no  loss  of  engine  performance.  At  present,  this  system  is  not  practical  for  vehicle  engines because of its size, weight, and complexity. Research is being done using zeolite  molecular  sieves  to  reduce  NOx  emissions.  These  are  materials  that  absorb  selected  molecular compounds and catalyse chemical reactions. Using both SI and CI engines, the  efficiency  of  NOx  reduction  is  being  determined  over  a  range  of  operating  variables,  including AF, temperature, flow velocity, and zeolite structure. At present, durability is a  serious limitation with this method.  H2S emissions occur under rich operating conditions. Chemical systems are being  developed that trap and store H2S when an engine operates rich and then convert this to S02  when operation is lean and excess oxygen exists. The reaction equation is  H2S + 02 = S02 + H2 |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=AVBjNCtqe4M&list=PL215741C530D11AFB&index=5&t=0s |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 629-631. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : 3- POLLUTANT FORMATION AND CONTROL**

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| **Topic of Lecture :** Catalytic converters |
| **Introduction:**  A  catalytic  converter  is  a  vehicle  emissions  control  device  which  converts toxic  by-products  of  combustion  in  the  exhaust  of  an  internal  combustion  engine  to  less  toxic  substances  by  way  of  catalysed  chemical  reactions.  The  specific  reactions  vary  with  the  type  of  catalyst  installed. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Most  present-day  vehicles  that  run  on gasoline  are  fitted  with  a  three  way  converter,    so  named  because  it  converts  the three  main  pollutants  in  automobile  exhaust:   carbon  monoxide,  unburned  hydrocarbon and  oxides  of  nitrogen. |
| **Detailed content of the Lecture:**  carbon  monoxide,  unburned  hydrocarbon and  oxides  of  nitrogen  **Fig. Catalytic converter**  Figure  shows  a  three  way  catalytic  converter.  The  front  section(  in  the  direction  of  gas  flow)  handles  NOx  and  partly  handles  HC  and  CO.  The  partly  treated  exhaust  gas  is  mixed  with  secondary  air.  The  mixture  of  partly  treated  exhaust  gas  and  secondary  air  flows  into  the  rear  section  of  the  chamber.  The  two  way  catalyst  present  in  the  rear  section  takes  care  of  HC  and  CO.  1.Reduction  of  nitrogen  oxides  to  nitrogen  and  oxygen:  2NOx  →  xO2  +  N2  2. Oxidation  of  carbon  monoxide  to  carbon  dioxide:  2CO  +  O2  →  2CO2  3. Oxidation  of  unburnt  hydrocarbons  (HC)  to  carbon  dioxide  and  water:  CxH2x+2  +  [(3x+1)/2]  O2  →  xCO2  +  (x+1)  H2O.  **CATALYSTS**  I. supported catalysts  a) noble metals.  b) transition metals.  II. unsupported metallic alloys  **NO REDUCTION CATALYSTS**   * Copper oxide – chromia. * Copper oxide - vanadia. * Iron oxide – chromia. * Nickel oxide pelleted on monolithic ceramic and metallic supports. * Monel metal. * Rare earth oxides.   **HC / CO OXIDATION CATALYSTS**   * Nobel metal catalysts such as activated carbon, palladium or platinum. * Transition metal oxide catalysts such as copper, cobalt, nickel and iron chromate, vanadium or manganese promoted versions of these materials.   **CATALYSTS REQUIREMENTS**   * High conversion efficiency under transient conditions. * Effective for wide range of T. * Must withstand poisoning action of additives. * Must be able to withstand thermal shock. * Must be suitable for vehicle operation for 50,000 miles. * Convert into harmless products. * Cheap and readily available. |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=AVBjNCtqe4M&list=PL215741C530D11AFB&index=5&t=0s |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 629-631. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : 3 - POLLUTANT FORMATION AND CONTROL**

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| **Topic of Lecture :** Selective Catalytic Reduction and Particulate Traps |
| **Introduction:**  A  diesel  particulate  filter  (or  DPF)  is  a  device  designed  to  remove  diesel particulate  matter  or  soot  from  the  exhaust  gas  of  a  diesel  engine.  Wall-flow  diesel  particulate  filters  usually  remove  85%  or  more  of  the  soot  and  under  certain  conditions  can  attain  soot  removal  efficiencies  of  close  to  100%. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  ,  intended  for  disposal  and  replacement  once  full  of  accumulated  ash.  Others  are  designed  to  burn  off  the  accumulated  particulate  either  passively  through  the  use  of  a  catalyst  or  by  active  means  such  as  a  fuel  burner  which  heats  the  filter  to  soot  combustion  temperatures;  engine  programming  to  run  when  the  filter  is  full  in  a  manner  that  elevates  exhaust  temperature  or  produces  high  amounts |
| **Detailed content of the Lecture:**  **CATALYSTS REQUIREMENTS**   * High conversion efficiency under transient conditions. * Effective for wide range of T. * Must withstand poisoning action of additives. * Must be able to withstand thermal shock. * Must be suitable for vehicle operation for 50,000 miles. * Convert into harmless products. * Cheap and readily available.   **Diesel particulate filter (Particulate Trap)**  A  diesel  particulate  filter  (or  DPF)  is  a  device  designed  to  remove  diesel particulate  matter  or  soot  from  the  exhaust  gas  of  a  diesel  engine.  Wall-flow  diesel  particulate  filters  usually  remove  85%  or  more  of  the  soot  and  under  certain  conditions  can  attain  soot  removal  efficiencies  of  close  to  100%.  Some  filters  are  single-use,  intended  for  disposal  and  replacement  once  full  of  accumulated  ash.  Others  are  designed  to  burn  off  the  accumulated  particulate  either  passively  through  the  use  of  a  catalyst  or  by  active  means  such  as  a  fuel  burner  which  heats  the  filter  to  soot  combustion  temperatures;  engine  programming  to  run  when  the  filter  is  full  in  a  manner  that  elevates  exhaust  temperature  or  produces  high  amounts    **Fig. Diesel particulate filter**  Of  NOx  to  oxidize  the  accumulated  ash,  or  through  other  methods.  This  is  known  as  "filter  regeneration".  Cleaning  is  also  required  as  part  of  periodic  maintenance,  and  it  must  be  done  carefully  to  avoid  damaging  the  filter.  Failure  of  fuel  injectors  or  turbochargers  resulting  in  contamination  of  the  filter  with  raw  diesel  or  engine  oil  can  also  necessitate  cleaning. |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=AVBjNCtqe4M&list=PL215741C530D11AFB&index=5&t=0s |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 632-634. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : POLLUTANT FORMATION AND CONTROL**

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| **Topic of Lecture :** Methods of measurement ,Emission norms and Driving cycles |
| **Introduction:**  An   exhaust   treatment   technology   that   substantially   reduces   diesel   engine  particulateemissions  is  the  trap  oxidiir.  A  temperature-tolerant  filter  or  trap  removes  the  particulate material from the exhaust gas; the filter is then "cleaned off" by oxidizing the  accumulated particulates. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**   * Smoke and Particulate measurement * Indian Driving Cycles and emission norms * Standards In India |
| **Detailed content of the Lecture:**  **Smoke and Particulate measurement;**  An   exhaust   treatment   technology   that   substantially   reduces   diesel   engine  particulateemissions  is  the  trap  oxidiir.  A  temperature-tolerant  filter  or  trap  removes  the  particulate material from the exhaust gas; the filter is then "cleaned off" by oxidizing the  accumulated particulates. This technology is difficult to implement because: (1) the filter,  even when clean, increases the pressure in the exhaust system; (2) this pressure increase  steadily rises as the filter collects particulate matter; (3) under normal diesel engine operating  conditions the collected particulate matter will not ignite and oxidize; (4) once ignition of the  particulate occurs, the burnup process must be carefully controlled to prevent excessively  high  temperatures  and  trap  damage  or  destruction.  Trap  oxidizers  have  been  put  into  production for light-duty automobile diesel engines. Their use with heavy-duty diesel engines  poses  more  difficult  problems  due  to  higher  particulate  loading  and  lower  exhaust  temperatures.  Types of particulate filters include: ceramic monoliths, alumina-coated wire mesh,  ceramic foam, ceramic fiber mat, woven silica-fiber rope wound on a porous tube. Each of  these has different inherent pressure loss and filtering efficiency. Regeneration of the trap by  burning up the filtered particulate material can be accomplished by raising its temperature to  the ignition point while providing oxygen-containing exhaust gas to support combustion and  carry away the heat released. Diesel particulate matter ignites at about**500** to 600·‹C. This is  above the normal temperature of diesel exhaust so either the exhaust gas flowing through the  trap during regeneration must be heated (positive regeneration) or ignition must be made to  occur at a lower temperature with catalytic materials on the trap or added to the fuel (catalytic  regeneration). Catalytic coatings on the trap reduce the ignition temperature by up to 200C.  **Indian Driving Cycles and emission norms**  **Driving Cycle:**  The  driving  cycle  for  both  CVS-1  and  CVS-3  cycles  is  identical.  It  involves  various  accelerations,  decelerations  and  cruise  modes  of  operation.  The  car  is  started  after  soaking  for  12  hours  in  a  60-80  F  ambient.  A  trace  of  the  driving  cycle  is  shown  in  figure.  Miles  per  hour  versus  time  in  seconds  are  plotted  on  the  scale.  Top  speed  is  56.7  mph.  Shown  for  comparison  is  the  FTP  or  California  test  cycle.  For  many  advanced  fast  warm-up  emission  control  systems,  the  end  of  the  cold  portion  on  the  CVS  test  is  the  second  idle  at  125  seconds.  This  occurs  at  0.68  miles.  In  the  CVS  tests,  emissions  are  measured  during  cranking,  start-up  and  for  five  seconds  after  ignition  are  turned  off  following  the  last  deceleration.  Consequently  high  emissions  from  excessive  cranking  are  included.  Details  of  operation  for  manual  transmission  vehicles  as  well  as  restart  procedures  and  permissible  test  tolerance  are  included  in  the  Federal  Registers.  **CVS-1 system:**  The  CVS-1  system,  sometimes  termed  variable  dilution  sampling,  is  designed  to  measure  the  true  mass  of  emissions.  The  system  is  shown  in  figure.  A  large  positive  displacement  pump  draws  a  constant  volume  flow  of  gas  through  the  system.  The  exhaust  of  the  vehicle  is  mixed  with  filtered  room  air  and  the  mixture  is  then  drawn  through  the  pump.  Sufficient  air  is  used  to  dilute  the  exhaust  in  order  to  avoid  vapour  condensation,  which  could  dissolve  some  pollutants  and  reduce  measured  values.  Excessive  dilution  on  the  other  hand,  results  in  very  low  concentration  with  attendant  measurement  problems.  A  pump  with  capacity  of  30-  350  cfm  provides  sufficient  dilution  for  most  vehicles.  Before  the  exhaust-air  mixture  enters  the  pump,  its  temperature  is  controlled    by  the  heat  exchanger.  Thus  constant  density  is  maintained  in the  sampling  system  and  pump.  A  fraction  of  the  diluted  exhaust  stream  is  drawn  off  by  a  pump  P2  and  ejected  into  an  initially  evacuated  plastic  bag.  Preferably,  the  bag  should  be  opaque  and  manufactured  of  Teflon  or  Teldar.  A  single  bag  is  used  for  the  entire  test  sample  in  the  CVS-1  system.  Because  of  high  dilution,  ambient  traces  of  HC,  CO  or  NOx  can  significantly  increase  concentrations  in  the  sample  bag.  A  charcoal  filter  is  employed  for  leveling  ambient  HC  measurement.  To  correct  for  ambient  contamination  a  bag  of  dilution  air  is  taken  simultaneously  with  the  filling  of  the  exhaust  bag.  HC, CO and NOx measurements are made on a wet basis using FID, NDIR and  chemiluminescent detectors respectively**.**  Instruments  must  be  constructed  to  accurately  measure  the  relatively  low  concentrations  of  diluted  exhaust.  Bags  should  be  analyzed  as  quickly  as  possible  preferably  within  ten  minutes  after  the  test  because  reactions  such  as  those  between  NO,  NO2  and  HC  can  occur  within  the  bag  quite  quickly  and  change  the  test  results.  **CVS-3 SYSTEM:**  The  CVS-3  system  is  identical  to  the  CVS-1  system  except  that  three  exhaust  sample  bags  are  used.  The  normal  test  is  run  from  a  cold  start  just  like  the  CVS-1  test.  After  deceleration  ends  at  505  seconds,  the  diluted  exhaust  flow  is  switched  from  the  transient  bag  to  the  stabilized  bag  and  revolution  counter  number  1  is  switched  off  and  number  2  is  activated.  The  transient  bag  is  analyzed  immediately.  The  rest  of  the  test  is  completed  in  the  normal  fashion  and  the  stabilized  bag  analyzed.  However  in  the  CVS-3  test  ten  minutes  after  the  test  ends  the  cycle  is  begun  and  again  run  until  the  end  of  deceleration  at  505  seconds.  This  second  run  is  termed  the  hot  start  run.  A  fresh  bag  collects  what  is  termed  the  hot  transient  sample.  It  is  assumed  that  the  second  half  of  the  hot  start  run  is  the  same  as  the  second  half  of  the  cold  start  run  and  is  not  repeated.  In  all,  three  exhaust  sample  bags  are  filled.  An  ambient  air  sample  bag  is  also  filled  simultaneously.  **STANDARDS IN INDIA:**  The  Bureau  of  Indian  Standards  (BIS)  is  one  of  the  pioneering organizations  to  initiate  work  on  air  pollution  control  in  India.  At  present  only  the  standards  for  the  emission  of  carbon  monoxide  are  being  suggested  by  BIS  given  in  IS:  9057-1986.  These  are  based  on  the  size  of  the  vehicle  and  to  be  measured  under  idling  conditions.  The  CO  emission  values  are  5.5  percent  for  2  or  3  wheeler  vehicles  with  engine  displacement  of  75cc  or  less,  4.5  percent  for  higher  sizes  and  3.5  percent  for  four  wheeled  vehicles.  IS:  8118-1976  Smoke  Emission  Levels  for  Diesel  vehicles  prescribes  the  smoke  limit  for  diesel  engine  as  75  Hatridge  units  or  5.2  Bosch  units  at  full  load  and  60-70  percent  rated  speed  or  65  Hatridge  units  under  free  acceleration  conditions.  EMISSION STANDARDS:   * + First Indian emission regulations-1989   + Indian started adopting European emission and fuel regulations for 4- wheeled light-duty and for heavy-duty vehicles.   + Indian emission regulations still apply to 2 and 3 wheeled vehicles.   REGULATORY AGENCIES:   * + Ministry of Environment and Forests   + Central pollution control Board (CPCB)   + State pollution control Boards (SPCBs) in respective states.   + Pollution control committee- in respective territories.   OVERVIEW OF EMISSION NORMS IN INDIA:  1991 - idle to limits for Gasoline vehicles. Free acceleration smoke for Diesel vehicles.  1992 - Mass Emission Norms for Diesel vehicles.  1996 - Revision of Mass emission norms. Mandatory fitment of Catalytic converter in Metros on Unleaded gasoline.  2000 - India 2000(Equivalent to Euro I) Norms. Bharat stage II Norms for Delhi.  2001 - Bharat Stage II (Euro II) norms for All metres; Emission norms for CNG&LPG Vehicles  2003 - Bharat stage II (Euro II) Norms for II major cities.  2005 - April 1 – Bharat stage III (Euro III) norms for II major cities.  2010 - Bharat stage III Emission norms for 4 wheelers for entire country BS IV (Euro IV)- for II major cities.  11 major cities – Delhi, Mumbai, Kolkata, Chennai, Bangalore, Hyderabad, Ahamedabad, Pune, Surat, Kanpur, Agra. Unleaded Gasoline- introduced in 1995 100% in 2000. |
| **Video Content / Details of website for further learning (if any):** https://www.youtube.com/watch?v=AVBjNCtqe4M&list=PL215741C530D11AFB&index=5&t=0s |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 635-639. |

**Course Faculty**

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**LECTURE HANDOUTS**

**IV/VII**

**MECH**

**Course Name : ADVANCED I.C ENGINES**

**Unit : IV- ALTERNATIVE FUELS**

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| **Topic of Lecture :** Alcohol Properties, Suitability, Merits and Demerits |
| **Introduction:**  Alternative  fuels,  known  as  non-conventional  or  advanced  fuels,  are  any  materials  or  substances  that  can  be  used  as  fuels,  other  than  conventional  fuels.  Conventional  fuels  include:  fossil  fuels  (petroleum  (oil),  coal,  propane,  and  natural  gas),  as  well  as  nuclear  materials  such  as  uranium  and  thorium,  as  well  as  artificial  radioisotope  fuels  that  are  made  in  nuclear  reactors**.** |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**    This  mixture  may  also  not  be purified  by  simple  distillation,  as  it  forms  an  azeotropic  mixture.  Biobutanol  has  the  advantage  in  combustion  engines  in  that  its  energy  density  is  closer  to  gasoline  than  the  simpler  alcohols  (while  still  retaining  over  25%  higher  octane  rating);  however,  biobutanol  is  currently  more  difficult  to  produce  than  ethanol  or  methanol.  When  obtained  from  biological  materials  and/or  biological  processes,  they  are  known  as  bio  alcohols  (e.g.  "bioethanol").  There  is  no  chemical  difference  between  biologically  produced  and  chemically  produced  alcohols. |
| **Detailed content of the Lecture:**  **4.2 Types:**   Alcohols   Vegetable  oils   Bio-diesel   Bio-gas   Natural  Gas   Liquefied  Petroleum  Gas   Hydrogen  **4.3 Alcohols**  Alcohol  has  been  used  as  a  fuel.  The  first  four  aliphatic  alcohols  (methanol,  ethanol,  propanol,  and  butanol)  are  of  interest  as  fuels  because  they  can  be  synthesized  chemically  or  biologically,  and  they  have  characteristics  which  allow  them  to  be  used  in  internal  combustion  engines.  The  general  chemical  formula  for  **alcohol fuel is CnH2n+1OH.**  Most  methanol  are  produced  from  natural  gas,  although  it  can  be  produced  from  biomass  using  very  similar  chemical  processes.  Ethanol  is  commonly  produced  from  biological  material  through  fermentation  processes.  This  mixture  may  also  not  be  purified  by  simple  distillation,  as  it  forms  an  azeotropic  mixture.  Biobutanol  has  the  advantage  in  combustion  engines  in  that  its  energy  density  is  closer  to  gasoline  than  the  simpler  alcohols  (while  still  retaining  over  25%  higher  octane  rating);  however,  biobutanol  is  currently  more  difficult  to  produce  than  ethanol  or  methanol.  When  obtained  from  biological  materials  and/or  biological  processes,  they  are  known  as  bio  alcohols  (e.g.  "bioethanol").  There  is  no  chemical  difference  between  biologically  produced  and  chemically  produced  alcohols.  One  advantage  shared  by  the  four  major  alcohol  fuels  is  their  high  octane  rating.  This  tends  to  increase  their  fuel  efficiency  and  largely  offsets  the  lower  energy  density  of  vehicular  alcohol  fuels  (as  compared  to  petrol/gasoline  and  diesel  fuels),  thus  resulting  in  comparable  "fuel  economy"  in  terms  of  distance  per  volume  metrics,  such  as  kilometres  per  liter,  or  miles  per  gallon.  **Advantages**   Is  cheaper  and  more  efficient  and  does  not  damage  environment  as  much.   Made  from  a  renewable  energy  source,  corn  in  the  US,  sugar  cane  in  Brazil,  or  anything  else  that  can  produce  ethanol.   It  reduces  certain  greenhouse  emissions,  CO  and  UHC's   Higher  octane  rating,  engine  can  have  higher  compression  **Disadvantages**   Less  energy  content,  it  has  1/3  less  energy  than  gasoline   Emits  cancer  causing  emissions  40x  more  than  gasoline.  Acetaldehyde,  and  formaldehyde.   Takes  more  energy  to  produce  that  it  you  get  out.  only  83%  back.  Material  incapability.   Ethanol  destroys  aluminium,  rubber,  gaskets,  and  many  other  things,  so  special  materials  are  used  in  FFV's  and  to  transport  it.   May  corrode  parts  of  engine,  you  may  have  to  fill  in  more  often  as  alcohol  runs  out  quickly. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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**LECTURE HANDOUTS**

**IV/VII**

**MECH**

**Course Name : ADVANCED I.C ENGINES**

**Unit : IV-ALTERNATIVE FUELS**

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| **Topic of Lecture :** Hydrogen Properties, Suitability, Merits and Demerits |
| **Introduction:**  Hydrogen  fuel  is  a  zero-emission  fuel  which  uses  electrochemical  cells  or  combustion  in  internal  engines,  to  power  vehicles  and  electric  devices.  It  is  also  used  in  the  propulsion  of  spacecraft  and  can  potentially  be  mass-produced  and  commercialized  for  passenger  vehicles  and  aircraft. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Hydrogen  is  one  of  two  natural  elements  that  combine  to  make  water.  Hydrogen  is  not  an  energy  source,  but  an  energy  carrier  because  it  takes  a  great  deal  of  energy  to  extract  it  from  water.  It  is  useful  as  a  compact  energy  source  in  fuel  cells  and  batteries. |
| **Detailed content of the Lecture:**  Hydrogen  fuel  is  a  zero-emission  fuel  which  uses  electrochemical  cells  or  combustion  in  internal  engines,  to  power  vehicles  and  electric  devices.  It  is  also  used  in  the  propulsion  of  spacecraft  and  can  potentially  be  mass-produced  and  commercialized  for  passenger  vehicles  and  aircraft.  Hydrogen  is  one  of  two  natural  elements  that  combine  to  make  water.  Hydrogen  is  not  an  energy  source,  but  an  energy  carrier  because  it  takes  a  great  deal  of  energy  to  extract  it  from  water.  It  is  useful  as  a  compact  energy  source  in  fuel  cells  and  batteries.  Hydrogen  is  the  lightest  and  most  abundant  element  in  the  universe.  It  can  be  produced  from  a  number  of  feedstock’s  in  a  variety  of  ways.  The  production  method  thought  to  be  most  environmentally  benign  is  the  electrolysis  of  water,  but  probably  the  most  common  source  of  hydrogen  is  the  steam  reforming  of  natural  gas.  Once  produced,  hydrogen  can  be  stored  as  a  gas,  liquid,  or  solid  and  distributed  as  required.  Liquid  storage  is  currently  the  preferred  method,  but  it  is  very  costly. Hydrogen-powered  vehicles  can  use  internal  combustion  engines  or  fuel  cells.  They  can  also  be  hybrid  vehicles  of  various  combinations.  When  hydrogen  is  used  as  a  gaseous  fuel  in  an  internal  combustion  engine,  its  very  low  energy  density  compared  to  liquid  fuels  is  a  major  drawback  requiring  greater  storage  space  for  the  vehicle  to  travel  a  similar  distance  to  gasoline  **Advantages:**   Emits  only  water  vapour,  assuming  there  is  no  leakage  of  hydrogen  gas   It  can  store  up  to  3x  as  much  energy  as  conventional  natural  gas.  **Disadvantages:**   Leakage  of  H  gas  (see  above)  will  have  detrimental  impacts  on  the  stratosphere  (California  Institute  of  Technology)   Production  of  hydrogen  gas  currently  relies  on  natural  gas  and  electrolysis  and  to  replace  all  the  vehicles  would  require  10x  as  much  as  currently  is  used   Storage  is  really  tough  because  hydrogen  is  such  a  low  density  gas   Distribution and infrastructure needs to be refurbished to cope with hydrogen,  which  can  metals  by  making  them  brittle   Use in fuel cells requires catalysts, which usually require a component metal  (most  often  platinum).  Platinum  is  extremely  rare,  expensive  and environmentally  unsound  to  produce. |
| **Video Content / Details of website for further learning (if any): NIL** |
| **Important Books/Journals for further learning including the page nos.:**  Panneer Selvam, R, “Engineering Economics”, Prentice Hall of India Ltd, New Delhi, 2001. Pg no (4-6). |

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**LECTURE HANDOUTS**

**IV/VII**

**MECH**

**Course Name : ADVANCED I.C ENGINES**

**Unit : IV- ALTERNATIVE FUELS**

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| --- |
| **Topic of Lecture :** Compressed Natural Gas Properties, Suitability, |
| **Introduction:**  Natural  gas  is  a  naturally  occurring  hydrocarbon  gas  mixture  consisting  primarily  of  methane,  but  commonly  including  varying  amounts  of  other  hydrocarbons,  carbon  dioxide,  nitrogen  and  hydrogen  sulfide.  Natural  gas  is  an  energy  source  often  used  for  heating,  cooking,  and  electricity  generation.  It  is  also  used  as  fuel  for  vehicles  and  as  a  chemical  feedstock  in  the  manufacture  of  plastics  and  other  commercially  important  organic  chemicals |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Natural  gas  is  found  in  deep  underground  natural  rock  formations  or  associated  with  other  hydrocarbon  reservoirs  in  coal  beds  and  as  methane  clathrates.  Petroleum  is  also  another  resource  found  in  proximity  to  and  with  natural  gas.  Most  natural  gas  was  created  over  time  by  two  mechanisms:  biogenic  and  thermogenic.  Biogenic  gas  is  created  by  methanogenic  organisms  in  marshes,  bogs,  landfills,  and  shallow  sediments.  Deeper  in  the  earth,  at  greater  temperature  and  pressure,  thermogenic  gas  is  created  from  buried  organic  material. |
| **Detailed content of the Lecture:**  Natural  gas  is  an  energy  source  often  used  for  heating,  cooking,  and  electricity  generation.  It  is  also  used  as  fuel  for  vehicles  and  as  a  chemical  feedstock  in  the  manufacture  of  plastics  and  other  commercially  important  organic  chemicals.  Natural  gas  is  a  naturally  occurring  hydrocarbon  gas  mixture  consisting  primarily  of  methane,  but  commonly  including  varying  amounts  of  other  hydrocarbons,  carbon  dioxide,  nitrogen  and  hydrogen  sulfide.    biogenic  and  thermogenic.  Biogenic  gas  is  created  by  methanogenic  organisms  in  marshes,  bogs,  landfills,  and  shallow  sediments.  Deeper  in  the  earth,  at  greater  temperature  and  pressure,  thermogenic  gas  is  created  from  buried  organic  material.  **Advantages:**   Natural  gas  (largely  methane)  burns  more  cleanly  than  the  other  fossil  fuels  (45%  less  carbon  dioxide  emitted  than  coal  and  30%  less  than  oil)   It  is  easily  transported  via  pipelines  and  fairly  easily  using  tankers  (land  and  sea)   It  can  be  piped  into  homes  to  provide  heating  and  cooking  and  to  run  a  variety  of  appliances.   Where  homes  are  not  piped,  it  can  be  supplied  in  small  tanks.   It  can  be  used  as  a  fuel  for  vehicles  (cars,  trucks  and  jet  engines)  where  it  is  cleaner  than  gasoline  or  diesel.   It  is  used  to  produce  ammonia  for  fertilizers,  and  hydrogen,  as  well  as  in  the  production  of  some  plastics  and  paints.   It's  relatively  abundant,  clean  burning  and  seems  easy  to  distribute.   It's  also  lighter  than  air,  so  if  there  is  a  leak  it  will  tend  to  dissipate,  unlike  propane,  which  is  heavier  than  air  and  pools  into  explosive  pockets.   It  can  be  used  for  heating,  cooking,  hot  water,  clothes  dryer,  backup  generator  power,  and  so  forth.   Some  places  will  supply  it  to  your  house  by  way  of  underground  pipes.   Natural  gas  is  more  economical  than  electricity,   It  is  faster  when  used  in  cooking  and  water  heating  and  most  gas  appliances  are  cheaper  than  electrical  ones.   Gas  appliances  also  do  not  create  unhealthy  electrical  fields  in  your  house.  **Disadvantages:**   Even  though  it  is  cleaner  than  coal  and  oil,  it  still  contributes  a  large  amount  of  carbon  dioxide  to  greenhouse  gases.   By  itself  natural  gas  is  mostly  methane,  which  is  21  times  more  dangerous  for  greenhouse  warming  than  carbon  dioxide  so  any  leakage  of  the  gas  (from  animals,  landfills,  melting  tundra,  etc.)  contributes  strongly  to  greenhouse  emissions.   If  your  house  is  not  properly  insulated  it  can  be  very  expensive.   It  can  leak,  potentially  causing  an  explosion. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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**LECTURE HANDOUTS**

**IV/VII**

**MECH**

**Course Name : ADVANCED I.C ENGINES**

**Unit : IV- ALTERNATIVE FUELS**

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| --- |
| **Topic of Lecture :** Compressed Natural Gas Merits and Demerits |
| **Introduction:**  Vegetable  oil  is  an  alternative  fuel  for  diesel  engines  and  for  heating  oil  burners.  For  engines  designed  to  burn  diesel  fuel,  the  viscosity  of  vegetable  oil  must  be  lowered  to  allow  for  proper  atomization  of  the  fuel;  otherwise  incomplete  combustion  and  carbon  build  up  will  ultimately  damage  the  engine. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  This  type  of  fuel  is  better  for  the  atmosphere  because,  unlike  other  fuels,  it  does  not  give  off  harmful  chemicals  which  can  influence  the  environment  negatively.  The  popularity  of  biodiesel  fuel  is  consistently  increasing  as  people  search  out  alternative  energy  resources.  Biodiesel  refers  to  a  vegetable  oil-  or  animal  fat-based  diesel  fuel  consisting  of  long-chain  alkyl  (methyl,  propyl  or  ethyl)  esters.  Biodiesel  is  typically  made  by  chemically  reacting  lipids  (e.g.,  vegetable  oil,  animal  fat  with  an  alcohol  producing  fatty  acid  esters. |
| **Detailed content of the Lecture:**  **Benefits of vegetable oil run vehicles:**   CO2  neutral   Economical,  cheaper  than  diesel   Excellent  system-energy  efficiency  (from  raw  "crude"  to  refined  product)   Sulphur-free   Protects  crude  oil  resources   100%  biodegradable   Non-hazardous  for  ground,  water,  and  air  in  case  of  a  spill   Low  fire  hazard  (flashpoint  >  220°C)   Practical  to  refuel  at  home   Easy  to  store,  more  ecological  than  bio-diesel   A  chance  for  the  farming  community  and  agriculture  **Disadvantages of vegetable oil run vehicles:**   Loss  of  space  and/or  vehicle  load  capacity  due  to  additional  fuel  storage   Loss  of  manufacturer  guarantee  in  new  vehicles  for  use  of  an  alternative  fuel   Motor  oil  needs  to  be  replaced  more  often  in  a  direct  injection  engine  as  a  safety  precaution  to  avoid  build-up   Currently  no  public  network  of  filling  stations  are  available,  must  refuel  at  home  **Biodiesel**  Fuel  that  is  made  from  natural  elements  such  as  plants,  vegetables,  and  reusable  materials.  This  type  of  fuel  is  better  for  the  atmosphere  because,  unlike  other  fuels,  it  does  not  give  off  harmful  chemicals  which  can  influence  the  environment  negatively.  The  popularity  of  biodiesel  fuel  is  consistently  increasing  as  people  search  out  alternative  energy  resources.  Biodiesel  refers  to  a  vegetable  oil-  or  animal  fat-based  diesel  fuel  consisting  of  long-chain  alkyl  (methyl,  propyl  or  ethyl)  esters.  Biodiesel  is  typically  made  by  chemically  reacting  lipids  (e.g.,  vegetable  oil,  animal  fat  with  an  alcohol  producing  fatty  acid  esters.  Biodiesel  is  meant  to  be  used  in  standard  diesel  engines  and  is  thus  distinct  from  the  vegetable  and  waste  oils  used  to  fuel  converted  diesel  engines.  Biodiesel  can  be  used  alone,  or  blended  with  petro  diesel.  Biodiesel  can  also  be  used  as  a  low  carbon  alternative  to  heating  oil. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

**Course Faculty**

**Verified by HOD**

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**LECTURE HANDOUTS**

**IV/VII**

**MECH**

**Course Name with Code : ADVANCED I.C ENGINES**

**Unit : IV-ALTERNATIVE FUELS**

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| --- |
| **Topic of Lecture :** Liquefied Petroleum Gas Properties, Suitability |
| **Introduction:**  Liquefied  petroleum  gas,  also  called  LPG,  GPL,  LP  Gas,  liquid  petroleum  gas  or  simply  propane  or  butane,  is  a  flammable  mixture  of  hydrocarbon  gases  used  as  a  fuel  in  heating  appliances  and  vehicles. LPG  is  prepared  by  refining  petroleum  or  "wet"  natural  gas,  and  is  almost  entirely  derived  from  fossil  fuel  sources,  being  manufactured  during  the  refining  of  petroleum  (crude  oil),  or  extracted  from  petroleum  or  natural  gas  streams  as  they  emerge  from  the  ground.**LPG is a**  **mixture of propane and butane (this is called autogas).** |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  There  is  reduction  in  power  output  for  LPG  operation  than  gasoline  operation.   Starting  load  on  the  battery  for  an  LPG  engine  is  higher  than  gasoline  engine  due  to  higher  ignition  system  energy  required.   LPG  system  requires  more  safety.  In  case  of  leakage  LPG  has  tendency  to  accumulate  near  ground  as  it  is  heavier  than  air.   This  is  hazardous  as  it  may  catch  fire.   Volume  of  LPG  required  is  more  by  15  to  20%  as  compared  to  gasoline.   LPG  operation  increases  durability  of  engine  and  life  of  exhaust  system  is  increased. |
| **Detailed content of the Lecture:**  Relative  fuel  consumption  of  LPG  is  about  ninety  percent  of  that  of  gasoline  by  volume.   LPG  has  higher  octane  number  of  about  112,  which  enables  higher  compression  ratio  to  be  employed  and  gives  more  thermal  efficiency.   Due  to  gaseous  nature  of  LPG  fuel  distribution  between  cylinders  is  improved  and  smoother  acceleration  and  idling  performance  is  achieved.   Fuel  consumption  is  also  better.   Engine  life  is  increased  for  LPG  engine  as  cylinder  bore  wear  is  reduced  &  combustion  chamber  and  spark  plug  deposits  are  reduced.   As  LPG  is  stored  under  pressure,  LPG  tank  is  heavier  and  requires  more  space  than  gasoline  tank.   There  is  reduction  in  power  output  for  LPG  operation  than  gasoline  operation.   Starting  load  on  the  battery  for  an  LPG  engine  is  higher  than  gasoline  engine  due  to  higher  ignition  system  energy  required.   LPG  system  requires  more  safety.  In  case  of  leakage  LPG  has  tendency  to  accumulate  near  ground  as  it  is  heavier  than  air.   This  is  hazardous  as  it  may  catch  fire.   Volume  of  LPG  required  is  more  by  15  to  20%  as  compared  to  gasoline.   LPG  operation  increases  durability  of  engine  and  life  of  exhaust  system  is  increased.   LPG  has  lower  carbon  content  than  gasoline  or  diesel  and  produces  less  CO2which  plays  a  major  role  in  global  warming  during  combustion.  The  normal  components  of  LPG  are  propane  (C3H8)  and  butane  (C4H10).  Small  concentrations  of  other  hydrocarbons  may  also  be  present.  Methane  -  0%, Ethane  -  0.20%, Propane  -  57.30%,Butane  -  41.10%, Pentane  -  1.40% |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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**LECTURE HANDOUTS**

**IV/VII**

**MECH**

**Course Name : ADVANCED I.C ENGINES**

**Unit : IV-ALTERNATIVE FUELS**

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| --- |
| **Topic of Lecture :** Liquefied Petroleum Gas Merits and Demerits |
| **Introduction:**  Liquefied  petroleum  gas,  also  called  LPG,  GPL,  LP  Gas,  liquid  petroleum  gas  or  simply  propane  or  butane,  is  a  flammable  mixture  of  hydrocarbon  gases  used  as  a  fuel  in  heating  appliances  and  vehicles. LPG  is  prepared  by  refining  petroleum  or  "wet"  natural  gas,  and  is  almost  entirely  derived  from  fossil  fuel  sources,  being  manufactured  during  the  refining  of  petroleum  (crude  oil),  or  extracted  from  petroleum  or  natural  gas  streams  as  they  emerge  from  the  ground.. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**   Relative  fuel  consumption  of  LPG  is  about  ninety  percent  of  that  of  gasoline  by  volume.   LPG  has  higher  octane  number  of  about  112,  which  enables  higher  compression  ratio  to  be  employed  and  gives  more  thermal  efficiency.   Due  to  gaseous  nature  of  LPG  fuel  distribution  between  cylinders  is  improved  and  smoother  acceleration  and  idling  performance  is  achieved.   Fuel  consumption  is  also  better |
| **Detailed content of the Lecture:**   LPG  operation  increases  durability  of  engine  and  life  of  exhaust  system  is  increased.   LPG  has  lower  carbon  content  than  gasoline  or  diesel  and  produces  less  CO2which  plays  a  major  role  in  global  warming  during  combustion.  The  normal  components  of  LPG  are  propane  (C3H8)  and  butane  (C4H10).  Small  concentrations  of  other  hydrocarbons  may  also  be  present.  Methane  -  0%  Ethane  -  0.20%  Propane  -  57.30%  Butane  -  41.10%  Pentane  -  1.40%  **Advantages**   LPG  is  cheaper  than  petrol  (up  to  50%)   It  produces  less  exhaust  emissions  than  petrol   It  is  better  for  the  engine  and  it  can  prolong  engine  life   In  some  vehicles,  it  can  provide  better  performance   Has  a  higher  octane  rating  than  petrol  (108  compared  to  91).  **Disadvantages**   It  isn't  highly  available   The  initial  cost  for  converting  your  vehicle  to  LPG  can  cost  up  to  $3000.  However  the  average  car  can  repay  the  cost  of  the  conversion  in  about  2  years   It  has  a  lower  energy  density  than  petrol   No  new  passenger  cars  come  readily  fitted  with  LPG  (they  have  to  be  converted)   The  gas  tank  takes  up  a  considerable  amount  of  space  in  the  car  boot |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
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**LECTURE HANDOUTS**

**IV/VII**

**MECH**

**Course Name : ADVANCED I.C ENGINES**

**Unit : IV-ALTERNATIVE FUELS**

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| **Topic of Lecture :** Bio Diesel Properties, Suitability |
| **Introduction:**  Fuel  that  is  made  from  natural  elements  such  as  plants,  vegetables,  and  reusable  materials.  This  type  of  fuel  is  better  for  the  atmosphere  because,  unlike  other  fuels,  it  does  not  give  off  harmful  chemicals  which  can  influence  the  environment  negatively.  The  popularity  of  biodiesel  fuel  is  consistently  increasing  as  people  search  out  alternative  energy  resources. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Biodiesel  refers  to  a  vegetable  oil-  or  animal  fat-based  diesel  fuel  consisting  of  long-chain  alkyl  (methyl,  propyl  or  ethyl)  esters.  Biodiesel  is  typically  made  by  chemically  reacting  lipids  (e.g.,  vegetable  oil,  animal  fat  with  an  alcohol  producing  fatty  acid  esters |
| **Detailed content of the Lecture:**  Biodiesel  is  meant  to  be  used  in  standard  diesel  engines  and  is  thus  distinct  from  the  vegetable  and  waste  oils  used  to  fuel  converted  diesel  engines.  Biodiesel  can  be  used  alone,  or  blended  with  petro  diesel.  Biodiesel  can  also  be  used  as  a  low  carbon  alternative  to  heating  oil.  **Advantages:**  Using  biofuels  can  reduce  the  amount  of  greenhouse  gases  emitted.  They  are  a  much  cleaner  source  of  energy  than  conventional  sources.   As  more  and  more  biofuel  is  created  there  will  be  increased  energy  security  for  the  country  producing  it,  as  they  will  not  have  to  rely  on  imports  or  foreign  volatile  markets.   First  generation  biofuels  can  save  up  to  60%  carbon  emissions  and  second.  Generation  biofuels  can  save  up  to  80%.Biofuels  will  create  a  brand  new  job  infrastructure  and  will  help  support  local  economies.  This  is  especially  true  in  third  world  countries.  There  can  be  a  reduction  in  fossil  fuel  use.   Biofuel  operations  help  rural  development.   Biodiesel  can  be  used  in  any  diesel  vehicle  and  it  reduces  the  number  of  vibrations,  smoke  and  noise  produced.   Biodiesel  is  biodegradable.  **Disadvantages:**   Biofuel  development  and  production  is  still  heavily  dependent  on  Oil.   As  other  plants  are  replaced,  soil  erosion  will  grow.   A  lot  of  water  is  used  to  water  the  plants,  especially  in  dry  climates.   Deforestation  in  South  America  and  South  Eastern  Asia  causes  loss  of  habitat  for  animals  and  for  indigenous  people  living  there.   New  technologies  will  have  be  developed  for  vehicles  for  them  to  use  these  fuels.  This  will  increase  their  prices  significantly |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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**LECTURE HANDOUTS**

**IV/VII**

**MECH**

**Course Name : ADVANCED I.C ENGINES**

**Unit : IV-ALTERNATIVE FUELS**

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| **Topic of Lecture :** Bio Diesel Merits and Demerits |
| **Introduction:**  Fuel  that  is  made  from  natural  elements  such  as  plants,  vegetables,  and  reusable  materials.  This  type  of  fuel  is  better  for  the  atmosphere  because,  unlike  other  fuels,  it  does  not  give  off  harmful  chemicals  which  can  influence  the  environment  negatively.  The  popularity  of  biodiesel  fuel  is  consistently  increasing  as  people  search  out  alternative  energy  resources.. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Biogas  typically  refers  to  a  gas  produced  by  the  breakdown  of  organic  matter  in  the  absence  of  oxygen.  It  is  a  renewable  energy  source,  like  solar  and  wind  energy.  Furthermore,  biogas  can  be  produced  from  regionally  available  raw  materials  and  recycled  waste  and  is  environmentally  friendly  and  CO2  neutral. |
| **Detailed content of the Lecture:**  Biogas  is  produced  by  the  anaerobic  digestion  or  fermentation  of  biodegradable  materials  such  as  manure,  sewage,  municipal  waste,  green  waste,  plant  material,  and  crops.  Biogas  comprises  primarily  methane  (CH4)  and  carbon  dioxide  (CO2)  and  may  have  small  amounts  of  hydrogen  sulphide  (H2S),  moisture  and  siloxanes.  The  gases  methane,  hydrogen,  and  carbon  monoxide  (CO)  can  be  combusted  or  oxidized  with  oxygen.  This  energy  release  allows  biogas  to  be  used  as  a  fuel.  Biogas  can  be  used  as  a  fuel  in  any  country  for  any  heating  purpose,  such  as  cooking.  It  can  also  be  used  in  anaerobic  digesters  where  it  is  typically  used  in  a  gas  engine  to  convert  the  energy  in  the  gas  into  electricity  and  heat.  Biogas  can  be  compressed,  much  like  natural  gas,  and  used  to  power  motor  vehicles.  **Advantages of Biogas Energy**   It’s  a  renewable  source  of  energy.   It’s  a  comparatively  lesser  pollution  generating  energy.   Biomass  energy  helps  in  cleanliness  in  villages  and  cities.   It  provides  manure  for  the  agriculture  and  gardens.   There  is  tremendous  potential  to  generate  biogas  energy.   Biomass  energy  is  relatively  cheaper  and  reliable.   It  can  be  generated  from  everyday  human  and  animal  wastes,  vegetable  and agriculture  left-over  etc.   Recycling  of  waste  reduces  pollution  and  spread  of  diseases.   Heat  energy  that  one  gets  from  biogas  is  3.5  times  the  heat  from  burning wood.   Because  of  more  heat  produced  the  time  required  for  cooking  is  lesser.  **Disadvantages of Biogas Energy**   Cost  of  construction  of  biogas  plant  is  high,  so  only  rich  people  can  use  it.   Continuous  supply  of  biomass  is  required  to  generate  biomass  energy.   Some  people  don’t  like  to  cook  food  on  biogas  produced  from  sewage waste.   Biogas  plant  requires  space  and  produces  dirty  smell.   Due  to  improper  construction  many  biogas  plants  are  working  inefficiently.   It  is  difficult  to  store  biogas  in  cylinders.   Transportation  of  biogas  through  pipe  over  long  distances  is  difficult.   Many  easily  grown  grains  like  corn,  wheat  are  being  used  to  make  ethanol.  This  can  have  bad  consequences  if  too  much  of  food  crop  is  diverted  for  use  as  fuel.   Crops  which  are  used  to  produce  biomass  energy  are  seasonal  and  are  not  available  over  whole  year. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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**LECTURE HANDOUTS**

**IV/VII**

**MECH**

**Course Name : ADVANCED I.C ENGINES**

**Unit : IV-ALTERNATIVE FUELS**

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| **Topic of Lecture :** Engine Modifications |
| **Introduction:**  Hydrogen  fuel  has  higher  brake  thermal  efficiency  and  even  can  operate  at  lower  engine  loads  with  better  efficiency.  It  can  be  noticed  that  brake  thermal  efficiency  is  improved  to  about  31  percentage  with  hydrogen  fuelled  engine  compared  to  gasoline  fuelled  engine.  Comparison  of  brake  thermal  efficiency  of  the  fuels  is  shown  in  Fig.  Here  brake  thermal  efficiency  of  hydrogen  is  much  better  than  the  brake  thermal  efficiency  of  gasoline  engine  even  at  a  low  speed. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  NOx  levels  of  both  engines.  Significant  decrease  in  NOx  emission  is  observed  with  hydrogen  operation.  Almost  10  times  decrease  in  NOx  can  be  noted,  easily.  The  cooling  effect  of  the  water  sprayed  plays  important  role  in  this  reduction.  Also  operating  the  engine  with  a  lean  mixture  is  kept  NOx  levels  low. |
| **Detailed content of the Lecture:**  4.17 Engine Design modiﬁcation for all other Alternative Fuels  Spark plugs  Use  cold  rated  spark  plugs  to  avoid  spark  plug  electrode  temperatures  exceeding  the  auto-ignition  limit  and  causing  backﬁre.  Cold  rated  spark  plugs  can  be  used  since  there  are  hardly  any  spark  plug  deposits  to  burn  oﬀ.  Ignition system  Avoid  uncontrolled  ignition  due  to  residual  ignition  energy  by  properly  grounding  the  ignition  system  or  changing  the  ignition  cable’s  electrical  resistance.  Alternatively,  the  spark  plug  gap  can  be  decreased  to  lower  the  ignition  voltage.  Injection system  Provide  a  timed  injection,  either  using  port  injection  and  programming  the  injection  timing  such  that  an  initial  air  cooling  period  is  created  in  the  initial  phase  of  the  intake  stroke  and  the  end  of  injection  is  such  that  all  fuel  is  inducted,  leaving  no  fuel  in  the  manifold  when  the  intake  valve  closes;  or  using  direct  injection  during  the  compression  stroke.  Hot spots  Avoid  hot  spots  in  the  combustion  chamber  that  could  initiate  pre-ignition  or  backfire.  Compression ratio  The  choice  of  the  optimal  compression  ratio  is  similar  to  that  for  any  fuel,  it  should  be  chosen  as  high  as  possible  to  increase  engine  eﬃciency,  with  the  limit  given  by  increased  heat  losses  or  appearance  of  abnormal  combustion  (in  the  case  of  fuel  primarily  pre-ignition). |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : V - RECENT TRENDS**

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| **Topic of Lecture :** Air assisted Combustion |
| **Introduction:**  Homogeneous  charge  compression  ignition  (HCCI)  is  a  form  of  internal  combustion  in  which  well-mixed  fuel  and  oxidizer  (typically  air)  are  compressed  to  the  point  of  auto-ignition.  As  in  other  forms  of  combustion,  this  exothermic  reaction  releases  chemical  energy  into  a  sensible  form  that  can  be  transformed  in  an  engine  into  work  and  heat. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  A  mixture  of  fuel  and  air  will  ignite  when  the  concentration  and  temperature  of  reactants  is  sufficiently  high |
| **Detailed content of the Lecture:**  **Methods**  A  mixture  of  fuel  and  air  will  ignite  when  the  concentration  and  temperature  of  reactants  is  sufficiently  high.  The  concentration  and/or  temperature  can  be  increasd  by  several  different  ways,  1.  High  compression  ratio  2.  Pre-heating  of  induction  gases  3.  Forced  induction  4.  Retained  or  re-inducted  exhaust  gases  Once  ignited,  combustion  occurs  very  quickly.  When  auto-ignition  occurs  too  early  or  with  too  much  chemical  energy,  combustion  is  too  fast  and  high  in-cylinder  pressures  can  destroy  an  engine.  For  this  reason,  HCCI  is  typically  operated  at  lean  overall  fuel  mixtures    In**an HCCI engine (which is based on the four-stroke Otto cycle)**,  fuel  delivery  control  is  of  paramount  importance  in  controlling  the  combustion  process.  On  the  intake  stroke,  fuel  is  injected  into  each  cylinder's  combustion  chamber  via  fuel  injectors  mounted  directly  in  the  cylinder  head.  This  is  achieved  independently  from  air  induction  which  takes  place  through  the  intake  plenum.  By  the  end  of  the  intake  stroke,  fuel  and  air  have  been  fully  introduced  and  mixed  in  the  cylinder's  combustion  chamber.  Fig .1 Homogeneous charge compression ignition  As  the  piston  begins  to  move  back  up  during  the  compression  stroke,  heat  begins to  build  in  the  combustion  chamber.  When  the  piston  reaches  the  end  of  this  stroke,  sufficient  heat  has  accumulated  to  cause  the  fuel/air  mixture  to  spontaneously  combust  (no  spark  is  necessary)  and  force  the  piston  down  for  the  power  stroke.  Unlike  conventional  spark  engines  (and  even  diesels),  the  combustion  process  is  a  lean,  low  temperature  and  flameless  release  of  energy  across  the  entire  combustion  chamber.  The  entire  fuel  mixture  is  burned  simultaneously  producing  equivalent  power,  but  using  much  less  fuel  and  releasing  far  fewer  emissions  in  the  process. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : RECENT TRENDS**

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| **Topic of Lecture :** Homogeneous charge compression ignition engines |
| **Introduction:**  The  nitric  oxide  formation  during  the  combustion  process  is  the  result  of  group  of  elementary  reaction  involving  the  nitrogen  and  oxygen  molecules.  Different  mechanism  proposed  is  discussed  below. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  This  mechanism  proposed  by  Eyzat  and  Guibet  predicts  NO  concentrations  much  lower  that  those  measured  in  I.C  engines. |
| **Detailed content of the Lecture:**  **Advantages**   HCCI  provides  up  to  a  30-percent  fuel  savings,  while  meeting  current  emissions  standards.   Since  HCCI  engines  are  fuel-lean,  they  can  operate  at  a  Diesel-like  compression  ratios  (>15),  thus  achieving  higher  efficiencies  than  conventional  spark-ignited  gasoline  engines.   Homogeneous  mixing  of  fuel  and  air  leads  to  cleaner  combustion  and  lower  emissions.  Actually,  because  peak  temperatures  are  significantly  lower  than  in  typical  spark  ignited  engines,  NOxlevels  are  almost  negligible.  Additionally,  the  premixed  lean  mixture  does  not  produce  soot.   HCCI  engines  can  operate  on  gasoline,  diesel  fuel,  and  most  alternative  fuels.   In  regards  to  gasoline  engines,  the  omission  of  throttle  losses  improves  HCCI  efficiency.  **Disadvantages**   High  in-cylinder  peak  pressures  may  cause  damage  to  the  engine.   High  heat  release  and  pressure  rise  rates  contribute  to  engine  wear.   The  auto  ignition  event  is  difficult  to  control,  unlike  the  ignition  event  in  spark  ignition  (SI)  and  diesel  engines  which  are  controlled  by  spark  plugs  and  in-cylinder  fuel  injectors,  respectively.   HCCI  engines  have  a  small  power  range,  constrained  at  low  loads  by  lean  flammability  limits  and  high  loads  by  in-cylinder  pressure  restrictions.   Carbon  monoxide  (CO)  and  hydrocarbon  (HC)  pre-catalyst  emissions are  higher  than  a  typical  spark  ignition  engine,  caused  by  incomplete oxidation  (due  to  the  rapid  combustion  event  and  low  in-cylinder  temperatures)  and  trapped  crevice  gases,  respectively. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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**LECTURE HANDOUTS**

**IV/VII**

**MECH**

**Course Name : ADVANCED I.C ENGINES**

**Unit : RECENT TRENDS**

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| **Topic of Lecture :** HCCI engines advantage Disadvantage |
| **Introduction:**  Internal combustion engines (ICE) operate by burning fossil fuel derivatives. Exhaust  Emissions are their major contribution to environmental pollution. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**    Lean-burn  means  pretty  much  what  it  says.  It  is  a  lean  amount  of  fuel  supplied  to  and  burned  in  an  engine's  combustion  chamber.  Normal  air-to-fuel  ratio  is  on  the  order  of  15:1  (15  parts  air  to  1  part  fuel).  True  lean-burn  can  go  as  high  as  23:1. |
| **Detailed content of the Lecture:**    **Working Principle**  A  lean  burn  mode  is  a  way  to  reduce  throttling  losses.   An  engine  in  a  typical  vehicle  is  sized  for  providing  the  power  desired  for  acceleration,  but  must  operate  well  below  that  point  in  normal  steady-speed  operation.  Ordinarily,  the  power  is  cut  by  partially  closing  a  throttle.   However,  the  extra  work  done  in  pumping  air  through  the  throttle  reduces  efficiency.   If  the  fuel/air  ratio  is  reduced,  then  lower  power  can  be  achieved  with  the  throttle  closer  to  fully  open,  and  the  efficiency  during  normal  driving  (below  the  maximum  torque  capability  of  the  engine)  can  be  higher.   The  engines  designed  for  lean  burning  can  employ  higher  compression  ratios  and  thus  provide  better  performance,  efficient  fuel  use  and  low  exhaust  hydrocarbon  emissions  than  those  found  in  conventional  petrol  engines.   Ultra  lean  mixtures  with  very  high  air-fuel  ratios  can  only  be  achieved  by  direct  injection  engines.   The  main  drawback  of  lean  burning  is  that  a  complex  catalytic  converter  system  is  required  to  reduce  NOx  emissions.   Lean  burn  engines  do  not  work  well  with  modern  3-way  catalytic  converter  which  requires  a  pollutant  balance  at  the  exhaust  port  so  they  can  carry  out  oxidation  and  reduction  reactions  so  most  modern  engines  run  at  or  near  the  stoichiometric  point.   Alternatively,  ultra-lean  ratios  can  reduce  NOx  emissions.  **Lean burn engine**  A  lean  burn  mode  is  a  way  to  reduce  throttling  losses.   An  engine  in  a  typical  vehicle  is  sized  for  providing  the  power  desired  for  acceleration,  but  must  operate  well  below  that  point  in  normal  steady-speed  operation.  Ordinarily,  the  power  is  cut  by  partially  closing  a  throttle.   However,  the  extra  work  done  in  pumping  air  through  the  throttle  reduces  efficiency.   If  the  fuel/air  ratio  is  reduced,  then  lower  power  can  be  achieved  with  the  throttle  closer  to  fully  open,  and  the  efficiency  during  normal  driving  (below  the  maximum  torque  capability  of  the  engine)  can  be  higher.   The  engines  designed  for  lean  burning  can  employ  higher  compression  ratios  and  thus  provide  better  performance,  efficient  fuel  use  and  low  exhaust  hydrocarbon  emissions  than  those  found  in  conventional  petrol  engines.   Ultra  lean  mixtures  with  very  high  air-fuel  ratios  can  only  be  achieved  by  direct  injection  engines.   The  main  drawback  of  lean  burning  is  that  a  complex  catalytic  converter  system  is  required  to  reduce  NOx  emissions.   Lean  burn  engines  do  not  work  well  with  modern  3-way  catalytic  converter  which  requires  a  pollutant  balance  at  the  exhaust  port  so  they  can  carry  out  oxidation  and  reduction  reactions  so  most  modern  engines  run  at  or  near  the  stoichiometric  point.   Alternatively,  ultra-lean  ratios  can  reduce  NOx  emissions. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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**LECTURE HANDOUTS**

**IV/VII**

**MECH**

**Course Name : ADVANCED I.C ENGINES**

**Unit : V - RECENT TRENDS**

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| --- |
| **Topic of Lecture :** Variable Geometry turbochargers |
| **Introduction:**  Internal combustion engines (ICE) operate by burning fossil fuel derivatives. Exhaust  Emissions are their major contribution to environmental pollution. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  An internal-combustion engine with a divided ignition cylinder that uses the ignition of  rich fuel in a small chamber near the spark plug to improve the combustion of a very  lean mixture throughout the rest of the cylinder. |
| **Detailed content of the Lecture:**  The  stratified  charge  engine  is  a  type  of  internal-combustion  engine  which  runs  on  gasoline.  It  is  very  much  similar  to  the  Diesel  cycle.  The  name  refers  to  the  layering  of  the  charge  inside  the  cylinder.  The  stratified  charge  engine  is  designed  to  reduce  the  emissions  from  the  engine  cylinder  without  the  use  of  exhaust  gas  recirculation  systems,  which  is  also  known  as  the  EGR  or  catalytic  converters.  Stratified  charge  combustion  engines  utilize  a  method  of  distributing  fuel  that  successively  builds  layers  of  fuel  in  the  combustion  chamber.  The  initial  charge  of  fuel  is  directly  injected  into  a  small  concentrated  area  of  the  combustion  chamber  where  it  ignites  quickly.  **5.3.1 Principle:-**  The  principle  of  the  stratified  charge  engine is  to  deliver  a  mixture  that  is  sufficiently  rich  for  combustion  in  the  immediate  vicinity  of  the  spark  plug  and  in  the  remainder  of  the  cylinder,  a  very  lean  mixture  that  is  so  low  in  fuel  that  it  could  not  be  used  in  a  traditional  engine.  On  an  engine  with  stratified  charge,  the  delivered  power  is  no  longer  controlled  by  the  quantity  of  admitted  air,  but  by  the  quantity  of  petrol  injected,  as  with  a  diesel  engine.  **5.3.2 Working:**   One  approach  consists  in  dividing  the  combustion  chamber so  as  to  create  a  pre-combustion  chamber  where  the  spark plug  is  located.  The  head  of  the  piston  is  also  modified.   It  contains a  spheroid  cavity  that  imparts  a  swirling  movement  to the  air  contained  by  the  cylinder  during  compression.  As  a result,  during  injection,  the  fuel  is  only  sprayed  in  the  vicinity  of  the  spark  plug.  But  other  strategies  are  possible.   For  example,  it  is  also  possible  to  exploit  the  shape  of  the  admission  circuit  and  use  artifices,  like  ‚swirl‛  or  ‚tumble‛  stages  that  create  turbulent  flows  at  their  level. All  the  subtlety  of  engine  operation  in  stratified  mode occurs  at  level  of  injection. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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**LECTURE HANDOUTS**

**IV/VII**

**MECH**

**Course Name : ADVANCED I.C ENGINES**

**Unit : V - RECENT TRENDS**

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| --- |
| **Topic of Lecture :** Common Rail Direct Injection Systems |
| **Introduction:**  This  comprises  two  principal modes:  a  lean  mode,  which  corresponds  to  operation  at  very low  engine  load,  therefore  when  there  is  less  call  on  it,  and  a ‚normal‛  mode,  when  it  runs  at  full  charge  and  delivers  maximum  power. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**   In  the  first  mode**,** injection  takes  place  at  the  end  of  the  compression stroke.  Because  of  the  swirl  effect  that  the  piston cavity  creates,  the  fuel  sprayed  by  the  injector  is  confined near  the  spark  plug.  As  there  is  very  high  pressure  in  the cylinder  at  this  moment,  the  injector  spray  is  also  quite  concentrated. |
| **Detailed content of the Lecture:**   The  ‚directivity‛  of  the  spray  encourages  even greater  concentration  of  the  mixture.   A  very  small  quantity  of fuel  is  thus  enough  to  obtain  optimum  mixture  richness  in  the zone  close  to  the  spark  plug,  whereas  the  remainder  of  the  cylinder  contains  only  very  lean  mixture.   The  stratification  of air  in  the  cylinder  means  that  even  with  partial  charge  it  is also  possible  to  obtain  a  core  of  mixture  surrounded  by  layers of  air  and  residual  gases  which  limit  the  transfer  of  heat  to  the cylinder  walls.   This  drop  in  temperature  causes  the  quantity of  air  in  the  cylinder  to  increase  by  reducing  its  dilation,  delivering the  engine  additional  power.   When  idling,  this  process makes  it  possible  to  reduce  consumption  by  almost  40%  compared to  a  traditional  engine.  And  this  is  not  the  only  gain.  Functioning  with  stratified  charge  also  makes  it  possible  to lower  the  temperature  at  which  the  fuel  is  sprayed.   All  this  leads  to  a  reduction  in  fuel  consumption  which  is  of  course  reflected  by  a  reduction  of  engine  exhaust  emissions.  When  engine  power  is  required,  injection  takes  place  in  normal  mode,  during  the  admission  phase.   This  makes  it  possible  to  achieve  a  homogeneous  mix,  as  it  is  the  case  with  traditional  injection.   Here,  contrary  to  the  previous  example,  when  the  injection  takes  place,  the  pressure  in  the  cylinder  is  still  low.   The  spray  of  fuel  from  the  injector  is  therefore  highly  divergent,  which  encourages  a  homogeneous  mix  to  form.  **Advantages Of Stratified Charge Engine**   * Compact,  lightweight  design  &good  fuel  economy. * Good  part  load  efficiency. * Exhibit  multi  fuel  capability. * The  rich  mixture  near  spark-plug  &lean  mixture  near  the  piston  surface * provides  Cushing  to  the  exploit  combustion. * Resist  the  knocking  &  provides  smooth  resulting  in  smooth  &  quite  engine * operation  over  the  entire  speed  &  load  range. * Low  level  of  exhaust  emissions,  Nox  is  reduced  considerably. * Usually  no  starting  problem. * Can  be  manufactured  by  the  existing  technology. * **Disadvatages** * For  a  given  engine  size,  charge  charge  stratification  results  in  reduced. * These  engines  create  high  noise  level  at  low  load  conditions. * More  complex  design  to  supply  rich  &  lean  mixture  &  quantity  is  varied * with  load  on  the  engine. * Higher  weight  than  of  a  conventional  engine. * Unthrotlled  stratified  charge  emits  high  percentage  of  HC  due  to  either * incomplete  combustion  of  lean  charge  or  occasional  misfire  of  the  charge  at * low  load  conditions. * Reliability  is  yet  to  be  well  established. * Higher  manufacturing  cost. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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**Course Name : ADVANCED I.C ENGINES**

**Unit : V- RECENT TRENDS**

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| **Topic of Lecture :** Common Rail Direct Injection Systems |
| **Introduction:**  The initiation of a flame in the combustion chamber of an automobile engine by any hot  surface other than the spark discharge |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  The  hot  bulb  engine,  or  hot  bulb  or  heavy  oil  engine  is  a  type  of  internal  combustion  engine.  It  is  an  engine  in  which  fuel  is  ignited  by  being  brought  into  contact  with  a  red-hot  metal  surface  inside  a  bulb  followed  by  the  introduction  of  air  (oxygen)  compressed  into  the  hot  bulb  chamber  by  the  rising  piston |
| **Detailed content of the Lecture:**  .  .  There  is some  ignition  when  the  fuel  is  introduced  but  it  quickly  uses  up  the  available  oxygen  in  the  bulb.  Vigorous  ignition  takes  place  only  when  sufficient  oxygen  is  supplied  to  the  hot  bulb  chamber  on  the  compression  stroke  of  the  engine.  Most  hot  bulb  engines  were  produced  as  one-cylinder  low-speed  two-stroke  crankcase  scavenging  units.  **5.4.1 Operation and working cycle**  The  hot-bulb  engine  shares  its  basic  layout  with  nearly  all  other  internal  combustion  engines,  in  that  it  has  a  piston,  inside  a  cylinder,  connected  to  a  flywheel  via  a  connecting  rod  and  crankshaft.  The  flow  of  gases  through  the  engine  is  controlled  by  valves  in  four-stroke  engines,  and  by  the  piston  covering  and  uncovering  ports  in  the  cylinder  wall  in  two-strokes.  The  type  of  blow-lamp  used  to  start  the  Hot  Bulb  engine.  In  the  hot-bulb  engine  combustion  takes  place  in  a  separated  combustion  chamber,  the  "vaporizer"  (also  called  the  "hot  bulb"),  usually  mounted  on  the  cylinder  head,  into  which  fuel  is  sprayed.  It  is  connected  to  the  cylinder  by  a  narrow  passage  and  is  heated  by  the  combustion  while  running;  an  external  flame  such  as  a  blow-lamp  or  slow-burning  wick  is  used  for  starting  (on  later  models  sometimes  electric  heating  or  pyrotechnics  was  used).  Another  method  is  the  inclusion  of  a  spark  plug  and  vibrator  coil  ignition.[citation  needed]  The  engine  could  be  started  on  petrol  and  switched  over  to  oil  after  it  had  warmed  to  running  temperature.  The  pre-heating  time  depends  on  the  engine  design,  the  type  of  heating  used  and  the  ambient  temperature,  but  generally  ranges  from  2”5  minutes  (for  most  engines  in  a  temperate  climate)  to  as  much  as  half  an  hour  (if  operating  in  extreme  cold  or  the  engine  is  especially  large).  The  engine  is  then  turned  over,  usually  by  hand  but  sometimes  by  compressed  air  or  an  electric  motor. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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**LECTURE HANDOUTS**

**IV/VII**

**MECH**

**Course Name : ADVANCED I.C ENGINES**

**Unit : V-RECENT TRENDS**

|  |
| --- |
| **Topic of Lecture :** Hybrid Electric Vehicles |
| **Introduction:**  Overhead  camshaft,  commonly  abbreviated  to  OHC. a valve  train configuration  which  places  the  camshaft  of  an  internal  combustion  engine  of  the  reciprocating  type  within  the  cylinder  heads  ('above'  the  pistons  and  combustion  chambers)  and  drives  the  valves  or  lifters  in  a  more  direct  manner  compared  to  overhead  valves  (OHV)  and  pushrods |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  Typical emissions  contain primary greenhouse gases – carbon dioxide (CO2), methane (CH4) and nitrous  oxide (N2O). All criteria pollutants – carbon monoxide (CO), total nitrogen oxides (NO  x), sulfur dioxide (SO2), non-methane volatile organic compounds (NMVOC) and  particulate matter (PM) are the other major components |
| **Detailed content of the Lecture:**  **Single overhead camshaft**  Single  overhead  camshaft  (SOHC)  is  a  design  in  which  one  camshaft  is  placed  within  the  cylinder  head.  In  an  inline  engine,  this  means  there  is  one  camshaft  in  the  head,  whilst  in  an  engine  with  more  than  one  cylinder  head,  such  as  a  V  engine  or  a  horizontally-opposed  engine  (boxer;  flat  engine)  „  there  are  two camshafts:  one  per  cylinder  bank.    **Fig.6.Single overhead camshaft**  (b) **Double overhead camshaft**  A  double  overhead  camshaft(DOHC)  valve  train  layout  (also  known  as  'dual  overhead  camshaft')  is  characterised  by  two  camshafts  located  within  the  cylinder  head,  one  operating  the  intake  valves  and  one  operating  the  exhaust  valves.  This  design  reduces  valve  train  inertia  more  than  a  SOHC  engine,  since  the  rocker  arms  are  reduced  in  size  or  eliminated.    **Fig.7. Double overhead camshaft**  A  DOHC  design  permits  a  wider  angle  between  intake  and  exhaust  valves  than  SOHC  engines.  This  can  allow  for  a  less  restricted  airflow  at  higher  engine  speeds.  DOHC  with  a  multivalve  design  also  allows  for  the  optimum  placement  of  the  spark  plug,  which  in  turn,  improves  combustion  efficiency. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

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| Logo_MEC  **LECTURE HANDOUTS**  **IV/VII**  **MECH** | **MUTHAYAMMAL ENGINEERING COLLEGE**  **(An Autonomous Institution)**  **(Approved by AICTE, New Delhi, Accredited by NAAC & Affiliated to Anna University)**  **Rasipuram - 637 408, Namakkal Dist., Tamil Nadu** | **L-44** |

**Course Name : ADVANCED I.C ENGINES**

**Unit : V-RECENT TRENDS**

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| **Topic of Lecture :** NOx Absorbers |
| **Introduction:**  The  coolant  sensor  monitors  engine  temperature.  The  PCM  uses  this  information  to  regulate  a  wide  variety  of  ignition,  fuel  and  emission  control  functions.  When  the  engine  is  cold,  for  example,  the  fuel  mixture  needs  to  be  richer  to  improve  drivability.  Once  the  engine  reaches  a  certain  temperature,  the  PCM  starts  using  the  signal  from  the  O2  sensor  to  vary  the  fuel  mixture |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**  This  is  called  "closed"  operation,  and  it  is  necessary  to  keep  emissions  to  a  minimum. |
| **Detailed content of the Lecture:**    **Throttle position sensor (TPS)**  The  throttle  position  sensor  (TPS)  keeps  the  PCM  informed  about  throttle  position.  The  PCM  uses  this  input  to  change  spark  timing  and  the  fuel  mixture  as  engine  load  changes.  A  problem  here  can  cause  a  flat  spot  during  acceleration  (like  a  bad  accelerator  pump  in  a  carburetor)  as  well  as  other  drivability  complaints.  **Airflow Sensor**  The  Airflow  Sensor,  of  which  there  are  several  types,  tells  the  PCM  how  much  air  the  engine  is  drawing  in  as  it  runs.  The  PCM  uses  this  to  further  vary  the  fuel  mixture  as  needed.  There  are  several  types  of  airflow  sensors  including  hot  wire  mass  airflow  sensors  and  the  older  flap-style  vane  airflow  sensors.  All  are  very  expensive  to  replace  **Manifold absolute pressure (MAP)**  The  manifold  absolute  pressure  (MAP)  sensor  measures  intake  vacuum,  which  the  PCM  also  uses  to  determine  engine  load.  The  MAP  sensor's  input  affects  ignition  timing  primarily,  but  also  fuel  delivery.  **Knock sensors**  Knock  sensors  are  used  to  detect  vibrations  produced  by  detonation.  When  the  PCM  receives  a  signal  from  the  knock  sensor,  it  momentarily  retards  timing  while  the  engine  is  under  load  to  protect  the  engine  against  spark  knock.  **EGR position sensor**  The  EGR  position  sensor  tells  the  PCM  when  the  exhaust  gas  recirculation  (EGR)  valve  opens  (and  how  much).  This  allows  the  PCM  to  detect  problems  with  the  EGR  system  that  would  increase  pollution. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
| **Important Books/Journals for further learning including the page nos.:**  R.K.Rajbut, “Internal Combustion Engines”, Lakshmi Publications of India LTD,Chennai, ISBN 81-7008-637-X.Pg No 32- 35. |

**Course Faculty**

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**Course Name : ADVANCED I.C ENGINES**

**Unit : V-RECENT TRENDS**

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| **Topic of Lecture :** Onboard Diagnostics |
| **Introduction:**  In internal combustion engines, Gasoline Direct Injection (GDI), also known as Petrol  Direct Injection or Direct Petrol Injection or Spark Ignited Direct Injection (SIDI) or Fuel  Stratified Injection (FSI), is a variant of fuel injection employed in modern two-stroke  and four-stroke gasoline engines. |
| **Prerequisite knowledge for Complete understanding and learning of Topic:**   The gasoline is highly pressurized, and injected via  a common rail fuel line directly into the combustion chamber of each cylinder, as  opposed to conventional multi-point fuel injection that happens in the intake tract, or  cylinder port. |
| **Detailed content of the Lecture:**  **Operation**  The  major  advantages  of  a  GDI  engine  are  increased  fuel  efficiency  and  high  power  output.  Emissions  levels  can  also  be  more  accurately  controlled  with  the GDI  system.  The  cited  gains  are  achieved  by  the  precise  control  over  the  amount  of  fuel  and  injection  timings  that  are  varied  according  to  engine  load.  In  addition,  there  are  no  throttling  losses  in  some  GDI  engines,  when  compared  to  a  conventional  fuel-injected  or  carbureted  engine,  which  greatly  improves  efficiency,  and  reduces  'pumping  losses'  in  engines  without  a  throttle  plate.  Engine  speed  is  controlled  by  the  engine  control  unit/engine  management  system  (EMS),  which  regulates  fuel  injection  function  and  ignition  timing,  instead  of  having a throttle  plate  that  restricts  the  incoming  air  supply.  Adding  this  function  to  the  EMS  requires  considerable  enhancement  of  its  processing  and  memory,  as  direct  injection  plus  the  engine  speed  management  must  have  very  precise  algorithms  for  good  performance  and  drivability.  The  engine  management  system  continually  chooses  among  three  combustion  modes:  ultra-lean  burn,  stoichiometric,  and  full  power  output.  **Ultra lean burn or stratified charge mode**  is  used  for  light-load  running  conditions,  at  constant  or  reducing  road  speeds,  where  no  acceleration  is  required.  The  fuel  is  not  injected  at  the  intake  stroke  but  rather  at  the  latter  stages  of  the  compression  stroke.  The  combustion  takes  place  in  a  cavity  on  the  piston's  surface  which  has  a  toroidal  or  an  ovoidal  shape,  and  is  placed  either  in  the  centre  (for  central  injector),  or  displaced  to  one  side  of  the  piston  that  is  closer  to  the  injector.  The  cavity  creates  the  swirl  effect  so  that  the  small  amount  of  air-fuel  mixture  is  optimally  placed  near  the  spark  plug.  This  stratified  charge  is  surrounded  mostly  by  air  and  residual  gases,  which  keeps  the  fuel  and  the  flame  away  from  the  cylinder  walls.  Decreased  combustion  temperature  allows  for  lowest  emissions  and  heat  losses  and  increases  air  quantity  by  reducing  dilation,  which  delivers  additional  power.  This  technique  enables  the  use  of  ultra-lean  mixtures  that  would  be  impossible  with  carburettors  or  conventional  fuel  injection.  **Stoichiometric mode**  is  used  for  moderate  load  conditions.  Fuel  is  injected  during  the  intake  stroke,  creating  a  homogeneous  fuel-air  mixture  in  the  cylinder.  From  the  stoichiometric  ratio,  an  optimum  burn  results  in  a  clean  exhaust  emission,  further  cleaned  by  the  catalytic  converter.  **Full power mode** is  used  for  rapid  acceleration  and  heavy  loads  (as  when  climbing  a  hill).  The  air-fuel  mixture  is  homogeneous  and  the  ratio  is  slightly  richer  than  stoichiometric,  which  helps  prevent  detonation  (pinging).  The  fuel  is  injected  during  the  intake  stroke. |
| **Video Content / Details of website for further learning (if any):**  https://www.youtube.com/watch?v=zKA4TYMgiqU |
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