An evaluation of global market potential for LPG and CNG Vehicles and Alternative Fuel Conversion Equipment reveals that the number of LPG/CNG kits sold globally was 2.9 million in 2006 and estimated that it will reach 8 million by 2012. LPG kits will continue to dominate the market in the European Union (EU), Russia and Turkey and other markets of the world. India and Iran accounted for 20% of global sales of CNG kits in 2006. While aftermarket sales of LPG/CNG kits currently hold more than 85% of total global kit sales, OEM kit sales will steadily increase to reach more than 27% of total number of units sold by 2012. An appropriate infrastructure (i.e. sufficient number of tank stations) along with required support from governments will accelerate the growth of LPG and CNG as an alternative fuels \[135\].

CNG and LPG conversion system stores, transfers, vapourizes (in case of LPG system), mixes fuel with air and finally makes it ready to be combusted in the engine cylinder.

Mechanical conversions systems for CNG and LPG are basically identical with some exceptions. Storage tanks are different for LPG system. A vapourizer is necessary in LPG conversion systems to vapourize LPG to a low pressure vapour. In CNG conversion system, a high pressure regulator (HPR) is necessary to reduce high pressure of natural gas (200 bar) to a low pressure. While in LPG system HPR is not required due to low pressure in LPG storage tank. Electronic conversion system supports are similar for both CNG and LPG system.

The specifications for LPG as vehicular fuel is governed by an Indian Standard (IS 14861:2000). This fuel is called Auto LPG. Many RTO-recognized agencies in all major cities offer conversion kits. There are number of kits approved by government institutes for various brands and models of vehicles. Italy has the highest number of LPG-driven vehicles, and it is the pioneer manufacturer of LPG systems.

The conversion kit for LPG mainly consists of storage tank, vapourizer, solenoid for Gasoline and LPG and changeover switch with tank-level indicator. The capacity of storage tank is 40 to 60 liters and it is permanently fixed to the vehicle chassis. The tank
is designed to withstand pressure build-up and is sufficiently crash-proof and bullet-proof. The tank must be hydro-tested every year and certificate of latest testing must be displayed near LPG filling valve on the vehicle. A multi-function valve on the tank facilitates filling and limits to 80% of its volumetric capacity for safety purpose. The valve also has a safety relief valve, fusible plug, shut-off valve and level indicator.

5.1 Working Principle of CNG fuel system

CNG is stored on-board the vehicle under pressure in the fuel storage cylinder to a maximum pressure of approximately 200 bar. When the valve in the fuel storage cylinder is opened, CNG at cylinder pressure flows through the excess flow valve and to the T connector. From T connector, CNG at cylinder pressure flows to the three way valve. A high pressure gauge is mounted on the cylinder side of three way valve to show cylinder pressure. From three way valve it flows to the high pressure filter. From high pressure filter, CNG at cylinder pressure flows to the high pressure regulator (HPR). The HPR reduces the pressure of the CNG in one stage from cylinder pressure to 14 bar.

From HPR, CNG flows through gas shut off valve (GSOV), which is normally closed. It requires an electric signal from air-fuel ratio (AFR) controller to open. This is a desirable safety feature, if the engine stops or is turned off, fuel flow automatically stops.

From GSOV, CNG flows to Low Pressure Regulator (LPR). As CNG flows through LPR, pressure is reduced in two stages from HPR output pressure to slightly less than atmospheric pressure, it is very important that outlet pressure of regulator and inlet pressure of air fuel mixer be matched properly.

From LPR, NG flows to air fuel mixer, the fuel passage is normally closed. A vacuum signal from the engine cranking or running is required to draw fuel from fuel outlet. This is a desirable safety feature, if the engine stops or is turned off, fuel flow automatically stops. When mixer receives desired vacuum signal from the engine, it draws metered amount of NG from pressure regulator and blends it with air at proper stoichiometric ratio to achieve peak engine performance over complete operating range.

Overview of basic CNG and LPG conversion system are shown in fig. 5.1 and fig. 5.2 respectively. The main components of CNG/LPG conversion system are shown in fig. 5.3 and LPR / Vapourizer body is shown in fig. 5.4.
Fig. 5.1. Overview of basic CNG conversion system\textsuperscript{[136]}. 

Fig. 5.2. Overview of basic LPG conversion system\textsuperscript{[136]}. 

Fig. 5.3. Components of CNG/LPG conversion system.

Fig. 5.4. Low Pressure Regulator (LPR)/Vapourizer.
The fuel system consists of following major parts:

- Unidirectional Receptacle Valve
- Excess flow check valve
- Burst Disc
- Three way valve
- High pressure gauge with indicator
- High pressure filter and low pressure filter
- High pressure regulator (HPR)
- Low pressure regulator (LPR)
- Gas shut off valve (GSOV)
- Air fuel ratio (AFR) solenoid
- Over speed controller
- Air-fuel mixer
- Gaseous Fuel Tank
- AFR controller and engine speed governor
- Injector cable emulator (in case vehicle is multipoint fuel injection)
- Change over switch
- Hoses and fittings
- Pipes
- Exhaust gas oxygen (EGO) sensor
- Catalytic converter

**Unidirectional Receptacle Valve**

It is one way valve used for refuelling as shown in fig 5.5. It is to be ensured that cap is closed after filling is done. Valve has a cut off switch as a safety device which cuts off the ignition circuit when the cap is not fitted.

The system consists of one valve for filling tank and other for delivery to the intake manifold. It is a non-return valve, thus filling of tank and delivery to the engine is
accomplished through same system and no separate valves are mounted. It is very tightly fitted on the tank using bolts and rubber packing to avoid minor leakage. For filling gas from gas filling station, filler valve is mounted on it. From gas station, filling equipment is fitted on filler valve and gas is filling up into the tank at high pressure\textsuperscript{[88]}.

![Unidirectional Receptacle Valve](image)

Fig. 5.5. Unidirectional Receptacle Valve.

The basic features are stated below:

1. In case of an accident or leakage, the automatic operation of solenoid is shut off gas supply.
2. It has manual shut off lever to control the operation.
3. There is a provision of fusible plug which melts down if temperature increases and hence the gas releases.
4. There is a pressure relief valve which operates when gas pressure in tank exceeds the limiting pressure.

**Excess flow check valve**

This valve normally remains in open position and it closes automatically in the direction of flow for which it is designed, when a predetermined flow limit is exceeded. Excess flow valve checks for excess flow of gas in incident of any leakage. It is a safety device assembled with T connector.
Burst disc

A fusible disc is a safety device which comes into action when pressure in the cylinders exceeds 300-330 bar. The fusible disc fuses at pressure more than 300-330 bar and helps venting high pressure gas in the cylinder to escape in atmosphere through certain vent hoses.

Change Over Switch

The switch is wired into the vehicle’s electrical system, allowing for functioning fuel gauge, as well as proper automatic switching between CNG/LPG and gasoline (along with a dashboard-mounted manual switch). There must be connections to the engine’s electronic control unit (ECU) so that the engine controller can adjust for different fuel settings.

Vehicles with an electronic injection system will probably need an electronic emulator. When the engine is operating on CNG/LPG fuels, the fuel injectors will not send any information to other sensors in engine - this will light up the “check engine” light and give incorrect diagnostic readings. The emulator fakes the signals so the ECU can operate properly.

![Fig. 5.6. Dashboard fuel switch/gauge.](image)

High Pressure Filter

It filters CNG before it being sent to the system along with all kinds of suspended dust particles and oil globules from entering into HPR. It is to be replaced within twelve months of use. For maintenance procedure, close all cylinder valves and start the engine, continue till the engine stops on its own. Ensure there is no gas in the system. Remove the
drain plug at the bottom of the filter assembly. Drain all oil, moisture, etc. Refit the drain plug and check for leakage[127].

First stage regulator / HPR

HPR is a single stage regulator. It is mounted between high pressure filter and gas shut off valve. It is not field serviceable. The primary function of HPR is to accept fuel at storage container pressure up to 200 bar, and reduce it to an outlet pressure of 14 bar. This is necessary because of high storage pressure of CNG. It is heated by engine coolant to eliminate freezing of any moisture during pressure drop. It is equipped with safety relief valve, which will release pressure if it exceeds normal limit. This protects low pressure components downstream. The safety relief valve is actuated by pressure only and no temperature actuation is provided. The pressure relief valve will reset after opening and reducing the pressure. It is not to be replaced after operation. Since HPR is heated by engine coolant, it must be mounted near the radiator to avoid air being trapped into regulator.

Normally, HPR is set at the manufacturing end and should not be adjusted in the field. Improper installation may damage surroundings. For maintenance purpose, for every 50000 kms running of vehicle, HPR should be removed and check for output pressure at authorized service centre [127]. If output pressure is found to be more than 14 bar, it should be replaced with a new one. Also it should be check for any leakage after installation.

Second stage regulator / LPR

The function of second stage regulator is to reduce pressure of gas from 14 bar to 0.7 bar absolute, which is slightly below atmospheric pressure.

LPR is reducing gas pressure, allowing a regular flow of gas every time the engine requires. It is equipped with two natural gas reduction stages that allow stability at high pressure solenoid valve upstream from the first stage. The absorption of heat taken from parts of regulator, heated with liquid of engine cooling circuit, prevents gas from freezing during fall in pressure.

The flow of gas necessary for engine idling is obtained through main gas pipe due to vacuum generated by engine. It includes an electronic starting device with a built-in
safety system that trips and shuts off gas solenoid valve if engine is switched off or even stalls.

After receiving an electric signal from air-fuel ratio (AFR) controller, GSOV opens and CNG flows to inlet port of LPR. As CNG flows through LPR, the pressure is reduced in two stages. In first stage gas flows through inlet union through duct to the first stage valve and enters into the first stage chamber. Here pressure is reduced from 14 bar to 3” to 6” of water column (wc), which is equivalent to 0.00747 bar to 0.015 bar. The pressure of gas on the walls of this chamber expands the first stage diaphragm by overcoming the resistance of calibrated spring. This first stage diaphragm is connected to lever fulcrum which acts on the first stage valve. Due to open-close movement, diaphragm creates a pressure balance. The pressure in this stage is kept constant by force of spring that presses downwards due to effect of pressure under diaphragm, which pushes it upwards. This way under diaphragm, gas enters into first stage chamber and passes to the second stage. Practically, gas enters into first stage and gas pressure generates a force that pushes first stage diaphragm up. The diaphragm, though, has a spring above it that pushes it down with a counter-force (spring force) corresponding to pressure generated in this stage. The generation of two counteracting forces makes the lever to close gas inlet orifice.

The second stage which is also known as low pressure stage consists of a rubber diaphragm attached to the steel lever by an aluminum cap. This stage actually communicates with the engine through gas outlet pipe, leading to mixer and thus subject to negative pressure generated in mixer when throttle valve is opened.

Practically when acceleration takes place, a force is created that pushes second stage diaphragm inwards into reducer, thus allowing gas to pass through orifice to second stage, from where the same quantity that comes out finally is sucked out of reducer into mixer, and then fed into the engine. The sensitivity of spring that holds up lever is set by adjuster on the side of reducer.

The vacuum generated by engine produces an axial movement of second stage diaphragm which being connected to lever and opens second stage valve, permitting the gas to reach second stage chamber through orifice and finally to the engine by means of special pipes. Valve opening, closing and lever seal is obtained due to calibrated spring.
This spring acts on the lever by means of pin that ensures seal when the engine is turned off. The device is made up by solenoid valve controlled by an electronic device that gives current only when engine starts. Once the engine starts, device releases lever of second stage and permits gas to outgo valve of second stage to reach the engine. If engine do not starts, coil de-energizes the core and spring exerts again pressure on lever which further closes the gas flow. This happens also if the engine should stop for any reason. When current is supplied, the electronic device activates coil for a predetermined gap which releases lever of second stage and supplies a sufficient quantity of gas to start engine.

To maintain the stoichiometric ratio, regulator needs to change position of second stage diaphragm. The position of diaphragm is depends on atmospheric pressure and engine vacuum, which is connected to LPR control port through A/F solenoid. In normal condition it senses the atmospheric pressure and delivers gas at higher side. After receiving signal from A/F solenoid, it will connect engine vacuum to diaphragm through LPR control port. A/F solenoid will reduce gas pressure as require and maintain stoichiometric ratio.

**Air Fuel Solenoid**

Normally it connects atmospheric pressure to LPR control port. After getting signal from A/F controller, it connects mixer vacuum to LPR control port. Top port is connected to mixer with hose, center port is connected to LPR control port with rubber tube & bottom port is left open to atmosphere.

A solenoid valve is an electro-mechanical valve which is controlled by electric current through a solenoid coil. Solenoid valve may have two or more ports. In case of two-port valve, the flow is switched on or off. In case of three-port valve, the outflow is switched between two outlet ports. Multiple solenoid valves can be placed together on a manifold. Solenoid valves are the most frequently used control elements in fluidics. They are used to shut off, release, distribute or mix fluids. They are found in many application areas. Solenoids offer fast and safe switching, high reliability, long service life, good medium compatibility of materials used, low control power and compact design. A solenoid valve must be installed on fuel line in between tank and regulator. This valve cuts the flow of gas when vehicle is running on gasoline when engine is shut off. It also has a filter built in, which removes any dirt in the fuel.
The solenoid converts electrical energy into mechanical energy which, in turn, opens or closes the valve mechanically. A direct acting valve has only a small flow circuit, shown in section E in fig. 5.7. Solenoid valves may use metal or rubber seals and may also have electrical interfaces to allow easy control. A spring may be used to hold the valve opened or closed when it is not activated.

![Cross-section of solenoid valve](image)

Fig. 5.7. Cross-section of solenoid valve.

A-Input side, B-diaphragm, C-Pressure chamber, D-Pressure relief conduit, E-solenoid, F-output side.

As shown in fig.5.7 valve is in closed position initially. The fluid under pressure enters at ‘A’ and a weak spring pushes elastic diaphragm ‘B’ to downward side. The diaphragm has a pinhole through its centre which allows a very small amount of fluid to flow through it. This fluid fills the cavity on other side of diaphragm so that pressure is equal on both sides of diaphragm. While pressure is same on both sides of diaphragm, the force is greater on upper side which forces the valve in closed position. The small conduit ‘D’ is blocked by a pin which is armature of solenoid ‘E’ and pushed down by a
spring. If solenoid is activated by drawing pin upwards through magnetic force from solenoid current, fluid in chamber ‘C’ will flow through conduit ‘D’ to output side of the valve. The pressure in chamber ‘C’ will drop and incoming pressure will lift the diaphragm thus opening main valve. Fluid now flows directly from ‘A’ to ‘F’. When solenoid is actuated and the conduit ‘D’ is closed, the spring needs very little force to push the diaphragm down and the main valve closes. In practice there is often no separate spring, the elastomeric diaphragm is moulded so that it functions as its own spring, preferring to be in the closed shape.

**Over Speed Controller**

It is used to govern engine speed, when engine rpm reaches more than rated speed, it gives electric signal to over speed solenoid to reduce fuel flow by 80%. If engine speed is increased to maximum operating range, it cuts the supply of shut off valve to govern engine speed.

**Gas Injectors:**

These are used for conversion systems, where similar to multipoint fuel injection system, individual gas injectors control gas flow into each cylinder further controlled by a processor unit.

**Emulator/Simulator:**

The electronic fuel injection (EFI) system is generally kept non-functional at CNG/LPG operation. In some engines feedback signals from the fuel injectors fed back to the electronic control units (ECU). Under CNG operation the emulator simulates dummy feedback signals to the ECU, maintaining its normal operation with gasoline. This component may not be necessary for all models of EFI engines.

![Fig. 5.8 Emulator.](image-url)
**Exhaust gas Oxygen (EGO) Sensor and Speed sensors**

Often these are required in close-loop gas flow-control CNG conversion systems. After getting heat from exhaust gases, it counts the amount of oxygen passing through exhaust gas and gives the signal to air-fuel controller in DC voltage form.

**Catalytic Converter**

It is located between silencer muffler and exhaust manifold. Three-way catalytic converter is installed in exhaust pipe, which controls outgoing exhaust emission to minimum levels. The unit consists of ceramic substrate of honey-comb structure. This is coated with catalyst material consisting of precious metals such as platinum and rhodium. This catalyst material enhances the rate of chemical reactions. Following chemical reaction takes place while exhaust gas passes through the catalytic converter.

\[
\begin{align*}
2NO_2 & \Rightarrow N_2 + 2O_2 \quad (5.1) \\
2HC + 3O & \Rightarrow H_2O + 2CO_2 \quad (5.2) \\
CO + O & \Rightarrow CO_2 \quad (5.3)
\end{align*}
\]

The reduction catalyst is the first stage of catalytic converter. It uses platinum and rhodium to reduce NO\textsubscript{x} emissions. When NO and NO\textsubscript{2} molecule contacts catalyst, it separates out nitrogen atom from its molecule and holds on to it, release oxygen in the form of O\textsubscript{2}. The nitrogen atoms bond with other nitrogen atoms that are also stuck to the catalyst, forming N\textsubscript{2}.

The oxidation catalyst (platinum and palladium) is second stage of catalytic converter. It oxidizes the unburned hydrocarbons and carbon monoxide. This catalyst aids the reaction of CO and hydrocarbons with remaining oxygen in exhaust gas\textsuperscript{[137]}.

**Gas Flow Meter**

The compact residential gas flow meter (fig.5.9) is designed to measure volumes of natural gas, LPG and all non-corrosive gases very accurately. During the preliminary test controls on the sonic nozzle test benches, all meters are tested at Q\textsubscript{min}, 0.2 times Q\textsubscript{max} and Q\textsubscript{max}\textsuperscript{[138]}.
Fig. 5.9. Gas flow meter.

**Specifications:**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Make</strong></td>
<td>Germany</td>
</tr>
<tr>
<td><strong>Gas Type</strong></td>
<td>Natural gas, LPG and all non-corrosive gases</td>
</tr>
<tr>
<td><strong>Cyclic Volume</strong></td>
<td>1.2 dm³</td>
</tr>
<tr>
<td><strong>Operating Temperature</strong></td>
<td>-25° C to + 55° C</td>
</tr>
<tr>
<td><strong>Storage Temperature</strong></td>
<td>-30° C to + 70° C</td>
</tr>
<tr>
<td><strong>Maximum Operating Pressure</strong></td>
<td>0.5 bar for steel version</td>
</tr>
<tr>
<td><strong>Measuring Range</strong></td>
<td>G4</td>
</tr>
<tr>
<td></td>
<td>: Q$_{\text{min}}$ = 0.04 m³/hr</td>
</tr>
<tr>
<td></td>
<td>: Q$_{\text{max}}$ = 6 m³/hr</td>
</tr>
<tr>
<td><strong>Pulse Generator</strong></td>
<td>Standard 0.01 m³/pulse</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>G1.6, G2.5, G4</td>
</tr>
</tbody>
</table>

**Operating Principle**

It is positive displacement diaphragm type gas flow meter with a twin chamber measuring unit. The twin chambers are fitted with flexible and gas-tight diaphragm which is actuated by the differential between inlet and outlet pressure. The gas enters one side of the diaphragm pan while on the other side it comes out through a separate port on the valve. When one side is full, the rotating mono-valve moves on to next position, allowing the gas to fill empty side. A transmission gear and mechanical coupling or stuffing box
transfers the reciprocating motion to mechanical retrofitted index \[139\]. The measuring unit is housed in a robust gas-tight casing.

**Construction**

- **Casing**

  With its casing in steel, high protection against corrosion is ensured by 500 hours salt fog spray test resistant cataphoresis treatment. The extreme strength of case joint is achieved by rolling the belt and compressing the flanges into contact with a sealant applied between the faces, thus forming gas-tight joint.

- **Measuring Unit**

  The achievement of fixed stroke mechanism is the result of precision and high quality automation. It eliminates the need for an adjustable tangent. The long life synthetic diaphragms coupled to well-proven movement design combine to give excellent stability and accuracy during whole life of meter.

  All materials have been selected for their superior resistance to chemicals and gas. A back run stop prevents the meter from running backwards in case of tempering.

**AIR FUEL MIXER:**

After reducing pressure of the gaseous fuel (CNG/LPG) in low pressure regulator/vapourizer, gas is mixed with air for combustion. This process is called mixing and it is done outside the combustion chamber. The device used to mix gaseous fuel with air is called MIXER.
As seen in the fig. 5.10, the section of mixer is like a converging-diverging nozzle. The section at centre is called throat. When the accelerator is pressed, suction is created in the engine and hence air is drawn at a greater rate. The air filter sucks air from atmosphere. As shown in fig. 5.10, there is a converging section of nozzle, through which air enters from air filter due to engine suction. The velocity of air increases in converging section and its pressure drops. At the throat section of mixer, velocity is higher and pressure is at its lowest value below atmospheric.

The gaseous fuel in the vapourizer is at nearly atmospheric pressure due to pressure difference and velocity difference, thus fuel is entrained in the mixer. In general, three inlet ports are provided on the periphery of the throat section at 120°. Fuel enters into the mixer at throat section and proper mixing with air takes place.

In mixer, air-fuel mixture again expands in diverging section and its velocity drops and pressure rise is negligible. Then mixture enters the engine combustion chamber. Generally different types of engines have different geometry of mixers. The flow of air and fuel is again controlled by solenoid valve. Fig. 5.11 shows air-fuel mixer of maruti make, 800 cc engine.
Fig. 5.11. Air-Fuel Mixer.

For MARUTI 800 engine, the standard dimensions of an air-fuel mixture are as follows:

Material - alluminium alloy
Diameter (throat): 26 mm
Slot Width : 3.5 mm, 3 slots at an angle of 120° at throat periphery

**Diaphragm:**

Diaphragm is a specially designed rubber coated fabric of specific engineering designed layout fitted with metal, rubber or/and plastic parts. It is used where hermetically sealing & flexible working is required by dividing two volumes of interchanging dimensions, interchanging pressures usually of different media.

Fig. 5.12. Diaphragm of 1st stage and 2nd stage vapourizer/LPR.
The diaphragm for LPG/CNG Auto conversion kits are made from ozone resistant nitrile rubber reinforced with Nylon for strength and held with a special gasket sheet meant for high temperature and oil resistance. Diaphragm thickness varying between 0.2 mm to 0.3 mm reinforced with 0.1 mm thick Nylon sheet with a breaking strength of 125 kg/sq cm.

**Fuel Tank/Cylinder:**

**CNG cylinder:**

CNG cylinders can be made of steel, aluminium or composite material. Light weight composite (fibre-wrapped thin metal “ISO 11439 CNG-3”/ fibre-wrapped plastic “ISO 11439 CNG-4”) cylinders are especially beneficial for vehicular use because they offer significant weight reduction compared to steel and aluminium cylinders which leads to lower fuel consumption.

CNG storage tanks are available in different shapes and sizes depending upon the application. The main two types of storage tanks commonly used are cylindrical tank and toroidal tank.

Since CNG is a gaseous fuel, storage capacity for CNG in a vehicle is comparatively less than that of Gasoline. The quantity of CNG filled by the dispenser during refuelling also depends upon pressure at the dispensing station. At maximum permitted filling pressure (200 bar), an amount of 8/9/10 kg CNG is stored in 40/50/60 liters size cylinders respectively which is equivalent to approximately 11.2/12.5/14 liters of Gasoline equivalent. However the gas quantity depends on ambient conditions and actual fill pressure.

The quantity of the CNG in the cylinder usually depends on two factors pressure and temperature. But there is a significant effect of compressibility factor on the quantity of CNG in cylinder.
The compressibility factor $z$ is a correction factor to the Boyle Gay-Lussac Law

\[ P \times V = z \times R \times T \]  

(5.4)

The $z$ factor is depending on gas composition and temperature, e.g. at 250 bar and 20° C, $z = 1.45$, at 150 bar and 20° C, $z = 1.18$.[3]

**Vapour withdrawal low pressure LPG cylinder:**

Vapour withdrawal LPG fuel tanks are designed for fuel systems that require fuel to be supplied to pressure regulator in vapour form. Since propane expands 270 times as it changes from a liquid to a vapour, far less fuel can flow through fuel line to engine. As a result, vapour withdrawal systems are used primarily on small displacement engines.
Inside the fuel tank is a dip tube attached to a vapour outlet port. This dip tube is designed so that open end is positioned in vapour space above 80% liquid level of fuel tank when tank is properly positioned horizontally or vertically. It is very important that fuel tank should not be filled more than 80% of total water capacity with LPG. Over-filling and/or incorrect positioning of the fuel tank may allow liquid propane to enter the vapour fuel system through the vapour outlet port of tank, causing fuel system to malfunction and frost formation.

On vapour withdrawal fuel systems, propane stored as liquid in fuel tank, is allowed to vapourize in the tank before entering fuel system. Since propane absorbs heat when it vapourizes, the surface area of fuel tank must be capable of supplying enough heat from the surrounding air to support vapourization process. If the surface area of fuel tank is not large enough to support vapourization process, fuel pressure will drop and reduction of engine power output may result. Frost forming on outside of fuel tank is an indication that the surface area of fuel tank is not large enough to support rate of vapourization.

**Liquid withdrawal low pressure LPG cylinder:**

Liquid withdrawal LPG fuel tanks are designed for fuel systems that require fuel to be supplied to the pressure regulator in liquid form. Inside the fuel tank is a dip tube attached to a liquid outlet port. This dip tube is designed so that ‘open end’ reaches the bottom of fuel tank when tank is positioned properly. Incorrect positioning of the fuel tank may allow propane vapour to enter liquid outlet port of tank. A lack of engine power output and/or frost on fuel tank is an indication that the tank is not positioned properly.

LPG storage tanks are available in torpedo or donut shape. Torpedo tanks generally have more capacity, but will take more space in vehicle. Donut tanks are designed to fit in the spare wheel space of vehicle. In vehicles having large empty space, multiple tanks can be used to increase fuel storage capacity.

Generally the gas filled in tank is lesser than the full capacity for safety purpose. In case of any accident or collision, the tank may get deformed and there are chances of leakage of gas in the compartment which can lead to dangerous explosion. For safety purpose an extra pipe is kept in the multi function valve. This is mainly for venting out
the excess gas. If while filling or due to any reason, the gas leaks out, this pipe guides the gas out of the vehicle compartment.

Vapourizer converts the liquid propane to a gas. The primary heat source for this vapourization is engine-jacket water which flows through specially designed water jackets cast into vapourizer body. It is necessary that propane fuel systems draw from bottom of the tank rather than the top. If engine feed were drawn from gas phase, heavier and higher boiling components in LPG would gradually become concentrated in liquid phase creating a liquid mass with low vapour pressure and high freezing point. This liquid would create various problems in the fuel feed system. Therefore, LPG systems draw from the bottom of tank and send liquid through a vapourizer which is heated by engine coolant.

![Fig. 5.15 Donut tank and torpedo tank for LPG.](image)

LPG fuel tank is installed, along with a refuelling port, fuel lines and pressure safety valves. A filter “fuel lock” removes particles that may be present in propane. LPG tanks are constructed of heavy gauge steel, in compliance with Boiler and Pressure Vessel Code of American Society of Mechanical Engineers (ASME) to withstand a pressure of 70 bar. Normal working pressures of tanks vary with ambient temperature and quantity of fuel in tank. LPG systems limit the liquid level to 80% of total tank volume by a stop fill valve. Common operating pressures are in the range of 9 to 12 bar. Tanks are equipped with pressure relief valves that will release fuel vapour to the atmosphere to prevent tank explosion under abnormally high pressure conditions.

**High Pressure gauge:**

It indicates gas pressure in the tank. It is mounted on unidirectional receptacle valve.
Timing Advance Processor (TAP):

Timing signal processor is used in CNG/LPG vehicles. It sends specific signals to ECU of vehicle and as a result advances the spark timing. This results in good pickup and mileage on such alternate fuels. Timing Advance Processor is used in manual transmission vehicles.

**Setting:**

![Symbol for IDLE SETTING, LED, and ADVANCE](image)

**Steps:**

1. Press Throttle for advancing timing.
2. Set Idle Setting preset till LED glows.
3. Adjust Advance port till satisfactory result.
4. Condition 1: If Advance Port at minimum side means there is no advance.
5. Condition 2: If LED is not glow means there is no advance.
6. Condition 3: If there is LED indication, increase Idle Setting preset to Maximum side.

**Wiring Details:**

1. Green: Gas Solenoid
2. Black: Battery Negative
3. White/Violet: TPS
4. Grey: Sensor Side
5. White: ECU side

Fig. 5.16. Working of timing advance processor \(^{140}\).
This unit allows optional spark advances (e.g. 6, 9, 12, 15° BTDC), generally during accelerating conditions. The processor modifies the spark advance signal to the electronic ignition system accordingly. Use of this improves peak power and acceleration performance of vehicle running on CNG, while retaining the performance with gasoline.

5.2 Design of a Lever of LPR

This lever is used to maintain constant pressure inside 1st stage chamber of LPR. When the gas cylinder inlet valve is open, CNG released at maximum pressure of 200 bar which is reduced at 14 bar through HPR mounted on the CNG cylinder. CNG at maximum pressure of 14 bar enters through the valve of 1st stage chamber of LPR. The details of components of LPR/vapourizor are shown in fig.5.17 and fig.5.18.

Straight lever with parallel forces acting in the same plane is considered. F is a fulcrum about which the lever is capable of turning. For this lever, fulcrum is in between the load (gas force, W) and effort (spring force, P). The perpendicular distance between the load point and fulcrum (AO= \(l_1\)) is known as load arm, and perpendicular distance between the effort point and fulcrum (OB = \(l_2\)) is known as effort arm.

According to the principle of moment,

\[ W \times l_1 = P \times l_2 \]

or

\[ \frac{W}{P} = \frac{l_2}{l_1} \]

i.e. Mechanical Advantage, \( M.A. = \frac{W}{P} = \frac{l_2}{l_1} \)  \hspace{1cm} (5.5)

The ratio of the effort arm to the load arm, i.e. \( l_2/ l_1 \) is called leverage.
Fig. 5.17 Components of Low pressure regulator/Vapourizor-1

Fig. 5.18 Components of Low pressure regulator/Vapourizor-2
The valve rests over valve seat which is secured to casing fixed at the inlet of 1st stage chamber of LPR. The location of spring and its distance from fulcrum are so adjusted that the gas pressure acting upward on valve exceeds normal limit, it lifts the valve and lever with its spring force. The gas enters inside the 1st stage chamber until pressure increases up to required limit to close the valve. The pressure inside the 1st chamber decreases when the gas flows through the 2nd stage chamber to engine intake manifold (i.e. when engine starts), the spring force compresses the end of lever on downward side and valve seat open and thus high pressure gas enters into the 1st stage chamber through valve. The valve is held on its seat against upward gas pressure which must be equal to spring force i.e. when the valve is closed.

![Fig. 5.19 Free body diagram of a lever of LPR.](image)

As the gas inlet pressure from HPR mounted on CNG cylinder is 14 bar,

We have \( p_1 = 14 \text{ bar} = 1.4 \text{ N/mm}^2 \)

Let us assume diameter of orifice through which gas enters into 1st stage chamber is 5 mm,

The maximum gas load \( (W) \), at which the valve opens out, is given by,

\[
W = \frac{\pi}{4} \times d_1^2 \times p_1
\]

(5.6)

Where, \( d_1 = \) diameter of orifice = 5 mm

\( p_1 = \) Gas pressure at valve inlet of 1st stage chamber = 1.4 N/mm²

\[
W = \frac{\pi}{4} \times 5^2 \times 1.4
\]

\[
= 27.48 \text{ N}
\]

\[\approx 30N\]
If a large load is to be lifted by a small effort, then effort arm should be much greater than the load arm.

Let us assume \( l_2 = 3 \times l_1 \) \hspace{1cm} (5.7)

So

\[
M.A. = \frac{W}{P} = \frac{l_2}{l_1} = 3
\]

\[
Leverage = \frac{OB}{OA} = 3
\]

For valve seat to be closed, for lever AOB, take moment @ O,

\[
W \times OA = F \times OB \hspace{1cm} (5.8)
\]

Where \( F \) = spring force required,

\[
AO = l_1 = \text{load arm and}
\]

\[
OB = l_2 = \text{effort arm}
\]

\[
F = \frac{30}{3}
\]

\[
= 10 \text{ N}
\]

To facilitate lever inside casing of pressure regulator assume \( l_1 = 8 \text{ mm} \),

As, \( \frac{l_2}{l_1} = 3 \),

\[
\therefore \frac{l_2}{8} = 3,
\]

\[
\therefore l_2 = 24 \text{ mm}.
\]

5.3 Design of 1st stage cylindrical chamber of LPR

Pressure of gas filled inside the 1st stage chamber = \( p_2 \)

To find out dimensions of cylindrical geometry of casing of 1st stage chamber,

\[
p_1 \times v_1 = p_2 \times v_2 \hspace{1cm} (5.9)
\]
Where, \( v_1 \) = volume of valve chamber in mm\(^3\),
\[
v_2 = \text{volume of } 1^{st} \text{ stage chamber of pressure reducer in mm}^3,
\]
Assume length of orifice channel, \( l_1 = 35 \text{ mm} \).
\[
v_1 = \left( \frac{\pi}{4} \right) \times d_1^2 \times l_1 \tag{5.10}
\]
\[
= \left( \frac{\pi}{4} \right) \times 5^2 \times 35
\]
\[
= 700 \text{ mm}^3
\]
From standard data available, gas pressure reduced to 0.07 N/mm\(^2\) (0.7 bar) in 1\(^{st}\) stage of regulator, so let us take
\[
p_2 = 0.07 \text{ N/mm}^2 = 0.7 \text{ bar}
\]
\[
p_1 \times v_1 = p_2 \times v_2
\]
\[
: 1.4 \times 700 = 0.07 \times v_2
\]
\[
: v_2 = 14000 \text{ mm}^3
\]
Assume length of 1\(^{st}\) stage cylindrical chamber of pressure reducer, \( l_2 = 20 \text{ mm} \) and consider volume for gas of entire chamber is reduced because of casting parts, lever assembly and supports, and it is considered as 20% of total volume.
\[
v_2' = (0.2) \times \left( \frac{\pi}{4} \right) \times d_2^2 \times l_2 \tag{5.11}
\]
Where \( v_2' \) = actual volume for gas trap in 1\(^{st}\) stage chamber and
\[
d_2 = \text{diameter of } 1^{st} \text{ stage cylindrical chamber}
\]
\[
: 14000 = (0.2) \times \left( \frac{\pi}{4} \right) \times d_2^2 \times 20
\]
\[
: d_2 = 65 \text{ mm}
\]
Let, \( v_3 \) = volume of 2\(^{nd}\) stage chamber of pressure reducer in mm\(^3\),
\[
d_3 = \text{diameter of } 2^{nd} \text{ stage cylindrical chamber} = 134 \text{ mm}, \text{ and}
\( l_3 = \text{length of 1st stage cylindrical chamber of pressure reducer} = 20 \text{ mm} \)

\[
v_3 = \left( \frac{\pi}{4} \right) \times d_3^2 \times l_3
\]

\[
= \left( \frac{\pi}{4} \right) \times (134 \times 10^{-3})^2 \times (20 \times 10^{-3})
\]

\[
= 2.82 \times 10^{-4} \text{ m}^3
\]

Let, \( V_{\text{cyl.}} = \text{volume of each cylinder of engine in mm}^3 \),

\( d_c = \text{bore diameter} = 68.5 \text{ mm}, \) and

\( l_c = \text{stroke} = 72 \text{ mm} \)

\[
V_{\text{cyl.}} = \left( \frac{\pi}{4} \right) \times d_c^2 \times l_c
\]

\[
= \left( \frac{\pi}{4} \right) \times (68.5 \times 10^{-3})^2 \times (72 \times 10^{-3})
\]

\[
= 2.653 \times 10^{-4} \text{ m}^3
\]

### 5.4 Design of spring for 1st stage of LPR

Required spring force to maintain the position of lever is 10 N. Let us design spring for maximum of 45 N. Consider a deflection of 16 mm using the value of spring index as 15.

The maximum permissible shear stress for spring wire is 220 MPa and modulus of rigidity is 80 kN/mm\(^2\) \[^{[141]}\].

Load, \( W = 45 \text{ N} \)

Deflection, \( \delta = 16 \text{ mm} \)

Spring Index, \( C = D/d = 15 \)

Maximum shear stress, \( \tau = 220 \text{ N/mm}^2 \)

Modulus of rigidity, \( G = 80000 \text{ N/mm}^2 \)

Let, \( D = \text{Mean diameter of spring coil, and} \)

\( d = \text{Diameter of spring wire.} \)
Fig. 5.20 Spring of 1st stage of LPR

Wahl’s factor, \( K = \left[ \frac{(4C-1)}{(4C-4)} \right] + \left[ \frac{0.615}{C} \right] \) \[ (5.14) \]

\[ = \left[ \frac{(4 \times 15 - 1)}{(4 \times 15 - 4)} \right] + \left[ \frac{0.615}{15} \right] \]

\[ = 1.09 \]

Maximum shear stress, \( \tau \)

\[ \tau = 220 = \left( \frac{K \times 8 \times W \times C}{\pi \times d^2} \right) \] \[ (5.15) \]

\[ \therefore 220 = \left( \frac{1.09 \times 8 \times 45 \times 15}{\pi \times d^2} \right) \]

\[ \therefore d = 2.9 \text{ mm} \]

Mean diameter of spring coil \( D = C \times d \) \[ (5.16) \]

\[ = 15 \times 2.9 \]

\[ = 43.5 \text{ mm} \]

Outer diameter of the spring coil, \( D_o = D + d \) \[ (5.17) \]

\[ = 43.5 + 2.9 \]

\[ = 46.4 \text{ mm} \]

Let,

Number of turns of the coils = \( n \)

\[ \delta = \left( \frac{8 \times W \times C^3 \times n}{G \times d} \right) \] \[ (5.18) \]
\[ 25 = \frac{8 \times 45 \times 15^3 \times n}{(80000 \times 2.9)} \]

\[ n = 3 \]

For squared and ground ends, the total number of turns, 
\[ n' = n + 2 \]
\[ = 3 + 2 \]
\[ = 5 \]

Free length of the spring, 
\[ L_F = (n' \times d) + \delta + (0.15 \times \delta) \]
\[ = (5 \times 2.9) + 16 + (0.15 \times 16) \]
\[ = 33 \text{ mm} \]

Pitch of the coil, 
\[ p = \frac{P_F}{(n' - 1)} \]
\[ = \frac{33}{(5 - 1)} \]
\[ = 8.25 \text{ mm} \]

Spring Index, Stiffness or Spring Constant, 
\[ k = \frac{W}{\delta} \]
\[ = \frac{45}{16} \]
\[ = 2.81 \text{ N/mm} \]

Bar length required to manufacture spring, 
\[ L = \pi \times D \times n' \]
\[ = \pi \times 45 \times 4 \]
\[ = 527.8 \text{ mm} \]

**5.5 Mass flow rate of gaseous fuel through LPR**

Densities of gases and vapours vary significantly with both temperature and pressure. The compressibility factor has to be considered for the flow of gases through orifices.

One dimensional compressible flow under following assumptions is considered.
• The gas is considered to be perfect and it confirms perfect gas relation

\[ p = \rho \times R \times T \]  

(5.24)

• The adiabatic flow is considered, i.e. no heat transfer to and from the fluid.

• The gaseous fluid is flowing through a duct of slowly varying cross-section and the fluid properties change only in the direction of flow.

• The gaseous flow is considered frictionless and non-viscous.

• No external work done on or by the gas.

**Basic thermodynamic relations:**

Analysis of compressible flow of gases is described by five variables namely velocity \( V \), pressure \( p \), temperature \( T \), fluid density \( \rho \) and the governing equations are those of mass, momentum and energy. The state of a flowing gas involves consideration of an additional variable, the compressibility factor \( Z_g \) which is related to pressure and temperature by the characteristic gas equation.

\[ p \times v = m \times Z_g \times R \times T \]  

(5.25)

Density \( (\rho) \) is a measure of the amount of fluid contained in a given volume and is defined as mass per unit volume.

\[ \rho = \frac{m}{V} \]  

(5.26)

where \( m \) is mass of gas having volume \( V \).

From the characteristic gas equation, density can be expressed as,

\[ \rho = \frac{p}{R \times T} \left( \frac{M_g}{Z_g} \right) \]  

(5.27)

where \( M_g \) = molecular weight of gas,

\( Z_g \) = compressibility factor for gas.

\( R \) = gas constant.

In vapourizer, change in state of gaseous fluid takes place at constant temperature.

For one-dimensional flow, continuity equation gives
\[ m = \rho \times A \times V \]  
\[ (5.28) \]

Where \( m \) = mass flow per unit time  
\( A \) = flow area  
\( V \) = fluid velocity and  
\( \rho \) = mass density.

For application, mass flow is taken constant and hence continuity equation can be written as:

\[ \rho \times A \times V = C \]  
\[ (5.29) \]

Table 5.1 shows values of densities of natural gas at various pressures. The values of compressibility factor and density have been calculated from eq. 5.24.

Table 5.1 Compressibility factor and density at various pressures \cite{142}.

<table>
<thead>
<tr>
<th>Pressure (bar)</th>
<th>Compressibility Factor ‘( Z_f )’</th>
<th>Density (kg/m(^3))</th>
</tr>
</thead>
<tbody>
<tr>
<td>14 203</td>
<td>0.95886</td>
<td>12.06</td>
</tr>
<tr>
<td>12 174</td>
<td>0.96474</td>
<td>10.28</td>
</tr>
<tr>
<td>10.35 150.075</td>
<td>0.96959</td>
<td>8.82</td>
</tr>
<tr>
<td>10 145</td>
<td>0.97062</td>
<td>8.51</td>
</tr>
<tr>
<td>1.04 15.08</td>
<td>0.99694</td>
<td>0.86</td>
</tr>
<tr>
<td>0.8 11.6</td>
<td>0.99765</td>
<td>0.66</td>
</tr>
<tr>
<td>0.7 10.15</td>
<td>0.99794</td>
<td>0.57</td>
</tr>
<tr>
<td>0.6896 10</td>
<td>0.99797</td>
<td>0.57</td>
</tr>
<tr>
<td>0.5517 8</td>
<td>0.99838</td>
<td>0.45</td>
</tr>
<tr>
<td>0.015 0.2175</td>
<td>0.99995</td>
<td>0.01</td>
</tr>
</tbody>
</table>
In LPR three working stages are there to deliver gas from HPR to the engine.

\[ m = \rho_1 \times A_1 \times V_1 = \rho_2 \times A_2 \times V_2 = \rho_3 \times A_3 \times V_3 \quad \text{(5.30)} \]

Maximum mass flow rate measured in experiment is 0.063 m³/min

\[ \therefore m = \frac{0.063}{60} \times 0.01 = 1.05 \times 10^{-5} \text{ kg/sec} \]

The corresponding working pressure in stage three is 0.015 bar and density is 0.01 kg/m³. To facilitate LPR in free space nearby engine,

let us consider diameter of cylindrical chamber = 130 mm

\[ m = \rho_3 \times A_3 \times V_3 \]

\[ \therefore 1.05 \times 10^{-5} = 0.01 \times \left[ \frac{\pi}{4} \times (130 \times 10^{-3})^2 \right] \times V_3 \]

\[ \therefore V_3 = 0.079 \text{ m/sec} \]
\[ = 79 \text{ mm/sec} \]

For working of stage two, the working pressure in stage two is 0.8 bar and corresponding density is 0.66 kg/m³.

\[ m = \rho_2 \times A_2 \times V_2 \]

\[ \therefore 1.05 \times 10^{-5} = 0.66 \times \left[ \frac{\pi}{4} \times (80 \times 10^{-3})^2 - \frac{\pi}{4} (67 \times 10^{-3})^2 \right] \times V_2 \]

\[ \therefore V_2 = 0.0106 \text{ m/sec} \]
\[ \therefore V_2 = 10.6 \text{ mm/sec} \]

The working pressure in stage one is 10 bar and corresponding density is 8.51 kg/m³

\[ m = \rho_1 \times A_1 \times V_1 \]

\[ \therefore 1.05 \times 10^{-5} = 8.51 \times \left[ \frac{\pi}{4} \times (5 \times 10^{-3})^2 \right] \times V_1 \]

\[ \therefore V_1 = 0.0628 \text{ m/sec} \]
\[ \therefore V_1 = 62.8 \text{ mm/sec} \]