CHAPTER FIVE

Fuel Metering For S.I. Engines

Carburetor or the injection system meters the amount of fuel to be delivered into the air stream, which is, depends on load. Any two of the following could determine load:

a) Torque, **b)** Engine speed, **c)** Throttle position, **d)** Rate of airflow, **e)** Pressure in the inlet manifold.

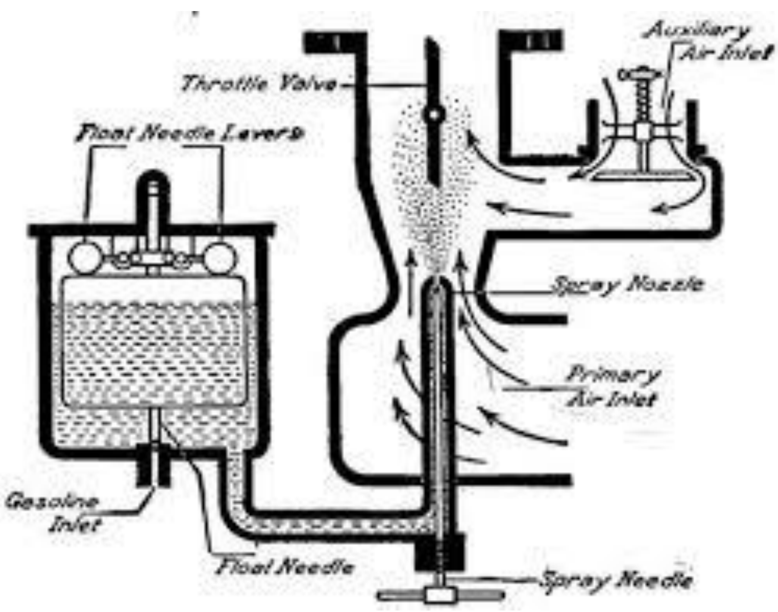
5-A Carburetor

5.1 Carburetion:

Is the process of preparing fuel-air mixture, this process is done outside the engine through a device called a carburetor.

The basic or main element of most carburetors consists of an air passage of fixed geometry containing a venturi-shaped restriction. A fuel nozzle is located in the venturi throat and is supplied with fuel from a constant-level float chamber. A throttle down stream in the venture controls air.

As air enters the engine due to the pressure differential between the surrounding atmospheric air and the partial vacuum in the cylinders during intake strokes, it is accelerated to high velocity in the throat of the venturi.



By Bernoulli's principle, this causes the pressure in the throat (P_d) to be reduced to a value less than the surrounding pressure (P_a), which is about one atmosphere. The pressure above the fuel in the fuel-floating chamber is equal to atmospheric pressure as the floating chamber is vented to surroundings. Therefore, there is a pressure differential through the fuel supply capillary tube and this forces fuel flow into the venturi throat. As the fuel flows out of the end of the capillary tube, it breaks into very small droplets, which are carried away by the high velocity of air. These droplets then evaporated and mixed with the air in following intake manifold. As engine speed is increased, the higher flow rate of air will create an even lower pressure in the venturi throat. This creates a greater pressure differential through the fuel capillary tube, which increases the fuel flow rate to keep up with the greater air flow rate and engine demand.

The level in the fuel reservoir (floating chamber) is controlled by a float shut off (needle valve). Fuel comes from a fuel tank supplied by an electric fuel pump on most modern automobiles, by a mechanical driven fuel pump on older automobiles, or even by gravity on some small engines and historic automobiles.

The throttle controls the air flow and thus the engine speed. There is an idle speed adjustment which sets the closed throttle position such that some air can flow even at fully closed throttle. An idle jet is added, which gives better fuel flow control, at idle and almost closed throttle position.

The process of carburetion is affected by the following factors:

1) Time: when the engine speed increases the time available for mixture formation is small.

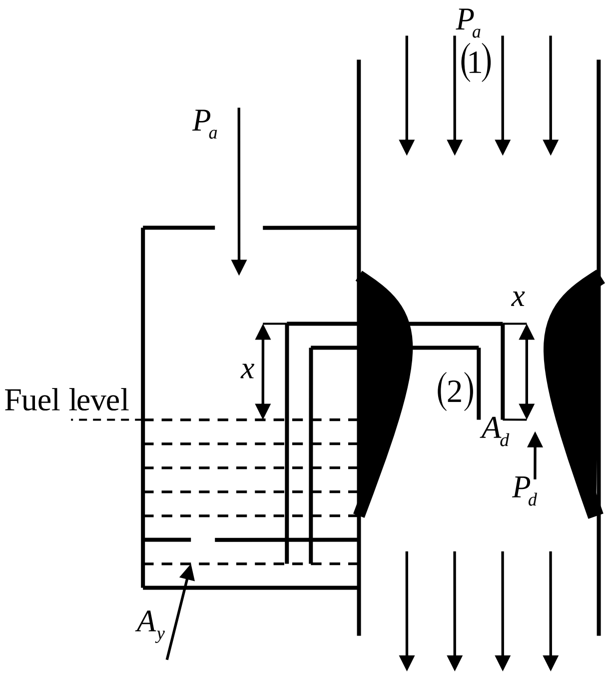
2) Quality of fuel: petrol consists of various hydrocarbons having different volatility.

3) Operation condition: (temperature and pressure of the ambient).

4) The design of the induction system and combustion chamber.

5.2 Carburetor Flow Equations:

5.2.1 Air Mass Flow Rate:



$$\boxed{\dot{m}_{air} = \dot{m}_a = C_a.A_d.\sqrt{2.\rho_a.\Delta P_d}} \quad \dots (5\text{-}1)$$

Where:

$\dot{m}_a =$ Air mass flow rate (kg/s)

$C_a =$ Air-flow discharge coefficient

$A_d =$ Venturi throat area (m^2)

$\rho_a =$ Air density (kg/m^3)

$\Delta P_d =$ Static pressure difference between atmospheric and venture throat area

$$\Delta P_d = P_a - P_d \quad (N/m^2) \quad \dots (5\text{-}2)$$

$P_a =$ Atmospheric static pressure

$P_d =$ Static pressure at venturi throat

$$\Delta P_d = \Delta h.\rho.g \quad (N/m^2) \quad \dots (5\text{-}3)$$

$\rho =$ Manometer fluid density (kg/m^3)

$g =$ 9.8 $(m/\sec^2)$

$\Delta h =$ Pressure head difference across (1) and (2) in (meter)

5.2.2 Fuel Mass Flow Rate:

$$\boxed{\dot{m}_{fuel} = \dot{m}_f = C_f . A_y . \sqrt{2\rho_f . (\Delta P_d - g . \rho_f . x)}} \quad \ldots (5\text{-}4)$$

Where:

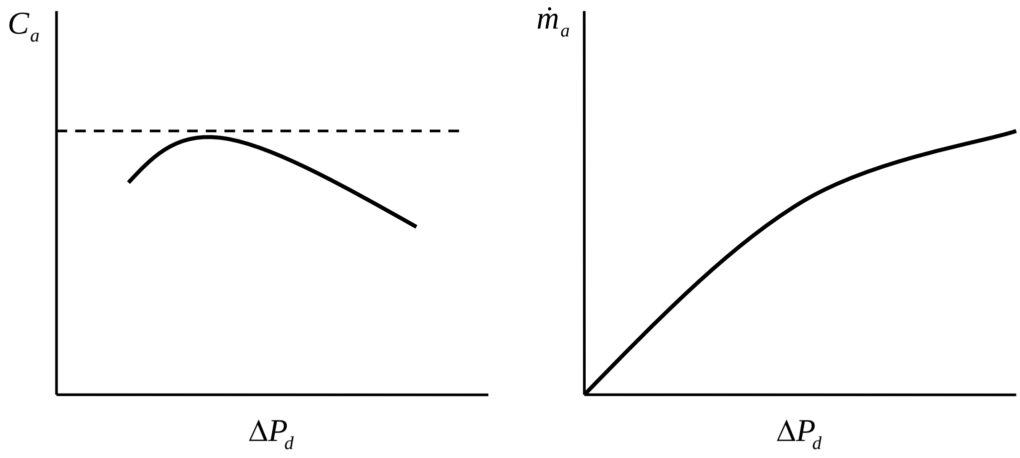
$\dot{m}_f$ = Fuel mass flow rate (kg/s)

A_y = Fuel orifice area, jet area (fuel jet area) (m^2)

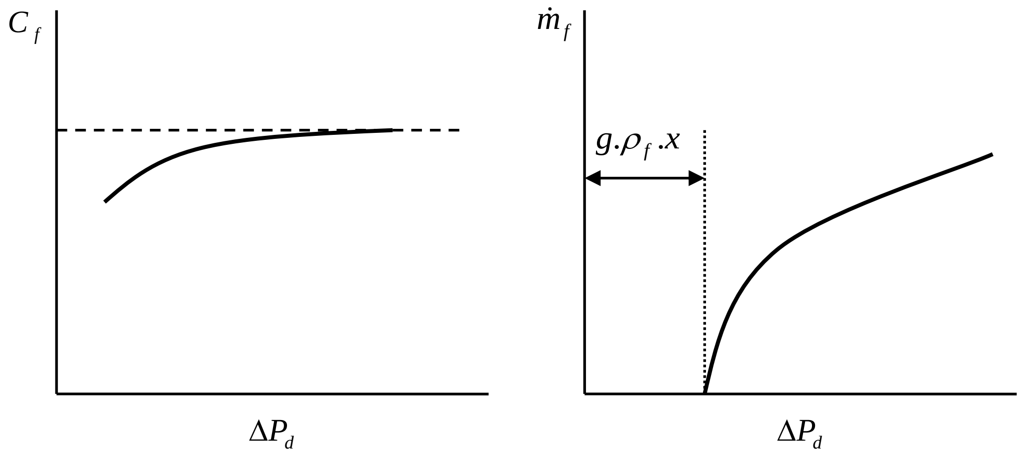
C_f = Fuel discharge coefficient

ρ_f = Fuel density (kg/m^3)

x = Distance between fuel level and the high of capillary tube (m)



For Venturi Throat Area



For Fuel Jet Orifice

5.2.3 Excess Air Coefficient (λ):

Is the ratio of the amount of air enters the engine during combustion (actual mass of air) to the theoretical amount needed during combustion (stoichiometric mass of air).

$$\lambda = \frac{\dot{m}_a)_{actual}}{\dot{m}_a)_{stoich}}$$

$$\lambda = \frac{A_d.C_a.\sqrt{2.\rho_a.\Delta P_d}}{AF)_{stoich}.A_y.C_f.\sqrt{2.\rho_f.(\Delta P_d - g.\rho_f.x)}} \qquad \text{… (5-5)}$$

$$\lambda = \frac{1}{AF)_{stoich}} * \frac{A_d}{A_y} * \frac{\sqrt{2.\rho_a}}{\sqrt{2.\rho_f}} * \frac{C_a}{C_f} * \sqrt{\frac{\Delta P_d}{\Delta P_d - g.\rho_f.x}}$$

<u>Assume</u>: $(g.\rho_f.x)$ is small compared to (ΔP_d), therefore it could be neglected.

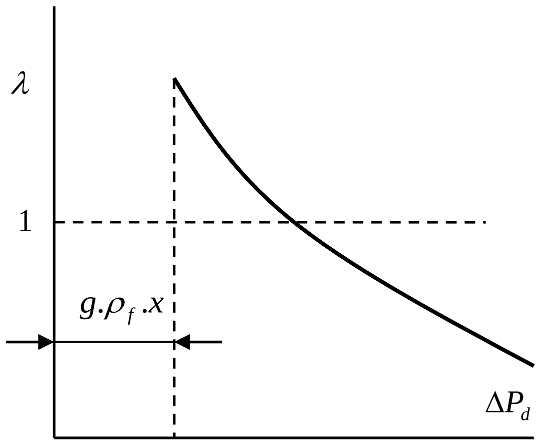
$\frac{1}{AF)_{stoich}}$, $\frac{A_d}{A_y}$, and $\frac{\sqrt{2.\rho_a}}{\sqrt{2.\rho_f}}$ are constants

$$\boxed{\lambda \cong const. * \frac{C_a}{C_f}} \qquad \text{… (5-6)}$$

At the same temperature:

ΔP_d is small, $\lambda > 1$ (lean mixture)

ΔP_d is large, $\lambda < 1$ (rich mixture)



5.2.4 The Effect of Altitude on AF ratio:

The temperature and pressure of air decreases with increasing altitude as given by the following expressions:

$$\boxed{T_{alti} = T_s - 0.0065h} \qquad \text{… (5-7)}$$

$T_{alti} =$ Temperature of air at altitude (K)

$T_s =$ Temperature of air at certain level (K)

$h =$ Altitude (m)

$$\boxed{h = 19200.\log_{10}\left(\frac{1.03}{P_{alti}}\right)} \qquad \text{… (5-8)}$$

P_{alti} = Pressure $\left(kg_f / cm^2\right)$

$$\frac{(AF)_{\text{altitude}}}{(AF)_{\text{at certain level}}} = \sqrt{\frac{\rho_{altitude}}{\rho_s}}$$

$\rho_s =$ Air density at certain level

$$\boxed{\therefore \frac{(AF)_{\text{alti}}}{(AF)_{\text{s}}} = \sqrt{\frac{\rho_{alti}}{\rho_s}} = \sqrt{\frac{P_{alti}}{T_{alti}} * \frac{T_s}{P_s}}} \qquad \text{… (5-9)}$$

Where:

$P_s =$ Air pressure at certain level

5.3 Types of Carburetors:

There are two basic types of carburetors:

5.3.1 Fixed Venturi (F.V.) or fixed jet type

5.3.2 Variable Venturi (V.V.) or variable jet type

The size of venturi and the size of the fuel jet are changed with speed. Both types may be:

- **a)** Down draft carburetor (vertical venturi tube with air flowing from the bottom): is best in that gravity assists in keeping the fuel droplets flowing in same direction as the air flow. Along runner (passage between throttle and intake manifold) that allows more distance and time for evaporation and mixing is also good.
- **b)** Updraft carburetor: for special reasons of space and/or other considerations, some engines are fitted with updraft carburetors. These need high flow velocities to carry the fuel droplets in suspension against the action of gravity.
- **c)** Side draft carburetors: were developed with air flowing horizontally. These generally need higher flow velocities to keep the fuel droplets suspended in the air flow, and with higher velocities come greater pressure losses.

5.4 Auxiliary Devices and System of Carburetors:

- **a)** ***Choke system (starting system)***; when the choke is partly closed, less air is admitted into the carburetor and a high vacuum is built up in the venturi. This causes intensive outflow of the fuel from idling jet.
- **b)** ***Idle running system***; this system insure operation of the engine without load, especially at low speed (throttle is almost completely closed).
- **c)** ***Main jet (main metering jet)***; control the economy or cruise range. The main metering system or jet must be compensated to provide essentially constant lean or stoichiometric mixture over the (20% to 80%) air flow range.
- **d)** ***Economizer or power compensating system***; used to supplies an additional amount of fuel under full load (maximum power) as wide-open throttle is approached.

e) ***Altitude compensation system***; is required to adjust the fuel flow to changes in air density.

f) ***Acceleration pump***; this pump enriches the mixture during acceleration of the engine. When the throttle is sharply opened, the air response is almost instantaneous but the fuel flow lags, thus the pump help to over-come this lag.

5.5 Altitude Compensate System:

The effects of increasing in altitude on the carburetor could be consider as;
Air density changes with ambient pressure and temperature, with changes due to changes in pressure with altitude being most significant, while ambient temperature variation, winter to summer can produce change of comparable magnitude, the temperature of the air entering the carburetor for warmed-up engine operations is controlled to within much closer tolerance by drawing an appropriate fraction of the air from around the exhaust manifold. A number of methods can be used to compensate for changes in ambient pressure with altitude:

1) **Venturi Bypass Method:** to keep the air volumetric flow rate through the venturi equal to what it was at sea level atmospheric pressure (calibration emdition), a bypass circuit around the venturi for the additional volume is provided.
2) **Auxiliary Jet Method:** an auxiliary fuel-metering orifice with a pressure controlled tapered metering rod connects the fuel bowl to the main wall in parallel with the main metering orifice.
3) **Fuel Block-Section Method:** as altitude increases, an aneroid bellows moves a tapered metering rod from an orifice near the venturi throat admitting to the bowl an increasing amount of the vacuum single developed at the throat.
4) **Compensate Air-Bleed Method:** the orifices in the bleed circuits to each carburetor system are filled with tapered metering pins actuated by a single aneroid bellows.

Example (1): for simple carburetor; venturi diameter is 20 (mm), $C_a = 0.85$, $\rho_a = 1.2$, $C_f = 0.66$, fuel orifice diameter (fuel jet diameter) = 12.5 (mm), $x = 5$ (mm). Determine the AF ratio when the pressure drop = 0.07 (bar) and $\rho_f = 750(kg/m^3)$.

Solution:

$$\dot{m}_{air} = \dot{m}_a = C_a.A_d.\sqrt{2.\rho_a.\Delta P_d}$$

$$\dot{m}_{fuel} = \dot{m}_f = C_f.A_y.\sqrt{2\rho_f.(\Delta P_d - g.\rho_f.x)}$$

$$AF = \frac{A_d}{A_y} * \frac{C_a}{C_f} * \frac{\sqrt{2.\rho_a.\Delta P_d}}{\sqrt{2\rho_f.(\Delta P_d - g.\rho_f.x)}}$$

$$AF = \left(\frac{20}{1.25}\right)^2 * \left(\frac{0.85}{0.66}\right) * \left(\frac{\sqrt{2*1.2*0.07}}{2.*750*\left(0.07 - 3.678*10^{-4}\right)}\right) = 13.22$$

Notice: $\boxed{g.\rho_f.x = 750*9.81*\frac{5}{1000} = 36.78 \cong 3.678*10^{-4}(bar)}$

In case neglecting the value of (x) and assuming that the fuel at the edge, the solution could be ((x) عند إهمال قيمة واعتبار الوقود عند الحافة):

$$AF = \frac{A_d}{A_y} * \frac{C_a}{C_f} * \frac{\sqrt{\rho_a}}{\sqrt{\rho_f}} = \frac{0.85}{0.66} * \left(\frac{20}{1.25}\right)^2 * \sqrt{\frac{1.2}{750}} = 13.2$$

Example (2): A petrol engine has a fuel consumption of 10 (liter/hr). The air-fuel ratio is (15). The venturi throat diameter is 20 (mm). Determine the diameter of jet if the top of the jet is 5 (mm) above the fuel level in the float chamber. The barometer reads 750mmHg, the temperature is $32^\circ C$, $C_a = 0.85$, $\rho_f = 750(kg/m^3)$ and $C_f = 0.7$.

Solution: air density at $32^\circ C$ and $\left(\frac{750}{760}*1.013\right)bar$ is:

$$\rho_a = \frac{\frac{750}{760}*1.013*10^5}{287*(32+273)} = 1.143(kg/m^3)$$

$$AF*\dot{m}_f = \dot{m}_a = A_d*C_a*\sqrt{2*\rho_a*\Delta P_d}$$

$$\frac{15}{1}*\left(\frac{10*10^{-3}}{3600}\right)*700=\frac{\pi}{4}\left(\frac{20}{1000}\right)^{2}*0.85*\sqrt{2*1.143*\Delta P_{d}}$$

$$\Delta P_{d}=5218\left(N/m^{2}\right)$$

$$\dot{m}_{f}=A_{y}*C_{f}*\sqrt{2\rho_{f}*\left[5218-\left(700*9.81*\frac{5}{1000}\right)\right]}$$

$$\frac{10*10^{-3}}{3600}*700=A_{y}*0.7*\sqrt{2*700(5218-34.335)}$$

$$A_{y}=1.031\left(mm^{2}\right)=\frac{\pi}{4}*d^{2}$$

$$\therefore d=1.145(mm)$$

Example (3): A petrol engine has the following parameters at see level: AF=14, T=27 $^{\circ}C$, P=1.03bar. Calculate the AF ratio at the altitude of 5000 (m).

Solution:

$$T_{alti}=T_{s}-0.0065h=27-0.0065*5000=-5.5^{\circ}C$$

$$h=19200*\log_{10}\frac{1.03}{P_{alt}}$$

$$5000=19200*\log_{10}\frac{1.03}{P_{alt}}$$

$$\log_{10}\frac{1.03}{P_{alt}}=0.2604\Rightarrow\frac{1.03}{P_{alt}}=1.821$$

$$\therefore P_{alt}=0.565(bar)$$

$$\frac{(AF)_{\text{alti}}}{(AF)_{\text{s}}}=\sqrt{\frac{\rho_{alti}}{\rho_{s}}}$$

$$(AF)_{\text{alti}}=14*\sqrt{\frac{0.565}{267.5}*\frac{300}{1.03}}=11$$

5-B Electronic Fuel Injection System (EFI)

The Electronic Fuel Injection System can be divided into three basic sub-systems. These are the: **(1)** Fuel Delivery System, **(2)** Air Induction System, and **(3)** Electronic Control System.

1) The Fuel Delivery System:

- ❖ The fuel delivery system consists of the fuel tank, fuel pump, fuel filter, fuel delivery pipe (fuel rail), fuel injector, fuel pressure regulator, and fuel return pipe.
- ❖ Fuel is delivered from the tank to the injector by means of an electric fuel pump. The pump is typically located in/or near the fuel tank. Contaminants are filtered out by a high capacity in line fuel filter.
- ❖ Fuel is maintained at a constant pressure by means of a fuel pressure regulator. Any fuel that is not delivered to the intake manifold by the injectors returned to the tank through a fuel return pipe.

2) The Air Induction System:

- ❖ The Air Induction System consists of the air cleaner, air flow meter, throttle valve, air intake chamber, intake manifold runner, and intake valve.
- ❖ When the throttle valve is opened, air flows through the air cleaner, through the air flow meter, past the throttle valve, and through a well-tuned intake manifold runner to intake valve.
- ❖ Air delivered to the engine is a function of drive demand. As the throttle valve is opened further, more air is allowed to enter the engine cylinders.

3) Electronic Control System:

- ❖ The electronic control system consists of various engine sensors, Electronic Control Unit (ECU), fuel injector assemblies, and related wiring.
- ❖ The ECU determines how much fuel needs to be delivered by the injector by monitoring the engine sensor.

- ❖ The ECU turns the injectors on for a precise amount of time, referred to as injection pulse width or injection duration, to deliver the proper air/fuel ratio to the engine.

Basic System Operation:

1) Air enters the engine through the air induction system where it is measured by the air flow meter. As the air flows into the cylinder, fuel is mixed into the air by the fuel injector.

2) Fuel injectors are arranged in the intake manifold behind each intake valve. The injectors are electrical solenoids, which are operated by the ECU.

3) The ECU pulses the injector by switching the injector ground circuit on and off.

4) When the injector is turned on, it opens, spraying atomized fuel at the back-side of the intake valve.

5) As fuel sprayed into the intake air stream, it mixes with the incoming air and vaporizes duo to the low pressures in the intake manifold. The ECU signals the injector to deliver just enough fuel to achieve an ideal air/fuel ratio of 14.7:1, often referred to as stoichiometry.

6) The precise amount of fuel delivered to the engine is a function of ECU control.

7) The ECU determines the basic injection quantity based upon measured intake air volume and engine RPM.

8) Depending on engine operating conditions, injection quantity will vary. The ECU monitors variables such as coolant temperature, engine speed, throttle angle, and exhaust oxygen content and makes injection corrections which determine final injection quantity.

Advantages of Electrical Fuel Injection:

1) Uniform air/fuel mixture distribution
2) Highly accurate air/fuel ratio control throughout all engine operating conditions
3) Superior throttle response and power
4) Excellent fuel economy with improved control
5) Improved cold engine start-ability and operation
6) Simple mechanics, reduce adjustment sensitivity