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Flow Computation of Total Head Losses and Total Pressure Losses in a Typical Gasoline Fuel Injector System

Ejiroghne Kelly Orhorhoro[a], Ikpe Aniekan Essienubong[b], Oloke-Ehisuan Yohannan[c]

[a] *Cemek Machinery Company,Benin City, Nigeria.*

[b] *Department of Mechanical Engineering, Coventry University, Nigeria.*

[c] *Department of Mechanical Engineering, Univerity of Benin, Nigeria.*

Abstract

Pressure losses may result in delivery of inaccurate amount of fuel to each cylinder connected to the engine, thereby significantly reducing the distribution of fuel to each cylinder of the engine. For a typical gasoline port fuel injector system, there is a need for proper understanding of pressure and head losses. This study is centred on flow computation of total head losses and total pressure losses in a typical gasoline port fuel injector system. The pressure and head losses were calculated. The pressure losses due to diameter expansion and contraction were negligible. Total minor head losses were calculated for the gasoline fuel injection system, while major total pressure losses were obtained for the gasoline fuel. Therefore, a drop in pressure will lead to decrease in thrust, and an increase in specific fuel consumption and vice-versa.

Keywords: Pressure losses, Head Losses, Flow computation, fuel injector.

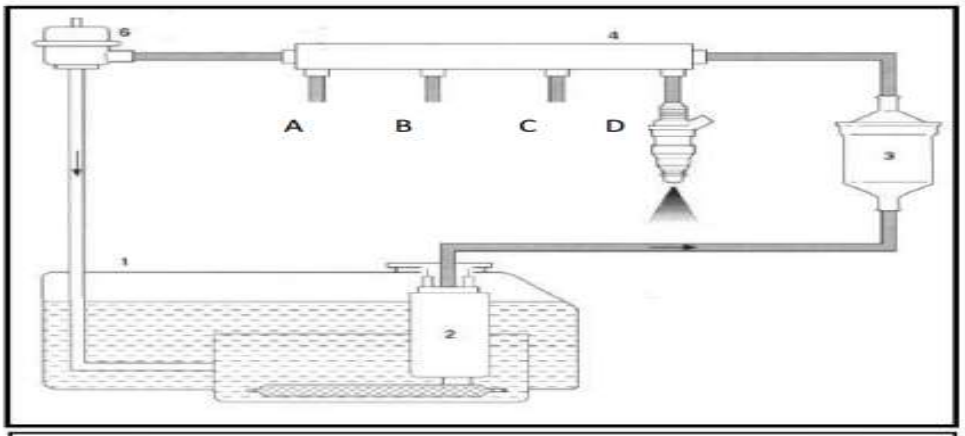
Introduction

Internal combustion engine incorporates a fuel injection system that enables the operation principles of a typical gasoline fuel injector. Fuel injection is the introduction of fuel in an internal combustion engine such as automobile engine, through an injector (Hardenberg, 1999). An internal combustion engine (ICE) is an example of heat engine in which the burning or combustion of a fuel occurs via an oxidation process usually in form of air or oxygen in a combustion chamber which make up the integral part of the working

fluid flow circuit (Suzuki, 1997). In an internal combustion engine, there is an expansion of high temperature and pressure gases that are produced by combustion and application of direct force to some components of the engine (Baumgarten, 2006). An **i**njector is a kind of pump that typically includes, steam ejector, eductor-jet pump or thermocompressor. It is of two categories namely; non-lifting and lifting. For the lifting injector, it make uses of the venture-effect of a converging-diverging nozzle to convert pressure energy of a motion fluid to velocity energy, which often result in development of low pressure zone that draws in and entrains a suction fluid (Chang et al., 2007). However, for the non-lifting injector, there is cold water-input which is fed by gravity. Non-lifting injector makes use of the principle of induced current to push water up to the boiler check valve (Fan et al., 1999). The premature boiling of feed water at very low absolute pressure is avoided by the venture effect (Heywood, 2000).

Port fuel injector system

In the Port Fuel Injector (PFI) system, the injector is located by the side of the intake manifold, where the injector supplies fuel into the air inside the intake manifold. The air-fuel mixture then flows through the intake valve and into the cylinder where one injector is mounted close to each cylinder for easy injection of atomized fuel to the intake valve (Baumgarten, 2006). Allocation of injector to each cylinder makes it possible for fuel distribution to occur at equal rate (Kumaravel et al., 2014). The two injectors B and D (Figure 1) operate simultaneously at a steady flow rate of 40litres/hour from each injector and the pressure regulator is returning 80litres/hour to the fuel tank.



Legend: 1-fuel tank; 2-electric fuel pump; 3-fuel filter; 4-fuel rail; 5-fuel injector; 6-fuel pressure regulator.

Figure 1: Gasoline Port Fuel Injection System

Fuel pressure regulator

The fuel pressure regulator is an important component for any electronic fuel injector (EFI) system, without it, the fuel rail will not be able to build up enough pressure to support the injectors with sufficient amount of fuel. In other words, the absence of fuel pressure regulator in electronic fuel injector will

cause the inability of the fuel to reach the injectors. Moreover, it can block the flow path to the fuel tank completely; thus, the fuel pump will try to force too much fuel into the injectors which will cause them to fail. To accommodate a successful fuel and air mixture, a proper fuel pressure is required in all situations, both at low and high revs, regardless of the power output. This is where the fuel pressure regulator is doing its job, to adapt the fuel supply to the fuel demand (Cengel et al., 2012). Therefore, it become necessary to determine the pressure and head losses in a typical gasoline fuel injector system.

Assumptions made

The following assumptions were made to determine the losses.

i. The flow through the system is steady.
ii. The flow is incompressible i.e. Ma < 0.3
iii. Flow is fully developed, and the entrance effect is neglected.
iv. Supply temperature is 21^0C
v. The density of gasoline at supply temperature is 744.7168kg/m^3
vi. Dynamic viscosity of gasoline is constant for the flow and taken as $\mu = 1.895 \times 10^{-5}$kg/m.s
vii. Material for the entire fuel supply system is copper and the roughness value is 0.0025mm
viii. Assume that the discharge coefficient is 0.5.
ix. Throughout all the system, head loses from diameter changes is very small and negligible.
x. The pipe connecting fuel pump to fuel filter is assumed to have equal length and diameter with that connecting the fuel filter to the fuel rail.

Nozzle diameter

To deliver 40litres/hour of gasoline at injectors B and D simultaneously as well as return 80litres/hour of gasoline at the pressure regulator to the fuel tank, the pump must supply enough work to overcome the pressure drop in the flow.

The volume flow rate at the nozzle

$$Q = Volume/Time \quad (1)$$

$$= \frac{40 \times 10^{-3} m^3}{3600 s} = 1.11 \times 10^{-5} m^3/s$$

Recall that the actual mass flow rate entering into the injector is a fraction of the supply,

$$\text{Actual mass flow} = C_d \times \text{ideal mass flow} \quad (2)$$

$$\dot{m} = C_d \times \rho Q$$

Where;
$\dot{m}$ = actual mass flow rate
C_d = coefficient of discharge
ρ = Density of the fluid
Q = Volume flow rate
Also,

$$\dot{m}_1 = \dot{m}_2 = \rho A_2 V_2 \quad \text{(Massey and Ward-Smith, 2006)} \tag{3}$$

Where;

$A_2 = \frac{\pi {d_2}^2}{4}$

And,

V_2 = Discharge velocity

Given that:

$V_2 = 25m/s,\ Q = 1.11 \times 10^{-5} m^3/s,\ C_d = 0.5$

Then,

$$\dot{m} = C_d \times \rho Q = \rho A_2 V_2 \tag{4}$$

$C_d \times Q = \frac{\pi {d_2}^2}{4} \times V_2$

${d_2}^2 = \frac{4 \times C_d \times Q}{\pi \times V_2} = \frac{4 \times 0.5 \times 1.11 \times 10^{-5}}{\pi \times 25} = 2.82 \times 10^{-7}$

$d = \sqrt{2.82} \times 10^{-7} = 5.31 \times 10^{-4} m = 0.531mm$

The nozzle diameter to produce 25m/s discharge is therefore 0.531mm

Pressure drop calculation

The total pressure loss in the system is the sum of all the pressure loss across each element of the injection system. To calculate the total pressure loss in the system the losses are categorised as follows.

i. Pressure loss between fuel pump to fuel filter (h_{2-3})
ii. Pressure loss at the fuel filter (h_3)
iii. Pressure loss between the fuel filter and the fuel rail Pressure loss (h_{3-4})
iv. Pressure loss at the fuel rail (h_4)
v. Pressure loss at the injectors $(h_{injectors})$
vi. Pressure loss between the rail pipe and the fuel tank(h_{4-1})
vii. Pressure loss at the fuel regulator (h_6)

Pressure Loss between Fuel Pump and Fuel Filter ΔP_{2-3}

For this kind of setup, at the pump, there will be pressure losses over the pipe length, pressure losses at the bends and pressure loss due to sudden change in diameter at the entrance and exit of the fittings.

Therefore;

$$h_{l(2-3)} = h_{lpipe} + h_{lbends} + h_{ldiameterexpansion} \tag{5}$$

There is a single pipe connecting the fuel pump to the fuel filter. The pipe is assumed to have equal length and diameter with that connecting the fuel filter to the fuel rail. The pipe has two bends of 90 degrees each. For this kind of setup, there will be pressure losses over the pipe length, pressure losses at the bends while the pressure loss due to changing diameter is neglected. Considering the pressure loss due to the sudden expansion and contraption at the fittings to be very minimal, the pressure loss due to diameter

expansion and contraption will be considered as negligible. Figure 2 shows pictorial Highlight of losses between pump and fuel.

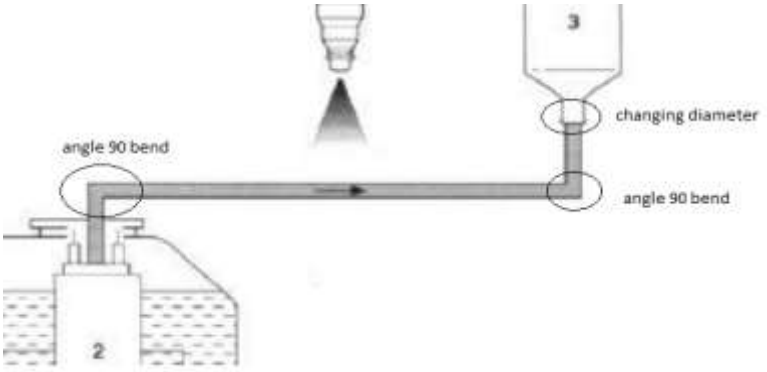


Figure 2: Pictorial highlight of losses between pump and fuel filter

Velocity calculation

The flow rate of in the system is assumed to be constant till the fuel reaches the fuel rail. This implies that the fuel discharge flow rate to the fuel rail is equal to the total flow rate at the fuel rate and consequently equal to the flow rate between pump and fuel filter.

That is,

$$Q_{2-3} = Q_{3-4} = Q_{injector} + Q_{back\ flow} \quad (6)$$

$$Q_{2-3} = Q_{3-4} = Q_{injector\ A} + Q_{injector\ B} + Q_{back\ flow} \quad (7)$$

$$= 40 + 40 + 80$$

$$= 160 litres/hour$$

$$= \frac{160 \times 10^{-3}}{3600}$$

$$= 4.44 \times 10^{-5} m^3/s$$

But,

$$Discgarge\ Velocity = \frac{Discharge\ flow\ rate}{Area} \quad (8)$$

$$v = \frac{Q_{2-3}}{\frac{\pi D^2}{4}} = \frac{4Q}{\pi D^2} \quad (9)$$

$$= \frac{4 \times 4.44 \times 10^{-5}}{\pi \times (0.005)^2} = 2.264 m/s$$

Reynolds Number

Reynolds number is given as:

$$R_e = \frac{\rho v D}{\mu} \tag{10}$$

Where,
μ= Kinematic Viscosity for gasoline which is 1.895×10^{-5} kg/m. s
ρ = Density for gasoline which is 744.7168 kg/m^3
D is the diameter of the pipe in meters

$$R_e = \frac{\rho v D}{\mu} = \frac{744.7168 \times 2.264 \times 0.005}{1.895 \times 10^{-5}} = 4.45 \times 10^5$$

Since the Reynolds number Re >> 4,000, this simply shows that the flow is turbulent. For a laminar flow to occur, Re must be less than 4,000.

Pressure Losses over the Pipe Length

Pressure loss in pipes is given as;

$$h_{lpipe} = f(R_e) \times (\frac{L}{D}) \times \frac{v^2}{2g} \tag{11}$$

Where:

$$f = \frac{0.25}{\left[Log\left(\frac{\varepsilon}{3.7D} + \frac{5.74}{R_e^{0.9}}\right)\right]^2} \tag{12}$$

L is the length of the pipe in meters
D is the diameter of the pipe in meters
V is the velocity of the flow through the pipe
R_e is the Reynolds number and is given as
ε: Surface Roughness (0.0025 x 10^{-3}m)

$$f(Re) = \frac{0.25}{\left[\log\left(\left(\frac{\varepsilon}{3.7d}\right) + \left(\frac{5.74}{Re^{0.9}}\right)\right)\right]^2}$$

$$= \frac{0.25}{\left[\log\left(\left(\frac{0.0025 \times 10^{-3}}{3.7 \times 5 \times 10^{-3}}\right) + \left(\frac{5.74}{445000^{0.9}}\right)\right)\right]^2}$$

$$= \frac{0.25}{[\log(1.3514 \times 10^{-4} + 4.7357 \times 10^{-5})]^2}$$

$$= \frac{0.25}{[\log 0.000182497]^2}$$

$$= \frac{0.25}{[-3.7387]^2} = \frac{0.25}{13.9782}$$

$$f(Re) = 0.01788$$

$$h_{lpipe} = f(R_e) \times \left(\frac{L}{D}\right) \times \frac{v^2}{2g} = \frac{0.01788 \times 1.2 \times 2.264^2}{0.005 \times 2 \times 9.81} = 1.11m$$

The major head loss is therefore1.11m

Pressure losses due to bends

The pressure losses due to bend is one of the many minor losses in flow of fluid through pipes. The representation in Figure 3 shows two location of such bend between the pump and the filter.

The two minor losses due to the 90^0 bends which can be estimated as,

$$h_{\text{lbends}} = k_l \times \frac{v^2}{2g} \tag{13}$$

Where:

k_l is the frictional factor due to flow across bends and is given 1.1 for 90^0 bends without vanes as shown in Figure 3.

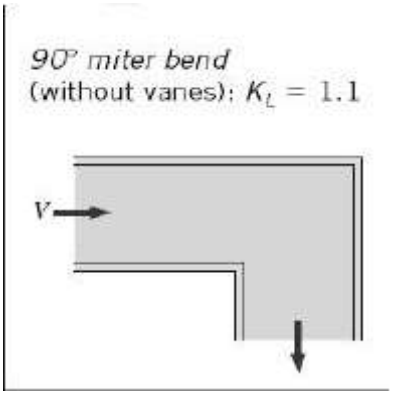


Figure 3: k_l value for pipe bends (Cengel et al., 2012)

$$h_{\text{lbend}} = 2\left(1.1 \times \frac{2.264^2}{2 \times 9.81}\right) = 0.5747m$$

Total Pressure loss

There will be pressure losses over the pipe length, pressure losses at the bends and pressure loss due to sudden change in diameter at the entrance and exit of the fittings.

Therefore;

$$h_{l(3-4)} = h_{lpipe} + h_{lbends} + h_{ldiameterexpansion}$$
$$h_{l(2-3)} = h_{lpipe} + h_{lbends} + h_{ldiameterexpansion} \quad (14)$$
$$= 1.11 + 0.5747 = 1.6847m$$

The total pressure loss is given as

$$\Delta P_{2-3} = \rho g h_{L\,(2-3)} \quad (15)$$
$$= 744.7168 \times 9.81 \times 1.6847$$
$$= 12307.86Pa$$

Pressure Loss at the Fuel Filter ΔP_3

Given that;

At $Q = 210 litres/hr$, the pressure drop is 0.35psi

Then at 160litres/hr ,

If the relationship between pressure drop and flow rate is linear,

Then

$$\Delta P_3 = \frac{0.35 \times 140}{210} = 0.233psi = 1606.478Pa$$

But,

$$\Delta P_3 = \rho g h_{l3}$$

Then:

$$h_3 = \frac{\Delta P}{\rho g} = \frac{1606.478Pa}{744.7168 \times 9.81} = 0.22mm$$

Pressure Loss between the Fuel Filter and the Fuel Rail Pressure Loss ΔP_{3-4}

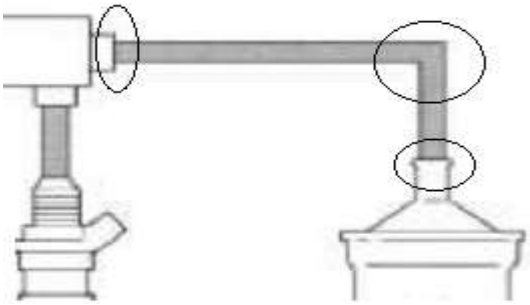


Figure 4: Head losses between the filter and fuel rail at a glance

$Q_{3-4} = 160 litres/hour = 4.44 \times 10^{-5} m^3/s$

But,

$$Discgarge\ Velocity = \frac{Discharge\ flow\ rate}{Area}$$

That is,

$$v = \frac{Q_{3-4}}{\frac{\pi D^2}{4}} = \frac{4Q}{\pi D^2} \quad (16)$$

$$= \frac{4 \times 4.44 \times 10^{-5}}{\pi \times (0.005)^2} = 2.264 m/s$$

Diameter of the pipe is equal 5 mm.
Length of the pipe is equal 1.2m

Pressure Losses over the Pipe Length

Pressure loss in pipes is given as;

$$h_{lpipe} = f(R_e) \times (\frac{L}{D}) \times \frac{v^2}{2g}$$

Where:

$$f(Re) = \frac{0.25}{\left[\log\left(\left(\frac{\varepsilon}{3.7d}\right) + \left(\frac{5.74}{Re^{0.9}}\right)\right)\right]^2}$$

$$= \frac{0.25}{\left[\log\left(\left(\frac{0.0025 \times 10^{-3}}{3.7 \times 5 \times 10^{-3}}\right) + \left(\frac{5.74}{445000^{0.9}}\right)\right)\right]^2}$$

$$f(Re) = 0.01788$$

Therefore

$$h_{lpipe} = f(R_e) \times \left(\frac{L}{D}\right) \times \frac{v^2}{2g} = \frac{0.01788 \times 1.2 \times 2.264^2}{0.005 \times 2 \times 9.81} = 1.11m$$

The major head loss is 1.11m

Pressure losses due to bends

There is a 90 ^{0} bend in the pipe hence the pressure loss due to the bends is given as:

$$h_{lbend} = 1.1 \times \frac{2.264^2}{2 \times 9.81} = 0.2874m$$

Total Pressure loss

$h_{l(3-4)} = h_{lpipe} + h_{lbends} + h_{ldiameterexpansion}$
$= 1.11 + 0.2874$
$h_{l(3-4)} = 1.3974m$
The total pressure loss is given as:
$\Delta P_{3-4} = \rho g h_{l3-4} = 744.7168 \times 9.81 \times 1.3974$
$= 10208.95\,Pa$
$\Delta P_{3-4} = 10.209kPa$

Pressure loss at the fuel rail ΔP_4

$Q_4 = 160litres/hour = 4.44 \times 10^{-5}m^3/s$
Diameter of the common rail is equal 12 mm.
Length is equal 0.36 m
But,

$$Discgarge\ Velocity = \frac{Discharge\ flow\ rate}{Area}$$

That is,

$$v = \frac{Q_4}{\frac{\pi D^2}{4}} = \frac{4Q}{\pi D^2}$$

$$= \frac{4 \times 4.44 \times 10^{-5}}{\pi \times (0.012)^2} = 0.393m/s$$

Reynolds number is given as:

$$R_e = \frac{\rho v D}{\mu}$$

$$R_e = \frac{\rho v D}{\mu} = \frac{744.7168 \times 0.393 \times 0.012}{1.895 \times 10^{-5}} = 1.8533 \times 10^5$$

Re >> 4,000, therefore the flow is said to be turbulent
There will be pressure losses over the pipe length, pressure losses at the bends and pressure loss due to sudden change in diameter at the entrance and exit of the common rail and the feed of the injector.
Therefore;
$h_{l4} = h_{lcommonpipe} + h_{lbends} + h_{ldiameterexpansion}$

Figure 5 shows the head losses between fuel rail at a glance

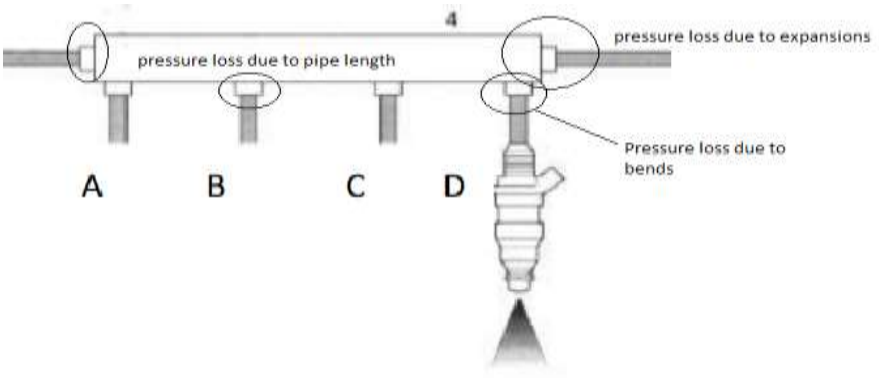


Figure 6: Head losses between fuel rails at a glance

Pressure Losses over the Pipe Length

Pressure loss in pipes is given as;

$$h_{lpipe} = f(R_e) \times (\frac{L}{D}) \times \frac{v^2}{2g}$$

Where:

$$f(Re) = \frac{0.25}{\left[\log\left(\left(\frac{\varepsilon}{3.7d}\right) + \left(\frac{5.74}{Re^{0.9}}\right)\right)\right]^2}$$

$$= \frac{0.25}{\left[\log\left(\left(\frac{0.0025 \times 10^{-3}}{3.7 \times 12 \times 10^{-3}}\right) + \left(\frac{5.74}{185334.27^{0.9}}\right)\right)\right]^2}$$

$$= \frac{0.25}{[\log(5.6306 \times 10^{-5} + 1.0417 \times 10^{-4})]^2}$$

$$= \frac{0.25}{[\log 0.000160476]^2}$$

$$= \frac{0.25}{[-3.7946]^2} = \frac{0.25}{14.3989} = 0.0174$$

$$f(Re) = 0.0174$$

$$h_{lpipe} = f(R_e) \times \left(\frac{L}{D}\right) \times \frac{v^2}{2g} = \frac{0.0174 \times 0.36 \times 0.393^2}{0.012 \times 2 \times 9.81} = 0.00411m$$

The major head loss is 0.00411m

Pressure losses due to bends

The pressure losses due to bend is one of the many minor losses in flow of fluid through pipes. The representation in Figure 6 shows two tee bends at the edge of the injectors.
The two minor losses due to bends can be estimated by:

$$h_{\text{lbends}} = k_l \times \frac{v^2}{2g} \tag{17}$$

Where:
K_L: is the frictional factor due to flow across bends and is given as 1 for the friction due to bends which is equal to 1 for 90^0 bends without vanes.

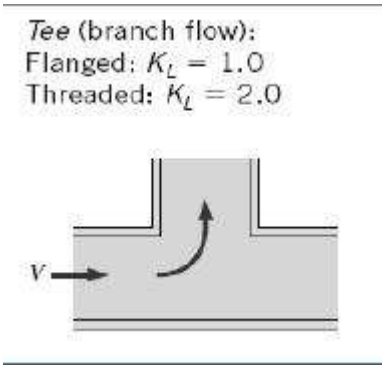


Figure 7: k_l value for pipe tee-bends (Cengel et al., 2012)

$$h_{\text{lbend}} = 2\left(1 \times \frac{0.393^2}{2 \times 9.81}\right) = 0.0157m$$

Pressure losses due to abrupt Expansion (changing in diameter)

The diameter expansion occurs between 5mm and 12mm at the fuel rail

$$h_{\text{ldiameterexpansion}} = \left(1 - \frac{A_1}{A_2}\right)^2 \times \frac{v^2}{2g} = \left(1 - \left(\frac{d_1}{d_2}\right)^2\right)^2 \times \frac{v^2}{2g}$$

$$= \left(1 - \left(\frac{5}{12}\right)^2\right)^2 \times \frac{0.393^2}{2 \times 9.81}$$

$$= (1 - 0.4167^2)^2 \times \frac{0.393^2}{2 \times 9.81}$$

$$= (1 - 0.1736)^2 \times \frac{0.393^2}{2 \times 9.81}$$

$$= (0.8264)^2 \times \frac{0.393^2}{2 \times 9.81}$$

$$= 0.6829 \times \frac{0.393^2}{2 \times 9.81}$$

$$h_{ldiameterexpansion} = 0.0538m$$

Total Pressure loss

$$h_{l4} = h_{lpipe} + h_{lbends} + h_{ldiameterexpansion} = 0.00411 + 0.0157 + 0.0538$$

$$h_{l(3-4)} = 0.07361$$

The total pressure loss is given as:

$$\Delta P_4 = \rho g h_{l4} = 744.7168 \times 9.81 \times 0.07361$$

$$= 537.77\ Pa$$

$$\Delta P_4 = 0.538kPa$$

Pressure loss at the injectors ΔP injectors

Diameter is equal 5 mm (0.005m).
Length is equal 70 mm (0.07m)

Velocity Calculation

The flow rate of the injector is 40litres/hr

$$Q_{injector} = 40litres/hr$$

$$= \frac{40 \times 10^{-3}}{3600}$$

$$= 1.11 \times 10^{-5} m^3/s$$

But,

$$Discgarge\ Velocity = \frac{Discharge\ flow\ rate}{Area}$$

That is,

$$v = \frac{Q_{\text{injector}}}{\frac{\pi D^2}{4}} = \frac{4Q}{\pi D^2}$$

$$= \frac{4 \times 1.11 \times 10^{-5}}{\pi \times (0.005)^2} = 0.565m/s$$

Reynolds Number

Reynolds number is given as:

$$R_e = \frac{\rho v D}{\mu}$$

D is the diameter of the pipe in meters

$$R_e = \frac{\rho v D}{\mu} = \frac{744.7168 \times 0.565 \times 0.005}{1.895 \times 10^{-5}} = 1.11 \times 10^5$$

Re >> 4,000, therefore the flow is said to be turbulent

Pressure loss in the injector is given as;

$$h_{injector} = f(R_e) \times (\frac{L}{D}) \times \frac{v^2}{2g}$$

Where:

$$f(Re) = \frac{0.25}{\left[\log\left(\left(\frac{\varepsilon}{3.7d}\right) + \left(\frac{5.74}{Re^{0.9}}\right)\right)\right]^2}$$

$$= \frac{0.25}{\left[\log\left(\left(\frac{0.0025 \times 10^{-3}}{3.7 \times 5 \times 10^{-3}}\right) + \left(\frac{5.74}{111000^{0.9}}\right)\right)\right]^2}$$

$$= \frac{0.25}{[\log(1.3514 \times 10^{-4} + 1.6524 \times 10^{-4})]^2}$$

$$= \frac{0.25}{[\log 0.00030038]^2}$$

$$= \frac{0.25}{[-3.5223]^2} = \frac{0.25}{12.4068}$$

$$f(Re) = 0.0202$$

Therefore,

$$h_{injectors} = 2 \times f(R_e) \times \left(\frac{L}{D}\right) \times \frac{v^2}{2g} = 2 \times \frac{0.0202 \times 0.07 \times 0.565^2}{0.005 \times 2 \times 9.81}$$

$$= 2 \times 0.004601$$

$$h_{injector} = 0.009202m$$

The total pressure loss is given as:

$$\Delta P_{injectors} = \rho g h_{injector} = 744.7168 \times 9.81 \times 0.009202$$

$$= 67.23\ Pa$$

$$\Delta P_{injectors} = 0.06723kPa$$

Pressure loss between the rail pipe and the fuel tank ΔP_{4-1}

Diameter is equal 4 mm (0.004 m).

Length is equal 1.3m

Velocity Calculation

The return flow rate 80litres/hr

$$Q_{injector} = 40litres/hr$$

$$= \frac{80 \times 10^{-3}}{3600}$$

$$= 2.22 \times 10^{-5} m^3/s$$

But,

$$Discgarge\ Velocity = \frac{Discharge\ flow\ rate}{Area}$$

That is,

$$v = \frac{Q_{\text{injector}}}{\frac{\pi D^2}{4}} = \frac{4Q}{\pi D^2}$$
$$= \frac{4 \times 2.22 \times 10^{-5}}{\pi \times (0.004)^2} = 1.767 m/s$$

Reynolds Number

Reynolds number is given as:

$$R_e = \frac{\rho v D}{\mu}$$

D is the diameter of the pipe in meters

$$R_e = \frac{\rho v D}{\mu} = \frac{744.7168 \times 1.767 \times 0.004}{1.895 \times 10^{-5}} = 2.7777 \times 10^5$$

Re >> 4,000, therefore the flow is said to be turbulent

Pressure loss between the rail pipe and the fuel tank is given as;

$$h_{4-1} = f(R_e) \times (\frac{L}{D}) \times \frac{v^2}{2g}$$

Where:

$$f(Re) = \frac{0.25}{\left[\log\left(\left(\frac{\varepsilon}{3.7d}\right) + \left(\frac{5.74}{Re^{0.9}}\right)\right)\right]^2}$$
$$= \frac{0.25}{\left[\log\left(\left(\frac{0.0025 \times 10^{-3}}{3.7 \times 4 \times 10^{-3}}\right) + \left(\frac{5.74}{277770^{0.9}}\right)\right)\right]^2}$$
$$= \frac{0.25}{[\log(1.6892 \times 10^{-4} + 7.2376 \times 10^{-5})]^2}$$
$$= \frac{0.25}{[\log 0.000241296]^2}$$
$$= \frac{0.25}{[-3.6174]^2} = \frac{0.25}{13.0859}$$
$$f(Re) = 0.0191$$

Therefore

$$h_{4-1} = f(R_e) \times (\frac{L}{D}) \times \frac{v^2}{2g}$$
$$h_{4-1} = \frac{0.0191 \times 1.3 \times 1.767^2}{0.004 \times 2 \times 9.81} = 0.9878m$$

The total pressure loss is given as:

$$\Delta P_{4-1} = \rho g h_{4-1} = 744.7168 \times 9.81 \times 0.9878$$
$$= 7216.54Pa$$
$$\Delta P_{4-1} = 7.217kPa$$

Calculation of minor loss

Assumptions

Pressure relief valve used in cars is a sophisticated kind of valve, it is not a simple valve used in regulating pressure in simple pipe flows. It was assumed as a diaphragm attached with the ‘’ball seat’’ by-pass valve (Cengel et al., 2012). But for the simplicity we took only the ball seat by-pass valve and thus considering the minor loss across it. There are different types of ball valves but we assumed the 1/3 closed ball valve because the other type is fully open valve, is going to be too humble to let fuel pass through it as if a little pressure is exerted by the fuel pump. Where the 2/3closed ball valve is going to be too harsh to let fuel at critical or high speed running of the engine and thus it can damage the fuel injectors at high speed. We need a balance between them so it can operate well in both the cases and thus 1/3 closed ball valve can serve the purpose well enough. From the valves and fitting chart the minor loss coefficient came out to be 5.5 for the Ball valve, 1/3 closed (Cengel et al., 2012).

$$h_m = k_b \frac{v^2}{2g} \tag{15}$$

$h_m = loss\ at\ the\ entrance$

Where k_b is the loss coefficient for 1/3 closed ball valve which from the chart is 5.5.

As we know the pressure regulator is placed on the return pipe so by taking it’s diameter for calculating the velocity.

$Internal\ diameter(d): 4mm\ or\ 0.04m$

$Volume\ flow\ rate(Q): 80\frac{ltr}{hr}\ or\ 2.2 \times 10^{-5} m^3 s^{-1}$

Here V is unknown so from continuity equation:

$Q = A \times V$

Get

$$V = \frac{Q}{A} \tag{16}$$

$$A = \frac{\pi D^2}{4}$$

By putting the values,

$$A = \frac{3.14 \times 0.004^2}{4}$$

$$A = 1.26 \times 10^{-5}\, m^2 \tag{17}$$

By putting equation (17) in equation (16)

$$V = \frac{2.2 \times 10^{-5}}{1.26 \times 10^{-5}}$$

$$V = 1.75\, m/s$$

By putting the value of equation (16) and k_b in equation (15),

$$h_{regulator} = 5.5 \times \frac{1.75^2}{2 \times 9.8}$$

$$h_{regulator} = 0.8594m$$

The total pressure loss is given as:

$$\Delta P_{regulator} = \rho g h_{regulator} = 744.7168 \times 9.81 \times 0.8594m$$
$$= 6278.488Pa$$
$$\Delta P_{regulator} = 6.278kPa$$

Table 1 shows the summary of head losses calculated for the engine fuel system

Table 1: Summary of head losses for the engine fuel system

SN	Components	Volume flow rate (m^3/s)	Length (m)	Diameter (m)	Velocity (m/s)	Reynolds number	Friction coefficient	Major loss (m)	KL for bends	Minor loss due to bend (m)	KL for Expansion	Minor loss due to expansion (m)	Head loss (m)	Pressure drop (Pa)
1	From Electric fuel pump to fuel filter	4.44×10^{-5}	1.2	0.005	2.264	4.45×10^{3}	0.01788	**1.11**	2.2	**0.5747**	0	**0**	**1.6847**	**12307.86**
2	At fuel filter	4.44×10^{-5}											**0.22**	**1606.478**
3	From fuel filter to fuel rail	4.44×10^{-5}	1.2	0.005	2.264	4.45×10^{3}	0.01788	**1.11**	1.1	**0.2874**	1.125	**0.414**	**1.3974**	**10208.95**
4	At fuel rail (common rail pipe)	4.44×10^{-5}	0.36	0.012	0.393	1.85×10^{3}	0.0174	**0.00411**	2.0	**0.0157**	0.6829	**0.0538**	**0.07361**	**537.77**
5	At two injectors (A&C)	1.11×10^{-5}	0.07	0.005	0.565	1.11×10^{3}	0.0202	**0.009202**	0	**0**	0	**0**	**0.009202**	**67.23**
6	From common rail pipe to the tank	2.22×10^{-5}	1.3	0.04	1.767	2.78×10^{5}	0.0191	**0.9878**	0	**0**	0	**0**	**0.9878**	**7216.54**
7	At regulator	2.22×10^{-5}									5.5	**0.8594**	**0.8594**	**6278.488**
			Sum of head losses										**5.2321**	**38223.318**

The total head loss for the Gasoline Port Fuel Injection System is $hl_{(total)} = 5.2321m$
The total pressure loss for the Gasoline Port Fuel Injection System is $\Delta P_{total} = 38223.318Pa$

Conclusion

The flow rate of the system was constant till the fuel reaches the fuel rail. This implies that the fuel discharge flow rate to the fuel rail is equal to the total flow rate at the fuel rate and consequently equal to the flow rate between pump and fuel filter. Throughout the analysis, Re >> 4,000 was obtained, this implies that the flow is turbulent. Thus, the presence of bends observed. The minor head losses are caused by frictional loses due to bends and the change in diameters. However, for the major head losses such as pressure losses, it was due to frictional loses in the pipes due to the fluid to overcome shear viscous resistance resulting from shear and normal forces of the pipe internal surface.

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