

Fundamentals of Automotive Systems
Prof. C. S. Shankar Ram
Department of Engineering Design
Indian Institute of Technology – Madras

Module No # 05
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Analysis of Carburetor - Part 01

Ok good morning so let us get started with today's class ok. So a quick recap of where we stopped this in the last class. We were looking at the simple carburetor and this is a schematic of the same. So we have air taken from the atmosphere entering to the section labeled as A-A prime and that flows through a venturi which is a restriction in the cross section and the pressure drop drops when the air flows through the venturi ok.

And the pressure drop is a maximum when the throat of venturi right and that the air speed will be highest ok. And what we have is that like we have something called as a fuel dispersing nozzle or a fuel discharge nozzle placed at the throat of the venturi and that is connected to this float chamber which contains fuel right. The float chamber ensures that the fuel level is maintained at almost a constant value.

And essentially the as the air flows and the pressure drops there is a pressure difference that is created between the top surface of the fuel in the float chamber and the pressure at the throat of the venturi. And that essentially results in the flow of fuel through the fuel discharge nozzle if the pressure drop is significant enough. So today we are going to derive some simple expressions to figure out first of all when will the flow happen and then what will be flow rates of the mass and the fuel. Because the flow rate of the mass and the fuel is going to affect the fuel air ratio right. So that is something which we are going to analyze today.

And as we discussed the top surface of the fuel in the float chamber is placed a little bit below the tip of the fuel dispersing nozzle or the fuel discharge nozzle to ensure that there is no accidental leakage of the fuel right when there is a pressure drop ok. So we want to carefully regulate the amount of fuel you know like through the fuel discharge nozzle. So today we will also figure out the role of the throttle valve and the choke valve as we do the analysis.

And the term carburetor depression is used to refer to the difference in the pressure between the top surface of the fuel in the float chamber and the tip of the fuel discharge nozzle that is at the venturi throat ok. So just a few quick notations we define the section A-A prime as the section at the entry to the carburetor which we also label as section 1 ok. And the throat is labeled as B-B prime which is also referred to as section 2 and section 3 is the top surface of the fuel ok in the float chamber.

So we will write down the corresponding equation as we go along. So before we begin our analysis let us look at the main components of the carburetor ok.

Just a quick recap to clearly list what are all the main components. So the main components include the float chamber where the fuel is stored and then we have the venturi ok then we have the fuel discharge nozzle or the fuel dispersing nozzle and then we have the throttle valve and the choke valve. So please note that the section downstream of the throttle valve is connected to the intake manifold and then to the intake valve ok so and thereby to the cylinder ok.

So that is the downstream connection ok from the throttle valve. So let us make a few assumptions in our analysis. So let me state all the assumptions that we are going to make. So the first assumption is that we are going to assume the flow process to be steady and uniform. Please note that these are all approximations ok. So the second one is the inlet kinetic energy of air is neglected ok.

So that means that section 1 is when air is taken from the atmosphere the speed of air is assumed to be small such that kinetic energy is negligible ok. So the next assumption is that heat and work interactions between the carburetor and its surroundings are neglected ok. So this is another assumption. So the next one is that we assume all the processes at least involving air to be isentropic ok and air is treated as an ideal gas ok.

So that like we can use the ideal gas equation of state $PV = mRT$ ok. The next assumption is that we will assume that the fuel is incompressible and when we want to analyze the motion of the fuel the flow of fuel will use the Bernoulli's equation. Bernoulli's equation makes use of

other assumption also right. Bernoulli's equation we write for flow along a streamline right. So we are going to make all those assumptions. And we will take constant specific heats for air ok.

Assumptions:

- i) Steady uniform flow
- ii) Inlet KE of air is neglected
- iii) Heat and work transfer are neglected
- iv) Isentropic process. Air is treated as an ideal gas
- v) Fuel is incompressible
- vi) Constant specific heats for air.

So these are some assumption which we are going to make in this analysis ok. So now let us go and apply the balance of energy or the conservation of energy for the flow of air ok. So between the inlet section A-A prime and the throat section B-B prime. So let us apply the balance of energy ok between these two sections. So if I go up this is my inlet section A-A prime and then we are going to look at what happens in the B-B prime ok which is the throat section ok. So we are going to apply the balance of energy under all these assumption ok.

So this is where you know like as I mentioned as one of the outcomes of this course right is to use what we learnt in basic first year Thermodynamics, Fluid Mechanics, Dynamics and so on right for the analysis of automotive system. So under all these assumption we have already learned that the balance of energy can be rewritten in this form.

Applying the balance of energy for the flow of air between the inlet section AA' and the throat section BB'

$$\underbrace{q}_{\approx 0} - \underbrace{w}_{\approx 0} = (h_2 - h_1) + \frac{v_2^2 - v_1^2}{2} + \underbrace{g(Z_2 - Z_1)}_{\approx 0}$$

$$\Rightarrow V_2 = \sqrt{2(h_1 - h_2)} \quad \underbrace{\uparrow}_{\text{Constant Specific Heat}} \quad \sqrt{2C_p(T_1 - T_2)}$$

Recall that, for an isentropic process,

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\Rightarrow V_2 = \sqrt{2C_p T_1 \left(1 - \frac{T_2}{T_1}\right)} = \sqrt{2C_p T_1 \left(1 - \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}\right)}$$

So it is going to be q minus w equals h_2 minus h_1 plus v_2 square minus v_1 square by 2 plus g times z_2 minus z_1 ok. So this is the equation for the balance of energy. So now here applying all the approximation that we are assumption made we have neglected heat and work transfer. So we will take all those both terms of the left hand side to be almost 0. So and then we are neglecting the inlet kinetic energy of air ok and for the flow of air we will neglect the change in potential energy to be negligible ok. So considering the flow of air right so these are some approximation that we are making.

So if we do this so the speed of air at section 2 which is the throat we are going to get it as square root of 2 times h_1 minus h_2 . So assuming constant specific heat I can rewrite this as square root of 2 times c_p times T_1 minus T_2 . So here we assume constant specific heats ok. So this is the simplification that we have ok. Now recall that for an isentropic process so we are going to use the isentropic equation of state what do we have for an isentropic process we know PV^γ equal constant ok.

Intern if I want to write in terms of temperature so what we are going to get is that like we are going to get T_2 by T_1 is going to equal to P_2 by P_1 to the power γ minus 1 by γ ok. So that is going to be the process relationship for isentropic processes relating pressure and temperature. So if we make use of this so the speed of air at the section 2 can be rewritten as square of 2 $C_p T_1$ minus T_2 let us take T_1 outside so we are going to get 1 minus T_2 by T_1 ok.

So we are just take we are just written T_1 minus T_2 as T_1 time 1 minus T_2 by T_1 ok. So now we substitute for T_2 by T_1 we are going to get 2 $C_p T_1$ 1 minus P_2 by P_1 to the power γ minus 1 by γ right. So this what we get as the expression for the speed of air at the venturi throat.

Now the mass flow rate of air at the venturi throat is of course this is obtain from applying the conversation of mass right. So I am directly going to write down the equation. So it is going to be $\rho_2 A_2 v_2$. So what is this what are these parameter? So this is the density of air at the throat

section ok. So this is the cross section area of the venturi throat ok through which the air flows ok.

Thus, the mass flow rate of air at the venturi throat is

$$\dot{m}_a = \rho_{a2} A_2 v_2 = \left(\frac{P_2}{RT_2} \right) A_2 \sqrt{2C_p T_1 \left(1 - \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \right)}$$

↑ Area of the venturi throat
↑ Density of air at the venturi throat

$$= \frac{P_1 A_2}{RT_1 \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}}} \left(\frac{P_2}{P_1} \right) \sqrt{T_1} \sqrt{2C_p \left(1 - \left(\frac{P_2}{P_1} \right)^{\frac{\gamma-1}{\gamma}} \right)}$$

$$\Rightarrow \dot{m}_a = \frac{P_1 A_2}{R \sqrt{T_1}} \sqrt{2C_p \left[\left(\frac{P_2}{P_1} \right)^{\frac{2}{\gamma}} - \left(\frac{P_2}{P_1} \right)^{\frac{\gamma+1}{\gamma}} \right]}$$

A coefficient of discharge is introduced to obtain

$$\dot{m}_a = \frac{C_{Da} P_1 A_2}{R \sqrt{T_1}} \sqrt{2C_p \left[\left(\frac{P_2}{P_1} \right)^{\frac{2}{\gamma}} - \left(\frac{P_2}{P_1} \right)^{\frac{\gamma+1}{\gamma}} \right]}$$

So the cross section area of the venturi throat through which the air is flowing ok. And v_2 we have anyway evaluated above. So what are we going to get ρ_{a2} I can rewrite as $\frac{P_2}{RT_2}$ correct. So this we are writing as $\frac{P_2}{RT_2}$ right using the ideal gas equation of state. A_2 you will keep it as it is then we will essentially substitute for v_2 which will be $C_p T_1$ times $1 - \frac{P_2}{P_1}$ to the power $\gamma - 1$ by γ .

So now we are just going to make a few algebraic simplifications to get the final equation. So what we are going to do is that we will write this equation as $P_1 A_2$ multiplied by $\frac{P_2}{P_1}$ to begin with right. So then we will get $P_2 A_2$ which was there in the numerator outside the square root right. So I am writing P_2 as P_1 times $\frac{P_2}{P_1}$ I can do that and then like R times T_2 we

already know the process relationship right that is going to be P_2 by P_1 to the power γ minus 1 by γ correct.

So I am substituting for T_2 . Then what can I do I can take square root of T_1 1 outside the square root ok. The T_1 outside the square root then I will get square root of T_1 then we are left with $2 C_p$ 1 minus P_2 by P_1 to the power γ minus 1 by γ right. We are almost set now. So if we simplify this we will see that we will get $m \dot{a}$ which is the mass flow rate of air through the venturi is going to be equal to $P_1 A_2$ divided by R times square root of T_1 ok.

So that we get because there is a T_1 in the denominator and square of T_1 in the numerator so we get square root of T_1 in the denominator then if we simplify and take all the factors involving P_2 by P_1 inside the square root what we are going to get is a following. So we will get $2C_p P_2$ by P_1 2 power γ minus P_2 by P_1 γ plus 1 by γ ok so this is what ok. This is how this expression would be simplified.

So please note that we have made a quite a few assumptions in this analysis right and typically there are always going to be energy losses right. So what we is typically done in fluid mechanics is that once we derive such ideal expressions we introduce what is called as a coefficient of discharge which lumps all the losses and discrepancies which are encountered due to the simplifying assumption made in the analysis process right.

So a coefficient of discharge is introduced to obtain $m \dot{a}$ as C_d . So C_d is the coefficient of discharge for this flow of air ok times $P_1 A_2$ divided by R square root of T_1 times square root of $2 C_p$ multiplying P_2 by P_1 power γ minus P_2 by P_1 γ plus 1 by γ . So this is the equation for the mass flow rate of air ok. So immediately one can observe that the mass flow rate of air through the venturi section depends on the ambient air condition right.

Because it is dependent on P_1 and T_1 which is which is represent the ambient air temperature or the intake air pressure and temperature right. So that is the first observation. The second observation is that like the mass flow rate of air obviously depends on the venturi throat area which is by and large fixed. Now more importantly how can I regulate this mass flow rate of air by regulation P_2 because if you look all other parameter C_d is we have to calibrate based on experiments are is fixed ok.

$T_1 P_1$ are fixed once you give me an ambient source right, they may slightly vary ok depending on the local ambient conditions ok A_2 is fixed once we fix the carburetor design. So the main what to say parameter or variable in this equation which can be changed with the engine operation to vary the mass flow rate of air is P_2 ok. And that is where the role of these valves come into play ok.

Let us say the choke valve is completely open this throttle valve you know it can be rotated ok. When we apply the accelerator pedal, we are essentially going to rotate this throttle valve. So we are going to increase and decrease the opening downstream. And please note that throttle valve is connected to the intake manifold and thereby to the cylinder through the intake valve right. So what is going to happen?

If I open the throttle valve by varying extents I am going to adjust P_2 right because let us say I open the throttle valve by a great extent what will happen the pressure at point 2 will further drop down right. Because it is going to be connected to the cylinder and during the suction stroke right. So the pressure at point 2 will drop. So once P_2 drops we are going to have more mass flow rate of air into the cylinder right.

So then what will happen to the fuel flow rate? We are going to look at that now ok. So we can immediately observe that adjusting the throttle valve will essentially ensure that we get a variable flow rate of air ok depending on the operating condition ok. So let us go back yeah ok.

Applying Bernoulli's equation for the flow of fuel

$$\frac{P_3}{\rho_f} + \underbrace{\frac{V_3^2}{2}}_{\approx 0} + gZ_3 = \frac{P_2}{\rho_f} + \frac{V_2^2}{2} + gZ_2$$

\swarrow
 $P_3 \approx P_2$

$$V_2 \sqrt{\frac{2(P_3 - P_2)}{\rho_f} + 2g(Z_3 - Z_2)} = \sqrt{\frac{2(P_1 - P_2)}{\rho_f} + 2gh}$$

So now let us apply the Bernoulli's equation for the flow of fuel. So if we apply the Bernoulli's equation for the flow of fuel please note that we are going to apply the Bernoulli's equation

between the throat section and the top surface of the fuel in the float chamber ok. So those are the 2 points between which we are going to apply the Bernoulli's equation. So if we apply the Bernoulli's equation what is going to happen?

We will get P_3 by $\rho_f v_3^2$. Let me put the subscript f to indicate that is the speed of the fuel right by $2 + gz_3$ is going to be equal to P_2 by $\rho_f v_2^2$ by $2 + gz_2$ ok. Please note the subscript 2 indicates the section at the venturi throat, 3 indicates the what to say top surface of the fuel in the float chamber ok. So that is the labeling that we are using and we the subscript f indicates fuel ok.

So once again we are going to make a few assumptions. The first assumption is that like in the float chamber of the top surface the speeds are low so we neglect the kinetic energy of the fuel ok. So that is something which we are going to neglect. So if we do this and please note that P_3 what can we say about P_3 it is almost going to be equal to P_1 right. So P_3 is vented to the top surface of the fuel is vented to the atmosphere in the float chamber right.

So P_3 is going to be near atmospheric and that is going to be a pressure at the intake section to the carburetor also. So P_3 is approximately going to be equal to P_1 . So if we make all these approximations what we are going to get is the following. So v_2 is going to be equal to square root of $2(P_3 - P_2) / \rho_f + 2g(z_3 - z_2)$ correct I am just rearranging the term. Now what does $z_3 - z_2$ it is going to be minus h because z point 3 is below point 2 ok $z_3 - z_2$ going to be minus h.

You remember that parameter h that we marked in the schematic. So this was h right it is the difference between the top surface of the fuel and the tip of the fuel discharge nozzle ok. So that is going to be h as a result. So this equation will simplify as $2 \times \text{square root of } (P_3 - P_1) - 2gh$ ok. So thus, the mass flow rate of fuel is including a coefficient of discharge is going to be Cdf.

So Cdf is going to be coefficient of discharge for the fuel flow system ok. So Cdf times ρ_f which is the density of the fuel times the area of the fuel discharge nozzle ok I cannot take A_2 that is the throat of the venturi right that the cross sectional area of the throat. So now I need to take the area of the fuel discharge nozzle which we are calling as A_f ok times v_2 . So if we get

this we will get $C_{d,f}$ time ρ_f time A_{fj} multiplied by square root of $2(P_1 - P_2)$ by ρ_f minus $2gh$ ok. So this is what we will get ok. So this is the expression for the mass flow rate of fuel ok.

Thus the mass flow rate of fuel flow is

$$\dot{m}_f = C_{d,f} \rho_f A_{fj} V_{2,f} = C_{d,f} \rho_f A_{fj} \sqrt{\frac{2(P_1 - P_2)}{\rho_f} - 2gh}$$

Area of the fuel discharge nozzle
 Density of the fuel
 Coefficient of discharge for the fuel flow system

Please note that $C_{d,f}$ is the coefficient of discharge for the fuel flow system ok. ρ_f is the density of fuel ok A_{fj} is the area of the fuel discharge nozzle ok at the tip ok that is A_{fj} ok. So these are the various parameters.