Fundamentals of Combustion (Part 2)
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Lecture - 43
Analysis of One Dimensional Combustion Wave (Contd.)

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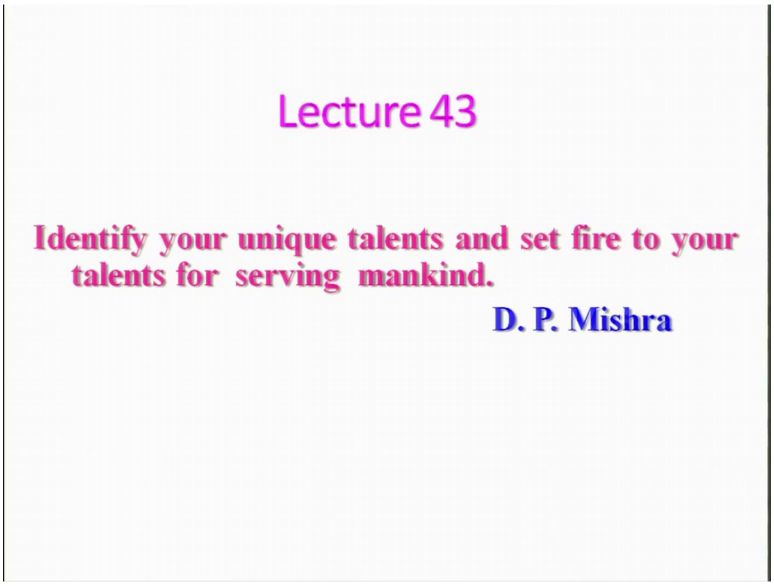

Let us start this lecture with the thought process. Identify your unique talents and set fire to your talents for serving mankind. In the last lecture, we basically derived you know various relationship for one dimensional combustion wave. In the process, we derived two important relationships. One is the Rankine relationship other is Rankine Hugoniot relationship. And we will be using those relationships and trying to understand the various regimes of the deflagration and detonation in other words when the detonation can occur, when the deflagration will occur that we will be discussing about.

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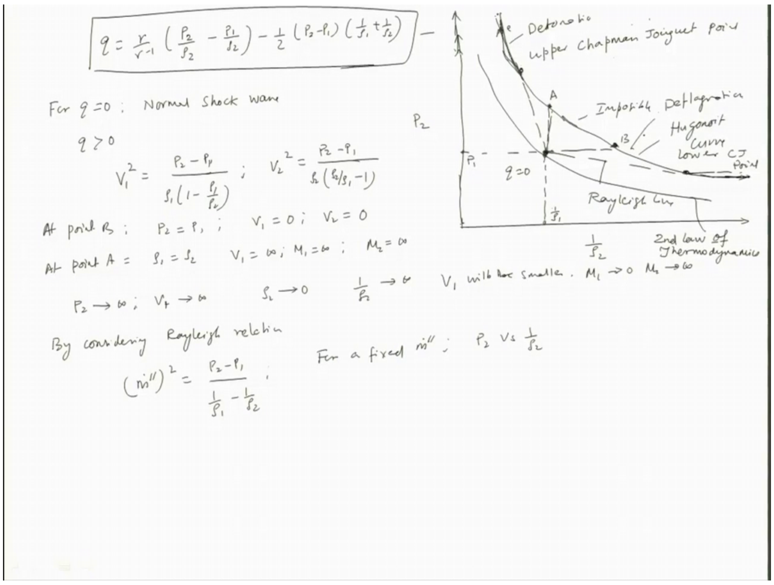

So, let us now invoke basically the Rankine Hugoniot relationship. If you recall that we had derived this Rankine Hugoniot relationship, this is q is equal to gamma, gamma minus 1 P 2 by rho 2 minus P 1 by rho 2 P 2 minus P 1 into 1 minus rho 1 plus 1 minus rho 2 and this is basically the Rankine Hugoniot relationship and if you look at if I take this q as 0 right for example, if I take 0 and if I plot this P 2 versus 1 over rho 2 for a particular P 1 and rho 1, right I will get a relationship like this that is I am plotting P 2 1 over rho 2 and for a particular P 1 and rho 1, right. So, you will get a relationship and this is for a,particular, this is your basically P 1 and 1 over rho 1. This is this region and this is q corresponding to q is equal to 0 and this is corresponding to normal shock wave because this is one dimensional.

So, therefore, it is corresponding to 1 once again, but if it is q is greater than 0, that means some finite value, then naturally what will happen? There will be another curve will be easily coming. Now, if I consider this as my initial point, then it will be like this. This is my initial points. So, what will happen let us see and this will be and I can consider this as a. This is point I can say this is the basically A and this is your B and this region goes towards you know very high values, right these goes towards infinity kind of things. If I consider this case as A and B, right and there will be other regions, let us now invoke our relationship what we had derived for the velocity, right. V1 square we know that is nothing, but your P 2 minus P 1 rho 1, 1 minus rho 1 by rho 2. Isn't it? This is the one we derived, right.

Now, if I consider this as P 1 and this is also this correspond to P 2, so P 1 and P 2 is same is not it? At the point B what is happening at point B? What is happening P 2 is equal to P 1 or not this is your P 1 to start with initial right, but P 2 is here. So, therefore P 2 is same as the P 1 because the same line, no straight line, ok. That means, this expression V 1, then what it will be? V1 will be 0, right. So, therefore it is basically if it is 0, then what will be V 2? Then, V 2 also will be 0. Yes or no?

Student: Yes sir.

Right, why because V 2 square we can write down P 2 minus P 1 rho 2 rho 2 by rho 1 minus 1, right which is not possible. Yes or? No, is it possible? No. So, similarly if you look at point A what it would be? Point A M 1 because point A what happened? Rho 1 is equal to rho 2. Yes or no? Because the same point.

Right, the rho 1 and rho 2, this is corresponding to what? This point corresponding to?

Student: Rho 2.

Rho 2, right and this is corresponding to rho 1. So, both are same. So, therefore, V 1 will be?

Student: Infinity.

Infinity. So, also M 1 will be infinity and what will be M 2? M 2 will be also

Student: Infinity.

Infinity. Yes or no? So, therefore this is not possible. That means, in between it will be impossible. Of course, there is another way of also looking at. You will find out this will be negative you know of the square so, therefore it cannot be. So, this is not possible. That means, only this region is possible. If you look at here, what is happening P 2 in this case anywhere here what is happening? At this point P 2 is very high value. Let us say this point somewhere P 2 is very high value. So, you can say that when P 2 is tending towards infinity, what will happen to V 2 or what happen to V 1? V 1 also will be tending towards infinity for a particular finite density, right. If V 1 P 2 is, then means B 1 will be tending towards infinity where this region right because this is very high value as compared to P 1.

Are you getting? So, therefore, that also will be infinity and in the similar way, you can say at this region like P 2 will be very small right and you can also find out that this will be very low velocities, P 2 when is tending towards or rather I can put other way around arguments, right, that is in this case what is happening rho 2 is tending towards what? Very larger value means. Rho 2 is tending towards very small, rho 2 is tending towards 0. This side, yes or no? This side 1 by rho 2 is very high value, 1 by rho 2 is tending towards infinity means what rho 2 is 0 tending to 0, right. If it is there, then what will happen?

Then, V 1 rho 2 is infinity, right. That means, if it is this will be 0. So, there will be some finite values, right. That means, rho 1 will be having some velocity and P 2 is also smaller, right it is going toward that. So, that V 1 will be smaller, right. So, M 1 will be tending towards smaller means tending towards 0 and M 2 tending towards infinity which is really not possible because you cannot have M 1 is 0 and M 2 will be very high value. It is not possible.

So, therefore certain region it is not really possible, right. So, this will be considered. So, what we will do now, we will be looking at basically Rayleigh relationship. Now, by considering relation we can get minus P 1 over rho 1 minus 1 over rho 2. So, if I plot this thing, P 2 versus from this relationship I can have basically plot P 2 versus 1 over rho 2 for a particular value of mass flux rate for a fixed mass flux rate P 2 versus 1 by rho 2.

What it would be? It will basically a straight line. Isn't it? Yes or no? It is a linear, right. So, therefore, what I will say if I will be trying to intersect this overnight curve, this is known as hugoniot curve, right because we have discussed from the Rankin Hugoniot curves, right. So, if I will do that, what I will start from here, right and it will be a straight line, right. It will be kind of things and this line is known as Rayleigh line and this point which ever will be tangent, this will be tangent to the hugoniot curve that is known as the upper. This is the upper one; there is a lower upper one here. We call this as a upper Chapman Jouguet line point.

This is known as basically in short form you can say CJ. Similarly, there will be another point here and this is known as lower CJ point. CJ means Chapman Jouguet point, right and these will be having a velocity right which will be corresponding to this hugoniot curve and keep in mind that this will be very high velocity. This is detonation and this is this portion from here to there that region is known as the deflagration and keep in mind that this in the normal shock wave generally this portion will be not possible due to the violation of second law of thermodynamics and because the entropy we will be, it will be decreasing, lower branch is not possible.

What we will be looking at? Now, we will be looking at this portion from A to this region and B to this region and C that, where it will be possible and various regime will be discussing about.

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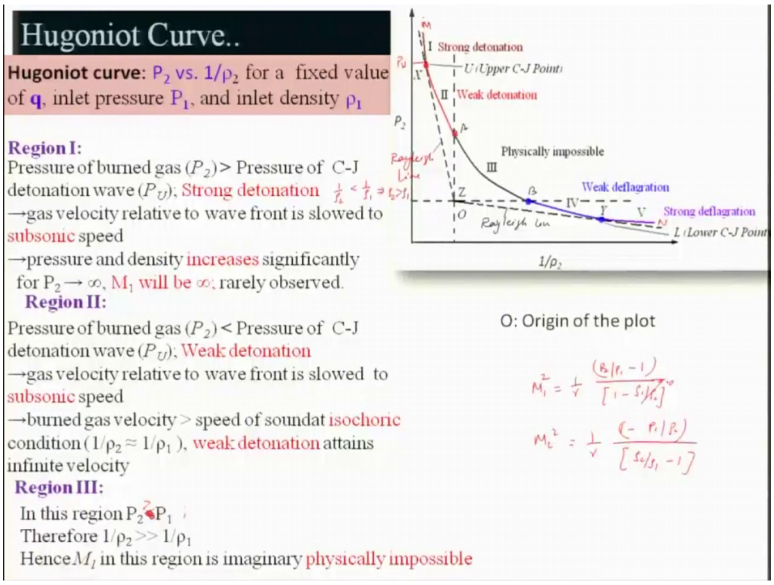

So, as I told you just to make it very clear that when this Hugoniot curves being plotted, P 2 versus 1 over rho 2, you will get that this curve which add marked in the last slide as A and this is your B, right and this portion is physically impossible, right and this line is basically the Rayleigh line and as I told that there will be various regimes here. The regime 1, regime 2, regime 3, regime 4 and regime 5 and this portion is known as from this point because there is the tangent point X between the Hugoniot curve and Rayleigh line is basically known as the upper Chapman Jouguet point and from here onwards is a strong detonation, which is not really possible in nature.

Whereas, the weak detonation from this region and from B to Y is the weak deflagration and Y 2 L, right. This region right that is Y 2 kind of you know we can say that maybe and this I can say is M right, Y 2 n is the strong deflagration. Let us look at region 1. In the region 1, what happen is P 2 is far greater than P u and P u is corresponding to this point like if it is let us say very high right because this is this point I can call as basically P u and in this case what is happening because 1 by rho 2 will be less than 1 by rho 1.

That means, rho 2 is greater than rho 1. Yes or no? Rho 2 is greater than rho 1 and if it is case, then you can look at what is happening to mach number M 1 1 by gamma P 2 by P 1 minus 1 by 1 minus rho 1 by rho 2. So, if you look at basically there is a rho 2 is much higher than the rho 1. Therefore, this will be very small. This may be tending towards 0 if it is very high, right.

So, therefore what happened the mach number will be very high m 1 and what happened to M 2? This is square, ok. M 2 square is 1 over gamma and 1 minus P 1 by P 2. So, m 2 square also will be very rho 2 is very high as compared to rho 1. So, therefore, it will be also very high value and P 2 of course is a very high value as compared to P 1. So, therefore, it will be 1. I mean like it will be higher values.

So, gas velocity relative to wave front is slowed to the subsonic speed and pressure density increases significantly. That means P 2 rho to M 1 tending towards rarely observed. You cannot really get M 1. The inlet velocity is being so high, very infinite towards end. I am talking about here in this region from that onwards, right. So, therefore, it is basically not possible to have this region, right really observed and region 2, this portion if you look at the pressure P 2 is less than the pressure of CJ detonates point P u, which is of course the weak detonation region and the gas velocity related to wave front is slow to the subsonic speed in this region. So, therefore, it is really possible.

The burnt gas velocity is greater than the speed of sound at isochoric process because isochoric means what the density is almost same as that in this region you know like if you look at in this region basically density is approximately same as that. So, therefore, it is possible, but here it is going up very you know kind of things higher and weak detonation attends you know at under these conditions that you know attains infinitive velocity.

So, therefore, if this is not possible as we had seen earlier, region 3 in this region is P 2 less than P 1 because P 2 if you look at in this region, P 1 is here. No sorry, this will be P 2 should be greater than P 1 and therefore, the density 1 by rho 2 is here in this region. Actually there is rho 1 and 1 by rho 2 is greater than 1 by rho 1. In this region, it will be higher, right and therefore, as it will M 1 in this region imaginary because if you look at this in this case, rho 2 is smaller. If it is smaller, this will be very higher value as compared to 1. So, therefore it is imaginary or physically impossible.

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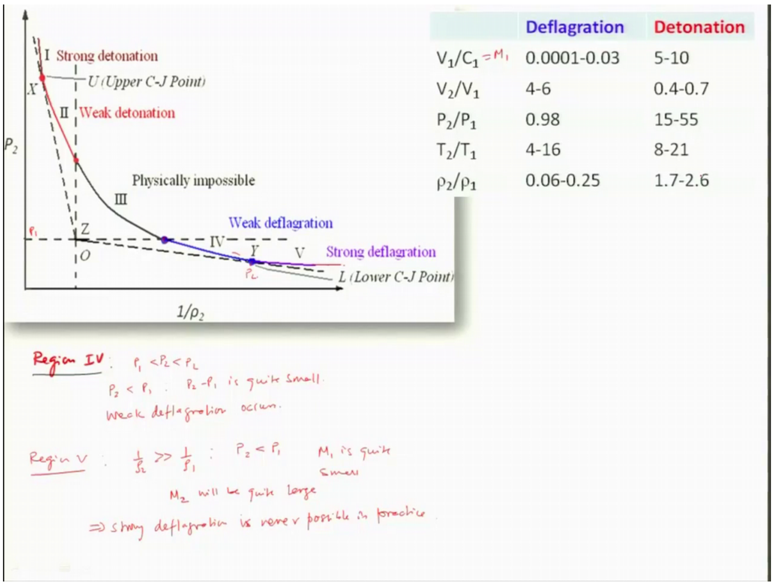

So, region 4, so this is if you look at in between what is happening this region? P 2 is lying between PL. This is corresponding to PL, right and also P 1 is corresponding to this one, right this portion. And gas velocity related to wave front is accelerated, right and as a result what will happen this isobaric because process which will be taking place in this region, there woiuld not be much change in the pressure. If you look at between this and this region, the pressure woiuld not be changing much, right although P 2 is less than P 1 and the difference P 2 minus P 1 is quite small. So, therefore it will be really possible to have the deflagration weak deflagration occurs the region. In this case, what is happening the density 1 over rho 2 is far greater than rho 1 in this region from here to this strong wave which will be taking place in this region, right whereas, P 2 is very less than P 2 because P 1 is here and P 2 is very less.

So, as a result what will happen, the M 1 is quite small, right and M 2 will be quite large which is impossible, which is not possible or never possible in practice. Therefore, the strong deflagration is never possible in practice. Why? Because if the flow is super subsonic, you know like at the initial state and then, you cannot have a supersonic flow without the formation with any soft wave. So therefore this is not really possible and the strong deflagration is impossible to occur in nature and keep in mind that we will be basically discussing about the weak deflagration. That means, the pre mixed flame basically will be weak duplication between this region. Actually this is not possible.

So, in between this region you know which will be discussing about, similarly the weak detonation is possible whereas the strong detonation is not possible. Let me give you some values. What is happening you know in case of deflagration and detonation if you look at V 1 C 1, this is nothing, but your what your mach number 1 is very low whereas, the detonation it will be 5 to 10. It is very high. Unless it is beyond 4 or something, detonation woiuld not occur, right and V 2 by V 1 is 4 to 6 whereas, it is other way around that is 0.4 to 0.7.

Just opposite of that and P 2 by P 1 is 0.98. If it is almost negligibly small, you can say it is not changing approximately equal to 1 and whereas, here the pressure is 15 to 55 kind of very high pressure across the combustion wave and T 2, T 1 is 4 to 16 whereas, here it is much higher level and density of course is a small change, but here it is other way around. It is much higher at 1.7 to 2.6. So, this is the range I am giving, so that you can see it is just opposite behaviour you can see between the deflagration and detonation and detonation leads to the explosion and one has to avoid that.

Of course, nowadays people are talking about pulse detonation engine using the detonation as energy source you know or enhancing the combustion process and then, reduce the emission and also, you know have an engine, but it gives a lot of noise and that is the bigger per hurdles for the development of pulse detonation engine.

Thank you very much. We will take up an example in the next lecture to discuss about how to handle this detonation and deflagration in that.

Thank you very much.