Indian Institute of Technology Madras

NPTEL

National Programme on Technology Enhanced Learning

COMBUSTION

Lecture 46
Spray Comustion

Prof. S R Chakravarthy
Dept. of Aerospace Engineering IIT Madras

So in most of the spray applications one of the inputs that we have to give to the problem is what is called as an initial spray droplet size distribution in fact when we look at these the strayed spray distribution function it says we need to actually look at a bin of certain droplet radius and a bin of certain droplet velocities and a bin of certain droplet locations and so on. So typically for example you do something called a PDPA experiment in order to try to find out what is the droplet velocities and as well as droplet sizes simultaneously.

So it is possible for us to actually measure them together, but you do that in a particular experiment and then you want use that as a inlet condition to let us say a flow field in where for example this burner is now fitted into a combustor or a reactor and so on, so obviously the positions are not going to exactly be the same you are going to only get dry statistics sort of it rather than exactly know what the positions of the droplets are in this experiment.

So the best thing that normally people do is if you now want to fit a certain burner with a let us say oil spray you at least have to know what will be the droplet size distribution at the inlet to this combustor from the burner exit and therefore we have to look we need to know what is called as a initial droplet size distribution.

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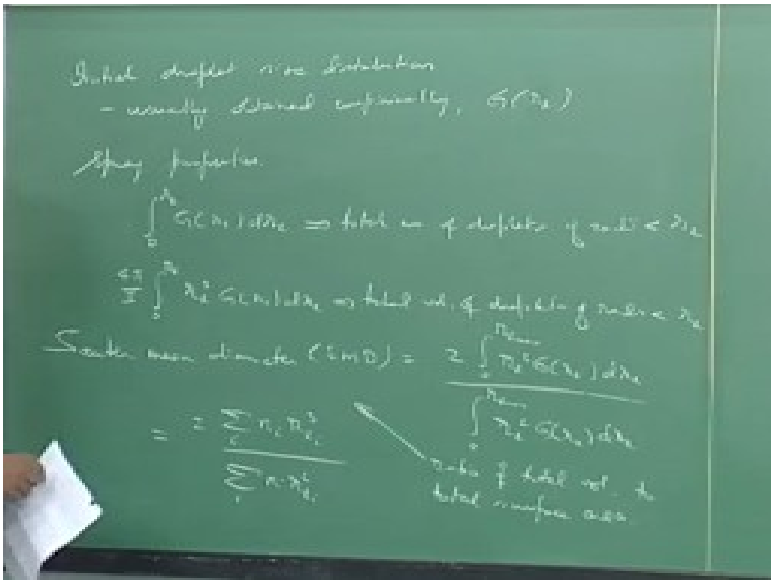

Initial droplet size distribution

- usually obtained empirically, $G(r_l)$

Spray properties

$$\int_0^{r_l} G(r_l)\,dr_l \Rightarrow \text{total no. of droplets of radii} < r_l$$

$$\frac{4\pi}{3}\int_0^{r_l} r_l^3 G(r_l)\,dr_l \Rightarrow \text{total vol. of droplets of radii} < r_l$$

$$\text{Sauter mean diameter (SMD)} = \frac{2\int_0^{r_{max}} r_l^3 G(r_l)\,dr_l}{\int_0^{r_{max}} r_l^2 G(r_l)\,dr_l}$$

$$= 2\frac{\sum_i n_i r_{l_i}^3}{\sum_i n_i r_{l_i}^2}$$

ratio of total vol. to total surface area

This is usually obtained empirically course there are recent efforts to actually try to computationally plug this as well by taking into account the sharing of liquid sheets or liquid rods liquid tubes kind of thing by the aerodynamic as well as hydro dynamic effects and so on. But of course there is a lot more that needs to be done computationally in order to be able to predict droplet size distributions accurately at the moment I think they are mostly used for design of atomizers from a qualitative viewpoint, like for example if you now change some parameters how does it affect the droplet size distribution kind of thing.

But they are always benchmarked and calibrated against experimental data that is obtained so this is basically like let us say you used with a symbol go Gf RL with this you should actually be able to obtain several spray properties, so the spray properties based on the droplet size distribution or integral 0 to RL DRL this actually is the total number of droplets ready are less than or RL and you can also look at the volume. So 4 / 3 5 integral 0 to RLRL^3 g RL DRL that is the total volume of droplets of radii less than order right.

Now many times we use this quantity called the sorter main diameter or SMD which can be written as the form of integral it can be written as integral 0 to it is a certain maximum RL that you have in the distribution RL3 cubed g RL d or l / integral 0 to RL max RL2, GRL, DRL, so notice that you are going to get something like an average radius out of this but SMD is actually a diameter so you have a number 2 a factor to dare to make that a diameter essentially or okay then there is one more way by which you can define this which could be more familiar that is 2 Σ / NI RLI ^{3} / Σ / I Ni RLI ^{2}.

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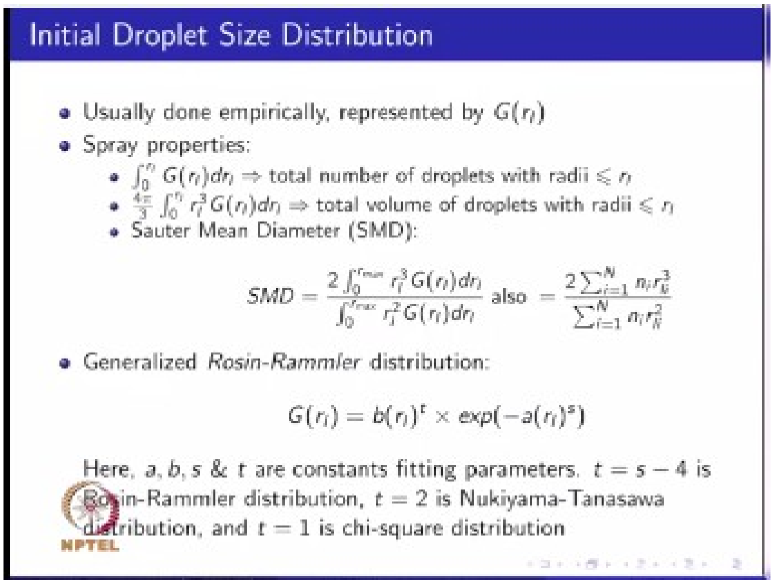

Initial Droplet Size Distribution

- Usually done empirically, represented by $G(r_l)$
- Spray properties:
  - $\int_0^{r_l} G(r_l)dr_l \Rightarrow$ total number of droplets with radii $\leqslant r_l$
  - $\frac{4\pi}{3}\int_0^{r_l} r_l^3 G(r_l)dr_l \Rightarrow$ total volume of droplets with radii $\leqslant r_l$
  - Sauter Mean Diameter (SMD):

$$SMD = \frac{2\int_0^{r_{max}} r_l^3 G(r_l)dr_l}{\int_0^{r_{max}} r_l^2 G(r_l)dr_l} \text{ also } = \frac{2\sum_{i=1}^{N} n_i r_N^3}{\sum_{i=1}^{N} n_i r_N^2}$$

- Generalized *Rosin-Rammler* distribution:

$$G(r_l) = b(r_l)^t \times exp(-a(r_l)^s)$$

Here, a, b, s & t are constants fitting parameters. $t = s - 4$ is Rosin-Rammler distribution, $t = 2$ is Nukiyama-Tanasawa distribution, and $t = 1$ is chi-square distribution

Now this is actually something that is that is more familiarly used because typically what we do is we now have a bunch of droplets and then we now try to size them into bins of certain elemental really radius bins and then you now count the number of droplets that are there in each bin that is NI and so on. So you essentially get what is called as a histogram and if the bin size is very small that means you are now counting a large number of droplets and then placing them over smaller resolutions lot higher resolutions of radii then this can actually become an integral right.

So the integral definitions are typically when the histogram a bin sizes are small and you can now try to fit a curve out of the histograms rather than keep the mass histograms themselves but this would actually hold have histograms, and essentially the idea of put the solid mean diameter in both these definitions is we are looking at basically a ratio of total volume to total surface area right. So ratio of total volume to total surface area so you know when you now have atomization of a spray and if the atomization is very fine then the total surface area is actually very large.

So if you now have a larger and larger atomization done of course the volume corresponding to it is also preserved so typically if you have the same radius for all droplets then it did not matter you will get the same mean radius regardless of how you actually averaged you did a arithmetic average let us say so for example this is the total number of droplets and then if you now have a integral 0 to RL or oral Max or l GRL DRL / integral 0 to r l max GRLDRL right, that would actually be the arithmetic mean and this would be like the sort of mean diameter you can also have like a weight mean diameter and soon so all these things will actually amount to the same if the release of all the droplets are the same okay but when you do not have the radii of all the droplets progressively higher and higher weight ages is going to shrink the size the average size basically here in this case you can clearly see that you have a large surface area then that is going to actually pull down the mean right.

So you typically what is done in order to get this the smooth curve that we talked about is when from the histogram data you can now fit a what is called as a rosin rambler distribution.

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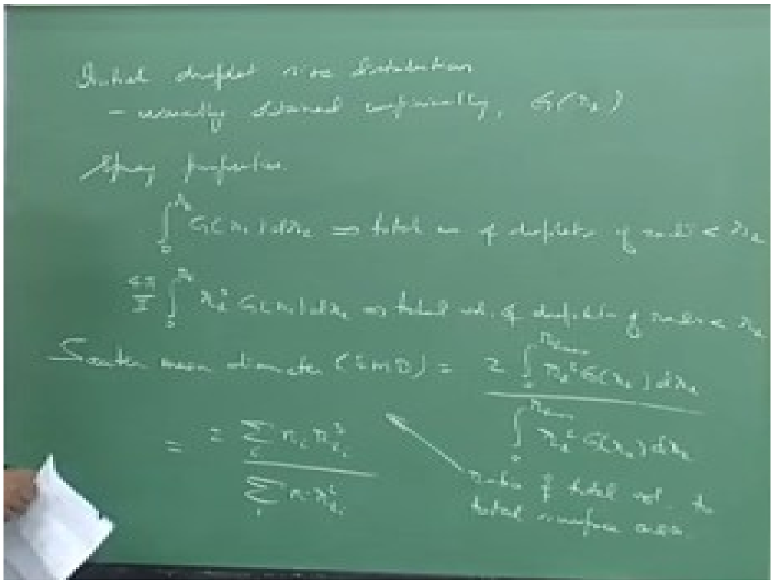

Initial droplet size distribution

– usually obtained empirically, $G(r_l)$

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$$= 2\frac{\sum_i n_i r_i^3}{\sum_i n_i r_i^2}$$

Ratio of total vol. to total surface area

So this is very popular, so the generalized rosin rambler distribution for a sprays is so the distribution function g g of RL = v of r l to the power t exponential negative a of RL color s, so here a b s and T or constants that are used to fit the data to this distribution so a be s T or constants constant fitting parameters all right, now there are special cases, so T for example T = s - 4 is rosin rambler distribution that is the original version number T = 2 corresponds to what is called as a Nukiyama ton of oz' distribution and s equals one is what is called as a chi-square distribution and so on. So you now have these four constants what we should be looking for in trying tech fit curve is four conserved parameters.

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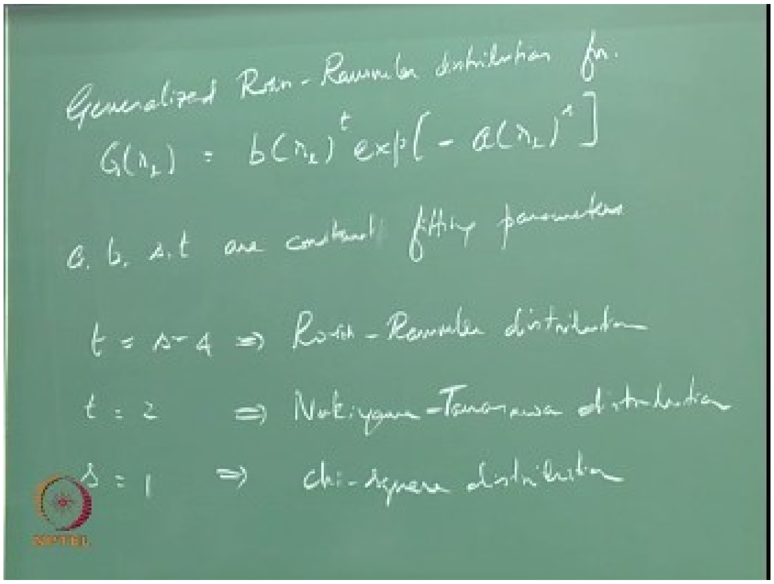

Generalized Rosin - Rammler distribution fn.

$$G(r_L) = b(r_L)^t \exp[-a(r_L)^s]$$

a, b, s, t are constant fitting parameters

$t = s - 4 \Rightarrow$ Rosin - Rammler distribution

$t = 2 \Rightarrow$ Nukiyama - Tanasawa distribution

$s = 1 \Rightarrow$ chi - square distribution

So essentially the four characteristics that we should be looking for is pro characteristics n the total number of droplets which is something that we saw.

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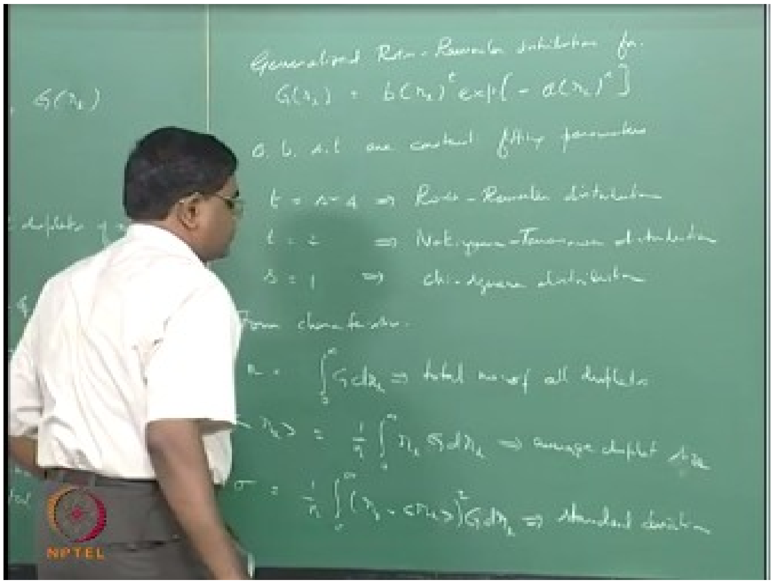

Generalized Rosin-Rammler distribution fn.

$G(r_l) = b(r_l)^c \exp[-a(r_l)^s]$

a, b, s, c are constant fitting parameters

$c = s-4$ ⇒ Rosin-Rammler distribution

$c = 2$ ⇒ Nukiyama-Tanasawa distribution

$s = 1$ ⇒ chi-square distribution

Some characteristics

$N = \int_0^\infty G\,dr_l$ ⇒ total no. of all droplets

$\langle r_l \rangle = \frac{1}{N}\int_0^\infty r_l G\,dr_l$ ⇒ average droplet size

$\sigma = \frac{1}{N}\int_0^\infty (r_l - \langle r_l \rangle)^2 G\,dr_l$ ⇒ standard deviation

But here we try to take all droplets so 0 to infinity G DRL the total number of droplets total number of all droplets then you have a mean which is defined as 1 / N this is the arithmetic mean 0 to infinity or l g drl which is the average droplet radius work in 70 CE sighs σ.

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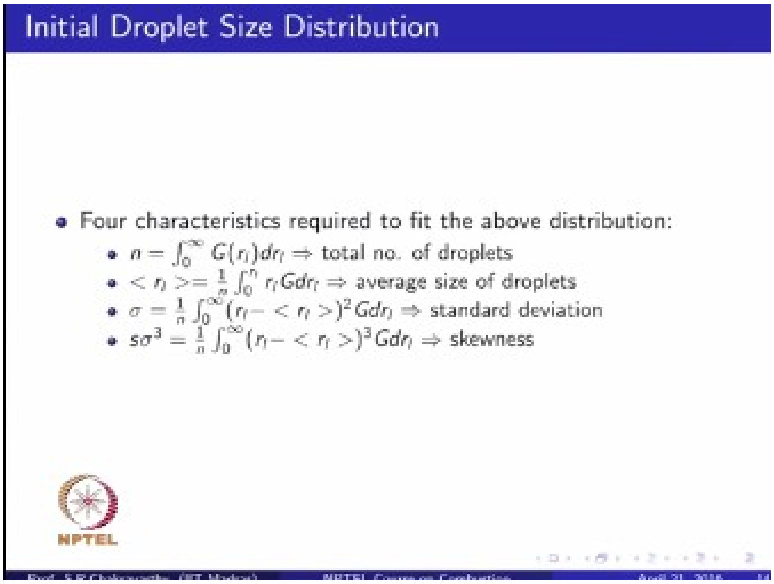

Initial Droplet Size Distribution

- Four characteristics required to fit the above distribution:
  - $n = \int_0^\infty G(r_l)dr_l \Rightarrow$ total no. of droplets
  - $< r_l >= \frac{1}{n}\int_0^{n} r_l G dr_l \Rightarrow$ average size of droplets
  - $\sigma = \frac{1}{n}\int_0^\infty (r_l - < r_l >)^2 G dr_l \Rightarrow$ standard deviation
  - $s\sigma^3 = \frac{1}{n}\int_0^\infty (r_l - < r_l >)^3 G dr_l \Rightarrow$ skewness

So when somebody say sighs usually they talk about diameter that is the colloquial parlance but in this case we are actually referring to radius so keep that in mind sometimes these definitions might be different and then you are off by a factor of two many times who okay, so you know what to suspect, so σ equals 1 / N 0 to infinity RL - the mean or the whole square or GD RL which is the standard deviation.

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And finally you have the this skewness which is s x σ^3 = l / N integral 0 to infinity or l minus mean of our elk the whole cubed g dr l which is the skewness so if you are now able to actually get some data with which you know the mean or the total number and the standard deviation and its skewness you can fit the distribution that satisfies these things right, and then try to obtain the constants and then now you have a curve that is a standard template let that follow the standard template, good.

So with this what we then do what we can do is once you have a good description of the droplet size distribution we now look at the conservation equations for a spray flow, so convey conservation equation of course pay flow including combustion of space so conservation equations here we want to now define row f as the mass of the gaseous mixture a per unit volume of the two phase mixture.

So you now have a two phase mixture with droplets in there and in gas and the gas it gas in turn is a mixture of gases alright, so this is basically the mass of the gaseous mixture per unit volume of two phase mixture the ρ G is actually the gas density, so it is to say that row f is kind of like taking into account the two-phase part of it but road Rho G is without taking into account the two-phase part of it right. So if you want to distinguish these two then ρ F / ρ G is nothing but 1 minus integral should say actually double integral you want to go back to the spray distribution function taken into account different velocities for different droplets.

So then that would be 4 / 3 π RL cubed divided at times F DRL d you then the overall continued equation for the gas for the gas is a ∂ derivative of ρ F with respect to time plus a divergence of divergence with respect to X of ρ F V vector it is equal to negative double integral ρ L times 4 π or l squared or l dot F DRL d u.

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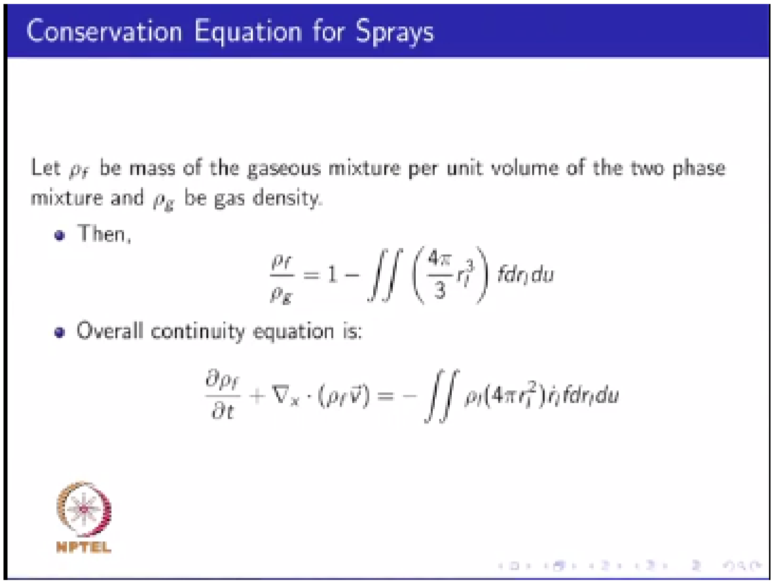

Conservation Equation for Sprays

Let ρ_f be mass of the gaseous mixture per unit volume of the two phase mixture and ρ_g be gas density.

- Then,

$$\frac{\rho_f}{\rho_g} = 1 - \iint \left(\frac{4\pi}{3} r_l^3 \right) f dr_l du$$

- Overall continuity equation is:

$$\frac{\partial \rho_f}{\partial t} + \nabla_x \cdot (\rho_f \vec{v}) = - \iint \rho_l (4\pi r_l^2) \dot{r}_l f dr_l du$$

So here what is going on is you know this is this is basically the rate at which the liquid evaporates or its surface regresses and then produces gas right, so since they say this dr l by d t where the RL decreases as time increases you need to have a negative quantity to make sure that you're adding master this to the gas. So this is basically the this is coming from reduction on the liquid moss liquid mass due to droplet evaporation causing gas phase density variation right basically what you are saying is whatever mass that is that is lost by the liquid is added to the gas because masses to be conserved right.

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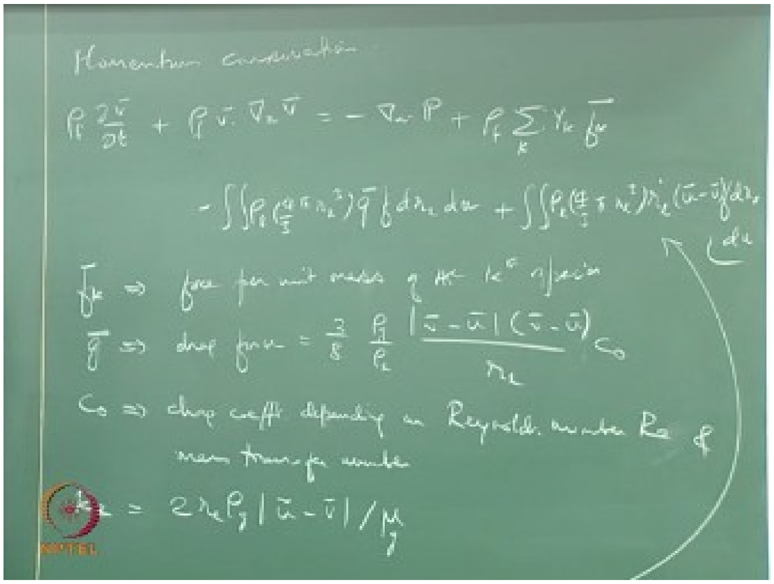

Momentum conservation

$$\rho_f \frac{\partial \bar{v}}{\partial t} + \rho_f \bar{v}\cdot\nabla_x \bar{v} = -\nabla_x P + \rho_f \sum_k Y_k \bar{f_k}$$

$$-\iint \rho_l \left(\frac{4}{3}\pi r_l^3\right)\bar{g}\, f \, dr_l\, du + \iint \rho_l \left(\frac{4}{3}\pi r_l^3\right)\dot{r}_l (\bar{u}-\bar{v}) f \, dr_l\, du$$

$\bar{f_k} \Rightarrow$ force per unit mass of the kth species

$\bar{g} \Rightarrow$ drag force $= \frac{3}{8}\frac{\rho_g}{\rho_l}\frac{|\bar{v}-\bar{u}|(\bar{v}-\bar{u})}{r_l} C_D$

$C_D \Rightarrow$ drag coeff. depending on Reynolds number Re & mass transfer number

$Re = 2 r_l \rho_g |\bar{u}-\bar{v}| / \mu_g$

So the momentum and momentum conservation is ρ f ∂ρ F times ∂derivative of V vector with respect to time plus ρ F V vector dot divergence with respect to X of V is equal to minus divergence with respect to X of the stress tensor including the normal stress namely the hydrodynamic pressure right + ρ F a σ / k for species y k FK that the body force so we will name these once we finish writing the full equation then you have another term which is coming from the evaporation 4 / 3 π r L cubed oh no this is this is the drag on the droplet this is the drag experienced by the droplets from the gas and in turn the droplets exert an equal and opposite drag on the gas okay.

Then we will talk about that plus the thing that I was just mentioning which is the momentum that is imported due to droplet evaporation, so that comes from ρ l 4 / 3 π RL 3 RL dot u -V F DRL d u right. So here FK is the force per unit mass decade species that is basically the acceleration experienced by the kth species this typically is different for different species if you have things like ions that are subjected to an electric field or magnetic field and so on.

So Kth species g is the drag force that is equal to 3 / 8 ρ g / ρ l modulus of the relative velocity times the relative velocity to give you the direction divided by RL x CD now CD is the drag coefficient drag coefficient depending on depending on Reynolds number and mass transfer number. So it will also depend because you now have an evaporating droplet so depends on mass transfer number Reynolds number re so Reynolds number is re = 2 RL that gives you the diameter times density times the relative velocity magnitude divided by the gas viscosity.

So that is taking care of the did this term on the right hand side and finally this term is basically the momentum transferred to the gas by the vaporizing moss because when the gas comes out of the surface of droplets it now imports a momentum to the gas around, so this momentum transfer by the vaporizing master the gas.

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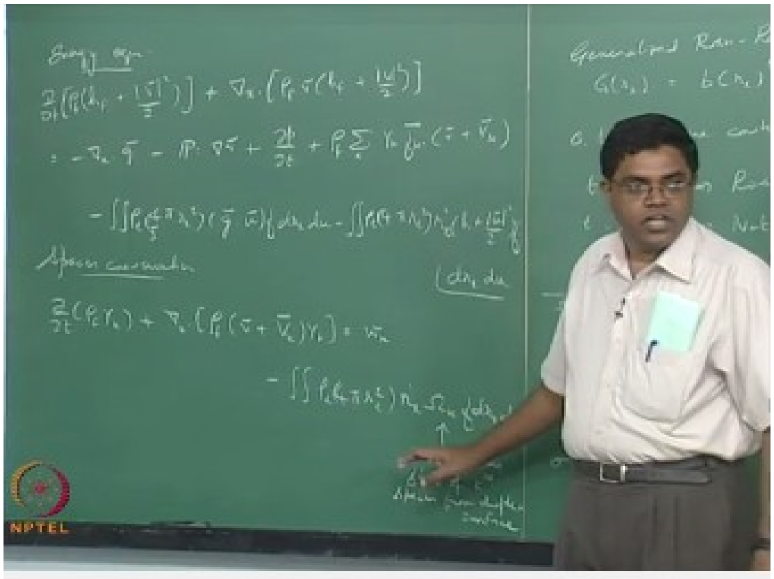

Similarly we could also write the energy equation ∂ derivative with respect to time of ρ F x HF + v square by 2 + divergence with respect to x of rho f v hf + v square over 2 this is the total energy equation that means it includes the kinetic energy also equals minus divergence with respect to X of Q vector minus the stress tensor dotted with gradient of V, so this is basically it tends a gradient of a vector is a tensor the stress tensor is a second order tensor the for this is actually a double dot product you are giving rise to your scalar finally as part of the energy equation plus the partial derivative of pressure with respect to time that is for the that is coming from the PV work and then you have the effect of body force ok YK f K vector dot V plus capital v k this is the diffusion velocity of the KH species keep in mind this is what the momentum equation is all about.

So this is the total energy equation if you got the thermal equation a thermal energy equation alone that would be by dotting dot with v which is the mixture gaseous mixture average velocity, so that this might go away but this would still stay right. So the body force acts on the actual level velocity of the species which includes the diffusion velocity as well as the average velocity of the mixed the gaseous mixture minus then you have a couple of terms that are specific to droplets.

So you now have a ρ l 4 3π RL cubed g you this is the work done go to the drag force times F DRL du - integral ρ L 4 pi r l squared that the surface area times r l dot h + u modulus squared times F DRL d u right.

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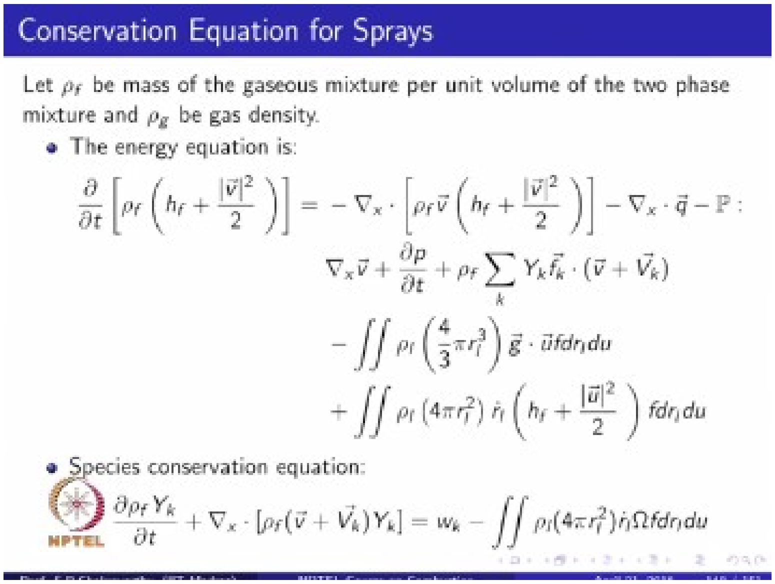

Conservation Equation for Sprays

Let ρ_f be mass of the gaseous mixture per unit volume of the two phase mixture and ρ_g be gas density.

- The energy equation is:

$$\frac{\partial}{\partial t}\left[\rho_f\left(h_f+\frac{|\vec{v}|^2}{2}\right)\right] = -\nabla_x\cdot\left[\rho_f\vec{v}\left(h_f+\frac{|\vec{v}|^2}{2}\right)\right]-\nabla_x\cdot\vec{q}-\mathbb{P}:\nabla_x\vec{v}+\frac{\partial p}{\partial t}+\rho_f\sum_k Y_k\vec{f_k}\cdot(\vec{v}+\vec{V_k}) - \iint\rho_l\left(\frac{4}{3}\pi r_l^3\right)\vec{g}\cdot\vec{u}f dr_l du + \iint\rho_l\left(4\pi r_l^2\right)\dot{r}_l\left(h_f+\frac{|\vec{u}|^2}{2}\right)f dr_l du$$

- Species conservation equation:

$$\frac{\partial\rho_f Y_k}{\partial t}+\nabla_x\cdot[\rho_f(\vec{v}+\vec{V_k})Y_k] = w_k - \iint\rho_l(4\pi r_l^2)\dot{r}_l\Omega f dr_l du$$

Need to go back and check here I think this must be 4 this must be four or 4 π Rl square because we are looking at the surface evaporation then finally we have the species conservation which is rather straightforward with respect to time ∂derivative of ρ F YK plus divergence with respect to X of ρ F V plus capital v k YK so this takes care of the diffusion mass flux equal to the chemical production minus you also have production of the KH species of the gas from drop that evaporation right.

So ρ L 4 πr square r l squared or l dot Ω k f DRL d you where Ω k is actually the radial mass flux of KH species from droplet surface okay.

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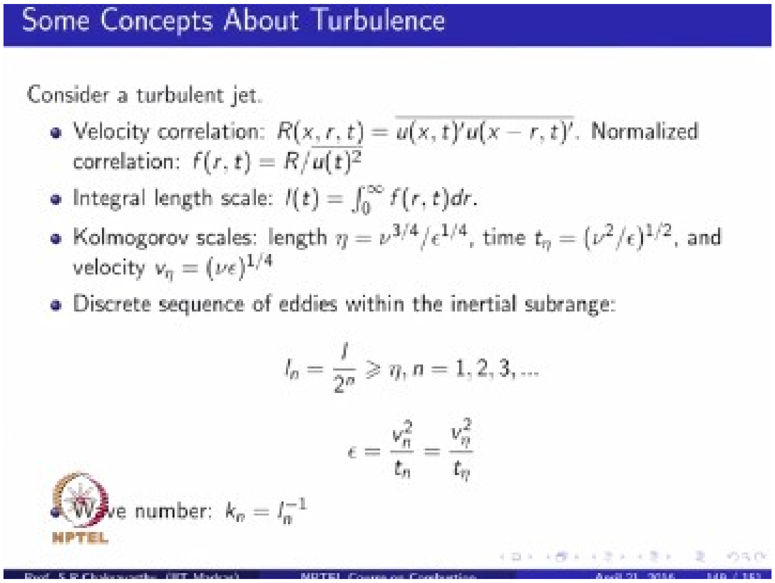

Some Concepts About Turbulence

Consider a turbulent jet.

- Velocity correlation: $R(x,r,t) = \overline{u(x,t)'u(x-r,t)'}$. Normalized correlation: $f(r,t) = R/\overline{u(t)^2}$
- Integral length scale: $l(t) = \int_0^\infty f(r,t)dr$.
- Kolmogorov scales: length $\eta = \nu^{3/4}/\epsilon^{1/4}$, time $t_\eta = (\nu^2/\epsilon)^{1/2}$, and velocity $v_\eta = (\nu\epsilon)^{1/4}$
- Discrete sequence of eddies within the inertial subrange:

$$l_n = \frac{l}{2^n} \geqslant \eta, n = 1, 2, 3, ...$$

$$\epsilon = \frac{v_n^2}{t_n} = \frac{v_\eta^2}{t_\eta}$$

- Wave number: $k_n = l_n^{-1}$

Just could squeeze some space there for writing that so what then happens is if you now write out these equations is a sort of similar to the governing equations that we wrote for a homogeneous combustion that means all species being gaseous, but here this is for heterogeneous combustion where you are now throwing in a bunch of liquid droplets typically fuel droplets and in each of these equations you can see that there is a source term that is coming out at least one or two search terms that are coming up because of the droplet that means the droplet would now add mastery gases it could now import momentum and couple of different ways energy in a couple of different ways and also throw in particular species into the gas and therefore bring comes in a source jumps in the in the equations.

Now what you have to imagine here is let us suppose that we try to solve this for atypical flow field which is quite turbulent there are some very nice research that have been done which now begin to look at what is the effect of the turbulence on these droplets and what is the effect of these droplets on the turbulence okay so typically what happens when you now have a locally high Reynolds number situation based on the mean based on the relative velocity between the gas and the droplet velocity you could now have a wake that is sharing behind the droplet okay.

So you now have a overall turbulent field into which now the droplet is actually moving following the turbulent flow around but as it is moving it's also producing awake behind it and this week is obviously of length scale of the order of the droplet size rather than that of the characteristic dimensions of your combustor or your burner or something which the overall turbulent prevailing turbulence is of a length scale off.

So what happens is you now have these multiple length scales of turbulence the larger length scale corresponding to the combustor geometry and the small length scales of the wake turbulence from these droplets, so a snap shot for example if you were to now do something like a PIV of this and take like a planar data of what the flow field is you will now have like a large scale motions captured over the larger area with like pockets of intense small scale turbulence here and there because the droplets have just gone past these planes here and there.

So that is typically described as a Swiss cheese because if you now take like Swiss cheese you love whole have these lots of these holes that these holes now filled up but in this case the droplet turbulence this is pretty interesting. The other thing now if you now begin to think about these droplets burning rather than just evaporating and let us suppose that we were talking about the group combustion number which now allows for individual droplets to have flames associated with them we never really talked about what happens when you have droplets in motion right.

So the kind of even the kind of pictures that we drew were as if like the droplets specially and do you have an envelope flame that is spherically symmetric about the drop that assuming the

Doppler itself is spherical to begin with, that is all right but when you now have a droplet in motion because of the motion the flame now becomes a symmetric right. So a simpler experiment for that would be if you now have a droplet and then you have a let us say a gas flow that is coming from the bottom you now have a flame that is now getting elongated along the flow direction right.

And you could still think about something like a envelope flame that is enveloping the drop that all around but getting elongated along the direction of the flow right, but then as you now increase the relative velocity between the droplet and the gas you now get into a situation where you no longer have an envelope flame you now have what is called as a vague flame that means.

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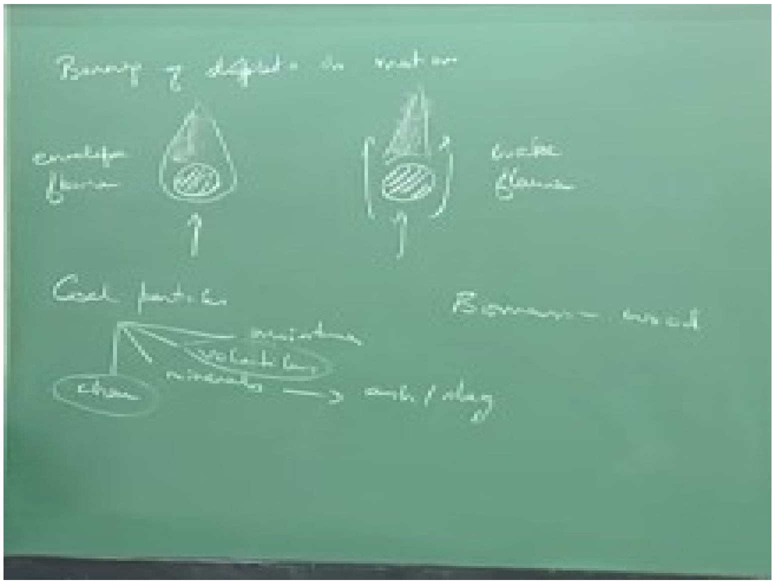

So if you now have a droplet and then you have a flow relative to the droplet airflow relative to the droplet coming up you now have an envelope flame that is envelope in this and elongating in the direction of the flow this is what we would call as a envelope flame and if you now have a greater relative velocity between the two you actually begin to have a only a vague finish that means the flow goes around and actually causes like a liftoff of the flame similar to how you have lifted flames you now have the flame getting really confined only to the downstream part which is what is called as a big flame.

So this is something that typically happens in these cases that's a droplet and let's see that the flame there behind you okay, I want to stop talking about droplet combustion but we are still in the subject of what is called as heterogeneous combustion that means we are talking about some of the reactants or some of the species chemical species in general or in different phase when compared to the other others right.

So far until we were talking about droplet combustion it was all homogeneous combustion that means we were typically talking about all the species being of the same phase and that is that is a gaseous phase but the moment you start talking about droplet combustion we are beginning to step into heterogeneous combustion and yesterday we mentioned the situation of let us say coal combustion where you have like single particle combustion rather than a cloud combustion that's because of lesser volatiles.

So just quickly talk about a coal combustion and other solid combustion we also mentioned for example metal combustion where it is similar to droplet combustion because by the time the metals are actually burning they melt and so you have molten metal droplets that are burning and it is although it may seem like we are actually burning solids in reality you might end up burning liquids.

So if you now think about coal particles the problem mainly with the coal particles is it is essentially twofold one it is okay, before we move in the context of talking about coal particles if you want to now go back to liquid fuels you can still talk about something called a single component liquid fuels versus multi-component liquid fuels okay.

So what is meant by single component vs multi component is if you now take a fuel for example like methanol okay you are essentially talking about only one chemical composition or only one chemical substance there but if you now looking at something like diesel it is actually made up of a large number of different hydrocarbons okay. And each of those different hydrocarbons has different volatilities and you could now get into volatiles that are actually what r volatilizing from somewhere near the core through the less volatile substance and penetrating through that and then coming out as gas right.

So one of the dramatic examples for that is for example if you now have something called aluminized gel kerosene kerosene itself is a is a is a multi-component fuel on top of hurt you now let us say you try to gel it with aluminum and aluminum is less volatile obviously when compared to kerosene so what happens in these kinds of situations where you have a mixture of materials that are of different volatility is the more volatile substance, so that the less volatile substance will actually begin to accumulate on the surface as the surfaces regressing right.

And as it now accumulates and the surface is regressing and shrinking the density of the less volatile substance actually increases and it actually begins to form more like a shell for example in the case of aluminum it could even get sintered together like a shell and except and when it is interred it is like a porous structure through which you now have the more volatile substance get evaporated right.

At some stage this does shrinking continuously will now cost this and then of course you have more and more aluminum breaching the surface right from within and therefore you now have the shell actually kind of hardened you do not necessarily have it porous anymore and you know have a gas because the more volatile substances actually evaporated from within the shell and it now starts acting up with pressure right.

So when you now tries to pressurize the shell the shell breaks and then it now becomes smaller fragments, so similarly you know this is quite dramatic when compared to that if you now simply have multi-component liquid fuel droplets that means you have everything is liquid nothing is really concentrating and forming a hot shell there but if you if you know look still look at liquids the more volatile wants can actually volatile from the core and bubble through the less volatile once and can cause what is called a secondary atomization that being said now shatters the less volatile once into smaller droplets which for from it from a single parent droplet.

So the single payer and drop that itself was actually obtained by atomization but then you now have a secondary atomization because of this, so such things are possible when you now look at coal particles you have a similar scenario where it is not really as the coal particle is not a single component substance right it is a solid particle alright and typically you pulverize it into very small sizes but you are essentially going to have a bunch of different things first thing you know you have a lot of moisture which is pretty bad because this is not going to burn right then you have what is called the volatiles which is what is exactly going to burn right and burn fast and or evaporate fast or get released into the combustion zone quite quickly.

Then you have the minerals which are bad because they are not going to actually aid the combustion but they are going to actually finally bring in ash and what is called a slag so this ash who could in the combustion zone become like a molten region and then as droplets or liquid molten liquid form they could go and get splashed against the combustor walls and so on so this produces a ash and slag and then of course you also have char. So this goes through a solid phase combustion and gives rise to residue and so effectively you are now looking at only two parts of this that are giving rise to energy the other ones could actually soak up energy alright.

And this is pretty important because in the case of Indian coals which is an Indian really relies a lot on coal and there is a lot of reserves here for quite some time that we can burn but it is all very high ash content okay. So the ash content could be as high as somewhere like thirty to forty percent it is almost like we have colon ash rather than ash and cold okay, so that is a kind of situation we have as far as school is concerned.

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Similarly you can also think about this sort of a composition for biomass okay, so if you now think about biomass which essentially is let us say the most common commonly encountered biomasses would but then it can also come up with lots of calls all kinds of things like for example even rice husk is considered like biomass okay, so you can burn any of these things a lot of aggravates can be used in incineration or gasification there are lots of technologies that are getting developed through these things.

So typically again you have to characterize what is the moisture content watch the volatiles content what is the minerals content what the chart content, so doing this kind of thing is what is called as approximate analysis trying to find out what are the different percentages of these different things and then in turn you also have to find out what is the elemental composition of the energy containing constituents and that is what is called as ultimate analysis right.

So typically one of the major problems with biomass and coal more with biomass because you have varied kinds of biomass in the first place but even for the same kind of biomass and for coal the problem is different locations value mind them or where you what I call harvest them you will have different compositions of these. So you have to do the approximate and ultimate analysis for these first to get an idea of what kind of energy content they have and what kind of ash problems you are going to face and soon in these things.

But then once you are in a position to actually do like pulverized coal particles then the analysis is not very different from what we have done so far, and it all takes us back to having diffusion flames or premix flames and so on of course these things typically will be turbulent flames and we will talk about a little bit about turbulent flames but to but a gaseous framework okay yeah in next few days I will stop here for the day.

Production and Post Production

M V Ramchandran
G Ramesh
K R Mahendra Babu
Soju Francis
S Subash
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Udaya Sankar
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Karthi

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Administrative Assistant
K S Janakrishman

Principal Project Officer
Usha Nagarajan

Video Producers
K R Ravindranath
Kannan Krishnamurthy

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