IMPACT OF FLOW OF FLUIDS IN FOOD PROCESSING AND PRESERVATION

Lecture05

LECTURE 05 : INTRODUCTION TO EQUATION OF CONTINUITY

Good afternoon my dear students and friends. As you know already, we have taken four prelim classes, ok. We have taken four prelim classes, wherein, we have given glimpses of the food itself, food and its processing and preservation. Some concept, we have already given, right? and our course is on fluid flow. So, why did we give those prelims? Because, we want you to understand the subject, which, I am going to teach you, I am teaching you rather in this course.

Of course, along with me another faculty will be there at the end. So, we will teach you the different aspects of impact of flow in food processing and preservation. Of course, this flow is of fluid. We will tell in detail what is fluid etc. But, if you remember, I had told you earlier that, this typical course is also suitable for, yes, agricultural and food engineering, only food engineering, food process engineering, mechanical

engineering, civil engineering. Like that many disciplines, because, the flow of fluid is required by every discipline. So, its behavior, how it is controlled, all these are supposed to be known under different conditions, different situations. So, we will arrive at some deductions, because, a little mathematics is also required for this course right? It is not like the food process and preservation, or dairy process technology, like that. This is a multidisciplinary course that is why

many many discipline students having a little mathematical background, at least differential equations are well off. Why well off? Because, they can understand that every time it is not possible to go to the mathematics in detail. Then the course has no value, mathematics over takes everything, right? So, we start with that and we begin with equation of continuity, right?

So, this is the equation of continuity plus and to go for equation of continuity, we give example that many unit operations in processing or in different disciplines, they require to know the flow and its behavior of the fluid that is the most important part that is flow and its behavior of the fluid. And this is not only in processing, but, also in many many disciplines, this is required. Obviously, they are also doing processing. This is not necessary that all the time it has to be food, which is the material, but, it can be any other thing.

Then, it comes, we started with flow of fluid, right? Then what is fluid? We can say that, the fluid that does not permanently resist distortion and hence will change its shape, right? If I take this pen and apply some force, right? it will break. But, if I would have taken, what we call rubber band, and then apply the force, yes, the moment you are applying force it will get distorted,

but, again, it will get back its shape, right? So, a fluid is that which does not permanently resist distortion and hence will change its shape, ok. This was a solid pen. So, it will get broken. So, it cannot be given as an example, but any other similar thing

which, can be given some shape, that also, you know you do bubble gum, right? So, you give a pressure it gets deformed and it does not come back, of course, right? but, here, it is that, which, does not permanently resist because of obviously pressure, hence will change its shape. So, what are those? Like liquids, like gases, like vapors, these obey the same laws, and example of these are water, air, carbon dioxide,

oil, milk etc., many are there, right? So, that does not permanently resist distortion and hence will change its shape with pressure that is known as fluid. There are two types of fluids, one is called incompressible fluid and another is called compressible fluid, right? Obviously, from the word incompressible, it appears that in appreciably affected by the change in pressure, so that, fluid, which does not appreciably change

under pressure, that is called incompressible fluid. Obviously, example could be most of the liquids, right? So, it is not in appreciably affected or we can call it is not permanently or appreciably getting changed, it is called inappreciably affected. So, the change could be, not significant, that is, what is in an incompressible, with change in pressure, but then what is compressible? Compressible are those, which, appreciably is affected, if the pressures are subjected to.

Here, the change is appreciable. So, you must accept the effect of pressure on the changes. So, that is compressible. So, two types of fluids, one is incompressible and another is compressible. And we said, fluid that does not permanently resist, distortion, and will obviously change its shape with pressure, right?

Now, another term, which is very important, that is called continuity. You remember, in the beginning, we started with equation of continuity. So, what is meant by continuity, right? Like between 1 and 2 there are, there can be 10 numbers, there can be 100 numbers, there can be 1000 numbers. So, as you define, so is the continuity, right?

So, continuity of a fluid is considered as a continuous distribution of matter or continuum till a smallest volume of the fluid contains a large enough number of molecules, so that a statistical average is meaningful and the macroscopic properties such as density, pressure etc., varies smoothly or continuously from point to point, right? I repeat, then, it will be more striking on the brain that is a fluid is said to be continuous or is considered as a continuous distribution of matter or a continuum till a smallest volume, as small as you can think of, right? A smallest volume of fluid contains a large enough number of molecules, so that

a statistical average is meaningful and the macroscopic properties such as density, pressure, etcetera vary smoothly or continuously from a point to another point, right? Macroscopic properties like density, pressure, value temperature etcetera etc., right? So, we said, we give the example of 1 to 2, right? in between you can put 10 numbers, you can put 100 numbers, you can put 1000 numbers right? 1, 1.01, 1.001, 1.0001, like that as many as you can. But, here we are saying that, you have to take in a such way that a smallest volume, this volume can be as small as you can think of, infinitesimally small, what we say, right? delta V, that is infinitesimally small, as small as you can think of.

If you think, 10 to the power of minus 3 is a small volume, fine for you, if you think 10 to the power minus 9 is a small volume, fine, no problem. Only it has to satisfy the condition that the number of molecules present in that volume, what you have taken as the smallest volume, must show a statistical average, which is meaningful, and the macroscopic properties, they change smoothly from one point to another point, right? It is a continuous change, no discrete or disruption of the property values. it is a continuous within that volume element, which you have considered, right?

Obviously, you have heard the Avogadro number of molecules, right? So, at least, minimum those numbers should be there, so that your statistical average is meaningful and the macroscopic properties are smoothly changing continuously from one point to another point. So, this concept of continuity is particularly emphasized on deriving the equation of continuity, right? So, another very important

parameter, we define here, that is momentum transfer, right? So, momentum transfer, we call that, a fluid can be under static condition or fluid can be at rest or it can be under dynamic condition or in motion, right? whatever we like. So, static condition or at rest, that is one type and dynamic condition or in motion, that is another type, right> So, fluid under statics or fluid at rest and fluid under dynamic condition or fluid in motion, wherein momentum is transferred.

So, momentum transfer or transport is usually used, right? So, we can, what is that, momentum, rho g, right? rho into g is the momentum, ok will come afterwards, after defining some of the parameters, ok. This is continuity and momentum transfer.

Now, another thing, as I said earlier, that is differential equations of continuity and momentum transfer. For that, let us also explain our situation that, overall mass energy and momentum balances are on arbitrary finite volume, called a control volume, or which, things needed are state of inlet and outlet of these streams and exchanges with surroundings, no need of knowledge of what is going on inside the volume element. Like, inside that control volume, it is not required to be known, but we are supposed to know what is the situation, what is the condition at the inlet and at the exit of that volume element or control volume, whatever we call.

So, a differential element for a control volume is used. So, differential balance is made in a single phase and integrated to the phase boundary using the boundary conditions. In this single phase, we mean that if it is in solid rather if it is in liquid, it is in liquid. If there is a phase change from liquid to vapor or the other way vapor to liquid, then that continuity, we are not saying, we are saying, we are going up to that condition, where integration is done up to the boundary level, right? The phase boundary is the limit, up to that we can integrate, right? So, always we start with the differential equation of the conservation of mass and also of momentum, in general, from any unwanted terms if there be any, are discarded.

So, it is in general, conservation of mass or conservation of momentum, in general, that is to be applied, right? Then, differential momentum balance to be derived, based on Newton's second law and it allows to determine variation of velocity with position and time, pressure drop in laminar flow and it can be used for turbulent flow, with certain modifications. Definitely, surely, or without any ambiguity, pressure drop for laminar flow, it can be very well done, but also can be used for turbulent flow with some modifications.

Now, we said that the differential momentum balance is derived from the Newton's second law. So, what is that Newton's second law? Newton's second law is stating that the rate of change of momentum of a system is equal to the summation of all the forces acting on it and that acts in the direction of the net force, right?

I repeat, the second law of Newton, or Newton's second law can be said that the rate of change of momentum of a system is equal to the summation of all the forces acting on that system and it acts in the direction of the net force. So, mathematically, we can say it to be summation of F, force is equals to d p / d t, or rather d rho / d t, rather, this is not d p, d rho / d t, right? where, no this is d p / d t, yes. summation of force is equal to dp / dt right, where, p is the m and v, some product of m v, right?

And these equations are called equation of changes, which tells variation of properties with position and time. summation of properties with position and time, right? So, d p / d t is equal to summation of all the forces, right? and P is nothing, but product of m v. Now, from the physics we know that p is equals to m v and this represents linear momentum, which is the product of systems mass and velocity, m is the mass, v is the velocity. And this is what we have shown in that equation.

So, this represents that p represents momentum m represents mass and v represents velocity, right? So, the second law, that shows, an object's momentum is directly proportional to both its mass and velocity. So, a larger, faster object has more momentum than a smaller slower object, right?

And the SI unit of it is, that is, for momentum, is kg meter per second, kg into meter per second, kg is the mass and meter per second is the velocity. So, what we say that we know that, if we throw this heavy unit with a velocity v and this lighter unit with the same velocity v, the momentum transfer of this will be much more than that of this, though, the velocities are same, right? That is why at a same velocity, if a small vehicle is hitting another unit the extent of damage to that is much less compared to if a heavier vehicle, hitting that object may be, with the same velocity, because, that momentum transfer is much much higher, because of the mass, though in both the cases, velocity may be, say 30 meter or 40 meter per second, or hour, things like that.

So, this says that a heavier object is definitely impacting with a larger and faster impact compared to that of a lighter object. The differential momentum between the two and this differential momentum is because, the velocity could be same, but the mass is altogether different, right? So, I gave that example of the accident. There should not be any ambiguity that if a heavier vehicle impacts with a velocity v say 50 meter per hour or sorry 50 kilometer per hour, and if one lighter vehicle is hitting that same object with 50 kilometer per hour,

the impact of the former is much more than that of the latter, right? In the former case it could be very very fatal and the later case it may not be so, right? And we said that unit of this momentum is nothing, but kg into meter per second. Then we derive, rather we define some of the derivatives, maybe in this class it will not be over, but I will only define then I will explain in the next class, that, time derivative. There are three derivatives, time derivatives.

One is called partial time derivative, another is called total time derivative and the third one is called substantial time derivative. So, the partial time derivative is defined as, if the variable is say, density, rho, then the partial time derivative can be written as del rho / del t. and this indicates a local change of density with time at a fixed position x, y, z. Then total time derivative can be said as, if velocities in x, y, and z directions are dx / dt, dy / dt and dz / dt respectively, then the total time derivative, of course, is a function of time and velocity components, that is d rho / dt can be said as equal to del rho / del t plus del rho / del x X dt / dx plus del rho / del y X dy / dt plus del rho / del z X dz / dt. There is a mistake, I hope you can find it out.

In the last term it is dz / dt, then substantial time derivative that can be said that it is a time derivative or the derivative that follows the motion, I will explain, that is d rho / dt is equal to del rho / del t plus v x del rho / del x plus v y / del rho del y plus v z del rho / del z, where, vx vy vz are the velocity components of the stream velocity v, ok. Now, time is up we will tell in the next class explain it, ok. Thank you.