Fundamentals of Gas Dynamics

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Week – 01
Lecture – 01
Introduction

Welcome to the first class of Gas Dynamics. I will introduce you what do we discuss here in compressible flow. Introduction, what are fluids? Fluids are substances which continuously deform due to shear.

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So, if I define my fluids as substance that deform continuously due to some shear force. Now this can be gas or liquid. I will compare to the solids the intermolecular forces are weak in fluids; now compare to solids.

Now, if I define that as my fluids, I can have two scenarios liquids and gases. So what is the difference between a liquid and a gas? With respect to the course liquid is something which has a finite volume or it takes the shape of the container. Now more technically the density is assumed constant or rate of change of density due to pressure is negligible. What do we mean by that? 0 or density, not a function of pressure.

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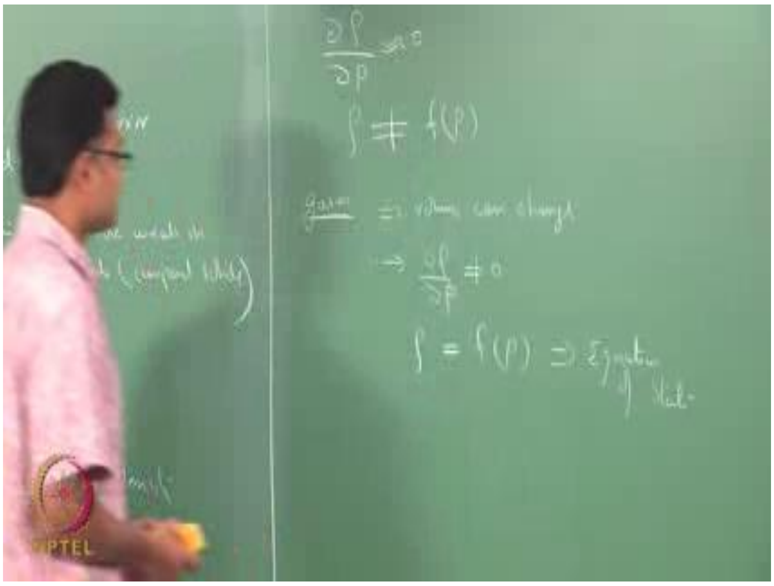

In liquids density is assumed constant or the density is not going to change due to the applied pressure. Whereas, in gases the volume is not finite, the rate of change of density due to pressure is not equal to 0, it is going to change. Or, the density is a function of pressure which leads to something called Equation of State. So there is some function of pressure that is going to give you a density. The relation between pressure and density and probably temperature is going to give something called Equation of State.

That is my definition of liquids and gases. And we are going to study the flow of gases here, where the density is going to change with applied pressure and that is the subject of compressible flow which is the gas dynamics.

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Now, there is another assumption associated with it which we will strictly restrict to and is valid for this particular course something called Continuous. Which is, I would have several particles or several molecules in a container of gas and it is difficult to track these individual particles. Hence, what I would assume is the system is made of continuous substance and I am not going to track these particles, the property would be any property that is associated with this gas is average of all the particles contained in that. So with this assumption you would define your density to be delta mass by delta volume with the limit delta volume tending to some small value. So that is the assumption we are going to think.

So, in outer space you have different particles located at larger distances, so those particles are separate particles and they can collide each other and the continuum assumption is not going to be valid there. We are not going to study those kinds of flows; we are going to study regimes well within this. This also means that the characteristic dimension of the container or the flow the container or the domain in which we are studying the flow, the dimension d is must larger than something called the mean free path.

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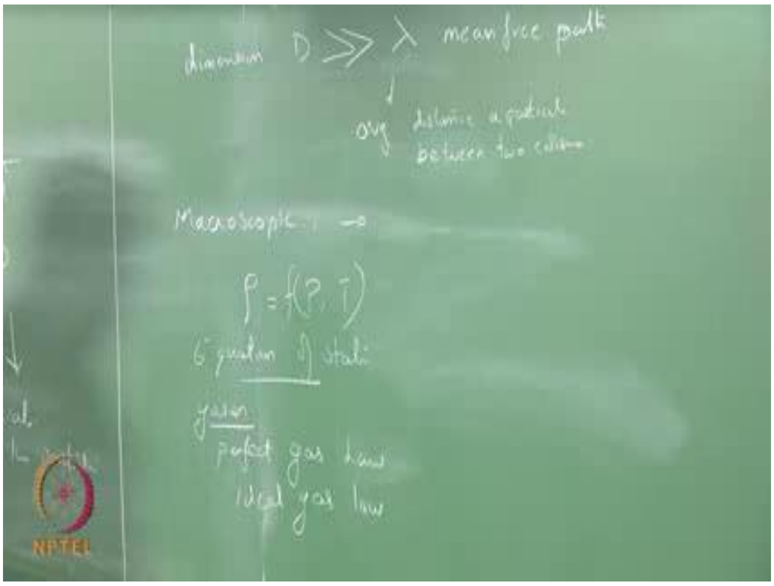

Mean free path is nothing but the average distance a particle might have taken between two collisions. So of our system is something like this, where we have a continuous flow continue mechanics that is valid in the domain we are going to study. So, define something called a Macroscopic property, which essentially means that we are not tracking individual properties of these fluid particle or larger we are going to have an average property of the entire system.

Now, as I told you the density is now a function of pressure and probably temperature to which gives to something called Equation of State. This relation of density pressure and temperature is valid for gases, liquids and solids. For liquids and solids you will have lengthy equations which may be polynomial, may be SCD’s function, or an exponential function. But, what is to be understood here is that there is no single equation that is valid for the entire set of liquids or solids or gases, some equation may be valid for some regimes of temperature or pressure. You will see different kinds of equations of state. One popular equation of state for gases is the perfect gas law or the ideal gas law, which relates pressure and density of this form.

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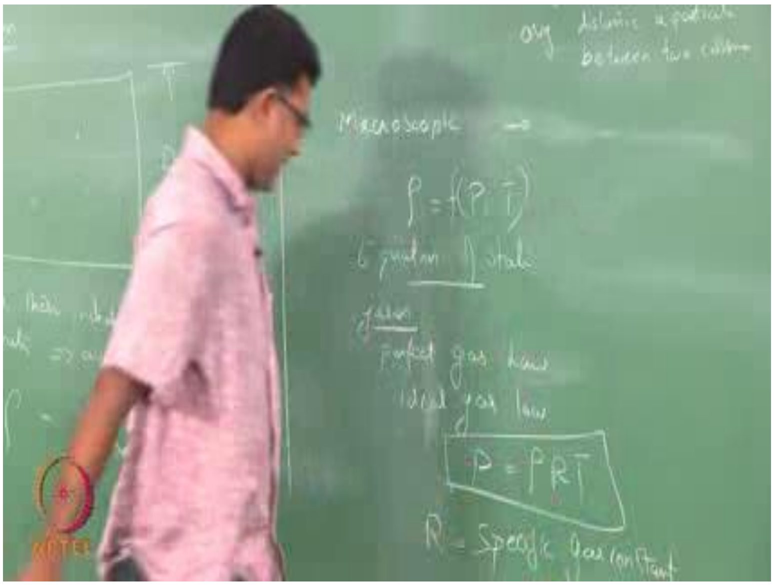

Where, R is something called Specific gas constant. As the name suggest this relation is valid only for some specific gases. If we use this specific constant of air this equation is valid for air.

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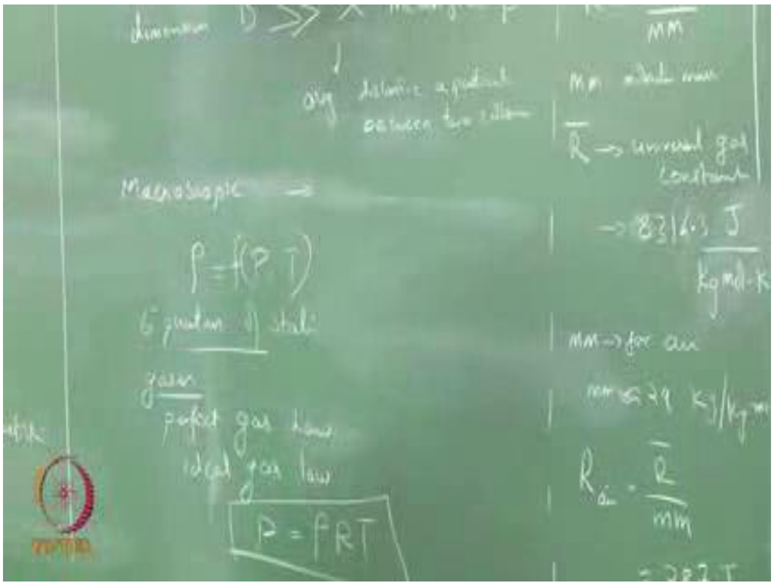

Now, you can relate the specific gas constants are which something called Universal gas constant in the following form. Where, R equals R universal gas constant by mm, mm is molecular mass. The value of R bar which is the universal gas constant, as the name suggest is universal is valid for all gases. Say 8314.3 joule per kilo mole Kelvin. Example for mm for air is approximately 29 again kilo gram per kilo gram mole. So, the value of R for air is going to be R bar by mm which is going to be approximately 287 joule per kg Kelvin.

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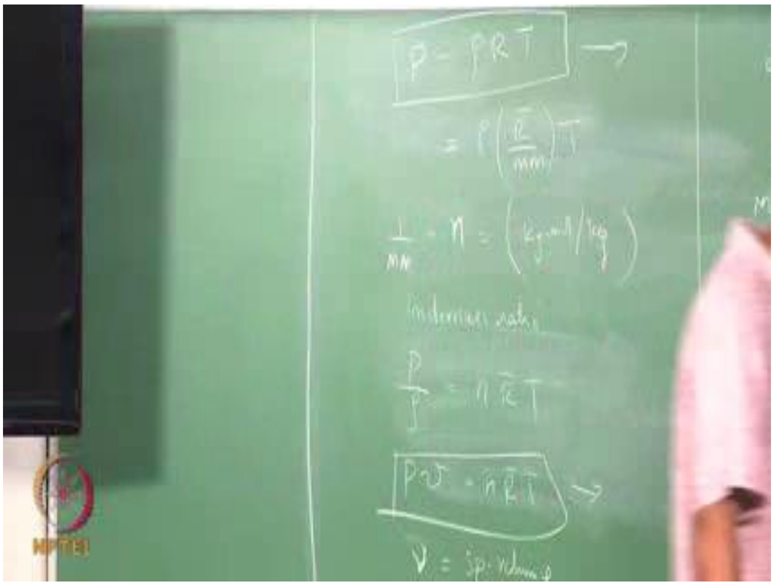

In this equation P equals rho R T which is the ideal gas equation. We have used R as this specific gas constant and if I rewrite that in terms of, ok. So, 1 by mm is typically written as n which is nothing but the inverse of this kilo gram kilo mole per k g. This is something called Mole mass ratio. If I substitute n there my P by rho is n R bar T. And I can rewrite this as P v n R bar T, where v is my specific volume.

So, these relations which are ideal gas relation assumes there are no intermolecular forces or the intermolecular forces are negligible. Now this law is valid for most gases in moderate temperature and pressure. And ideal gas does not mean that it is not present or it is an imaginary fluid, it is just that it is valid for most of the everyday life gases moderate pressures and temperatures that is around 1 bar and 300 Kelvin.

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Now, I have defined the continue fluid that is subjected to say some pressure. If i have a fluid element of volume v or v stroke, it is subjected to some pressure P. So for every d p there is a change in volume which is d v, so there is a pressure that is acting on the fluid element from all sides and there because of that there will be a change in volume. Now I can define compressibility beta as the rate of change of this. I will write for the time being d v by p. So, the compressibility is defined as the volume change due to the pressure. Now this volume change can also happen due to temperature, so it is essentially a function of temperature and pressure.

Now if I attain this change in volume at constant temperature rewrite this as this form and I call this compressibility as Isothermal Compressibility. Or, in the same logic I can define something called isentropic compressibility as at constant entropy. So, if I attain this volume change due to pressure at constant entropy then that compressibility is defined as isentropic compressibility. If I attain that change in volume due to pressure at constant temperature it is called Isothermal Compressibility.

Now we also know that density is nothing but one by specific volume. Now if I am talking about specific volume change here then I can rewrite these equations say for example, beta t I substitute this in here, so substitute 2 in 1 I should get 1 by rho d rho by d p at constant temperature. Or my d rho is beta T rho into d p, which essentially tells me that there is a change in density for every change in pressure. Now, for this to happen the beta T should be large, if the beta T is very small for the isothermal compressibility is very small there is not going to be much change in your density.

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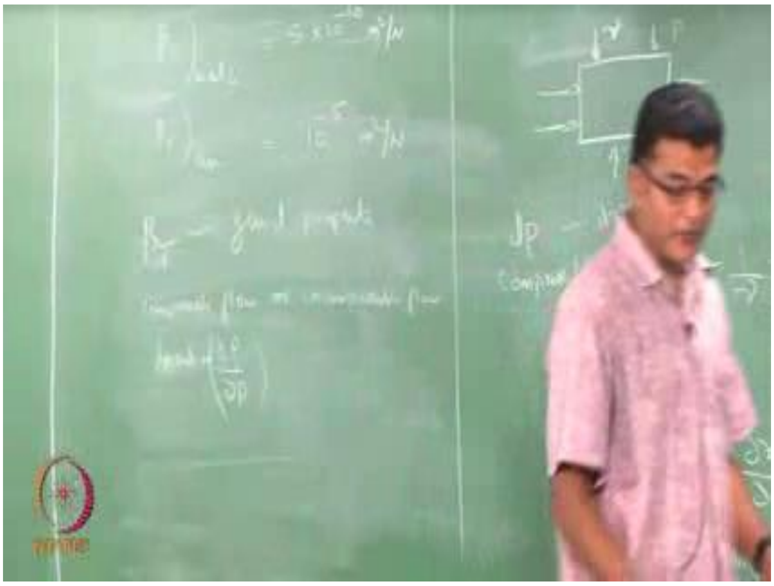

So, if you look at the compressibility of water the value is, so the unit should be the inverse of pressure so that is going to be meter square per Newton and beta T of air is 10 power minus 5, so that is 5 orders more than water. So the compressibility of air is 5 or it is more than water which means that a flow of air is likely to be compressed for the same delta P as in the case of water. You need a fluid with high compressibility to have a delta rho change due to delta P.

So, compressibility is a fluid property. For the compress flow to be compressible you need to have high compressible. So the compressibility if fluid property, but flow being compressible or not, it is not entirely this definition. The flow being compressible or incompressible depends on the d rho by d p value. So, the fluid property compressibility is a necessary factor for flow being compressible, but just because it has a large compressibility does not mean that the flow is going to be compressible. So, the air at very slow speed can still be incompressible.

I will end this particular lesson with this. So next class we will have a thermo dynamics; first law, second law.