Energy Equation for an Ideal Fluid

SPEAKER Bob Holmes: Okay, as I've mentioned earlier, this particular lecture, Lesson 4, is a linchpin to understanding the rest of the course. We're probably at the most important concept of the entire course. It's the energy equation. If you don't understand this, you'll have trouble the rest of the course. So this is maybe a lesson that you wanna listen to and view a couple times to make sure that you understand and can master the main points.

All right, so for the energy equation, we're gonna apply the conservation of energy. And we're going to--in that application of the conservation of energy, we're gonna assume that we have an ideal fluid. And by ideal, I mean, that there's no shearing stress. There is no friction. We know that in real life there's friction. As you move through the air, if you were an astronaut coming back from outer space in the space shuttle. We know that as you enter the earth's atmosphere the friction from the air on the space shuttle builds up a lot of heat. And so we know that we have friction or we have resistance to the flow in any kind of fluid that we have here on the earth. But for our purposes today, we're going to assume that we have an ideal fluid. We have no friction. We have no energy loss due to that friction. So if we have an ideal fluid that we were looking at the space shuttle coming back into the earth's atmosphere, there will be no heat buildup. There will be no need for those heat tiles on the space shuttle to protect the astronauts inside, because we'd have no heat, which is an energy loss from that friction.

So as we look through this, we're gonna consider the diagram that you have on the screen. And I'm going to consider a one-pound parcel of water, that's at Point A on my streamline. And you'll notice there I have the bed of the stream and it goes down and we have a drop and then it comes back and levels out. Then I've drawn a couple streamlines. The top, the uppermost streamline is the water surface. That in itself is a streamline. And then I have the streamline where the Parcel A is. It's sort of halfway between the water surface and the bed of the river.

Now you'll notice that I have a datum that's horizontal. And if you've ran any kind of stream gauging operations, you know that we survey in datum or control. We'll usually run GPS or levels in from a known benchmark and we'll know exactly how high that--what zero gauge datum is

compared to mean sea level. We have this datum where we call that zero. Everything is referenced from that in this particular drawing. You'll notice that where the stream tube or where the one-pound parcel of water is, we've got that at Point A, it is a distance ZA above the datum.

Now I want you to consider that we have three types of energy here in this flowing water. We have kinetic energy. We have potential energy, and we have something we call pressure potential energy. Now the potential energy is the weight times the distance above the datum. In our discussion in this class, we will use the energy units as energy per pound of flowing water. For Section A, in the diagram, the potential energy of one pound of water is ZA, okay? That would be my potential energy is equal to ZA units. That would be foot pounds per pound of water. Because the units on energy are force times the distance. But here in our fluid, we're always gonna talk about per pound of flowing water. So we've got foot pounds per pound, or we simply call it feet. We have length units for energy. Well, sometimes it's hard for students to understand how we get that, especially if you're taking physics classes, we express our energy units in length terms, because we're always talking about per unit weight of the fluid or per pound of the fluid.

The pressure potential energy is that that's due to what we could do with that fluid. So if we have a neutrally buoyant--let's say that we had a plastic bag and the bag had no weight to it, and it contained a pound of fluid and it was at location A. And you'll notice as it's animated on your graph with no expenditure of energy, we could very simply move that particular partial. It could move all the way to the top and we can float that, because it's neutrally buoyant. That distance that it moved, YA, is called the pressure potential energy. Now typically what's going to happen in most of our applications, we're going to assume that the potential energy is going to be referenced to the bed, and our pressure potential is gonna be equal to the depth. That's what typically is going to happen in these lectures.

Now the effective potential energy for any parcel fluid is the same and equal to the sum of the depth and the distance of the bed above the datum, okay? So that's called our effective potential energy. Now, don't get confused with a lot of these terms. You know, you don't have to memorize all of these. What I'm after in this particular section is you kinda understand the concepts. These

things will kinda come, especially as you work the problems and you get used to the flow of things. Well, typically for purposes of this derivation, we're showing you the streamlines. We're showing you the neutral buoyancy, et cetera. But the main concept to take home here is that the potential energy is usually gonna be referenced from that zero datum, wherever you establish it at to the bed of the river, and that the pressure potential is going to be the depth. That distance from the bed of the river to the water surface.

Now the sum of the pressure head and the head, the head being the potential energy, those are other interchangeable terms that we use, again, another source of potential confusion for you. That is going to be called the potential--piezometric head. Now for those of you that done anything in groundwater applications where you've had to measure wells or well heads, we're talking about piezometers. So that would be where you would drive a sand point or you've used a Geoprobe or drilled a well and you have inserted a plastic pipe with some well screen, et cetera, and we're gonna go out and measure the elevation below the land surface of that water. We always call those piezometers. And so that's piezometric head, which is gonna be the same kind of concept. And you can think of maybe if you had at the river was a well or you had a stilling well, those are piezometric measurements, that's a piezometric head. All right, so that's a concept of piezometric head.

Now the last concept that we wanna discuss here is the kinetic energy. From physics, we know that the kinetic energy of a particle of mass, M, and a speed of velocity, V, is defined as one-half the mass times the velocity squared. That's a concept you can look up in any physics book. Now, for a pound of water, it has a mass of one over G. Remember from Newton's Second Law, we've got the force is equal to mass times acceleration. Now weight being a force and the acceleration being the acceleration of gravity in this particular case, we can algebraically manipulate that Newton's Second Law equation and we can say that the mass is equal to one pound divided by the acceleration of gravity, G. Again, in our English units, we're gonna use 32.2 feet per second squared as our value for G.

Now if we do some manipulation there and substitute that value of the mass of one over G into

our equation that we've said where the kinetic energy is equal to one-half mass times the velocity squared, if we insert that one over G in there, we come up with the kinetic energy being equal to V squared over two G. This is also known as the velocity head. And as you'll look on your diagram there, you'll see that we have lines drawn above the water surface at the top that goes up to this total head line, which is dotted at the top. And so if we sum up the potential energy plus the pressure potential energy plus the kinetic energy, we come up with the total head. And that value between the water surface and that total head line is called the velocity head, which is a measure of the kinetic energy.

Now, for an ideal fluid, we said that we had no frictional resistance in the fluid, therefore the total energy along a streamline is constant. So if you're at the water surface and you move from Point A down to Point B, and even though you dropped in elevation, we know that that particular velocity or that particular energy does not change. That total energy along that streamline is the same. So we can write our energy equation where we go from upstream to downstream, and we can say that the velocity squared at Section A divided by two G plus the depth of YA plus the elevation above the datum to the bed of the river, ZA, is equal to the velocity downstream at Section B squared divided by two G plus the depth of location B, which is YB, plus the elevation above the datum at location B, which is equal to ZB, and that's constant. We'll use this concept quite a bit. Now you're gonna use that to solve the problems. One thing I don't want you to get confused about is that in some of our lectures we'll use the value of Y to express the depth and some we'll use the value of D. So those sometimes are used interchangeably. And you'll see that in fluid mechanics and open channel textbooks quite often. In this particular case, I've used Y. We could have used H or--as a value, or D for depth. You always should look at it in the context of how it's being used.

That concludes our lecture here on the energy equation.