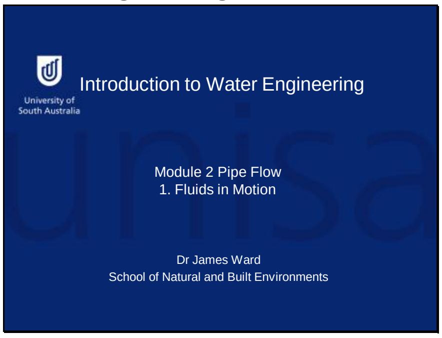
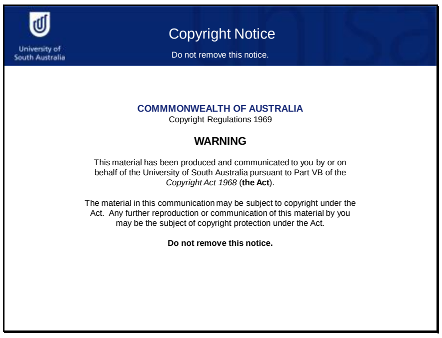
Slide 1



Welcome to Module 2, fluids in motion

Slide 2



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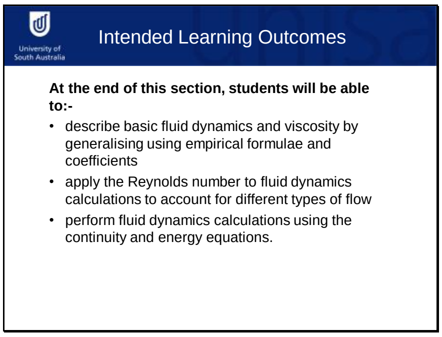
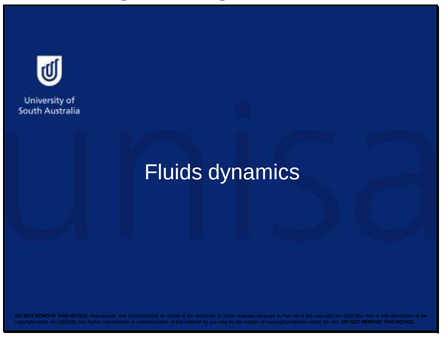
Slide 3



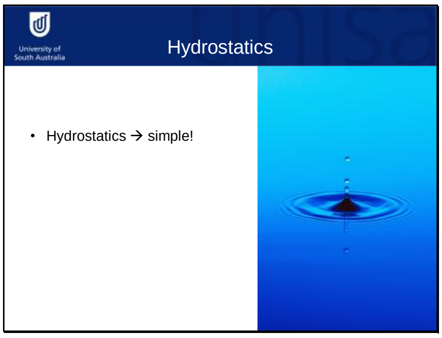
The intended learning outcomes from this presentation are to be able to perform a series of calculations related to fluid dynamics accounting for different types of flow. You'll also learn how and when to use the continuity and energy equations of fluid dynamics.

Slide 4



Lets start by looking at fluid dynamics.

Slide 5

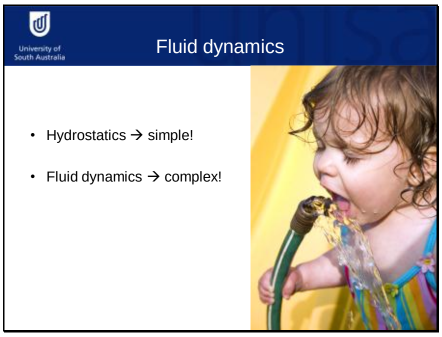


So far we've been looking at hydrostatics,

which deals with the weight of water in a system. It considers stationary fluids, where there's no friction, turbulence or viscosity effects.

Image source: Microsoft clip art

Slide 6

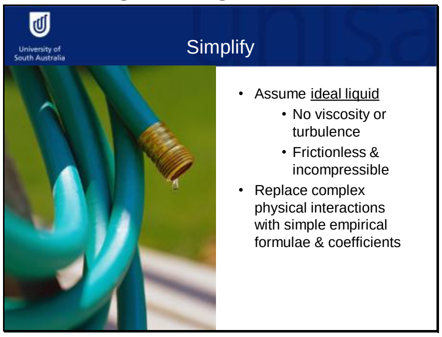


Whereas Hydrostatics was fairly straightforward,

Our next area of study, fluid dynamics, or fluid flow, is relatively complex.

Image source: Microsoft clip art

Slide 7



To work with fluid dynamics, we need to simplify by using assumptions.

The first assumption's that fluid behaves as an "ideal liquid", which means

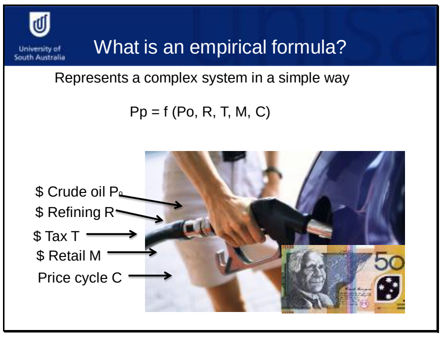
no viscosity or turbulence is present, and

it's frictionless and incompressible.

The really complex physical interactions that occur in fluid dynamics are replaced with simple empirical formulae and coefficients.

Image source: Microsoft clip art

Slide 8



Okay, you might not be familiar with what we mean by "empirical formula".

An empirical formula represents a complex system in simple way.

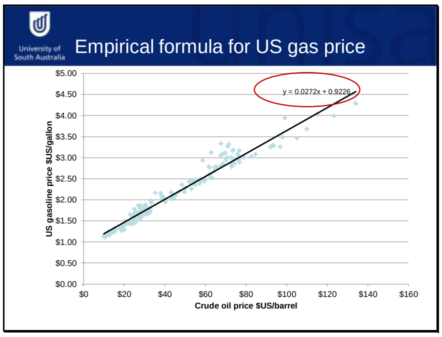
An example of complex system is the price of petrol. It depends on several variables including

crude oil price, refining costs, tax, retail margin, and some sort of weekly price cycle.

Representing the price of petrol using all these variables is really complex.

Image source: Microsoft clipart
http://www.travel-australia.org/money.html

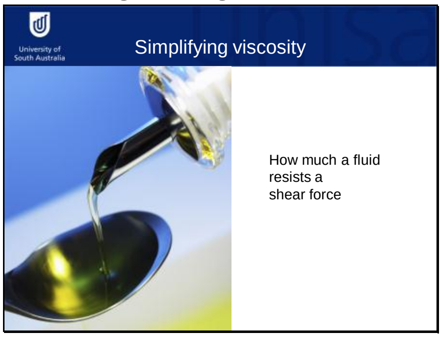
Slide 9



However, if we're not too fussy about capturing the detailed dynamics of the petrol price, we can just plot the petrol price against the crude oil price, and deduce an empirical formula for petrol price

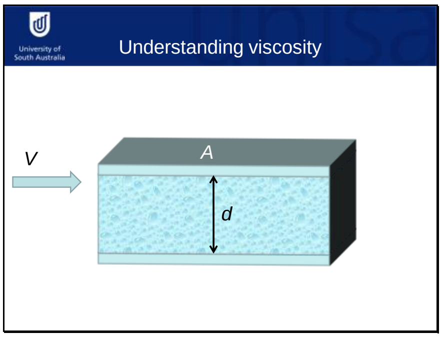
based on the straight line equation of this graph. It's strength is that it becomes a simple calculation, reducing the complexity. The weakness of an empirical formula like this is that it doesn't tell us any detail about the underlying processes, like all of those variables we identified on the previous slide – but it works well enough anyway. In fluid dynamics, most of the time we employ similar assumptions so we can avoid dealing with all the microscopic complexities of fluid movements, and only consider the behaviour of the bulk fluid as a function of key parameters.

Slide 10



One of the fundamental physical properties affecting fluid flow is the viscosity. Viscosity is a measure of how much a fluid resists a shear force. As an example, honey is a high viscosity fluid, whereas water has less viscosity. The viscosity of the fluid impacts on the internal friction of fluid flow and in practical terms, high viscosity fluids are more resistant to movement.

Slide 11

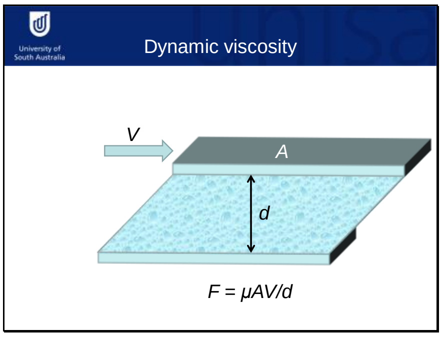


To understand viscosity,

consider this picture of fluid sitting between two flat plates of area A, separated by a distance d,

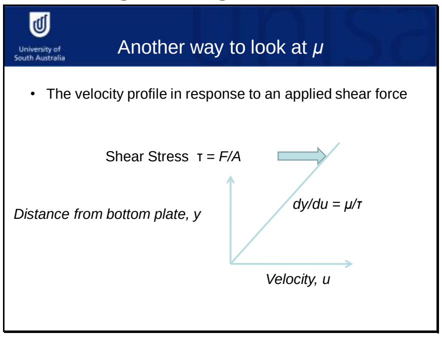
and now imagine one of the plates is being moved a velocity V.

Slide 12



Technically, viscosity is used to find the force that would be needed to move that plate with a given velocity, and would depend on its area. The force F is equal to (dynamic viscosity, mew, times area A, times velocity V) divided by distance, d.

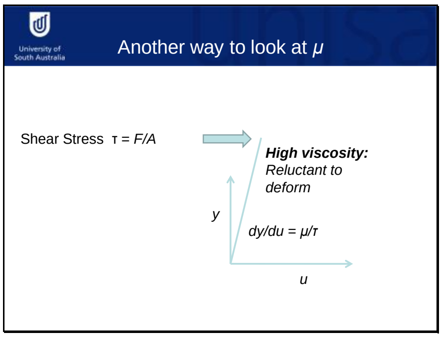
Slide 13



There's another way to look at the viscosity, which is to consider the velocity profile in response to an applied shear stress.

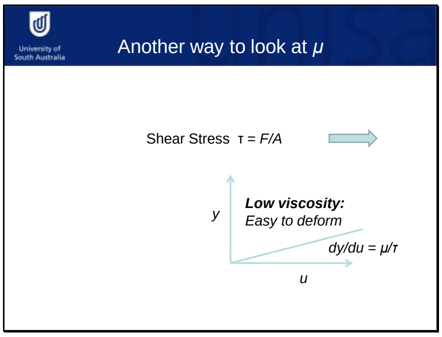
Shear stress (tau) is force divided by area. The slope of the given line affects how velocity responds to the force. What we're really seeing here is that the further we move away from the bottom plate, which is the distance y in this graph, the greater the velocity we can achieve from a given shear stress. The slope of the line is given as the dynamic viscosity (mew) over shear stress (tau).

Slide 14



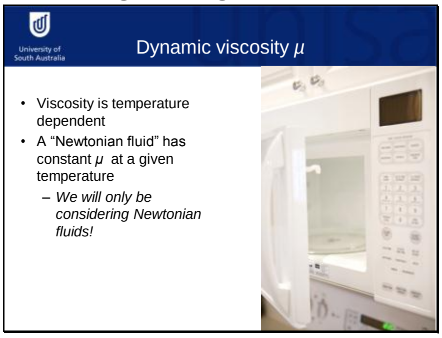
For a High viscosity liquid, like honey or thick oil, the given force will provide only a small velocity. You can imagine trying to drag a knife through honey – it's a lot harder than slicing a knife through water and a relatively large force only results in a relatively small velocity. Try this at home and enjoy a tasty snack while you're doing it!

Slide 15



For low viscosity fluid, like water, the same amount of force will give a much higher velocity.

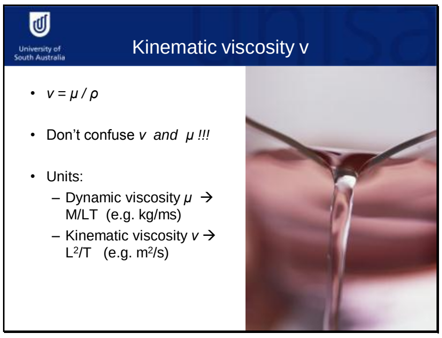
Slide 16



Viscosity changes with temperature. As an example, consider what happens when you heat honey in the microwave - it becomes very thin. In contrast a "Newtonian fluid" has a constant dynamic viscosity at a given temperature. We'll only be considering "Newtonian fluids" in our fluid dynamics so if you're particularly interesting in the dynamics of honey flow, I apologise.

Image source: microsoft clipart

Slide 17



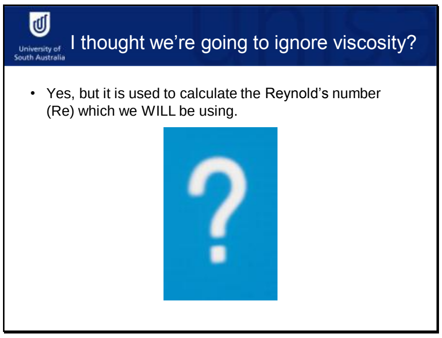
Mew was dynamic viscosity; sometimes viscosity is expressed as Kinematic viscosity, which is dynamic viscosity divided by the density of the fluid.

The two types of viscosity have different units.

The dimensional expression of dynamic viscosity is mass divided by (length × time); so, a typical unit would be kilograms per metre-second. Kinematic viscosity is expressed as length squared over time so a typical unit is metres squared per second.

Image source: microsoft clipart

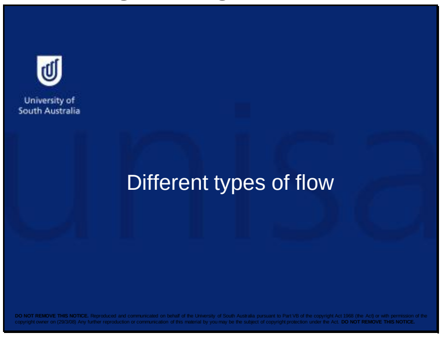
Slide 18



Although we're not going to worry about calculating viscosity or looking at how viscosity might change with temperature, we do need to use a value of viscosity to calculate what's called the Reynold's number. Reynold's number tells us about the nature of fluid flow in pipes and channels.

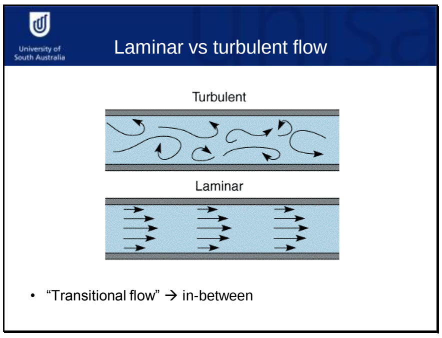
Image source: microsoft clipart

Slide 19



So let's look at different types of flow.

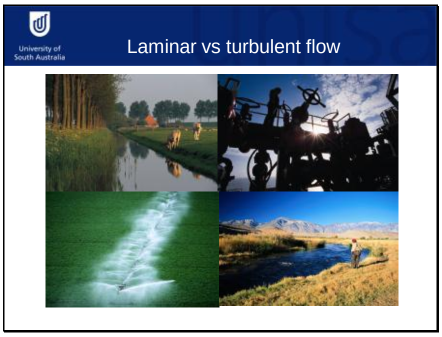
Slide 20



Flow can be laminar or turbulent, or in between, which is called transitional. Laminar flow involves fluid particles moving along parallel pathlines, whereas turbulent flow involves a tumbling, crashing motion.

Image source: http://blog.nialbarker.com/wp-content/uploads/2010/03/laminar_turbulent_flow.gif

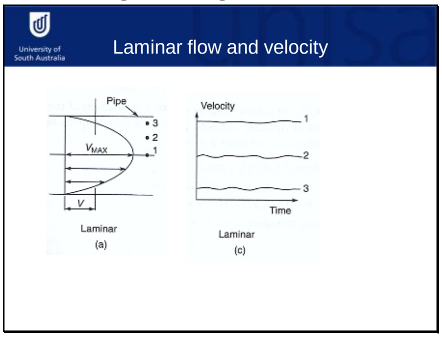
Slide 21



Laminar flow involves slow, even movement of water typical of viscous fluids. We don't actually see much laminar flow in water engineering, but one exception is ground water which flows very slowly. It's far more common in water engineering to come across fast moving fluids that show turbulent flow. Or we might see flow somewhere in between laminar and turbulent, which is known as transitional.

Image source: Microsoft clipart

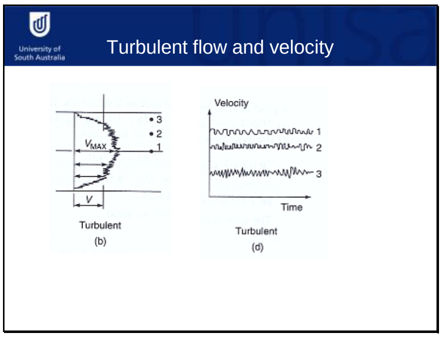
Slide 22



Lets consider three positions 1, 2 and 3 in a pipe of fixed diameter. For laminar flow, at all points there's almost constant velocity. We'd expect the fluid to be moving faster in the middle than at the edges of the pipe because towards the edges it's being slowed down due to friction. But the point here is that in laminar conditions, the velocity profile is relatively even.

Image source- Les Hamill 2011, Understanding hydraulics.

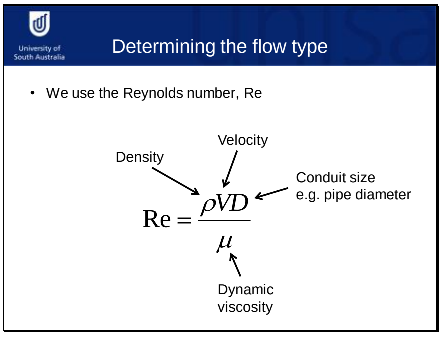
Slide 23



If we move to a turbulent flow situation, with the same points 1, 2 and 3 in the pipe as before, the velocities are more erratic and would change over time as the fluid bounces along in a tumbling motion.

Image source- Les Hamill 2011, Understanding hydraulics.

Slide 24



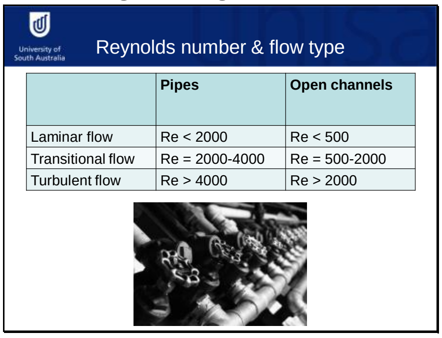
A few slides back we mentioned the Reynold's number.

This is used to determine whether the flow is laminar or turbulent.

Reynold's number =

density rho,
times velocity V
times conduit size, D,
all divided by the dynamic viscosity, mew.

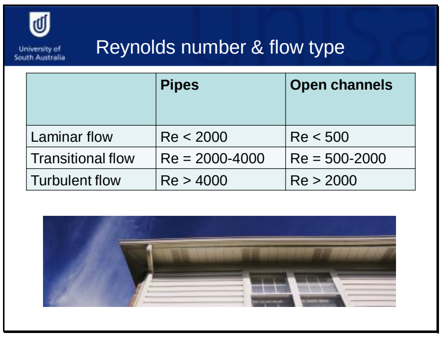
Slide 25



Large values of Reynolds number correspond to turbulent conditions, and smaller values correspond to laminar flow. In a pipe, if the Reynold's number is less than 2000, the flow condition is considered to be laminar; for values over 4000, it's turbulent and in between 2000 and 4000, the flow's referred to as "transitional". These values have been found by experimental work and this is an example of the empirical nature of fluid dynamics.

Image source: Microsoft clipart

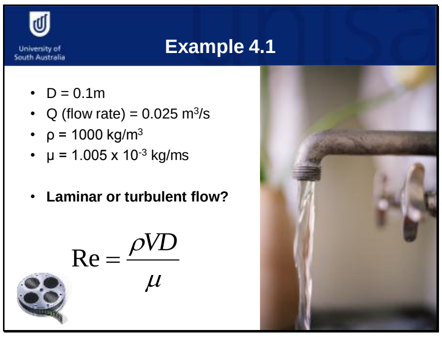
Slide 26



In open channels, the experiments have shown that the same basic relationship holds except that the critical values of the Reynolds number are different to pipes. In open channels if Reynold's number is less than 500, flow's laminar; for over 2000, it's turbulent and in between it's transitional.

Image source: Microsoft clipart

Slide 27



Here's an example where we want to know if flow's laminar, turbulent or transitional. The situation is a fairly high flow rate of 25 litres per second, in a 10 centimetre diameter pipe. The value of dynamic viscosity here is a typical value for water under fairly normal temperature conditions.

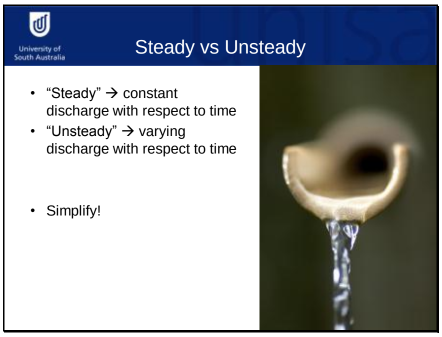
So here you just need to work out the Reynolds number. If you get stuck at all, check the example in the text book.

Image source: Microsoft clipart

Slide 28

The next section is the continuity equation.

Slide 29



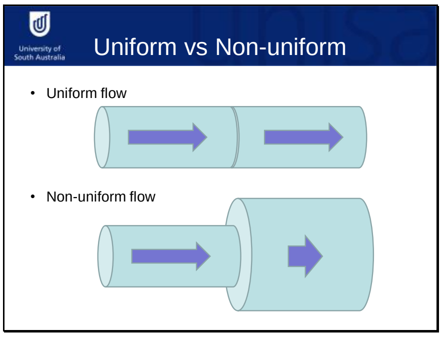
Flow can be steady, if the discharge is constant with respect to time.

Flow can also be unsteady, if there's varying discharge with respect to time.

Unsteady situations, like large pipe systems, are complicated to analyse. In this introductory course for water engineering, we'll ignore minor fluctuations and assume flow is steady.

Image: microsoft clipart

Slide 30

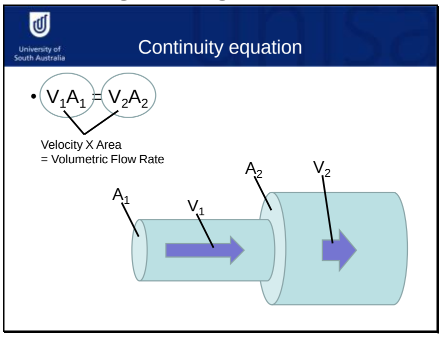


Flow can also be uniform or non-uniform.

In uniform flow, fluid passes through a constant cross-sectional area and the velocity of the fluid is constant everywhere.

In non-uniform flow, fluid passes through a changing cross sectional area and as a result, the velocities are different in the different sections of pipe. In this case the smaller diameter pipe will carry a higher velocity and the larger diameter pipe will carry a smaller velocity, even though both parts of the pipe have the same flow rate passing through them.

Slide 31

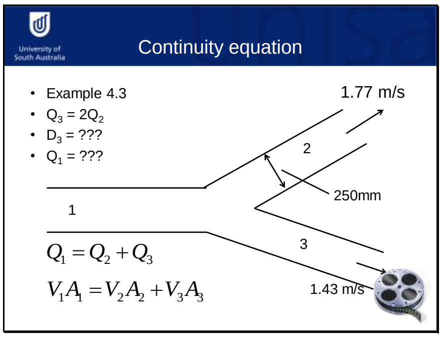


Let's look at that in a bit more detail.

Here we're introducing what's called the "continuity equation", which says that the product of the velocity and the cross-sectional area is constant. So the velocity V1 in the thin section, which has cross sectional area A1, is equal to the V2A2. You can see that this means V2 is going to be smaller than V1 in order to balance the continuity equation.

It's important to note that the Velocity, V times Area, A is the volumetric flow rate, which we usually call Q.

Slide 32



Here's another example of the continuity equation.

In this case we've got a flow entering from the left, which is Q1. Assuming there are no leaks, this inflow has got to be balanced by the outflow, which is Q2 plus Q3.

If we substitute Q equals V times A from the previous slide, we can see V1A1 equals V2A2 plus V3A3.

Now, in this particular example we've been given a bit of extra information which is that we know the flow in pipe number 3, Q3, is equal to double the flow rate in pipe 2.

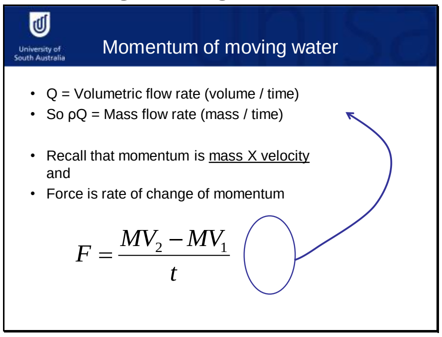
We want to find out the diameter of D3 and the flow rate in the inflowing pipe, Q1. See how you go with it, and as usual the solution procedure's available in the text book.

Slide 33

Let's stop for a minute and think about the sorts of engineering involved in a large-scale water pipe. When we're supplying water to cities, it's pretty common to transport water over at least a few kilometres, in pipes over a metre in diameter. Water in a pipe like this could easily have a mass of many thousands of tonnes, a similar mass as, say, a large freight train or cargo ship. So when we try to get it to speed up, slow down or change direction there's a huge amount of momentum that needs to be considered.

Image source-
http://upload.wikimedia.org/wikipedia/commons/7/7d/800px-Trans_Alaska_Pipeline_Denali_fault_shift.JPG

Slide 34



Volumetric flow rate, Q, is volume divided by time.

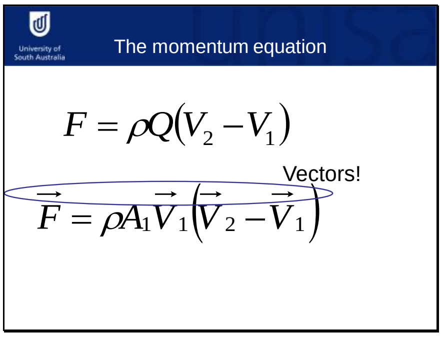
So if we multiply the volumetric flow rate by density, it becomes a mass flow rate, mass over time.

Hopefully you can remember from your physics that momentum is mass times velocity, and

Force can be expressed as the rate of change of momentum over time.

If we rearrange this slightly, we can actually express force as the mass flow, which we said was rho times Q, multiplied by the change in velocity.

Slide 35

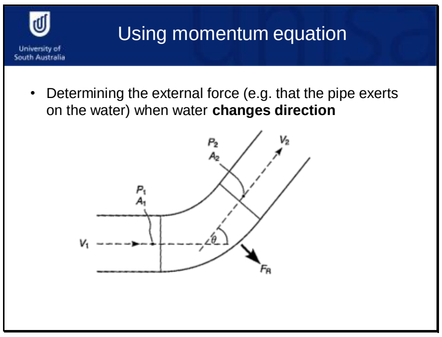


The momentum equation is force F, equals density rho, times flow rate Q, times by the velocity change (V2 minus V1).

Strictly we should write this with vector signs

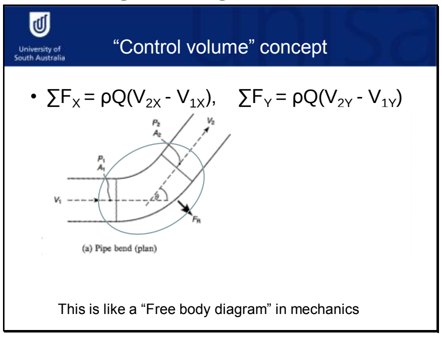
Because directions are required in momentum equations. What we mean here is we’re interested in the change in velocity, not speed. So as water gets carried around a bend in a pipe, even if it’s moving at a uniform speed, there’ll be a force exerted on the pipe bend. As we said before, large pipelines carry an enormous mass of water. The supports for bends in the pipe need careful structural engineering to account for not just the physical weight of the water but also the force due to the water changing direction.

Slide 36



Let’s look at how the momentum equation can be used to determine the external force when water changes direction.

Slide 37



This image shows a horizontal pipe bend, which turns through angle theata. Because momentum and velocity are vectors, we need to resolve them into X and Y components for analysis. What the momentum equation really says is that it’s the net force, or the vector sum of all forces, that’s equal to rho Q V2 minus V1.

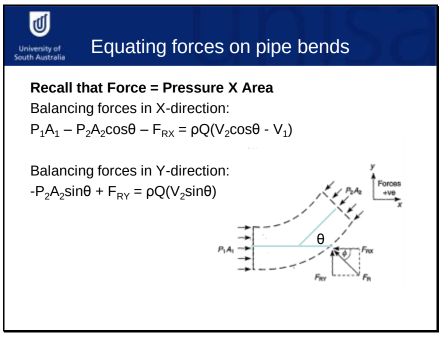
So the sum of the forces in the X-direction are equal to the momentum equation in the X-direction and the sum of the forces in the Y-direction equals the momentum equation in the Y-direction.

Now what we’re going to do is take what’s called a “control volume” and use it to find the reaction force, FR acting on a pipe bend.

The Control volume concept’s similar to the free body diagram you might have used in mechanics. By working out the different forces acting on the control volume we can find the net force and solve the momentum equation.

Image source- Les Hamill 2011, Understanding hydraulics.

Slide 38

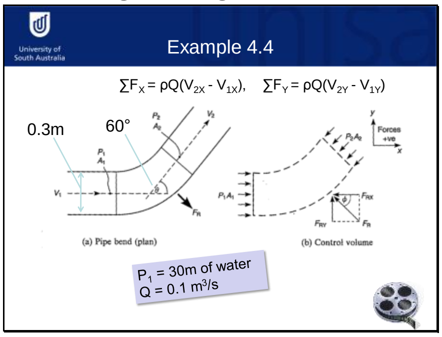


Using the pressure in the pipe and the cross-sectional area, we can work out the forces acting on each end of the control volume, which will be P1A1 and P2A2.

So we work out the net force in the X direction, which is P1A1, minus the X component of P2A2, minus the X component of the reaction force FR. And this equals the momentum equation using the X component of the two velocities.

Then we do the same thing in the Y-direction. In this case both the P1A1 term and the V1 term disappear, because neither of those have a Y component. Obviously this time we use “sin” instead of “cos”.

Slide 39

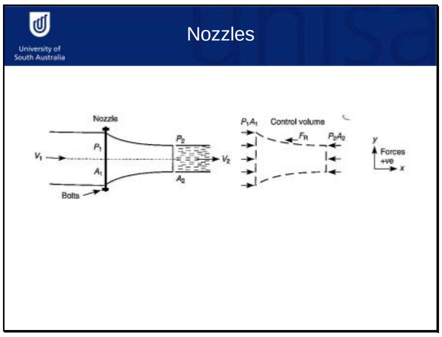


So here's an example to practise on. You'll need to be able to do similar calculations. You've been given the pipe diameter and the angle of the bend.

We're also told the pipe's running at a pressure equivalent to 30 metres of water, which you'll need to convert to Pascals using P equals rho G H. And the flow rate's 100 litres a second. See if you can work out the reaction force FR using the procedure we've just gone through. Check the procedure in the text book if you need to. Don't forget to re-combine your X and Y components at the end to work out the overall magnitude and direction of FR.

Image source- Les Hamill 2011, Understanding hydraulics.

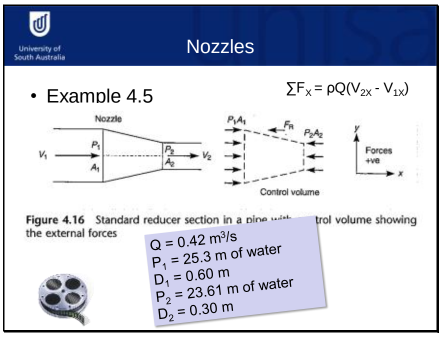
Slide 40



When we force water through a nozzle or some other contraction, the cross-sectional area reduces so the velocity increases according to the continuity equation. Because this is a change in velocity there has to be a change in momentum and that means there'll be a reaction force. Imagine holding a garden hose with a high flow rate coming out of a tight nozzle on the end – hopefully you can imagine that you might feel a significant force. Anyway, we can use the same control volume concept as before to work out the reaction force.

Image source- Les Hamill 2011, Understanding hydraulics.

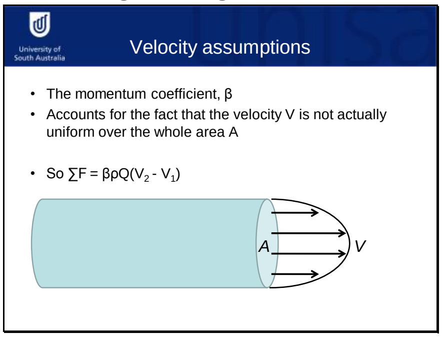
Slide 41



Here's an example. This is a nozzle-type contraction where water flows from a wide diameter into a small diameter pipe, so the velocity undergoes an increase.

We've been told water's flowing at 420 litres a second, which is actually a pretty high flow rate. The big pipe's 60 centimetres in diameter and the small pipe's half as wide. We've been given upstream and downstream pressures in "metres of water" which you'll have to convert to Pascals just like last time. Use the control volume concept to solve the momentum equation. In this case it's simpler because it's all happening in one direction, so you don't have to resolve it into X and Y components. Consult the text book if you need to.

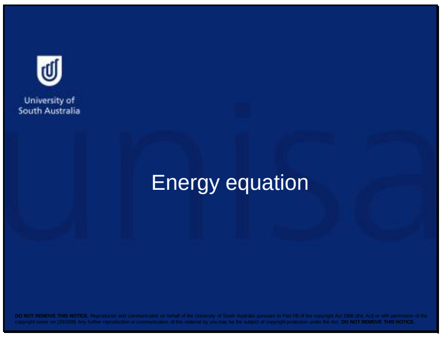
Slide 42



We said at the beginning that we'd make a few assumptions. Well, our first "fudge" factor is for velocity. We know that velocity actually varies across a pipe, from being very small at the edges to a maximum in the middle. To account for the non-uniformity of velocity, we'll introduce a momentum coefficient, "beta".

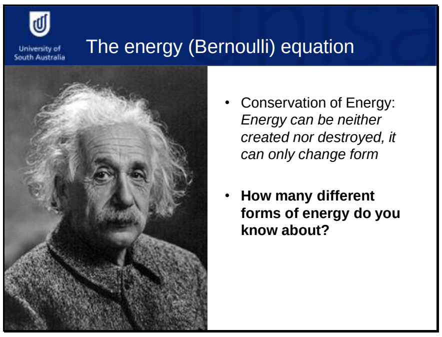
For simplicity, the momentum coefficient is assumed to be 1 but it's included so you can adjust it to correct for non-uniformity if you need to.

Slide 43



Next we look at the energy equation

Slide 44



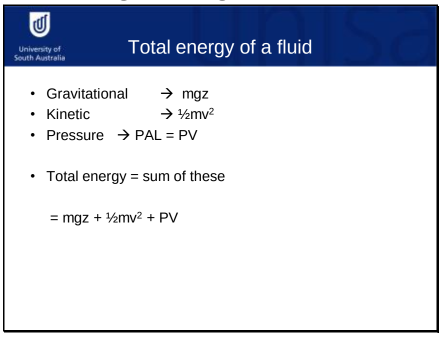
The energy or Bernoulli equation comes from the concept of the conservation of energy,

that is that energy can be neither created nor destroyed, it can only change form.

Try to brainstorm the different forms of energy you're aware of.

Image http://en.wikipedia.org/wiki/Albert_Einstein

Slide 45



The total energy of a fluid is the sum of the Gravitational, kinetic and pressure energies. The gravitational energy equals mass m, times gravity g, times elevation, z;

Kinetic energy equals half mass m, times the velocity v squared;

The pressure energy is probably not one you're familiar with. It equals pressure, P, times area A times length L, or Pressure times volume, V.

So the total energy of a fluid can be given by this formula

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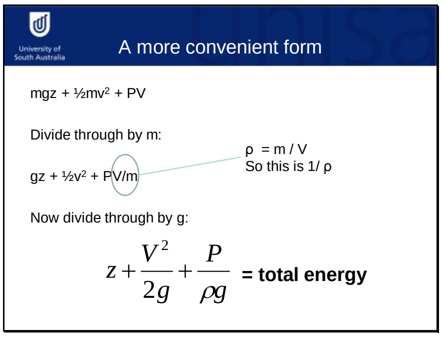

To simplify this calculation, first of all

the total energy gets divided by mass.

Now on the end here we've got volume divided by mass, which is the inverse of density, rho.

Now we divide by gravity; so the total energy equation becomes just elevation, z, plus the (velocity squared over 2 g) plus (pressure divided by rho g). The Z term is elevation head, the "V squared on 2 g" term is velocity head, and the "P on rho g" term is pressure head.

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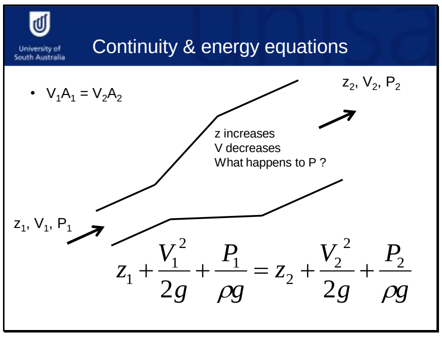


The Energy equation is an important additional calculation to complement the continuity equation.

For example, lets consider water moving uphill in a pipe that is changing from narrow to wide diameter.

At the other end we'll have a different value of Z, a different velocity and maybe a different pressure.

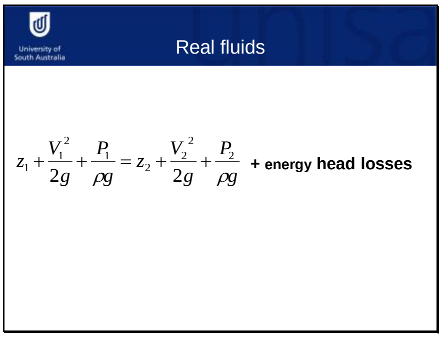
Based on the geometry, presumably we can tell what the difference in elevation is going to be

And from the continuity equation we can work out what happens to V

But what about pressure?

Because of the conservation of energy, we know that the total energy at point 1 is equal to the total energy at point 2, so this brings together all of the terms. It's a really powerful relationship. For instance if we know the pressure P1, and we can work out the change in elevation and the two velocities, we can use the energy equation to work out the pressure P2. Or if we measure the pressure difference we can actually use this to work out flow rate, as long as we know the two pipe diameters. We'll look at these concepts more in next week's lecture on flow measurement, and in the second practical.

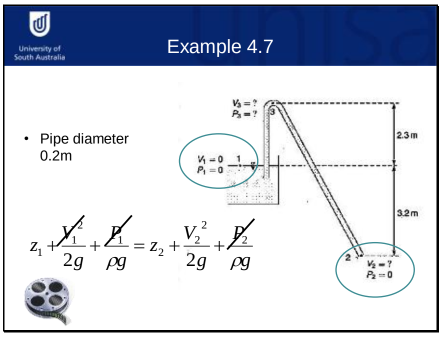
Slide 48



In real fluids,

we also need to add energy head losses to account for friction when the fluid passes from point 1 to point 2. But we'll deal with those in lecture 6.

Slide 49



The energy equation is a powerful tool, but there are lots of variables – Z1, V1, P1, Z2, V2, P2... Luckily, there are some useful tricks we can apply to work out fluid flow. Here's an example from the text book. We've got a 20cm diameter pipe with water being siphoned out of a tank to a location 3.2 metres below the water surface. We want to know the velocity of water in the pipe. You can assume the water level in the tank stays constant and there are no energy head losses. The energy equation looks complicated but here's the first trick.

Let point 1 be a point on the water surface of the tank. It's perfectly valid. The nice thing about this is that it's a relatively stationary body of water so the velocity can be assumed to be zero. And being on the water surface, we're at atmospheric pressure so P1 = zero too.

Next we up set our point 2 at the outlet, which is also at atmospheric pressure.

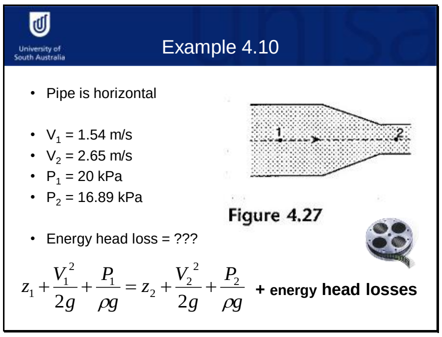
So if you evaluate the energy equation from point 1 to point 2,

V1
P1
And P2 all cancel, so you can determine the velocity V2 from the elevation difference Z1 minus Z2. Hopefully then you can figure out how

to solve V3 and P3 using the energy equation. Use the textbook for help if you need to.

Image source- Les Hamill 2011, Understanding hydraulics.

Slide 50



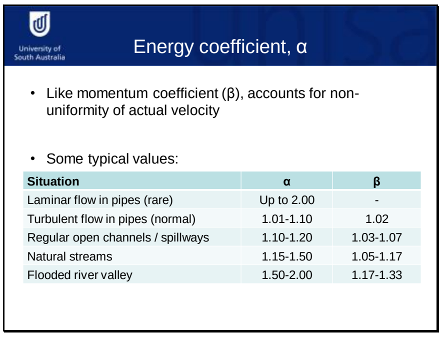
$$z_1 + \frac{V_1^2}{2g} + \frac{P_1}{\rho g} = z_2 + \frac{V_2^2}{2g} + \frac{P_2}{\rho g} \text{ + energy head losses}$$

Here's an example where you've been given everything you need to calculate the total energy upstream and downstream of a pipe contraction.

You need to calculate the difference in total energy in order to work out what the head loss is between the two points. Hopefully you won't need to follow the worked example but it's in the book if you need it.

Image source- Les Hamill 2011, Understanding hydraulics.

Slide 51



Situation	α	β
Laminar flow in pipes (rare)	Up to 2.00	-
Turbulent flow in pipes (normal)	1.01-1.10	1.02
Regular open channels / spillways	1.10-1.20	1.03-1.07
Natural streams	1.15-1.50	1.05-1.17
Flooded river valley	1.50-2.00	1.17-1.33

Another coefficient we use to simplify fluid dynamics is the energy coefficient, alpha. Just like the momentum coefficient, the energy coefficient also deals with the non-uniformity of actual velocity. Usually, the value of energy coefficient is little higher than 1 but for normal pipe flow it doesn't account for much more than about 10% difference.

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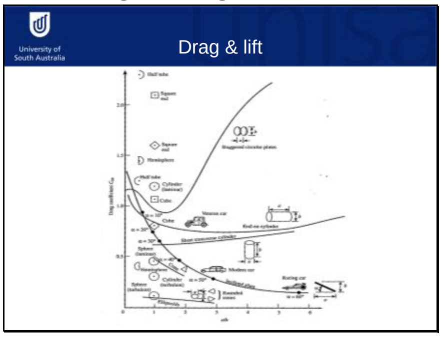
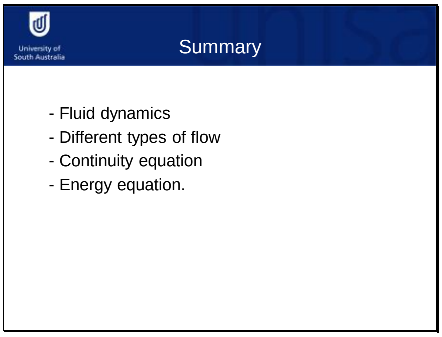


Other considerations in fluid dynamics include Drag and lift. We’re not spending time on this, apart from alerting you to the basic concept – you can read more about it. The general idea is that when an object moves through a fluid, the drag force is proportional to velocity squared and the frontal area of the object, and different shaped objects have different coefficients of drag. This diagram is from figure 4-30 in the textbook and just shows the approximate drag coefficient, Cdr, of various body shapes at Reynold’s values of 10 to the power of 5. So right up the top you can see a half tube with the open section facing into the fluid, which has a really high coefficient of drag, over 2, whereas a half-tube facing the other way is closer to a drag coefficient of one. We’ll come back to drag in week 10 when we look at dimensional analysis.

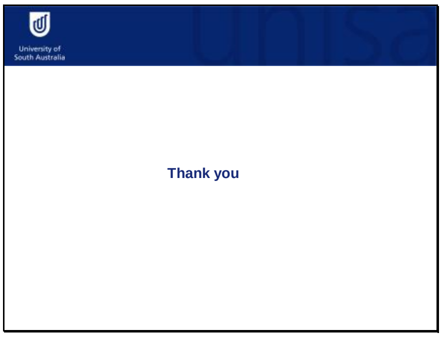
Image source- Les Hamill 2011, Understanding hydraulics.

Slide 53



So, in summary, we’ve looked at simplifying and characterising fluid flow using the Reynolds number, and we’ve used the concepts of volumetric continuity and conservation of energy to solve fluid dynamics problems that involve changes in velocity, elevation and pressure.

Slide 54



If you’ve got any questions or desire further clarification please post a question or comment on the Discussion Forum.