Flow regimes in gas-liquid flows

When a gas and a liquid are forced to flow together inside a pipe, there are at least 7 different geometrical configurations, or *flow regimes*, that are observed to occur. The regime depends on the fluid properties, the size of the conduit and the flow rates of each of the phases. The flow regime can also depend on the configuration of the inlet; the flow regime may take some distance to develop and it can change with distance as (perhaps) the pressure, which affects the gas density, changes. For fixed fluid properties and conduit, the flow rates are the independent variables that when adjusted will often lead to changes in the flow regime.

Here are three regimes for air-water flow in a 1.27 cm in pipe.

These videos are from **"Two Phase Flow Regimes in Reduced Gravity", NASA Lewis Research Center Motion Picture Directory 1704.**

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The video was taken at 400 fps and the projection is at 29.97 fps.

Bubbly flow

Superficial gas velocity = .16 m/s, Superficial liquid velocity = .90 m/s.

In this example of bubbly flow, the liquid flow rate is high enough to break up the gas into bubbles, but it is not high enough to cause the bubbles to become mixed well within the liquid phase. If the pipe were oriented vertically, the phase orientation would be symmetric, but there would likely be "slip" between the phases and the gas would not move at the same speed as the liquid.

Annular flow

Superficial gas velocity = 7.4 m/s, Superficial liquid velocity = .08 m/s.

In annular flow, the liquid coats the walls. However, because of gravity, the liquid distribution is not symmetric with much more liquid on the bottom of the pipe than the top. The velocity of the gas is large enough to cause waves to form in the liquid and also to atomize some liquid. The maximum possible wave amplitudes scale, for liquid layers that are not too thin, as roughly the liquid thickness.

Slug flow

Superficial gas velocity = .17 m/s, Superficial liquid velocity = .08 m/s.

The slug regime, is characterized by the presence of liquid rich slugs that span the entire channel or pipe diameter. These travel at a speed that is a substantial fraction of the gas velocity and occur intermittently. They cause large pressure and liquid flow rate fluctuations. The movie shows the approach of one slug. It looks like a large flow surge, or a large wave. Other movies of slugs would show much more gas entrainment or that the liquid slug clearly touches the top of the pipe. The length to diameter ratio of slugs varies greatly with flow rates, pipe diameter and fluid properties. If the diameter is very large, the Froude number, g d/U^2 can always be large and slug flow, where the entire diameter is bridged, will not form.

Instead roll waves, which are breaking traveling waves, will be seen. Liquid may or may not coat the entire pipe because there will be substantial atomization.

Here are the same flow rates if **gravity** is reduced to an insignificant level.

Bubbly flow

Superficial gas velocity = .13 m/s, Superficial liquid velocity = .89 m/s.

In this example of bubbly flow, there is no gravity so that there is no buoyancy force on the gas bubbles. Thus they mix freely within the liquid.

Annular flow

Superficial gas velocity = 8.1 m/s, Superficial liquid velocity = .08 m/s.

Now that gravity is removed, the liquid distribution is uniform around the pipe. Large disturbance waves still occur but they are seen as "ring - like" disturbances. The absence of gravity also increases the amplitude to film depth ratio of traveling waves because there is no liquid drainage from the wave caused by gravity.

Slug Flow

Superficial gas velocity = .16 m/s, Superficial liquid velocity = .08 m/s.

In the absence of gravity, the liquid distribution is uniform and the slugs are now liquid "trapped" between traveling "Taylor Bubbles". This flow will not experience large pressure fluctuations and the flow rate fluctuations occur only on the size of the bubbles. This is close to the idealized slug regime that is considered in the calculations below.

The calculations in the notebook given below show directly that for the easily calculable case of laminar flow, the flow regime greatly influences the pressure - drop flow rate relation. Thus, if design or operation of a device requires accurate knowledge of flow rate and pressure drop, there is a need to know the flow regime. The rates of heat and mass transfer are also often important in process equipment and the movies suggest that these will also depend significantly on the flow regime!

In the mathematica notebook, Effect of flow regime on pressure drop, we will see that the geometric configuration of the phases can greatly affect the pressure drop. Also, consider how heat transfer to the pipe would be affected if the pipe were being heated by flames.