Elementary Aspects of Two-Phase Flow in Pipes

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Chemical engineers frequently encounter the flow of a mixture of two fluids in pipes. Liquid-gas or liquid-vapor mixtures are encountered in condensers and evaporators, gas-liquid reactors, and combustion systems. Also, the transport of some solid materials in finely divided form is accomplished by making a slurry of the solid particles in a liquid, and pumping the mixture through a pipe. Liquid-liquid mixtures are encountered when dealing with emulsions as well as in liquid-liquid extraction.

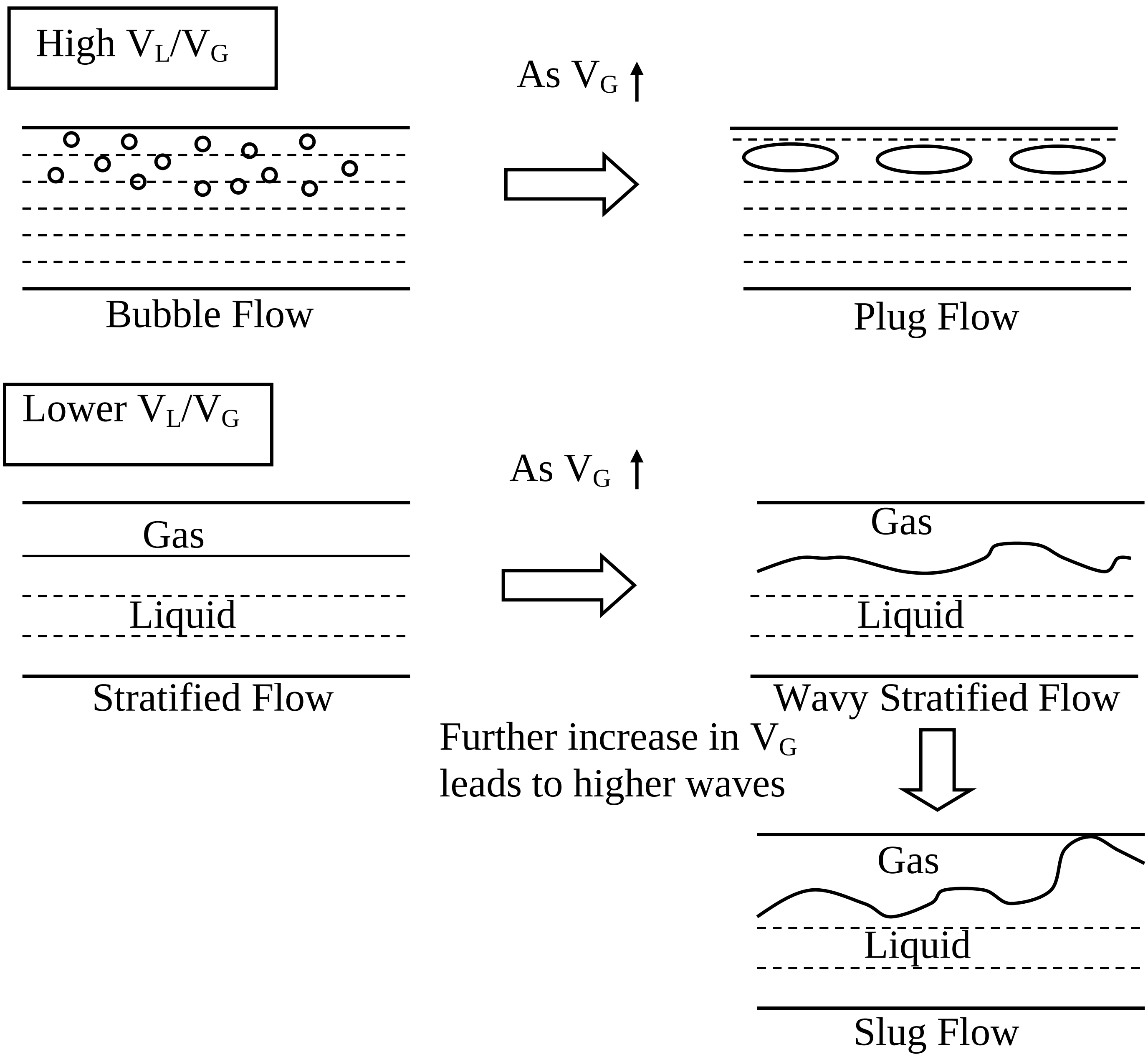
Two-phase flow is a difficult subject principally because of the complexity of the form in which the two fluids exist inside the pipe, known as the flow regime. Toward the end of these notes, we'll see some examples of these regimes. It is difficult to construct a model from first principles in all but the most elementary situations. Dimensional analysis is used to establish the relevant groups to aid in designing suitable experiments. Most available empirical results are applicable only to gas-liquid two-phase flow. A little reflection will convince you that the orientation of the pipe makes a difference in the flow regime because of the role played by gravity and the density difference between the two fluids.

In two-phase flow, the concept of hold-up is important. It is the relative fraction of one phase in the pipe. This is not necessarily equal to the relative fraction of that phase in the entering fluid mixture.

The usual question for the engineer is that of calculating the pressure drop required to achieve specified flow rates of the gas and the liquid through a pipe of a given diameter. To make design calculations involving two-phase flow, Perry's Handbook is a useful resource. It summarizes correlations that are currently used in industry. Also, an informative chapter in Holland and Bragg (1995) is devoted to gas-liquid two-phase flow. Here, we only consider the qualitative features of gas-liquid flow in a horizontal pipe to give you an appreciation of the complexity of two-phase flow when compared with the flow of a single fluid phase.

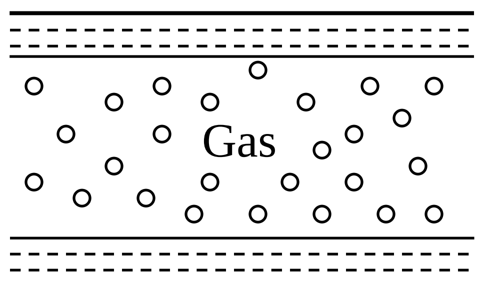
The sketches on the following pages depict various regimes of co-current two-phase flow in a horizontal pipe through which a gas-liquid mixture is flowing. We use V_L and V_G to designate the superficial velocity of the liquid and gas phases, respectively. We first consider a situation where the ratio V_L / V_G is large, and then the regime where the ratio is lower.

Consider a mixture that is almost completely liquid. This means that the ratio V_L / V_G is large. In this case, the gas is present in the form of small bubbles that will rise to the top portion of the pipe as depicted in the sketch on the left. As the gas flow rate is increased, the bubbles become larger as shown on the right. Further increase in V_G leads to annular mist flow through the intermediate stage of slug flow; these new terms are defined later.



Now, consider lower values of the ratio V_L / V_G. The sketches show what happens in this situation. Now, there is enough gas to form a layer at the top of the pipe. This type of flow is called "Stratified Flow." As V_G is increased, waves begin to appear on the surface of the liquid, and this type of flow is called "Wavy Stratified Flow." Further increase in the gas velocity leads to the formation of higher wave crests that contact the pipe wall. The gas then flows in the form of slugs, leading to the term "Slug Flow."

Eventually, at large values of the gas velocity, we encounter a flow regime that is known as "annular mist flow." In this case, the liquid flows in the form of a thin film on the wall of the tube, with the gas flowing in the core, thus forming an annulus. Most of the liquid is entrained in the gas in the form of small drops; this is the reason it is called a mist. In the figure, the liquid drops entrained in the gas are exaggerated in size.



Annular mist flow

References

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Perry's Chemical Engineers Handbook, 7th Edition. 1997 (Ed: R.H. Perry, D.W. Green, and J.O. Maloney), McGraw-Hill, New York.