13.5.1.1: Horizontal Flow

The typical regimes for horizontal flow are stratified flow (open channel flow, and non open channel flow), dispersed bubble flow, plug flow, and annular flow. For low velocity (low flow rate) of the two liquids, the heavy liquid flows on the bottom and lighter liquid flows on the top as depicted in Figure 13.2. This kind of flow regime is referred to as horizontal flow. When the flow rate of the lighter liquid is almost zero, the flow is referred to as open channel flow. This definition (open channel flow) continues for small amount of lighter liquid as long as the heavier flow can be calculated as open channel flow (ignoring the lighter liquid). The geometries (even the boundaries) of open channel flow are very diverse. Open channel flow appears in many nature (river) as well in industrial process such as the die casting process where liquid metal is injected into a cylinder (tube) shape. The channel flow will be discussed in a greater detail in Open Channel Flow chapter. As the lighter liquid (or the gas phase) flow rate increases (superficial velocity), the friction between the phases increase. The superficial velocity is referred to as the velocity that any phase will have if the other phase was not exist. This friction is one of the cause for the instability which manifested itself as waves and changing the surface from straight line to a different configuration (see Figure 13.3). The wave shape is created to keep the gas and the liquid velocity equal and at the same time to have shear stress to be balance by surface tension. The configuration of the cross section not only depend on the surface tension, and other physical properties of the fluids but also on the material of the conduit.
As the lighter liquid velocity increases two things can happen (1) wave size increase, and (2) the shape of cross section continue to deform. Some referred to this regime as wavy stratified flow but this definition is not accepted by all as a category by itself. In fact, all the two phase flow are categorized by wavy flow which will proven later. There are two paths that can occur on the heavier liquid flow rate. If the heavier flow rate is small, then the wave cannot reach to the crown and the shape is deformed to the point that all the heavier liquid is around the periphery. This kind of flow regime is referred to as annular flow. than the distance, for the wave to reach the conduit crown is smaller. At some point, when the lighter liquid flow increases, the heavier liquid wave reaches to the crown of the pipe. At this stage, the flow pattern is referred to as slug flow or plug flow. Plug flow is characterized by regions of lighter liquid filled with drops of the heavier liquid with Plug (or Slug) of the heavier liquid (with bubble of the lighter liquid). These plugs are separated by large “chunks” that almost fill the entire tube. The plugs are flowing in a succession (see Figure 13.4). The pressure drop of this kind of regime is significantly larger than the stratified flow. The slug flow cannot be assumed to be as homogeneous flow nor it can exhibit some average viscosity. The "average" viscosity depends on the flow and thus making it as insignificant way to do the calculations. Further increase of the lighter liquid flow rate move the flow regime into annular flow. Thus, the possibility to go through slug flow regime depends on if there is enough liquid flow rate.

Choking occurs in compressible flow when the flow rate is above a certain point. All liquids are compressible to some degree. For liquid which the density is a strong and primary function of the pressure, choking occurs relatively closer/ sooner. Thus, the flow that starts as a stratified flow will turned into a slug flow or stratified wavy flow after a certain distance depends on the heavy flow rate (if this category is accepted). After a certain distance, the flow become annular or the flow will choke. The choking can occur before the annular flow regime is obtained depending on the velocity and compressibility of the lighter liquid. Hence, as in compressible flow, liquid–liquid flow has a maximum combined of the flow rate (both phases). This maximum is known as double choking phenomenon. The reverse way is referred to the process where the starting point is high flow rate and the flow rate is decreasing. As in many fluid mechanics and magnetic fields, the return path is not move the exact same way. There is even a possibility to return on different flow regime. For example, flow that had slug flow in its path can be returned as stratified wavy flow. This phenomenon is refer to as hysteresis. Flow that is under small angle from the horizontal will be similar to the horizontal flow. However,
there is no consensus how far is the "near" means. Qualitatively, the "near" angle depends on the length of the pipe. The angle decreases with the length of the pipe. Besides the length, other parameters can affect the "near."

Fig. 13.5 Modified Mandhane map for flow regime in horizontal tubes.

The results of the above discussion are depicted in Figure 13.5. As many things in multiphase, this map is only characteristics of the "normal" conditions, e.g. in normal gravitation, weak to strong surface tension effects (air/water in "normal" gravity), etc.

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