What Two Phase Flow Regime Maps Narrate

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Introduction

Determining flow regime for two phase flow is important not only for those correlations which are using it for pressure drop calculation but also for process and piping design. But specifying flow regime is not always simple job because:

- There are lots of maps for horizontal and vertical flow but there is no generally accepted map
- Different maps give different flow regimes at the same flow and pipe condition
- Number of flow regimes differs from map to map
- Definition of flow regime differs from map to map

Maps presented by Shell's DEP have a great privilege over other available maps because both maps have been developed by single source. They are using same parameters on X and Y axis to specify the flow regime for vertical and horizontal pipes. Furthermore, the definition of regimes is consistent so that comparison between flow regime in vertical and horizontal lines is possible.

Flow regime

Superimposing vertical and horizontal flow regime maps shown in Figures 1 and 2 respectively, you will realize that:

- It is not possible to have stratified (smooth or wavy) flow in vertical pipe. Stratified flow regime in horizontal pipe is mainly changed to slug or plug flow in vertical pipe.
- Slug or plug flow are dominant flow regimes in vertical pipes as shown in a quite wide range of Figure 2.
- Mist flow maintains unchanged when line orientation is changed from horizontal to vertical and vice versa.
- There is condition in which flow regime is slug in both vertical and horizontal portion of line (about $Fr_G = 0.1$ $Fr_L = 1.0$).
- Bubble flow remains bubble flow when line orientation changes from horizontal to vertical but not vise versa
- Most of the time, intermittent (slug or plug) flow regimes changes to bubble when pipe turns from horizontal to vertical.

According to below equations, liquid and vapor flow rates, densities and pipe diameter are main inputs for determining two phase flow regime.

$$Fr_L = \frac{W_L}{\pi d^2}\sqrt{\frac{1}{g d \rho_L (\rho_L - \rho_G)}}$$

and

$$Fr_G = \frac{4W_G}{\pi d^2}\sqrt{\frac{1}{g d \rho_G (\rho_L - \rho_G)}}$$

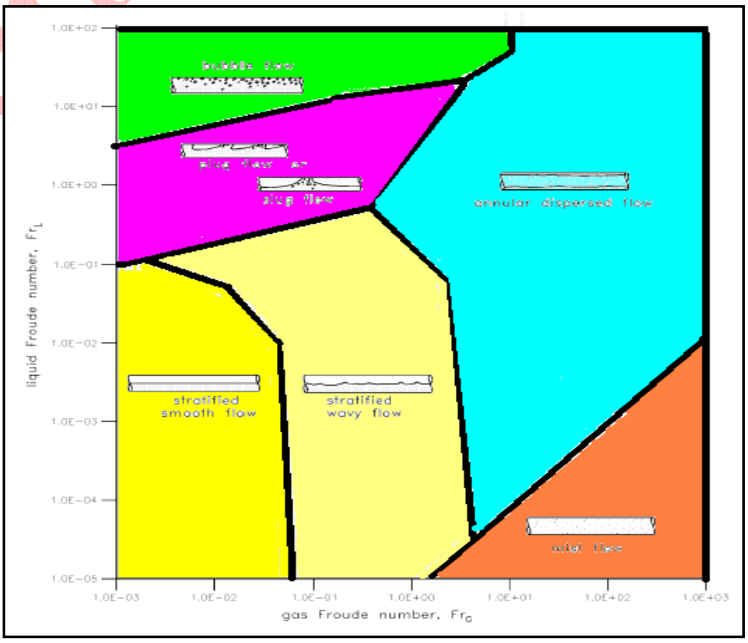

Figure 1 – Two phase flow map for horizontal pipe

Where

W: Mass flow rate, kg/sec

ρ: Density, kg/m^3

d: Pipe internal diameter, m g: Gravity acceleration, 9.81m^2/sec

Since fluid properties are dedicated by process nature, pipe diameter is the only parameter that can be changed by designer to avoid undesirable flow regimes such as slug or plug. They can lead severe vibration and erosion. The destructivity level reduces from slug/plug flow to stratified flow, and minimum at annular, mist and bubble flow. Pipe diameter changes cause flow regime to move on diagonal lines shown in Figure 2. Depending on the current location of two phase flow system (based on Fr_G and Fr_L) on map, it can be decided whether line size should be increased or decreased. For example, at point "A" line size reduction is obviously more effective than line size increase to get rid of slug flow. According to Figure 2, it is really impossible to change annular flow regime to mist by line size change, etc.

Sometimes, it is not really practical to ensure the desired flow regime considering different operational cases (summer/winter, SOR/EOR, design/turn down, peak/off-peak) to which process piping is exposed.

- Among all operation cases, low and high pressure cases must be checked because of its effect on gas and liquid flow fraction (W_L/W_G) and the density of both phases.
- Among all operation cases, the range of gas and liquid flow rate should be examined to ensure no undesirable flow regime or pressure drop will take place all over range of plant operation.
- Among all operation cases, low and high molecular weight due to its impact on the density of both phases should be checked.
- Among all operation cases, low and high temperature due to its impact on the density of both phases should be checked.

Case Study

One of the typical systems where all of these parameters are dynamically changing by time and location is flare network downstream of depressuring valve releasing two phase flow. Process parameters variation is explained below:

- Flow rate

During initial stage of depressuring, the depressuring rate is high but as depressuring continues flow rate decreases. Liquid and vapor fraction is changing by time and location because of flare network pressure and temperature variation during depressuring.

- Pressure

Because of high initial flow, flare network pressure is initially high which reduces as flow reduces. Furthermore, different locations of flare network will have different pressures at the same time. Pressure approaches atmospheric pressure when gas moves towards flare.

- Temperature

High differential pressure (pressure drop) across depressuring valve in initial stages will result in very low temperature in flare side which will disappear when system pressure reduces. Furthermore cold temperature will dissipate after travelling some distance exchanging heat with surrounding.

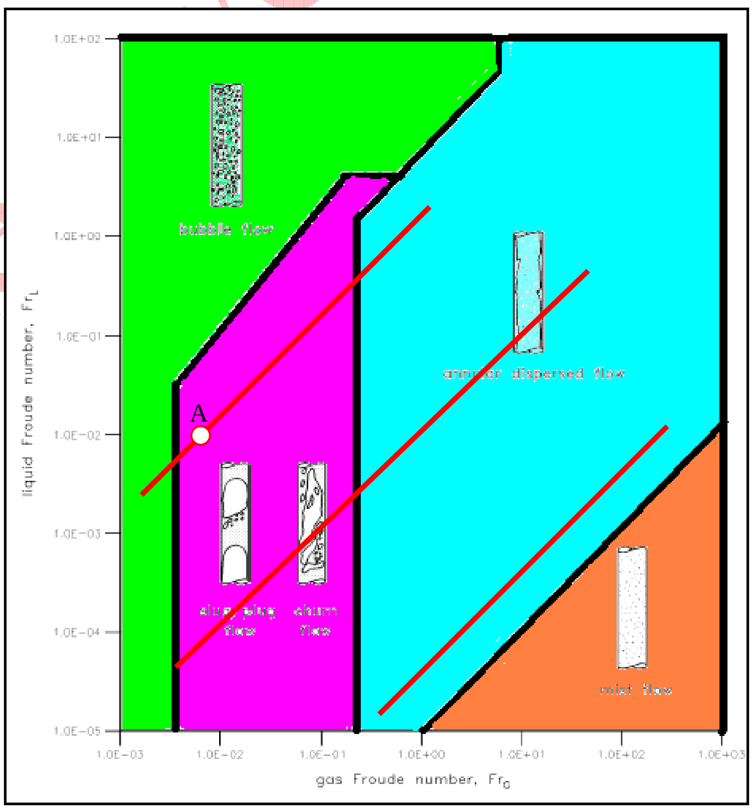

Figure 2 –Two phase flow map for vertical (upward) pipe

- Molecular weight

The molecular weight of fluid which is initially released is lower than fluid in later stages.

- Pipe size

Pipe size keeps changing from lateral to sub-header and from sub-header to main header.

- Pipe orientation

Depressuring outlet line shall be free draining to flare header so vertical upward pipe is not expected but vertical downward and horizontal runs are very common in flare system.

Conclusion

Because of the changes in above mentioned parameters, flow regime keeps changing from depressuring valve outlet nozzle to flare knock out drum inlet nozzle. The same phenomenon is also observed in all two phase process lines. It is almost impractical to guarantee that undesired flow regimes won't happen in two-phase pipes unless the process conditions is very far from slug or plug boundary and process variables don't change considerably within entire operation range. Therefore, in absence of detailed flow regime study, process and piping design should be capable of handling slug and plug flow.

Contact

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