

LIFE OF FIELD STABILITY OF A NORTH SEA OIL DEVELOPMENT

Abstract

Transient operability issues can significantly affect the NPV of subsea developments. Severe slugging, for example, can dictate major design parameters such as flowline routes and diameters and hence affect the overall CAPEX. It can also affect revenue by reducing the operability of flowline-riser systems. Consequently, such issues should be analysed at the earliest possible opportunity during design. By automating the analysis of the output from transient multiphase flow simulators, it is possible to gain a greater understanding of the operability of such systems during conceptual design. This case study describes a method employed by Feesa on several previous Flow Assurance operability studies.

The Stability Problem

In many oil and gas developments incorporating multiphase flowlines, system instability is a major Flow Assurance concern due to the excessive demands large changes in oil and gas flow rates place upon the processing facilities. Multiphase surges come in three forms:

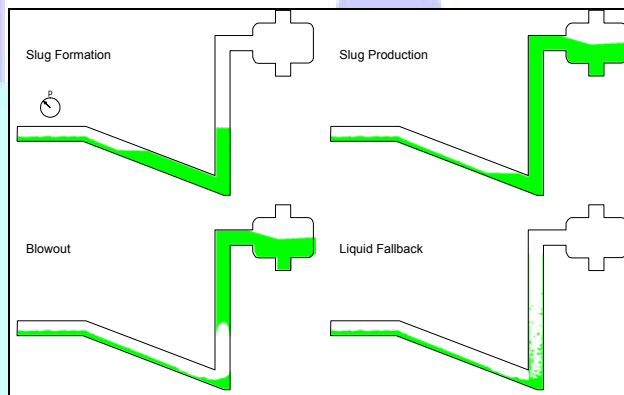
1. *Hydrodynamic Slugs*: A property of the stratified flow regime where slugs are formed due to instability of waves at certain flow rates.
2. *Terrain Induced Slugs*: Caused by accumulation and periodic purging of liquid in dips along the flowline, particularly at low flow rates.
3. *Operationally Induced Surges*: Created by forcing the system from one steady state to another. For example, during ramp-up or pigging operations.

As these three forms of surges are quite different, they require different analytical techniques. This case study focuses on terrain induced surges, in particular riser base or severe slugging.

The severe slugging phenomenon is illustrated in Figure 1. The phenomenon is a cyclical production of liquid and gas coupled with cyclical flowline pressure fluctuations. The first phase of the cycle is referred to as ‘slug formation’. Here the base of the riser has become blocked with liquid preventing free passage of gas. The pressure in the pipeline then increases as more liquid runs down to the base of the pipeline increasing the size of the liquid slug. The system continues in this fashion until the pressure has built sufficiently to overcome the gravitational head associated with the liquid slug. The system is then hydrodynamically unstable and the liquid slug is

discharged rapidly up the riser followed immediately by a gas surge as the pipeline blows down. The pressure in the pipeline then returns to a low value, leading to insufficient gas velocities to carry the liquid up the riser, and the process is repeated.

Figure 1 Schematic of Severe Slugging



Severe slugging is considered the most important of the three surges as it usually generates the most violent surging behaviour. Hydrodynamic surges can usually be accommodated in a modestly sized slug catcher and are of less concern, which is fortunate because accurate prediction of this phenomenon remains beyond the state-of-the-art. Operationally induced surges can be significant but can also be controlled by suitable adjustment to the operating procedures.

However, flowline-riser instabilities such as severe slugging can be so extreme that the regime must be completely avoided. This can restrict the operating envelope of the system, require riser base gas lift or even limit the size of flowline/riser that may be used.

Figures 2 to 4 show example time traces for the riser outlet liquid flow rate (i.e. slug catcher inlet), flowing wellhead pressure and outlet gas flow rate during severe slugging. Such fluctuations could put excessive demands on:

1. The liquid production system due to excessive periodic liquid surges.
2. The sand-face due to excessive pressure/flow rate fluctuations.
3. The gas compression system due to excessive fluctuations in gas rate.

Figure 2 Typical Severe Slugging Q_{Lout} Time Trace

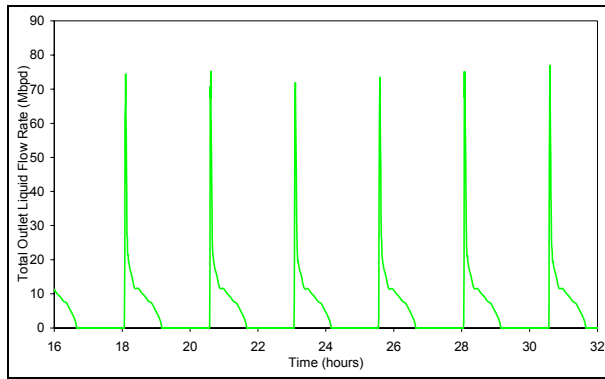


Figure 3 Typical Severe Slugging FWHP Time Trace

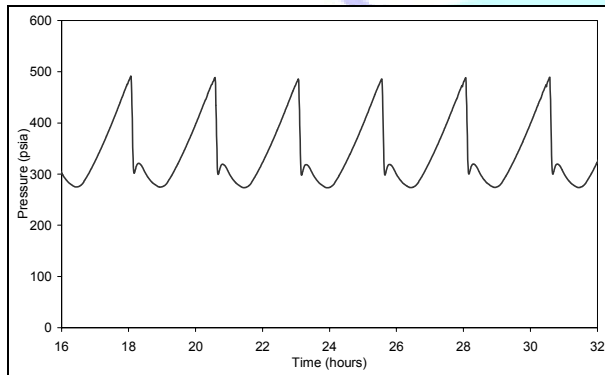
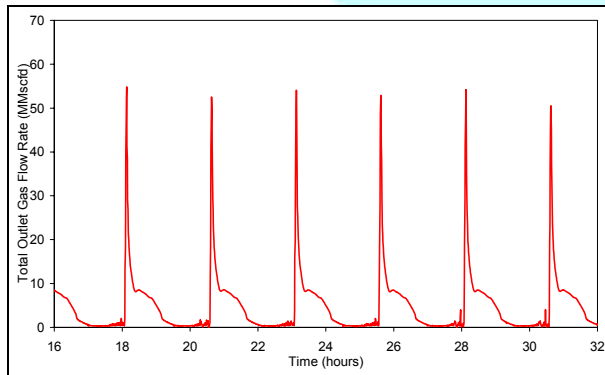


Figure 4 Typical Severe Slugging Q_{Gout} Time Trace



Therefore the threat of severe slugging and the efforts taken in order to avoid it, can have a major impact on the CAPEX, operability and indeed feasibility of a subsea development. The phenomenon must therefore be investigated at the earliest opportunity.

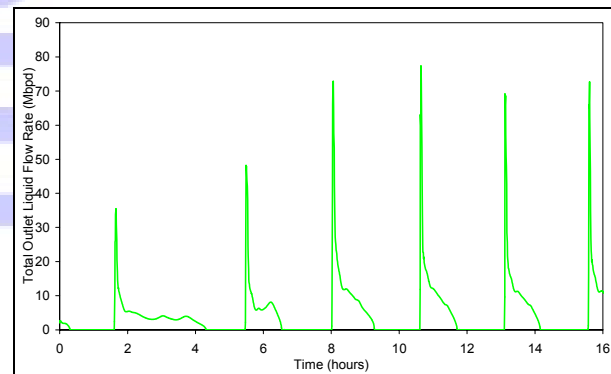
Simulation Methodology

Successful stability simulations require:

1. *A good multiphase flow correlation.* Severe slugs are liquid accumulations at the riser base caused by the rate of outflow up the riser being less than the rate of inflow to the riser base. Consequently, to accurately predict the stability boundaries a reliable multiphase flow correlation is required.

2. *Accurate flowline topography.* The flow rate at which the riser base begins to accumulate liquid depends on the flowline topography. Small and large scale undulations and other topographic features are known to affect the minimum stable turndown flow rate. As a result, large scale topographic features must be included in the flowline topography and a sensitivity study should be carried out to investigate the effect of small scale undulations that may not be identified in coarse bathymetric data.
3. *Appropriate boundary conditions.* The inlet and outlet conditions should closely approximate the behaviour of the actual upstream and downstream systems if instabilities are to be modelled correctly. Inappropriate boundary conditions can dampen or amplify the fluctuations in the unstable region and will even affect the position of stability boundary. Careful thought must be given to the level of detail required from the study.
4. *Fully developed flow.* Transient simulations require initial conditions to begin the simulation. These conditions are then updated as time progresses subject to the boundary conditions and defining equations of the system. In order to assess the stability of the system during normal operation, it is essential to ensure ‘fully developed flow’. Consequently, it is important to run the simulation for a significant length of time to ensure that start-up transients, arising from the selection of initial conditions, have decayed leaving the underlying transient behaviour. Figure 5 is an example of a developing severe slugging simulation, fully developed behaviour is achieved after approximately 12 hours.
5. *Long simulation time.* Once fully developed flow has been achieved the model must be simulated for a sufficient time in order to capture the full periodicity of any surges and to make sure that the system is actually fully developed.

Figure 5 System Developing into Severe Slugging



Measuring Instability

There are three commonly used measures of system instability:

1. *Slug catcher liquid surge volume.* A common measure of instability, is the slug catcher liquid surge volume required.
2. *Flowing wellhead pressure (FWHP) fluctuations.* This is a useful measure as it quantifies the effect of instability on the subsurface systems, in particular the completion length. Typically, operators limit the amplitude of short duration FWHP fluctuations to about 50 psi, to avoid potential formation damage.
3. *The rate of change of gas flow rate.* This is a measure of the potential impact on the gas compression systems. Large swings in gas flow rate would require rapid changes to the recycle rate around the compressors, which is undesirable. In detail design phases, the response of compressor systems should be assessed with a combined subsea/topsides transient simulator. However, for conceptual design such detail is seldom required.

Unfortunately, large parametric stability analyses with the commercially available tools can be quite costly to perform. First, there is the high fixed cost of the transient multiphase flow software itself and then there is the cost associated with the man-hours required to analyse the transient output. Currently, the commercially available transient multiphase flow software are restricted in their post-processing capabilities. To reduce the costs of performing these studies, Feesa has developed a suite of *Visual Basic software* to automate the process of data analysis. These software operate on the time-trace data spewed out of the simulation software and generate parametric stability maps of predefined stability measures.

Stability Maps

With automatic techniques available for data processing, it is possible to then cover a wide range of system parameters. The results can then be plotted in the form of stability maps (for example in GOR-watercut-flow rate space), onto which the production profile can be overlaid. The benefit of this method, as opposed to only running points selected from the production profile, is that the engineer gets to a more detailed picture of the ‘lay of the land’, and can easily determine the proximity of the system to the unstable region. This helps to compensate for the lack of accuracy in the multiphase simulation results by encouraging the engineer to design systems that operate well into the stable zone thus offering an adequate margin of safety.

Examples of such stability maps are shown in Figures 6 to 8 for a 15 km 8-inch tieback in the North Sea. The plots are shown in the form of FWHP fluctuations in watercut/flow rate space for three different GORs. The matrix of simulations includes 126 cases covering the whole range of the production profile. The full batch of runs took about 48 hours to complete.

Figure 6 725scf/stb GOR Stability Map

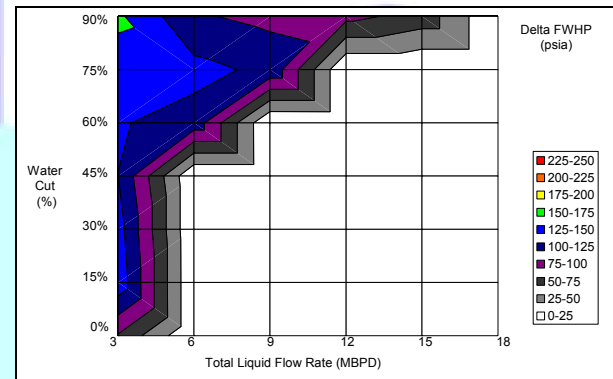


Figure 7 1000scf/stb GOR Stability Map

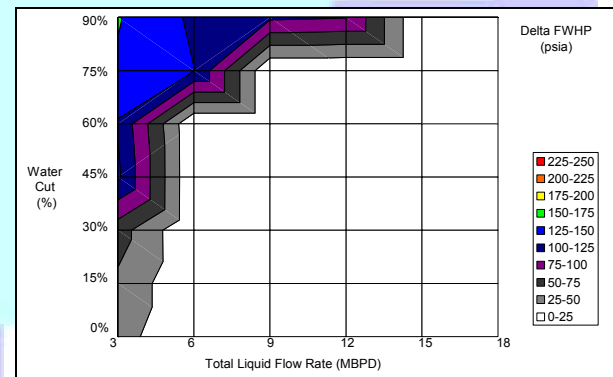
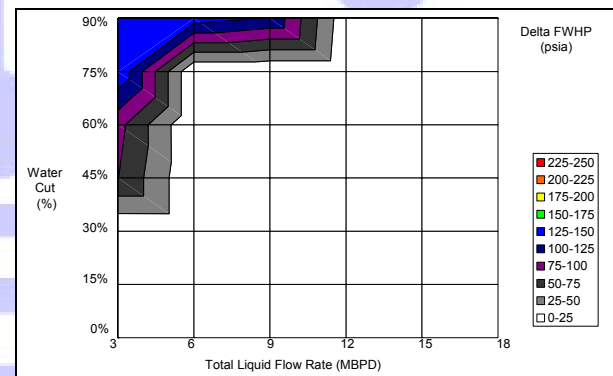


Figure 8 1500scf/stb GOR Stability Map



As can be seen, the general trend of these maps is that the unstable (coloured) region grows with watercut and shrinks with GOR. The reason for this is because increasing the gas flow rate (by either increasing the overall flow rate or the GLR) stabilises the system by

increasing the velocity. The likelihood of liquid accumulation is less at higher velocities, thus the propensity for severe slugging is reduced by assuring that liquids are swept from the flowline. Diameter has a similar effect, smaller diameters have larger velocities (for a given flow rate) and are therefore more stable.

It can also be seen that stability is discontinuous with flow rate, the transition between stable and unstable region is sharp and for a particular watercut and GOR one can define a minimum stable flow rate. This minimum stable flow rate is an important measure of the operability of the system.

In Figure 9, two production profiles, with and without well gas lift, are compared to their respective minimum stable flow rate curves (interpolated from Figures 6 to 8). As can be seen, well gas lift extends the production plateau and also drops the minimum stable flow rate in the flowline by increasing the flowline GLR. The difference in the stability curves increases throughout field life as the gas lift rate remained constant but the watercut increased and the total liquid flow rate reduced. Hence proportionally, the gas lift has a greater impact on GLR towards the end of field life.

Therefore, without gas lift at the well, not only does the system fall off plateau sooner, it is more likely to have stability problems at the end of field life (after about year 8). With gas lift the system should produce more and for longer. With or without gas lift the system has a significant stable turndown capability early in field life, though of course stability is not the only limitation on turndown. In Figure 10, the minimum stable flow rate curves are compared to minimum flow rate for 10 and 5 hour cooldown time curves. Here cooldown time is the maximum time the flowline can be shut-in for without entering the hydrate envelope on restart anywhere along its length. The minimum flow rate for a particular cooldown time decreases with field life as the watercut increases, as water has a significantly greater heat capacity than oil, hence temperatures are higher at larger watercuts. Figure 10 shows that though the system can be turned down on plateau to ~7 Mbpd and still remain stable, the cooldown time would be significantly reduced (from over ten hours to just over five). The implication of this depends upon the likely turndown requirements (for example the requirement to still produce with one of the wells shut-in for some significant period) and the cooldown time requirement of the production system. However, this case study demonstrates how some of the most important Flow Assurance issues can easily be compared and their constraint on the operability of the system understood.

Figure 9 Production Profile Min Stable Flow Rates

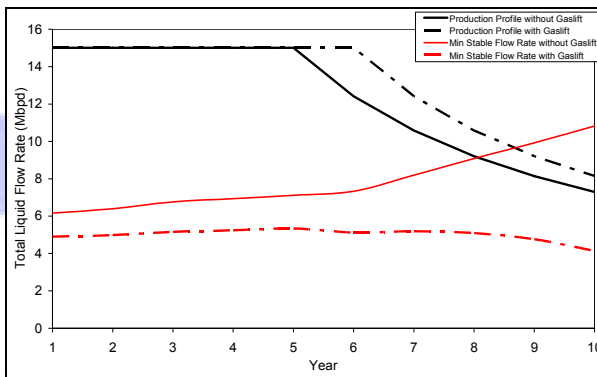
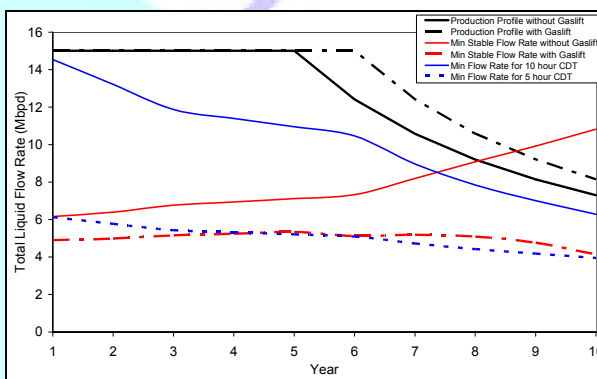


Figure 10 Production Profile Min Flow Rates



Conclusion

Transient issues such as multiphase instability can influence the selection of flowline route, the flowline diameter and the requirement for gas lift for a subsea oil development concept. Consequently, they can potentially have a significant negative impact on the Net Present Value (NPV) of a system and thus should be addressed as early in the design phase as possible, and in sufficient detail to ensure a robust concept passes through to the later design phases.

A method has been proposed which makes the best use of multiphase flowline simulators in the analysis of severe slugging leads to the generation of parametric stability maps. The concept of stability maps is not new, although they are seldom used in the oil and gas industry due to the expense of transient pipeline simulators and the requirement for engineers to manually analyse large quantities of transient output data.

However, with the development of automatic data processing methods, it is now possible to carry out comprehensive sensitivity studies of system stability. These provide great insight into the behaviour of flowline-riser systems, thus allowing the engineer to produce robust designs which avoid unstable and problematical conditions.