Pigging as a Flow Assurance Solution – Avoiding Slug Catcher Overflow

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This paper sets out to provide an initial method of assessing the bypass requirements for pigging of a two-phase gas/liquid pipeline. The use of bypass or high bypass pigging is an established concept that has been discussed many times before. The aim here is to provide an initial indication of where they can work. Given a limited volume at the slug catcher and pump out rate (resulting from economics or other practical considerations), it is possible that a pig will remove too much liquid from the pipeline leading to overload of the slug catcher and subsequently tripping the pipeline. With liquid level control on the slug catcher and slug suppression, the receiving terminal will see a period of no gas. This may be undesirable from a process point of view. Liquid volumes arriving at the slug catcher or separator may be reduced by using an inefficient pig (unpredictable) or by slowing down the pig and aerating the liquid slug using bypass. This paper provides a first pass design method for such pigs, examines the background for their use and provides a case study or example to demonstrate the application.

Introduction

Many pipelines are run under two-phase flow conditions from well flowlines to production and export pipelines between platforms and on to shore. The lines can be predominantly gas lines with a condensate dropping out or a true two-phase mixture of oil and gas. Either way, pigging is often required for maintenance, liquid control or inspection and this can cause problems at the receiving end.

Figure 1 shows a typical graph of liquid content in a pipeline against flowrate. As the flow increases, the liquid content reduces as more and more liquid is swept from the line. The volume of liquid in the line depends largely on the nature of the fluids and the topography of the pipeline. Launching a pig into this system will remove the majority of this liquid (depending on the design of the pig) and this will end up in the slug catcher at the receiving facilities. Pigging is required to manage these liquids in the line and to provide general maintenance tasks such as wax management, corrosion and hydrates control and cleaning.

A typical set up is shown in Figure 2 where liquid enters the receiving facility and into the slug catcher or Knock Out Drum. The pipeline ends at the pig receiver. From here, the pipework takes fluids from the line into the slug catcher and on to the processing facility. The separator has a set pump out capacity or rate. In some conditions this pump may not be able to handle the liquids fast enough to allow the vessel to be drained. This may cause a high-level trip or with suppression systems in place, a slowdown of the liquid into the system. In this case, no gas will enter the system for the duration of the pig receipt. The result is a trip that causes a loss in production or reduced throughput.

If the pipeline trips this will cause production to be shut down. Shutting down production has inevitable economic consequences in the short term and restart of the pipeline may be difficult. In a waxy system, gel can settle in the pipe and care would be needed when restarting the pipeline. On cool down, hydrates can occur and there may be a need to depressurise the system. On restart, the line can enter the hydrate zone and this needs to be handled.

Transient computer simulations are performed to assess the effect of pigging on the system. Such programs are frequently very focused on the multiphase aspect of the model and are lacking in some respects in how the pig is represented. The representation of bypass is further complicated and not always easy to interpret in real life. Additionally, the cost of running such models is high and it would be advantageous to have a simplified model to allow some initial judgements to be made.

Reducing Slug Catcher Overload

There are two possibilities for reducing the effects of pigging the system: -

- Running a low efficiency pig. Less efficient pigs reduce the volume removed from the pipeline. An example of a less efficient pig would be a sphere where this will leave a certain amount of liquid behind in the line. There are correlations available for predicting this remaining liquid and an example of this is provided in Figure 3. Other pigs have been developed that can run through the pipeline without taking any liquids out at all. Such pigs operate on wheels and have undersized seals. They effectively blow through the pipeline without removing mush liquid. The undersize can then be progressively reduced and the liquid slowly removed from the line.

  This is not always the best solution for a steady state pigging and maintenance campaign to remove liquid inventory on a regular basis as the pig are not efficient and several runs are required to take the liquid out of the line;

- Running a bypass pig. Bypass pigs reduce the volumetric flow of liquid from the pipeline. Since the pig is still efficient, all the liquid (essentially) is taken from the line but removed at a much lower rate. The pig velocity is reduced as a percentage of the gas drive. The liquid ahead of the pig is aerated and so it is spread over a greater length of pipeline. This is shown in Figure 4. The effect is a reduced flowrate of liquid into the slug catcher and this can be matched to the pump out rate.

  The additional advantage is that gas continues to flow into the receiving facilities while the pig is being received. This aids process control and allows customer demands to be met while liquid is being removed from the line.

There are variable bypass pigs but these are generally used in Inspection Pigging to provide a reduction in velocity at the end of lower pressure pipelines. Such a technique may be useful if pig wear results in insufficient flow bypass towards the end of the pipeline. The effect of pig wear and lubrication effects should be taken into account when designing such a pig.

Increased gas velocity in lower pressure lines towards the end of the line can have a double-edged effect in that more liquid is removed by the gas but also the rate of pigging is very high. Bypass percentage tends to fall off at higher velocities and the effect is reduced. High gas flow can be used to remove liquid before launching pigs at lower flows. This may be a possibility when pigging is infrequent. Pigging at higher flows may not be a problem as there is less liquid in the line.

It is important when using bypass pigs that they are operated in a safe manner. A pig with too much bypass may stall in the pipeline at a bend for instance or at some restriction in the line. As the majority of the liquid is present in the line at low velocity or flow, then it is important to establish that there is no problem with stalling when the pig is launched at these rates. Bypass calculations can be performed to establish this.

In order to provide a safe design for the pig and to meet the needs of the system, the following simplified model is proposed.

Bypass Pig Model

A simplified bypass model is presented to allow an initial assessment of the problem to be made. This takes into account the volume of liquid in the pipeline, the pig parameters and the two-phase flow ahead of the pig. Single-phase gas drive is assumed upstream of the pig in this instance.

The model is presented in Appendix A below. The model accepts inputs such as flowrate, gas pressure at the required point in the pipeline (towards the end of the pipeline is of most interest here), gas parameters and pig parameters such as differential pressure and percentage bypass by area. Using this information, the pig velocity is calculated. This is then be used to estimate the liquid and gas mass flows ahead of the pig. The result is a gas fraction and a liquid fraction for the aerated liquid slug downstream of the pig. From this analysis, the liquid flowrate into the receiving facilities can be estimated.

Additional Constraints

The model allows an initial estimation of how to pig the pipeline and remove any liquids without flooding the slug catcher. It allows the user to assess if this approach is practical in the first place without having to embark on a costly analysis. However, this section indicates a number of additional practical aspects that must be taken into account: -

- The effect of pig wear is important and must be considered. Pig seal wear can reduce the pig differential pressure and this can then reduce the bypass flow through the pig. The bypass is minimised at the end of the pipeline, where it is needed the most;
- Other lubrication effects must be established such as the effect of the fluid in the pipeline. Waxy conditions can reduce the pig differential pressure and so the bypass rate will reduce;
- The pig design must be checked over a range of differential pressures to establish if the design is robust. Choice of a practical range of conditions will allow the wear and lubrication aspects mentioned above to be taken into account and the effect of features such as bends and restrictions in the pipeline where the pig could reasonably stall;
- The model is based on steady state calculations with no account of elevation changes. This is in order to allow a first pass to be made. Steep risers and elevation changes over the pipeline will have a marked effect and must be considered in the overall analysis once feasibility has been established.

The following case study demonstrates a typical example for estimating pig bypass design.

Case Study, 20” Line with liquid build up

The case study has been taken from the reference used in writing this paper [1]. In the original work performed on bypass pigging, the authors used a two-phase flow simulation package to provide an indication of liquid hold-up entering the receiving facilities. The pipeline in question is running between two platforms and is 20” in diameter. The actual internal diameter is 468.3mm. The line is 10km in length and transports gas and condensate at a rate of 8.3mmscmd. The inlet pressure is simulated at 100bars.

A total liquid inventory of 172m^3 is assumed in the pipeline. The maximum separator liquid volume is 20m^3 with a maximum pump out rate of 74000bbl/day. The line is analysed with and without active level control. In the first case, the flow rate will be actively reduced into the line and the pig will be slowed even further. In the second case, there will be a possibility of halting production as the high-level alarm can be tripped.

The analysis output, based on the model above, is summarised in Figure 5. This shows the outlet liquid flow rate (solid line) against percentage bypass by area. At low percentage area bypass, the flowrate of liquid is high and would result in an overflow of the slug catcher, given no level control to suppress incoming fluids. For example, at 5% area bypass through the pig, the incoming liquid flow is 213kbbl/day compared with a peak pump out rate of 74kbbl/day. It is therefore necessary to increase the bypass rate. The analysis shows that a bypass of 10% by area is sufficient to minimise the liquid flow into the separator to match the pump-out rate. This matches the output from the reference [1], where 10% bypass by area is specified.

The authors of the paper point to problems with pigs sticking in the line and with wear effects. Such aspects can be taken into account. It is clear that the resulting flow bypass (up to 63% by flow, see Figure 5) is very high and this can lead to problems with the pig in features such as bends or thick walled sections. The analysis must be extended to account for such aspects: -

- The analysis will be performed with a typical pig differential pressure level in the pipeline. A required bypass size will be obtained but it is necessary to establish if this will cause stalling problems in features such as bends where pig differential pressure increases;
- The model should take into account aspects of wear, where the pig differential pressure reduces over the length of the line. Using this, there may be insufficient bypass by the time the pig reaches the end of the line. The final model takes such aspects into account;
- The effect of increasing gas flow velocity should be taken into account in low-pressure systems. This will have the effect of reducing pig bypass at the end of the line where it is most required.

Once a satisfactory solution has been obtained this should then be checked using multiphase simulator programs. This will provide the final confidence that the system is working. It is nevertheless worth gaining an understanding of how bypass is represented in such models.

References

[1] Bypass pigs for two phase flow pipelines, Wu, Spronsen, Klaus and Stewart, Shell;

[2] Modelling of Multiphase Pigging Operations, Yeung, Lima and Montgomery, Cranfield University and Petrobras, BHR Group Multiphase Conference Proceedings.

Appendix A, Estimation of liquid flow to the separator

Bypass pigging is used to aerate a liquid slug ahead of a pig. It is required to know how much physical bypass is required based on a percentage of the pipeline cross sectional area. The following model is set out to provide this information as a first pass tool. It is based on simple steady state two-phase calculations. Once it has been established that it is feasible to use such a bypass pig, then the output should be checked using multiphase simulations.

The pig velocity can be determined by using a simple orifice calculation based on the percentage of bypass flow through the pig and the gas parameters. The following equations are used to establish the liquid fraction in the slug downstream of the pig. The dryness fraction is provided by: -

$$\chi = \frac{m_{gas}}{m_{gas} + m_{liquid}} \qquad \text{…Equation 1}$$

The velocity ratio is then given by: -

$$K = \sqrt{1 + \left(\frac{v_{gas}}{v_{liquid}} - 1 \right) \chi} \qquad \text{...Equation 2}$$

The gas fraction is then provided by: -

$$\alpha_{gas} = \frac{\chi v_{gas}}{\chi v_{gas} + K(1 - \chi) v_{liquid}} \qquad \text{...Equation 3}$$

From here, the liquid fraction can be calculated. This can then be used to estimate the liquid hold up in the line and the flowrate of liquid into the processing facilities. The following variables are listed: -

χ Dryness Fraction;
m_{gas} Gas mass flow rate;
m_{liquid} Liquid mass flow rate;
K Velocity ratio;
α_{gas} Gas Fraction.

Figure 1, Typical curve of Line Liquid Content

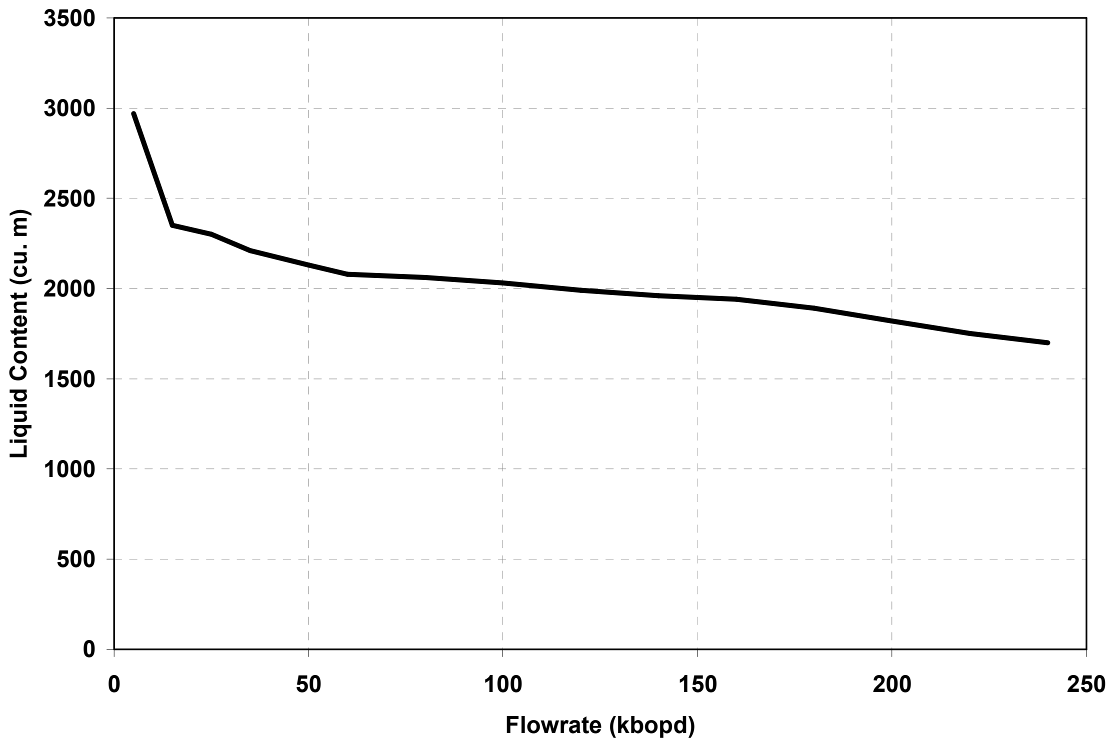

Figure 2, Separator at the Receiving Facilities

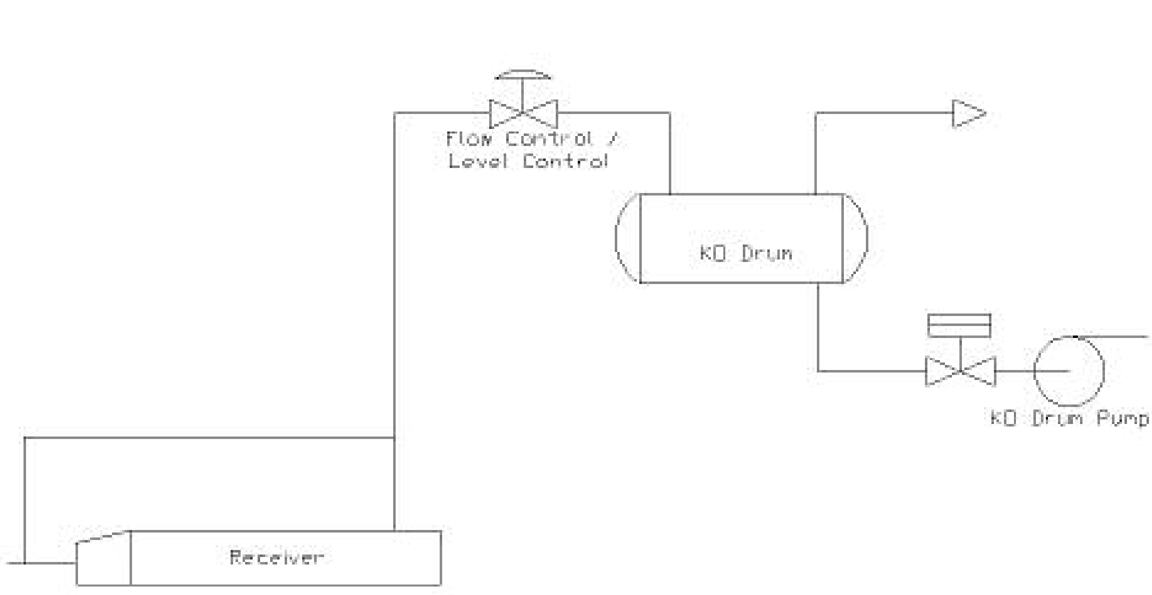

Figure 3, Example of Reduced Pigging Efficiency using Spheres

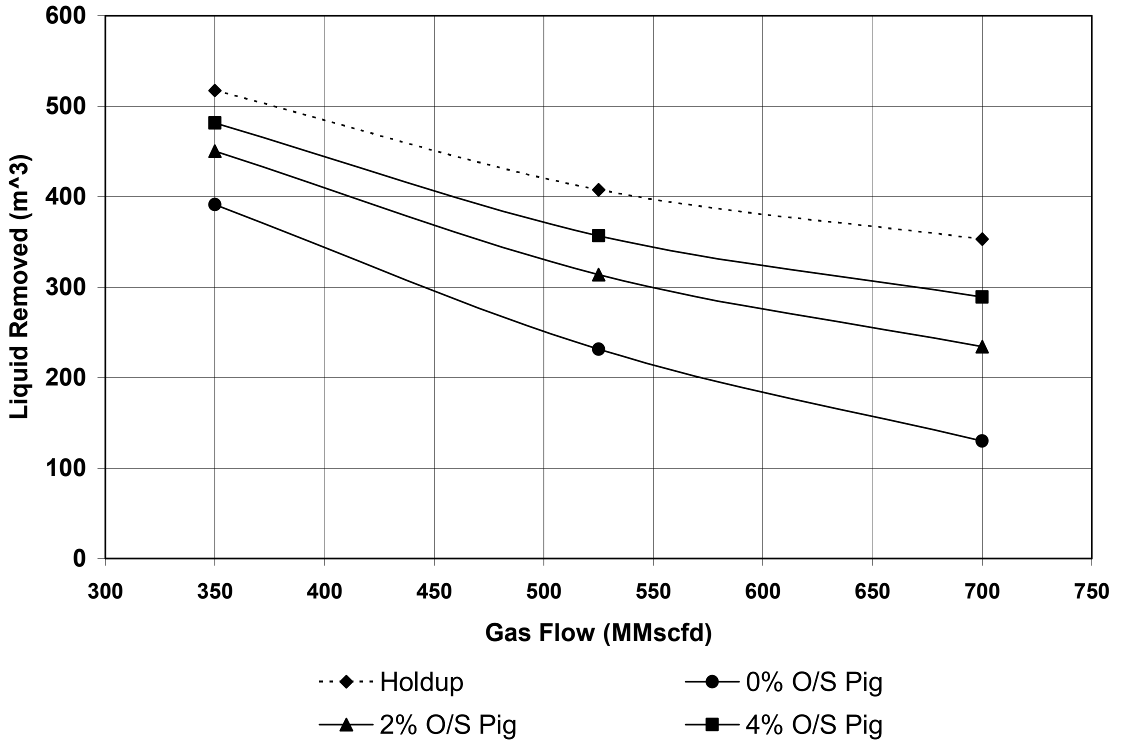

Figure 4, How the Bypass system works

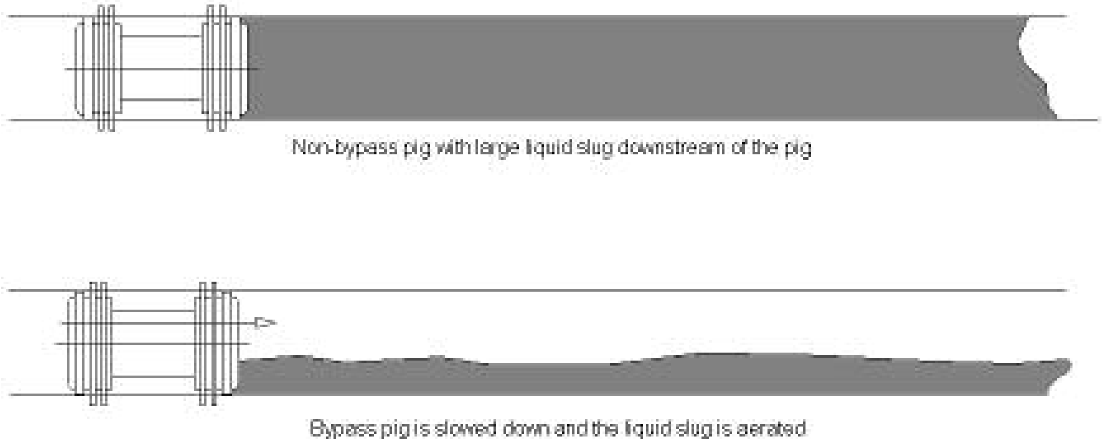

Figure 5, Case Study Outlet Liquid Flowrate as a function of Bypass