DOES YOUR FLOWLINE SYSTEM PUT YOUR FACILITY UNDER STRESS?

Or how to match pipeline to process and improve production by over $18mn per year

Andrew John Howell

Director Oil & Gas Solutions, Aspen Technology, Calgary, Canada

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ABSTRACT

The application of transient pipeline hydraulic analysis coupled with dynamic process simulation software is, for the first time, allowing engineers and operations personnel to quickly determine the integrity of pipeline and production facilities. At a particular set of well, flow line and tie back conditions how far is the production system from entering the severe slugging region? How much more production can be achieved before severe slugging is reached. In the severe slugging region what is the amplitude and cycle time of slug flow. Do your production and pipeline conditions favor the establishment of severe slugging? Does your production control system work against your pipeline system and promote unstable flow regimes? Exactly why is the separator pressure control valve the size it is and how is it controlled. A new unique approach to integrating transient pipeline simulation and dynamic process facility simulation shows how the industry can begin to address these very real questions. With a proven case study of a

major exploration pipeline-to-facility system this paper will demonstrate the benefits of full dynamic production system modeling and will encourage the reader to stress the production control system and see how it would respond. In this case, the benefits from improved production efficiency were in excess of $18mn per year.

INTRODUCTION

In practice, production facilities are often designed in separate stages as isolated sets of equipment items. As an example the flow lines and separation trains are often designed distinct from each other. The production facilities are built from steady state computed heat and material balances, often provided by process simulation. These material balances often do not account for enough pressure drop within the system and problems can be encountered when trying to commission such facilities. Dynamic process simulation has, until now, been considered somewhat of a mitigation step after commissioning, if problems occur. The hydraulic simulation of flow lines is treated as a separate discipline and can use separate thermodynamics e.g. black oil or PVT analysis, distinct from the compositional thermodynamics of the process simulation. Often, a ‘macro world’ or a ‘statistical’ guess at possible formation of slugging flow regimes, cycle time and amplitude of slugs is inferred from the steady state hydraulics, using age old rules of thumbs or experience. In particular the steady state flow regime is used as a correlating parameter. Separator design is then conducted from the amalgamation of steady state process simulation and correlating flow regime with an element of known design engineering practice. In advanced facility designs, a transient hydraulic simulation may be performed to check for slug flow conditions. The size of process equipment and the specification of the production process control system can then be performed within a separate discipline from the correlating parameters available. Detailed design then follows, including the specification of advanced control systems. Oil and Gas advanced process control is often relatively generic and not model based.

The difficult work begins at the commissioning stage when production problems occur and a combination of wrongly sized equipment and an inflexible control system means that the only solution is to cut back on production rates. Dynamic process simulation is often only performed after the realization of production problems and is used in a trouble-shooting capacity. It is the Design Engineer's responsibility to use all methods available at the design stage to ensure flow assurance, a controllable process and the integrity of the production facilities. New advances in the coupling of hydraulic and process simulation, in both steady state and transient modes, is leading to better guarantees of flow assurance and facilities integrity. This paper will examine a proposed facility design and show how performing coupled transient flow line and dynamic process simulation, early enough, can prevent significant production problems.

Figure 1 shows the, all too familiar, project impact curves that report most of the costs of a design being committed early on by the initial design decisions. Most of the costs incurred by these decisions are not accruing until late on in the procurement and commissioning phase when the impact of any design changes is considerably less.

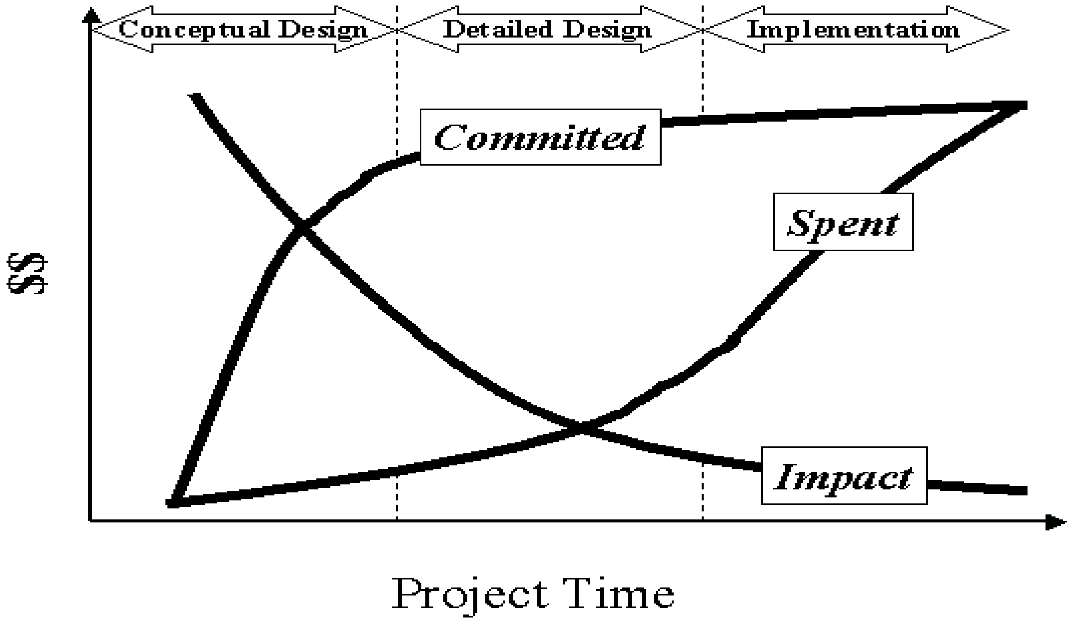

FIGURE 1 : Design Curve

PROCESS DESCRIPTION

A new production system has been designed by conventional techniques, including steady state process and steady state hydraulic flow line simulation. The hydraulic analysis indicates that the flow line may have the potential to enter the intermittent flow regime and hence form slug flow. However, the initial production system was designed using steady state simulation only. The detailed design stage added the process equipment sizes and process control strategy. Whilst detailed design was being completed it was decided, based on the steady state flow regime parameters to conduct a flow assurance study of the 10.8 km flow line from the sea-bed production manifold to the platform based production separation system. The flow assurance study used transient pipeline simulation to study wax, hydrate and corrosion prevention. The operator was further persuaded to conduct a transient flow line study coupled to a dynamic process simulation for a dynamic simulation of the entire production facility. This was largely due to the existence of a dynamic process simulation from facilities design control work performed by the process department and a desire by a progressive asset management team to check the integrity of the production system.

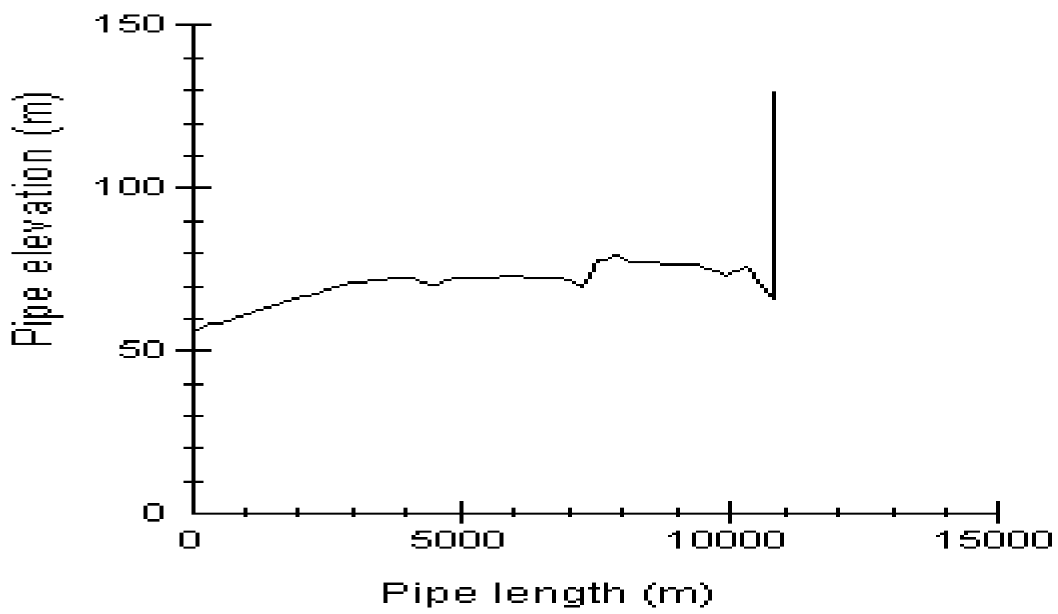

FIGURE 2 : Flow Line Profile

Figure 2 shows the Flow Line Profile in the production system from the Inlet Manifold Valve. The Flow Line is 10.8 km in length with some undulations leading into a riser of height 70 m. The riser delivers the production flow to the 3-Phase Separator. The 3-

Phase Separator has a pressure controller acting on the pressure control valve (Vapour Valve) and both associated oil and water level controllers. The complete Production System Process Flow Diagram is shown in *Figure 3.* The composition of the oil / gas / water system is given in *Table 1.*

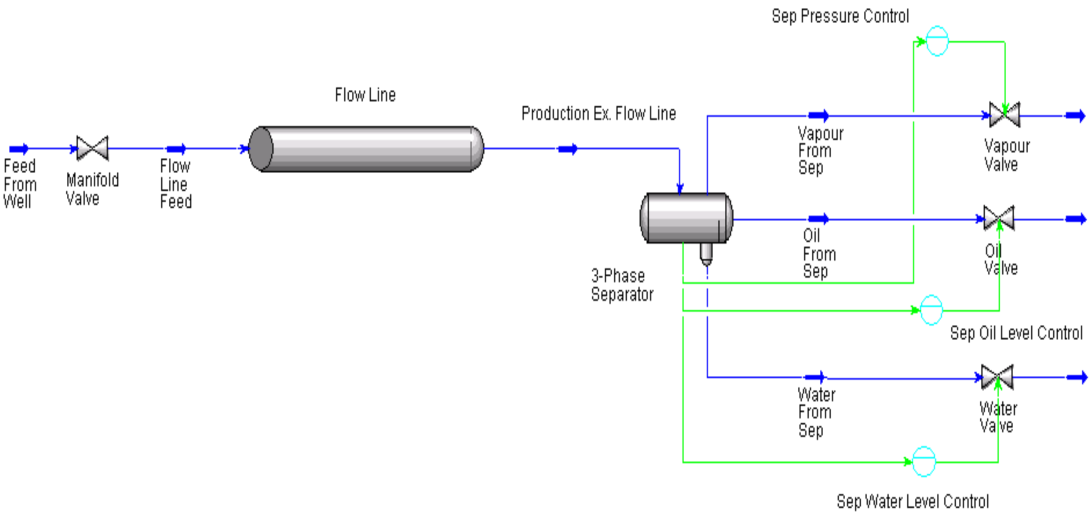

FIGURE 3 : Production System Process Flow Diagram

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METHODOLOGY

The dynamic process simulator uses an implicit Euler[1] integration method around ordinary differential equation models of the individual unit operations at three frequencies (volume, energy & composition). The transient flow line hydraulic simulator uses a method that conserves mass, momentum and energy for each phase around a non-conservative, ill-posed, semi-implicit, first order numerical scheme. Conventional philosophy of linking dynamic process and transient hydraulics, is to have the transient hydraulics manipulate the stream properties in the dynamic process simulation and control the time step solution. The new method employed in this paper is to use the transient hydraulic simulator to submit pressure / flow equations into the dynamic process solver and solve simultaneously. The transient hydraulics then calibrates the equations in the dynamic process simulator after each time step. This new methodology results in a more robust solution, with more accurate results, and an increase of twenty or so in solution time over conventional methods, ensuring real time solution can be attained easily.

Nitrogen	0.56
CO2	0.56
Methane	45.27
Ethane	10.4
Propane	5.07
i-Butane	3.66
n-Butane	3.55
i-Pentane	3.15
n-Pentane	3.04
n-Hexane	2.7
n-Heptane	2.37
n-Octane	2.08
n-Nonane	1.86
n-Decane	1.578

H_2O	14.09

TABLE 1 : Production Composition Profile In Mole %

RESULTS

The transient pipeline simulator was run in isolation, with a fixed inlet pressure of 15000 kpa, a fixed flow rate of 83560 kg/h and a fixed end separator pressure of 7600 kpa produces the profile shown in *Figure 4.*

FIGURE 4 : Flow Line Liquid Profile Without Process Interaction

The model profile is one of a two-phase system with the capability to form slug flow. However, at the given conditions, the flow line is not slugging and the process would appear to be stable. The real nature of the production problems can be studied once the transient flow line simulation is connected to the dynamic process simulation. *Figure 5* shows the trace of oil and gas flow rates from the combined simulation as the pressure controller attempts to control the separator pressure to 7600 kpa.

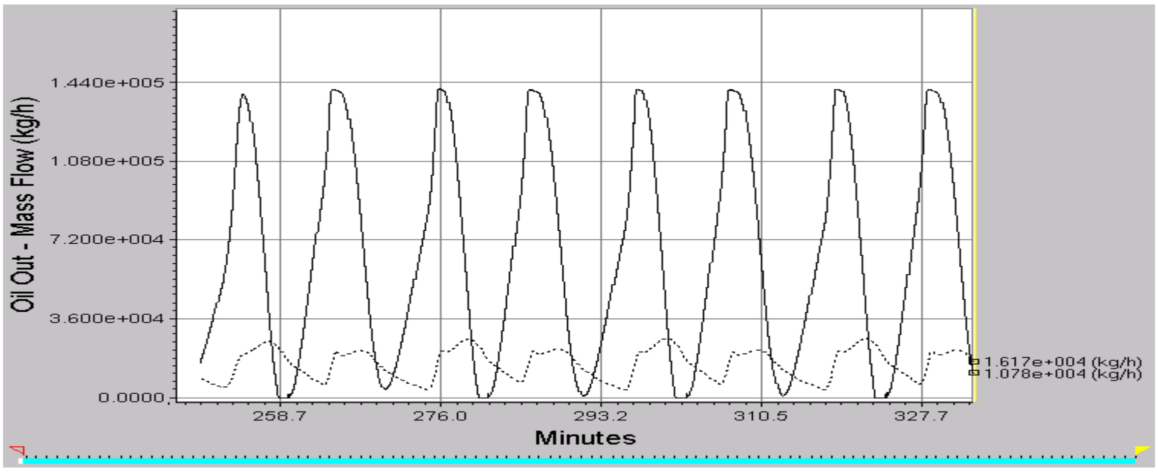

FIGURE 5 : Flow Line Oil Rate and Gas Rate (dotted) With Process Dynamics and Transient Flow line Integrated

The pressure controller continually cycles across the pressure set point and the instability of the pressure control caused by the size of the pressure control valve and the wrong controller Proportional Integral Derivative (PID) time constants imposes a instability on the flow line outlet conditions. This instability forces the flow line into the severe slugging region. Basically, the pressure at the riser base rises and compresses a gas slug trapped behind the liquid column in the riser. Eventually momentum effects take over and unload the riser into the 3-Phase Separator. A characteristic pattern of liquid slug flow followed by a gas flow rate peak a small time later is established. The slug cycle time is 11 minutes and the amplitude of the slug flow is around 69000 kg/h. As a result the oil percent level in the 3-Phase Separator cycles between 35 and 55% and there is also a 15% swing in the water level in this separator. In fact, the way this separator had been designed water would have flooded the weir and there would have been water break through in the oil line. Also, the disengagement space in the 3-Phase Separator oscillates to an extent that the specified mesh pad would struggle to maintain a satisfactory amount of liquid carry over in the overhead gas line.

The integration of transient and dynamic simulation used in this predictive study has been calibrated on a number of field simulations and tested against known slug cycle times and flow amplitudes. In all cases of comparison to known field slugging cases the simulation agrees to within 10%. The cycle time of around 11 minutes in this proposed production system is not uncommon with that measured in other light oil systems, which exhibit terrain (riser) induced slug flow. In almost all cases a modification to the production control system can achieve conditions that will promote a stable flow regime within the pipeline system. With a predictive model one also has the ability to examine other key process parameters such as equipment sizes, locations, hold up and resistance to flow before the system is ever built and commissioned.

In the production system studied in this paper the design, although at the detailed stage, was still conceptual. A number of process parameters could be still changed. From the response of the integrated transient Flow Line and process dynamic simulation it was clear that the key process parameters to achieve stable production system operation, at the fixed inlet conditions, were the pressure control valve size and the pressure control system time constants. Originally the pressure control valve was specified at a C_v of 40 (USGPM). The pressure controller proportional gain (K_c) was 2.0 and the integral time constant (T_I) was 1.0 with no derivative control. Closely followed, historical, design engineering practices were used to give these values. A detailed study of the production system resulted in a new pressure control valve size with a C_v of 20 and new pressure controller parameters of K_c at 0.5 and T_I at 5.0. The control parameters result from a detailed tuning study using, known, tuning techniques e.g. Ziegler Nichols[2] within the simulation environment. These new parameters used in the integrated dynamic production facilities simulation produce the trace in *Figure 6.*

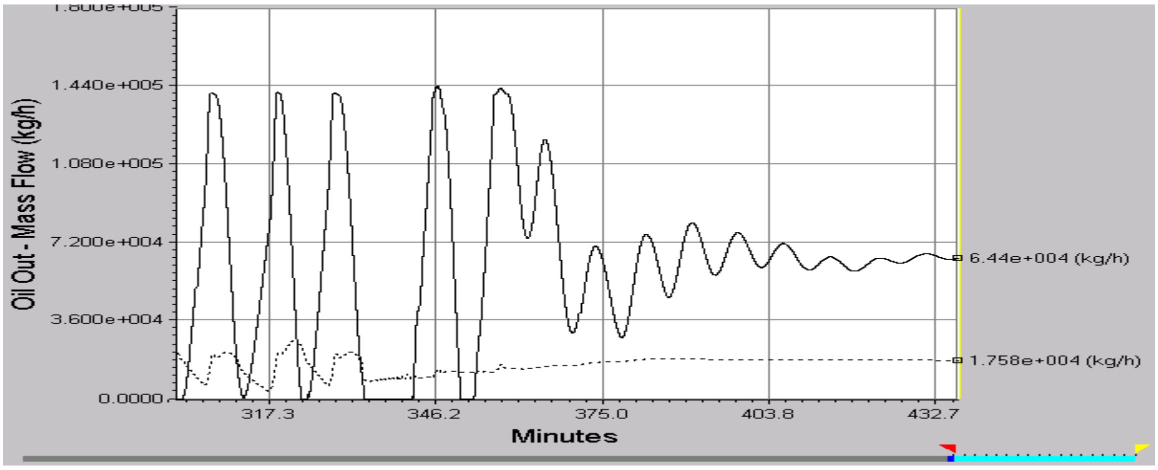

FIGURE 6 : Flow Line Oil Rate and Gas Rate (dotted) With Process & Dynamics Tuned

The new parameters were introduced at a time of 350 minutes into the previous, unstable, solution. The response of the system is to remove the instability in pressure around the 3-Phase Separator, ensuring a constant riser base pressure. The slug flow effects decay away and the flow line and 3-Phase Separator system then behave in a predictable manner. In this case the improved performance translates to greater than $18mn per year in production gains over the original commissioning point had the initial, flawed design been built. Fortunately the insight given by a full dynamic simulation of the production facilities in detailed design stage can mitigate operational problems.

CONCLUSIONS

The integration of transient hydraulic and process dynamic simulation ensures that full studies of proposed flow line and process interactions can be studied for a proposed field development. Such studies can be performed in the early design stages when change impact is at a maximum and the committed capital expenditure at a minimum. The use of such simulation tools can dramatically improve the flow assurance, reliability and integrity of production systems. This paper has shown where the integrated dynamic simulation has highlighted flaws in the original conceptual design such that the production pressure control system can drag the production flow line into the severe slugging region, establishing cyclical slug flow. The techniques used for integrating transient hydraulic flow with process dynamics produces a reliable, real time, solution to what is a complex problem that has not been fully tackled in the past. Applications of these techniques could also easily apply to as-built systems that show the characteristics of process induced slug flow or include modifications and revamps to existing facilities. A number of studies have been completed that have tuned the process control system to achieve stable and maximum production flow rates. Using these techniques one can check if the proposed production control system is stressed, if the production system promotes unstable flow or if your control system can work against you. In this way hypothetical slug flow regimes will remain hypothetical and stable production systems will operate. Couple with that the continual analysis of the facilities under a changing fees from reservoir decline and the engineer has a powerful desktop tool to aid process and facility understanding. The authors of this paper encourage you to stress your production control system, before it stresses you.

REFERENCES

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