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THE CASE FOR TRANSIENT SIMULATION

DESKTOP SIMULATION

The Hydraulic Analysis Group have been studying the effect of hydraulic behaviour in pipelines since the early 1970's and know that transients can cause significant operational issues, sometimes with catastrophic results. The fact is – all pipelines exhibit transient behaviour to some degree. Pumps and valves must be operated on pipelines to start and stop flow and it is their operation that cause flow and pressure changes in pipelines that are transmitted at the local wave speed in an upstream and downstream direction.

The severity of the transient (often called surge and the more curious name of water hammer) is affected by many parameters, including but not limited to pump run up and run down times, valve opening and closing rates, pipeline diameter, pipe wall thickness, pipe material, pipe length, the elevation profile, environmental factors, the fluid type, its phases, and its composition. Control schemes applied to pipeline equipment can then significantly change equipment reaction which then dynamically impacts the pipelines' hydraulics.

The need to control the severity of the pressures also depends on several factors including the pipeline rating and its allowable maximum and minimum operating pressures. The allowable pressures (maximum normal operating pressure and maximum allowable surge pressure) will primarily depend on the pipe material, and its wall thickness – which would most likely vary in more complicated pipeline systems.

It is a complex consideration, and the overall consequences can only be estimated by using a transient simulator that can accommodate all parameters. For maximum accuracy and to be able to capture rapid surge effects, the simulator needs to calculate the dynamic reaction (in terms of velocity and pressure change) at small distance increments along the pipework (often called the dx), at small increments in time (often called the dt). The common approaches used to calculate these effects are the method of characteristics and finite element methodologies.

It follows that the parameters that dictate the severity of the surge pressures could be modified to reduce them. Some pipe characteristics can be changed at the design stage, often after a surge analysis has been undertaken. Alternatively, there are options to limit the surge pressures by slowing down the rate at which the velocity and pressure vary which usually means more gradual pump speed changes and changing the way an opening or closing valve affects the flow. If pipeline and equipment characteristics cannot be changed, surges can be minimised and suppressed using additional equipment such as relief valves, surge vessels and equipment control that is often administered via a Supervisory Control and Data Acquisition system (SCADA).

REALTIME SIMULATION

The data acquired from instrumentation and equipment signals, provides critical information to an operator via a SCADA system, which helps understand the pipelines current and historical operation. Some of the control may be automated at the local level within the RTU (a flow or pressure control valve for example) or it may be administered at the SCADA level where a full operational picture of the pipeline is available. These automated processes can range from simple cause and effect operations to Artificial Intelligence routines that aim to limit transients, calm the operation, and operate the pipeline in the most optimal way.

SCADA systems were first installed on oil and gas pipelines in the late 1970's to early 1980's with the first true SCADA system being installed on the Mersey to Aldermaston oil pipeline in 1980. The contents of Oil and Gas pipelines are hazardous with some carrying products that can cause 2 destruction to the environment with leakage having the potential to inflict serious illness and even death. It is no surprise to see great care taken with the transportation of these products with instrumentation and communications installed. The measured data can support real time simulators and facilitate the close monitoring and control of the pipeline, so minimising surge effects and by consequence their propensity to leak.

Water pipelines do not transfer a hazardous product so there has been much less of a concern if they leak or burst but water networks have become more and more complex, often expanding to operate beyond their originally designed intention. Their complexity, their lack of instrumentation, their operation beyond the original intent and the fact that the users are free to extract as much water as they wish in any manner they like, makes them increasingly difficult to understand, let alone control. The situation is changing, especially in the Middle Eastern countries where water is a more precious commodity but more recently in the UK as focus on leakage increases and more instrumentation, communications and SCADA systems are being employed. Water management systems that employ real time simulators are now being given very serious consideration to supplement SCADA systems and provide a more accurate and clearer picture of the entire operation. When installed, they support a range of applications such as leak detection, product balancing, security of supply, quality tracking, demand forecasting and the expected effects of those demands on the network. These real-time systems are meant to ingest live data at frequencies that can be as fast as every 1s, then simulate the new state before the new data arrives. They should be equipped with a detailed control scheme model to fully cover the drivers causing pipeline transients.

The real time simulator needs to be a true transient simulator if it is going to mimic reality and be of sufficient accuracy to provide meaningful results. Many attempts have been made to try and use steady state simulators for real time simulation, but this approach is unlikely to succeed as pipelines and networks are never a steady operation. Steady state solvers assume that all flow conditions (and properties such as temperature) are constant with respect to time. Their advantage lies in the ability to rapidly calculate distributed steady state pressure conditions. They should be used only when the end state or sequence of long-term states is of interest and that makes them best suited for pipeline design and long-term forecasting applications.

SIMULATING IN REALTIME

Consider a simple A to B pipeline with flow and pressure measurement at both ends. Regular high frequency updates in the measurement data at the boundaries i.e., start and end locations can be fed to the simulator so that the pipelines' dynamic hydraulic conditions can be calculated along its length.

Under steady conditions, the flow and pressure profile may look something like the following [01], if the pipeline diameter does not change, and the elevation is flat.

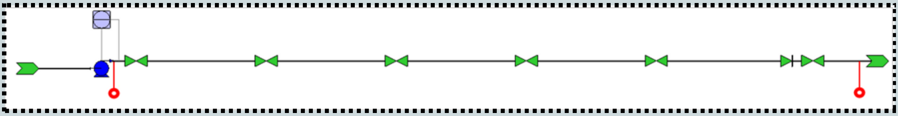
A steady state simulator will read the measured upstream flow and downstream pressure. It will then assume a steady flowrate throughout the pipeline and calculate a pressure profile that perfectly matches the steady state reality.

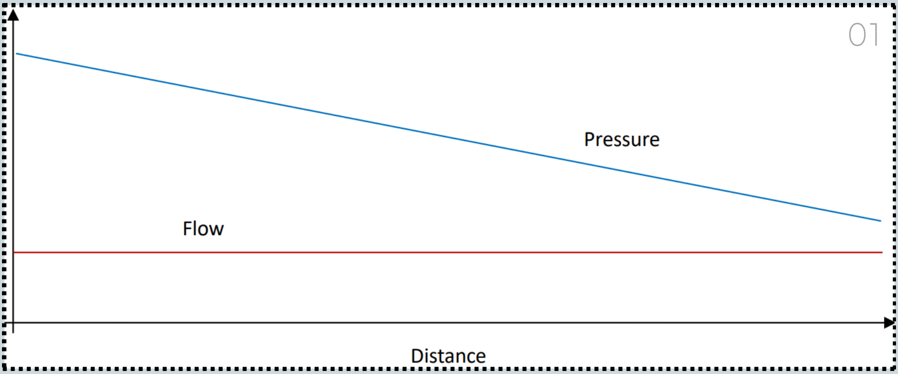
A simulator with a transient solver continually calculates the variance in flow and pressure along the pipeline length. If the pipeline is steady, it will establish that the change in flow and pressure at each dx and at each dt is zero and so it will determine the same flow and pressure profile (taking more time to do so).

Now consider a fall in the upstream flowrate to zero due to a pump shutdown. The resulting flow and pressure reduction will be transmitted along the pipeline as in the example below [02].

The steady state simulator sees that the upstream flow is zero (if the upstream boundary it is driven by flow). It assumes it to be zero throughout the pipeline and calculates a flat pressure profile set by the downstream pressure (if the downstream boundary it is driven by pressure). It therefore calculates a flow and pressure profile that is significantly different to that in reality and will continue to do so until the pipeline flow becomes steady again [03].

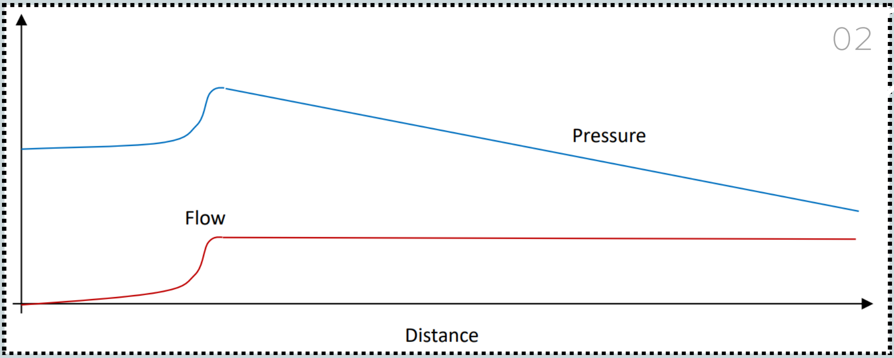
If upstream and downstream pressures were used, the steady state simulator would establish a steady flowrate (dashed red line) to satisfy the measured pressure drop and determine a linear pressure drop between the two (dashed blue line) [04].





SIMULATING IN REALTIME

02



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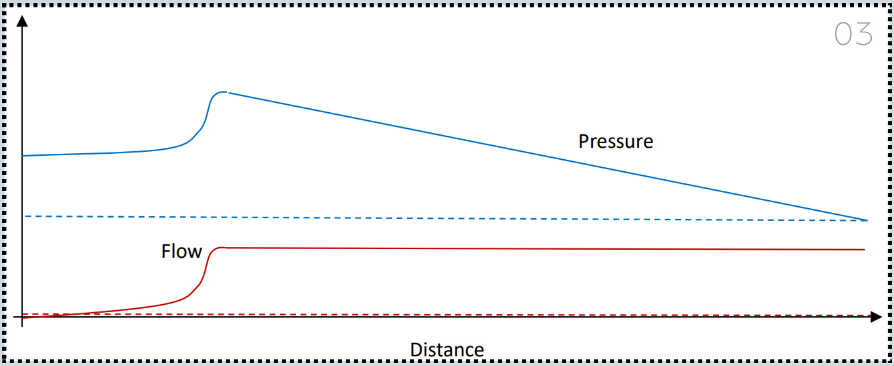

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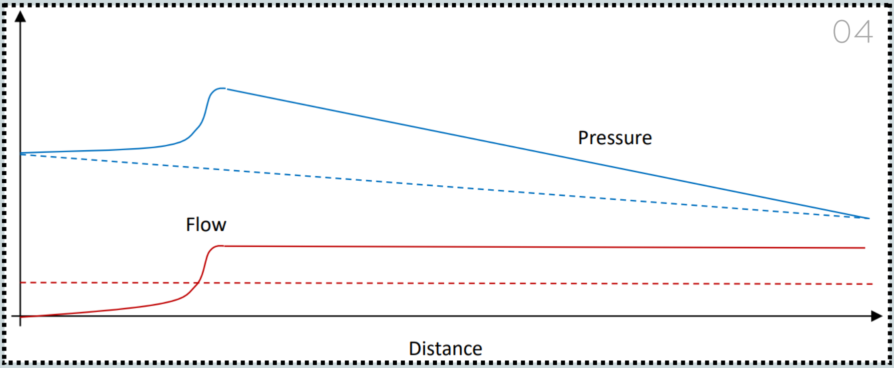


SIMULATING IN REALTIME

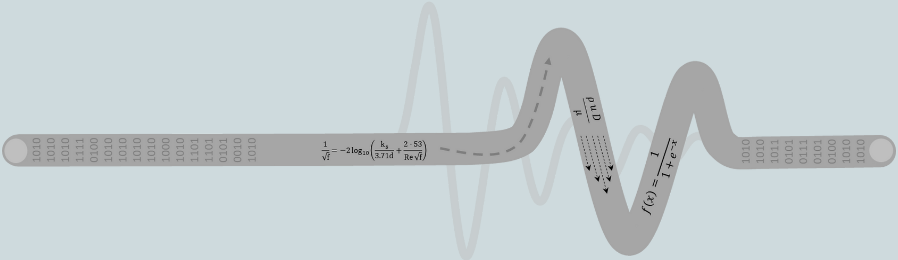
Regardless of the combination of measurements used at the boundary locations (pressures or flows), there will be an associated variable error in pressure and flow. The pressure and flow conditions may be impossible to resolve with a steady state solver (for example, the pressure at some point within the pipeline may erroneously reach vapourisation pressure). The solver then has one of three options that depend on its level of error checking.

- Fail to solve and terminate / crash.
- Attempt to distribute the inherent error.
- Wait until the transients have dissipated and a solution becomes possible again.

Now consider a complex water network with many inlets and outlets, many consumers, and many items of operational equipment. It is a logical conclusion that a steady state simulator can't achieve a set of conditions that match reality throughout much of its operation.

The time taken for a transient change to move through a network can be long, during which time a steady state solution is either inaccurate or cannot be solved. A networks' continual change in operation means that steady state solutions need to distribute the error and that can take so long that they fail to solve within the update frequency of the measured data.

A true transient simulator will match the conditions as closely as possible under all operations so it will not only be more accurate (and all the functions it feeds, including leak detection), it will be more robust and that is an imperative requirement for a real time simulator. Unfortunately, the driving instrumentation data and any estimates in consumer usage may be inaccurate and, in some cases, erroneous. A well performing incoming data verification and replacement process must therefore be part of the real time simulators' processes.



WHY INVEST IN TRANSIENT SIMULATION?

01

A transient simulator can be used throughout all stages of a pipeline's lifetime. At the design stage it can be used to determine the surge and normal operating pressures that it may experience and adjust its design accordingly.

03

A seamless transfer of the live simulators' conditions to a copy of the simulator in the desktop environment can then help ensure that subsequent hydraulic analyses use true starting conditions. A training tool for the control room operators

04

There is a compelling case for a transient simulator tool, sometimes called a digital twin, to follow your pipelines' complete lifecycle and be repeatedly utilised to help achieve not only a safe operation but an operation that can maintain a cost effective and secure delivery

02

In its operational phase, the same simulator can be used to troubleshoot and refine its operation, especially if it needs to expand or change its delivery capacity. That same simulator can take all those high frequency flow and pressure measurements to provide operational clarity and support a range of additional pipeline management applications. Today's technologies even allow users (operational and managerial) to access the live calculations through web-based browser displays and provide detailed GIS based information and network performance metrics in a dashboard format.

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