

RISK ASSESSMENT FOR MAJOR HAZARDS AND PROJECT EVALUATION – ASSESSING THERMAL RISKS IN SUBSEA PRODUCTION OPERATIONS

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Many offshore, onshore and subsea pipelines and process systems have associated integrity and production flow-related hazards.

One of the major operational issues in subsea production systems is from thermal-related risks. Subsea systems manage production from the wellhead to a host facility and can sit in deepwater in excess of 2000 metres. This adds many challenges both to ongoing operation and intervention. Systems must have a high level of integrity and reliability with thermal issues playing a major part in their success. Due to the deepwater the duration and hence cost of the operations is significantly increased. Therefore the subsea equipment has to be qualified for longer cooldown periods. There is a strong emphasis on system reliability as the industry strives to reduce shutdown costs.

During subsea production there are a number of instances where thermal performance of the equipment is of the utmost importance.

1. During system start-up
2. In the event of a shutdown in production (either planned or unplanned)
3. During operation

During system start-up significant pressure drops across chokes can produce significant volumes of fluids at low temperatures (due to the large pressure drop across the choke). This has two potential issues; the first is related to the potential for hydrate formation, and the potential blockages that may form. The second relates to the temperature of the production system and pipeline itself dropping below its qualified material temperature. As a result this may cause system integrity issues.

It is important that these potential issues are evaluated at the design phase. For example choke operations (both subsea and topside) should be understood and managed and appropriate materials selected (especially close to the choke where the lowest temperatures are experienced) for subsequent installation and construction procedures at design.

In the event of an unplanned production system shutdown, the system is reliant only on the heat stored in the pipework and trapped production fluids. There may not be time to go through the required procedures to depressurise, inhibit or purge. Such procedures help to avoid the formation of blockages due to hydrates as the system cools due to the surrounding subsea environment and the trapped hydrocarbons fall below their respective hydrate formation temperatures.

Although hydrate formation is well understood, the industry is looking at subsea equipment with better thermal

performance in order to reduce the escalating cost of chemical injections. In some instances hydrate formation can lead to a plugged line. In this condition chemical inhibitors may not help to alleviate the issue with manual intervention the only solution. Intervention, especially in deepwater is costly and time consuming.

In pipeline bundles, single-skin pipelines or pipe-in-pipe systems the thermal performance (cooldown performance) is relatively simple to design and understand. The thermal performances of downstream pipelines are often sufficient to keep trapped fluids above hydrate formation temperatures. This allows sufficient time to assess an unplanned shutdown and either restart or go into a depressurisation or flushing sequence. It is the upstream production system (production trees, manifold and connection systems) that has reduced thermal performance and therefore is the largest threat to potential blockages. The upstream production system has added complexities of the geometrical nature and intervention requirements (ROV access etc). The insulation design in the vicinity of the drill centre (production Xmas Trees, manifolds and connection systems, flow meters etc) is more complex but equally critical to the pipeline design.

While a production system is in operation thermal issues are, on the face of it relatively simple. Warm production fluids pass through the drill centre itself with relatively little temperature loss and the risk of blockage from hydrates is mainly associated with the pipeline length (loss in temperature along the pipeline). Temperature loss can be managed through thermal design of the pipeline itself and chemical injection. However, where systems are typically thermally designed to retain heat, high temperature and high pressure wells can muddy the waters somewhat.

Equipment such as flow meters and actuated valves on manifolds and trees are insulated such that they do not cause cold spots and increased risk of hydrate formation. Many such devices have components that have maximum temperatures to which they are qualified for operation. It is therefore important to account for this under high temperature production (where the insulation may actually cause overheating). Insulation schemes should be designed and assessed to ensure overheating is avoided or, where this is not possible, equipment that needs to be re-qualified has to be identified.

ASSESSMENT, ANALYSIS AND DESIGN

Assessing the process related issues and hence thermal mechanisms within such systems can help evaluate such

occurrences as hydrate formation, minimise operational risks and reduce operational cost related to equipment and chemicals required.

Computational fluid dynamics (CFD) is an engineering analysis tool capable of solving any flow-related or thermal scenario in what is analogous to a “virtual test facility”. The engineering skill is how to deliver an insight into operational risks and for a skilled engineer to utilize this engineering tool to help deliver a design or process solution that can reduce the impact of the associated risk.

By understanding the flow characteristics required to cause a potential (or known) risk, possible mitigation techniques can be investigated and an engineering answer obtained. For instance, with CFD all of the potential variables can be explored. The position and flow rate of a required chemical inhibitor can be optimised both reducing the risk of system integrity and offering a means of minimising the amount of chemicals required.

CFD analysis enables understanding of the relationship between fluid flow and heat transfer in complex geometries such as a Xmas Tree or manifold system. Prospect’s analysis experience has been validated against full scale testing, providing confidence in the methodology used to perform such analyses.

CFD analysis can be useful at each stage of a design and field life cycle. During the design cycle it can be used to assess and prevent possible issues and understand best practices (whether this is process and mechanically related) to gain maximum performance by analysing the fluid flow field and associated thermal performance. CFD is increasingly being used to troubleshoot issues during operation. Following analysis a solution is often more difficult to implement as major redesign once in operation costs both time and money.

Well start-up is a critical phase where extreme cold production fluid could lead to surrounding equipment experiencing temperatures outside material qualification limits.

The significant pressure difference upstream and downstream of a choke can generate an expansion of gas passing through the valve. The main characteristic of this phenomenon is a significant decrease in fluid temperature that cools surrounding materials both upstream and downstream. This poses a risk to material qualifications and hydrate formation in the downstream system. This cooling is of prime concern when the well is first started as the downstream side of the choke is pressurised. The cooling effect (Joule-Thomson effect) reduces as the downstream pressure increases through time following the opening of the choke.

The thermal stress generated in the choke valve with the very cold fluid on one side and the warm well fluid on the other can induce risk of failure. Accurate simulations of the heat transfer through the different components of the valve can help to understand and optimize the opening procedure. Downstream of the choke, multilayer flexible jumpers made from various structured layers have materials with different qualification temperatures. Accurate

temperature predictions in the different parts of the pipeline have recently been used to optimize the start-up of a new production line.

In the case of start-up simulations, the main objective of the CFD analysis is to understand the thermal behaviour of the different components. It is therefore paramount to optimize the start-up procedure to reduce costs and risks.

Accurate representations of complex geometries are created in order to reproduce the thermal behaviour of the components. Figure 1 shows an example of the geometry created to replicate a particular Xmas Tree. In this example production gas enters through the green surface (bottom left of image) and passes through the red pipe exiting at the bottom right of the image. The choke in this case is located at the junction of the production pipe on the right hand side. Outer surfaces have been shaded for representation purposes. Each section of material in the model is applied with the same thermal properties as you would have in the production Xmas Tree.

A transient inlet boundary condition was set up to simulate the change in temperature and mass flow over time and the model calculated the temperature distribution in the surrounding system over a period of several hours. The cooling influence of the seawater was also taken into account by applying fixed temperatures and simulation derived heat transfer coefficients to the outer walls of the model. Figure 2 shows the temperature profile in the system when the cold migration was at the maximum and under worst case conditions which involved production gas at the same temperature as the surrounding seawater.

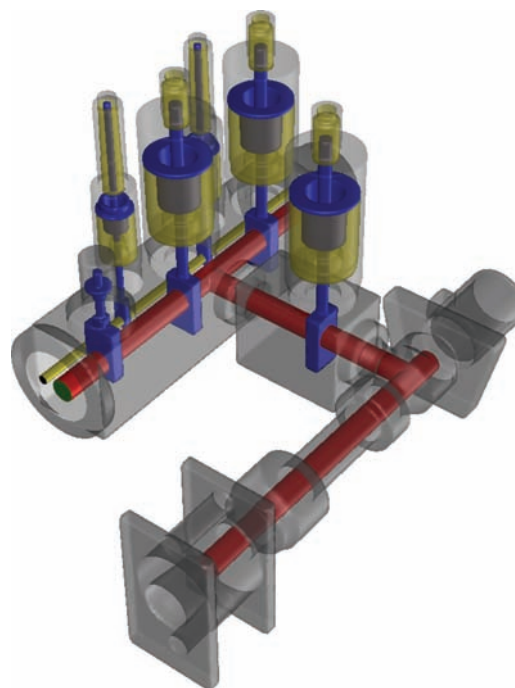


Figure 1. Xmas Tree model created from supplied data

In this example the minimum temperature of a section of pipework and within a seal near to the choke were reported over time. These minimum temperatures were then compared with the known thermal limits of the surrounding materials.

Computational analysis has the important benefit of being able to model fluid behaviour explicitly and allows for forced and free flowing convection, this allows the modelling of thermal effects. In ensuring efficient subsea production of hydrocarbons, a subsea Xmas Tree must be free from blockages caused by such adverse formations as hydrates. During system production this can be achieved through insulation and chemical inhibition. However, in the event of a shutdown the trapped production fluids must remain above the hydrate formation temperature for a period of time. This time has to be significantly long enough to allow the operator to assess the situation without the need for significant intervention procedures such as system depressurisation or flushing.

Hydrates formation is a function of temperature and pressure and in the event of system shutdown cold spots provide a major risk. Tools such as CFD can be used to consider whether the hydrate formation temperature is reached and to design insulation systems to help reduce this risk. During production the fluid bore and surrounding fluid dead-legs remain warm and in most parts there are large amounts of replenishment of the fluid. In the event of a shutdown

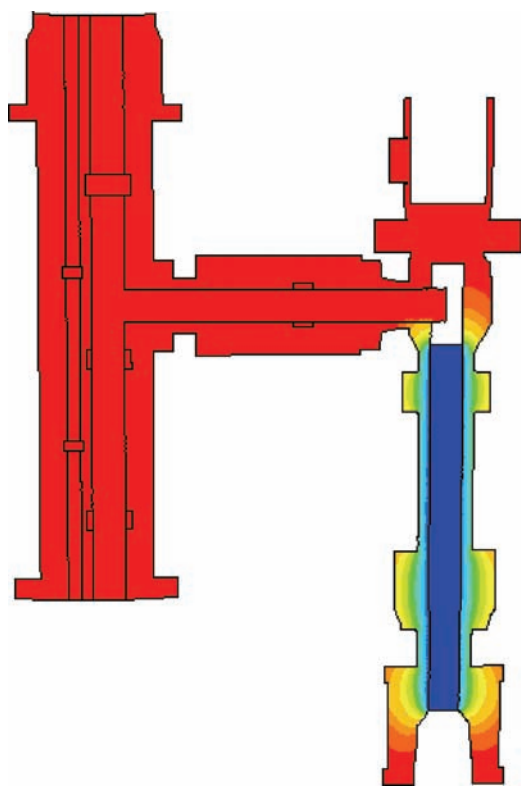


Figure 2. A slice through the Xmas Tree model showing warm (red) and cold (blue) temperature contours

(therefore no replenishment) cooling takes place due to the low temperature seawater surrounding the system.

Fluid in the production bore must be kept above the hydrate formation temperature for the entirety of the given assessment period before production is re-started or more significant action is required. During cooldown the only fluid movement is due to convection which is not enough alone to prevent hydrate formation.

CFD analysis has been used to predict fluid temperatures in Xmas Tree systems during production and cooldown (of the order of 10 hours). The use of CFD for this extent is a relatively new field in subsea technology and something in which Prospect has invested heavily in time over the last 5 years. The models required for the accurate prediction of heat transfer with these systems are large. Modelling these systems require an in-depth understanding of the cell sizes (for which the equations are solved within) that are appropriate and which make for computational efficient simulations.

Figure 3 shows temperature contours in a subsea production valve on the Xmas Tree after 10 hours of cooldown. Here the warm production fluid (orange) will be safe from hydrate formation while the cold spots (blue) have the necessary mechanisms to cause an issue.

The accuracy of the simulations has been proved in the extensive physical cooldown testing Prospect has been involved in with all of the Xmas Tree insulation designs. Prospect have used “virtual” thermocouples to monitor temperature at various locations during production and cooldown. Typically 100’s of locations are monitored in an SPS cooldown. These locations are the same as those of the actual thermocouples on the test. Typically results between the CFD and test have matched to within a few degrees. As the CFD models have been created from CAD data the temperature discrepancies can be attributed to differences between design drawings and the test model.

Areas which are cold enough to experience hydrate formation have to be insulated, taking into account the needs of the various electronic components which must remain cooler and space restrictions, to keep warm pro-

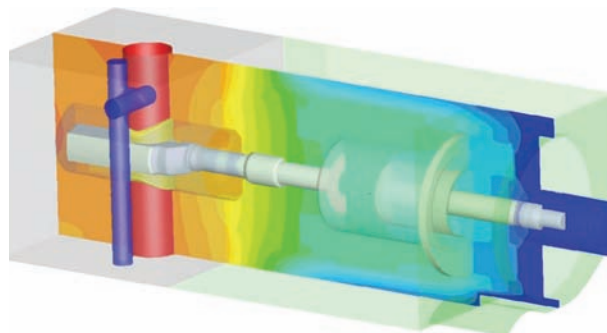


Figure 3. Contours of temperature (warm is orange, cold is blue) within a Xmas Tree valve showing where hydrates can form

duction temperatures in. System purging is an additional method used to mitigate against hydrate formation.

Following the initial analysis of the Xmas Tree, insulation was applied and the valve and the simulation re-run to check that a hydrate-forming thermal environment was avoided. This analysis saved time and money as it did not require full-scale testing of different configurations and gave insight into equipment that without such analysis was not possible.

Understanding and managing flow and thermal fields in and around such developments is becoming more important as the oil and gas industry strives to understand and minimise risks caused by such adverse processes as cold temperature migration and hydrate formation. Computational analysis helps understand the problems, design a system that minimises risks and tackle issues early in the design process since prevention is infinitely preferable to cure.