SPE Brazil Flow Assurance Technology Congress
Rio de Janeiro, Brazil, November 06 – 08 2024

Wax/Hydrate Flow Assurance in a North Sea Pipeline-Riser System: Integrated Production Modelling for Long Subsea Tieback Challenges

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Abstract

Improved flow assurance is needed to tackle challenges during petroleum fluids movement across the total production system, considering the interconnectedess of various parts from pore to sales. This paper reports a mechanistic, compositional modelling of a subsea gas condensate pipeline-riser system in the North Sea. Model objectives were to forecast hydrate and wax risks, predict operating conditions for formation, assess impacts on facility throughput, well deliverability and reservoir performance, and guide mitigation measures in flow assurance for production optimisation. Integrated production modelling (IPM) tools were used to process secondary data through a graphical user interface (GUI) that linked different software packages within the suite and considered the entire asset as a composite system. Fluid composition data from crude assays were fed into PVTp to generate PVT data, then imported to GAP with process parameters to predict hydrate and wax deposition in the pipeline system. GAP model was linked to RESOLVE to run manual and automatic mitigation programs for wax and hydrate deposition. Predicted data obtained were plotted against relevant functions to analyse effects of these issues and modelled mitigation schemes on production for manual and automatic mitigation runs. Wax risk was detected by GAP at the pipeline section connecting two wells, hydrate risk was detected at another pipeline section, and two other sections indicated both hydrate and wax risks. A proactive approach to wax-hydrate monitoring was recommended to enable detection and troubleshooting of production issues. Although these IPM tools are steady state, they should find application in mature fields with declining production rates that approximate this flow regime. The incorporation of dynamic simulators was also advocated to enable composite models by future research and simulations run in transient state as IPM undergoes regular upgrades. Only one recent study in the literature was found to report the use of the modelling tools of this paper for wax or hydrate flow assurance. This study is hoped to provide unique approach to integrated flow assurance from reservoir to point of sales; a key advantage of IPM. The recommendations had informed the development of a transient simulator by the software provider.

Keywords

Gas condensate system; wax and hydrate co-deposition; integrated flow assurance modelling

Introduction

Multiphase flow of petroleum reservoir fluids though subsurface and surface facilities usually involves interactions between gas, liquid and solid phases in reaction to changes in pressure, temperature and composition. Temperature drops could lead to precipitation of solids such as wax and hydrate crystals. Flow assurance thus needs to be designed into the entire petroleum asset from the reservoir, through wells and pipeline systems to the refinery or export terminal, as gas, oil and water move through the total production system as shown in Figure 1. In response, integrated asset modelling (IAM) was developed by a major operator and later christened integrated production modelling (IPM) by a software developer. Used interchangeably, IAM and IPM consider the entire petroleum asset from pore to sale as a composite system for fluid handling processes that assure field economics.

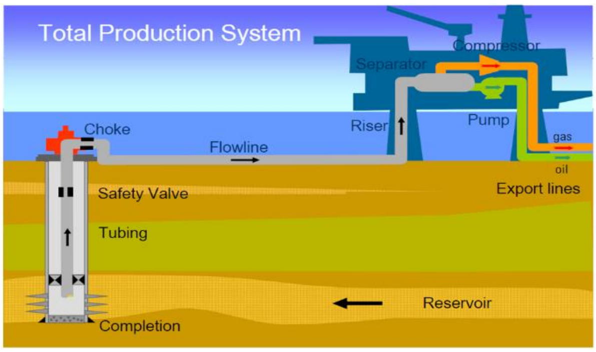

Figure 1. Flow Assurance in Total Petroleum Production System [1]

Pipelines and risers play crucial roles in offshore field developments. Considering their high capital costs, keeping facilities in active service remains essential for unhindered fluid movement to enable fiscalisation, processing, and sales [2]. The case study is in the North Sea, where most assets are mature, operating costs are increasing and government revenues have dropped due to production decline [3]. Flow assurance optimisation in a timely manner is one way of salvaging this, delivering greater returns on investment to operators and maximising value from expensive assets.

Several studies had attempted to address wax and hydrate deposition in either subsurface and surface equipment and facilities using experimental, numerical modelling or a combination of both approaches. Though their results and inferences have significantly contributed to knowledge about solids control, most of the methodologies have remained standalone and have not been replicated by other works, standardised or commercially applied. Yin et al. (2016) had reviewed classical and modern hydrate dissociation kinetic models, proposed further improvements and reviewed the working principles by comparing different simulation packages. It, however, only focused on subsurface flow but did not treat surface facilities. This study seeks to extend these advances to pipelines and risers using an integrated computer-based model for better results. By considering the entire asset as a total production system, IPM workflows enable a holistic detection and mitigation of flow assurance issues from source to sink rather than a traditional standalone approach.

Methodology

Case Study Description

LM pipeline, with 814 km length and 966.4 mm internal diameter (ID), is one of the world's longest subsea gas pipelines. It was commissioned in 1993 to export natural gas from Norway to Belgium at maximum suction pressure of 14.9 MPa and minimum delivery pressure of 8.3 MPa. There are no valves or compressors along the entire pipeline length. At certain times, sand washed on the sea bottom causes burial of sections of the pipe. Advanced flow simulation studies on it had considered sea currents, pipe internal surface and some other parameters to model its behaviour under varying environmental and operational conditions.

Data Collection and Analysis

Secondary data on fluid properties such as oil density, gas density, oil flow rate, gas flow rate, dead oil viscosity, gas-oil ratio (GOR), paraffin and asphaltene content, saturates content, aromatic content, resin content, pipe diameter, pipe section length, pipeline length and geometry, initial loop pressure and temperature, cooling time, etc. were processed to predict the flow conditions before, during and after hydrate and wax formation. Table 1 shows the designed properties of LM pipeline-riser system, which were used as input data for the mechanistic model. Data for both fluid and pipeline were obtained and extrapolated from case studies, published papers and laboratory results available from the literature. These data on the North Sea were used to feed the GUI of IPM GAP-PVTP-RESOLVE to predict hydrate and wax deposition in the facility. The compositional mode was selected as the properties being modelled depend largely on the fluid compositions, which were obtained from the industry regulator in Norway. Due to the long pipelines and risers to be modelled, hydro-2P mechanistic flow model was used as specified by the software developer [5] and rule-based solver selected for running forecasts. The simulation results were interpreted with the aid of IPM software manuals, official videos, tutorials and relevant literature; with deviations in specific situations accounted for. Model results were also matched with secondary data for gap analysis. These analyses formed the basis for the conclusions and recommendations to fill the knowledge gaps and suggest means of obtaining better results.

Table 1. Input Data for LM Pipeline Wax–Hydrate Modelling [4]

Parameter	Magnitude	Units
Pipeline Length	814	Km
Inner Diameter (ID)	966.4	mm
MAOP at Inlet (maximum)	14.9	MPa
MAOP at Inlet (minimum)	8.3	MPa
Capacity	42	scm/d

Scope of the Study

Two major flow assurance problems – waxes and hydrates – formed the focus of this study. It was based on production facilities that include LM pipeline-riser system in a gas condensate asset in the North Sea. Some reservoir data such as bubble point, gas-oil ratio (GOR), reservoir temperature and pressure were extracted from well test results to populate the base models on PVTp and GAP to aid estimation of surface fluid properties by the interlinked simulators.

Model Description

IPM suite consists of interconnected software tools that enable flow assurance engineers dynamically model reservoirs, producer and injector wells, and surface pipeline networks as a total production system. OpenServer and RESOLVE give IPM suite connectivity to third party software such as Excel, OLGA and Eclipse for reservoir and process simulations.

GAP is embedded with simultaneous fluid descriptions for any phase; enabling properties to be modelled, predictions run and complete petroleum systems optimised for maximum hydrocarbon production. This case is a gas condensate with known composition, so Peng-Robinson (PR) equation of state (EoS) under compositional model was selected as it models better densities than SRK and other EOS for gas and condensate systems, being closer to reality. PR-EoS is expressed by Equations 1 and 2, which

$$(P+\frac{\alpha a}{v^2+2b\tilde{v}-b^2})(\tilde{v}-b)=RT \tag{1}$$

$$\alpha=\left[1+\left(0.37464+1.54226\omega-0.26992\omega^2\right)\left(1-\sqrt{T_r}\right)\right]^2 \qquad (2)$$

underly reservoir-well-surface data conversions across the IPM tools [6].

RESOLVE achieves strong parallelisation of solver algorithms, allowing topography of connected systems, either upstream or downstream. Non-linear optimisation in GAP and successive linear optimisation in RESOLVE enables flow assurance mitigation modelling, be it for one problem or interacting problems. This integration distributes optimisation problems over all RESOLVE applications, as shown in Figure 2.

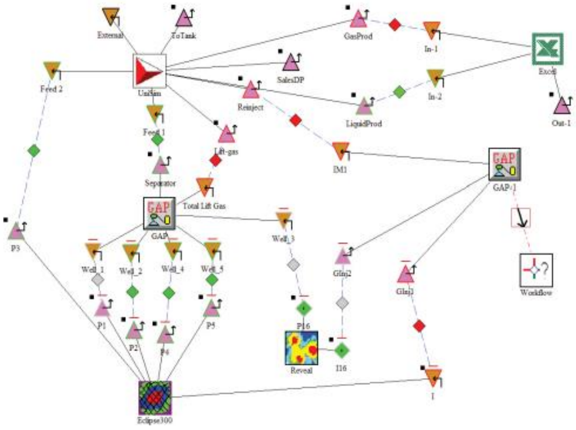

Figure 2. Total Production System on RESOLVE [5]

PROSPER performs two-phase fluid descriptions. For this case, ‘retrograde condensate’ was selected in drop-down menu as fluid type to be modelled. PROSPER has PVT handling capabilities for both black oil and compositional models. EOS compositional option was selected for this work as it allows proper characterisation of real reservoir fluids proven to result in reliable predictions by phase behaviour models without the need for tuning [7]. Also, EOS matches more accurately with laboratory results, modern reservoir simulators are usually written in general compositional formulation and using a black oil model would require PVT properties to be converted internally to a two-component ‘compositional model’ made up of surface oil and surface gas [8].

Modelling Objectives

The objective of the RESOLVE model was to guide the GAP model towards allocation of rates between the wells that does not pose wax risk. Operationally, this will provide the well head choke settings required to be implemented in the field. This was simulated in IPM to furnish the operations and maintenance team with the required information for field optimisation decisions. The RESOLVE file was set up to create and execute appropriate workflows at every timestep of prediction, giving an accurate view of:

- Requisite design and operational tolerances.
- Actions necessary to inhibit wax and hydrate occurrence and their scheduling sequence.
- Total asset performance.

Model Setup

Separator pressure of 655 psig was set on PVTp as lower boundary condition for WAT prediction and reservoir pressure as upper boundary condition. To calculate the amount of solid wax deposited in the pipeline and riser, a range of temperatures and pressures were inputted into PVTp to run multiphase flash calculations based on PR EOS. GAP was used to predict operating conditions for wax and hydrate formation, while series of workflows were developed on RESOLVE to model the mitigation schemes for both flow assurance problems. MBAL linked the reservoir properties to the GAP-RESOLVE composite models, PVTp provided the fluid properties and implemented the inbuilt PR EoS model selected for the study, while PROSPER fed well dynamic parameters into the flow assurance models. Model results from the GUI linking GAP and RESOLVE through a visual workflow were imported to Excel.

Fluid Property Correlations

The following fluid PVT property correlations were selected while setting up the models for this study as recommended by the software provider for North Sea gas condensates [9].

Oil Viscosity:	Lohrenz, Bray Clark (LBC)
Gas Viscosity:	Lohrenz, Bray Clark (LBC)
Hydrate Model:	Munck et al.
Wax Model:	Pedersen

Results and Discussion

The results for the wax model in this study had been reported by a recent paper [10] by the present authors, so this paper focuses on the hydrate model results. IPM suite has provisions for hydrate modelling in manual and automatic modes for both detection and mitigation workflows during operations (all in steady state) and shut-in (mostly transient conditions, respectively. For this study, there was no access to a transient simulator as at then, so manual detection and mitigation was performed.

GAP detected wax risk at a pipeline section connecting two wells, hydrate risk at another pipeline section, while two other sections were found to face both hydrate and wax risks as indicated by the pink nodes in Figure 3.

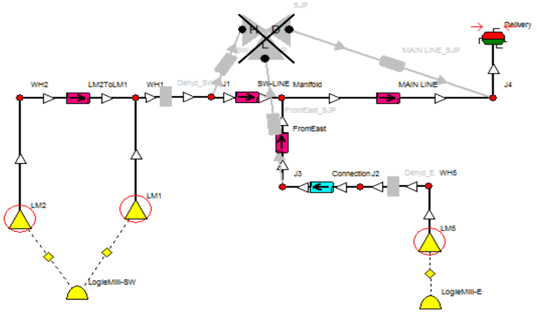

Figure 3. GAP Model of LM Pipeline/Riser System

Figure 4 is the phase diagram from hydrate modelling, the green line indicating the operating envelope for hydrate formation risk.

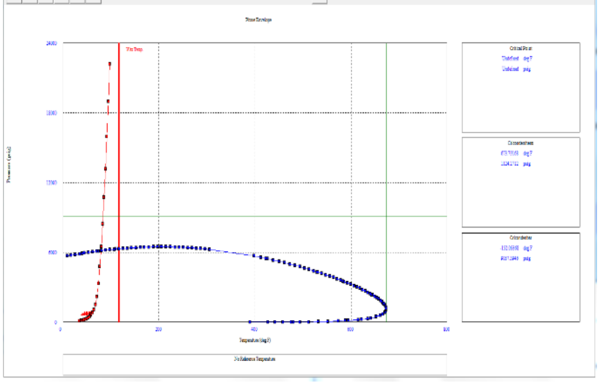

Figure 4. Phase Envelope for Hydrate Prediction

Mitigation strategies include increasing flow rate by using less wellhead chokes, methanol injection modelled on RESOLVE, heating modelled using pipeline temperature profile and hydrate acceptance with pigging. The hydrate acceptance option was selected with regular pigging to mitigate hydrate blockage risks, while also mitigating wax risks, for economic benefits. To optimize pigging frequency, the pigging schedule obtained from wax mitigation simulation reported in the first part of this work [10] is recommended.

Well LM5 had experienced sharp production decline from 30/07/2006, requiring immediate pigging of its connecting lines. Pigging increased gas rate slightly up to 04/12/2006, then declined further till 01/12/2017. The lines connecting wells LM1 and LM2, however, responded better to pigging as illustrated by Figure 5.

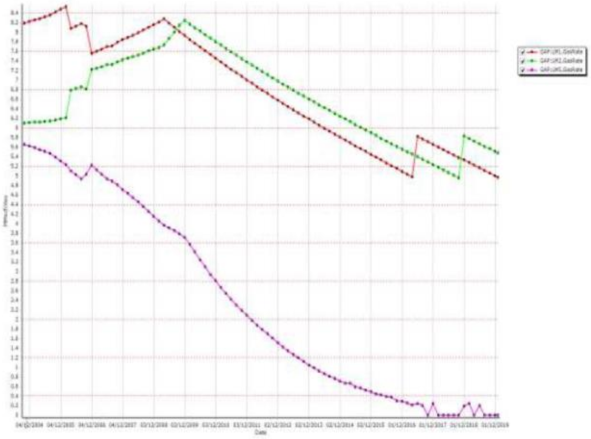

Figure 5. Gas Rate–Production Time plots for Wells LM1, LM2 and LM5 on RESOLVE

Even when production rates declined, they maintained the 5MMscf/d benchmark until the end of the productive life of the field.

Conclusions

This paper demonstrated how flow assurance problems co-exist in petroleum systems, validating some assertions in the literature. It also showed how a single appropriate solution could have synergistic effect on more than one problem using IPM techniques.

Proactive and integrated approaches to wax/ hydrate management in multiphase flow are recommended to enable early detection and mitigation of production issues before escalation. For instance, Well LM5 workover might have been avoided if the issues had been diagnosed and sorted early, thus saving costs and preventing downtime. Ongoing transient simulations and experiments will improve the results of this study.

Acknowledgments

The research was funded by the Niger Delta Development Commission (NDDC) Postgraduate Foreign Scholarship 2015. Coventry University (CU) facilities were used for this research while both authors were there. IPM Suite were donated by PE Limited to CU. They are all appreciated.

Responsibility Notice

The authors are the only persons responsible for the paper content .

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