Intelligent Flexible Pipe Structures for Tie-back Developments

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Abstract

The need for more intelligent pipelines is becoming ever more apparent as future developments are more challenging due to greater water depths, complex flow assurance challenges and longer tie-backs.

This paper presents the results of a study performed into developing a tie-back to an existing field by using flexible pipe structures that carry multiple functions such as active heating, fibre optics and electric and hydraulic control functions.

A major benefit of using these types of advanced flexible pipe structures is that flow assurance challenges such as hydrate formation can be mitigated and monitored on demand.

Brown field developments would benefit from combining multiple functions required for a tie-back into a single structure. The installation campaign can be reduced and is therefore subject to less weather down time. Moreover, a single structure allows for easier integration into existing infrastructures.

The flexible pipe structures required for these types of developments and presented in this paper have been designed within the context of a specific field within the Asia Pacific region using field proven technology.

The key finding of this paper will provide the industry insight towards applying more intelligent flexible pipeline technology for future developments.

Introduction

Flexible pipelines for the oil and gas industry have been around since the 1970’s with several thousands of kilometres that have been manufactured, installed and in operation. With the discovery of deeper and more challenging fields, the need for intelligent pipelines has become more apparent.

This paper provides a brief introduction into flexible pipelines and offers the many options that can be applied to a flexible pipe which makes it intelligent. This will be demonstrated through a technical feasibility study of the expansion of a field already in operation known as the Tui Oil field.

Though intelligent pipelines can take many forms, two significant and proven categories of flexible pipe are known as the Integrated Service Umbilical (ISU) and Integrated Production Bundle (IPB). The ISU, as its name suggests, combines the function of both an umbilical and flexible pipeline. The IPB is essentially the same as an ISU, except for the fact that an IPB has an active heating component as part of its assembly. Both structures are made of a core and an assembly.
Core

The core of an ISU/IPB is a standard flexible structure. Flexible structures are made of several different layers. Each layer performs a different function. The innermost layer is known as an interlocking carcass, this acts to withstand any hydrostatic collapse which the pipe may have to resist. Above that, there is a leak-proof plastic sheath, known as the pressure sheath. This leak proof plastic sheath keeps the bore fluid contained. The pressure vault acts to withstand the internal pressure of the bore fluid. Then there are two sets of armour wires, these are cross-wound for torsional stability. These wires take any tensile loading which the flexible pipe experiences. The final layer in a standard flexible pipe structure is a plastic sheath which prevents sea water ingress into the annulus. The annulus is the area between the two plastic sheaths.

Assembly

The assembly can comprise of a bundle of hoses, cables, steel tubes, optical fibres and insulation which are wrapped around the core. Assembly components can typically be used for gas lift, chemical injection, hydraulic lines, power communication cables, heat tracing wires and more. The assembly is held together by high strength tapes and a plastic outer sheath.

Technical Feasibility Study

The application of an intelligent pipeline and its benefits can be demonstrated through a technical feasibility focussed on the Tui Oil Field expansion. As part of this study, tie-back solutions which comprise of a production flowline, umbilical, gas lift flowline and gas export flowline are considered.

The Tui field is situated offshore in the Taranaki basin in New Zealand. It is situated 50 km off the coast of New Zealand. A field which has been in operation since 2007, Tui was New Zealand’s first stand-alone subsea development. As part of its subsea field layout, it comprises of four wells which are linked back to an FPSO.

Figure 1: Tui Oil Fields Development
Design Data

The following data as shown in Table 1 and Table 2 has been provided by AWE. Table 1 depicts the main criteria needed for the design of the flexible structures which in this case is a production flexible flowline, a gas lift flexible flowline and gas export flexible flowline.

<table>
<thead>
<tr>
<th>Data</th>
<th>Production Flowline</th>
<th>Gas Lift Flowline</th>
<th>Gas Export Flowline</th>
</tr>
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<tbody>
<tr>
<td>ID (inch)</td>
<td>9.5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Design Pressure (PSI)</td>
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<td>3988</td>
<td>3988</td>
</tr>
<tr>
<td>Design Pressure (Barg)</td>
<td>307</td>
<td>275</td>
<td>275</td>
</tr>
<tr>
<td>Design Temperature (°C)</td>
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<td>55</td>
<td>65</td>
</tr>
<tr>
<td>Service Life (years)</td>
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</tr>
<tr>
<td>Service</td>
<td>Sweet</td>
<td>Sweet</td>
<td>Sweet</td>
</tr>
</tbody>
</table>

Table 1: Client Requirements for Flexible Structures

Table 2 depicts the functions needed as part of the umbilical design. The umbilical components are part of a previous umbilical design supplied for the project hence each component has been qualified for its function.

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Power/ Communication Line</td>
</tr>
<tr>
<td>1</td>
<td>Dual Hydraulics</td>
</tr>
<tr>
<td>3</td>
<td>Chemical Injection</td>
</tr>
<tr>
<td>1</td>
<td>Spare</td>
</tr>
<tr>
<td>4</td>
<td>Gas Lift Hose</td>
</tr>
</tbody>
</table>

Table 2: Umbilical Functions

Solution

The base case would be to supply these as three separate flexible pipeline structures and one umbilical. The alternative is to combine the functions of the gas lift, production and umbilical into one pipeline known as the IPB resulting in the manufacture, supply and operation of only two pipelines. This will be explained further in the following sections.

9.5” Integrated Production Bundle

The combination of a gas lift, production and umbilical into one pipeline takes the form of an IPB in which the production line forms the core, the gas lift and umbilical form the assembly. The advantages of an IPB in this situation are reduced installation time, reduced complexity of the field and optimised thermal performance.

Reduced installation time and reduced complexity of the field arises from the fact that there is one structure instead of three. Reduced installation time is especially beneficial in this case because the Taranaki basin is known for harsh weather conditions. The reduced complexity of the field means fewer pipes on the seabed and a cleaner subsea field layout. This is advantageous for fields with existing infrastructure. Optimised thermal performance of the pipeline arises from the fact the gas lift
tubes have been integrated into the structure, so where the production line would have the highest temperature, the gas lift would have the lowest and vice-versa. Optimised thermal performance is beneficial as it could keep the production line above a critical value thereby mitigating against hydrate formation.

The cross section of the IPB is presented in Figure 2b. The IPB design is made up of a standard rough bore (with interlocking carcass) structure which forms the core and an assembly. The assembly consists of six thermoplastic hoses, two cables and four steel tubes. The thermoplastic hoses can either be used for chemical injection or hydraulic controls. The cables are used as power and communication cables for the operation of subsea equipment and the 3” gas lift line has been split into four 1” steel tubes. The details of these components can be found in Table 3. All these components are evenly distributed around the flexible pipe for torsional stability and are separated by fillers. Fillers act to keep these components in place as well as transfer any mechanical loading the pipeline may see to the core. Both fillers and components are wound in an S-Z manner around the core of the flexible pipe resulting in torsional stability of each of these components [4].

![3D representation of an IPB](image1.png)

![Cross section of an IPB](image2.png)

**Figure 2a (left): 3D representation of an IPB Figure 2b (right): Cross section of an IPB**

<table>
<thead>
<tr>
<th>Component</th>
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<th>Rating</th>
<th>Purpose</th>
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<tbody>
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<td>350-13-33-06T</td>
<td>5000 PSI DWP</td>
<td>Chemical Injection</td>
</tr>
<tr>
<td>1</td>
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<td>5000 PSI DWP</td>
<td>Chemical Injection</td>
</tr>
<tr>
<td>2</td>
<td>350-19-33-02T</td>
<td>5000 PSI DWP</td>
<td>Hydraulic</td>
</tr>
<tr>
<td>2</td>
<td>350-19-33-02T</td>
<td>5000 PSI DWP</td>
<td>Hydraulic</td>
</tr>
<tr>
<td>3</td>
<td>ECPS 634 BLUE</td>
<td>6mm2 Quad, Screened &amp; Armoured</td>
<td>Power/ Communication</td>
</tr>
<tr>
<td>3</td>
<td>ECRS 634 RED</td>
<td>6mm2 Quad, Screened &amp; Armoured</td>
<td>Power/ Communication</td>
</tr>
<tr>
<td>4</td>
<td>N/A</td>
<td>5000 PSI DWP</td>
<td>Gas Lift</td>
</tr>
<tr>
<td>Type 1, 2, 3 and 4</td>
<td>Fillers</td>
<td>N/A</td>
<td>Load Transfer</td>
</tr>
</tbody>
</table>

Table 3: Summary of Bundle Components
9.5” Integrated Production Bundle – Options

In detailed design, the following options could be applied which are advantageous in terms of cost savings and/ or performance enhancing. These include the following:

- Similar outer diameter components,
- Adding passive insulation,
- Active heating and/ or
- Temperature monitoring.

The use of similar outer diameter components allows the use of one filler type which reduces the manufacturing complexity of the flexible pipe structure. Passive insulation takes the form of strips of synthetic foam which can be added as part of the assembly. Active heating and temperature monitoring will be further discussed below.

Active Heating

There are three alternative methods to provide active heating functionality to a flexible pipeline namely; hot water circulation, the use of heat tracing cables within the armour layer and/or a dedicated active heating section above the core of the flexible pipe. Active heating is useful in cases where hydrate formation is an issue and the bore fluid has to be kept above a critical temperature. It is especially useful for shutdown and restart operations. Each method has its merits and demerits which will be further discussed.

The use of hot water circulation is beneficial as where the hot water is injected; it is warmest where the production line is coldest. However, this method can mean an increase in diameter which is not optimal. This is where active heating with the use of heat tracing cables is advantageous.

Where the heat tracing cables are incorporated into the structure, every few tensile armour wires are replaced by a heat tracing cable. The number and location of these cables depend on the heating requirements which are governed by a number of factors such as water depth, length of pipeline section, bore fluid temperature and critical temperature of the bore fluid. If the design of the flexible is governed by tension, a dedicated heating layer above the core of the flexible pipe can be created. The design of the heat tracing cables itself is unique in the sense that it is a 3-phase star connection circuit which means that the sum of the current phases is nil. Therefore no return cable is necessary [5], ensuring a compact solution.

Temperature Monitoring System

Technip’s system of temperature monitoring is known as the Distributed Temperature Sensors (DTS) system. This system provides continuous temperature measurement along the length of flowline with the use of optical fibres.
Small bore stainless steel tubes are incorporated in the tensile armour layer during manufacture. Every fourth tensile armour wire is replaced by a steel tube sometimes with plastic fillers on either side to ensure structural integrity of the steel tubes. At one end fitting termination, the steel tubes are joined to provide a continuous loop. Post manufacture, the optical fibre is inserted into these steel tubes through a blow down technique. This process involves the use of fluid drag to run the fibre through the control line. A pump pressurizes the system, the tubes provide the drag and the fittings allow fluid to flow through the system directing the fibre in the line. The loop in the termination allows the optical fibre to be inserted one end and retrieved through the other end. This means that there is access to both ends of the optical fibre. Double-ended measurements can then be made with no fibre splicing, thereby increasing the accuracy of the measurements [3].

The DTS principle works through pulses of light which are sent down the optical fibre. The ratio of intensities of the two wavelength separated components of the back scattered light yields the temperature at the point of scattering. The time in which it takes from when the pulse was sent and when the back scattered light returns gives the location of the temperature. As a result, a temperature versus distance graph for the whole length of the optical fibre can be constructed. The principle is known as Raman OTDR (Optical Time Domain Reflectometry).

Graphical User Interface

A dedicated system can be created according to project requirements to facilitate the user interface of the system. This can consist of obtaining raw data along the length of the riser system. This can then be split into critical locations along the length of the riser such as touch down point, gas-lift injection point, and topside. Other functions can be implemented into the system such as alarms in case of detection of cold or hot spots to prevent against hydrate formation and temperature fluctuations in the flexible pipe. More information can be found in [3].

4” Gas Export Line

The nominal option of the 4” Gas export line is a standard flexible pipe structure. However, with the use of intelligent options such as active heating, the need for dehydration of gas prior to export onshore could be revisited. This would be particularly useful for situations where it is not feasible to have an offshore processing facility. Active heating would take the form of electrical heat tracing cables integrated into design of the flexible pipe structure.
Technology Qualification and Track Record

Integrated Service Umbilicals (ISU) have been installed and in operation for a number of years. The current track record stands at 18. Therefore, this section will focus mainly on the technological advances of IPBs and other intelligent technology. A number of tests have been performed to determine the validity of these intelligent pipeline solutions. These take into account the mechanical behaviour of the pipe subjected to installation loads and hydrostatic loads, the thermal behaviour of the pipe due to the integration of active and passive heating, and fatigue behaviour of the pipe.

The first test began in 1998/1999. A test sample was fabricated incorporating active heating by hot water circulation. The sample consisted of a 8” ID flexible pipe with 11 hoses distributed around the core and passive insulation in the form of 30 mm of syntactic foam above. This sample was subjected to several heating and cooling phases. This qualification program resulted in the development of a calibrated software in which the global heat exchange coefficient (U-value) of an IPB can be accurately determined as well as a software that is capable of modelling the thermal and hydraulic coupling of an IPB verifying its performance with regards to flow assurance issues [1].

Then in 2000, a Joint Industry Research and Development Program (JIP) was set up between Technip and participants. This was sponsored by Demo 2000 with the objective to qualify active heating for a flexible pipe. As part of this JIP, two electrical heat tracing technologies were tested. The sample incorporated two designs; namely; heat tracing cables as part of the assembly (dedicated heating layer) and heat tracing as part of the armour wires. The sample was then submerged in water and subjected to more than 10 different heating and cool down simulations. Test results were then used to validate the design of the IPB as well as software used in the design of IPBs.

The JIP also led to the creation of the Distributed Temperature Sensor (DTS) system which was devised in order to monitor the temperature along the length of the flexible pipeline during the test. The DTS system was integrated into the test sample as part of the tensile armour wires as well as part of the bundle layer.

To complement thermal testing, a full scale test was performed studying the behaviour of electrical cables laid in an SZ manner over a core structure. It was found that the dynamic fatigue cycling as well as the heating and cool down phases had no effect on the integrity of the electrical systems. A layer by layer dissection found no significant damage to any of the IPB components [3].

Figure 4a (left) & 4b (right): Previously manufactured IPBs
The JIP paved the way for its first offshore application off the coast of West Africa, Ref [3]. This project is situated in Block 17, 135 km offshore in water depths of between 1200 m and 1500 m. For this project, a quantity of eight 10.75” IPBs were supplied. The IPB designed consisted of six heat tracing cables, thermal insulation, DTS system and 24 gas lift tubes evenly distributed around the core of the IPB. A test sample was manufactured prior to final supply which was subjected to a full scale test campaign in which the crushing, fatigue and thermal behaviour of the pipe was validated. A full scale test was performed in a vertical configuration as this is more representative of real-life conditions.

Since this project, IPBs have also been manufactured for other offshore projects. These include two 10” gas lift IPB risers which have been installed of lengths 1200m and currently, IPB risers and flowlines which are being manufactured in Le Trait.

Conclusion

With the discovery of more challenging fields, the implementation of intelligent pipelines provides a qualified solution for both new and existing fields. These intelligent pipeline solutions take the form of an Integrated Service Umbilical (ISU) and Integrated Production Bundle (IPB) which can incorporate umbilical functions, active heating components and the DTS system.

The key advantages of integrating intelligent options are improved thermal performance, reduced complexity of existing fields/ new fields and minimised installation time. Improved thermal performance can be applied through several means (active heating, passive heating etc.) which is extremely valuable in cases where the temperature of the bore fluid needs to be kept above a certain critical value. The reduction in complexity of a subsea field lay-out and minimised installation time arises from incorporating three different flexible structures (gas lift, production and umbilical) into one pipeline solution.

Though the ISU design has been in service for many years, the IPB is a more recent technology. The IPB is qualified by numerous test programs performed by Technip which validates the performance of its active heating elements and DTS system. The positive results of these test programs have paved the way for its use on offshore projects; the IPB risers have been successfully implemented on two West of Africa field developments and are due to be installed on a project in Brazil.
Nomenclature

DWP – Design Working Pressure
DTS – Distributed Temperature Sensor
FPSO – Floating Production Storage and Offloading
GUI – Graphical User Interface
ID – Inner Diameter
IPB – Integrated Production Bundle
ISU – Integrated Service Umbilical
JIP – Joint Industry Program
ODTR - Optical Time Domain Reflectometry

References