ITP InTerPipe

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The McPIPE™ Extended Cooldown System:

One week (and more) of Safe Cooldown

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1 Introduction

ITP and J. Ray McDermott (McDermott) have developed an insulated flowline system named McPIPE™, based on intellectual property from both companies, that combines excellent U-values (0.5 to 1 W/(m².K) – 0.09 to 0.18 BTU/(hr.ft².°F)) and extended cooldown times of one week or more, an improvement of an order of magnitude over conventional designs.

The McPIPE™ design is based on the ITP insulated pipe-in-pipe design (Izoflex™) that has been implemented on TFE’s Tchibéli field in offshore Congo and that has been selected for Shell’s Bonga development offshore Nigeria (1100 m waterdepth – 3600 ft). The main difference with conventional pipe-in-pipe systems is that this system incorporates a Phase Change Material (PCM) between the insulation and the flowpipe. The PCM stores a large amount of heat during normal operation, and will release it slowly during a production stop. The system is only slightly larger than a conventional pipe-in-pipe (1/2” to 1” overthickness) and can be installed by the existing lay barges using either the S or J lay methods.

The McPIPE™ is an alternative to heat traced systems in that it is the only other system to offer cooldowns of more than 48 hours, with the added advantage of being entirely passive, thus offering a very high degree of reliability.

The extended cooldown of the McPIPE™ enables the development of a range of flexible solutions and procedures for oilfield operation, i. e. ultra long step-outs, brownfield developments with reduced CAPEX and allows hurricane weathering at a reduced cost.

Extensive testing has been undertaken on an internally funded prgram and further experimental tests will be conducted within the scope of a Joint Industry Project.

2 Industry needs and typical applications

The large scale deepwater discoveries of these last years have lead to the development of challenging production schemes, usually based on a large, central production facility (FPSO, TLP,…) linked with up to 30-100 km of insulated flowlines.

A central concern deals with providing the equipment and back-up systems enabling safe shut down of the complete grid in all situations. In case of unexpected production shutdowns the flow assurance system must provide the Operator with sufficient time to put the flowlines in a safe situation, preventing the formation of hydrates that might obstruct the pipeline.

The typical flow assurance philosophies will provide the Operator with a “no touch” time of a few hours (2-6 hours) in which he can restart the production with no further action on the pipelines. This period is followed by a longer duration (10-20 hours) in which the hydrate-prone fluids are circulated out of the production lines and replaced by inert fluids. In any case, and whatever the insulation method, the total duration of the allowed cooldown period does not exceed 24 hours with a U-value of 1 $W/(m^2.K)$ or 48 hours with a U value of 0.5 $W/(m^2.K)$. The short no-touch period only rarely allows bringing in replacement equipment, therefore the production facilities must essentially be autonomous and all important equipment must be backed up.

This induces large payloads on the production facilities (with their collateral financial disadvantages), that are not directly productive. The McPIPE™ has the potential to change the back-up philosophy in oilfield developments which may lead to significant economies in CAPEX.

Also, even in the case of programmed shutdowns, there are gains to be made from extending the cool-down time. For short shutdowns (less than a week) the production fluids can be left in the flowlines. This means that the production losses resulting from winding down the production gradually over the last 24 hours up to the actual complete stop are eliminated. In a typical Gulf of Mexico application, it would mean that the flowlines can weather hurricane-type shutdowns (3-5 days), with no specific operation on the flowlines.

Other typical applications for an extended cool-down technology are brownfield developments where the flexibility of the McPIPE™ system will reduce the requirements on existing facilities. The McPIPE ™allows sequential circulation of new and existing flowlines – simultaneous circulation is not necessary.

3 McPIPE™ lay-out

The McPIPE™ is based on an ITP pipe-in-pipe construction (as used on the TotalFinaElf Tchibéli Project offshore Congo and the Shell Bonga Project, offshore Nigeria) with an intermediate thin-walled liner pipe between the flowpipe and the insulation material. This liner pipe makes up a closed reservoir against the inner pipe into which the PCM is installed.

The system comprises three concentric pipes,

1. the inner pipe is a thick walled pipe designed for containing the wellstream pressure,
2. the intermediate pipe is a thin-walled pipe welded to the inner pipe at its extremities, this is just a container for the PCM
3. the outer pipe is designed for mechanical performance for both installation and operation activities

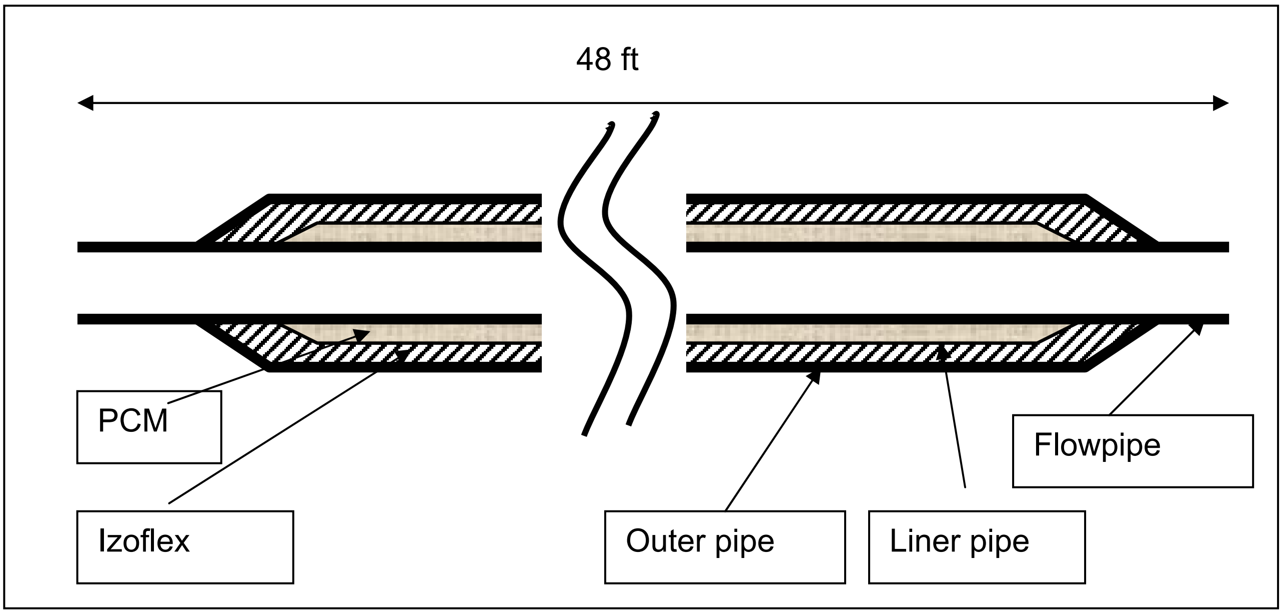

Figure 1: McPIPE™ schematic lay-out

Offshore, the flowline is made up by welding the inner pipes of each quadjoint together in the J-lay tower, and then installing a thermally insulated sleeve (proprietary ITP design) over the weld to secure both thermal insulation and mechanical strength at this location.

It is not necessary to include PCM at the field joint location, because current industry knowledge on hydrate formation shows it will not have a negative impact on the flow assurance performance of the system. This point is discussed in more detail below, para 4.3.

The McPIPE™ system offers an innovative and field proven technique for deepwater field developments. This pipe-in pipe system is unique in that:

- Local content is used during the fabrication process
- The need for centralizers are eliminated
- A single weld is required for field joints
- Insulation material integrity is maintained
- Lay tension can accurately be determined for the system

3.1 PCM selection

3.1.1 PCM characteristics

The design criteria governing the choice of a PCM are the maximum temperature of the wellstream and the critical temperature under which flow assurance can no longer be guaranteed. The critical temperature is generally in the 19-22°C range, and it is therefore sound engineering to choose a PCM with a melting point slightly above this temperature.

There are two families of PCM phase change materials: hydrocarbon based and mineral based. The hydrocarbon based materials are of the paraffin or long chain acids type (C16-C20) and have the advantage of a high temperature tolerance and the possibility of adjusting melting temperatures. From a heat storage point of view, they are less efficient than mineral based PCMs. Hydrated salts, which are the most cost efficient PCMs, will release 6-700 MJ/m^3 for a temperature variation between 40°C and 20°C, against only 300-450 for hydrocarbon based PCMs. As a comparison, the equivalent volume of steel will release less than 75 MJ over the same temperature range. The results presented herebelow employ a hydrated salt PCM with a phase change temperature of 26°C.

3.1.2 Ageing

The preferred PCM offers the advantage of being well known both in the oil industry (brine for drilling) and in the food industry (coolant in refrigeration installations). Its ageing properties are therefore well documented. A specific test programme implemented by ITP and JRMcDermott, confirms that the encapsulation of the PCM between the flowline and the intermediate liner pipe reduces interactions to a very low level.

Furthermore, thermal cycling of the PCM by the manufacturer has shown that the thermal performance is unaffected by more than 4000 cycles. This is more than a PCM will ever experience under oilfield conditions: given the cooldown duration of one week or more, it is highly unlikely that a McPIPE™ will undergo more than one full thermal cycle per month over the field life, that is 240 cycles for 20 years.

3.2 Insulation material selection

3.2.1 Identification

Supported with its design & fabrication experience (over 45 miles (75 km) of double wall pipe already operating in the North Sea and 15 miles (25 km) operating in the Gulf of Guinea), the consideration of all the aspects of design and fabrication leads ITP to conclude that, to secure the design and cost aspects, it is generally advantageous to minimise outer pipe diameter and therefore to use the best industrially available insulation material which combines high thermal performances and good mechanical behaviour.

The benefits are straightforward :

- less steel
- less steel related works (welding etc.)
- no need for centralizer

- less offshore field jointing works
- easier fabrication process (easier handling etc.)

Additional benefits in terms of mechanical design are :

- less bending stresses for the same radius of curvature;
- better collapse resistance;
- built-in on-bottom stability.

3.2.2 Izoflex™ and its thermal performances

Classical insulating materials draw their efficiency from their opacity and their ability to imprison air (or other thermally efficient gas) and keep it from installing convection cells.

The only way to go further in thermal efficiency is to reduce gaseous conduction. Physically this means preventing gas molecules from colliding. This is achieved with a material with cell sizes smaller than the mean free path of the gas molecules, so that they spend their time rebounding on solid walls instead of interacting.

This is the founding principle for the Izoflex patented microporous thermal insulation which outperforms conventional insulation by a factor between 3 to 10 as demonstrated by the following tables based on data obtained from both full scale thermal tests performed during product development and regular quality control testing during production.

Material	Typical thermal conductivity $BTU.hr^{-1}.ft^{-1}.°F^{-1}$	Typical thermal conductivity mW/(m.K)
PP syntactic	90.10^{-3} – 110.10^{-3}	150-200
PU syntactic	60.10^{-3} - 90.10^{-3}	100-150
Glass fibre	18.10^{-3} - 24.10^{-3}	30-40
PU light foam	11.10^{-3} – 18.10^{-3}	20-30
IZOFLEX™	4.10^{-3} - 6.10^{-3}	5-7

Table 1 Thermal properties of conventionally used insulating materials.

Regular thermal tests performed for quality control during the Tchibéli Project, (100 assemblies tested out of 2100) demonstrated a U-value of 0.4 W/(m$^{2\cdot}$K) in the mainline (0.072 BTU.hr^{-1}.ft^{-2}.°F^{-}1) with only 15 mm (0.6'') Izoflex™ around a 10" pipeline.

The Izoflex™ material also shows excellent mechanical behaviour against compressive loads (there are no cells that may collapse and make the material creep).

In particular this means that the material has :

- resistance to vibrations;
- resistance to compression (to withstand laying loads and even hydrostatic pressure);
- resistance to high temperatures for HP/HT field developments (the core material can withstand up to 900°C).

3.2.3 Combination of PCM and insulation material

The combination of PCM with an insulation material allows the separate optimization of the in-flow efficiency and cooldown performance of the pipe system. A typical ITP PiP design will offer a cooldown time of 1-2 days, and any duration in excess of that will depend on the amount of PCM that is designed into the system.
In order to compare, calculations have been carried out for three systems of identical size: a McPIPE™, a conventional PiP insulated with Izoflex™, and a PU insulated PiP.

Pipe insulation type and thickness	U-value	Maximum stepout – reduced production [1]	Cooldown time
McPipe: Izoflex+PCM (17 mm + 17 mm)	0.5 W/(m².K)	30 km (18 miles)	7.4 days
Izoflex alone (34 mm)	0.25 W/(m².K)	60 km (40 miles)	2.5 days
PU foam + PCM (17 mm + 17 mm)	2 W/(m².K)	7 km (4.5 miles)	1.8 days

Table 2: Comparative thermal performance of various PiP systems.

Three conclusions can be drawn from this table.

- The McPIPE™ provides a large operational safety margin against unexpected shutdowns even in the case of a degraded production scenarios where the oil is flowing at only 1 ft/s.
- The large stepout allowed by the highly insulated conventional PiP is not enough to ensure flow assurance as the transit time is of the order of the cooldown time: the window for decision making is reduced to a few hours and other hydrate inhibition strategies will have to be implemented, for example continuous methanol injection.
- Associating a PCM with a less efficient insulation material (PU foam) is of little interest because the heat leaks rapidly out of the system: a conventional Izoflex™ insulated PiP of the same size will be both better insulated, allow longer step-outs and be of a simpler construction, all of which are conducive to producing more hydrocarbons from further away from the processing facility.

4 Salient features of a McPIPE™

4.1 Typical performance

Given that an efficient use of a PCM necessitates a high-performance insulation, a McPIPE™ will necessarily be insulated to a level of 0.7 W/(m².K) or better. The minimum practical thickness of PCM will be of the order of 10 mm, leading to a minimum cooldown time around 4-5 days. For less demanding applications, the specifications can be met with conventional insulated PiP.
The overall size of the system is compact: for a deepwater application, the outer pipe will be about 4”-5” bigger than the flowline (i. e. 8”/12” pipe arrangement, 10”/16”, 14”/18” etc.). This provides cooldown times of a week or better, along with a U-value of 0.5 W/(m².K).

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[1] Distance over which the oil temperature decreases from 55°C to 35°C. 8” flowline, producing at a reduced rate of 0.3 $m.s^{-1}$ (1 ft/s - 4,600 bbl/day). Nominal flow rate: 15,200 (bbl/day).

4.2 Long stepouts

For long step-outs, a key figure is the ratio between the transit time and the cooldown time offered by the system. It should be at least 2 or 3 under nominal flow conditions to allow a sufficient margin for decision making in case of emergency shut downs and production at a reduced flowrate. For example, if there is a transit time of one day at the nominal production rate and a cooldown time of one day also, there is no margin for stopping the production or even for allowing a reduced flowrate – the wellstream will arrive below the critical temperature at the production facility. Thus, the maximum stepout has to be calculated for a reduced flowrate, e. g. 0.3 $m.s^{-1}$, against a nominal flowrate of 1 $m.s^{-1}$.

The McPIPE™, by allowing a separate optimization of cooldown time up to 10-15 days is compatible with the safe operation of 100-160 km flowlines (60-100 miles) that have typical nominal transit times of 1-2 days (6 days in degraded mode). This is today the only way to transport hydrate-prone crudes over such long distances

4.3 Cooldown at the Field joint

The field joint is a location where heat will draw off from the pipe at a higher rate than elsewhere because of the leak path along the welded connection between inner and outer pipes. Typically, on quad joints, the effect of the Field joint on the overall thermal performance will be of the order of 5-10%, i.e. if the mainline thermal performance is 0.5 $W/(m^2.K)$, the overall thermal performance including the Field joints will be 0.52 to 0.55 $W/(m^2.K)$.

However, having short, cooler sections every 48 m (every quadjoint) does not impair the thermal performance as assessed by the overall U-value. Current knowledge of hydrate formation shows that hydrates do not form in quantities during the cooldown while the fluids are still; rather, they will appear during a start-up phase when the fluids start flowing and the subcooled species mix[2].

In the case of the McPIPE™, this risk is averted because, upon start-up, the cooler fluids from a short Field joint section, will move into a long warmer section which will increase its temperature. In parallel, the cool section at the Field joint will be warmed by the fluids from the mainline. A worked-out example for the fluid is presented in the graph below, showing that it will see its temperature oscillating slightly as it moves from cold to warm section, on to the next Field joint section, etc. The result is that the oil temperature will oscillate around an average temperature about 1 °C below the mainline pipe temperature. Therefore, with a PCM phase change temperature of 26°C, 3-6°C above characteristic hydrate formation temperatures, the subcooled fluids will melt out harmlessly.

The calculation hypotheses are quite conservative because the following have not been taken into account:

- temperature increase in Field joints as the oil moves along
- presence of water, which is necessary for hydrate formation, increases fluid heat capacity
- longitudinal mixing or heat conduction which will even out temperatures
- heat of formation for the hydrates,

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[2] Y. F. Makogon, Hydrates of Hydrocarbons, 1997, PennWell Publishing Company.

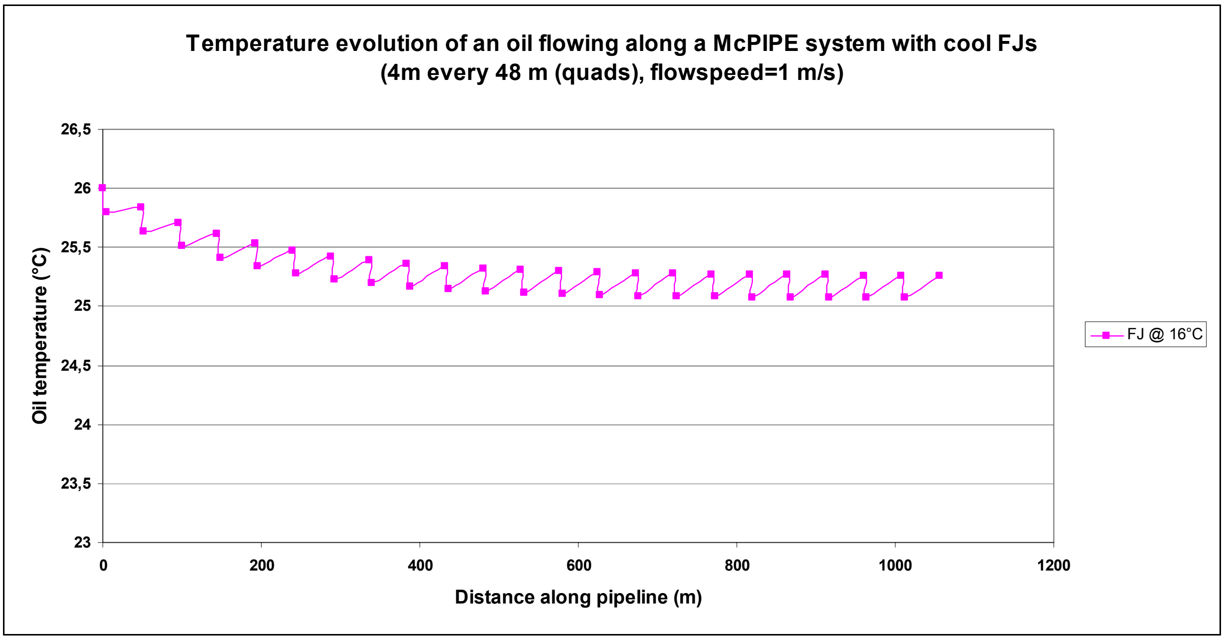

Figure 2: Calculated thermal evolution of oil flowing into a McPIPE™ system at start up. Turbulent flow has been assumed.

4.4 Heat-up and cooldown

An often raised question with the McPIPE™ system is the time required to heat the system, because it is sometimes believed that this duration is symmetrical to the cool-down time. This is not the case, because the heat flows are vastly different in the two cases. As an example, for a 12” flowline, designed for a 50,000 bbl/day production, heat losses during cool-down will be 10-15 W/m assuming a U-value of 0.5 W/(m².K) or 200-300 kW for a 20 km flowline, whereas heat input from the well during production will be more than 10 MW (a factor of 50) with a wellhead temperature of 65°C (150°F).

The warm-up time is therefore much shorter than the cooldown time. For the above pipe it will be less than a day, when the cooldown time is of the order of 1-2 weeks.

4.5 Fabrication and Installation

Local content, welding time and centralizers have been key issues during fabrication and installation for many conventional pipe-in pipe systems. The McPIPE™ system design and installation requirements are engineered with particular attention to:

- Onshore fabrication
- Quad joint
- Field joint
- Lay method

These areas under discussion have been addressed for McPIPE™ to achieve a cost effective system, that maintains standard mechanical design requirements, such as B31.4 and B31.8 and API RP 1111 and to ensure installation avoids falling on the critical path for floating host installations.

The McPIPE™ system utilizes a conventional and simple onshore fabrication that allows a high productivity process. The McPIPE™ system can be installed with the use of quad or double joints. The onshore fabrication for these stalks is typical of any load out for pipe in pipe systems. The inner, intermediate and outer pipe is prepared at a welding prep station, the J-lay collars will be welded and both the intermediate and outer pipes will undergo swaging with the ITP patented machine. All processes involve local content and guarantee a technology transfer to the area. Each quadjoint is a fully compartmented providing an added safety against thermal performance loss in case of an accidental breaching of the outer pipe.

A further advantage of the production process is that it allows thermal testing prior to load-out of as many pipes as required by the operator. ITP has implemented procedures to individually test pipes selected at random during production. During the Tchibéli Project 100 pipes out of 2100 were tested.

The requirements for transportation and installation are that the process is:

- Cost efficient
- Time efficient
- Short assembly time for field joint
- An accommodating installation method

By nature of the excellent u-values the system can achieve, the McPIPE™ is designed particularly for deep and ultra deep waters, though the system is not limited to deepwater. Initial installation engineering has been performed McDermott DB 50 lay barge in mind. For installation with the McDermott DB 50 lay-barge the pipes will be manufactured in quadjoints.

The modelling techniques can be used with software such as OFFPIPE. The unique and patented design of the McPIPE™ system allows tension and stress to be modelled straightforwardly and appropriately. This provides a cost savings in both materials and installation as no excessive design conservatism is obliged on the system.

At publish of this paper, the McPIPE™ system is being evaluated under the participation of a joint industry project. This study will include a mechanical evaluation of:

- Distribution of stress on the swaged ends
- The passage of the pipe in the sagbend area
- Maximum bending moment allowed
- Effective tension
- The maximum horizontal allowed once installed

The McPIPE™ field joint is to be protected by a cast in place material such as polyurethane. As a minimum the field joint will:

- Provide adequate thermal insulation
- Withstand installation loads
- be applied in a short cycle time

The field joint for the McPIPE™ system offers advantages in cycle time as it requires only one weld. This converts to a substantial cost and time savings during offshore installation. The field joint is a proven technique that has been performing in the Tchibéli field, West Africa. It is characterized by a combined mechanical robustness, thermal efficiency and laybarge time reduction. Offshore cycle time is typically 5-minutes per field joint.

It is difficult to generalize the McPIPE™ system installation costs because of the interrelationships of costs, depth and U-value. Low U-values require a larger thickness of Izoflex™. Long cooldown times require a larger volume of PCM. Additionally, the depth rating also may require going to a larger carrier pipe diameter to accommodate both the thick outer wall due to stability (weight) and collapse. Therefore, system installation costs will be field dependant.

Studies have shown that other innovative solutions exist but due to complex installation requirements and depth limitations the technology cannot be applied in a cost effective manner. The installation of the McPIPE is straightforward and does not create the delays in installation time as other pipe–in-pipe systems.

5 McPIPE ™ system trials

In order to prove the validity of the McPIPE™ concept and to perform a first fabrication testing, JRMcDermott and ITP have built a full scale McPIPE™ joint.

Inner pipe	219.1 mm (8”) x 12.7 mm WT
Intermediate liner	273.1 mm (10”) x 4.2 mm WT
Outer pipe	323.9 mm (12”) x 5.2 mm WT
PCM thickness	22.2 mm
Izoflex thickness	15 mm

Table 3: Characteristics of McPIPE™ specimen (one joint)

The pipe was tested with an empty inner pipe, which is the most severe cooldown condition because there is no additional heat capacity from the transported fluids.

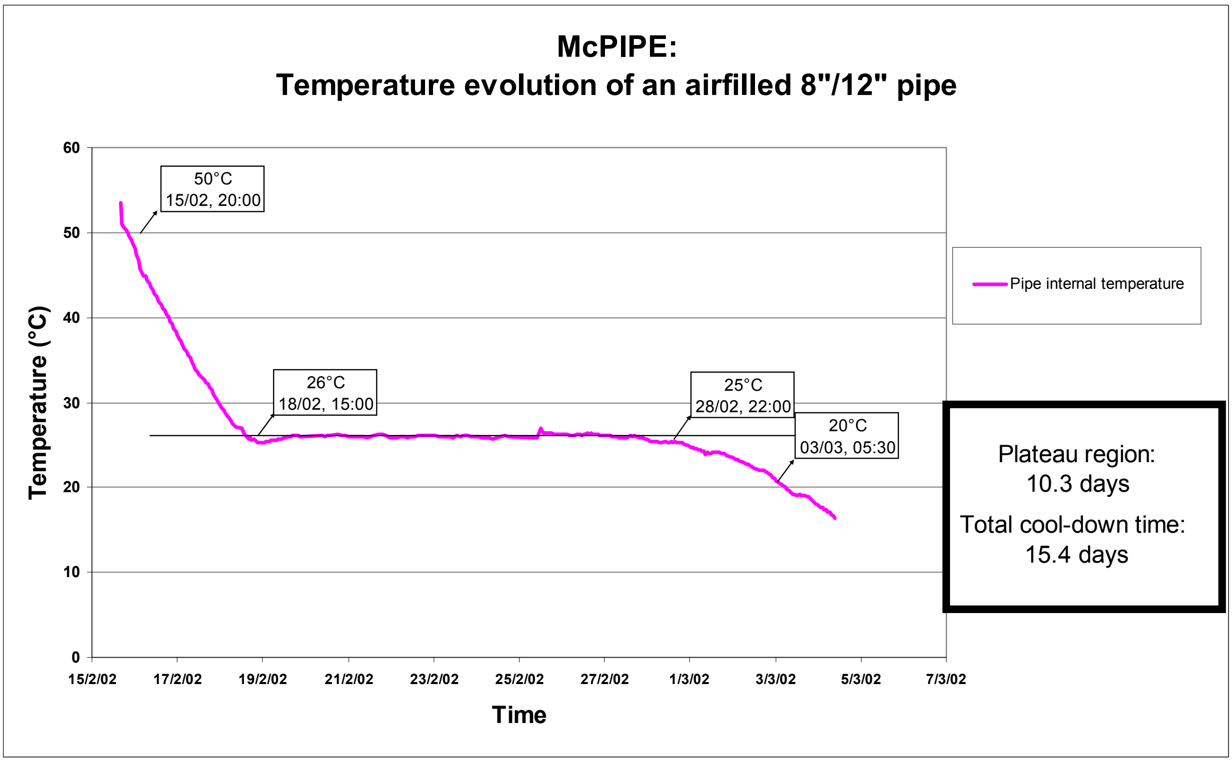

Figure 3: Experimentally measured thermal performance for an 8"/12" McPIPE™

The measured U-value in the pipe mainline section was 0.45 W/(m².K).

The average external temperature during the test was 7.4°C, which means that if the test had been performed in a 4°C environment, the cooldown time would have been 12-13 days.

The pipe was thermally cycled 3 times to provide repeat experiments that all showed a similar performance.

5.1 Further testing

In order to provide more detailed testing of a McPIPE™ system, a JIP administered by GPRI (Global Petroleum Research Institute) has been set up. This allows for the most appropriate vehicle to more thoroughly evaluate the system and tailor it to the specific needs of the oil production community.

The testing is being performed at the Advantica (formerly British Gas) test facility in Spadeadam, UK, on a McPIPE™ section, between October 2002 and January 2003. The test will comprise evaluation of

- heat-up performance
- cooldown performance
- Field joint effect.

The McPIPE™ section is a 24 m long, 8"/12" with a Field joint in the middle, and it is heated by circulating warm water at a rate of up to 20,000 bbl/day.

The external temperature is maintained at 4°C by lowering the test section into a trench filled with refrigerated water.

Other deliverables include a mechanical evaluation, fabrication and repair procedures and a precise cost evaluation.

6 Risk assessment

6.1 Passive system

The McPIPE™ insulation system is completely passive, meaning that there are no moving mechanical parts or components that need to be activated. It therefore offers a high degree of security to the operator.

6.2 Design and construction

The McPIPE™ construction is identical to the ITP designs that have been used or selected for the Tchibéli and Bonga Projects offshore Congo and Nigeria respectively.

The design and thermal performance of the ITP designs have been verified by numerous production tests and two JIP's conducted at ChevronTexaco's Humble, TX, test facility for BP, Shell, ExxonMobil, TotalFinaElf, Marathon and Phillips.

6.3 Materials

All the materials employed have a well-documented industrial history and are field proven. The main construction material is steel, the Izoflex material has now been selected for three major offshore projects and was evolved for the use of the nuclear industry about thirty-five years ago, and PCM materials having undergone extensive development ever since the first oil crises of the seventies, are used in the building and heater industries to take advantage of cheaper night-time electricity rates.

7 Conclusion

The McPIPE™ system, jointly developed by J. Ray McDermott and ITP, is a completely passive insulated system that offers a high level of insulation combined with an unprecedented flexibility in operation because of the extremely long cooldown periods.

It can be installed with a conventional laybarge such as the DB50.

It offers the only the technically credible solution, with existing components and construction techniques, to the deployment of very long pipelines (100km or more) for the transport of hydrate prone hydrocarbons.

Note : McDermott and ITP proprietary rights encompass: PCM insulated subsea pipelines, microporous material application; swaging process; offshore threaded and sliding connection; McPIPE™ system.