

Deep Water Flowlines & Risers: Optimization of the Installed Cost & Thermal Performance

Ex: the Shell Bonga Project

Christian Geertsen, Christophe Paillusseau,

ITP Interpipe, 11 quai Conti, 78430, France

Miguelangelo Thome,

Socotherm, Av Nilo Peçanha 50 Conj 1718, 20044 900 Rio de Janeiro, Brazil

ABSTRACT

For fields where the overall thermal performance requirement is a U-value of less than 3.5W/m²-K or 0.6 BTU/ft²-hr-°F between the wellhead and the topsides, cost-optimization is achieved by using the combination between a very well insulated pipe in pipe for the flowlines (U as good as 0.5 W/m²-K or 0.09 BTU/ft²-hr-°F), which therefore allows to relax the specification on the riser thermal performance and bring it within the feasibility limits of the wet insulation (5L syntactic PP) driving the overall installed cost down.

This architecture has been used for the Shell Bonga project for which the overall specified U-value was initially 2W/m²-K. The optimized solution finally selected by the Operator was to use a pipe in pipe for the flowlines that achieved a U-value better than 1W/m²-K and a 100mm 5LSyntPP wet insulation on the riser ($U_{\text{riser}}=2.5\text{W/m}^2\text{-K}$). The combination of the two allowed making significant cost savings while gaining on operation flexibility due to longer cooldown times on the flowlines.

With the growing number of deeper water field developments, the cost of the flowlines and risers are paramount and this combination of pipe in pipes and wet insulation allows meeting, or exceeding, the thermal performance while ensuring the economy and feasibility of the projects.

KEY WORDS: Pipe-in-pipe; syntactic PP; thermal insulation; deepwater; Bonga

INTRODUCTION

The conservation of fluid flow and the ability to restart production is a prime concern for the operation of a deepwater hydrocarbon production system.

The last 5-10 years have seen thermal management of the wellstream emerge as the single most used engineering tool for preventing blockages from obstructing the production lines.

It is generally recognized that keeping the well fluids from cooling down will prevent paraffin from depositing on the pipe walls during fluid flow, as well as forestall the formation of gas hydrates that are stable forms of ice

occurring when water and small gas molecules (methane, ethane, hydrogen disulfide, etc.) combine at temperatures around 20°C and pressures of 10-20MPa and above.

This overall flow assurance strategy is generally associated with a more specialized treatment of localized elements, such as spools, jumpers, manifolds that are more difficult to insulate efficiently, by injecting chemicals that will prevent the water from combining with the gas molecules.

Apart from these very local considerations, it is of interest to treat separately the risers and the flowlines, both because of the difference in flow characteristics, but also because the construction issues differ significantly.

This paper provides an overview of the issues and explains why two very different approaches to thermal insulation – wet insulation with solid PP materials and PiP with microporous insulation materials – can be technically combined to provide the best overall solution, both from a cost and a risk perspective¹.

FLOW ASSURANCE – THERMAL REACH

There are generally three temperatures of importance to design a hydrocarbon production system

- Well head inlet temperature
- Process inlet temperature
- And minimum preservation temperature for shutdown

The sea-bottom temperature is also of importance as it defines the temperature gradient across the insulating materials, but this is usually a constant 4°C for all deepwater projects, except for some very special cases.

The two first temperatures are related to the system in production and define a “temperature budget”, i. e. how many degrees (of temperature) can be lost during the

¹ Pipe-in-Pipe refers to a double walled pipe with an insulation material that is placed in the annular space. The outer pipe is designed to resist hydrostatic pressures and provide a watertight protection of the insulation material. Wet insulation refers to a single pipe that is insulated with a solid insulation material that can withstand hydrostatic pressures on its own. There is no outer pipe.

transportation of the fluid from the wellhead to the process facility (e. g. an FPSO). This will give a first value for the minimum insulation to be applied to the flowlines.

The latter temperature is related to the appearance of hydrates –the operator will chose to work with fluids at temperatures above the hydrate appearance temperature and allow himself a margin to take into account contingent cooling in case of a production stop.

Operationally, this margin is defined as a number of hours (“cooldown time”) that the operator requires before having to start up a preservation scheme to replace the hydrate-prone fluids inside the flowlines with inert (“dead”) oil. This duration results from a risk-based analysis and is usually in the 12-24 hour range, depending on flowline volume and topside pumping capacity, but it may go as high as 52 hours (author’s experience).

This cooldown time defines another insulation value which may very well be the driving criterion for insulation, especially if the cooldown is to be calculated with a gas-filled flowline, which will not pack nearly as much energy as a liquid-filled pipeline at typical pressures of 100 bars and less.

A last point that also should be considered is the internal cooling of the fluid. This is related to the expansion of the associated gas as it travels down the flowline (Joule-Thomson effect) and the vaporization of hydrocarbon liquids as the pressure decreases in the flowline. These phenomena are very often lumped together under the term ‘Joule-Thompson cooling’. They obviously are most present in the parts of the flowline experiencing the largest pressure drops, i.e. the risers. Thermal insulation has no influence on this effect.

In short, the thermal design of a pipeline has to consider:

1. thermal losses to the environment in flowing conditions
2. preservation time in case of shutdown
3. thermal losses due to internal processes

The different elements the thermal budget can be evaluated as follows:

1. Thermal losses in flowing conditions along the pipeline:

$$T_{out} = T_{sea} + (T_{in} - T_{sea}) \exp \frac{U\pi D}{Q_m C_{p_i}} x \quad (1)$$

2. Upon a shutdown, the pipe will cool with time according to the following equation:

$$T_{final} = T_{sea} + (T_{initial} - T_{sea}) \exp \frac{U\pi D}{H} t \quad (2)$$

3. In the riser section, internal processes will dominate the temperature evolution – typically 6 to 10°C can be lost due to pressure decrease.

For a cylindrically homogeneous construction, the U-value is evaluated according to the following equation:

$$U = \frac{\lambda}{R_{ref} \ln \frac{R_{ins} + th_{ins}}{R_{ins}}} \quad (3)$$

For pipes where different materials are layered on top of each other (typically wet-insulated pipes), the cumulative U-value is obtained by adding the individual U-values of each layer according to the following equation:

$$U^{-1} = \sum_i \frac{1}{U_i} \quad (4)$$

NOMENCLATURES

T_{in}	°C	inlet temperature of wellstream , typically well head temperature
T_{out}	°C	outlet temperature from pipe, for example at foot of riser
T_{sea}	°C	sea temperature, 4°C
T_{fint}	°C	temperature at start of cooldown
T_{final}	°C	temperature at the end of cooldown
U	W/(m ² .K)	Overall heat transfer coefficient for the pipe
D	m	Pipe diameter
Q_m	kg/s	Mass flow rate
C_p	J/(kg.K)	Thermal capacity of wellstream
x	m	distance along pipeline
H	J/(m.K)	combined thermal capacity of 1-m section of pipeline and wellstream
t	s	time from onset of cooldown
R_{ref}	m	Reference radius for calculation of U-value (usually flowline inner or outer surface)
R_{ins}	m	Insulation inner radius
th_{ins}	m	Thickness of insulation
λ	W/(m.K)	Thermal conductivity of insulation

The equations assume homogeneous material properties for the produced fluids and a homogeneous insulation for pipes which is generally sufficient for setting up a first model. More refined modelling will then be used in a later stage of the project.

Equation 1 is usually specified for the system operating at reduced capacity, i.e. at a “degraded” flowrate, such as 50% of the nominal flowrate.

Heat losses per kilometre of 0.5°C or less can then be obtained with the use of high performance insulation materials that provide U-values of less than 1 W/(m².K). The corollary is that if a wellhead temperature of 60°C is expected, and 20°C of reserve heat are required to face a nominal shutdown period of 24 hours, then a thermal reach of the system of up to 20-30 km can be used. With U-values down to 0.5 W/(m².K) as have been achieved by ITP on projects such as Total Tchibéli in Congo, even higher step-outs can be safely allowed.

INSULATION MATERIAL SELECTION

The ITP design is a particularly efficient implementation of a high performance insulation package specifically developed for pipeline insulation. The Izoflex™ insulation provides a thermal conductivity of less than 7mW/(m.K) against 14 mW/(m.K) for the best competing materials such as nanoporous products. This translates into a design requiring smaller outer pipes because less insulation material is needed.

Table 1 : Insulation material comparison table.

Material	Thermal conductivity
Wet insulation	
Syntactic PP	150-185 mW/(m.K)
Pipe-in-pipe	
Fibreglass	30-40 mW/(m.K)
PU foam	25 mW/(m.K)
Nanoporous material	14 mW/(m.K)
Izoflex™	7 mW/(m.K)

Notes:

1) Izoflex material is resistant to compression: no spacers are needed as it will keep inner and outer pipes separated by virtue of its own compression strength. This provides the following advantages:

- The construction is simplified
- There are no spacers with local point loads
- There are no additional heat losses due to thermal bridges at spacers
- There is no risk of spacers slipping and creating local cold points

2) Syntactic material thermal insulation is tailored to project-specific temperature and water-depth requirements by the inclusion of hollow glass micro-spheres the polypropylene matrix. The requirement for hardier spheres at large water-depths (thicker wall) will affect the conductivity negatively.

BONGA PROJECT THERMAL DESIGN

In the case of the Bonga project, an initial design required overall U-values of 2 W/(m².K) for the complete pipeline system, between wellheads and FPSO. This was to be achieved with Pipe-in-pipe in the flowlines and wet-coated insulation for the risers. For the risers, this was a very onerous design requirement. However, the careful consideration of the actual flow situation and the fact that the risers would *a priori* never see a configuration of gas sitting on top of water, but would always be separated by an oil interface due to the vertical configuration, allowed for a refined thermal insulation scheme: The U-value requirement was made more stringent on the horizontal (pipe-in-pipe) portion of the flowlines, whereas it was relaxed on the risers.

On the flowlines, a U-value of 0.9 W/(m².K) was eventually specified whereas it was relaxed to 2.5 W/(m².K) on the risers. This allowed conforming to the required FPSO arrival temperature and cooldown requirements, while providing a system that was more cost-efficient. Another advantage of the wet-insulated risers is that they provide much lower hang-off loads on the FPSO, thus requiring less reinforcement than double-walled pipes of the same thermal performance.

It is worth noting that the selected technology for the pipe-in-pipes is very flexible as regards thermal performance - the very high performance of the employed insulation material (microporous Izoflex) allows a cost-efficient optimization of thermal performances, even at a late stage in a project. Typically, the addition of 1 mm of Izoflex will add 10-15% to thermal performances without changing any of the mechanical calculations.

COST COMPARISON

As the thermal performances of wet-insulated pipes and PiP differ by a factor of at least two, they cannot be substituted on a like-for-like basis. As a consequence, any direct comparison on the basis of thermal performances would be misleading. The two systems provide different services and require different operating environments; they can therefore only be compared as parts of a greater whole.

Also, an important cost element is the offshore installation cost which is highly volatile (especially in today’s tight market) and project-dependent. The implementation of an efficient offshore field-jointing system can provide significant savings. A recent example was the Total Rosa Project where Saipem’s FDS installation vessel achieved lay-rates in excess of 2.5 km/day for ITP PiP in quad-joints.

Some cost elements can however be provided:

Material costs: for the Bonga SCR's, the cost of the wet insulation has been quoted at 350 \$/m (Berti et. al). For the PIP's the main material cost is the outer pipe: at 12" OD x 1/2"WT its weight stands at 97 kg/m.

Then, as concerns assembly of the pipes into double joints, one would think that costs are somewhat less for the wet insulation as only inner pipes have to be assembled, whereas PIP construction also has to consider welding of outer pipes. This is true when comparing identical pipes (i.e. flowlines), but in the Bonga case the comparison would be unfair to the SCR's as these had to be fabricated to tighter tolerances to accommodate fatigue issues, and also because exotic liner materials were included for some sections. This increases prices significantly on a per-weld basis.

In the end, although the wet-insulation is usually more expensive than PiP on an installed cost basis for U-values of 3 W/(m².K) or better, it provides significant savings when used for SCR's. The weight savings for an SCR as compared with a PIP is of the order of 100 tonnes per SCR on Bonga. The lower weight means that less structural reinforcement is needed at the hang-off points, turning into significant overall savings (several 100,000\$/SCR).

CONSTRUCTION

Pipe-in-pipe

In the case of the Bonga project, insulation material thicknesses of 7 mm provided the required performance on the pipe-in-pipes. These were built in the fabrication facility ITP had set up in Dunkirk.

During pipe-in-pipe construction, more than 20 pipes were thermally tested as part of project QA/QC. All were at least 10% better than the project requirement.

One double joint was also mechanically and thermally tested: it was bent to a radius of 100m 5 times and thermally tested afterwards. There was no measurable influence on the thermal performance.

Risers

The risers were insulated with a 102 mm thick 5-layer syntactic PP insulation system that was installed in Nigeria to enhance local content. Socotherm thus managed setting up a high performance insulation facility in a far-off location within the project schedule, no small feat.

Offshore installation

For the installation, pipes were handled as double joints on Acergy's (then Stolt) Polaris barge. The advantage of using a Socotherm system for the risers and an ITP system for the pipe-in-pipes was then particularly important. Both systems use a resin injection construction to provide mechanical and thermal continuity at the field joint. Although the requirements are different for the two

injected resins, it was found that rapidly curing PU-based polymers could be used in both cases. Therefore, the same resin injection equipment could be used for both types of field jointing.

The only requirements were to perform a thorough cleaning and re-calibration of resin mix-ratios at each change-over. This proved a considerable logistic advantage, allowing optimization of barge time.

CONCLUSION

The conclusions that can be drawn from the successful execution of the Bonga project is that thermal insulation should not be considered overall, with a single specification, but that careful consideration to constructional details and pipe configurations (risers are vertical, flowlines are horizontal) allows for a cost efficient optimization of the system, without sacrificing overall performance or heightening the technical risk.

It is further to this venture that ITP and Socotherm are now engaged in an active cooperation to provide both risers and flowlines from a single outlet.

REFERENCES

E. Berti, S. Judd, U. Okonkwo, F. Uralil, *Bonga Production Steel Catenary Risers Thermal Insulation: Pushing the Boundaries of Syntactic Polypropylene System Performance*, DOT Conference 2004, Vittoria, Brazil.