

# **COST-EFFECTIVE THERMAL INSULATION SYSTEMS FOR DEEP-WATER WEST AFRICA IN COMBINATION WITH DIRECT HEATING**

**Allan Boye Hansen**  
Thermotite AS  
P.O.Box 214, 7303 Orkanger  
Norway

And

Augustin Delesalle  
Thermotite AS  
P.O.Box 191, 59760 Grande-Synthé Dunkerque  
France

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## **ABSTRACT**

Long offsets and subsea tie-backs are becoming attractive scenarios for exploration and production of offshore hydrocarbon resources. Flow assurance associated with these field development scenarios is critical.

As offshore oil and gas production pushes into deeper water, the risk of hydrate plugging of pipelines and flowlines continues to grow, as does the cost of remediating any such plugs. Conventional methods of preventing hydrate plugs, such as blowdowns, hot oiling and methanol injection are costly and not entirely reliable. For example, at locations where the subsea manifold is higher than the riser base, or locations where the flowline route has substantial high and low spots to trap gas, the process of venting gas is very complex.

Conventional remediation techniques, requiring pressure blowdown, are also uncertain and it may take months to melt a hydrate plug.

The standard industry practice is to rely on enough passive insulation to overcome both the cool-down over the entire flowline length as well as providing a means of holding the temperature inside the flowline wax and hydrate formation temperatures.

This paper will examine the technical issues regarding use of polypropylene as the bulk material for flowline and riser insulation in deeper waters, particularly the 7-layer system which is used on several projects for deep water in the Gulf Of Mexico (GoM). Also, the paper will describe the prevailing opportunities with combination of polypropylene and direct electrical heating.

## BACKGROUND

The use of foamed Polypropylene as a Sub Sea Insulation System was developed by Norsk Hydro in the mid eighties. The development was carried out in partnership with Neste of Finland.

After a series of tests and prototype fabrication, the thermal insulation based on foamed polypropylene, was ready for the market launch in 1989. The system has since then been used as thermal insulation on major projects in the North Sea and Gulf of Mexico.

The unique system utilises a crosshead extrusion process, which unlike side wrap extrusion lends itself to the application of multi-layers. The first commercial use of the system was for the Oseberg field in 1989.

The technology has been developed to encompass high temperature (140°C) materials, Syntactic PP, and flexible weight coat systems. The unique application procedure allows for any combination of layers, giving complete flexibility in design. Deep-water projects are being developed with steel catenary risers. These, unlike the flowlines, see a considerable amount of dynamic motion during their lifetime. This coupled with waterdepth in excess of 1500m puts additional stresses on any coating system. Design to cater for the waterdepth and dynamic loads consists of a **seven-layer** system (see Figure 1) and shows the typical build-up of the seven-layer PP system for deep water applications.

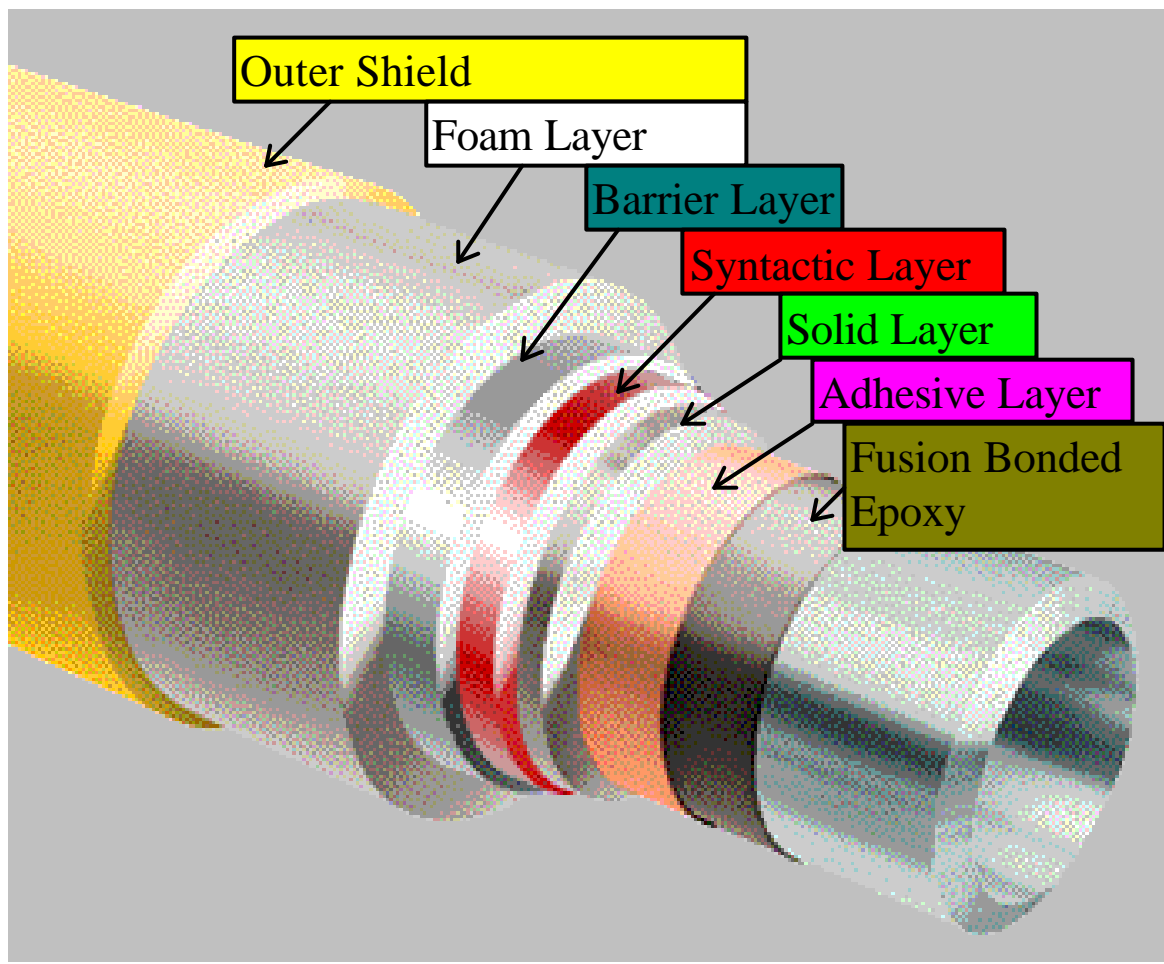


Figure 1. Sketch of a seven-layer PP system

# INSULATION OF DEEP WATER STEEL CATENARY RISERS

As field developments become deeper, the overall requirements of the insulation system becomes more demanding.

The system must be capable of withstanding the hydrostatic pressure with minimum collapse or creep. In addition, riser system must be capable of accepting a degree of flexing over the lifetime of the field. This cyclic loading of the riser must also be carried by the insulation without breakdown or deterioration of the insulation or anticorrosion properties.

Over the recent past new materials are seeing their way into subsea flowline insulation systems. These newer types of material, based on buoyancy technology, tend to be of a rigid construction and not suitable for dynamic applications.

As part of the development programme, the unique technology based on Polypropylene Insulation is suited for both the increased water depth and higher temperatures.

The seven layer PP system of insulation developed by Thermotite, has undergone significant cyclic and static bend testing. In addition, simulated service testing and autoclave verification testing has established operating parameters for the system in excess of 2000m and a maximum operating temperature in excess of 140 °C.

As part of the verification process a sample of coated 5” pipe was subjected to both cyclic and static bend testing. The cyclic test was carried out to simulate the anticipated strains involved in a dynamic riser system. The static test was performed to test the suitability of the construction for installation by a reel vessel.

To date all installations of dynamic riser systems, utilising the Thermotite Seven Layer coating system, have been carried out by the J lay method. This is primarily due to conservative thinking regarding potential increased susceptibility to fatigue of the riser pipe after the reeling process. For flowline applications the reeling process has proved extremely successful.

## QUALIFICATION FOR DEEP WATER

As has been highlighted above the system must be capable of flexing as well as imparting long term thermal insulation properties. To satisfy the long-term insulation requirements simulated service testing has been performed on the system.

This test comprises of inserting a coated section of pipe in an autoclave and pressurising the system to the working hydraulic pressure. The pipe then has hot oil passed through the bore and the external pressurised water is kept at a steady low temperature in line with seabed temperatures. Sensors are attached to the coating to monitor the heat flux and the compression of the coating. Through a number of these tests it has been established that the coating stabilises within 2 tot3 days.

A typical coating design for deep water is shown in Table 1.

Table 1. Typical Coating Design

FBE Coating Layer	Translucent Adhesive Layer	Solid Layer	Syntactic Poly-propylene Layer	Solid Poly-propylene Layer	Foamed Poly-propylene Layer	Outer Poly-propylene Shield Layer
300µm	300µm	9.7mm	25.4mm	3mm	33mm	5mm

## DYNAMIC AND STATIC BENDING TESTS

The following sections describes the test set-up and typical results from the dynamic and static bending tests executed during typical pre-qualification trials on the multi-layer polypropylene insulation system.

### Dynamic cyclic test objective

The aim of the cyclic bend test was to determine if the factory applied and the field joint insulation coating systems would be able to resist a typical load scenario encountered offshore.

The test criteria determined that the coating should not show detrimental distress or experiencing any significant degradation in the material characteristics/properties, the flexural strain reversals developed within the coated rigid risers during their excursions whilst in service.

### Static cyclic bend test objective

The aim of the static bend test was to determine the limiting radius of curvature with the subsequent limiting flexural tensile strains in the polypropylene coating and field joints.

The test criteria determined that the coating should not show detrimental distress or experiencing any significant degradation in their material characteristics/properties.

After completion of the dynamic and static tests the polypropylene coating was removed from the pipe string and field joint and subjected to a further programme of mechanical testing.

## TEST PROCEDURE

A partly coated 12.5m (41ft) long 5.5625-inch OD x 0.75-inch wall thickness carbon steel pipe joint was supplied for all the tests. An uncoated 4m (13.1ft) length of the same steel pipe was also supplied which was welded, on completion of the cyclic bend test, to the coated pipe joint to obtain the length of 14/15m (46/49ft) required for the static bend test.

The factory applied polypropylene based insulation coating system had been applied to the steel pipe over a length of approximately 9.9m (32.48ft) and within which were two field joint areas approximately 355mm (14.0 inches) and 930mm (36.6 inches) in overall length respectively.

The factory applied polypropylene-based insulation coating system was multi-layered with the following specified nominal thicknesses of materials as shown in Table 2:

Table 2. Coating Layer Build-Up for Bending Tests

FBE Coating Layer	Translucent Adhesive Layer	Orange Adhesive Layer	Syntactic Poly-propylene Layer	Solid Poly-propylene Layer	Foamed Poly-propylene Layer	Outer Poly-propylene Shield Layer
300µm	250µm	750µm	30mm	2mm	30mm	6.2mm

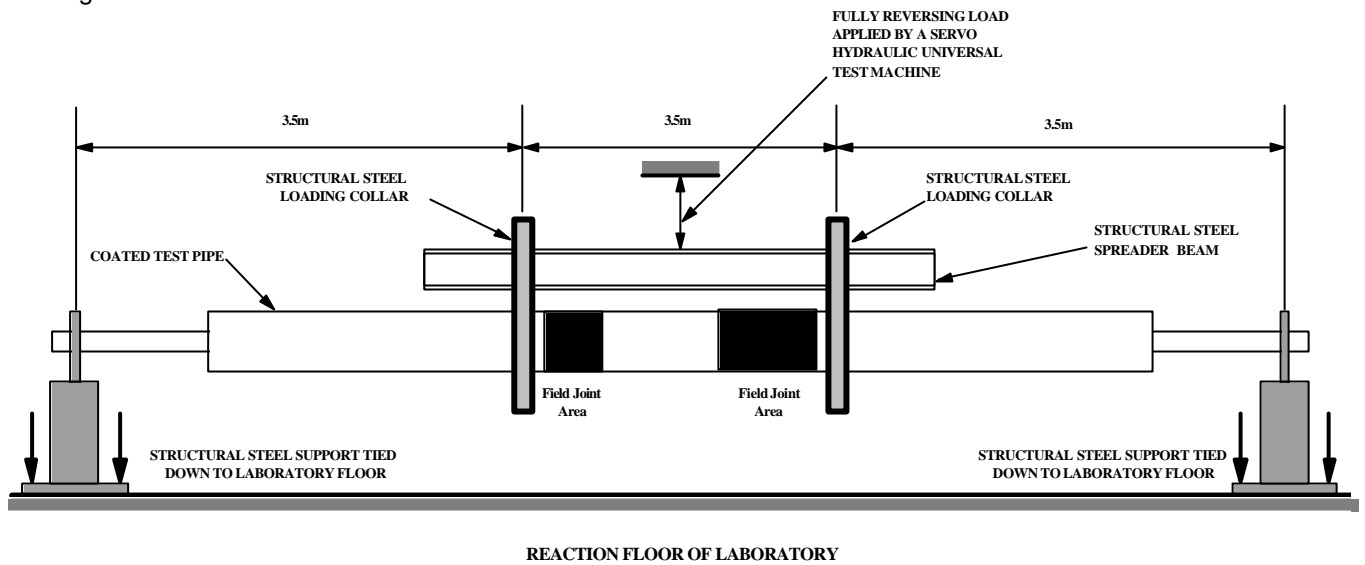
### Cyclic Bend Test

The four-point loading test arrangement, which was adopted for the cyclic bend test, is shown diagrammatically in Figure 3.

In the test arrangement the length of the test pipe between the two loading points was subjected to constant bending moment in the absence of shear forces. The length of the test pipe containing the two infilled field joint areas was located entirely within the region between the two loading points.

The test pipe was subjected to full reverse bending in which the maximum extreme fibre strains developed on diametrical opposite external surfaces of the steel pipe were  $\pm 0.0005$ . The test pipe was tested under displacement control throughout the duration of the test period using a combination of a servo hydraulic controlled universal test machine and the reaction floor of the laboratory. The test

was terminated after the test pipe had been subjected to a minimum of 10000 cycles of reversed bending.



### TEST ARRANGEMENT FOR CYCLIC BEND TEST

Figure 2. Cyclic Bending Rig Principles

#### Results

No significant visible signs of distress were noted on the external surface of either the factory applied insulation coating system or the field joint insulation coating system on the test pipe either during or on completion of the cyclic bend test.

On completion of the test the coated pipe joint was removed from the test arrangement and the uncoated length of steel pipe was welded onto one of its ends to increase the length of the test pipe to the 14/15m (46/49ft) required for the static bend test.

#### Static Bend Test

The test arrangement, which was used for the static bend test, is shown diagrammatically below. This test arrangement has been used extensively to simulate the cycles of reeling and straightening to which a pipeline is subjected when it is spooled and installed on the seabed using a reel ship. The test arrangement is widely accepted by the offshore industry and shown in Figure 3.

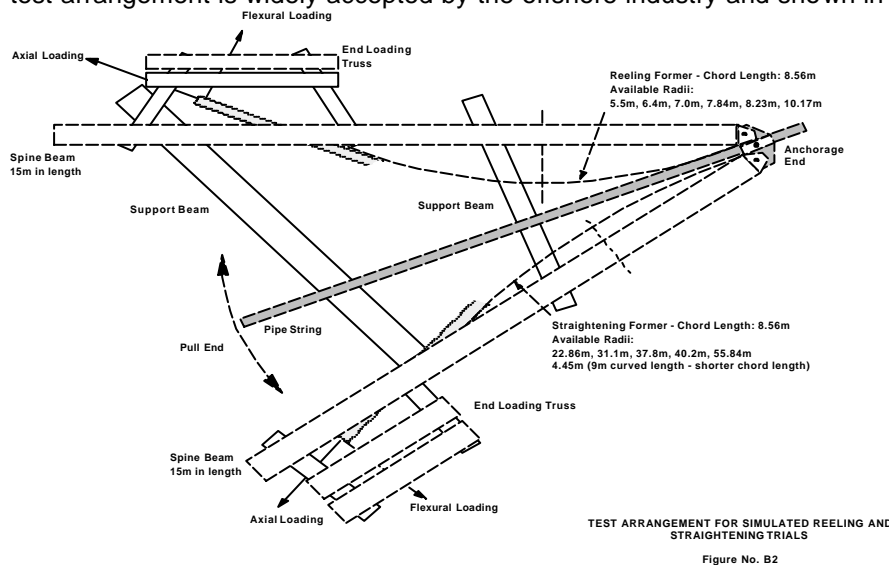


Figure 3. Static Bend Test Arrangement

In this case the test arrangement was used to bend the pipe string to a number of different radii of curvatures. The behaviour of the factory applied and the field joint insulation coating systems when the test pipe was bent around the succession of curved formers is shown below in Table 3.

Table 3. Curvatures and Corresponding Strains

Radius of Curvature of Former	Extreme Fibre Strain in the Steel Pipe	Extreme Fibre Strain in the Insulation Coating System*
55.84m (183.2ft)	±0.13%	±0.25%
40.2m (131.9ft)	±0.18%	±0.35%
31.1m (102.0ft)	±0.23%	±0.45%
22.86m (75ft)	±0.31%	±0.61%

## Results

There were no visible signs of distress on the external surfaces of either the factory applied insulation coating system or the field joint insulation coating system which had come into direct contact with the curved faces of the formers.

## DIRECT ELECTRIC HEATING OF FLOWLINES AND RISERS

Electric heating can be a very attractive alternative for both prevention and remediation of hydrate plugs having potentially high reliability and little adverse operational impact.

Improved reliability of flowlines is also critical in terms of operational costs. Direct heating may improve reliability and substantially reduce operational costs of subsea fields.

Electric heating may also prove effective in preventing or remediating paraffin plugging. In this case it may be possible to reduce capital costs by replacing conventional pigging loops with single heated flowlines.

Two direct heated systems are considered 1) the fully insulated system, requiring complete electrical insulation of the flowline from the seawater, and 2) the earthed current system, requiring electrical communication with the seawater through anodes or other means. For both systems, current is passed directly through the flowline pipe to provide heating.

An earthed current system will be implemented at the Statoil Åsgard field in the North Sea. The system is to be operational from October 2000.

Although direct heating can be applied and operated in several modes, this paper will concentrate on the main task within DeepStar, i.e. the fully insulated (closed) system.

In order to establish some figures regarding the competitiveness of direct heating systems, the project completed a cost comparison study based on the functional requirements (see Table 1) and the dimensioning factors as described in this paper. The cost comparison investigated pipe-in-pipe (PIP) as the existing technology base and used the directly heated alternatives for comparisons.

The items included for the direct heated systems are cable, pipe and coating, installation, topside equipment and other items. Wet mateable connectors are used for the alternatives. The cost comparison looks at a typical GoM flowline for deep-water applications, i.e. 8" OD X65 steel pipe with a U-value of 0.88 BTU/ft<sup>2</sup> hr °F (5.0 w/m<sup>2</sup>

°K). Cost comparison data are shown in Figure 4.

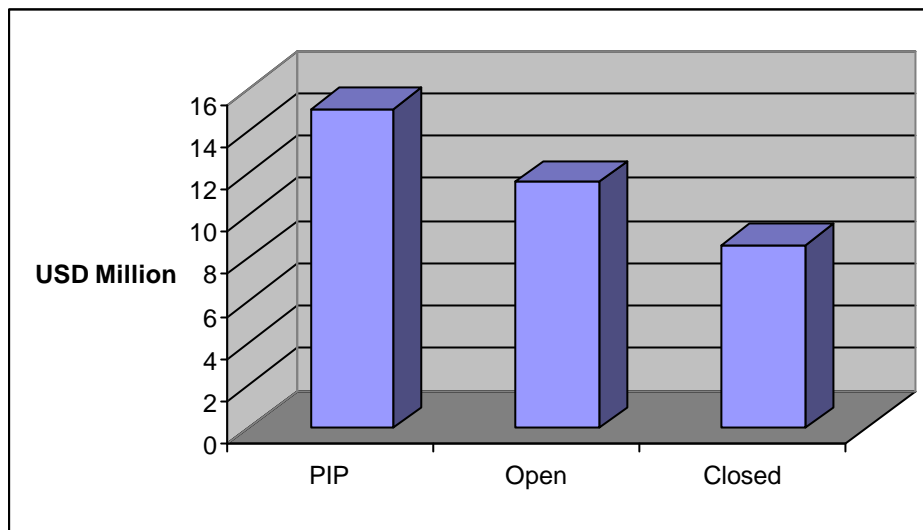


Figure 4. Cost Comparison for Direct Heating vs. Pipe-in-Pipe

## COMPARISON OF DIFFERENT INSULATION SYSTEMS

Polypropylene is not the only alternative for deep-water thermal insulation for flowlines and risers. Table 4 shows a summary with comparisons of different material options for deep water insulation of single flowlines and catenary risers as well as Pipe-in-Pipe (PIP)..

Table 4. Pros. & Cons. of different material options

System	PIP	Direct Heating	PU	EP
Pros.	<ul style="list-style-type: none"> <li>+ thermal performance</li> <li>+ track record</li> </ul>	<ul style="list-style-type: none"> <li>+ active system</li> <li>+ compensate thermal insulation reqs</li> <li>+ reliable</li> <li>+ reeling</li> <li>+ use low cost PP</li> </ul>	<ul style="list-style-type: none"> <li>+ high insulation value (k=0.1)</li> <li>+ good mech. performance</li> <li>+ long-term durable</li> <li>+ reeling</li> </ul>	<ul style="list-style-type: none"> <li>+ high insulation value (k=0.1)</li> <li>+ good mech. performance</li> </ul>
Cons.	<ul style="list-style-type: none"> <li>- difficult to install</li> <li>- high cost</li> <li>- add weight to host</li> <li>- long offsets</li> <li>- no repair if electric heat</li> </ul>	<ul style="list-style-type: none"> <li>- not field proven</li> <li>- repair methods (closed)</li> <li>- power reqs for open system (long lengths)</li> </ul>	<ul style="list-style-type: none"> <li>- high material cost</li> <li>- not suited for direct heating</li> <li>- HSE aspects</li> <li>- hydrolysis</li> </ul>	<ul style="list-style-type: none"> <li>- high material cost</li> <li>- not suited for direct heating</li> <li>- micro-cracking</li> <li>- hot/wet performance</li> </ul>

## SUMMARY

1. The development of polypropylene-based insulation systems has proved a cost-effective solution to sub sea insulation problems.
2. Its inherent flexibility and overall robust construction has also proved it suitable for use on rigid catenary riser systems.
3. With the development of combined direct heating and insulation systems, which are currently undergoing proving trials, will further enhance its use offshore.

## ACKNOWLEDGEMENTS

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