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PROJECT CO-ORDINATOR : Materials Engineering Research Laboratory Ltd. (MERL)

PARTNERS : Thermotite
MCS
Borealis
CSOL (Technip-Coflexip)

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EXECUTIVE SUMMARY

The DeFRIS (**De**epwater **F**lowline and **R**iser **I**nsulation **S**ystems) project has now completed its anticipated 36 month duration.

During this period a thorough review of all aspects of flow assurance issues, to identify the key requirements of thermal insulation systems, was performed. Issues addressed included hydrate and wax control, shutdown time limits etc. An assessment of the requirements for performing flow assurance calculations was also made and target ranges of thermal performance for the thermal insulation systems have been identified. Comparisons of thermal performance with alternative systems are also made as part of this task.

While gathering information from industry end-users, it has been possible to establish a ready network through which project developments can be disseminated. To facilitate this dissemination an Internet based web-site has been established at; www.merl-ltd.co.uk/defris. This provides the opportunity for discussion of issues raised as the project advances and for downloading published summaries/reports.

A further task has enabled a specification of the performance requirements for the thermal insulation systems to be developed. This task involved the identification of the operational requirements of the system. These operational requirements include structural, thermal and mechanical properties. An assessment is also made of the in-place loads to which the system will be subjected. A review of the options for installation and an identification of the installation performance requirements are also a requirement of this task. A full review of all aspects of thermal insulation systems has been performed as the first stage to development of empirical based software tools. These will allow easy and efficient design of global insulation systems. The software tool has been calibrated using the results of the local finite element analysis.

In terms of pipe insulation systems, effort has been focused on the development of two new systems *System X* and *System Y*. These have each pursued a particular requirement of the project; *System X* to extend the deepwater performance of foamed polypropylene systems and *System Y* to explore the use of alternative and novel materials under high temperature fluid conditions. This has been further supported by the work to develop improved design and analysis tools; i.e. to design, develop and install systems for high-duty service applications, and to evaluate existing, and develop improved, screening tests/methodologies.

A number of full-scale trials have been performed for the prototype (novel) polypropylene (PP) system which has been identified in the market as Thermotite TDF. The trials have explored and optimised the manufacturing process parameters and polymer ratios, along with a study of foaming techniques. Materials property tests including comparative thermal property measurement techniques have also been performed. A number of technical papers and journal articles have been published describing the enhancements of the novel PP system, *System Y* work and its findings, test methodologies, and the analysis tool developments.

Each of the partners' technical knowledge and understanding of the area has increased significantly as a result of the project and each has added to their portfolio of expertise, and in each case their product base.

OBJECTIVES OF THE PROJECT

The ultimate objective was to develop fully qualified insulation systems for future deepwater or high temperature fluid development scenarios.

Specific objectives of the project include:

- Establish future requirements and limitations of current systems/materials
- Develop new materials/systems (including examining the possibility of using recycled materials) to provide economical deepwater insulation.
- Develop effective screening test regime to allow long term service life to be predicted, negating the need to commit to costly manufacturing processes.
- Provide effective accelerated ageing regime to increase accuracy of Life Cycle Performance and Prediction.
- Improve system performance as a corrosion prevention layer
- Improve productivity of otherwise marginal wells
- Reduce requirement for forced extraction of oil field fluids due to increased viscosity following loss of temperature, saving energy
- Reduce occurrence of hydrate formation by maintaining fluid temperature reducing work-over costs
- Reduce the risk of unexpected failures by reduction of corrosion, reducing environmental risks and improving safety
- Extend field production/life
- Develop future industry standards which will reduce potential hazards and control costs through standard procedures
- Develop software design tools for deepwater applications

Socio-economic Objectives

Examination of the oil price, in relation to quotas imposed by OPEC, illustrates how powerful this organisation remains in terms of its power of control. This in turn illustrates how the EU economic area is exposed to potentially very high oil prices. It is therefore important for the EU to continue to develop internal oil finds and to locate resources in other non-OPEC areas of the world. These new developments will be predominantly in deep and ultra deepwater areas. This project will contribute to ensuring that EU companies have the technology to develop these deepwater oil resources as an alternative to OPEC supplies.

Societal needs

Supply of oil and gas is inherent to the life style of the European. As conflicts arise in the Persian Gulf, oil supply is threatened. As local fields become exhausted, the price of fuel may rise. As oil becomes more challenging to find, and extract costs go up also, this will directly affect the European household. An established production process based on the use of thermally insulated flowline/riser systems will contribute significantly in reducing the costs of providing the future energy needs of Europe, allowing the EU to become less dependent on other oil producing nations.

Employment, education, training and working conditions

The potential for employment generation exists with all of the partners; Thermotite in terms of the new technology developed and its adoption by the industry; MERL in terms of its capability to perform tests to a newly developed standard test specification. The technological expertise and software tools gained by MCS will be used to expand employment opportunities at their West of Ireland office. This project has resulted in the maintenance of existing staff in a changing industry, which is another positive aspect. Longer term, the ability to benefit from new fields to replace exhausted wells allows the current workforce to be maintained or even extended.

Two of the partners that have benefited from this project are located in peripheral areas of the EU, Thermotite in the West of Norway and MCS in the West of Ireland. This project will allow them to maintain and expand employment, thereby contributing to the economic development of these peripheral areas, which is a key EU policy. In the town where Thermotite has its base there are only 6000 inhabitants. Thermotite has 100 employees, and it is estimated that 500 people in the town are dependent on them. Further, CSO has its spool base in the same town with further employees and dependants. Clearly the growth of these business through projects such as this will help those local communities. MCS and MERL have within the past year undergone a restructuring with plans to expand and grow through employment. Already this project helped both companies support their existing work force and offer recruitment opportunities, MERL has recruited two new employees on the basis of this work.

Project partner summaries

The following summarises the role of each Partner, their respective skills/experience and contact point.

Co-ordinator

Materials Engineering Research Laboratory Ltd.
(MERL Ltd)
Tamworth Road
SG13 7DG Hertford
UNITED KINGDOM
Contact Person: SHEPHERD, Richard (Mr)

Materials Engineering Research Laboratory Ltd (MERL)

MERL, established in 1986, is an independent British research organisation based in Hertford, England. MERL is the leading independent research organisation world-wide that specialises in fatigue life determinations of rubber engineering materials, systems and components. MERL is a member of AIRTO (the Association of Independent Research Organisations), which is in turn a member of EACRO and is involved in a wide range of research activities as well as activities to disseminate advanced technology to SMEs.

Twenty specialist professional technical staff are employed at MERL, with postgraduate research experience in polymeric materials or components. These include specialists in designing and building dedicated test equipment for long term high duty tests. Senior staff at MERL have been responsible for a wide range of scientific publications relating to the oil & gas industry. MERL has an extensive range of laboratory test equipment with state-of-the-art equipment for evaluating insulation materials, including a rig for evaluating thermal conductivity at operating conditions (low temperature pressurised sea water and high temperature fluids). MERL staff also have extensive experience in the design of accelerated ageing tests for life cycle studies.

Participants

Thermotite AS
Gronora Industriomrade
7303 Orkanger
NORWAY
Contact Person: BOYE HANSEN, Allan (Mr)

Thermotite

Thermotite AS specialise in thermal insulation and anti- corrosion protection of pipelines. Situated south of the city of Trondheim, in the Orkanger Harbour, Thermotite AS is located within a purpose-built service-base for pipeline coatings and installation. The Orkanger Base has, in addition to Thermotite AS, an infrastructure for engineering, welding, fabrication and handling of sub-sea linepipe and structures. Thermotite AS has expanded its factory with a unique double jointing facility, capable of handling linepipe up to the length of 26 meter (80 feet). The equipment within the facility has been specially designed and built for handling sophisticated alloys, such as Duplex or 13% Cr, in addition to normal carbon steel pipes. The Thermotite AS coating facility offers complete flexibility, with five independent lines, one for anti-corrosion coating, and four for thermal insulation, allowing multiple projects to be manufactured simultaneously.

MCS
R&D DEPARTMENT
Galway Technology Park,
Parkmore, Galway,
IRELAND
Contact Person: CONROY, John (Mr)

MCS

MCS International is a firm of consulting engineers which provides a range of specialist design, analysis, software and technology services to clients in the offshore oil industry. MCS is an independent Irish company established in 1983, and there are 35 staff at offices in Galway (Ireland), Aberdeen (Scotland), Oslo (Norway) and the US (Houston). The staff of MCS are professionally qualified engineers, and the majority hold postgraduate degrees at Masters and PhD levels. Clients include most of the major oil companies and contractors throughout the world. MCS provides consultancy services ranging from feasibility / conceptual studies right through to detailed design in the areas of floating production systems, flexible risers and flowline systems, tanker loading systems (buoy/turret moored), mooring systems, steel catenary risers (SCRs), drilling risers and production risers. They can offer an integrated design approach for risers and mooring systems.

In support of the above activities, MCS has developed a comprehensive suite of design and analysis software, which is widely used in the industry. Their FLEXCOM-3D package, for example, is regarded as the industry standard program for advanced flexible riser analysis. Leading edge technology is essential for all of MCS's activities and they maintain a high level of R&D. This takes the form of joint industry projects (JIPs), EU funded projects and internally funded developments. A recent JIP which was supported by 20 oil companies and contractors has resulted in the new API Specification 17J and related RP for flexible pipes. Quality is a key part of their service, and the quality system at MCS is certified to ISO 9001.

Borealis AB
444 86 Stenungsund
SWEDEN
Contact Person: ANKER, Martin (Mr)

Borealis AB

Borealis is a major producer of plastics raw materials - namely, polyethylene and polypropylene. These are environmentally superior plastics known as polyolefins. Borealis' main business is polyethylene (PE) and polypropylene (PP) and they are one of the leading producers in Europe and also a significant supplier in key markets around the world. The Borealis Group produces over 3.5 million tonnes of PE and PP each year, and employs nearly 5,100 people. The output from the main manufacturing sites and compounding units is plastics raw material.

Technip-Coflexip Limited
OFFSHORE ENGINEERING DIVISION Stena House, Enterprise Drive
AB33 6TQ Westhill
UNITED KINGDOM
Contact Person: DENNIEL, Sylvain (Mr)

Technip-Coflexip Limited

Technip-Coflexip Limited is a highly integrated solutions provider in the global oil & gas subsea industry, able to offer field-proven, cost-effective solutions. They specialize in all aspects of subsea field development and operations, from engineering to product supply, and including installation, construction and services. Techhnip design and manufacture subsea flowlines, riser and umbilical systems, and have a good track record for providing economical subsea solutions that reduce Operators Capex and Opex.

The Technip fleet claims to be the largest and most advanced in the world of subsea construction and installation. Subsea pipelines are a particularly crucial component of any offshore development. Since installation and operating conditions vary greatly from one project to the next, Technip offer operators best-fit solutions for their field developments, with in depth knowledge of rigid, flexible and hybrid flowlines technologies. Technip's project teams and the products and services they deliver are based on a global workforce of 4000.

SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE RESULTS

Overview

The initial focus of the project was to establish communication with the end-user community in the Oil and Gas Industry: essentially these consist of the major operators. Having established points of contact within such organisations information was collected for the review and definition phase of the project. These contacts have, however, also provided a route for subsequent consultation and dissemination. Dissemination has also been greatly assisted by the opportunity provided to exhibit at Industry Trade Shows by the EC scheme which allowed participation on the European Commission stand at *Offshore Technology Conference 2002* in Houston Texas and *Offshore Northern Seas (ONS) Stavanger Norway*. Numerous contacts were made at these events and have been augmented by the development of a Project website through which final, summary, reports are channelled. A full review and definition of current practices has been completed and materials development and selection is well underway, with attention subsequently concentrated on two systems – known as *System X* and *System Y*. Novel materials and new developments in foaming technology have been examined, including one which utilises extant CO_2 offering zero environmental impact, negating the requirement for chemical foaming agents. Development of software analysis tools from an industry defined specification has been provided. In the laboratory a review of potential screening tests has been performed and experimental tests have been developed on materials provided from trials of *System X* as part of the development process for a suite of laboratory-scale screening tests. *System X* has been further refined and has been subject to a number of trials with associated commercial successes – and has become known as Thermotite Deepwater Foam (TDF).

The following sections summarise the project results from the perspective of each partner.

Materials Engineering Research Laboratory (MERL)

The following section summarises the work carried out at MERL during the three year Deepwater Flowline and Riser Insulation Systems (DeFRIS) EU funded 5th framework project. For MERL, as the co-ordinator and R&D partner, their role was to provide a test and evaluation function – principally for the *System X (PP)* development and an investigative function when exploring alternative systems and materials *System Y*.

Polypropylene system development *(System X)*

In conjunction with the project partners Borealis, Thermotite, MCS and Technip-Coflexip, several test series of pipeline insulation were formulated and extruded at the Thermotite manufacturing facility at Orkanger, Norway. These trials took place as follows:

Trial 1	September 2001
Trial 2	March 2002
Trial 3*	see text
Trial 4	October 2002
Trial 5	May 2003
Trial 6	August 2003

NB. Trial numbers are those associated by MERL and will be used throughout all MERL documents to describe each trial. Trial 3* was run at Thermotite but was discounted due to unsuitable initial test results. Trial 4 immediately superseded Trial 3.

Thermotite Deepwater Foams (known as TDFs), which are blends of a base PP and a high melt strength PP, were foamed and initially tested at Thermotite, Orkanger. Borealis developed the new insulation materials for use within the DeFRIS project. Trial 1 looked at a series of 14 pipes in September 2001. The aim of this trial was to investigate the foaming process and to determine the optimum package for the desired density of the insulation. Trial 2 was run in the first week of March 2002. A total of seven different set-ups were run. Two different PP base polymer grades were used, as well as two different high melt strength (HMS) PP grades, all from Borealis. The effect of different percentage loadings of HMS was tested.

The October 2002 trial (Trial 4) was performed to improve further the insulation foam properties from the March trial. Two pipes were selected from this trial for further analysis, based upon initial test results (Pipes 4 and 8). Trial 5 (May 2003) included full scale bending of pipes with field joints. The trial failed as both the field joint and the coating next to the field joint cracked. Analysing the failure mechanisms led to modifications of the manufacturing process before the next full-scale trial in August 2003 (Trial 6). This trial included pipes with both thin coatings (5 layers), and thick coatings (7 layers), and also included variations of field joint materials. Samples from this trial were subjected to a full scale bending trial successfully performed at a new facility in Orkanger in October 2003.

In addition to these trials, the project was also supplied with an undisclosed ‘competitive’ insulation system to run comparative tests.

Foam properties of all the experimental pipes were measured at several test houses which looked at thermal conductivity, density, mechanical properties, foam structure, tri-axial creep and density.

From each trial, samples were prepared for examination of the following properties:

- Tensile
- Compression
- Thermal constants (thermal conductivity, diffusivity, specific heat capacity)
- Poisson ratio

Different PP base polymer grades from Borealis were used in different combinations to develop the most suitable candidate systems. The partners also investigated analysis of different foaming agents to improve the foam structure. The ideal case would be to produce a homogenous foam structure, which should provide improved mechanical properties, (tensile, compression and creep). Furthermore, a homogenous foam structure is also believed to improve the insulation performance. It was therefore a major aim of this JIP to ensure that a homogenous foam structure was achieved.

Table 1 describes the functional requirements that the insulation needed to achieve and surpass, in order for a system to be deemed acceptable for use in service.

Table 1. **Functional specification for the insulation.**

DESIGN PARAMETER	VALUE
Water depth	<1200 m
Sea temperature	-2 ºC – 15 ºC
Pipe OD (nominal)	273,1 mm
Steel type	X65 (carbon steel)
Elongation at break, 23 ºC	>15%
Tri-axial compression strength at 5% compression	>15 MPa
Tri-axial compression creep at 20 ºC and 12 MPa, 20 years value	<5%
Thermal conductivity	≤0,17 W/mK

The work performed as a precursor, and during these prototype pipe evaluations, allowed a full suite of evaluation test methodologies to be developed providing a more thorough and representative screening/validation process tool. Perhaps most significantly, and critical to the overall performance of pipe coatings, a lab-scale measurement technique for thermal properties was evaluated allowing fully representative samples to be removed from pipe and tested without resort to special sample preparation and manufacture.

Comparison of Trials 1 to 6

Elongation at Break

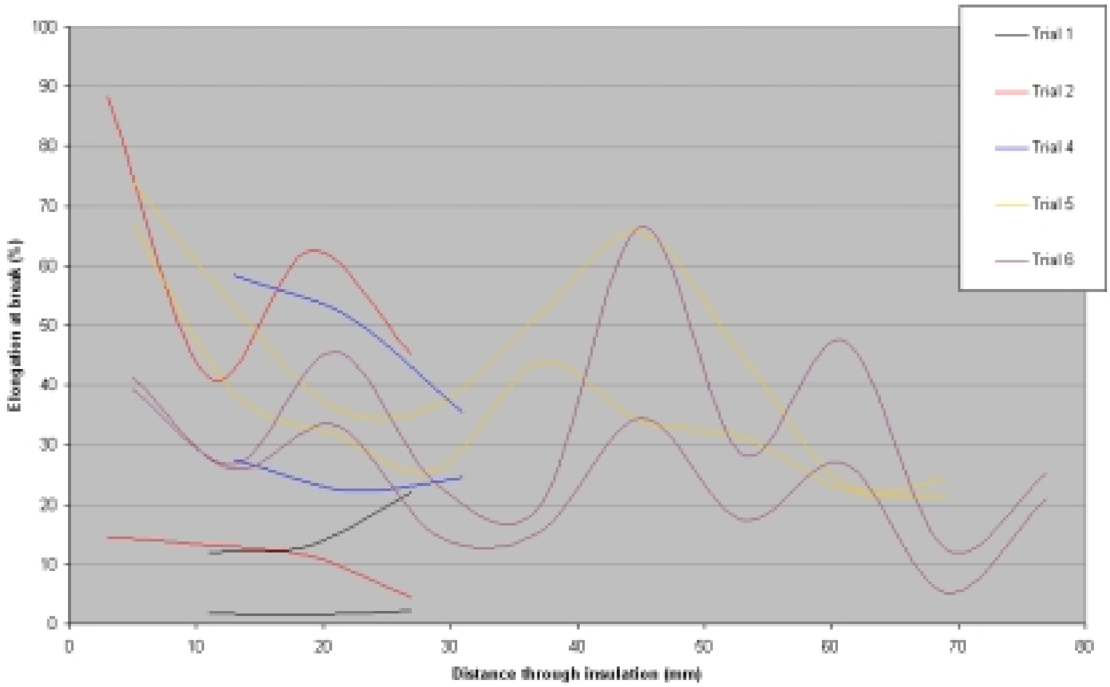


Figure 1: Trials 1 to 6 - Elongation At Break (min and max range) (23ºC)

Figure 1 shows the elongation at break data for all five trials. The data represent the minimum and maximum values measured for the pipes from each trial through the thickness of the insulation. nb. distance through insulation = 0mm, represents the surface of the steel pipe, with all following values being the through thickness properties of each material. The minimum acceptable elongation at break is 15% for this design and it can be seen that almost all of Trial 1 fails this criterion. Trial 2 looked at a wider range of material combinations and a significant improvement in performance was achieved, particularly relating to foam structure and homogeneity. Several results did fall below the target of 15% but could be attributed to experimental spread caused by 'notching' of the samples (due to larger foam pores). Trial 4 focused on the better blends/ratios from Trial 2 and elongation at break results show a further improvement and greater consistency of results.

Trial 5 used the improvements made in Trial 4 to develop a 7-layer system (as opposed to the earlier 5-layer pipes from Trials 1 to 4). Elongation properties throughout the thickness were >15% despite a drop in elongation towards the outside of the pipe insulation. (nb. the outer measurements did not include the solid PP protective layer. This was due to the curvature of the pipe preventing suitable sectioning of the samples).

Trial 6 essentially re-ran the pipes created in Trial 5, although Figure 1 shows that at several points through the thickness the elongation actually falls below 15%. Significant points are either side of layer 5 (solid PP), particularly between layer 5 and 6. This was further highlighted by tensile data taken from samples tested in the hoop direction from within the pipe.

<u>Tensile Strength</u>

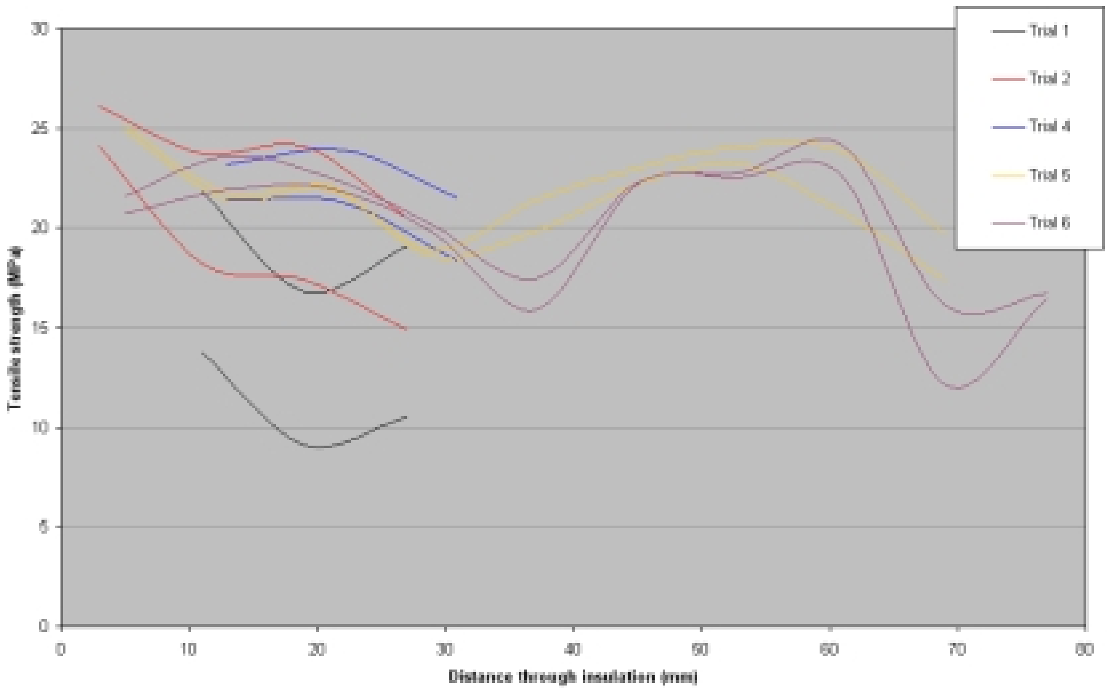


Figure 2: Trials 1 to 6 – Tensile Strength (min and max range) (23ºC)

Figure 2 shows the tensile strength data for all five trials. As with the elongation properties, significant improvements can be seen through Trials 1 to 4, with those improvements being maintained for Trials 5 and 6. Trial 5 was more consistent through the thickness, whereas Trial 6 showed a significant drop in tensile strength at the boundary between layer 4 (PP foam) and layer 5 (solid PP).

<u>Modulus</u>

Figure 3 describes the modulus data for all five trials. Again improvements can be seen through Trials 1 to 4, with Trial 4 almost achieving a target figure of 1.8 GPa. Borealis have developed their PP grades and increased the modulus from 1.2 to 1.8GPa in order to provide a stiffer material and thereby improve the long-term creep performance.

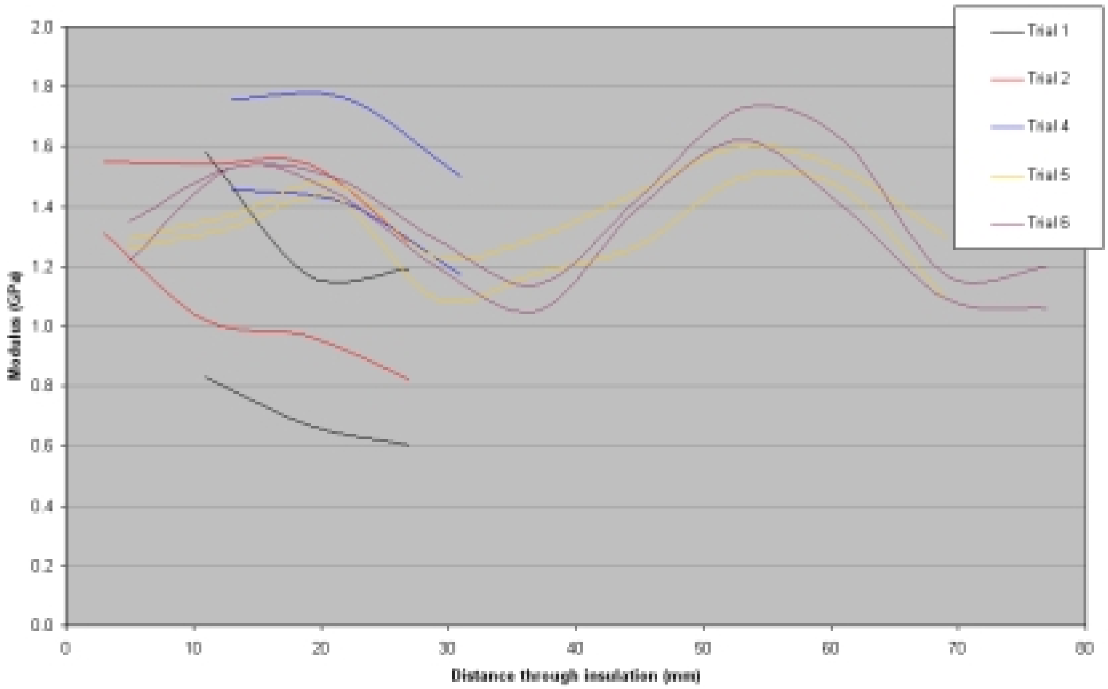


Figure 3: Trials 1 to 6 – Modulus (min and max range) (23ºC)

Trials 5 and 6 are less stiff and are a balance between the improved creep performance and flexibility/elongation for reeling purposes. Layer 6 (PP foam) in Trial 6 does have a significantly higher modulus between 50 and 60mm and whilst this would be suitable for long-term creep properties, it can be seen from Figure 1 that this has a detrimental effect on elongation performance.

Thermal conductivity

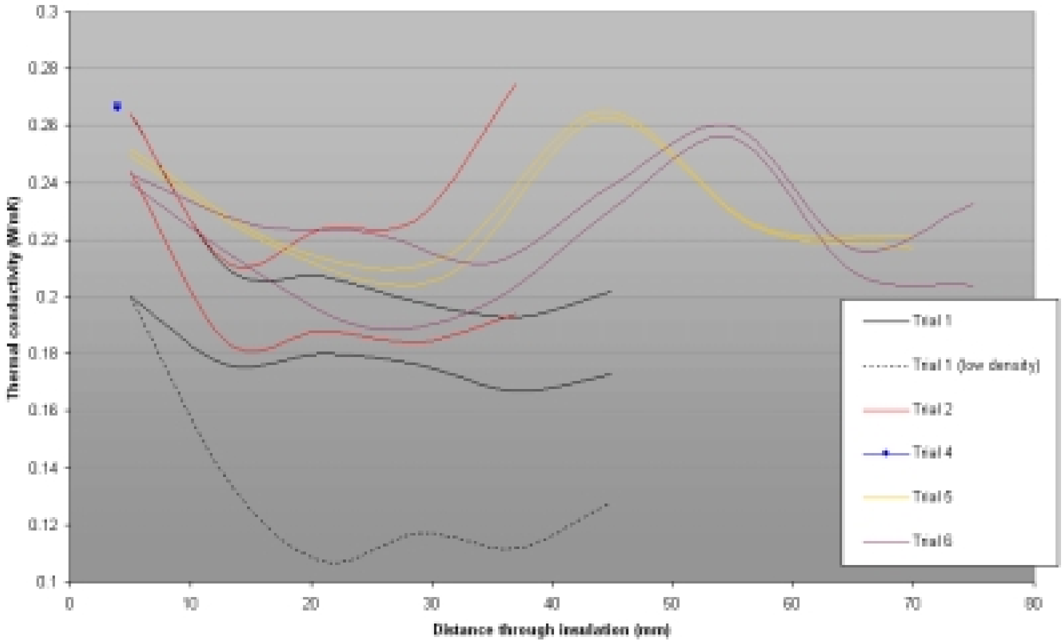


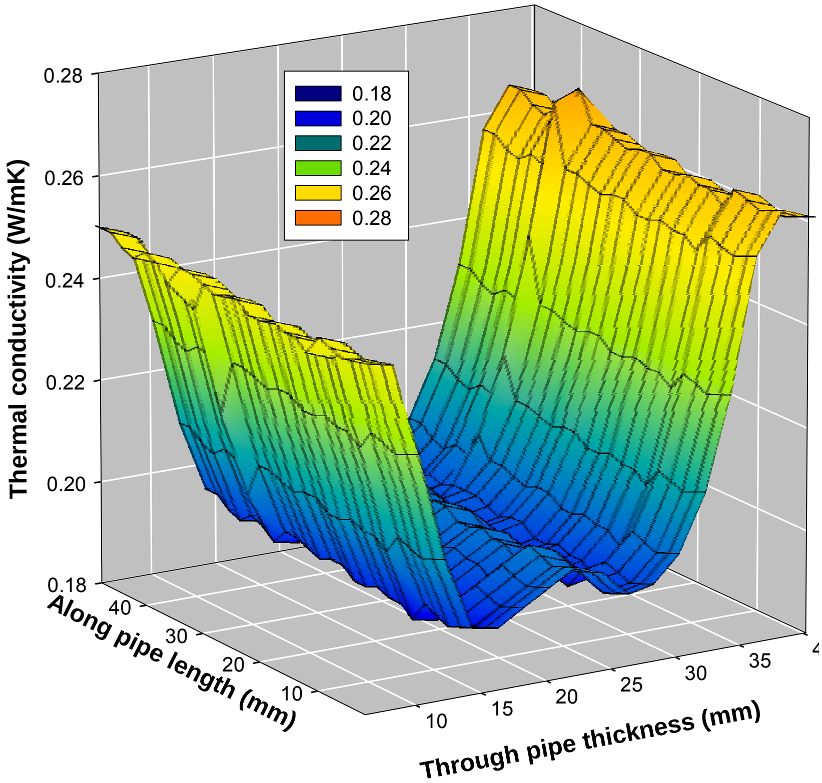
Figure 4: Trials 1 to 6 – Thermal Conductivity (min and max range) (23ºC)

Figure 4 shows the thermal conductivity (k) values for all the trials. Trial 1 achieved significantly low k-values for several of the pipes by creating lower density pipes (approx. 550 kg/m^3), thereby creating good insulative properties but poor mechanical properties. These pipes were deemed to be unsuitable for long-term use as an insulative coating and were not developed further. More dense PP foams (approx. 760 kg/m^3) were also produced that had higher k-values (0.17 to 0.21 W/mK). The thermal values of the pipes from all the trials were calculated using two new thermal analysis techniques. As part of the DeFRIS project brief, different thermal measurement techniques have been examined. As well as more conventional guarded hot plate measurements, this project has also looked at two novel thermal testing methods. The first technique is a high precision infrared optical scanner which makes use of a radiance heating method. Lippmann and Rauen at Thermal Conductivity Scanning (TCS) Schaufling, Germany are using a technique developed by Prof. Dr. Yuri Popov (Moscow State Geological Prospecting Academy). The theoretical model is based on scanning a sample surface with a focused, mobile and continuously operated heat source in combination with infrared temperature sensors. Two temperature sensors are situated in front of and behind a radiant heater, which are used to measure the temperature of the sample prior to, and after, heating.

The results obtainable are profiles of thermal conductivity along the samples, inhomogeneity of thermal conductivity and anisotropy: components of the thermal conductivity tensor for anisotropic solids. This technique was used for Trials 1 and 2.

The second method is a newly available thermal testing facility at MERL Ltd, capable of testing materials used across a wide range of industries. The Hot Disk method is an experimental technique developed from the concept introduced by the Transient Hot Strip (THS) technique, first described in Gustafsson et al. The Hot Disk method is particularly convenient since it is based on a sensor designed to minimise the sample size and maximise the sensitivity of the temperature recording, cf. Gustafsson. The Hot Disk Thermal Constants Analyser is a flexible system designed to measure the thermal transport properties- thermal conductivity, thermal diffusivity and specific heat capacity- of materials from cryogenic to high temperatures. The method is applicable to isotropic and anisotropic materials and in some cases to thin films deposited on substrates. The method does not require large samples, can be used on curved as well as flat specimens and can be non-destructive, unlike alternative thermal test methods. Samples can be tested under a range of temperature, pressure and environmental conditions. Unlike other methods it can be used to measure samples accurately after fluid exposure (e.g., moisture), as the technique does not drive out the absorbed fluid. The system is based on a patented Transient Plane Source (TPS) technique, which can be used to study materials with thermal conductivities from 0.005 to 500 W/mK and covering a temperature range from 30 to 1000K. This technique was used for Trials 4, 5 and 6 and typical data are shown below as figure 4a.

The data show that these trials had k-values higher than the desired 0.17 W/mK. This is most likely due to the new PP materials used in these trials. The standard PP grade has a k-value of approximately 0.22 W/mK, whereas the new materials appear to have k-values of about 0.25 W/mK. This higher conductive material must be accounted for when developing future systems. Lower density foams may be required to achieve the desired thermal conductivity properties.



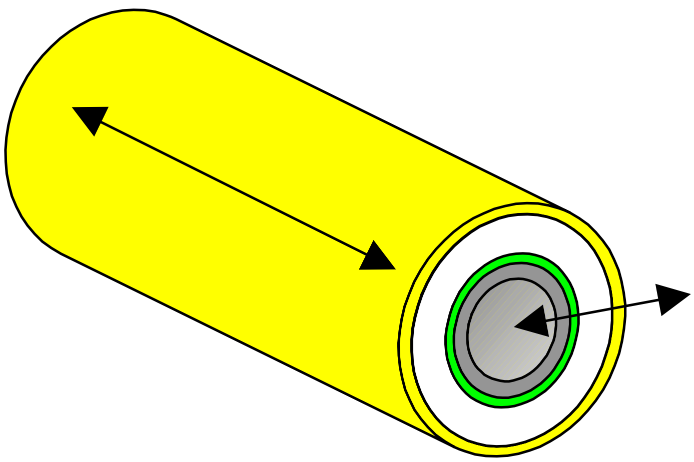


Figure 4a Thermal conductivity data of extruded layer PP foam sample (presented as 3D plot) and schematic of pipe

<u>Trial 6 - Passed and Failed Field Joints</u>

Two different types of field joint were tested during Trial 6. Both a standard field joint material (EA165E) and a newer material (EC166E) were tested. During the simulated reeling trials at Orkanger, the new EC166E field joint material failed whilst the standard EA165E material passed the test.

The two field joints tested in Trial 6 are shown in Figures 5 and 6. The elongation at break for the two materials are significantly different, with the 'passed' field joint capable of achieving elongations in excess of 200% at 23ºC. The 'failed' field joint fell below the desired 15% elongation at almost all points through the thickness. Similar results were seen for the tensile strengths of the two pipes with the 'passed' pipe having strengths ≥ 5 MPa above that of the 'failed' field joint.

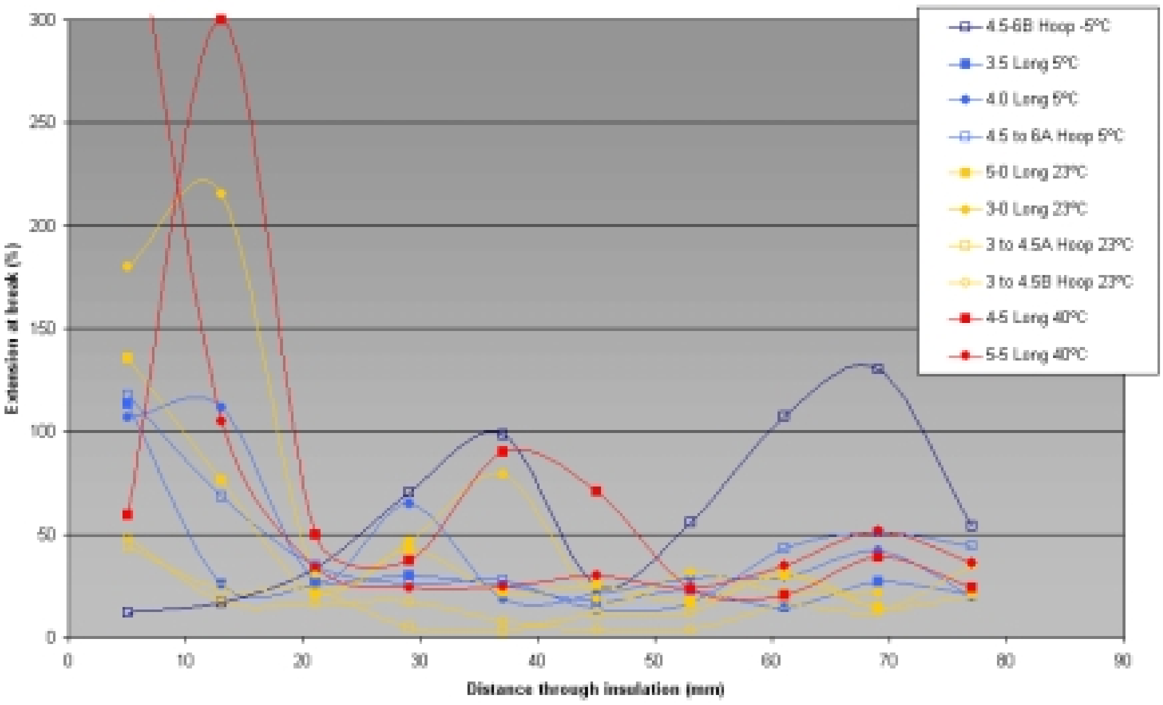


Figure 5: Passed Field Joint - Elongation At Break (-5, 5, 23 and 40ºC)

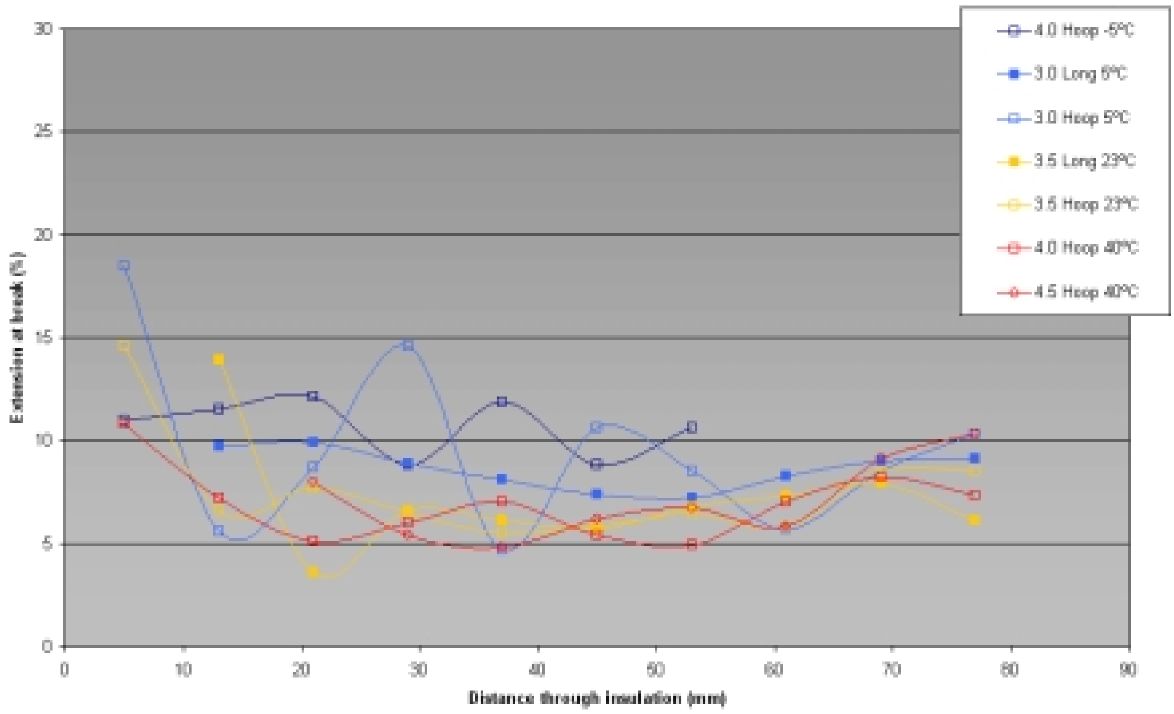


Figure 6: Failed Field Joint - Elongation At Break (-5, 5, 23 and 40ºC)

<u>Poisson ratio</u>

During the DeFRIS project, MERL have investigated methods of measuring the Poisson ratio of the materials under investigation. Initial work using strain gauges proved to be unsuitable for use with PP foams. An improved alternative, using two knife-edge clip gauges, was developed. The gauges were positioned to measure longitudinal and lateral strains. This system was found to be far more flexible than the alternative strain gauge solution, and also proved to be more repeatable.

Figures 7 and 8 show the average Poisson ratio values over strains between 0 and 5%. Samples have been loaded to 5% strain and then unloaded to 0%. This process has been repeated 3 times with Poisson ratio measurements being taken during the loading and unloading. The two figures show the significant effect that loading and unloading has on the Poisson ratio value.

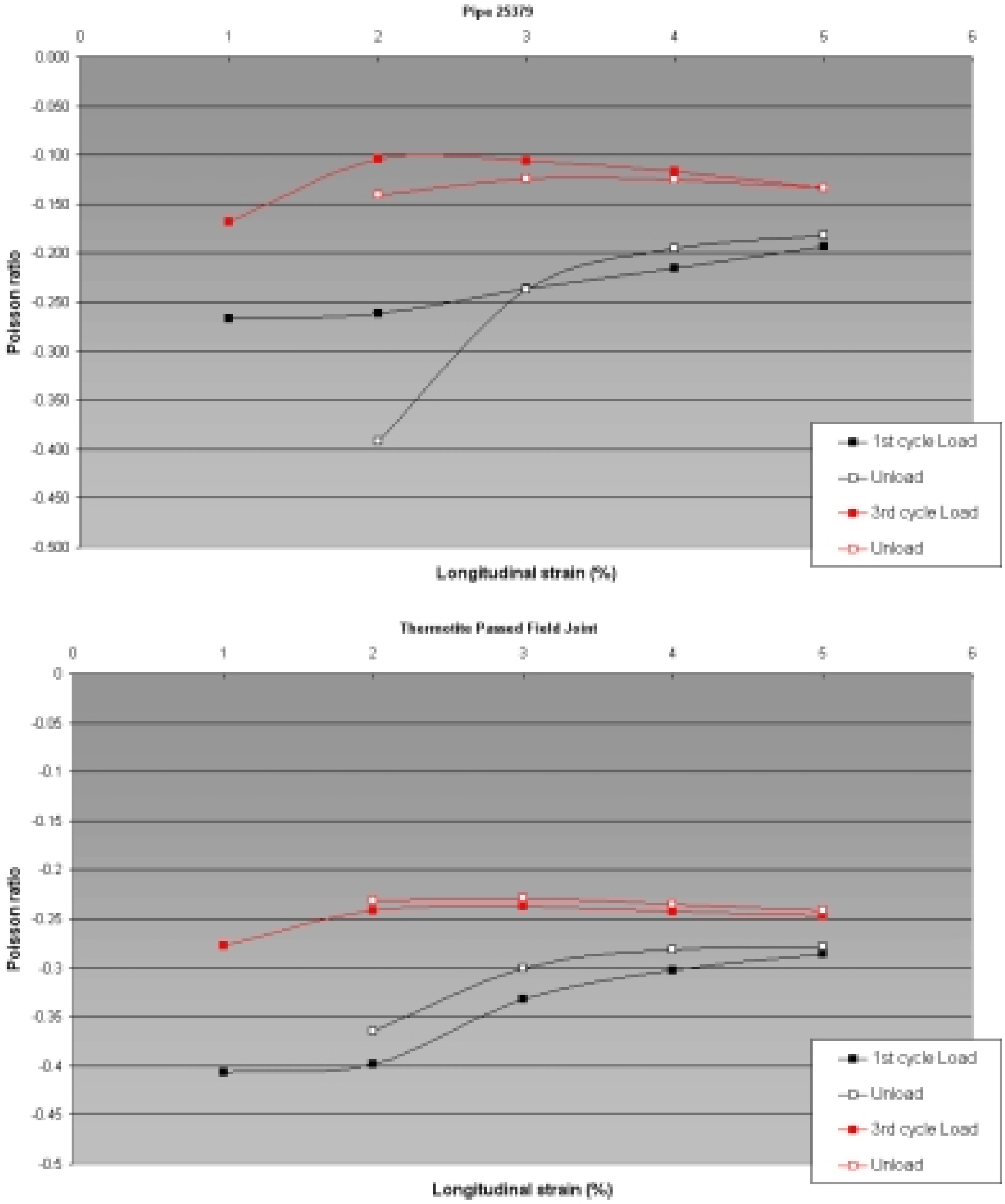


Figure 7a+b: Poisson ratio – Pipe 25379 and Passed field joint

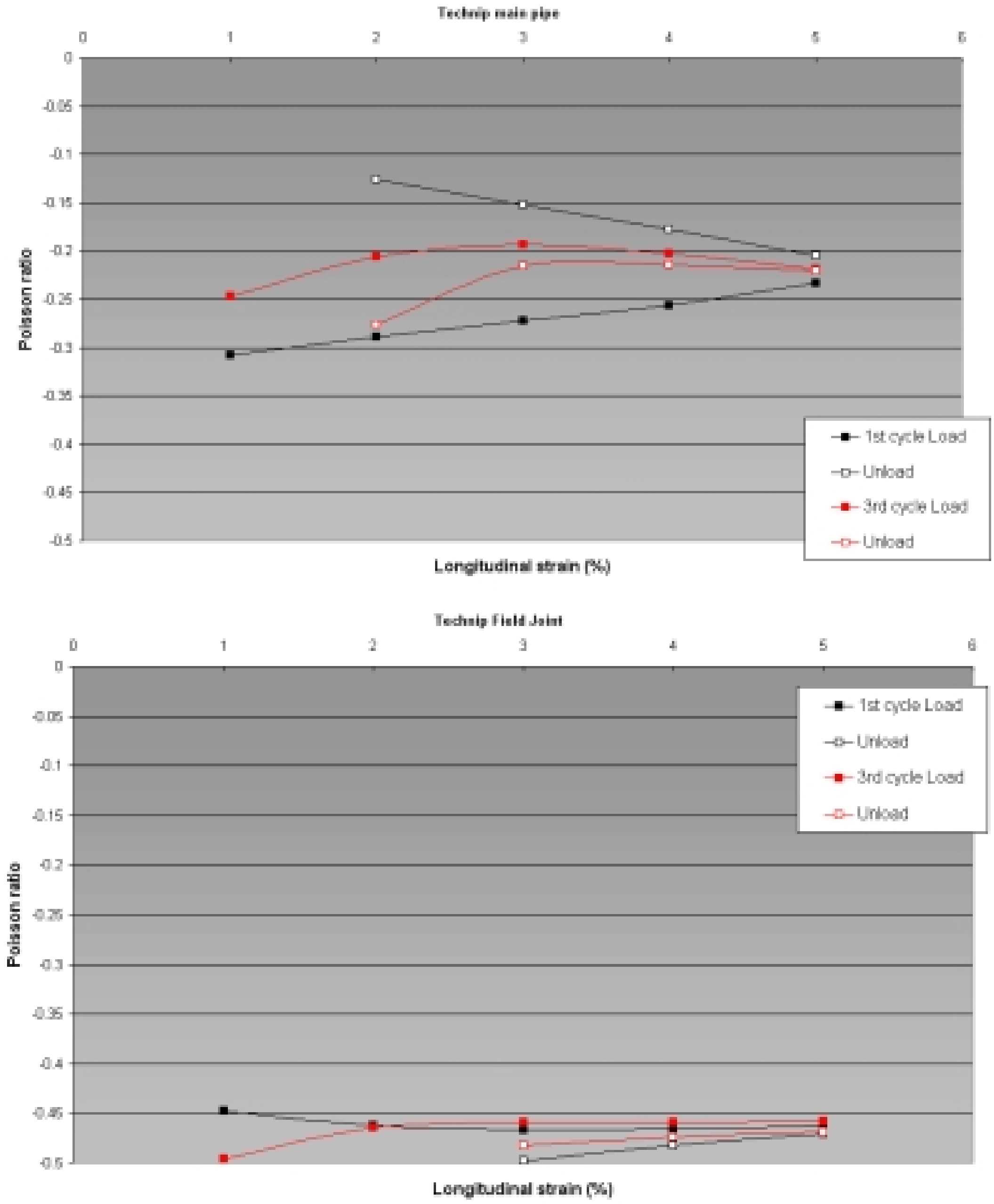


Figure 8a+b: Poisson ratio – Technip pipe and field joint

Most literature quotes a set value for the Poisson ratio of a material. The work carried out in this project shows that this clearly does not fully represent what happens to a PP material during tensile loading and unloading. Samples were also compression loaded but these results were inconsistent. Future work would benefit from an improvement to the test setup in order to measure the Poisson ratio more accurately during compressive loading.

Conclusions

Several of the new PP grades developed within the DeFRIS joint industries project have shown better deepwater and high temperature performance than previous PP materials. Tensile properties are above the requirements for these systems.

The partners feel that with careful tuning of the extrusion process and by lowering the density of the foam, a suitable balance between mechanical and thermal properties can be achieved. The foam structure and the homogenisation of the polymer melt have been optimised and meet the creep specification and the requirements from reel-lay operations.

It is worth reiterating from the Thermotite end-of-project summary report that Bredero Shaw Norway AS has already managed to secure two major contracts, i.e. the BP Thunderhorse and the Statoil Kristin projects through the DeFRIS development efforts.

Alternative systems and materials *(System Y)*

Candidate materials for system Y have been examined, and are described, and a variety of materials including polymeric, metallic, ceramic, composite and elastomeric have been evaluated. In particular, novel foaming techniques have been identified for certain higher performance (i.e. higher operating temperature) materials. An external composite shell has also been examined to assess its capability to withstand the deep water hydrostatic pressures, as well as those forces generated during installation (e.g. reeling). Their suitability is assessed in relation to the review and definition report presented to the project by MCS (DeFRIS/3). Recommendations for further work are made where more suitable materials are identified.

The materials considered have been examined and discussed in terms of their *technical* performance. It is recognised that economic parameters cannot be ignored; however, such considerations are complex and not just limited to the cost of the raw materials. Economic considerations should encompass manufacturing processes, installation techniques – including vessel trips and benefits created by thinner, high performance layers, improvements in long-term durability, possibility for recovery and reuse, and enhanced recovery of production fluids through improved performance.

Work has been conducted to check the MERL concept that a particular, novel, form of foamed ebonite might provide the required thermal etc properties for thermal insulation, and possess sufficient rigidity to withstand subsea pressures as required for pipeline service - and to develop suitable materials. The project has been successful when using styrene butadiene copolymer (SBR) as the base elastomer. A class of novel foamed ebonite materials has been developed, produced, and tested, to show that they have significantly superior (lower) thermal conductivity values than current standard foamed polypropylene (PP) materials, and further improvements are possible.

MERL's patented low temperature curing (LTC) process applying to elastomers (rubbers) has been used for a first, pre-foaming, elastomer curing stage. After subsequent foaming at a rather higher temperature, the extended foam-cell (pore) walls contain elastomer molecular chains oriented in a strong direction. Final stages at even higher temperatures to produce ebonisation consolidate this beneficial orientation, to produce relatively strong foamed products.

Cure-rate experimentation has led to foamed SBR LTCI (low temperature cure initiation) ebonites, with optimised cure characteristics to provide apparently stress-free material. This material possesses a high glass transition temperature T_g (113°C) to provide high stiffness up to that temperature, and has great resistance to degradation at very high temperatures. A range of physical property data have been obtained to conclude that foamed SBR LTCI ebonite possess significant improvements compared with current standard polypropylene levels, including significantly lower thermal conductivity values.

The combination of processes used in producing foamed SBR LTCI ebonites means that a great variety of these foamed products are possible in practice, allowing property levels to be tailored to a particular service application. As an example: versions should be possible for manufacturing the insulation-layer completely before assembly, or for part assembling (to one of several stages) before completing manufacturing.

Further review of potential *System Y* requirements are discussed in report DeFRIS/20 by Technip-Coflexip.

Thermotite

Bredero Shaw Norway AS (Thermotite) specializes in thermal insulation and corrosion protection of pipelines. The coating facility offers complete flexibility with four independent lines, one for anti-corrosion coating, and three for thermal insulation, allowing multiple projects to be manufactured simultaneously. The anti-corrosion coating consists of a thin layer of Fusion Bonded Epoxy (FBE) covered with another thin layer of a polypropylene (PP) based adhesive and a thicker solid PP layer. The thermal insulation is a foamed PP with a solid PP outer shield. The properties of the foamed PP are of utmost importance to the performance of the total system. Hence, the focus is on improving the foam characteristics.

Thermotite has been responsible for Work Package 2 - Materials Development and Selection, and WP 3 - Insulation Systems Development, of the DeFRIS Project. The major activity for Thermotite is to extend material capabilities and process windows to produce thermal insulation for deep water. This includes evaluation of different materials, manufacturing options and processes, produce samples for testing, and identify and review system characteristics.

This report summarizes the activities and results from the work undertaken by Thermotite in the project.

<u>Summary</u>

A TDF[1] full scale test series was performed at Thermotite, Orkanger, in September 2001 [1], and in March 2002 [2]. The major insulation materials used were new PP grades developed by Borealis within the DeFRIS project [3]. Another series of trials were performed in October 2002, in May 2003, and in August 2003. The October 2002 trial was performed to improve the insulation foam properties, from the March trial, further. The May 2003 trial included full scale bending of pipes with field joints. That trial failed as both the field joint and the coating next to the field joint cracked. Analyzing the failure mechanisms led to modifications to the manufacturing process before the next full scale trial in August 2003. This trial included pipes with thick coating and with thin coating, both with field joints, and was subjected to a full scale bending trial successfully performed in September 2003.

From each trial, samples were taken for examination of major properties:

- Coefficient of thermal conductivity
- Tensile properties
- Compression properties
- Foam structure

Different PP base polymer grades from Borealis were used in different combinations to develop the most suitable candidate systems.

Different foaming agents are tested to improve the foam structure. A homogenous foam structure will give better mechanical properties, both tensile, compression and creep

[1] TDF: Thermotite Deepwater Foam, a blend of a base PP and a high melt strength PP.

properties. Furthermore, a homogenous foam structure is also believed to improve insulation properties. These overall improvements make it possible to deploy PP insulation systems in deeper waters.

Foam properties are measured at independent test houses (different SINTEF departments: thermal conductivity, density and mechanical properties), at Borealis (foam structure), and in-house Thermotite (tri-axial creep and density). Samples were also sent to DeFRIS participant MERL for additional testing.

A blend with 70% base polymer and 30% HMS fulfills the specification for elongation at break with a relatively high margin. The specification requires >15%, and the lowest value measured on the March 2002 trial was 27%. A higher content of HMS makes the material more brittle and makes it somewhat challenging to meet the requirement on minimum elongation at break with a HMS content of e.g. 50%. A better tuning of the process parameters could still make this possible, giving even better creep performance at deeper waters and/or higher temperatures.

One of the tested samples met the thermal conductivity specification. Most samples gave test results around 0.18 W/mK, whereas the goal was ≤ 0.17 W/mK. This can be attributed to the use of stiffer materials and process conditions. Different test methods have also shown differences in k-values. The values given here are on the conservative side.

The samples were tested in tri-axial creep at different stresses and temperatures. The highest compressive stress induced is 12 MPa, representing a water depth of 1200 m. The specification of >15 MPa strength at 5% compression is, therefore, not yet documented. However, all tested specimens from the March 2002 trial had ≤ 2.0% strain at 12 MPa with a linear stress/strain curve indicating a much higher stress at 5% strain than the required 15 MPa.

Four of the seven samples from the March 2002 trial met the creep specification of an estimated < 5% compression after 20 years. For a typical design on a buried 10" pipe with a U-value requirement of 2.5 W/m^2K, the foam thickness would be reduced by creep from 61 mm to 54 mm with the material system developed in the DeFRIS project.

A third trial was performed in October 2002 for a better study of foaming agents and with a new, nucleated PP. This was done to improve foam structure further and for homogenization of the polymer melt. Testing of samples from that trial showed, however, that the change in raw materials, combined with existing process conditions, drastically reduced the ductility of the foam.

Thermotite then took on an internal development program with a series of trials to overcome the processing issues with the new material grades. After finishing the half-year internal program, pipes with field joints were produced for validation tests and full scale bending for the DeFRIS project.

Finally, after testing of pipeline coatings and two different field joint systems, the project chose the one that fulfilled the requirements put forward. The qualified system has subsequently been used in commercial applications.

Conclusions

New PP grades developed show better deepwater and high temperature performance than previous materials. Creep performance meets the requirements for the insulation system. Tensile properties are well within the requirements provided proper process conditions are observed.

The required coefficient of thermal conductivity is in range with a better tuning of the process and (slightly) lower density. The foam structure and the homogenization of the polymer melt are optimized and meet the creep specification and the requirements from reel-lay operations.

Bredero Shaw Norway AS has, through the DeFRIS development efforts, secured two major contracts, i.e. the BP Thunderhorse, and the Statoil Kristin projects.

Recommendations

The TDF system with a standard field joint system, and the same TDF system without field joint, are both suitable products and therefore recommended for reel-lay operations.

The thermal conductivity is of most importance with respect to insulation capacity. Different testing methods seem to give different k-values. Evaluation or development of new test methods as well as sample preparation for k-value measurements should be considered for follow-up work after this project.

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MCS Ltd

The DeFRIS project was concerned with solving the technological needs associated with subsea pipe insulation in future deepwater and old marginal oil wells. The aim of the project was to develop new systems that extend the productivity of marginal wells while reducing expensive workover treatments necessary to prevent the formation of hydrate plugs and wax deposits. The objectives of the DeFRIS project were to develop new materials/systems, new evaluation methods and new software to provide economical, validated, deepwater pipe and riser insulation systems.

The role of MCS in the DeFRIS project was the development of software tools for design of thermal insulation systems, development of new riser/flowline concepts and also to perform system cost analyses.

The following provides a summary of the work carried out and the deliverables achieved by MCS for the DeFRIS project. The workpackages and deliverables for which MCS were responsible are as follows,

1. Workpackage 1
   - D 1.1 - Field Development Scenarios
   - D 1.2 - Flow Assurance Issues
   - D 1.3 - Specification of Performance Requirements
   - D 1.4 - Environmental and Life Cycle Assessment
2. Workpackage 4
   - D 4.1 - Analysis Issues
   - D 4.2 - Specification of Software Tool Requirements
   - D 4.3 - Specification of Performance Requirements
   - D 4.4 - Software Tool, Version 1.0
3. Workpackage 6
   - D 6.1 - Potential Riser/Flowline Concepts
   - D 6.2 - Concept Design Report
   - D 6.3 - Specialised Concept Design Report
   - D 6.4 - Global Performance Requirements Report
   - D 6.5 - Installation Report
   - D 6.6 - Cost Comparison
4. Workpackage 10
   - D 10.1 - Validation Requirements
   - D 10.2 - Validation of Local FE Models
   - D 10.3 - Validation of Software Tools
   - D 10.4 - Software Tool, Version 2, including documentation

A summary of the work carried out for the deliverables listed above and descriptions of the deliverables themselves are contained below. Where appropriate, reference is made to the reports that have been prepared and issued over the duration of the project.

Workpackage - 1 Review, Definition & Assessment of Existing Practices

Objectives

The objective of workpackage 1 was to define in detail the operating conditions and requirements for current and future deepwater insulation applications for flowline and riser systems. Each of the tasks and deliverables of this workpackage is listed below.

Task 1.1 Field Development Scenarios

This task involved a review of current and future field developments where the use of thermally insulated systems is required or where these systems have been used. The field development scenarios identify the field layouts, offshore locations, vessel type, water depths, etc.

The deliverable D 1.1 for this task is a report entitled 'Field Development Scenarios' [2]. This report (DeFRIS/1 [2]) has been completed, and copies have been issued to all partners. Feedback was obtained from the end-user consultative group (ECG), regarding current and future requirements of insulation systems [10]; these comments have been incorporated into this document.

Task 1.2 Flow Assurance Issues

A thorough review of all aspects of flow assurance issues was performed as part of Task 1.2 in order to identify the key requirements of thermal insulation systems. Issues that were addressed included hydrate and wax control, shutdown time limits etc. An assessment of the requirements for performing flow assurance calculations was also made. Target ranges of thermal performance for the thermal insulation systems were identified. Comparisons of thermal performance with alternative systems were also made as part of this task.

The deliverable D 1.2 for this task is the report DeFRIS/2 [3]; this report is entitled 'Flow Assurance Issues'. Feedback and comments were obtained from the ECG with regard to the requirements of thermal insulation systems. These comments have been incorporated into this document. This report has been completed and copies have been issued to all partners.

Task 1.3 Performance Requirements

A specification of the performance requirements for the thermal insulation systems was developed in Task 1.3. This task involved the identification of the operational requirements of the system. These operational requirements included structural, thermal and mechanical properties. An assessment was also made of the in-place loads to which the system will be subject. A review of the options for installation and an identification of the installation performance requirements was also performed as part of this task.

Task 1.3 has been completed and a specification of the performance requirements of thermal insulation systems, DeFRIS/3 [4], has been completed. Copies of the specification were issued to all partners.

Task 1.4 Environmental and Life Cycle Assessments

This task required an assessment to be made of all environmental issues associated with the proposed thermal insulation systems. A comparison of the proposed systems with alternative and existing systems was made in order to identify the advantages/disadvantages of each. This assessment included all stages in the system life cycle.

Document number DeFRIS/4 [5], entitled, 'Environmental and Life Cycle Assessment' has been completed and copies have been circulated to the partners.

Summary

All tasks specified in workpackage 1 have been successfully completed. Deliverables D 1.1 – 1.4 have all been completed and issued to all partners. Subsequent comments from partners and also from the end-user consultative group (ECG) regarding these reports have been taken into account and, where necessary, reports have been updated to reflect these comments. In summary the operating conditions for current and future deepwater developments have been described in detail, thus satisfying the objectives of this workpackage.

Workpackage 4 Development Of Analysis Tools

Objectives

The initial objective of workpackage 4 was to perform detailed finite element analyses of potential insulation systems in order to evaluate thermal and mechanical performance characteristics. The main objective of this workpackage was to develop empirical based software tools, which will allow easy and efficient design of global insulation systems. This software tool has been calibrated using the results of the local finite element analysis.

Task 4.1 Review of Analysis Requirements

As part of Task 4.1 a review of all aspects of thermal insulation systems was performed. The main issues associated with the analysis of these systems were also identified in order to clarify the type of analyses required and the parameters to be included.

This task has been successfully completed. The deliverable from this task, D 4.1 has been combined with the deliverable D 4.2 from Task 4.2 to produce document DeFRIS/7 [6] entitled 'Analysis and Software Tool Requirements'. This document has been completed and issued to the partners.

Task 4.2 Specification of Requirements

A detailed specification of the requirements, based on the results of Task 4.1 was produced as part of this task. The specification was produced in order to identify local FE analysis requirements, and also included a detailed specification for the software tools.

This task has been successfully completed. The deliverable from this task, D 4.2, has been combined with the deliverable D 4.1 from Task 4.1, to produce document DeFRIS/7 [6] entitled ‘Analysis and Software Tool Requirements’. This document has been completed and issued to the partners.

Task 4.3 Local FE Analysis

Finite element analysis of the thermal insulation systems and local field joint regions was performed as part of this task. These analyses were carried out using the industry recognised finite element (FE) package ANSYS. The purpose was to assess the short and long term thermal and mechanical properties of the insulation systems. The results of these analyses were then used to validate the software tool.

This task is completed. Deliverable D 4.3, ‘Local FE Analysis and Software Tool Report’ [7], from this task has been completed. Copies of this report have been issued to the partners.

Task 4.4 Software Tool Development

Task 4.4 involved the development of an empirical based software tool for quick and easy design of thermal insulation systems. The tool developed is fully Windows 98/NT compatible, and includes a comprehensive GUI. The tool includes both global and local analyses. The primary focus of the software tool is on the thermal performance characteristics of insulation systems.

The deliverable D 4.4 (Software Tool, Version 1.0) from this task is completed. A demonstration of version 1.0 of the software tool DISDANS was given at the mid-term meeting hosted by MCS in Galway. A complete description of the software tool, DISDANS Version 1.0, is given in the MCS document DeFRIS/11 [7].

Summary

Tasks 4.1 and 4.2 have been successfully completed and report DeFRIS/7 [6] combining deliverables D 4.1 and D 4.2 has been completed and has been issued to all partners. Task 4.3 has also been successfully completed and the report DeFRIS/11 [7] has been issued to the partners. Version 1.0 of the software tool DISDANS (deliverable D 4.4) has also been completed as part of Task 4.4. In summary, the two main objectives of this workpackage namely the performance of detailed FE analysis of potential insulation systems for deepwater applications, and the development of software tools for the design and analysis of deepwater insulation systems, have been satisfied. Thus workpackage 4 has been successfully completed.

Workpackage 6 Insulated Riser/Flowline Concepts

Objectives

The objective of workpackage 6 was to evaluate the impact of proposed thermal insulation systems on the global characteristics of riser and flowline systems. Also, potential applications of the thermal insulation systems to specialised applications, and innovative concepts, were evaluated. In addition, installation and cost issues were addressed.

Task 6.1 Identification of Concepts

A review of current riser and flowline systems was performed as part of Task 6.1. Also, systems where thermally insulated pipes may be used were identified. Innovative applications of the thermal insulations systems to riser/flowline concepts were identified and evaluated as part of this task. These innovative applications included using combined insulation/buoyancy systems, and using insulation to improve fatigue life of SCRs.

Task 6.1 has been completed. Deliverable D 6.1, a report entitled “Potential Riser/Flowline Concepts – Study Basis”[8], has been completed. This document has been issued to the partners.

Tasks 6.2 & 6.3 Global Modelling of Systems/Specialised Concepts

Task 6.2 involved the global design of the riser and flowline concepts identified in Task 6.1. Typical aspects addressed included configuration design, extreme load case analysis, fatigue analysis and vortex induced vibration (VIV) analysis. The impact of the thermal insulation on the global performance of the system was also evaluated.

Task 6.3 involved the modelling of these specialised concepts. The potential application of thermal insulation systems to specialised concepts, and the effects of thermal insulation on the global performance of the system, were evaluated as part of this task.

Deliverables 6.2 and 6.3 have been combined into a single document, Doc. DeFRIS/28 [11]. This document also incorporates deliverables D 6.5 and D 6.6. This report has been completed and has been issued to the partners.

Task 6.4 Global Performance Requirements

A review of the results from Task 6.2 was carried out for Task 6.4. The global performance requirements for the thermal insulation systems were also identified for this task. Performance issues addressed included extreme loads, fatigue loads, abrasion, impact loads, environmental effects etc. This task resulted in the deliverable D 6.4, which is an update to the Performance Specification Report from WP1 [4].

Task 6.4 is complete. Deliverable D 6.4, “Global Performance Requirements of Thermal Insulation Systems”[9] has been completed and the document has been issued to the partners.

Task 6.5 Installation Issues

Task 6.5 involved an assessment of the potential installation options for the riser/flowline concepts developed as part of Task 6.3. An evaluation of the performance requirements, and a detailed cost estimate, have been carried out for the proposed installation methods. The results from this task are incorporated into the document DeFRIS/28 [11], ‘Potential Riser/Flowline Concepts – Study Report’

Task 6.6 Cost Comparison

A cost comparison of the concepts developed in Task 6.3 and 6.4 has been carried out. This cost comparison involved installation costs and manufacturing costs. The results of Task 6.6 are presented in the document DeFRIS/28 [11], ‘Potential Riser/Flowline Concepts – Study Report’.

Summary

All tasks associated with workpackage 6 are complete. Task 6.1 has been completed and a report, DeFRIS/12 [8], has been issued. Deliverables D 6.2, D 6.3, D 6.5 and D 6.6 have been incorporated into a single document, Document No. DeFRIS/28 [11], and this document has been completed. Deliverable D 6.4 has also been completed. All aspects relating to the impact of the proposed thermal insulation systems on the global response of the riser/flowline systems have been evaluated. This assessment involved a detailed study of the riser/flowline system considering all aspects from manufacture to installation and operating life. The results of this assessment have shown the potential economic and structural performance benefits of the application of the proposed thermal insulation systems to potential riser/flowline systems. Thus, workpackage 6 has been successfully completed.

Workpackage 10 – Validation Of Software Tools

General

The main objective of workpackage 10 of the DeFRIS project was to use the results from the experimental tests, and simulated service tests, to validate both the FE models and the software tool DISDANS. The results of this validation process were then used to upgrade the software tool. An additional objective of this workpackage was to commercialise the software tool.

Task 10.1 Review of Experimental Results

A thorough review of all experimental test results was performed for Task 10.1 in order to collate all test results, and identify the parameters to be used in the validation of the FE analysis models and the software tool. A methodology to be used in the validation was also outlined as part of this task. The deliverable D 10.1 for this task has been combined with the deliverables D 10.2 and D 10.3 in the report DeFRIS/29 [12].

Task 10.2 Validation of Local FE Models

The experimental results identified in the previous task were used for comparison with the analytical results, and any discrepancies have been resolved. Additional FE analysis was carried out in order to verify any enhancements required. The deliverable D 10.2 for this task has been combined with the deliverables D 10.1 and D 10.3 in the report DeFRIS/29 [12]

Task 10.3 Validation of Software Tools

In this task, the accuracy of the software tool was determined, by comparing the results of the software tool with the results of the simulated service test that was carried out. Any discrepancies between the results have been resolved, and any modifications required have been made to the software tool code. The deliverable D 10.3 for this task has been combined with the deliverables D 10.1 and D 10.2 in the report DeFRIS/29 [12]. This report has been completed and issued.

Task 10.4 Commercialisation of Software Tools

Task 10.4 of the DeFRIS project involved the commercialisation of the software tool DISDANS. In accordance with the objectives of this task, user documentation was produced for the software tool. This documentation includes a user's manual, and examples manual.

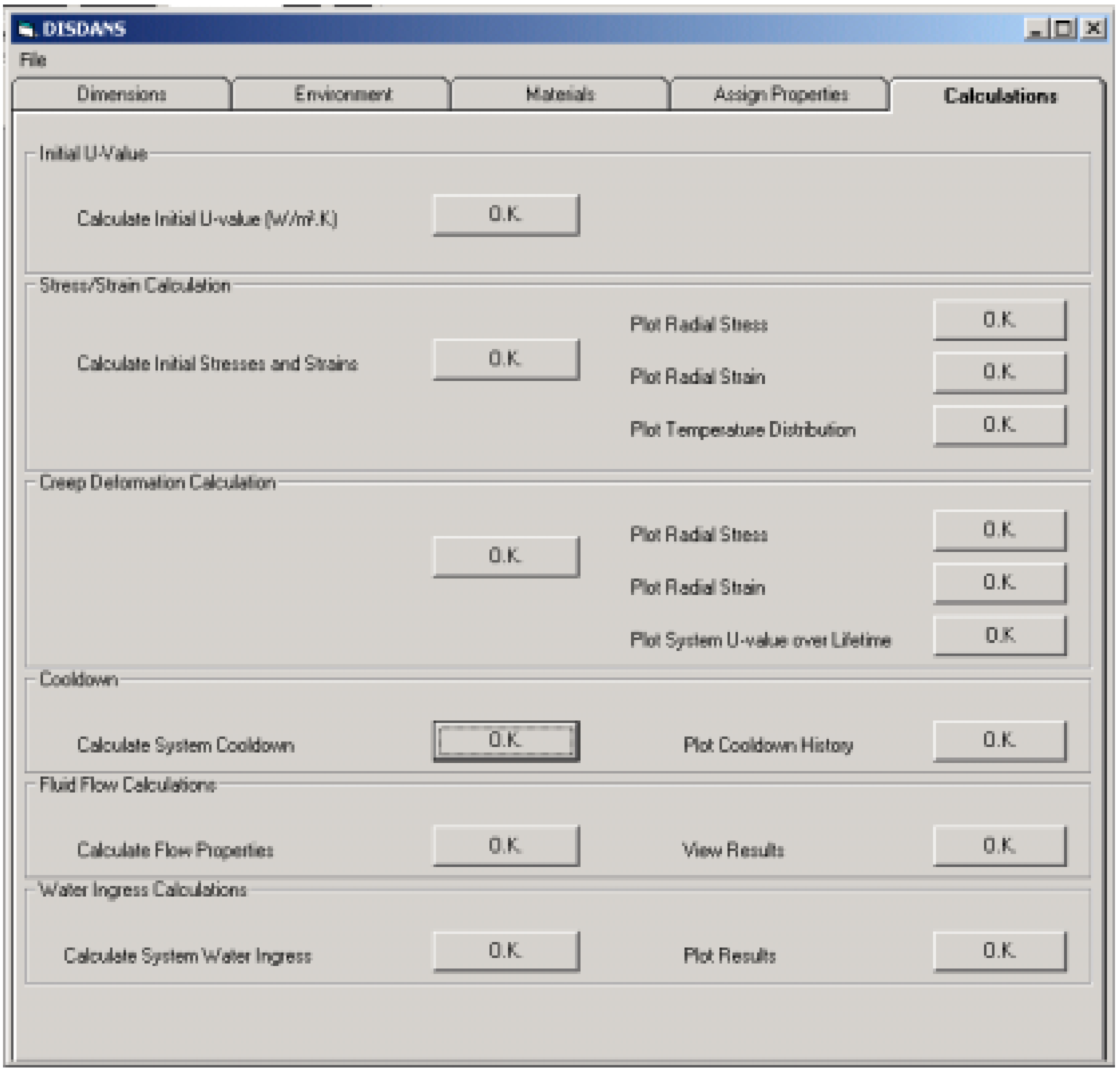
The user documentation is contained in the report DeFRIS/30 [13]. This document has been completed and issued.

Summary

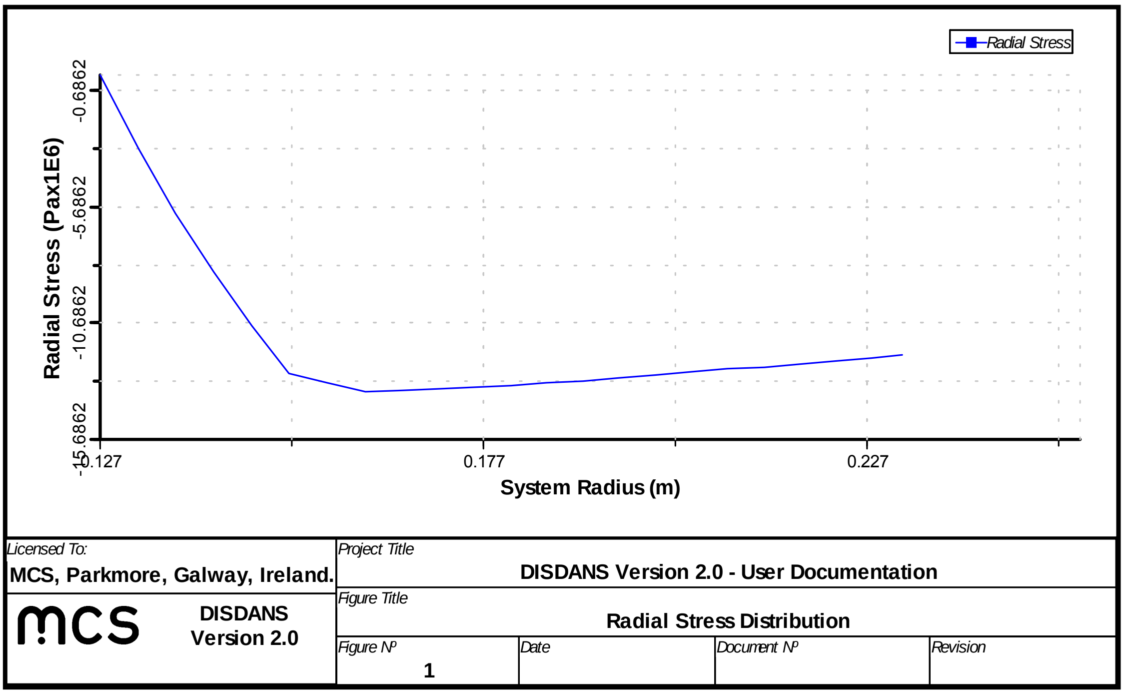
All deliverables of workpackage 10, for which MCS are responsible, have been completed. Where relevant, copies of reports have been forwarded to the project partners. Thus, workpackage 10 of the DeFRIS project has been successfully completed.

The software tool DISDANS has been fully validated with both FE and with the results of simulated service tests. Also, a user manual has been completed for the software, and DISDANS Version 2.0 has been added to the MCS software suite. The GUI of the DISDANS Version 2.0 program, in addition to sample program outputs, is illustrated below.

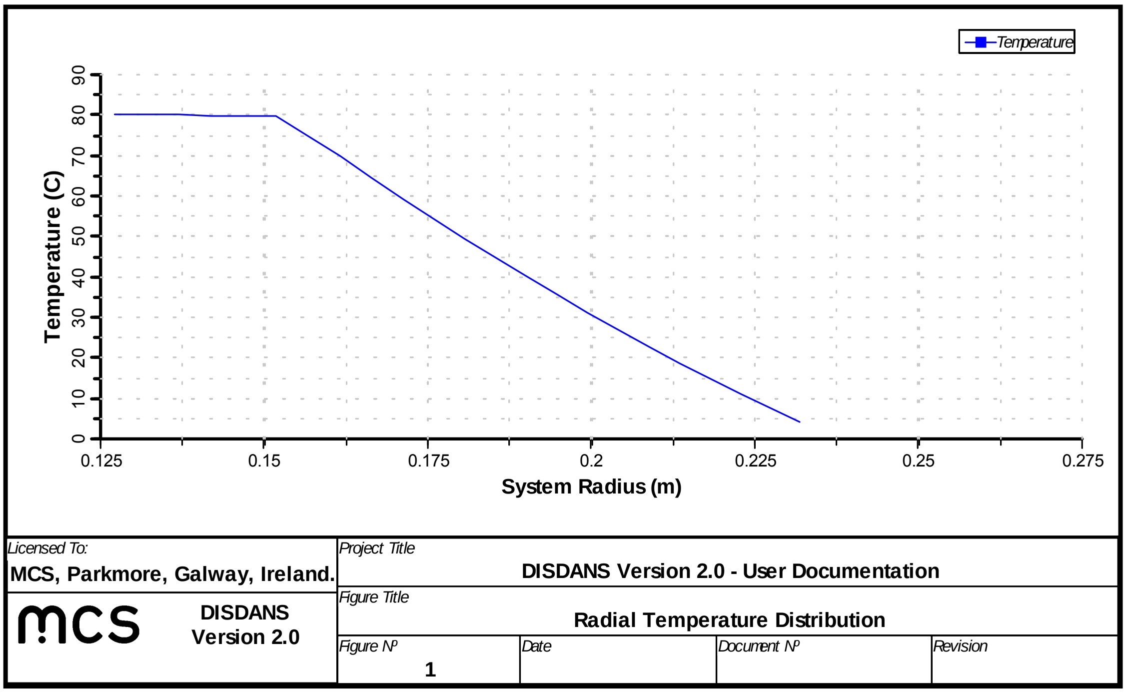
DISDANS GUI



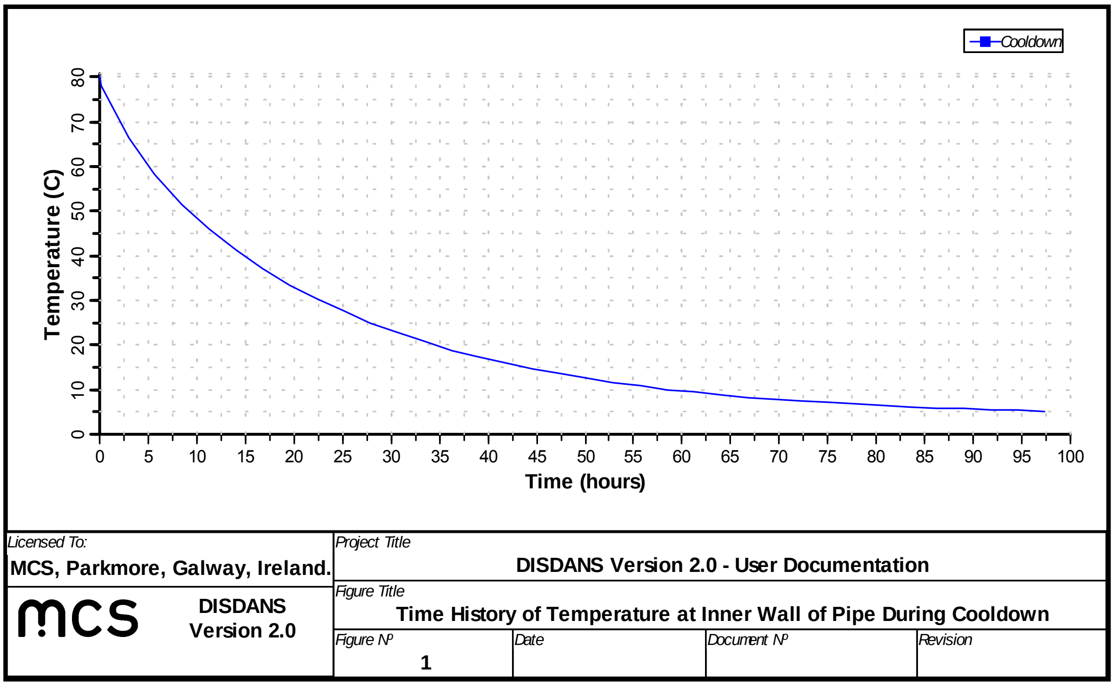
Radial Stress Distribution



Radial Temperature Distribution



Cooldown Response



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2. MCS International, "DeFRIS JIP – Task 1.2 – Flow Assurance Issues", Doc No. DeFRIS/2, Rev 02, December 2001.

4. MCS International, "DeFRIS JIP – Task 1.3 – Performance Requirements", Doc No. DeFRIS/3, Rev 02, December 2001.

5. MCS International, "DeFRIS JIP – Task 1.4 – Environmental and Life Cycle Assessment", Doc No. DeFRIS/4, Rev 02, December 2001.

6. MCS International, "DeFRIS JIP – Task 4.1&4.2 – Analysis and Software Tool Requirements", Doc No. DeFRIS/7, Rev 02, September 2003.

7. MCS International, "DeFRIS JIP – Task 4.3 – Local FE Analysis and Software Tool Report", Doc No. DeFRIS/11, Rev 01, June 2002.

8. MCS International,, "DeFRIS JIP – Potential Riser/Flowline Concepts - Study Basis", Doc No. DeFRIS/12, Rev 02, September 2003.

9. MCS, "DeFRIS JIP – Task 6.4 – Global Performance Requirements for Thermal Insulation Systems", Doc No. DeFRIS/13, Rev 01, April 2003.

10. MERL, "Current/Future Requirements – Interim Report from DeFRIS End User Consultative Group (ECG)", Document No. DeFRIS/5, November 2001.

11. MCS, "DeFRIS JIP – Potential Riser/Flowline Concepts - Study Report", Doc No. DeFRIS/28, Rev 01, September 2003.

12. MCS, "DeFRIS JIP – Validation of Software Tool", Doc No. DeFRIS/29, Rev 01, January 2004.

13. MCS, "DeFRIS JIP – DISDANS Version 2.0 – User Documentation", Doc No. DeFRIS/30, Rev 01, January 2004

Borealis

Background

Polypropylene (PP) has been recognised as one of the best technical and economical solutions for ensuring the long-term corrosion protection and thermal insulation of steel pipelines in offshore applications. The PP properties beneficial for pipe coating applications can be seen below:

- High temperature resistance from -20C to 140C
- Flexibility
- Low water absorption
- Thermal conductivity
- Impact resistance
- Abrasion resistance
- Creep resistance, long term performance
- Easy and stable processing
- High welding capability
- Environmental friendliness

Over the last 15 years PP foam has shown its excellence as thermal insulation of sub-sea pipelines. Favourable properties such as low water absorption, good insulation due to low thermal conductivity, and good compression strength, have promoted its use in various North Sea thermal insulation projects at water depths down to 400m. The fact that the insulated pipes are reliable and easy to install has further contributed to the success.

Polypropylene (PP) For Deep Water Offshore Applications

The trend towards greater water depths means tougher requirements for the PP foamed thermal insulation, such as higher demands on compression strength, in order to withstand the increased hydrostatic pressure. This trend has created the need for stiffer PP foam, with improved foam structure, for deep-sea applications.

Stiff polypropylene block copolymers (BA212E)

The new high-stiffness PP copolymer materials were developed to increase stiffness and impact resistance significantly, as well as improving creep resistance. This heterophasic PP material is a high crystalline material with a finely distributed and dispersed ethylene - polypropylene rubber phase. Good mechanical properties are shown over a wide temperature range, in addition to high abrasion and chemical resistance.

High Melt Strength Polypropylene (HMS-PP) (WB130HMS)

High strength, combined with increased drawability of the polymer melt, is the main characteristics for High Melt Strength Polypropylene (HMS-PP). A long-chain, branched, structure is introduced into the PP polymer, which has a positive influence on the foaming. The branched structure generates strain-hardening behaviour and increases considerably the drawability of the polymer melt. This changed behaviour of the polymer melt has been characterised using a uniaxial tensile tester, known as a Rheotens apparatus.

Due to the polymer modification of the HMS-PP, a controlled growth of bubbles can be observed, leading to stable foam with a closed-cell foam structure. Using a branched structure polymer improves processibility at foam extrusion, a technology where the polymer melt is forced to withstand elongational stresses.

Materials Development

PP foam density with varied content of BA212E and HMS-PP

Commercially produced thermal insulation systems show that a standard PP can be foamed from a density of 900 kg/m^3 down to approximately 700 kg/m^3 at controlled and stable process conditions by using chemical foaming agents. These densities correspond to a K-value of 0.22 for the solid PP, and 0.17 for the foam density of 700 kg/m^3 [1].

Extruding foam with the material combination of a stiff linear PP and a HMS-PP has made it possible to reduce foam densities, thereby increasing the insulation capacity compared to previously produced PP foam.

In a series of studies, stiff PP, HMS-PP, and combinations of the two, have been foamed in a laboratory extruder with a chemical foaming agent, to assess the influence of the foam density. The materials used in the test were the new HMS-PP (WB130HMS), and the stiff PP block copolymer (BA212E). By adding just 10% of HMS-PP the density has been significantly lowered from 660 kg/m^3 to 550 kg/m^3. When pure HMS-PP was foamed in the test, a density as low as 370 kg/m^3 was reached (Figure 9).

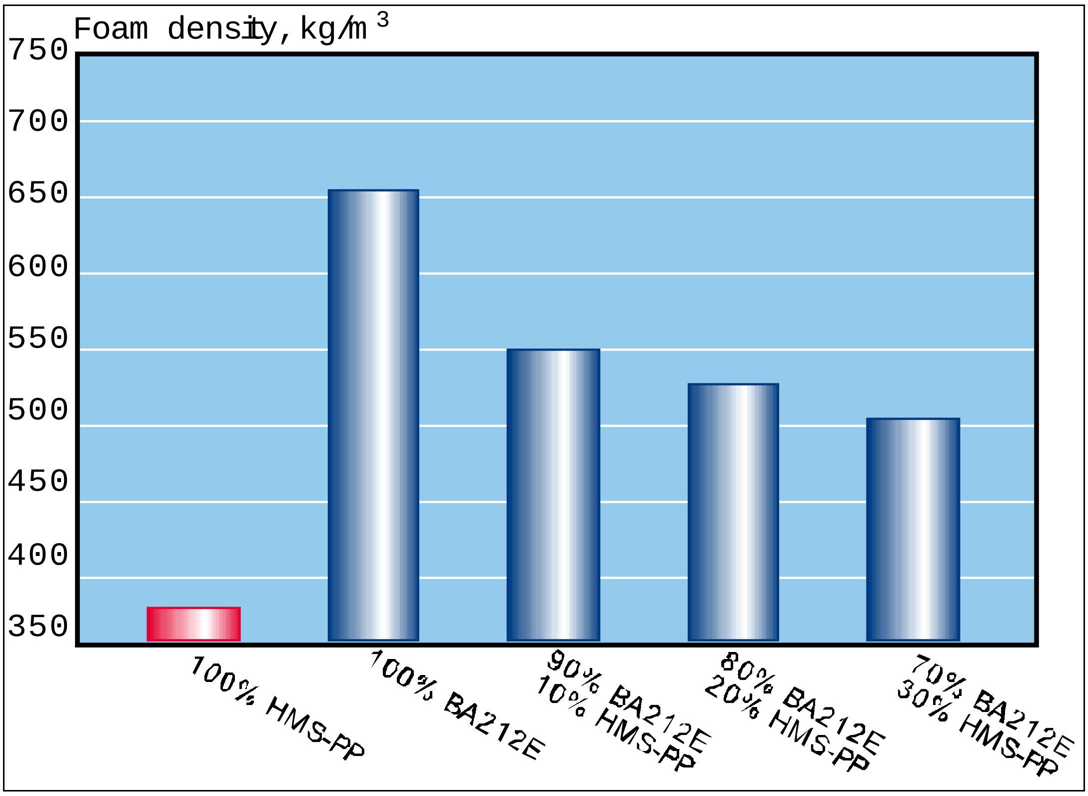

Figure 9 PP foam density with varied content of BA212E and HMS-PP

By combining a stiff linear copolymer polypropylene with a HMS-PP, the benefits of high melt strength and high melt elongation, result in excellent foam quality, characterised by evenly distributed bubbles, with a closed cell bubble structure in the pipe foam layer. The result leads to both higher compression strength and higher creep resistance. The compression strength is increased by 80% when using a mixture of stiff PP and HMS-PP compared to the reference PP (Figure 10).

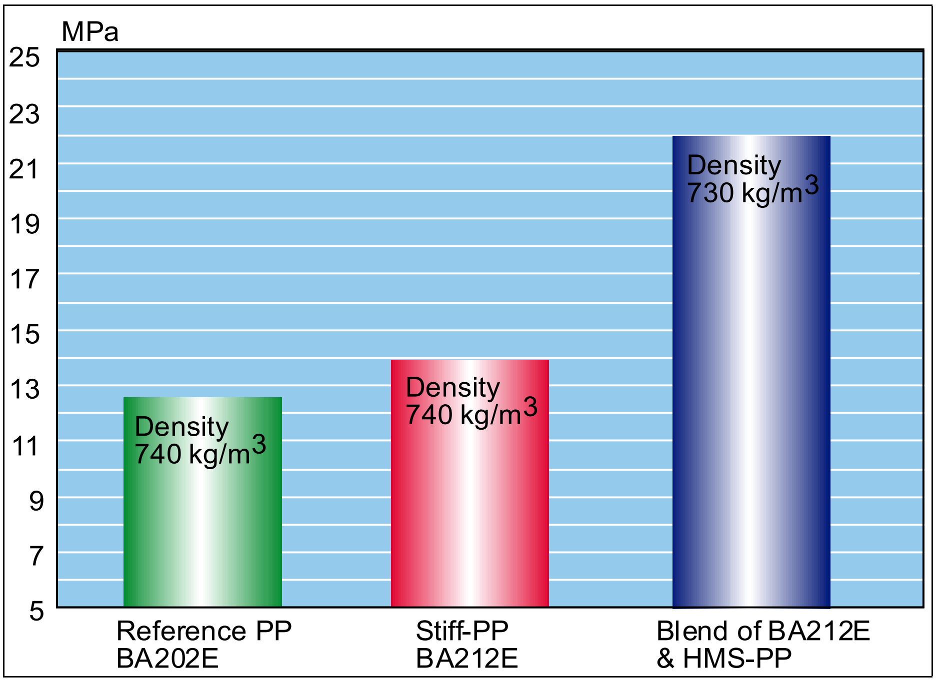

Figure 10 Compressive strength at 5% compression

PP Foam Structure

Within the DeFRIS project, a modified HMS-PP have been developed and produced in laboratory- and pilot-scale. The purpose was to produce a HMS-PP with lower MFR to improve the miscibility of the two PP components. The HMS-PP has been evaluated with regards to mechanical properties, and tested by Borealis in a laboratory extruder to evaluate the influence of the foamed density.

This new concept has been tested in combinations with different chemical foaming agents to improve the foaming structure. The foam structure is of main importance to reach an even insulation layer, and thereby optimal mechanical properties, for the foam. Out of these laboratory screening trials, the three most interesting blowing agents were further evaluated for full-scale pipe coating trials at Thermotite, Orkanger. For this full-scale trial, Borealis provided BA212E, HMS-PP produced in pilot scale, and arranged new chemical foaming agents to be tested.

Processing conditions at the extrusion step was the next step to be evaluated. The combination of materials and process parameters in the extruder was carefully tested to get the best out of the materials, and reach optimal mechanical properties. This evaluation was demonstrated both in a lab-extruder, and in full-scale equipment, at Thermotite. The foam structure of the PP foam, resulting from the process optimisation, has been studied by microscope (Figure 11). When HMS-PP is added to the mixture, the homogeneity of the foam structure is enhanced [2].

a) BA212E/HMS-PP (70/30)

b) BA212E Reference

Figure 11 Representative examples of the PP foam structure.

For further improvement of the foam structure, a production of nucleated HMS has been made. With an even better distribution of bubbles in the foam, and with even finer and more equal bubble size, there is a potential for reaching higher mechanical strength, i.e. with associated lower creep. The material has been used for foam trials in both laboratory and in full-scale production and in combination with different foaming agents [3].

BA150E with improved homogeneity

Adequate mixing, between BA212E and HMS-PP, is of vital importance to obtain PP foams with good mechanical and insulation properties [4]. Therefore the pre-compounded BA150E (70% BA212E/30% HMS-PP) was developed which shows improved foam quality and mechanical properties due to the enhanced homogeneity.
The effect on the improved foam quality is illustrated in Figure 12.

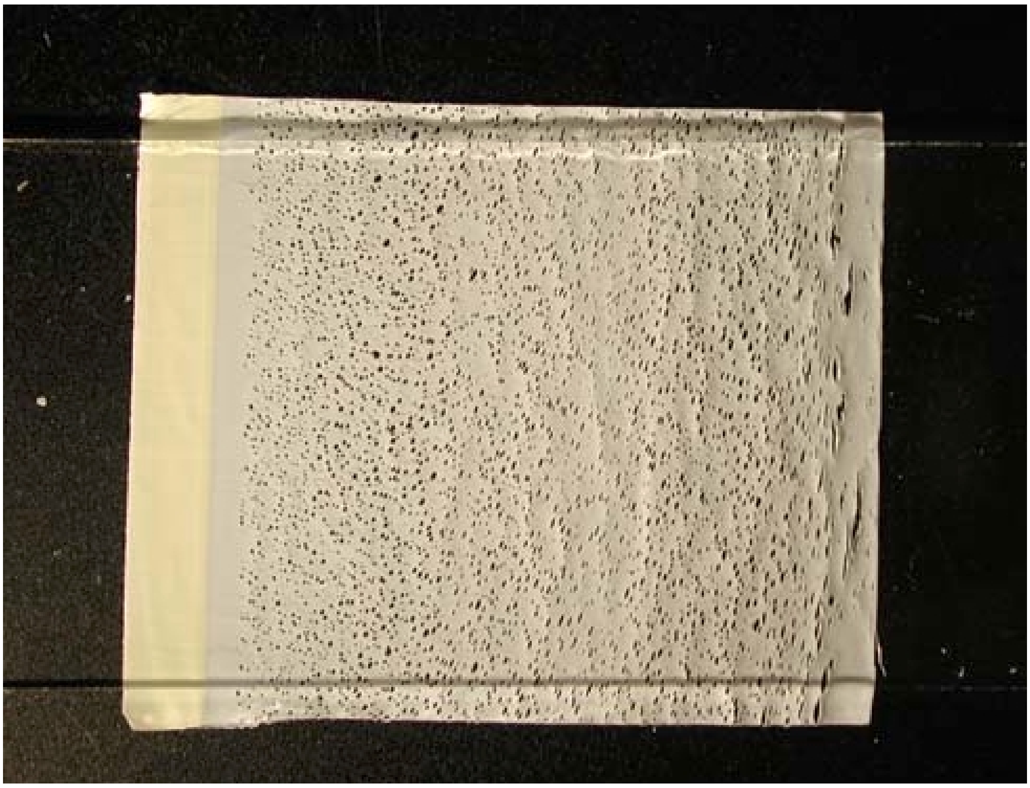

Figure 12 BA150E foam structure

BA150E has been evaluated with two versions of BA212E (with and without talc). BA150E based on BA212E with talc has a tensile modulus of 1880 MPa, compared to 1630 MPa for BA212E without talc. The corresponding results for elongation at break are 64% for BA212E with talc, compared to 420% with BA212E without talc. Consequently the best combination of materials, with respect to the elongation at break values, is BA212E without talc.

The creep resistance of BA150E was also improved compared with when BA212E and WB130HMS are mixed directly in the extruder.

K-value is a critical factor for the thermal insulation system. BA212E show a higher K-value compared with the reference BA202E, because of higher crystallinity. The HMS-PP products have different polymer morphology and appear to have a K-value between those of BA202E and BA212E.

Field Joint Materials

The evaluation and testing of field joint material has been part of the DeFRIS project. EA165E is modified with an elastomer and shows excellent low temperature impact resistance. At the full scale bending trials at Thermotite in Orkanger, the material was subjected to 4 complete bending cycles on a bending rig. EA165E passed the test successfully, and is therefore suitable for reel-lay installation.

Conclusions

The new generation of stiff PP polymers has resulted in a significant advance, seen in the PP foam used as thermal insulation in a multilayer pipe coating system. In addition to the stiff PP copolymer, HMS-PP based polymers can be added to improve the homogeneity of the PP foam, increasing the compression strength and improving creep resistance. This has resulted in a product that can withstand a greater hydrostatic pressure, without altering the thermal insulation performance. Thus the new PP foam can be introduced for use at significantly greater water depths.

Sufficient mixing between BA212E and HMS-PP is of vital importance to obtain PP foams with good mechanical and insulation properties. Therefore the pre-compounded BA150E (70% BA212E/30% HMS-PP) was developed which shows improved foam quality and mechanical properties due to enhanced homogeneity.

References

1. Rydin, Cecilia. DeFRIS - 12 Months Status Report. Borealis AB. Stenungsund, Sweden, 2001.
2. Rydin, Cecilia. DeFRIS - 18 Months Status Report. Borealis AB. Stenungsund, Sweden, 2002a.
3. Rydin, Cecilia. DeFRIS - 24 Months Status Report. Borealis AB. Stenungsund, Sweden, 2002b.
4. Rydin, Cecilia. DeFRIS - 30 Months Status Report. Borealis AB. Stenungsund, Sweden, 2003.

Technip-Coflexip

Background

Flow assurance and insulation have become one of the major focuses of the offshore oil and gas industry over the past years. A significant number of offshore fields are being developed, or are planned, for water depths in excess of 1000 m. Many of these deepwater fields are characterised by low well temperature (45-70°C), long tie-back distance, and high risks of hydrate and wax formation.

In order to meet increasingly stringent insulation performance requirements, thicker insulation designs are required. In addition, the insulation material must be able to maintain its integrity in wet and highly pressurised environments.

The aim of the DeFRIS JIP was to develop a high performance insulation material, and also to develop the knowledge of the mechanical and thermal performance of that insulation material in the short and long term. This programme was of great interest to Technip as it was addressing many of the key issues that Technip were investigating.

This section summarises the outcome of this JIP, from the perspective of Technip.

Summary

The results of the DeFRIS JIP have been particularly positive as far as Technip are concerned for the following reasons:

A new PP based product was qualified for reeling. This product is expected to generate potential insulation thickness reduction, which might translate into potential installation cost saving to Technip.

A material database was established for a range of the components of the PP based multi-layer system from Thermotite, thanks to the laboratory test carried out by MERL. Technip acquired a better understanding of the PP material properties, performance and capabilities.

Technip was able to test some key installation parameters at a full scale level (e.g. friction factor wet coating/tensioner pads).

Finally, it was possible to generate a finite element model capable of reproducing the results of a full-scale reeling and straightening simulation of a coated flowline. This model will be used with confidence for future Technip installation projects, in order to study the integrity of the steel pipes with a greater level of accuracy.

Reeling - background

Many of the deepwater offshore oil and gas fields currently under development have two major common technical issues to address. These are increasingly stringent insulating requirements. OHTCs as low as 0.5 $W/m^2.K$ are currently specified. In order to meet OHTC levels in the region of 2 to 3 $W/m^2.K$, the thickness of wet insulation coating needs to be significantly increased, to values in the order of 60 to 100 mm. The insulation coating material must be able to maintain its mechanical and thermal integrity in wet and highly pressurised environments.

These requirements have repercussions on the design and installation methods of wet insulation coated flowlines. The main issues as far as Technip are concerned are listed below, on the basis of the Technip / DeFRIS documents Ref. DeFRIS 10 [1] and DeFRIS 19 [2]:

- Increased insulation-coating influences the quantity of coated pipeline that can be reeled on the hub of the pipelay vessel. In some field development scenarios, the number of offshore installation trips could be increased, because of the increase of thickness of the insulation material. The project cost repercussions could be very significant.
- Thick coating can influence the global structural behaviour of the coated pipeline system during the reeling and un-reeling process. Discontinuity of mechanical and geometrical properties of the steel pipeline can generate local lift-off of the pipeline during reeling, and potentially ovalise the flowline - beyond an accepted critical level in a worst case scenario. A discontinuity of the coating stiffness, which can mainly occur at the coating / field joint coating interface (different material properties), can exacerbate the phenomenon previously described. The critical point occurs at flowline stalk tie-in during the reeling operation, whereby there is little time for the field joint coating to cool down.
- Access to good knowledge of insulation behaviour and performance, allowing accurate modelling of the coated flowline system.

The DeFRIS JIP provides Technip with key parameters in order to address the above issues. These are:

- Higher performance PP foam, as proposed by Borealis and Thermotite. The aim of this material was to increase the pressure resistance capability of the standard PP foam used by Thermotite as part of their well known multi-layer system. The increased pressure resistance of the PP foam allows targeting greater water depth, while also allowing the use of lighter material for a given hydrostatic pressure rating. The ability to decrease the foam density for a given pressure rating, permits a decrease of the thermal conductivity, enhancing the insulating performance of the material. Consequently, for a given target water depth, it is possible to decrease the thickness of insulation material necessary to meet the insulation performance (OHTC) required.
- A general review of different possible novel materials for use for future development. These are discussed in MERL / DeFRIS document DeFRIS/9 [3] and Technip / DeFRIS document DeFRIS/20 [4].
- A greater understanding of the properties of the material constituting the Thermotite multi-layer insulation system, see Thermotite /DeFRIS document DeFRIS/17 [5] and MERL/ DeFRIS document DeFRIS/14 [6].
- The ability to produce reeling finite element models and to verify their accuracy versus full-scale reeling tests, see Technip/ DeFRIS document DeFRIS/24 [7] and Thermotite/ DeFRIS document DeFRIS/18 [8].
- The ability to carry out full scale qualifications of polypropylene based multi-layer systems, see Technip/DeFRIS documents DeFRIS/21, 22 and 23 [9,10,11] and Thermotite/ DeFRIS document DeFRIS/18 [8].

Full-scale testing

As part of this JIP, Technip was mainly involved in the review [9] and organisation of full scale tests of a flowline coated with a multi-layered polypropylene based insulation coating system, using the novel material, which was developed by Borealis and Thermotite.

The full scale testing programme mainly comprised:

- A review of requirements [9].
- The reeling trial of insulated flowline joints [8,10]
- Tensioner pad testing [11]
- Service life and OHTC test, post reeling [12]

Review of Requirements [9]

This document provides a description and summary of a range of full scale tests that shall be carried out in order to qualify an insulation coating material fully, for installation and use over a duration of 20 years.

The aim of this document was to summarise the main tests required to demonstrate that the insulation material preserves the required integrity, and performance level, throughout assembly, construction, pipelay and long term service.

From that document, it was recommended that the following tests be carried out:

- Reeling and straightening simulation of an insulated pipeline.
- Tensioner pad testing, to demonstrate that the tensioner system of the CSO Deep Blue can keep the top tension, generated by the pipelay catenary of the coated pipeline, in deepwater.
- Service life test of the insulation in a wet pressurised environment to define the thermal performance, creep, and water intake of the insulation material, at the end of the field's life.

These tests are summarised below.

Reeling and Straightening Simulations

Two tests were carried out. These are described in greater detail in [8,10].

Both test series consisted in reproducing the strain level that the coated pipeline will experience, during the reeling and straightening phases of the offshore pipelay.

A number of multi-layer PP coating insulated flowline joints were subjected to two reeling and straightening cycles at the Heriot Watt University (HWU). The flowline joint was 10" OD nominal, and the coating system was 41.5mm thick nominal. The reeling radius was 9.75m, which corresponds to the radius of the CSO Deep Blue Hub. The environmental temperature was approximately 6^{o}C.

Two field joint coating systems (different cut back geometry) were tested as part of this testing series.

This reeling trial series resulted in the failure of the field joint coating and neighbouring coating. Poor application quality, and inconsistent properties of the bonding interface, were mainly to blame. Novel field joint coating material was also used. This may have contributed to, or have been at the source of, the failure.

A second testing series was later organised at the Technip Orkanger Spoolbase by Thermotite. For this testing series, three pipeline joints were insulated by an approximately

80 mm thick multi-layered PP insulation system. One of the 81 mm thick joints included a standard field joint coating, another included a new field joint coating system, the last did not include any field joint. Another pipe joint was insulated with a 50 mm thick coating system, including the alternative field joint coating system. The reeling operation was carried out on a 8.23m radius reel, representative of the CSO Apache at a temperature ranging between 6 and 13 ^{o}C.

The testing results were:

- 80 mm thick coating – No field joint = passed
- 80 mm thick coating – Standard field joint = passed
- 80 mm thick coating – New field joint = failed at FJC
- 50 mm thick coating – New field joint = failed at FJC

The above test results show that the coating system is reelable on the smallest main reel radius of any Technip pipelay vessel. It also confirms that the properties and design of the field joint coating has a significant impact on the reelability of the overall coating system. It was proven that a standard field joint coating system can be reeled to CSO Apache reel size for the test temperature range.

Tensioner Pad Testing

This test is presented in greater details in [11].

The purpose of this test was to show the integrity of the coating system, while subjected to radial compression of tensioner pads from the CSO Deep Blue, and an associated large tension load in the flowline. This test is representative of a tensioner system sustaining the top tension generated by the catenary load of a flowline, insulated with a multi-layer PP coating system.

Appropriate coefficients of friction, representative of a contact between a wet, solid, PP layer, and the actual tensioner pad design of the CSO Deep Blue, were measured. These will be implemented in the installation design procedure for the CSO Deep Blue.

The test piece used was a cut section from one of the test joints that experienced the reeling and straightening simulation at HWU. No coating failure or damage was witnessed during the test.

Simulated Service Test

This test is described in greater detail in [12].

A cut section from one of the test pieces, which experienced the reeling and straightening simulation at the Orkanger Spoolbase, was subjected to this simulated service test.

The purpose of the test was to simulate exposure of the coating to a pressurised water environment, representative of deepwater conditions. The inside of the flowline was heated in order to simulate circulation of hot hydrocarbon product. The aim of this test is to record the changes in the insulating performance of the coating system over an agreed test duration, which will be representative of the changes in the coating performance and water intake, over the expected field life.

The test set up has been completed. However, due to schedule reasons, it is not possible to produce test results at the time of writing of this document. These test results will be made available in the coming weeks.

Finite Element Analysis

As part of the DeFRIS JIP, Technip intended to use the results of the material laboratory test [6] for input in a finite element (FE) analysis model. The latest reeling trials [8] were simulated in FE.

The purpose of that exercise was to compare the results of the FE analysis and those of the full scale test, to assess the accuracy of the FE model.

This exercise is presented in greater detail in [7].

The main conclusions of this exercise were that there was a relatively good correspondence between the test results and the outputs of the FE analysis. Some little difference could be observed, but it was generally considered that this model could be used for future simulations of coated pipe reeling, with a reasonable degree of confidence. The main target of the FE analysis will be the study of the steel integrity during the different steps of the pipelay operation. It is considered that modelling the behaviour of the coating material, in order to assess the integrity of the coating material accurately, would require further work. In other words, it cannot be concluded at this stage that investigating the coating integrity with the FE model alone is accurate enough, and that full scale testing is still expected to be necessary.

References

1. ‘Reel Installation of Pipelines’, DeFRIS/10 document.
2. ‘Influence of Thick Coating on Pipeline Reeling’, DeFRIS/19 document.
3. ‘Review of System Y Candidate Materials’, DeFRIS/9 document.
4. ‘Review of System Y – Candidate Materials’, DeFRIS/20 document.
5. ‘Thermotite Trial Sept 2001’, DeFRIS/17 document.
6. ‘Review of test data and test data manual’, DeFRIS/ 14 document.
7. ‘DeFRIS Reeling Test at Orkanger Spoolbase – Test Results V FEA’, DeFRIS/24 document.
8. ‘Verification Trial on TDF Insulation System – Trial August 2003’, DeFRIS/18 document.
9. ‘Full Scale Qualifications of a Wet Insulated Flowline’, DeFRIS/21 document.
10. ‘Heriot Watt University Simulated Spooling & Straightening’, DeFRIS/22 document.
11. ‘Tensioner Pad Testing DeFRIS Pipe’, DeFRIS/23 document.
12. ‘Simulated Service Test’, DeFRIS/25 document.

LIST OF DELIVERABLES

Deliverables from the DeFRIS project consist, primarily, of a series of technical reports. The following table provides an index of these.

Report ref	Title	Who	Revision	Issue date
DeFRIS/1 DeFRIS 1.pdf	Field development scenarios	MCS		April 01
DeFRIS/2 DeFRIS 2.pdf	Flow assurance report	MCS		April 01
DeFRIS/3 DeFRIS 3.pdf	Specification/performance requirements	MCS		April 01
DeFRIS/4 DeFRIS 4.pdf	Env. & life cycle assessment	MCS		April 01
DeFRIS/5 DeFRIS 5.pdf	ECG feedback report (current practice)	MERL		Nov 01
DeFRIS/6 DeFRIS 6.pdf	Review of test techniques/methodology	MERL		Nov 01
DeFRIS/7 DeFRIS 7.pdf	Analysis requirements	MCS	Rev 02	Sept 03
DeFRIS/8 DeFRIS 8.pdf	Review of thermal testing methods & apparatus	MERL		Nov 01
DeFRIS/9 DeFRIS 9.pdf	Review of system Y candidate materials	MERL		Nov 01
DeFRIS/10 DeFRIS 10.pdf	Reel installation of pipelines	Technip-Coflexip		Nov 01
DeFRIS/11 DeFRIS 11.pdf	Local FE analysis report	MCS		Jun 02
DeFRIS/12 DeFRIS 12.pdf	Potential riser/flowline concepts – study basis	MCS	Rev 02	Sept 03
DeFRIS/13 DeFRIS13.pdf	Global performance requirements report	MCS		Dec 03
DeFRIS/14 DeFRIS 14.pdf DeFRIS14 Appendices.pdf	Review of tests/data manual	MERL		Oct 03
DeFRIS/15	Technology implementation plan (TIP)	MCS/all		Nov 03
DeFRIS/16 DeFRIS 16.pdf	Potential riser/flowline concepts - study report	MCS		Sept 03
DeFRIS/17 DeFRIS 17.pdf	Thermotite trial Sept 2001	Thermotite		Nov 03
DeFRIS/18 DeFRIS 18.pdf	Verification trial on TDF insulation system	Thermotite		Aug 03
DeFRIS/19 DeFRIS 19.pdf	Influence of thick coating on pipeline reeling	Technip-Coflexip		May 02

DeFRIS/20 DeFRIS 20.pdf	Review of System Y candidate materials	Technip-Coflexip		Nov 02
DeFRIS/21 DeFRIS 21.pdf	Full scale qualification of a wet insulated flowline	Technip-Coflexip		Oct 03
DeFRIS/22 DeFRIS 22.pdf	Heriot Watt University simulated spooling and straightening	Technip-Coflexip		Sept 03
DeFRIS/23 DeFRIS 23.pdf	Tensioner pad testing Defris pipe	Technip-Coflexip		Oct 03
DeFRIS/24 DeFRIS 24.pdf	DeFRIS reeling test at Orkanger Spoolbase – test results	Technip-Coflexip		Oct 03
DeFRIS/25 DeFRIS 25.pdf	Service performance tests/verification	Technip-Coflexip		Dec 03
DeFRIS/26 DeFRIS 26.pdf	Reel tests at Orkanger Spoolbase – test results v's FEA	Technip-Coflexip		Dec 03
DeFRIS/27 (NB This document)	Summary technical report	All		Dec 03
DeFRIS/28 DeFRIS 28 - Rev01.pdf	Potential riser/flowline concepts – study report	MCS		Dec 03
DeFRIS/29	Validation of FE models and software tool	MCS		Dec 03
DeFRIS/30	DISDANS Version 2.0 – user documentation	MCS		Dec 03

The list above includes descriptions of the development, validation and user documentation for DISDANS, a (delivered) standalone-design-tool for the development of coated flowlines.

A further deliverable is dissemination. This has been achieved via the End–user Consultative Group (ECG), and published technical papers and articles for the Oil & Gas Operators community. This effort is described below.

Dissemination

Having established dialogue with the end-users, the current limitations and future requirements of pipe and riser insulation systems have been defined (see below). Contacts have been kept informed, on an individual basis, of the progress of the project, and an opportunity was provided to attend the 12-month project meeting held in November 2001. While the initial response to this invitation was positive, actual attendance was poor, significantly affected by the terrorist attacks in September of that year, and subsequent corporate travel policies. At that meeting it was agreed that a web-site would be established to assist with ECG communication, and individual visits/meetings would continue taking advantage of conferences etc. Dissemination has also been greatly assisted by the opportunity provided to exhibit at Industry Trade Shows by the EC scheme, which allowed participation on the European Commission stand at *Offshore Technology Conference 2002* in Houston Texas, and *Offshore Northern Seas (ONS) Stavanger Norway*. Numerous contacts were made at these events and have been augmented by the development of a Project website through which final, summary, reports will be channelled. The various partners have presented a series of technical papers. These have included the OMAE conference held in Norway during the summer of 2002. This paper discussed "*Alternative Polymeric Systems For Future Deep-Water Insulation Applications*" as a result of work on *System Y*. This and other titles and abstracts are provided below;

Title: DeFRIS project: Alternative Polymeric Systems For Future Deep-Water Insulation Applications.

Abstract

There is a current problem with regard to the long-term performance of some materials used for subsea pipeline insulation. New oil & gas fields are increasingly being developed in deeper water, which therefore require insulation systems to function under more severe hydrostatic conditions involving increased pipe lengths. In addition to these issues, specific to deepwater, prospects with high temperature fluids requiring long tie-backs are now under consideration, some in the region of 150-160°C at the wellhead. High grade thermal insulation systems are required on flowlines to maintain production fluids at suitable temperatures during flowing conditions and also to keep the temperatures above minimum values during shut-in conditions. Many current polymeric insulation systems have operational temperature limitations well below these levels. MERL is acting as coordinator for a European Commission 5th Framework Funded project, DeFRIS (Deepwater Flowline & Riser Insulation Systems). This is a three year project currently completing the first twelve month period. This paper describes progress to date in the search for alternative polymeric systems for future high-duty insulation applications.

MERL also presented the following paper at the Offshore Engineering with Polymers conference, London, November 2003.

Title: Service Related Property Measurements on Novel Foamed Thermoplastic Insulation Systems for Deepwater Applications

Abstract

The EC funded DeFRIS (Deepwater Flowline and Riser Insulation Systems) joint industries project is nearing completion. Its main aims have been to resolve some of the technical requirements associated with subsea pipe insulation in future deep water and higher temperature wells, address the limitations of current systems and materials and to develop new materials/systems to provide economical deepwater insulation. The concept introduced in this project has been that of the material system – a combination of materials – to meet the insulation and mechanical performance requirements of this service. To achieve this, the project has developed an effective screening test regime to allow long-term service life to be predicted. The project has also developed design software to act on both a global level (modelling the pipe or riser) and the local level (modelling heat loss/retention) based on the generated physical data.

This paper describes the testing techniques used within the screening regime, focusing particularly on thermal, mechanical and physical property measurements of thermoplastic systems. Results obtained for several insulation systems are presented and discussed. A new and emerging thermal measurement technique has been used to measure the thermal properties of the deepwater systems. Static measurements as well as thermal property changes under load and also during long-term creep tests have been performed and are also discussed in this paper.

Thermotite and Borealis were joint authors of a paper presented at Offshore Technology Conference (OTC) 2002, Houston, Texas. This paper provided initial details of the novel polypropylene insulation technology that they have been working on as part of this project. The abstract is provided below:

Title: Development and Qualification of Novel Thermal Insulation Systems for Deepwater Flowlines and Risers based on Polypropylene

Abstract

Copyright 2002, Offshore Technology Conference
This paper was prepared for presentation at the 2002 Offshore Technology Conference held in Houston, Texas U.S.A., 6–9 May 2002.

Flow assurance including thermal insulation are critical elements in the design and operation of flowlines and risers in deep waters due to a combination of low temperatures, high pressures and economic drivers for high availability. The stringent requirements put new challenges on insulation systems and the paper will discuss a suitable insulation system that can meet these requirements.

MCS have, similarly, presented technical papers. These include the following, presented at the OMAE 2003 conference in Cancun, Mexico and at the SAMPE (Society for the Advancement of Material and Process Engineering). The SAMPE conference took place on 1-3 of April 2003 in Paris.

Title: Development of an analytical tool for the design of deepwater riser/flowline thermal insulation systems

Summary

The offshore oil and gas industry is predicting the discovery of more and more deepwater reservoirs. Increased water depths create a requirement for reliable pipelines to economically recover these deepwater fields and also to minimise flow assurance problems. Increased flow assurance problems in deeper waters increase the need for thermally insulated pipelines.

This paper presents an overview of the key issues in the analysis and design of thermal insulation systems, identifies and discusses how these are addressed by the design tools developed within the DeFRIS project and presents results used to validate the algorithms incorporated into the design tool.

Title: Short And Long-Term Performance Of Polymer Foam Insulation Systems In Deepwater Offshore Applications

Summary

Polymer foams have been used for pipeline insulation by the offshore oil and gas industry for some time due to their excellent insulation properties and low cost. Experience to date has been limited to water depths of about 1000m. New systems are now required to meet the insulation and mechanical performance requirements in planned developments in excess of 2000m. Multilayer systems, incorporating new foams capable of withstanding the pressures at these large depths, are being developed. Creep of these materials can result in significant densification of the foam layers over the design life leading to a degradation of the thermal performance. The design of such systems must therefore involve an assessment of both the short-term and long-term thermal and mechanical performance. This paper examines the characteristics of the insulation system and describes an analytical design tool that has been developed, which allows the designer to determine the system response over its lifetime.

This work was carried out as part of a Joint Industry Project funded by the EU. The contributions of the DeFRIS JIP members (Borealis, MCS International, MERL, Technip-Coflexip and Thermotite) to the development of the software tool is acknowledged.

Meetings and communication – Other Projects

MERL were made aware of 5FP project AURAM (contract ENK6-2000-00066) by their EC technical representative: the project is co-ordinated by ABB Norway. This project is focused on the replacement of conventional risers with light-weight composite risers. This, it is proposed, will have the effect of reducing overall weight on the associated topside structure/facility. The project aim is to develop a prototype riser section, a process that will include a life-time prediction tool.

MERL personnel (R Shepherd and R Martin) visited ABB (18^{th} April 2001 as part of ECG visits and partner meeting) in order to establish whether there was any likely synergy or duplication between AURAM and DeFRIS. The work in AURAM, to date, appears to have concentrated on production techniques for the composite parts, in particular the development of new pre-preg tape materials and winding techniques. The principal goal is to produce an economically viable prototype system. At present, insulation systems are not considered part of the project, however, it was agreed that a level of communication will be maintained between the two projects. This was a useful opportunity to introduce the two projects to each other.

A visit to an independent composite pipe manufacturer based in the Netherlands was made by Dr Ric Seddon of MERL, as a result of an enquiry to the project website. The company's products consisted of a thermoplastic liner with a fibre-reinforced outer layer, resulting in a flexible corrosion-free pipe, suitable for a broad range of chemicals and hydrocarbons at high pressure and temperature. The inner layer is typically made of cross-linked polyethylene, and is used in combination with a glassfibre epoxy laminate as the outer shell. This type of pipe is currently in service as a subsea methanol injection line in the North Sea. The Company contacted MERL through the DeFRIS website, and expressed an interest in the project regarding the potential use of alternative pipe materials. During the meeting, interest in using the DeFRIS pipe coating process either to coat sections of their composite pipe, and/or, put a composite outer shell on already extruded thermoplastic foam insulation, was expressed.

MANAGEMENT AND CO-ORDINATION ASPECTS

From the point of view of management and performance; the consortium has performed well on the technical front, but some partners have, apparently, had some difficulty with the administration of cost claims. Deliverables have generally been presented to schedule, and communication between partners has been good, see below.

Project level communications

In all nine project meetings have been held, attended by all partners:

1st project meeting 2nd November 2000 (Location – Thermotite, Orkanger, Norway)
2nd project meeting 11th December 2000 (Location – MERL, Hertford, UK)
3rd project meeting 24th April 2001(Location - Borealis, Stennungsund, Sweden)
4th Project meeting 27th November 2001 (Location – MERL, Hertford, UK)
5th Project meeting 5th March 2002 (Location – Thermotite, Orkanger, Norway)
6th Project meeting 18th June 2002 (Location – MCS, Galway, Eire)
7th Project meeting 8th October 2002 (Location – CSOL Aberdeen, UK)
8th Project meeting 9th April 2003 (Location - Borealis, Stennungsund, Sweden)
Final Project Meeting 1st September 2003 (Location – CSOL Aberdeen, UK)

The level of communication was greater in the first period of the project in order to establish the project team, plan the work programme, and negotiate the consortium agreement. Subsequent project meetings were held at 6-monthly intervals where possible.

Partner communications

Numbers of additional discussions between various partners occurred during the course of the project, and included a meeting which discussed Flowline and Riser concepts and the implication for installation costs etc., and culminating with the prototype pipe bending trial in Orkanger (Thermotite) in October 2003.

Partner contribution

Each of the partners has contributed significantly from their own expertise while also learning from the experience and extending their current/knowledge and product base, this is amply illustrated by the contribution of each partner to this report in earlier sections.

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RESULTS AND CONCLUSIONS

Overall the DeFRIS project has been successful on a number of fronts as indicated by the individual Partner reports. In summary goals have been achieved.

While gathering information from industry end-users, it has been possible to establish a ready network through which project developments can be disseminated.

A further task has enabled a specification of the performance requirements for the thermal insulation systems to be developed. This task involved the identification of the operational requirements of the system. These operational requirements included structural, thermal and mechanical properties. An assessment has also been made of the in-place loads to which the system will be subjected. A review of the options for installation and an identification of the installation performance has also been completed.

Following a full review of all aspects of thermal insulation systems it has been possible to develop empirical based software tools. These will allow easy and efficient design of global insulation systems. The software tool has been calibrated using the results of the local finite element analysis.

In terms of pipe insulation systems, effort has been focused on the development of two new systems *System X* and *System Y*. These have each pursued a particular requirement of the project; *System X* to extend the deepwater performance of foamed polypropylene systems and *System Y* to explore the use of alternative and novel materials under high temperature fluid conditions. This has been further supported by the work to develop improved design and analysis tools; i.e. to design, develop and install systems for high-duty service applications, and to evaluate existing, and develop improved, screening tests/methodologies.

As a result a several of the new PP grades developed within the DeFRIS project have shown better deepwater and high temperature performance than previous PP materials. Tensile properties are above the requirements for these systems and the partners feel that with further careful tuning of the extrusion process and by lowering the density of the foam, a suitable balance between mechanical and thermal properties can be achieved. The foam structure and the homogenisation of the polymer melt have been optimised and meet the creep specification and the requirements from reel-lay operations.

The new generation of stiff PP polymers has resulted in a significant advance, seen in the PP foam used as thermal insulation in a multilayer pipe coating system. In addition to the stiff PP copolymer, HMS-PP based polymers can be added to improve the homogeneity of the PP foam, increasing the compression strength and improving creep resistance. This has resulted in a product that can withstand a greater hydrostatic pressure, without altering the thermal insulation performance. Thus the new PP foam can be introduced for use at significantly greater water depths.

Sufficient mixing between BA212E and HMS-PP is of vital importance to obtain PP foams with good mechanical and insulation properties. Therefore the pre-compounded BA150E (70% BA212E/30% HMS-PP) was developed which shows improved foam quality and mechanical properties due to enhanced homogeneity.

A number of full-scale trials have been performed for the prototype (novel) polypropylene (PP) system which has been identified in the market as Thermotite TDF. The trials have explored and optimised the manufacturing process parameters and polymer ratios, along with a study of foaming techniques. Thermotite has already managed to secure two major contracts, i.e. the BP Thunderhorse and the Statoil Kristin projects through the DeFRIS development efforts.

Materials property tests including comparative thermal property measurement techniques have also been performed. A number of technical papers and journal articles have been published describing the enhancements of the novel PP system, *System Y* work and its findings, test methodologies, and the analysis tool developments.

Finally from the point of view of installation the main conclusions of the project were that there was a relatively good correspondence between the test results and the outputs of the FE analysis. Some little difference could be observed, but it was generally considered that this model could be used for future simulations of coated pipe reeling, with a reasonable degree of confidence. The main target of the FE analysis will be the study of the steel integrity during the different steps of the pipelay operation. It is considered that modelling the behaviour of the coating material, in order to assess the integrity of the coating material accurately, may still require further work.

Each of the partners' technical knowledge and understanding of the area has increased significantly as a result of the project and each has added to their portfolio of expertise, and in each case their product base.