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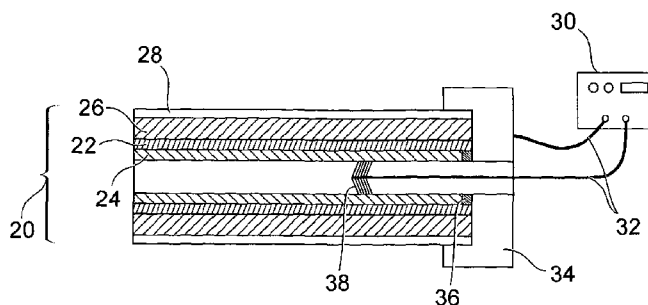


Fig. 2

(57) Abstract: A method of testing an unbonded flexible pipeline comprising a polymer pressure sheath, the method comprising at least the steps of: (a) transmitting an electromagnetic signal along the polymer pressure sheath; (b) seeking one or more reflected signals; and (c) analysing the or each reflected signal to determine one or more characteristics of the electrical permittivity of the polymer pressure sheath. In this way, a non-invasive electromagnetic signal can be generated to be passed along the polymer pressure sheath of the pipeline, and any reflected signals can be interpreted and analysed to ascertain any change in the dielectric properties of the polymer pressure sheath, in particular the presence or existence of one or more discontinuities such as cracks or holes, in advance of possible failure, in particular catastrophic failure, of the polymer pressure sheath. Characteristics of the reflected signal(s) can include distance, extent, etc. of discontinuities along the pipeline. This invention can be applied both to new pipelines during their manufacture and/or instalment, as well as existing pipelines being in situ or in service, thereby providing a single method for analysing all forms of pipelines.

METHOD OF TESTING AN UNBONDED FLEXIBLE PIPELINE

The present invention involves a method of testing an unbonded flexible pipeline, particularly but not exclusively in or for an underwater or below
5 the seabed pipeline, particularly but not exclusively in an in service or in-situ underwater pipeline, and particularly using reflectometry techniques such as time domain reflectometry (TDR).

Unbonded flexible pipelines are complex structures of overlapping metallic
10 and polymer layers, each with a specific quality and function that combine to form a strong, versatile, corrosion resistant pipe. The use of flexible pipelines in developing complex deepwater assets worldwide is proving to be a popular, cost effective and technically sound option. Their high strength-to-weight ratio and corrosion resistance compared to
15 conventional carbon steel pipes makes them capable of transporting a range of aggressive products in challenging environments.

The exact configuration of each pipeline, including the number and thickness of each layer, will depend on its final application and takes into
20 consideration water depth, pressures, likely fatigue stresses and composition of production fluids. Generally, one layer is an inner polymeric pressure sheath, acting as the only conveyed fluid sealing layer within the pipeline structure. Therefore, the integrity of this layer is usually crucial to the safe and reliable operation of the pipeline.

25 Figures 1a and 1b of the accompanying drawings show a part-cutaway perspective diagram and a cross-sectional diagram respectively of a typical flexible pipeline 2 comprising a number of concentric layers. The thicknesses of the layers in Figure 1b are not to scale to assist clarity.

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From the outside to the inside, the pipeline 2 shown in Figures 1a and 1b comprises an outermost layer 4 being an external thermoplastic sheath to protect the internal layers from the environment/water ingress. Next, there are one or more, shown in the example as two, crosswound tensile armours 6 intended to be resistant to axial and torsional forces. Thirdly, there is a pressure vault layer 8 formed by an interlocked steel pressure wall. This is intended to resist internal and hydrostatic pressure, as well as radial compression.

The second innermost layer is a polymer pressure sheath 10. The innermost layer of the flexible pipeline shown in Figures 1a,b is an inner carcass 12 adapted to resist hydrostatic pressure and radial compression whilst supporting the polymer pressure sheath 10. This layer can typically be 316 stainless steel.

Each one of the overlapping layers has a specific role to play in the overall performance of the flexible pipeline 2, and a failure in any one layer can lead to loss of integrity and possible catastrophic failure of the pipeline 2. However, aging of the polymer pressure sheath 10 is known to be one of the major causes for loss of integrity as recorded in surveys conducted on flexible pipelines.

Such sheaths are generally formed by one or more polyamides, which can include one or more nylon polymers. A range of materials under the Trade Mark RILSAN (RTM) are known in the art, the most common being polyamide 11 or "PA-11". Indeed, almost two thirds of the current flexible pipelines in service have PA-11 pressure sheathes, and the ageing of PA-11 has been responsible for a number of pipe failures over the years.

The ageing of polyamide sheaths is due to hydrolysis reactions at elevated

temperatures in the presence of water and acidic environments. This reaction breaks the chemical links within the polymer and leads to embrittlement. The material may progressively lose its ductility and finally become too brittle to resist to the curvature variations of the pipe.

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It is well known that there is a correlation between the ageing and the molecular weight of the polyamide due to the hydrolysis reaction reducing the length of the polyamide molecules, and therefore reducing the molecular weight of the material. The molecular weight of the polymer is usually characterised by solution viscosity measurements (by a sample being dissolved in a solvent), but other methods such as light scattering or size-exclusion chromatography can also be used.

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US2005/0247103 A1 shows a method for assessing the life expectancy of a polymer lined pipe involving the use and creation of pre-aged witness coupons which characterises and monitors the rate and extent of chemical and physical ageing of the polymer in the structure during use in the field. However, this requires regularly retrieving such coupons followed by a separate analysis in a laboratory.

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US5317252 describes a dosimeter with reproducible changes in electrical permittivity characteristics, using an electrode pattern in the form of an interdigitated capacitor positioned on the substrate being tested, which is not readily practical for testing in situ or long underwater flexible pipes.

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One object of the present invention is to provide a simpler method of inspection of a polymer pressure sheath in an unbonded flexible pipeline.

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Another object of the present invention is to provide a direct assessment of a polymer pressure sheath in an unbonded flexible pipeline to provide a

more accurate service life.

According to one aspect of the present invention, there is provided a method of testing an unbonded flexible pipeline comprising a polymer pressure sheath, the method comprising at least the steps of:

- (a) transmitting an electromagnetic signal along the polymer pressure sheath;
- (b) seeking one or more reflected signals; and
- (c) analysing the or each reflected signal to determine one or more characteristics of the electrical permittivity of the polymer pressure sheath.

In this way, a non-invasive electromagnetic signal can be generated to be passed along the polymer pressure sheath of the pipeline, and any reflected signals can be interpreted and analysed to ascertain any change in the dielectric properties of the polymer pressure sheath, in particular the presence or existence of one or more discontinuities such as cracks or holes, in advance of possible failure, in particular catastrophic failure, of the polymer pressure sheath. Characteristics of the reflected signal(s) can include distance, extent, etc. of discontinuities along the pipeline.

The present invention can be applied both to new pipelines during their manufacture and/or instalment, as well as existing pipelines being in situ or in service, thereby providing a single method for analysing all forms of pipelines.

The flexible pipeline may be any suitable pipeline able to allow the transmission or conveyance of an electromagnetic signal along a polymer pressure sheath, usually being one or more longitudinal layers forming the pipeline, and also able to transmit or convey one or more reflected signals

created by the electromagnetic signal, either in return, or along one or more other paths to a location where such reflected signals can be monitored and detected, and optionally also interpreted.

- 5 The pipeline may be formed from one or more pipes, for example a single pipe integrally formed as a single length of pipeline. More usually, the pipeline is formed from two or more, usually a number of, identical or similar pipes or pipe sections brought together by the use of one or more connection arrangements known in the art. The formation and
10 arrangement of pipe sections to form an underwater hydrocarbon-conveying pipeline is known in the art.

The method of the present invention is particularly suitable to provide a non-destructive evaluation of a polymer layer in a flexible pipeline which is
15 usually hidden, and can extend some distance, generally being wholly or substantially underwater, including under the seabed.

According to one embodiment of the present invention, the unbonded flexible pipeline is a hydrocarbon conductor such as a riser, generally for
20 the passage of one or more hydrocarbons such as oil, gas, etc. between a source and a collector, being wholly or partly underwater.

The method of the present invention is useable on the flexible pipeline shown in the accompanying Figures 1a,b. The skilled person in the art is
25 aware of the possible construction, make-up and variations of flexible pipelines involving a polymer pressure sheath.

The electromagnetic signal can be created by any suitable signal generator, and conveyed using any suitable coupling antennas or other
30 coupling device or devices, such as passing an electrical signal next to or

near to the polymer pressure sheath, in particular forming an electrical circuit around the polymer pressure sheath.

5 According to another embodiment of the present invention, the pipeline further comprises one or more metallic layers on either side of the polymer pressure sheath, such as one or more armours or armour layers, and a metallic carcass layer, on at least one side, preferably on either side, of the polymer pressure sheath. Such layers can assist in the propagation of an electromagnetic signal in the polymer pressure sheath, and/or act as a
10 guide to the electromagnetic signal as it passes along the polymer pressure sheath.

One or more characteristics of the electromagnetic signal can be varied, such as the magnitude and/or phase of the signal at particular
15 frequencies, and/or the amplitude of the signal at particular instants in time, and this can assist in considering the interpretation of the reflected signal(s) and thus determination of the extent of any discontinuities in the pipeline. Such characteristics may be based on variations in the electrical signal extracted from the electromagnetic signal wave in the polymer
20 layer.

For example, an electrical signal used to generate the electromagnetic signal of step (a) may comprise one or more components and/or pulses, and is preferably one or more voltage pulses, generally provided by a
25 voltage pulse generator. Another variation is the use of a frequency swept sine wave or pseudo random noise, and the present invention is not limited to time domain methods with impulses or step waveforms.

Thus, according to one embodiment of the present invention, the electrical
30 signal generating the electromagnetic signal comprises one or more

voltage pulses.

According to another embodiment of the present invention, the electrical signal generating the electromagnetic signal comprises one or more
5 frequency swept sine waves.

Reflectometry can have a time domain basis, a frequency domain basis, and/or a cross-correlation with wideband signals, etc.

10 Preferably, the method of the present invention uses time domain reflectometry. Time Domain Reflectometry (TDR) is a well known and proven technology for inspecting electrical transmission lines and cable harnesses.

15 In using TDR, the skilled person is able to take account of known inhomogeneities, particularly when the or each reflected signal is interpreted using a system which is calibrated to take account of such inhomogeneities, for example by the use of one or more software analysis programs or processes.

20 Electrical TDR relies upon the ability of an item under test to support the transmission of electromagnetic waves. If a short pulse is transmitted at one end of a transmission line for example, and if the transmission line has a constant characteristic impedance, Z_0 and is terminated with a
25 resistance equal to Z_0 , then the pulse will be completely absorbed by the termination resistance. If however there are discontinuities in the characteristic impedance of the transmission line or the termination of the transmission line is not matched, then a proportion of the transmitted wave or signal will be reflected from each discontinuity. These reflected waves
30 will be further reflected as they encounter more discontinuities. A

proportion of the energy in the reflections eventually returns to the point of transmission where it may be monitored as the received or reflected signal(s). The relative timing and magnitude of the monitored pulses is dependent upon the dielectric properties of the medium and the location of the discontinuities.

A number of factors contribute to discontinuities of the characteristic impedance of a transmission line. The characteristic impedance of a transmission line is determined by the geometry and the relative permittivity of the material. Localised inhomogeneities within the material will affect its dielectric properties, and thus the characteristic impedance, caused by variation in the complex relative permittivity due to ageing, temperature gradients or variation in humidity will result in discontinuities.

As polymer pressure sheaths are generally made from a polyamide such as RILSAN (RTM), these are generally relatively good electrical insulators or dielectric materials. Where the polymer pressure sheath is particularly sandwiched between good electrical conductors, this particular configuration represents a transmission path that is more capable of supporting the propagation of electromagnetic waves. Layers in a flexible pipeline, such as metallic carcass and armour layers forming a pressure vault, are normally made from steel/stainless steel, which is a relatively good electrical conductor.

Thus, the method of the present invention can comprise wavelength propagation or the further step of propagating the wavelength of the electromagnetic signal to extend the length of the pipeline being tested.

The present invention uses electromagnetic signals, in particular the application of reflectometry, to monitor such inhomogeneities by applying

a short electrical pulse between for example the carcass and the pressure vault of a flexible oil pipe and observing the reflected signals.

5 The electrodes for an electrical signal can be one or more of the metallic (reinforcing) layers near to, generally in contact with, the inner and outer surfaces or the polymer pressure sheath. In particular, the pipeline could be viewed as a coaxial cable, with the central conductor being an inner carcass layer (generally made with stainless steel, whose main function is preventing pipe collapse under hydrostatic pressure), the insulation layer
10 being the polymer pressure sheath, and the outer conductor being the pressure vault and the tensile armour layers (generally made with carbon steel; to withstand the fluid pressure and the tensile stresses).

15 According to a further embodiment of the present invention, the method of the present invention can use a wide-ranging frequency sweep in order to determine the complex impedance of the polymer pressure sheath as a function of frequency. Then, a Vector Network Analyser (VNA) could be used in step (c) of the method of the present invention, for example to apply an inverse Fourier transform to the frequency domain
20 measurements or S-parameter reflection coefficients such as S₁₂, to yield a set of transformed measurements that are exactly equivalent to the direct application of the reflectometry such as TDR. This is further advantageous as the overall energy in the 'transmitted' signal is significantly more than that normally used for direct TDR, because it is
25 continuous, the signal to noise ratio of the measurements is enhanced.

Thus, according to one preferred embodiment of the present invention, the method is able to measure the electrical properties of a nylon pressure sheath with frequency domain TDR by using inner carcass and armour
30 layer(s) as electrical conductors to guide an electromagnetic pulse down

the nylon layer to measure variations in its characteristic impedance through reflected signals. The impedance changes caused by variations in permittivity due to aging and degradation will give a reflected signal(s) and a measurement thereof, generally one or more of its characteristics, can be correlated against known CIV values to evaluate, or assist in evaluating, the integrity of the nylon layer.

The present invention can be deployed for a number of different applications, in particular:

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1. A monitoring role for new build projects and specifically risers and production jumpers. This involves attaching connections from a network analyser or the like to inner carcass and armour layers at the end termination during manufacture and end-termination assembly. For production jumpers the network analyser could be marinised in a suitable pressure vessel and connected back to a manifold SCM via flying leads and electronic plug connections.

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2. An inspection role for existing in-service pipe. As it is not feasible to access inner carcass and armour layers of a flexible pipeline that has already been manufactured and installed, electrical connections for providing the present invention could be made across the inner carcasses at the flange connections of two separate flexible pipes of a pipeline. This could be at the riser base or any other flange connection of two pipes. The electromagnetic signal could then be created in the polymer pressure sheath layer as described herein with the electrical conductors acting as the guide.

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According to another embodiment of the present invention, the or each reflected signal is interpreted by comparison against the corrected

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inherent viscosity of the polymer pressure sheath. In this way, the reflected signal(s) can be analysed by comparing the characteristic impedance of the polymer pressure sheath along a given length of flexible pipeline and referencing this values against known CIV values for the same material. The inspection range at each location will be dependant on a number of factors that include conductivity of the conductors, geometry and amount of ageing in the polymer pressure sheath. The size of reflection from anomalous areas can also indicate the extent of degradation through the thickness of the thermoplastic layer.

Advantages of the present invention include:

1. The technology can be applied to new build as well as installed pipelines.
2. The flexible pipeline can be tested while in situ.
3. No modifications to in-service pipelines are required.
4. No coupons are required or used topside or subsea.
5. A non-destructive method of testing.
6. The polymer pressure sheath such as a nylon layer can be screened over several meters rather than at localised locations like coupons.
7. The system can be fixed in place on new pipeline projects, so monitoring of defect areas can be carried out as the project progresses, rather than only when the pipeline or project is completed.
8. Results can be correlated with process data to give a more accurate integrity risk assessment of the flexible pipeline.
9. The electrodes are connected at end termination so there are no changes required to the manufacturing process of the flexible pipes and pipelines as such.
10. The technology can be deployed by conventional pigging methods or by a bi-directional vehicle for in-service pipe.

In particular, use of TDR allows testing to be carried out on a significant length of pipe rather than measurement of a small section or only a small coupon of material at a particular location along a pipeline. Such pipelines can be many metres long, some being up to 1000m or beyond. Thus, the present invention provides a very convenient non-invasive and non-destructive method of testing along a significant length of pipeline, which pipeline may already be in situ or in use/service.

In one embodiment of the present invention, the frequency of the electromagnetic signal is in the range 1 MHz to 2 GHz, preferably in the range 100 MHz to 2 GHz.

The use of higher frequencies in a TDR method also allows a reduction in the wavelength, which gives rise to finer spatial resolution of the measurements. Wave propagation phenomena have a large influence on signals, especially when the frequency is between 100 MHz and 2 GHz, and they are particularly useful where the wavelength is much smaller than the dimensions, in particular the length, of the pipeline being tested.

Another advantage of using higher frequencies is a better sensitivity to some molecular changes in the polymer pressure sheath, especially those relating to dipolar mobilities.

In another embodiment of the present invention, steps (a) and (b) are carried out from one end of the pipeline. For example, a metallic end-fitting is located and/or mounted at the end of the pipeline to which the required apparatus, units or devices are able to transmit an electrical signal to create the electromagnetic signal, and to seek one or more reflected signals. The reflected signal may be monitored using the same antenna as the transmitter unit, and measuring changes in high frequency

impedance or S-parameter reflection coefficients such as S11. The analyser (for example an oscilloscope with TDR facility or a Vector Network Analyser) could have a system or mechanism to separate the forward and reflected waves to enable the reflected wave(s) to be isolated and analysed.

Additionally and/or alternatively, at least step (b), preferably steps (a) and (b), are carried out in the pipeline, optionally using a pig (or other in-line tool). In this arrangement, a signal could be applied between two adjacent ends of two separate lengths of inner carcass that are mutually electrically isolated, for example by a flange. The signal thus propagates in both directions of the pipeline despite there being no direct connection to the armour layer. As for the situation in which the signal is applied between the inner carcass and the armour layer, the wave is guided within the pressure sheath by means of the electrical conductors (inner carcass and armour layer) that enclose it.

Pigs, etc. are well known devices used in pipelines, either being self mobile or propelled by one or more other devices or the fluid passing along the pipeline, so as to be able to provide one or more services in or along the pipeline from an internal position.

In another embodiment, the time of flight could be determined in steps (a) and (b) by means of measuring the round trip time (RTT). As with TDR, this could be implemented either in the time domain and/or the frequency domain.

The use of pigs for implementing TDR is also particularly useful to extend the method of the present invention beyond a pipe-pipe connection arrangement, such as a flanged gasket, forming the pipeline; in particular

a pipe-pipe connection which is electrically and/or electromagnetically inhibiting and/or insulating. The pigs can provide or support an electrical connection having an electrically conducting path on either side of such a pipe-pipe connection, so that any electrical signal and the electromagnetic
5 signal can transverse the break in the polymer pressure sheath created by the pipe-pipe connection arrangement. In this way, the method of the present invention can be extended along a pipeline comprising a number of otherwise electrically isolated or insulated pipes or pipe sections.

10 Thus, the method of the present invention could include wherein at least a portion of the flexible pipeline comprises two pipes and a flange connection, and the transmission of the electromagnetic signal of step (a) is carried out passed the flange connection.

15 The present invention particularly provides a method of testing an unbonded flexible pipeline for its ageing, degradation or both.

According to a second aspect of the present invention, there is provided a system for testing an unbonded flexible polymer pressure sheath, the
20 system comprising at least:

- (a) a transmitter for generating an electromagnetic signal along the polymer pressure sheath;
- (b) a monitor for seeking one or more reflected signals; and
- 25 (c) an analyser for analysing the or each reflected signal to determine one or more characteristics of the electrical permittivity of the polymer pressure sheath.

The present invention encompasses all combinations of various
30 embodiments or aspects of the invention described herein. It is

understood that any and all embodiments of the present invention may be taken in conjunction with any other embodiment to described additional embodiments of the present invention. Furthermore, any elements of an embodiment may be combined with any and all other elements of any of
5 the embodiments to describe additional embodiments.

Embodiments of the present invention will now be described by way of example only, and with reference to the accompanying drawings in which:

10 Figures 1a and 1b of the accompanying drawings show a part-cutaway perspective diagram and a cross-sectional diagram respectively of a typical flexible pipeline;

Figure 2 shows a first method of testing a flexible pipeline according to a
15 first embodiment of the present invention;

Figure 3 shows a second method of testing a flexible pipeline according to a second embodiment of the present invention; and

20 Figure 4 is a graph of several CIV against relative permittivity measurements.

The present invention provides an improved method for testing a pipeline.

25 Figures 1a and 1b are described hereinbefore, and show a typical flexible pipeline 2 created by five concentric layers, with the armour layer comprising two crosswound layers. Due to the positioning of the polymer pressure layer 10 between the inner carcass 12 and the pressure vault layer 8, inspection and integrity assessments of a polymer pressure
30 sheath layer in a flexible pipeline such as that shown in Figures 1a and 1b

while in service or in situ is extremely difficult. Lack of electrical continuity, interfaces between different materials, and the number and orientation of the layers are just a few of the problems facing non-destructive testing techniques conventionally used to inspect critical sections.

5

Thus, the conventional inspection and assessment techniques used to consider the integrity of an in service pipeline are limited, and often only comprise a visual inspection of the external thermoplastic sheath by ROV or divers, or monitoring of the annulus and video survey of the internal carcass. None of these provide a direct inspection of the polymer process sheath layer despite the high probability of loss of integrity caused directly by the ageing of the polymer process sheath.

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Figure 2 shows a first method of the present invention for testing an unbonded flexible pipeline 20.

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The pipeline 20 shown in Figure 2 at least comprises a polymer pressure sheath 22, an inner carcass layer 24, one or more armour layers 26, and a polymeric external sheath layer 28.

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Figure 2 also shows a TDR unit 30, generally including a vector network analyser (VNA). The TDR unit 30 is able to implement a frequency domain electrical signal to pass along the inner carcass layer 24 and armour layers 26 via two electrical conductors 32, an end-fitting 34, generally a metallic or metallic-based end fitting, more particularly an end termination, and a metal brush 38 within the inner carcass layer 24.

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The armour layers 26 and inner carcass layer 24 need not electrically connected, for example if the different sections of the pipeline are not electrically connected. The armour layers 26 can couple with the

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electrically conducting seawater (~5 S/m) through the external sheath layer 28, and so form an electrical circuit thereby, with the two sections of 'coaxial line' connected in series, but in antiphase. The coupling through the external sheath layer 28 may not be perfect, so that signals may also
5 able to propagate along two lengths of an external sheath, being guided by the armour layers and the seawater.

The signals could be pulsed DC, in the case of TDR or Time of flight (TOF) when implemented directly in the time domain, or swept AC signals in the
10 case of the VNA in the frequency domain.

The end-fitting 34 could be provided and/or fitted during manufacture of the pipeline 20 so as to conduct testing of the pipeline 20 during its
15 manufacture and/or initial installation. The end-fitting 34 could also be maintained on the pipeline 20 during installation and/or after installation and in service, so as to provide further and continued testing of the pipeline 20 after its manufacture and/or installation. In this regard, the end-fitting 34 could be marinised in a manner known in the art, optionally
20 with inclusion of the TDR unit 30 therewith, or with remote location of the TDR unit 30 by the electrical conductors 32.

Preferably, there are located one or more insulators, such as an insulating ring 36, between the inner carcass layer 24 and the end-fitting 34, so as to
25 provide or create electrical insulation thereinbetween, especially to avoid galvanic corrosion issues thereinbetween.

In use, the inner carcass and armour layers 24, 26 act as electrical conductors for an electrical signal to create an electromagnetic signal, in
30 particular an electromagnetic pulse, which can travel along the polymer

pressure sheath 22, guided between the electrically conducting inner carcass and armour layers 24, 26.

5 The electromagnetic signal is preferably based on a frequency sweep of the electrically applied signal to the inner carcass and armours between 1MHz and 1.6GHz. This frequency range creates signals having wavelengths in the range 300m - 0.1875m, which are generally much smaller than the length of the pipeline 20 under test (usually several hundred metres up to 1000m and beyond), and/or the length of testing
10 desired along the pipeline 20. Using longer wavelengths may increase possible wave propagation of the electromagnetic signal along the polymer pressure sheath 22, to allow long or longer lengths of pipeline 20 to be tested. The use of high frequencies improves sensitivity to some molecular changes in the polymer pressure sheath 22, especially those
15 related to dipolar mobility.

A TDR oscilloscope or VNA can provide yield graphs of the reflected signal as a function of time. The reflected signal(s) are created by discontinuities or inhomogeneities in the polymer pressure sheath 22. For
20 example, one or more cracks or holes in the polymer pressure sheath 22 will create a change in the impedance of the polymer pressure sheath 22. As such, a proportion of the transmitted electromagnetic signal will be reflected from each discontinuity. These reflected signals may be further reflected as they encounter more discontinuities. Such reflections can
25 then be monitored.

The method of testing in Figure 2 is to monitor for the receipt of reflected signals at the point of transmission of the electromagnetic signal. The or each reflected signal can then be interpreted to determine a characteristic
30 of the electrical permittivity of the polymer pressure sheath 22, particularly

by correlating it against the known CIV values of the polymer pressure sheath 22.

Figure 4 shows graphs of the real relative permittivity of a Rilsan [PA-11] layer against corrective intrinsic viscosities (CIV) based on different frequencies of the electrical signal causing the electromagnetic wave. As mentioned above, there is a clear well known correlation between the CIV and the ageing of Rilsan. A correlation between the real relative permittivity and the ageing can therefore be deduced from graphs such as those shown in Figure 4.

In addition, the real relative permittivity can affect the speed of propagation of the electromagnetic wave, (approximately and based on the inverse root law), whilst the imaginary permittivity (not shown in Figure 4 but also depending on the ageing) can affect the absorption of the electromagnetic wave. Step changes in either of these parameters will also cause reflections, whose analysis can also show characteristics of the electrical permittivity of the polymer pressure sheath, and hence be a test of the pipeline.

Figure 3 shows a second method according to the present invention of testing a second pipeline 40.

The second pipeline 40 comprises two pipes 40a, 40b with a gasket 42 forming a flange connection between the pipes 40a, 40b in a manner known in the art. Such a flange connection arrangement is typical of a situation for existing in service or in situ flexible pipes where end fittings are not directly achievable, whilst directed visual inspection of the polymer pressure sheath layer in pipes 40a, 40b is also not directly achievable.

In the second method of the present invention shown in Figure 3, each of the pipes 40a, 40b comprising the pipeline 40 comprise an inner carcass layer 42, a polymer pressure sheath layer 44 preferably being a nylon and even PA-11 material, one or more armour layers 46, and an external
5 sheath 48.

The layers and transmission and propagation of an electromagnetic signal along the polymer pressure sheath layer 44 is similar in the second method of Figure 3 as that shown in relation to the first method of the
10 present invention described above in relation to Figure 2. However, for the second embodiment shown in Figure 3, the TDR unit, and optionally also an analyser such as a vector network analyser, can be located in an internal-pipeline vehicle such as a pig 50.

15 Pigs are well known in the pipeline art, and can be self propelled, but are more usually propelled either by the product in the pipeline itself, or by one or more propelling vehicles such as a SIG tractor vehicle (IMV). An umbilical 52 or other type of tether can be provided from a launcher or from the launch for the pigs 50 to provide power and communications
20 thereto.

The pigs 50 include means such as wheels or rollers 54 known in the art to allow their movement against the inner surface of the pipeline 40. The pigs 50 can support one or more electrical connections, such as the
25 metal brushes 56 shown, to provide an electrical path between the inner carcasses 42 of the pipes 40a,b. Figure 3 also shows one pig 50 including a video camera 58 to assist location of the pigs 50 in use.

In use, it is preferred that each section of pipe 40a, 40b is electrically
30 isolated by the gasket 42. Each pig 50 is then located on either side of the

gasket 42 and is preferably stationary during the testing method. As described above in relation to the first testing method of Figure 2, an electrical signal is provided and measured between either the inner carcass and armour layers 42, 46, or two adjacent ends of separate lengths of inner carcass 42, to generate an electromagnetic signal which is able to transmit along the polymer pressure sheath layer 44. An impedance matching device may be needed to match the impedance of the TDR/VNA to the pipeline, which may have a much lower impedance.

Any discontinuities or inhomogeneities in the polymer pressure sheath 44 will create a reflected signal, which can be monitored by a relevant analyser in the pig 50 to determine the receipt of one or more reflected signals. Such reflected signals can then be analysed by the VNA in the pigs 50 for interpretation against the expected electrical permittivity of the polymer pressure sheath layer 44 based on its known CIV values.

Interpretation and analysis of reflected signals based on TDR is well known in the art to provide calculation of one or more characteristics (such as size) of the electrical impedance of the material under test. The distance of any discontinuity can also be estimated based on the time domain nature of TDR. In the present invention, the use of metal or metallic-based layers co-axially within and without the polymer pressure sheath layer provides particular guide or guidance for the electromagnetic signal.

Moreover, a vector network analyser (VNA) can be used with frequency domain TDR to more accurately determine the size, extent and position of discontinuities in a polymer pressure sheath such as the RILSAN materials, based on a comparison with previously determined permittivity measurements. This can determine different degrees of ageing. Using

different frequencies, impedance analysers can be used to measure the real and imaginary components of the impedance of the polymer pressure sheath to determine a correlation between its permittivity properties and its CIV values.

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Various modifications and variations to the described embodiments of the invention will be apparent to those skilled in the art without departing from the scope of the invention as defined herein. Although the invention has been described in connection with specific preferred embodiments it

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should be understood that the invention as defined herein should not be unduly limited to such specific embodiments.

Claims

1. A method of testing an unbonded flexible pipeline comprising a polymer pressure sheath, the method comprising at least the steps of:
- 5 (a) transmitting an electromagnetic signal along the polymer pressure sheath;
- (b) seeking one or more reflected signals; and
- (c) analysing the or each reflected signal to determine one or more
- 10 characteristics of the electrical permittivity of the polymer pressure sheath.
2. A method as claimed in claim 1 wherein the pipeline is an underwater pipeline, preferably a hydrocarbon conductor.
- 15 3. A method as claimed in claim 1 or claim 2 wherein the pipeline further comprises one or more metallic armour layers and a metallic carcass layer, preferably on either side of the polymer pressure sheath.
4. A method as claimed in any one of claims 1 to 3 wherein the
- 20 polymer pressure sheath is a polyamide, preferably including nylon.
5. A method as claimed in claim 4 wherein the polymer pressure sheath is Rilsan (RTM) PA-11.
- 25 6. A method as claimed in any one of the preceding claims wherein the electromagnetic signal is generated by an electrical signal comprising one or more voltage pulses.
7. A method as claimed in any one of the preceding claims wherein
- 30 the electromagnetic signal is generated by an electrical signal comprising

one or more frequency swept sine waves.

8. A method as claimed in any one of the preceding claims wherein the method uses time domain reflectometry.

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9. A method as claimed in claim 8 based on claim 7 wherein the method uses frequency domain time domain reflectometry.

10. A method as claimed in any one of claims 6 to 9 wherein the frequency of the electrical signal is in the range 1 MHz to 2 GHz, preferably in the range 100 MHz to 2 GHz.

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11. A method as claimed in any one of claims 6 to 10 wherein the wavelength of the electrical signal is smaller than a length of the pipeline being tested.

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12. A method as claimed in any one of the preceding claims comprising the further step of propagating the wavelength of the electromagnetic signal to extend the length of the pipeline being tested.

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13. A method as claimed in any one of the preceding claims wherein steps (a) and (b) are carried out from one end of the pipeline.

14. A method as claimed in any one of claims 1 to 12 being a non-destructive method of testing an in situ flexible pipeline.

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15. A method as claimed in claim 14 wherein step (b) is carried out in the pipeline, optionally using a pig.

16. A method as claimed in claim 14 or claim 15 wherein at least a

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portion of the flexible pipeline comprises two pipes and a flange connection, and the transmission of the electromagnetic signal of step (a) is carried out passed the flange connection.

5 17. A method as claimed in any one of the preceding claims wherein the or each reflected signal is interpreted by comparison against the corrected inherent viscosity of the polymer pressure sheath.

10 18. A method of testing as claimed in any one of the preceding claims for testing the ageing, degradation or both of the polymer pressure sheath.

19. A system for testing an unbonded flexible pipeline comprising a polymer pressure sheath, the system comprising at least:

15 (a) a transmitter for generating an electromagnetic signal along the polymer pressure sheath;
 (b) a monitor for seeking one or more reflected signals; and
 (c) an analyser for analysing the or each reflected signal to determine one or more characteristics of the electrical permittivity of the polymer
20 pressure sheath.

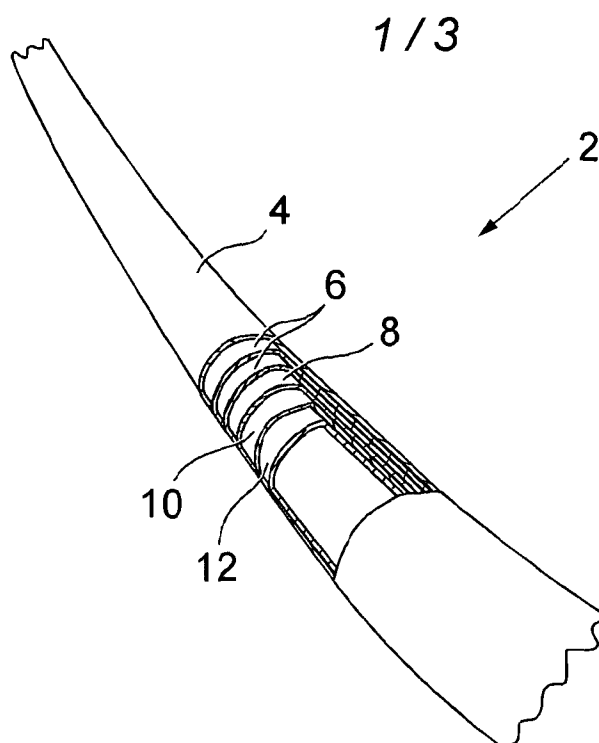


Fig. 1a

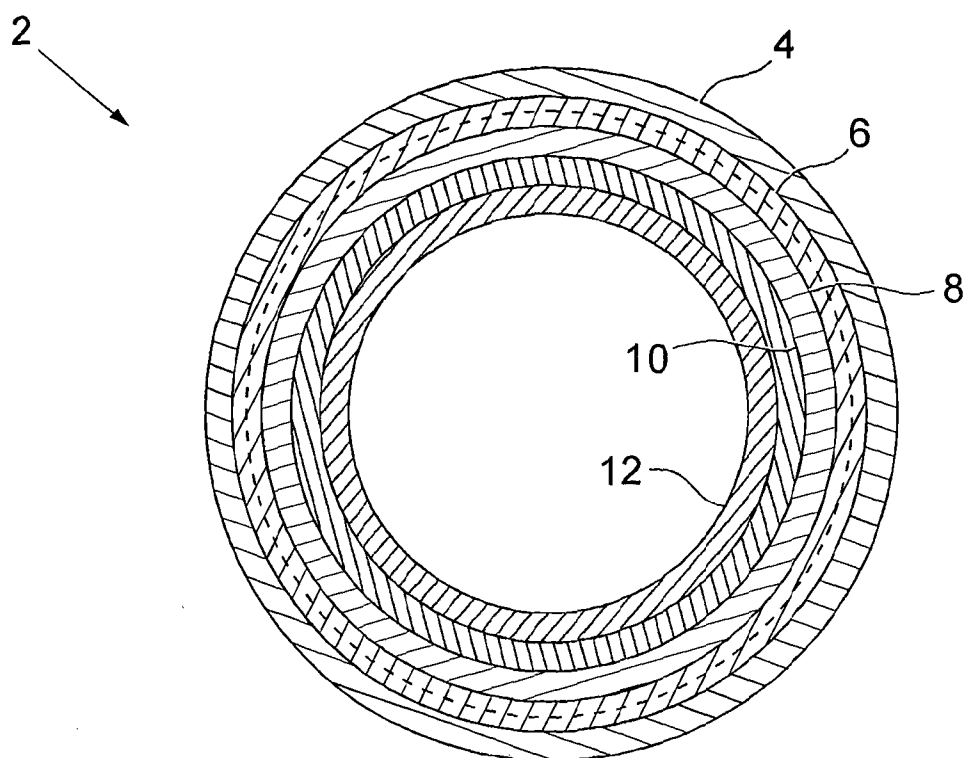


Fig. 1b

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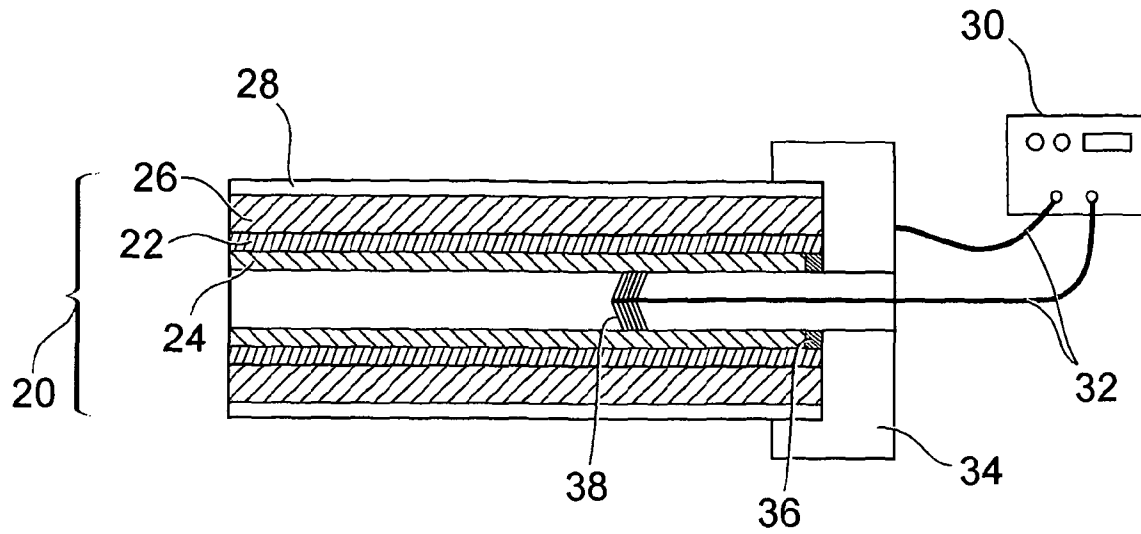


Fig. 2

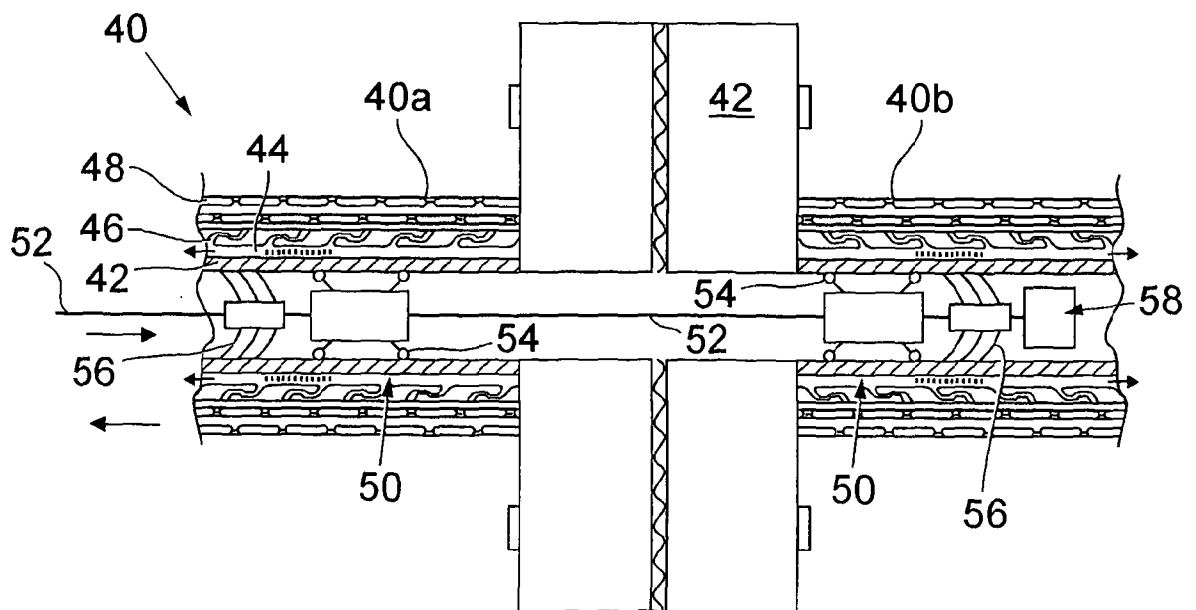


Fig. 3

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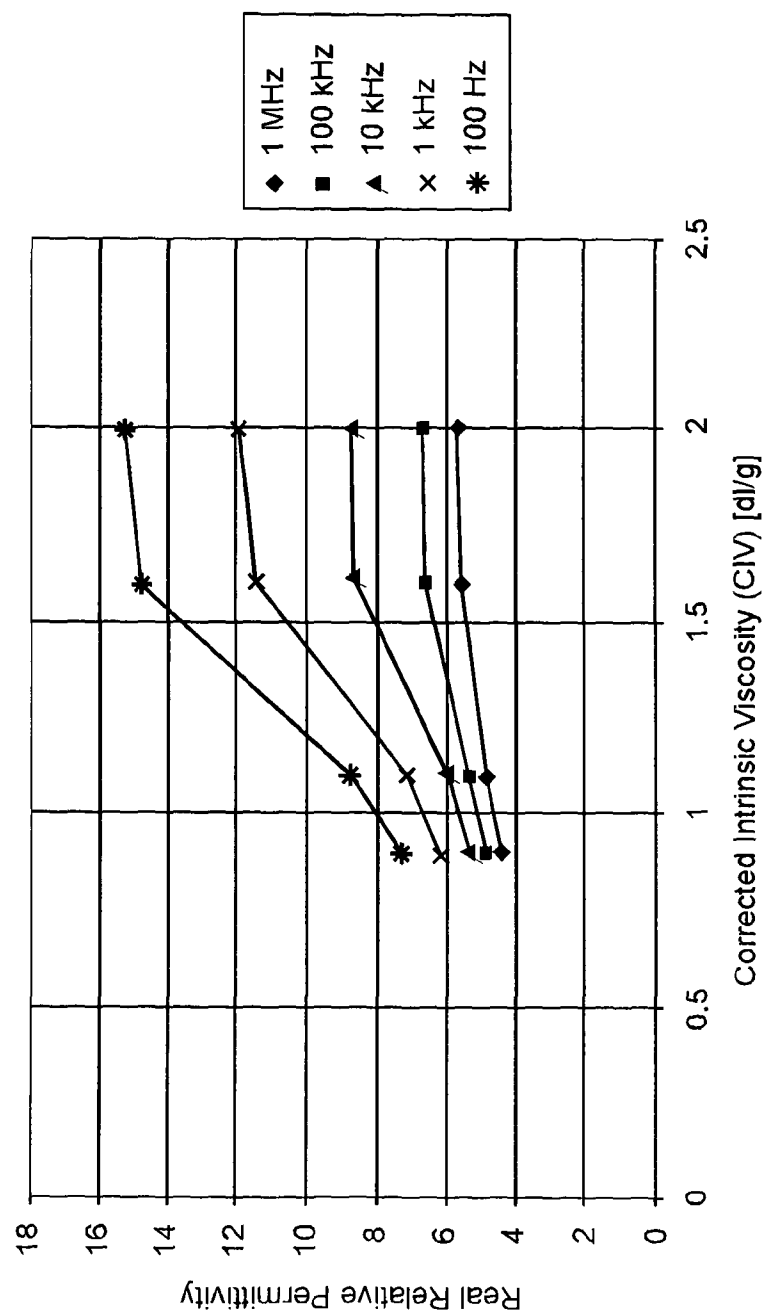


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2010/051443

A. CLASSIFICATION OF SUBJECT MATTER		
INV.	G01M3/14	G01M3/18 G01M11/00 G01M5/00
According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED		
Minimum documentation searched (classification system followed by classification symbols)		
G01N G01M F17D F16L H04B		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used)		
EPO-Internal, WPI Data, COMPENDEX		
C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 905 194 A (STRONG THOMAS P [US]) 18 May 1999 (1999-05-18) abstract figures 1-3 column 1, line 6 - column 4, line 37	1-19
X	US 2008/191706 A1 (BURNETT GALE D [US] ET AL) 14 August 2008 (2008-08-14) abstract figures 1a,1b paragraphs [0018] - [0044]	1-19
	-/--	
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "&" document member of the same patent family		
Date of the actual completion of the international search		Date of mailing of the international search report
21 December 2010		02/02/2011
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Nelva-Pasqual, F

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2010/051443

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2006/097112 A2 (NKT FLEXIBLES IS [DK]; GUDME JONAS [DK]) 21 September 2006 (2006-09-21) abstract figures 1,2 page 1, line 5 - page 2, line 10 page 3, lines 29-31 page 10 -----	1-19
A	OUT J M M ET AL: "Integrity of flexible pipe: search for an inspection strategy" ENGINEERING STRUCTURES, vol. 17, no. 4, May 1995 (1995-05), pages 305-314, XP002614976 DOI: 10.1016/0141-0296(95)00028-6 the whole document figure 1 page 308, column 1; table 1 -----	1-19
A	DR BOYUN GUO: "Offshore Pipelines" REFEREX, 2005, page 302PP, XP040426110 abstract figure 10.1, pages 119-125 pages 161-168 pages 219-232 -----	1-19

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Information on patent family members

International application No

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			EP 2135063 A1 23-12-2009
			WO 2008118498 A1 02-10-2008

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