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(54) METHOD FOR REMOVING HYDRATE PLUG FROM A FLOWLINE

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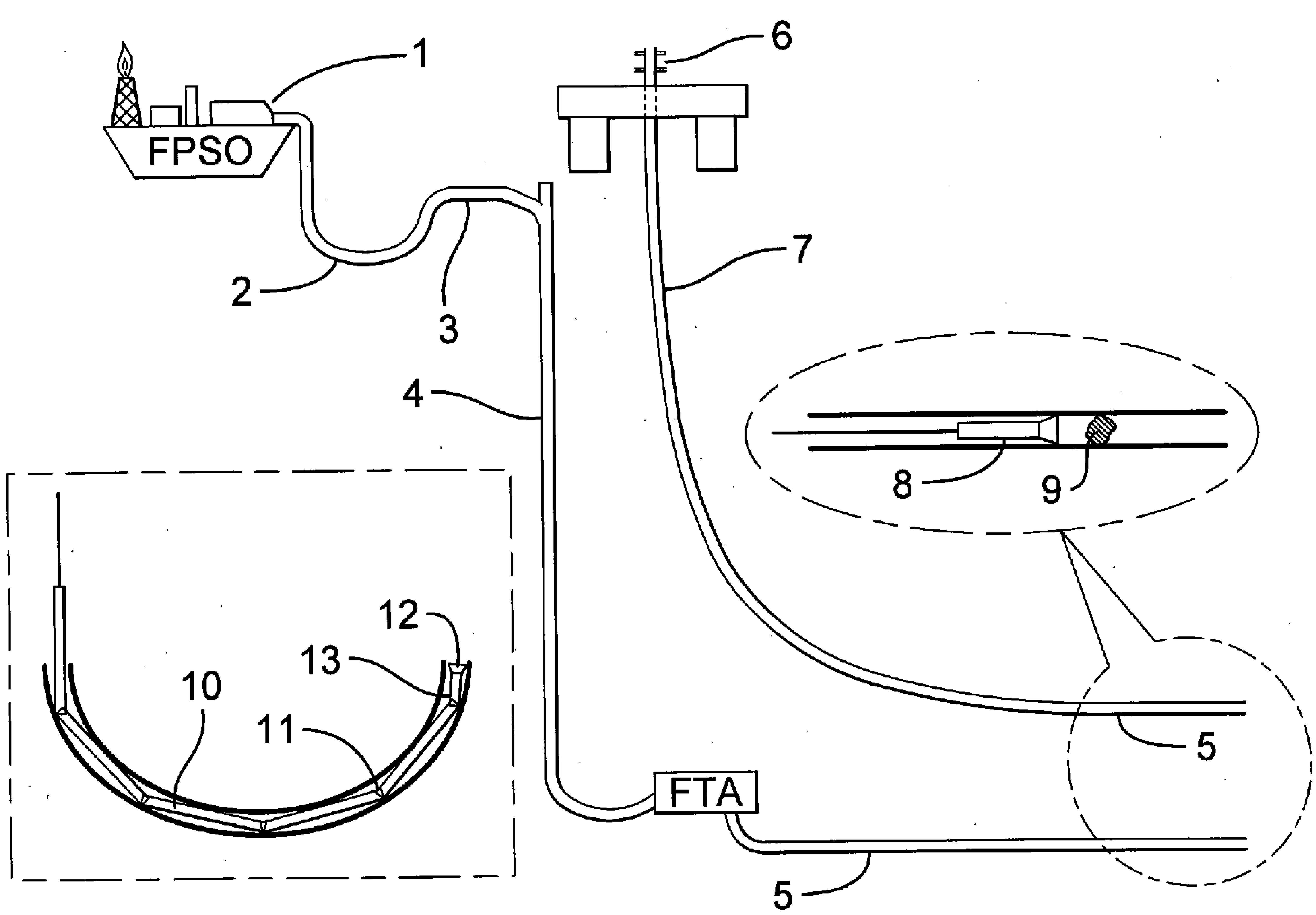
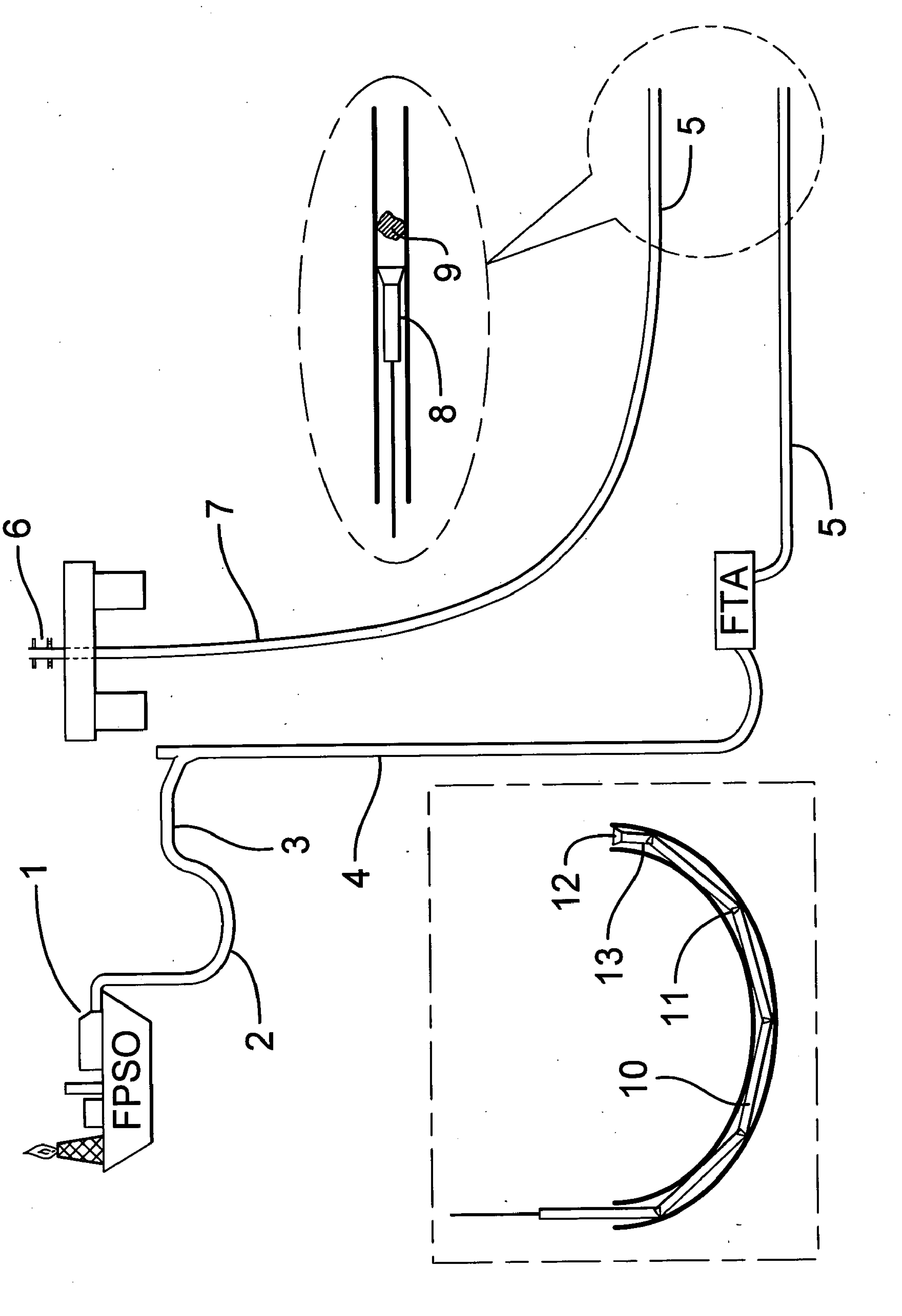
(57) **ABSTRACT**

A method of drilling through a blockage in a flowline using a remotely controlled electrically operated drilling tool that comprises a drill bit, a steering means, a pumping means, and a propulsion system wherein the drilling tool is connected either directly or indirectly to an electric cable and the drill bit is mounted on the steering means, the method comprising: introducing the drilling tool into the flowline; actuating the electrically operated propulsion system to move the drilling tool through the flowline to the location of the blockage; actuating the electrically operated steering means so that the drill bit is aligned with the blockage; actuating the electrically operated drill bit so that the drill bit engages with and drills through the blockage; and actuating the electrically operated pump so that when the drill bit engages with the blockage, fluid that is present in the flowline adjacent the blockage is passed over the cutting surfaces of the drill bit and cuttings from the blockage are transported away from the cutting surfaces of the drill bit suspended in the fluid.

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METHOD FOR REMOVING HYDRATE PLUG FROM A FLOWLINE

[0001] This invention relates to a method for re-starting the flow of a fluid through a flowline when the flowline has become blocked with a solid material such as gas hydrates, wax, mineral scale, asphaltenes or corrosion products. In particular, this invention relates to a method for re-starting the flow of a fluid through a subsea flowline.

[0002] Subsea flowlines may be used in the oil industry for transporting produced fluids from a wellhead to a riser through which the produced fluid passes to a surface separation facility. The surface separation facility may be on a platform or a Floating Production Storage and Offloading (FPSO) vessel. Subsea flowlines may also used for transporting gaseous streams comprising natural gas (gas export flowlines or gas injection flowlines).

[0003] A problem may arise when a subsea flowline is used for transporting a multiphase fluid that comprises crude oil and/or gas condensate, produced water and produced gas in that the flowline may become blocked with gas hydrate, owing to the temperature at the seabed being below the temperature at which gas hydrates are formed at typical flowline pressures, for example, the temperature external of the flowline may be in the range of 4 to 7° C. Similarly, gas hydrates may form in a subsea flowline that is used for transporting a gaseous stream that comprises natural gas and produced water.

[0004] A problem may also arise when a subsea flowline is used for transporting a heavy crude oil in that wax and/or asphaltene components of the crude oil may deposit onto the walls of the flowline. Similarly, mineral scale may deposit onto the walls of a flowline from the aqueous phase of a multiphase fluid. Finally, corrosion of the flowline may lead to corrosion products accumulating in the flowline. These deposits may restrict or prevent flow of the multiphase fluid.

[0005] Thus, the present invention relates to a method of drilling through a blockage in a flowline using a remotely controlled electrically operated drilling tool that comprises a drill bit, a steering means, a pumping means, and a propulsion system wherein the drilling tool is connected either directly or indirectly to an electric cable and the drill bit is mounted on the steering means, the method comprising:

introducing the drilling tool into the flowline;

actuating the electrically operated propulsion system to move the drilling tool through the flowline to the location of the blockage;

actuating the electrically operated steering means so that the drill bit is aligned with the blockage;

actuating the electrically operated drill bit so that the drill bit engages with and drills through the blockage; and

actuating the electrically operated pump so that when the drill bit engages with the blockage, fluid that is present in the flowline adjacent the blockage is passed over the cutting surfaces of the drill bit and cuttings from the blockage are transported away from the cutting surfaces of the drill bit suspended in the fluid.

[0006] Typically, the flowline is used for transporting a multiphase produced fluid comprising crude oil and/or gas condensate, produced water and produced gas. Alternatively, the flowline may be used for transporting a gaseous stream comprising produced natural gas and produced water. Thus, the fluid that is present in the flowline adjacent the blockage and that is passed over the cutting surfaces of the drilling tool is typically a liquid (for example, crude oil and/or gas condensate and/or produced water) or a gas, in particular, a "wet" natural gas.

[0007] The flowline may be either completely blocked such that there is a plug in the flowline or partially blocked such that the flowline has a substantially reduced flow channel, for example, a layer of gas hydrate, wax, asphaltene or mineral scale may be present on the inner walls of the flowline.

[0008] Where the flowline is completely blocked, the drilling tool typically drills a borehole through the blockage. There may be a single blockage or a plurality of blockages in the flowline. Where there are a plurality of blockages in the flowline, pressure communication is achieved once the drilling device has drilled a borehole through all of the blockages. The person skilled in the art will understand that "pressure communication" is achieved when the pressure downstream of the blockage(s), is equal to the pressure upstream of the blockage(s) as a result of a borehole being drilled through the blockage(s) (where upstream and downstream refer to the direction of flow of fluids through the flowline prior to a complete blockage forming in the flowline). Pressure sensors in the flowline or at a surface separation facility may be used to determine if pressure communication has been achieved. The pressure of the fluid upstream of a complete blockage (plug) or a plurality of blockages (plugs) is typically at least **100** bar, for example, 150 to 300 bar.

[0009] Where the flowline is partially blocked; the drilling tool may be used to remove deposits from the wall of the flowline thereby increasing the available flow channel through the flowline.

[0010] The flowline may be a land or subsea flowline. Where the flowline is a subsea flowline, the drilling tool may be passed into the flowline through a riser with the drilling tool suspended from the electric cable. For example, the drilling tool may be introduced into a riser tower via a pig launcher that is located in a turret of a FPSO vessel. Alternatively, the drilling tool may be introduced into a riser via a buoyancy tower. The tool may be introduced into a riser via a non-stationary surface entry point such as on an FPSO vessel. Thus, the entry point for the drilling tool may be above sea level (hereinafter referred to as "surface entry point"). An entry access system for the drilling tool is provided at the surface entry point. Typically, the entry access system for the surface entry point comprises a blow out preventer, lubricator, injector and winch system (for the cable). Preferably, the surface entry point is within 10 kilometres, for example, within 6 kilometres of the location of the blockage in the flowline. Once the drilling tool has been lowered down the riser (by gravity), the propulsion system is used to move the drilling tool through the flowline to a location immediately downstream of the blockage.

[0011] Alternatively, the drilling tool may be introduced into the flowline through a subsea entry point in the flowline, for example, a Pipeline End Termination (PLET) or a Flowline Termination Assembly (FTA). Typically, the flowline is provided with a plurality of entry points spaced apart along the flowline. The entry points may be positioned in side branches in the flowline. These side branches preferably have gentle curves to facilitate installation of the drilling tool in the flowline. Suitable side branches include Y shaped sections in the flowline, for example, Y shaped sections where the side branch has an angle of up to 20° relative to the longitudinal axis of the main flowline. The subsea entry points are provided with an entry access system that allows the drilling tool to be installed and recovered from the flowline in such a way as to prevent loss of containment of the flowline. Preferably, the entry access system comprises various components that might be found in a wellhead, such as a lubricator, a dual valving system, a wireline stuffing box, and a grease seal. Suitably, the wireline stuffing box comprises rubber packing elements that seal around the cable as it is run into and pulled out of the flowline. The grease seal provides a dynamic seal around the cable. Thus, the wireline stuffing box and grease seal assure passage of the cable into the flowline without loss of flowline fluids into the environment. Preferably, at least one of the valves is a shear-seal valve that is capable of cutting the cable in the event of an emergency. The dual valving system allows the drilling tool to enter the flowline via the lubricator. Typically, one of the valves is arranged above the lubricator and the other below the lubricator. The upper valve is opened thereby allowing the drilling tool to pass into the lubricator. The upper valve is then closed and the lower valve opened thereby allowing the drilling tool to pass into the flowline.

[0012] Where the drilling tool is introduced into the flowline through a subsea entry point, the drilling tool may be lowered to the subsea entry point from a floating vessel, with the drilling tool suspended from an electric cable. Preferably, the cable is arranged within a flowline intervention riser that may be deployed from the floating vessel. The flowline intervention riser may be latched to the subsea entry point of the flowline using a suitable connector. A means for releasing the riser, in the event of an emergency, may also be provided at the subsea entry point. Preferably, the flowline intervention riser terminates at the surface at a valving system that comprises at least one pressure valve, a wireline stuffing box, and a grease seal. Typically, a chemical injection facility is also provided at the surface thereby allowing a treatment chemical to be delivered to the flowline via the flowline intervention riser.

[0013] Alternatively, the drilling tool and associated equipment may be provided subsea with electrical power being supplied via an umbilical. This is advantageous for ultra deep water owing to a reduction in wave motion. For example, an electric cable may be laid alongside the flowline with wet-connect electrical connection points for the drilling tool provided adjacent the subsea entry points. Typically, subsea fluid reservoirs are provided for collecting any flowline fluids that may otherwise be released to the environment. Typically, the drilling tool is delivered to and connected to the subsea electrical connection point via a remotely controlled submersible vehicle (ROV). The drilling tool is provided with a sufficient length of additional electric cable, such that the drilling tool may be passed through the subsea entry point and along the flowline to the location of the blockage.

[0014] Preferably the subsea entry point that is used to deliver the drilling tool to the flowline is located downstream of the blockage (on the surface facility side of the blockage). Typically, the subsea entry point is within 10 kilometres, preferably, within 5 kilometres, for example, within 2.5 kilometres of the blockage. Once the drilling tool has entered the flowline, the propulsion system is used to move the drilling tool through the flowline to a location immediately downstream of the blockage.

[0015] Preferably, the electric cable is connected to the drilling tool by means of a connector, in particular, a releasable connector that provides an emergency disconnect for the drilling tool. Preferably, the electric cable is a conventional cable formed from reinforced steel that encases one or more wires or segmented conductors for transmitting electricity or electrical signals (hereinafter "conventional cable"). The conventional cable may be a braided steel cable. The electric cable may also be a modified "conventional cable" comprising a core of an insulation material having at least one electrical conductor wire or segmented conductor embedded therein; an intermediate fluid barrier layer; and, an outer flexible protective sheath. Suitably, the insulation material is comprised of a flexible plastic or rubber material. Preferably, the intermediate fluid barrier layer is comprised of steel. Suitably, the outer protective sheath is comprised of steel braiding. Preferably, the electrical conductor wire(s) and/or segmented conductor(s) embedded in the core of insulation material is coated with an electrical insulation material. The electric cable may also be a composite cable or a polymer cable as manufactured by Brand Rex. In addition, the electric cable may be a hybrid cable that comprises a tubing having least one electrical conductor wire and/or at least one segmented electrical conductor embedded in the wall thereof. Typically, the hybrid cable comprises a concentrically arranged inner metal pipe and outer metal pipe. Thus, the electrical conductor wire(s) and/or segmented cable(s) run through the annular space between the inner and outer metal pipes of the hybrid cable. Preferably, the electrical conductor wire(s) and/or segmented conductor(s) are embedded in an insulation material (for example, a flexible plastic or rubber material) that fills the annular space between the inner and outer pipe. Preferably, the electrical conductor wire(s) and/or segmented conductor(s) of the hybrid cable are coated with an electrical insulation material. Preferably, the hybrid cable is provided with a protective sheath, for example, steel braiding. It is envisaged that the cable may be designed such that it operates. at below optimum efficiency for transmitting electricity. Accordingly, the cable will generate and emit heat to its external environment. This is advantageous as it may prevent gas hydrate from forming in the immediate vicinity of the cable thereby allowing the cable and hence the drilling tool to be advanced through the flowline.

[0016] Generally, the electric cable has a diameter of less than 2 inches, preferably, less than 1 inch. Where the electric cable is a conventional cable, it is preferred that the cable has a diameter of less than 0.5 inches, for example, braided electric wireline is supplied in varying diameters, typically 7/32, 9/32, 5/16 and 7/16 inches. The electric cable has a length that is at least as long as the distance from the surface to the blockage in the flowline (or as long as the distance between the electrical subsea connection points and the blockage in the flowline). Where the electric cable is run from the surface, it typically has a length of up to 30,000 feet, for example, up to 24,000 feet. The electric cable should have minimal contact with the inner wall of the flowline so as to avoid any friction between the electric cable and the flowline. For example, the cable may be provided with cable centralisers. It is also envisaged that friction between the cable and the flowline may be minimised by coating the cable with a low friction material.

[0017] Suitably, the drilling tool is provided with an elongate housing. Typically, the elongate housing is of circular cross-section. Typically, the diameter of the elongate housing is in the range of 2 to 24 inches, preferably, 4 to 12 inches. Preferably, the elongate housing is a segmented housing. By "segmented" is meant that the housing comprises a plurality of housing segments that are joined together by flexible joints or flexible connectors, for example, knuckle joints. Typically, the segmented housing has a length in the range of 10 to 60 feet, for example, 20 to 40 feet. The length of each segment of the housing should be such that the drilling tool is capable of negotiating bends having a radius of less than 5 pipe diameters, in particular, bends having a radius of less than 3 pipe diameters. Thus, the length of the housing segments will be dependent upon the internal diameter of the flowline. Typically, each segment of the housing has a length in the range of from 1 to 10 feet. Preferably, the segmented housing comprises 4 to 30, for example, 10 to 20 segments. The segmented elongate housing is preferably pressure sealed up to the maximum operating pressure of the flowline. Typically, the segmented elongate housing is pressured sealed against a pressure of up to 600 bar absolute, for example, up to 400 bar absolute.

[0018] Where the plurality of housing segments are joined together via knuckle joints, these joints typically allow no rotation between adjacent housing segments. Preferably, each knuckle joint provides an angular deviation of up to 90°, for example, up to 45°. By "angular deviation" is meant the deviation of the longitudinal axis of a housing segment relative to the longitudinal axis of an adjacent housing segment. The knuckle joints are capable of pressure sealing, at a pressure up to the maximum operating pressure of the flowline, throughout the full rotation of the drilling tool. Typically, the ball sockets of the knuckle joints provide the rotation and angular deviation. Generally, seals in the knuckle joints provide the pressure sealing capability. Generally, the knuckle joints are selected from those knuckle joints that have at least one flow-through bore that may comprise part of at least one fluid channel through the housing of the drilling tool (see below). Suitably the knuckle joints have thread connections at each end that connect the knuckle joints to adjacent segments of the housing. However, the knuckle joints may have other "non-rotating" connections at each end (of the types typically used in wireline tools). Suitable knuckle joints are provided by, for example, National Oilwell Varco and Thru-Tubing Technology.

[0019] The segmented housing provides flexibility to the drilling tool enabling it to negotiate typical geometries of "flexibles" (S-shaped flexible flow lines), "goosenecks", catenary risers, 3D bends (bends in a flowline or riser having a radius of 3 pipe diameters), multiple bends in a riser or flowline arranged over a short distance (for example, 2 to 10 bends, over a distance of less than 100 metres, in particular less than 50 metres), or flowlines that traverse undulating terrains.

[0020] Where the flowline is completely blocked, there is a risk that the blockage (or plug) may re-form behind the drilling tool before pressure communication can be established across the blockage. Thus, in a preferred embodiment of the present invention, a drill bit is provided at both the front and rear of the drilling tool (i.e. at each end thereof). The presence of the drill bit at the rear of the drilling tool is advantageous as this additional drill bit may be used to remove debris (cuttings) when withdrawing the drilling tool from the flowline, or to remove the drilling tool from a blockage in the event that the drilling tool becomes stuck in the blockage or the blockage re-forms behind the drilling tool. Preferably, the drill bit at the rear of the drilling tool has cutting surfaces formed from a material that will not damage the electric cable. Typically, the drill bit at the rear of the drilling tool is a core drill. As an alternative to having a drill bit at the rear of the drilling tool, an electric heating means or laser may be provided at or near the rear of the drilling tool for melting any gas hydrate or wax that may re-form behind the drilling tool. Where the flowline is partially blocked, an advantage of providing a drill bit at each end of the drilling tool, is that deposits may be removed from the wall of the flowline when the drilling tool is passed in both a forward and reverse direction through the flowline. Thus, it is envisaged that the drilling tool may be moved backwards and forwards within the flowline a plurality of times, for example, 2 to 5 times, in order to substantially remove the deposit from the wall of the flowline. Where the deposits are of mineral scale, the mineral scale cuttings may be collected in a junk basket, see below.

[0021] Typically, an electric motor is located in the elongate housing of the drilling tool. The electric motor is capable of actuating a means for driving the drill bit. Typically, the means for driving the drill bit is a rotor (a rotating shaft). Where a drill bit is located at each end of the drilling tool, each drill bit may be mounted on a dedicated rotatable shaft that is driven by a dedicated electric motor. Alternatively, a single electrical motor may drive both drill bits that are mounted on dedicated rotatable shafts. Electricity is transmitted to the motor(s) via an electrical conductor wire or a segmented conductor encased in the electrical cable.

[0022] The drill bit(s) of the drilling tool is mounted on an electrically operated steering means, for example, a steerable joint, that is used to adjust the trajectory of the drilling tool (and hence the trajectory of a borehole that is being drilled through a blockage in the flowline). Electricity is transmitted to the steering means via an electrical conductor wire or a segmented conductor embedded in the electric cable. The steering means is preferably a continuously variable bent-sub or a continuously rotary steerable system that is capable of adjusting the bit orientation relative to the longitudinal axis through the drilling tool by from 0 to 10°, for example, 0 to 5° thereby allowing the drill bit to be aimed in any direction. Bent-subs and continuously rotary steerable systems are well known to the person skilled in the art. Typically, the trajectory of the borehole that is drilled through the blockage is adjusted, using the steering means, so that the borehole remains substantially parallel to the wall of the flowline. Preferably, the borehole is offset from the centre of the flowline, in particular, is close to the wall of the flowline.

[0023] Suitably, the propulsion system is connected either directly or indirectly to the elongate housing of the drilling tool. Typically, the propulsion system is a traction means, in particular, an electrically operated traction means. For example, the housing of the drilling tool may be provided with tractor feet, pads or wheels that may be extended in a radial direction into engagement with the walls of the flowline (or the bore hole that is being drilled through the blockage) and that are adapted to move the drilling tool through the flowline (or borehole). A suitable traction means is a Welltec™ wireline tractor. Suitably, the traction means also takes up the reactive torque generated by the means for driving the drill bit. Electricity may be transmitted to the traction means via an electrical conductor wire or segmented conductor of the electric cable and optionally via an umbilical. The drilling tool may be retrieved by either pulling on the electric cable or by running the electrical traction means in reverse such that the drilling tool moves in the reverse direction through the borehole that has been drilled through the blockage and then in a reverse direction through the flowline (whilst taking up the slack in the electrical cable, for example, using a wireline truck drum).

[0024] Preferably, the pumping means of the drilling tool is a remotely controlled electrically operated pumping means. Typically, the pumping means draws fluid that is present in the flowline adjacent the blockage over the cutting surfaces of the drill bit thereby entraining the cuttings in the fluid. Suitably, the fluid that is drawn over the cuttings surfaces of the drill bit is taken from a location adjacent to the blockage (on the surface facility side of the blockage). Preferably, the pumping means is located within the elongate housing of the drilling tool. Preferably, the fluid is passed to the cutting surfaces of the drill bit over the outside of the elongate housing of the drilling tool. However, it is also envisaged that the housing of the drilling tool may have a fluid channel therethrough (for example, a conduit) having an inlet for the fluid that is present in the flowline adjacent the blockage and an outlet that is in fluid communication with at least one fluid channel in the drill bit so that fluid is passed through the drilling tool and out over the cutting surfaces of the drill bit. Preferably, the inlet to the fluid channel is provided with a filter to prevent any cuttings from being recycled to the drill bit of the drilling tool.

[0025] Where the fluid that is pumped to the cutting surfaces of the drill bit is a liquid, the pumping means is typically a remotely controlled electrically operated downhole pump, for example, a suction pump or positive displacement pump. Where the fluid that is pumped to the cuttings surfaces of the drill bit is a gas, the pumping means is typically a compressor associated with an eductor. This type of pumping system is described in International Patent Application WO 2007/122393 and may be employed where drill cuttings are being conveyed by a gas.

[0026] Preferably, the elongate housing of the drilling tool has a fluid channel (or conduit) for transporting the suspension of cuttings away from the drill bit (that is mounted at the front of the drilling tool) such that the cuttings are deposited behind the drilling tool. Thus, this fluid channel has an inlet that is in close vicinity to the drill bit and an outlet that is at or near the rear of the drilling tool. Thus, the pumping means draws the suspension of drill cuttings through the inlet of the fluid channel and discharges said suspension via the outlet into the flowline behind the drilling tool. Preferably, this passage is in fluid communication with a discharge conduit that extends longitudinally (along the direction of the flowline) behind the housing of drilling tool such that the cuttings are deposited at a distance behind the drilling tool, for example, the conduit may extend at least 10 metres behind the drilling tool. Where the blockage is comprised of gas hydrate or wax, the drilling tool is preferably provided with an electric heating element or a laser that may be used to heat the suspension of cuttings as it is being passed through the fluid channel. For example, an electric heating element may be wound around the fluid channel (or conduit) and may be used to melt the hydrate cuttings or wax cuttings as the suspension of cuttings flows through the fluid channel (or conduit). Alternatively, a window may be provided in the fluid channel (or conduit) through which a laser beam is focussed into the suspension that is flowing through the fluid channel (or conduit). The laser beam is used to melt the hydrate cuttings or wax cuttings as the suspension of cuttings flows past the window in the fluid channel or conduit. The presence of the electric heating element or the laser may mitigate the risk of a gas hydrate or wax blockage re-forming behind the drilling tool.

[0027] Suitably, the drilling tool may be provided with a junk basket located behind the housing of the drilling tool for collecting any cuttings. The junk basket may be joined to the elongate housing of the drilling device via a flexible joint or flexible connector, in particular, a knuckle joint. Typically, the junk basket may be provided with an external screen, for example, a screen formed from fibre glass. Generally, the diameter of the junk basket is substantially the same as the diameter of the elongate housing of the drilling tool. Typically, the junk basket has a length of less than 10 feet, preferably less than 5 feet thereby allowing the drilling tool to negotiate the geometries discussed above. The fluid channel through the housing that is used for transporting the suspension of cuttings away from the drill bit has an outlet for discharging the suspension into the junk basket. Preferably, this outlet is located at or near the end of the junk basket that is joined to the elongate housing of the drilling device. The junk basket is also provided with an outlet, at the end remote from the elongate housing, for discharging fluid from the junk basket into the flowline behind the drilling device. Typically, the fluid is discharged from the junk basket via a discharge pipe that extends beyond (behind) the junk basket such that the fluid is discharged at a distance behind the drilling tool, for example, at a distance of at least 1 metre, preferably, at least 2 metres behind the drilling tool. Suitably, the inlet to the discharge pipe is located in the upper portion of the junk basket in order to mitigate the risk of the discharge pipe becoming blocked with cuttings. Preferably, the inlet to the discharge pipe is provided with a screen that has a sufficiently small mesh size to prevent the majority of the cuttings from passing out of the junk basket with the fluid. The mesh size of the screen is dependent upon the size of the cuttings. Thus, the larger sized cuttings disentrain from the fluid in the junk basket and are deposited at the bottom thereof An advantage of the junk basket is that this collects the cuttings thereby mitigating the risk of a blockage re-forming behind the drilling tool.

[0028] Suitably, the housing of the drilling device may be provided with a fluid reservoir for storing a treatment chemical. Suitably, the housing of the drilling device has an outlet at or near the drill bit that is in fluid communication with the fluid reservoir. A dedicated pump for the treatment fluid is provided within the housing and may be actuated to pump the treatment fluid from the fluid reservoir such that the treatment chemical is discharged from the outlet and is delivered to the blockage. Typically, a nozzle is provided at the outlet such that the treatment chemical is sprayed onto the blockage. It is envisaged that the treatment chemical will assist in removing the blockage from the flowline and/or will dissolve the drill cuttings. In the case of a hydrate blockage, the treatment chemical may be methanol or a glycol such as monoethylene glycol. In the case of a wax blockage the treatment chemical comprises an organic solvent such as xylene and a wax dissolver. In the case of an asphaltene blockage, the treatment chemical is an organic solvent such as xylene.

[0029] It is also envisaged that a tubing may be run from the surface together with the electric cable for delivering a treatment chemical to the blockage. Suitably, the tubing is a flexible tubing and may be either a continuous tubing or a jointed pipe. Preferably, the continuous tubing is coiled tubing, for example, metal coiled tubing or composite coiled tubing. Preferably, the tubing has an outer diameter of less than 2 inches. Typically, the tubing is bound to the electrical cable i.e. the tubing runs alongside the electric cable. Alternatively, the electric cable may be arranged within the tubing with the fluid delivered to the blockage via the annulus between the inner wall of the tubing and the cable. It is also envisaged that the electrical cable may be a hybrid cable (see above) such that a treatment chemical may be delivered to the blockage in the flowline through the bore that runs through interior of the hybrid cable. Suitably, the tubing or the hybrid cable discharges the treatment fluid behind the drilling tool (in close vicinity to the drilling tool) such that treatment fluid, optionally, together with flowline fluid, passes over the outside of the drilling tool to the drill bit, and the drill cuttings become entrained in the treatment fluid and optionally the flowline fluid.

[0030] Once a borehole has been drilled through the blockage(s) and pressure communication has been established across the blockage(s), the drilling tool may be removed from the flowline and a cold re-start of the flowline may be attempted. Where the flowline was blocked with gas hydrate, methanol is typically added to the cold re-start fluid at the wellheads or at a manifold in order to treat the freshly produced fluids. As an alternative to a cold re-start of the flowline, a treatment fluid may be delivered to the blockage to remove the remainder of the blockage. However, this is impractical if the blockage is remote from the point of delivery of the treatment fluid owing to the prohibitive cost of delivering large quantities of treatment fluid to the flowline.

[0031] Depending upon the design of the flowline system, a hot re-start may take place, for example, hot-oiling. In the case of a hydrate blockage, it is envisaged that the hot fluid that flows through the borehole in the blockage may begin to warm the surrounding hydrate to above the hydrate formation temperature such that the hydrate melts thereby increasing the diameter of the borehole until eventually all of the hydrate plug is removed. It is also envisaged that any hydrate cuttings that are deposited behind the drilling tool may become entrained in the flowing fluid thereby forming a hydrate slurry that is transported away from the drilling tool. Without wishing to be bound by any theory, it is believed that at least a portion of the hydrate cuttings may melt in the flowing hot fluid before the entrained hydrate cuttings reach the surface separation facility. Similarly, in the case of a wax blockage, the hot fluid that flows through the borehole in the blockage may warm the surrounding wax to above its melting point such that the melted wax dissolves in the flowing fluid thereby increasing the diameter of the borehole until eventually all of the wax has melted and the wax plug has been removed.

[0032] Where the drilling tool is introduced into the flowline via a riser, the drilling tool has a maximum outer diameter smaller than the internal diameter of riser thereby allowing the drilling tool to pass through the riser and the flowline. Preferably, the maximum outer diameter of the drilling tool is at least 1 inch, more preferably, at least 2 inches less than the internal diameter of the riser.

[0033] Where the drilling tool is introduced into the flowline via a subsea entry point, the maximum outer diameter of the drilling tool is less than the diameter of the entry point thereby allowing the drilling tool to enter the flowline via the subsea entry point. Preferably, the maximum outer diameter of the drilling tool is at least 0.5 inches less than, more preferably, at least 1 inch less than the diameter of the entry point.

[0034] Typically, a flow line has an internal diameter of at least 4 inches, for example, in the range of 6 to 36 inches. Typically, the maximum diameter of the drilling tool is at least 1 inch less than the internal diameter of the flowline, preferably, at least 2 inches less than the internal diameter of the flowline. Where the drill bit is a non-expandable bit, it is preferred that the diameter of the drill bit is slightly greater than the maximum diameter of the elongate housing of the drilling tool. Accordingly, this minimizes contact between the housing and the wall of the borehole that is drilled through a blockage thereby minimizing friction. Typically, the drill bit has a diameter that is about 1 inch greater than the maximum diameter of the elongate housing of the drilling tool. Suitably, the cutting surfaces on the drill bit are sized to form a borehole having a diameter of from 3 to 12 inches, preferably, 3 to 6 inches. Suitably, different sized drill bits may be connected to the drilling tool depending upon the internal diameter of the flowline and the size of the borehole that it is desired to drill through a blockage.

[0035] However, it is also envisaged that the drill bit may be an expandable drill bit, thereby allowing the borehole that is drilled through a blockage to have a diameter that is significantly greater than the maximum diameter of the housing of the drilling tool. Thus, the tool is passed through the flowline with the drill bit in a non-expanded state. Once the tool has reached the blockage, the drill bit is expanded. Typically, the expandable drill bit may be expanded to a diameter up to the diameter of the flowline. However, in order to avoid damaging the flowline, the expandable drill bit is preferably expanded to a diameter that is at least 0.125 inches less, preferably at least 0.25 inches less than the internal diameter of the flowline.

[0036] Alternatively, the drilling tool may be provided with an expandable reamer or expandable underreamer that is located immediately behind the drill bit. Suitably, the expandable reamer may be expanded to a diameter up to the internal diameter of the flowline. However, in order to avoid damaging the flow line, it is preferred that the expandable reamer is expanded to a diameter that is at least 0.125 inches less, preferably at least 0.25 inches less than the diameter of the flowline. Thus, the drill bit may drill a borehole through the blockage and the expandable reamer may then be used to enlarge the diameter of the borehole. Suitable expandable drill bits and reamers for use in the present invention are well known to the person skilled in the art.

[0037] The expandable reamer may be deployed once the drilling tool has drilled a borehole through a blockage. Thus, the borehole through the blockage may be enlarged by passing the drilling tool back through the borehole that has been drilled through the blockage. Alternatively, the expandable reamer may be deployed as the borehole is being drilled through a blockage. Thus, the reamer is employed to enlarge the borehole as it is being drilled through a blockage. An advantage of enlarging the borehole is that, after pressure communication has been established across the blockage, a greater volume of fluid is capable of flowing through the borehole. In the case of a hydrate or wax plug, this increases the rate at which the remainder of the hydrate or wax plug melts and hence reduces the time taken for complete removal of the hydrate or wax plug.

[0038] Suitably, the drilling tool may be provided with sensors that are electrically connected to recording equipment at the surface via electrical conductor wire(s) or segmented conductor(s) in the cable. Suitably, the sensors are located in proximity to the cutting surfaces of the drill bit. However, it is also envisaged that sensors may extend along the length of the drilling tool. These sensors may monitor the temperature and pressure at the cuttings surfaces of the drill bit(s), the proximity of the cutting surfaces of the drill bit(s) to the wall of the flowline, the temperature and pressure along the length of the drilling tool, the electric motor current, the angle of inclination of the tool, the angle of inclination of the steering means with respect to the longitudinal axis through the tool, and the precise location of the drilling tool in the flowline (determined using internal sensors and/or from the length of cable that has been deployed). Data may be continuously or intermittently sent to the surface thereby allowing the drilling tool, and hence the drilling operation, to be controlled in real-time. In particular, the torque on the drill bit may be calculated in real time from the electric motor current data. The torque may be calibrated so that it can be determined, in real time, whether the drill bit is drilling through a blockage in the flowline or has engaged with the wall of the flowline. Thus, the signals received at the surface may be monitored and electrical signals may be sent to the steering means, in response to these signals, so that the trajectory of the borehole that is being drilled through the blockage is automatically adjusted so as to avoid the risk of the drill bit damaging the walls of the flowline. Preferably, the signals that are transmitted between the surface and the drilling tool are controlled by a telemetry unit that is located within the housing of the drilling tool. Thus, digital signals that are either sensor readings which are sent to the surface or control signals that are sent down the electrical cable to the drilling tool may be controlled by the telemetry unit.

[0039] As discussed above, sensors on the drilling tool will be used to adjust the trajectory of the borehole through the blockage thereby mitigating the risk of the drill bit damaging the wall of the flowline. However, it is also envisaged that the cutting surfaces of the drill bit and/or reamer may be formed from a material that is softer than the steel that forms the walls of the flowline thereby further mitigating the risk of damaging the flowline. The material that forms the cutting surfaces of the drill bit and/or reamer must be sufficiently hard that the drill bit is capable of forming a borehole through the blockage and the reamer is capable of enlarging said borehole.

[0040] The present invention will now be illustrated by reference to FIG. **1**.

[0041] FIG. **1** shows a Floating Production Storage and Offloading (FPSO) vessel having a pig launcher **1** that is a suitable entry point for the drilling tool of the present invention. The drilling tool (suspended from an electric cable) is passed through the pig launcher **1**, flexible **2**, gooseneck **3** and riser **4** into a flowline **5**. Alternatively, the drilling tool may be introduced into flowline **5** via a Flowline Termination Assembly (FTA). FIG. **1** also shows a platform having a valve system **6** that may be used to introduce the drilling tool, suspended from a cable, down a steel catenary riser **7** and into flowline **5**. The drilling tool **8** and a hydrate plug **9** are shown in an enlargement of the flowline **5**. A more detailed drawing of the drilling tool **8** is also shown in FIG. **1**. The drilling tool comprises a plurality of housing segments **10** that are linked together via knuckle joints **11**, and a drill bit **12** mounted on a steering means **13**.

1-28. (canceled)

29. A method of drilling through a blockage in a flowline using a remotely controlled electrically operated drilling tool that comprises a drill bit, a steering means, a pumping means, and a propulsion system wherein the drilling tool is connected either directly or indirectly to an electric cable and the drill bit is mounted on the steering means, the method comprising:

introducing the drilling tool into the flowline;

actuating the electrically operated propulsion system to move the drilling tool through the flowline to the location of the blockage;

actuating the electrically operated steering means so that the drill bit is aligned with the blockage;

actuating the electrically operated drill bit so that the drill bit engages with and drills through the blockage; and

actuating the electrically operated pump so that when the drill bit engages with the blockage, fluid that is present in the flowline adjacent the blockage is passed over the cutting surfaces of the drill bit and cuttings from the blockage are transported away from the cutting surfaces of the drill bit suspended in the fluid.

30. A method as claimed in claim **29** wherein the flowline is a subsea flowline and the drilling tool is passed into the flowline either (i) through a surface entry point and a riser (with the drilling tool suspended from the electric cable), or (ii) through a subsea entry point in the flowline.

31. A method as claimed in claim **30** wherein a flowline intervention riser is deployed from a floating vessel and is latched to the subsea entry point and the drilling tool is lowered to the subsea entry point from the floating vessel, through the flowline intervention riser, with the drilling tool suspended from the electric cable.

32. A method as claimed in claim **30** wherein a subsea electric cable is laid alongside the flowline and is connected to an electric cable that runs from the surface through an umbilical wherein the subsea electric cable is provided with a wet-connect electrical connection point for the drilling tool, and wherein the drilling tool and sufficient additional electric cable to enable the drilling tool to reach the blockage is delivered to the wetconnect electrical connection point via a remotely controlled submersible vehicle (ROV); the drilling tool is connected to the wet-connect electrical connection point via the additional electric cable; and electricity is transmitted to the drilling tool via the umbilical, the subsea electric cable and the additional electric cable.

33. A method as claimed in claim **29** wherein the drilling tool comprises an elongate housing having a diameter in the range of 2 to 24 inches and a length in the range of 10 to 60 feet wherein the elongate housing comprises a plurality of housing segments that are joined together by flexible joints or flexible connectors and wherein the length of each segment of housing is in the range of from 1 to 10 feet and the flexible joints or flexible connectors provide an angular deviation of up to 90°, for example, up to 45° between adjacent housing segments such that the drilling tool is capable of negotiating bends in the flowline having a radius of less than 5 pipe diameters, in particular, bends having a radius of less than 3 pipe diameters.

34. A method as claimed in claim **29** wherein a drill bit is provided at the rear of the drilling tool that is actuated when withdrawing the drilling tool from the blockage or from the flowline.

35. A method as claimed in claim **29** wherein an electric motor is located in the elongate housing of the drilling tool and is capable of actuating a means for driving the drill bit.

36. A method as claimed in claim **29** wherein the steering means for the drill bit is a continuously variable bent-sub or is a continuously rotatable steerable system that is capable of adjusting the bit orientation relative to the longitudinal axis through the drilling tool by from 0 to 10°, for example, 0 to 5°

thereby allowing the trajectory of the borehole that the drilling tool drills through the blockage to be adjusted.

37. A method as claimed in claim **33** wherein the propulsion system is a traction means that is connected either directly or indirectly to the elongate housing of the drilling tool wherein the traction means comprises tractor feet, pads or wheels that are capable of being extended in a radial direction into engagement with the walls of the flowline (or into engagement with the walls of the bore hole that is drilled through the blockage) and that are adapted to move the drilling tool through the flowline (or borehole).

38. A method as claimed in claim **29** wherein the drilling tool is retrieved by pulling on the electric cable and/or by running the propulsion system in reverse such that the drilling tool moves in the reverse direction through the borehole that has been drilled through the blockage and then in a reverse direction through the flowline.

39. A method as claimed in claim **33** wherein the elongate housing of the drilling tool has a fluid passage having an inlet that is in close vicinity to the drill bit and an outlet that is at or near the rear of the drilling tool and the pumping means draws the suspension of drill cuttings through the inlet of the fluid channel and discharges said suspension via the outlet into the flowline behind the drilling tool.

40. A method as claimed in claim **39** wherein the fluid passage is in fluid communication with a discharge conduit that extends longitudinally behind the drilling tool, preferably, at least 10 metres behind the drilling tool, such that the cuttings are deposited at a distance behind the drilling tool.

41. A method as claimed in claim **33** wherein the drilling tool is provided with a junk basket located behind the housing of the drilling tool for collecting cuttings wherein the junk basket is joined to the elongate housing of the drilling device via a flexible joint or flexible connector.

42. A method as claimed in claim **33** wherein the housing of the drilling device is provided with a fluid reservoir that contains a treatment chemical, the fluid reservoir is in fluid communication with an outlet of the housing that is located at or near the drill bit, and an electrically operated pump is provided within the housing of the drilling device for pumping the treatment fluid from the fluid reservoir to the outlet, and wherein the pump is actuated so that the treatment fluid is discharged from the outlet and is delivered to the blockage.

43. A method as claimed in claim **30** wherein a tubing is run from the surface for delivering a treatment chemical to the blockage wherein the tubing either runs alongside the electric cable or the electric cable is arranged within the tubing.

44. A method as claimed in claim **29** wherein the electric cable has a borehole running therethrough and a treatment chemical is delivered to the blockage in the flowline through the borehole.

45. A method as claimed in claim **29** wherein the drill bit is a non-expandable bit and the cutting surfaces on the drill bit are sized to form a borehole having a diameter of from 3 to 12 inches, preferably, 3 to 6 inches.

46. A method as claimed in claim **29** wherein the drill bit is an expandable drill bit, the drilling tool is passed through the flowline with the drill bit in a non-expanded state and, when the drilling tool has reached the blockage, the drill bit is expanded to a diameter that is at least 0.125 inches less, preferably at least 0.25 inches less than the internal diameter of the flowline.

47. A method as claimed in claim **46** wherein the drilling tool is provided with an expandable reamer or expandable underreamer that is located immediately behind the drill bit and is capable of being expanded to a diameter that is at least 0.125 inches less, preferably at least 0.25 inches less than the diameter of the flowline and wherein the expandable reamer or underreamer is either deployed when the drilling tool is being withdrawn from the borehole that has been drilled through the blockage or as the borehole is being drilled through the blockage.

48. A method as claimed in claim **29** wherein the drilling tool is provided with sensors that are electrically connected to recording equipment at the surface via electrical conductor wire(s) or segmented conductor(s) in the electric cable wherein the sensors either continuously or intermittently transmit signals to the surface and the signals received at the surface are monitored and electrical signals are transmitted from the surface to the drilling tool in response to these sensor signals to control the operation of the drilling tool.

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