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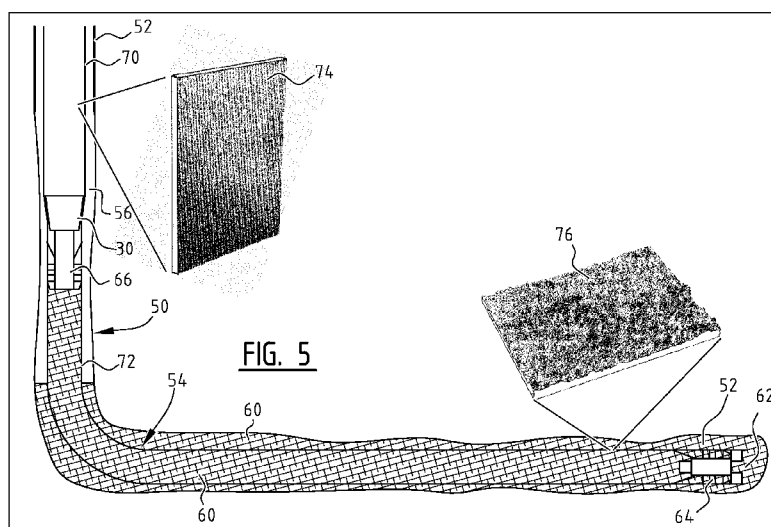
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(54) Title: METHOD AND SYSTEM FOR SURFACE ENHANCEMENT OF TUBULARS



(57) Abstract: The invention discloses a method and system for surface enhancement of a pipe. The method includes the steps of: introducing the pipe 54 in a wellbore 50; and applying a ribbed pattern 12 to the inner surface of the pipe 54. An expander cone 30, having a largest outer diameter which is larger than the initial inner diameter of the pipe 54 and having an outer surface provided with a correspondingly ribbed pattern 12, is moved through the pipe 54 to apply the pattern 12.

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METHOD AND SYSTEM FOR SURFACE ENHANCEMENT OF TUBULARS

The present invention relates to a method and a system for surface enhancement of tubulars. The method and system of the invention can be applied to smoothen or otherwise enhance the surface of tubulars for use in wellbores, including the inner surface of production casing or production tubing.

In the production of oil, gas and other minerals from subterranean wells, large numbers of pipe sections are often employed. These sections are typically connected by threaded connections. Pipe sections used in oil fields usually have a tapered, exteriorly threaded male end called a pin member. Such pin members are threaded into couplings, collars or integral female pipe sections, their threaded ends being referred to as box members. These box members have an interiorly threaded tapered end which corresponds with their respective pin members.

In some applications, pressurized fluid is pumped downhole through one or more of these pipes. For instance when drilling to unconventional oil and gas resources, which are located in reservoirs whose porosity, permeability, or fluid trapping mechanism do not allow the hydrocarbons to escape. These unconventional resources include for instance shale gas and tight gas sands. Large volumes of pressurized fracturing fluid are pumped from surface through one of the pipes, typically through the production casing or production tubing, into openings near the production zone to create fissures in the reservoir layer to enable the hydrocarbons to escape. This process is often referred to as hydraulic fracturing.

The required fluid pressure at surface to enable to fracture the reservoir formation is often very high, for instance in the order of 10,000 psi or more, sometimes even up to 18,000 psi (about 1200 bar) or more. The required pump power is rated in "hydraulic horsepower" (HHP), calculated as Injection Rate (bpm) * Pressure (psi) / 40.8. For instance, 80 bpm * 10,000 psi / 40.8 = 19,608 HHP. This would require for instance a minimum of twenty 1,000 HHP pumps or ten 2,000 HHP pumps.

As the pumping equipment needed to provide these high pressures is relatively expensive, there is a clear interest to reduce the required pressure. The fracturing fluid may for instance include friction reducers, which are chemicals used to reduce friction losses in the pipe while injecting the fracturing fluid. These friction losses in the pipe are for instance in proportion to the relative roughness of the inner surface of the pipe.

In various oil and gas applications, steel pipe is provided with a lining of corrosion-resistant material. These linings or coatings may also be applied to reduce friction losses. For example, it is known to bond to the interior of the pipe various epoxy-based coatings, as well as coatings containing polyethylene, polyvinyl chloride and other thermoplastic and thermosetting materials.

Of the various polymeric coating materials, arylene sulfide polymers have gained wide acceptance, see for instance US-3,354,129. Generally, these polymers consist of a recurring aromatic structure coupled in repeating units through a sulfur atom. Commercially available arylene sulfide polymers which have been used for coating oil and gas pipes and pipe couplings are polyphenylene sulfides. The polyphenylene sulfides used in oil and gas

applications exhibit high melting points, outstanding chemical resistance, thermal stability and are non-flammable. They are also characterized by high stiffness and good retention of mechanical properties at elevated temperatures as well as the ability to deform smoothly, thereby, for example, preventing the galling of threads, even at high thicknesses.

US-3,744,530 describes polyphenylene sulfide coated pipes, wherein the polyphenylene sulfide coating also contains a filler, such as iron oxide, in an amount of between 5% to 30%.

The present invention aims to further reduce friction losses in a pipe.

In according to the present invention, there is provided a method for surface enhancement of a pipe, the method including the steps of:

- introducing the pipe in a wellbore; and
- applying a ribbed pattern to the inner surface of the pipe.

In an embodiment, the step of applying the ribbed pattern comprises:

- moving an expander cone, having a largest outer diameter which is larger than the initial inner diameter of the pipe and having an outer surface provided with a correspondingly ribbed pattern, through the pipe.

Herein, the inner diameter of the pipe may be expanded less than 7%, for instance in the order of 5%.

The ribbed pattern may be applied to the inner surface of the pipe by moving an expander having a correspondingly ribbed outer surface through the pipe.

In another embodiment, the method comprises the steps of:

- introducing cement in the pipe from surface;

- introducing an expander cone on top of the cement;
- pumping the expander cone towards the downhole end of the pipe, thereby moving the cement to said downhole end and out of said downhole end into an annulus enclosing the pipe, and at the same time expanding the pipe. Thus, the step of surface enhancement may be integrated with the cement job, minimizing time and costs.

According to another aspect, the invention provides the use of the method as described above for surface enhancement of a pipe in a wellbore.

According to another aspect, the invention provides a system for surface enhancement of a pipe, the system comprising:

- a pipe string for introduction in a wellbore;
- an expander for expanding the inner diameter of the pipe, the expander having a largest outer diameter which is larger than the initial inner diameter of the pipe.

The invention will be described hereinafter in more detail and by way of example with reference to the accompanying drawings, in which:

Fig. 1A shows a perspective view of a detail of an exemplary surface of an untreated tubular;

Fig. 1B shows a cross-section of the detail of Fig. 1A;

Fig. 2A shows a perspective view of a surface of a tubular treated using an embodiment of the method of the present invention;

Figs. 3A to 3C shows cross-sections of embodiments of pipe surfaces according to respective embodiments of the present invention;

Figs. 4A to 4C show perspective views of embodiments of an expander to create the pipe surfaces of Figs. 3A-3C respectively;

5 Fig. 5 shows a cross-sectional side view of an embodiment of a method according to the present invention;

Fig. 6 shows a perspective view of a texture created on the inner surface of a pipe using an embodiment of the invention;

10 Fig. 7 shows a perspective view of a texture created on the inner surface of a pipe using another embodiment of the invention;

Fig. 8 shows a perspective view of a texture created on the inner surface of a pipe using yet another
15 embodiment of the invention; and

Fig. 9 shows a perspective view of an embodiment of an expander cone for creating the texture of one of Figures 6 to 8.

20 The present invention concerns the surface roughness of pipes as used in oilfield wellbores. Pipe herein is generally intended to include tubular pipe strings, such as casing or tubing strings, including multiple tubular sections which are mutually coupled.

25 To enable comparison between surfaces, respective surfaces may be defined by:

i) Average roughness S_a . Average roughness herein is the average roughness across an area of interest. Roughness is characterized as an absolute roughness parameter representing the height of surface features.
30 I.e., S_a is expressed as a unit of length indicating the average difference between a highest (peak) and a lowest (valley) feature of the respective surface. S_a may relate to surfaces having different spatial and height symmetry

features (e.g., milled vs. honed). Although these may have the same S_a , they may function quite differently. The S_a number is however suitable to indicate relative improvements after application of the method of the present invention;

ii) A relative pipe roughness may be calculated by the average roughness divided by the inner diameter of the pipe;

iii) Peak ratio Spk/Svk . Spk herein indicates the average distance between peaks, wherein Svk indicates a predetermined area. A higher peak ratio indicates that the surface is more likely to have a peaked surface which increases drag;

iv) $YRz/YRsm$ ratio. Herein, YRz indicates the average height of styluses or peaks, and $YRsm$ indicates the width of said styluses or peaks. A low $YRz/YRsm$ ratio indicates a surface which is provided with low amplitude and wide structures along the direction of fluid flow, which help to reduce drag;

v) Sdr . The Developed Interfacial Area Ratio Sdr is expressed as the percentage of additional surface area contributed by a texture, such as an applied texture of by an unwanted peaked texture, as compared to an ideal plane the size of the measurement region; and

vi) $NormVolume$, which indicates the amount of fluid necessary to fill the respective surface from the lowest valley to the highest peak.

Figure 1A shows a perspective view of a Scanning Electron Microscope (SEM) picture of the surface of a pipe as typically used in oil wells. Figure 1B shows a SEM picture of a cross-section of a detail of the surface shown in Figure 1A. The S_a is about $5.6 \mu m$, Sdr is about

18.9 μm , Spk/Svk is about 4.28, and YRz/YRsm is about 0.26.

5 The surface of pipes for hydrocarbon wellbores, including the inner surface thereof, can typically be characterized by: An Sa of more than 5 μm ; Sdr of more than 15 μm ; Spk/Svk of more than 3; YRz/YRsm of more than 0.2.

10 The method according to the present invention uses light expansion of the pipe diameter to decrease the surface roughness of the pipe. Light herein indicates a balance between maximum achievable expansion and expansion required to effectively reduce the surface roughness. Herein, maximum achievable expansion may be an increase of the diameter of about 20% or more, whereas
15 light expansion according to the invention implies an expansion of the diameter of 10% or less. Light expansion requires less energy than maximum expansion and has a significantly lower chance of problems, thus improving the efficiency. Obviated problems may include for
20 instance fluid tightness or integrity of connectors between pipe sections, the expander getting stuck during expansion, movement or failure of the pipe. On the other hand, reliability may require a minimum amount of expansion, due to tolerances of the inner diameter of the
25 pipe.

Balancing efficiency and reliability, to decrease the surface roughness of the pipe, the inner diameter of the pipe may preferably be expanded between about 3% to 7%. Herein, problems are substantially obviated. Relatively
30 little power is required for expansion. And at higher expansion ratios the surface roughness may increase.

Figure 2A shows a perspective view of a SEM picture of the surface of the pipe of Fig. 1A after a 3%

expansion of the inner diameter thereof. Figure 1B shows a SEM picture of a cross-section of a detail of the surface shown in Figure 2A. The Sa is about 0.44 μm , Sdr is about 0.53 μm , Spk/Svk is about 0.37, and YRz/YRsm is about 0.041. I.e., the surface roughness has been decreased considerably, and depending on the parameter the improvement is in the order of a factor of 5 to 10.

The surface roughness of pipes for hydrocarbon wellbores, including the inner surface thereof, can be improved by the method of the invention: An Sa of less than 5 μm ; Sdr of less than 10 μm ; Spk/Svk of less than 1; YRz/YRsm of less than 0.2.

More dramatic improvement however are possible, as the example of Figure 2A has: Sa between 0.22 and 0.85 μm ; Sdr about 0.53 μm ; Spk/Svk about 0.37; YRz/YRsm about 0.04. Upon expansion of more than 10%, the surface roughness may deteriorate with respect to light expansion.

In general, any one or more of the parameters indicating surface roughness as described above will typically be decreased about 50% or more using the method of the present invention. As indicated by the examples above however, the improvement may be more significant, wherein a respective parameter relating to the surface roughness, such as Sa, Sdr, Spk/Svk, etc., after light expansion may be less than 10% of the initial value before expansion.

As shown in Figures 3A, 3B and 3C, respective patterns comprising longitudinal ribs 10 may be applied to the internal surface of the pipe for further drag reduction. These ribs extend in axial direction, possibly along a substantial part of the total length of the pipe, for instance along more than 90% of the length thereof.

The ribbed patterns include triangles 12 (Fig. 3A) having a height or amplitude h and are located at a mutual distance or wavelength s . Alternatively, the ribs may have a semi-circular shape 14 (Fig. 3B) or a blade shape 16 (Fig. 3C). Also, adjacent ribs may be arranged at a larger mutual distance (not shown).

The pattern may include a so-called shark skin pattern, referring to the skin of sharks which is provided with similar longitudinal ribs to reduce drag. The skin of some fast swimming sharks is covered with a tiny grooved structure, which decreases the turbulent skin friction. This passive flow control method can be applied in the form of so called riblets as a technical application. a maximal skin friction reduction of 10% is possible.

In a practical embodiment, the mutual distance s is about 2 to 10 times the height h . For instance, h may be about 20 μm and s may be in the range of about 50 to 200 μm .

In the hydrocarbon industry, shark skin patterns have for instance been applied to the internal surface of gas pipelines or to the outside of ships. Conventionally, said patterns are milled or pressed into a film, which film is subsequently applied to the surface of interest.

The application of said patterns to the inner surface of an oilfield tubular however poses a problem. According to the invention however, a corresponding or inverse ribbed pattern 20 may be applied to the outside surface of an expander cone 30. For instance, to apply a triangular ribbed pattern 12, the outside surface of the corresponding expander cone 30 is provided with an inverse triangular pattern 22 (Fig. 4A). To apply a semi-circular ribbed pattern 12, the outside surface of the

corresponding expander cone 30 is provided with an inverse semi-circular pattern 22 (Fig. 4B). An to apply a blade shaped pattern 16, the outside surface of the corresponding expander cone 30 is provided with an
5 inverse blade shaped pattern 26 (Fig. 4C). Thus, the predetermined pattern is applied to the inner surface of the respective oilfield tubular during expansion thereof, as described above.

The drag-reducing efficiency of the ribbed surface
10 (Figs. 3A-3C) is about 2-10% in comparison with smooth surfaces, for instance about 5-7%.

The method and system of the invention may for instance be incorporated in a cement job, as shown in Figure 5. Figure 5 shows a wellbore 50 provided with a
15 casing 52 and a production tubing 54. An annulus 56 extends between the tubing 54 and the wellbore wall or the casing 52.

Cement 60 can be pumped into the annulus 56 via the downhole end 62 of the production tubing 54. Initially,
20 the cement is at surface applied between a bottom plug 64 and a top plug 66. The expander cone is arranged on top of the top plug 66. Subsequently, the assembly of cement, bottom plug 64, top plug 66 and expander cone 30 is pumped downhole, for instance using fluid pressure. While
25 the expander cone 30 moves through the tubing 54, the tubing section 70 above the cone 30 is expanded to a (slightly) larger inner diameter, whilst the downhole section 72 below the cone still has the initial inner diameter. Due to the expansion, the inner surface 74 of
30 the expanded section 70 is smoothened, having a decreased surface roughness with respect to the inner surface 76 of the downhole tubing section 72. When the bottom plug 64 reaches the downhole end of the tubing 54, the cement is

pushed through the plug and into the annulus 56. This process may continue until the top plug 66 reaches the bottom plug 64.

According to another aspect of the present invention,
5 the expander cone 30 may include a lubrication device (not shown). During expansion, the method includes operating the lubrication device to inject lubricant into an interface between the expansion surface and the tubular member
10 when a predetermined lubricant pressure is reached.

The lubrication device may comprise at least one reservoir for housing a lubricant. The expander cone 30 may be provided with at least one circumferential groove on the outer surface 32 thereof, which groove is
15 fluidically connected to the reservoir. During expansion, a lubricant injection mechanism will force the lubricant into the at least one circumferential groove while radially expanding and plastically deforming the pipe when the predetermined lubricant pressure is
20 reached.

The lubricant may be injected in an interface between the tubular member and the expansion device 30. The lubricant may include at least eight components selected from the group consisting of: a base oil; metal
25 deactivator; antioxidants; sulfurized natural oils; phosphate ester; phosphoric acid; viscosity modifier; pour-point depressant; defoamer; and carboxylic acid soaps.

In a practical embodiment, the lubricant may include
30 in the order of 77.81% canola oil; 0.04% tolyltriazole; 1.0% phenolic antioxidant; 10% sulfurized natural oil or sulfurized lard oil; 9% phosphate ester; 1% phosphoric acid; 0.8% styrene hydrocarbon polymer; 0.3% alkyl ester

copolymer; and 0.05% silicon based antifoam agent. In another embodiment, the lubricant may include: about 64.25% canola oil; 0.05% tolyltriazole; 1.0% aminic antioxidant; 2.0% phenolic antioxidant, 12% sulfurized natural oil or sulfurized lard oil; 12% phosphate ester; 1.5% phosphoric acid; 1.5% styrene hydrocarbon polymer; 0.5% alkyl ester copolymer; 0.2% silicon based antifoam agent, and 5% carboxylic acid soap.

The lubricant may include: about 90.89% canola oil; 0.02% tolyltriazole; 0.5% phenolic antioxidant; 4% sulfurized natural oil or sulfurized lard oil; 4% phosphate ester; 0.4% phosphoric acid; 0.08% styrene hydrocarbon polymer; 0.1% alkyl ester copolymer; and 0.01% silicon based antifoam agent.

Alternatively, the lubricant may include: about 68.71% canola oil; 0.04% tolyltriazole; 0.5% aminic antioxidant, 1.0% phenolic antioxidant; 12% sulfurized natural oil or sulfurized lard oil; 10% phosphate ester; 1.1% phosphoric acid; 1.5% styrene hydrocarbon polymer; 0.1% alkyl ester copolymer; 0.05% silicon based antifoam agent., and 5% carboxylic acid soap. In another embodiment, the lubricant includes: about 82.07% canola oil; 0.03% tolyltriazole; 0.5% aminic antioxidant, 0.5% phenolic antioxidant; 10% sulfurized natural oil or sulfurized lard oil; 5% phosphate ester; 0.5% phosphoric acid; 0.1% styrene hydrocarbon polymer; 0.2% alkyl ester copolymer; 0.1% silicon based antifoam agent, and 1% carboxylic acid soap.

In another embodiment, the lubricant includes: about 80.68% canola oil; 0.04% tolyltriazole; 1% phenolic antioxidant; 8% sulfurized natural oil or sulfurized lard oil; 9% phosphate ester; 1% phosphoric acid; 0.1% styrene hydrocarbon polymer; 0.1% alkyl ester copolymer; and

0.08% silicon based antifoam agent. Optionally, the lubricant includes: about 80.31% canola oil; 0.04% tolyltriazole; 1.1% phenolic antioxidant; 9% sulfurized natural oil or sulfurized lard oil; 8% phosphate ester; 5 0.8% phosphoric acid; 0.4% styrene hydrocarbon polymer; 0.3% alkyl ester copolymer; and 0.05% silicon based antifoam agent.

In another embodiment, the lubricant includes: at least 10% Graphite. The lubricant may include: at least 10 10% Molybdenum Disulfide in a thickener in with a dropping point above 350-400F.

In an embodiment, the pipe may be provided with a coating layer. The coating layer may for instance be applied at surface, before introducing the pipe string in 15 the wellbore. The coating layer may have a thickness in the range of about 10 μm to 200 μm . The coating may comprise a base polymer selected from the group of thermoplastics such as PEEK (Polyetheretherketone), PI (polyimide), PPS (polyphenylene sulfide), PEI 20 (polyetherimide), PMMA (Polymethylmethachylate), PVDF (Polyvinylidene fluoride), PA (polyamide), PVC (Polyvinyl chloride), and PE (Polyethylene), and thermoset plastics such as epoxy, phenolic, melamine, unsaturated polyester, and polyurethane. Said base polymer may 25 comprise a reinforcement, which may be a mixture of one or more of: short carbon fibre, PTFE, Graphite, nano oxide particle having a diameter below 20 nm. The blend may comprise additives to improve bonding with the reinforcement.

30 The coating layer may assist in, for instance, the forming of a texture using the method of the invention. Herein, an expander cone, such as shown in any of Figures 3A, 3B, 3C or 9, is forced through the inner passage of a

pipe. The conical outer surface 32 is provided with a number of ridges 34 extending substantially parallel to the length of the expander, i.e. in the direction which will be aligned with the axis of the oilfield tubular 54 (See Fig. 5). The ridges may have a shape such as shown in any of Figs. 3A-3C.

Fig. 6 shows a ribbed pattern formed in a coated inner surface of a pipe, using light expansion according to the method of the invention. The coating was based on PTFE (Polytetrafluoroethylene).

Fig. 7 shows a ribbed pattern formed in a coated inner surface of a pipe, using light expansion according to the method of the invention. The coating comprised a rust preventive solid lubricant. The texture of the pattern is smoother than the pattern in the PTFE coating shown in Fig. 6, and is therefore considered to provide a better result. Examples of rust preventive solid lubricant include for instance: Corrugator Krytox® 226 FG from DuPont™; 2-26® Multi-Purpose Lubricant 2005 from Applied Industrial Technologies; Air Dry MoS₂ Solid Film Lubricant Lubri-Bond®220 from Everlube Products.

Fig. 8 shows a ribbed pattern formed in a coated inner surface of a pipe, using light expansion according to the method of the invention. The coating comprised molybdenum disulfide within a graphite base (LC 300 cured). The texture of the pattern is smoother than the pattern in the PTFE coating shown in Fig. 6 as well as the pattern in the solid lubricant coating of Fig. 7, and is therefore considered to provide an even better result.

In an embodiment, the expandable pipe may comprise a steel alloy including: 0.065% C, 1.44% Mn, 0.01% P, 0.002% S, 0.24% Si, 0.01% Cu, 0.01% Ni, and 0.02% Cr.

According to another embodiment of the present invention, the expandable pipe may comprise a steel alloy including: 0.18% C, 1.28% Mn, 0.017% P, 0.004% S, 0.29% Si, 0.01% Cu, 0.01% Ni, and 0.03% Cr.

5 In yet another embodiment, the pipe may comprise a steel alloy including: 0.08% C, 0.82% Mn, 0.006% P, 0.003% S, 0.30% Si, 0.16% Cu, 0.05% Ni, and 0.05% Cr.

According to still another embodiment, the expandable pipe may comprise a steel alloy including: 0.02% C, 1.31% Mn, 0.02% P, 0.001% S, 0.45% Si, 9.1% Ni, and 18.7% Cr.

Tables 1 and 2 herein below provide examples of relative improvements of the features of the invention. Conditions used to compare the measurements are:

- Length of the pipe : 5486.4 m;
- 15 - Pump rate : 7000 l/minute;
- Kinetic viscosity : 1.00E-06 m²/s (water);
- rho : 1.00E+03 kg/m³ (water).

Table 1

20

Pipe inner surface	ID (")	ID (m)	f (Papaevange lou)	V (m/s)	Reynolds
Rusted	5	0,127	2,36E-02	9,21	1,17E+06
Clean	5	0,127	1,46E-02	9,21	1,17E+06
Coated	5	0,127	1,18E-02	9,21	1,17E+06
Light (1%) expansion	5.5	0,1283	1,14E-02	9,21	1,17E+06
Light (3%) expansion	5.15	0,1308	1,14E-02	8,68	1,14E+06

Table 2

Pipe inner	Sa	Relative roughness	Pressu re	Pressure	Relative
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surface	(μm)		loss (bar)	loss (psi)	pressure loss (%)
Rusted	254	2,00E-03	432	6269	161
Clean	25.4	2,00E-04	268	3883	100
Coated	2.54	2,00E-05	217	3142	81
Light (1%) expansion	0.5	1,57E-06	208	3018	78
Light (3%) expansion	0.5	1,53E-06	180	2616	68

According to the method of the present invention,
 "light" (less than 10%, for instance between 1% to 7%
 5 radial expansion) expansion may decrease the surface
 roughness of the pipe inner surface from Sa is 6-12
 micrometers down to 0.2 micrometers.

The best results are obtained when the light
 expansion is combined with the application of hydrophobic
 10 or hydrophilic coatings on the expanded inner surface of
 the pipe, either before or during expansion. Said coating
 may for instance fill valleys.

The drag reduction based on calculation of the
 Reynolds number is estimated up to 20-30% due to smoother
 15 inner pipe surfaces.

An additional improvement may be achieved by the
 application of a ribbed texture, which may provide a
 further drag reduction up to 10% in comparison with the
 smooth inner surface. The main challenge is the
 20 application of the ribbed texture, which according to the
 invention can be done during tubular expansion in-situ.

By combining two or more of the above-described
 improvements in a single trip, time and costs are
 limited.

The enhancements provided by the present invention may be related to one or more of the following:

- Significant decrease of surface roughness;
- Slightly increase in the strength of the pipe;
- 5 - Significantly limit surface fatigue of the pipe;
- Provide compressive residual stresses on pipe inner diameter;
- Decrease pipe inner diameter variation;
- Produce an inner surface with a customized
- 10 functionality by a combination of a special texture (shark skin for instance) and/or a coating imbedded in the inner surface due to plastic deformation after light expansion;
- Improve the corrosion resistance of the inner
- 15 surface of the pipe by eliminating the origin of corrosion spat;
- Eliminate misalignment in the threads of threaded connections between pipe section due to light expansion;
- Improve fouling resistance, reduce adhesion of wax,
- 20 scale and other depositions;
- A combination of these surface enhancements may also decrease liquid loading in gas wells.

The present invention is not limited to the above-described embodiments thereof, wherein various

25 modifications are conceivable within the scope of the appended claims. For instance, features of respective embodiments may be combined.

C L A I M S

1. A method for surface enhancement of a pipe, the method including the steps of:

- introducing the pipe in a wellbore; and
- 5 - applying a ribbed pattern to the inner surface of the pipe.

2. The method of claim 1, wherein the step of applying the ribbed pattern comprises:

- moving an expander cone, having a largest outer diameter which is larger than the initial inner diameter of the pipe and having an outer surface provided with a correspondingly ribbed pattern, through the pipe.

3. The method of claim 1 or 2, wherein the ribbed pattern comprises longitudinal ribs extending in axial direction of the pipe.

4. The method of claim 3, wherein the ribs are applied to extend along a substantial part of the total length of the pipe.

5. The method of claim 4, wherein the applied ribs extend along more than 90% of the length of the pipe.

6. The method of any of the previous claims, wherein the ribbed pattern is selected from the group of: triangle shape, semi-circular shape, and shark skin pattern.

7. The method of any of the previous claims, wherein the step of applying a ribbed pattern includes the step of:

- coating the inner surface of the pipe.

8. The method of claim 2, wherein the inner diameter of the pipe is expanded less than 10%.

9. The method of claim 2, wherein the inner diameter of the pipe is expanded between 1% to 7%

10. The method of claim 2, wherein the inner diameter of the pipe is expanded between about 3% to 5%.

11. The method of claim 2, including the step of:

- applying a hydrophobic or hydrophilic coating on the inner surface of the pipe, either before or during expansion.

5 12. The method of claim 1, including the step of:

- applying an anti-corrosive coating to the inner surface of the pipe.

13. The method of claim 2, comprising the steps of:

10 - introducing cement slurry in the pipe from surface;
- introducing the expander cone on top of the cement slurry;

- pumping the expander cone towards the downhole end of the pipe, thereby moving the cement slurry to said downhole end and out of said downhole end into an annulus enclosing the pipe, and at the same time expanding the pipe.

14. Use of the method of any of claims 1-13 for surface enhancement of a pipe in a wellbore.

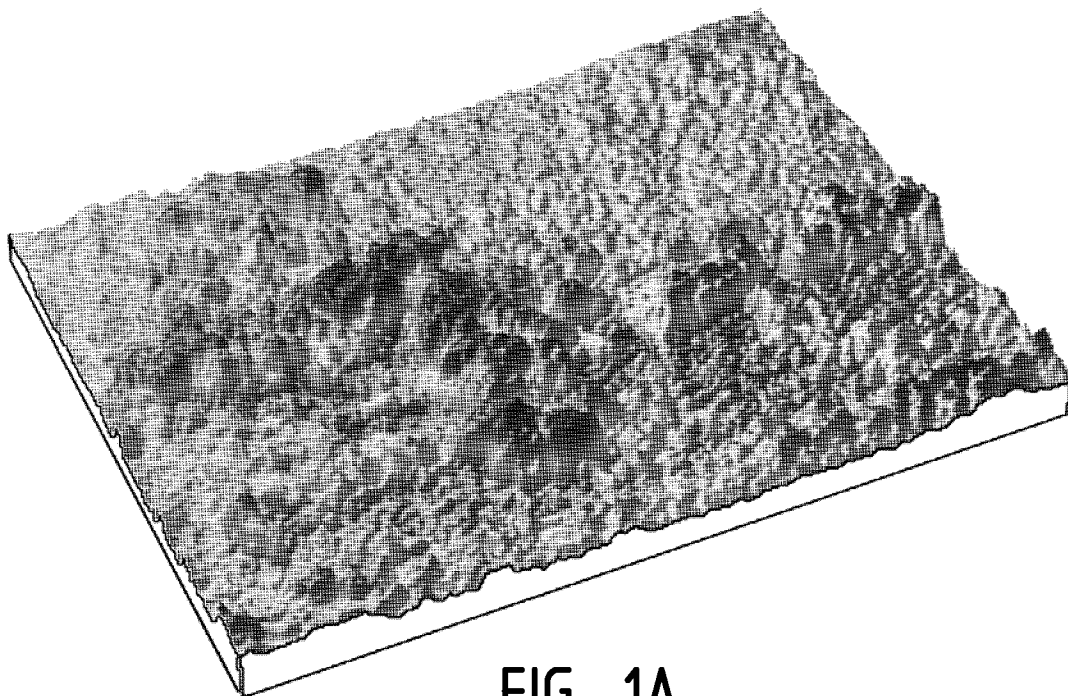
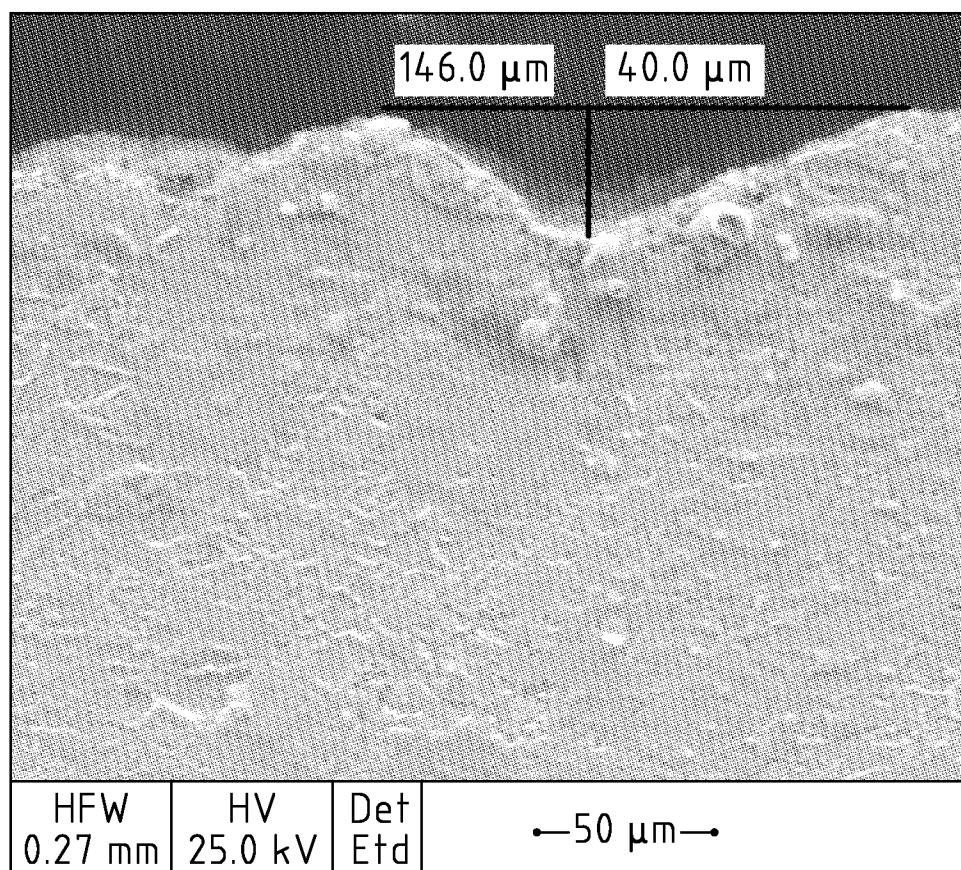
15 20 15. System for surface enhancement of a pipe, the system comprising:

- a pipe string for introduction in a wellbore;
- an expander cone for expanding the inner diameter of the pipe, the expander having a largest outer diameter which is larger than the initial inner diameter of the pipe and having an outer surface provided with a ribbed pattern to be applied to the inner pipe surface.

16. The system of claim 15, wherein the largest outer diameter of the expander cone is between about 1% to 7% larger than the initial inner diameter of the pipe.

30 17. Expander cone having a ribbed outer surface for applying a corresponding ribbed pattern to the inner surface of a pipe.

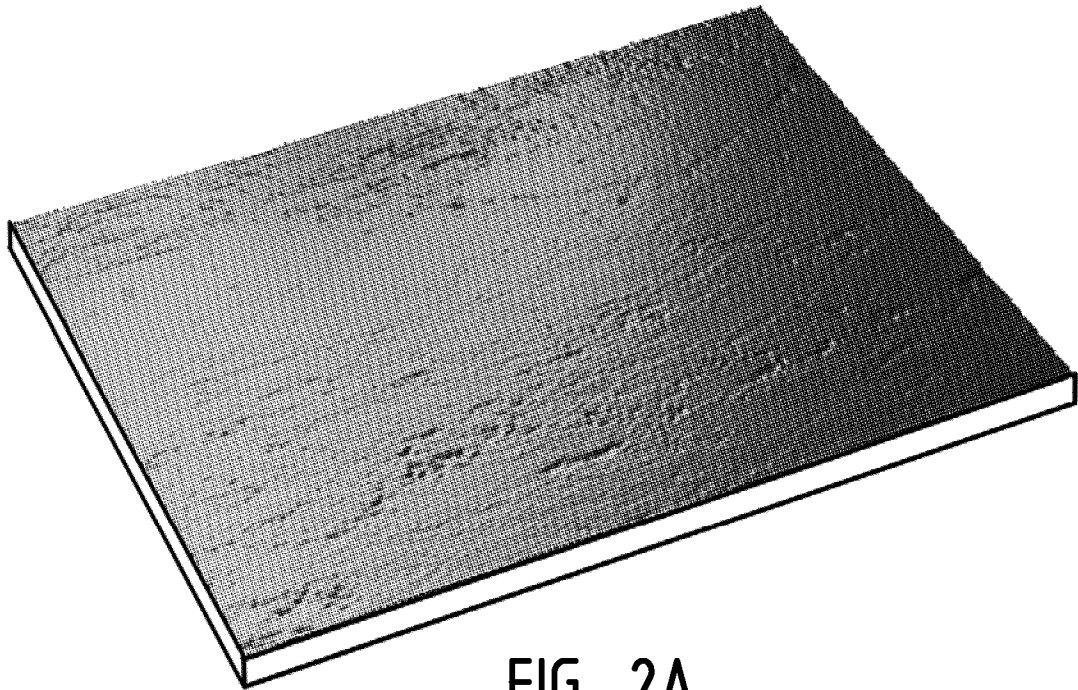
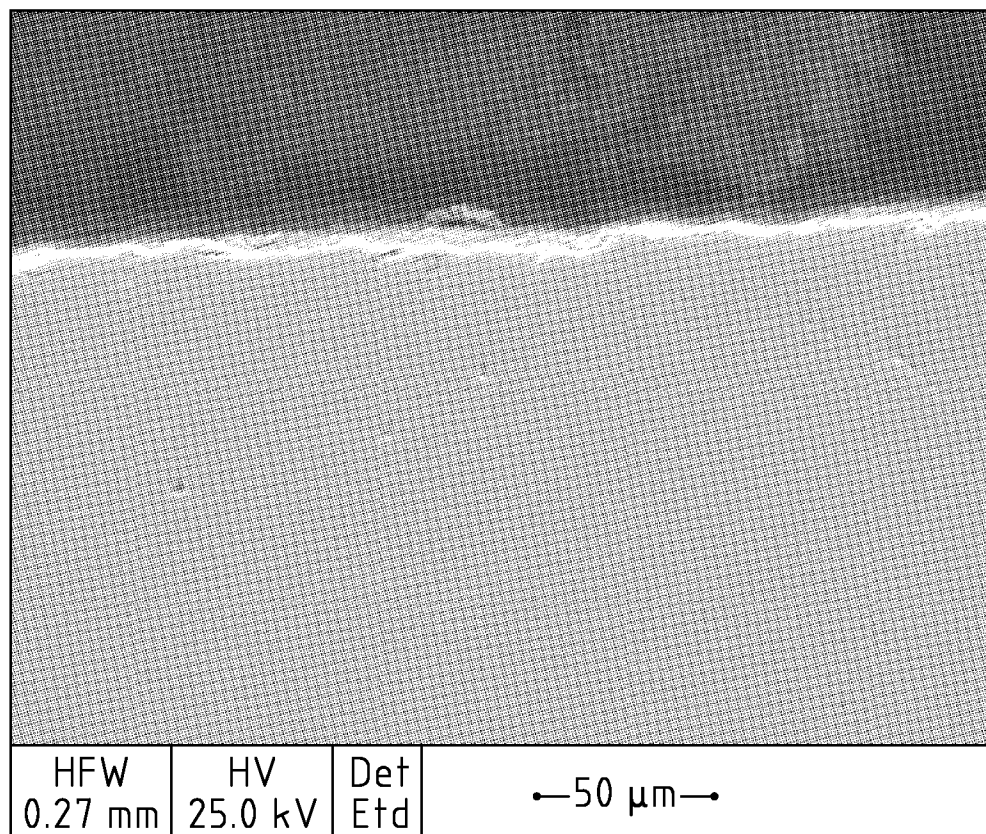
1/5

FIG. 1A

HFW 0.27 mm	HV 25.0 kV	Det Etd	—50 μm—
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FIG. 1B

2/5

FIG. 2AFIG. 2B

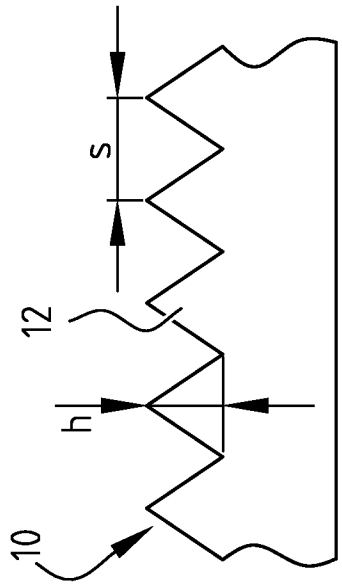


FIG. 3A

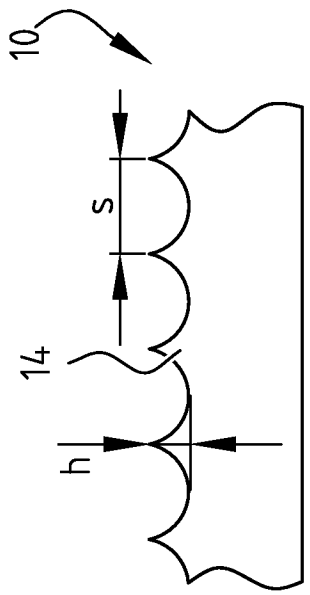


FIG. 3B

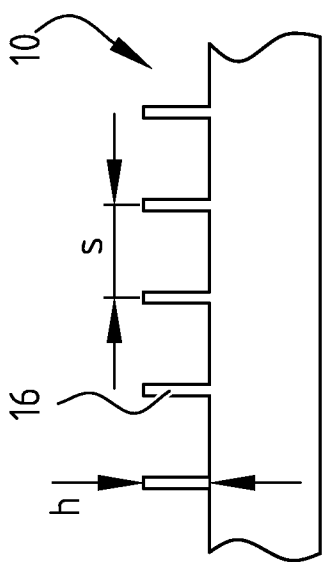


FIG. 3C

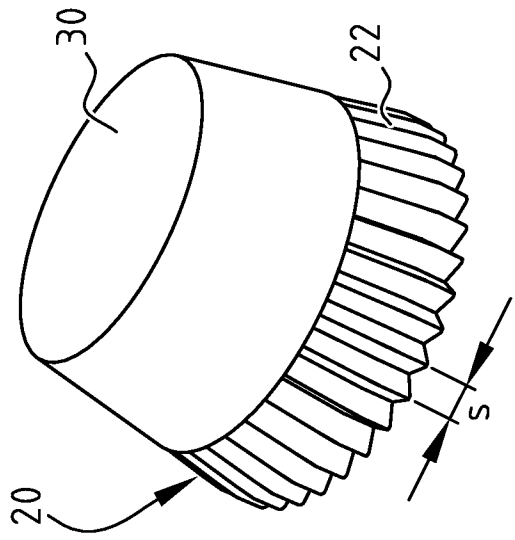


FIG. 4A

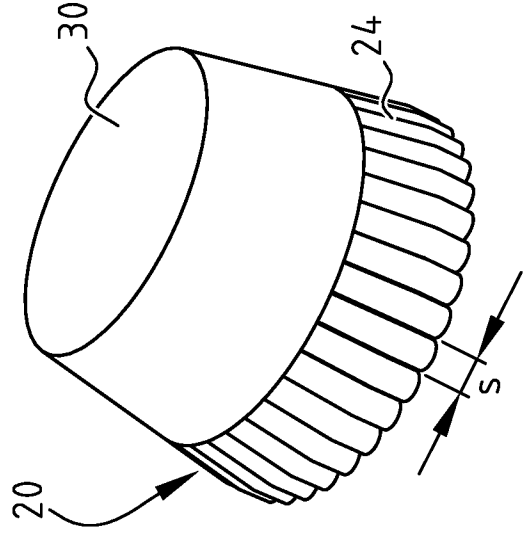


FIG. 4B

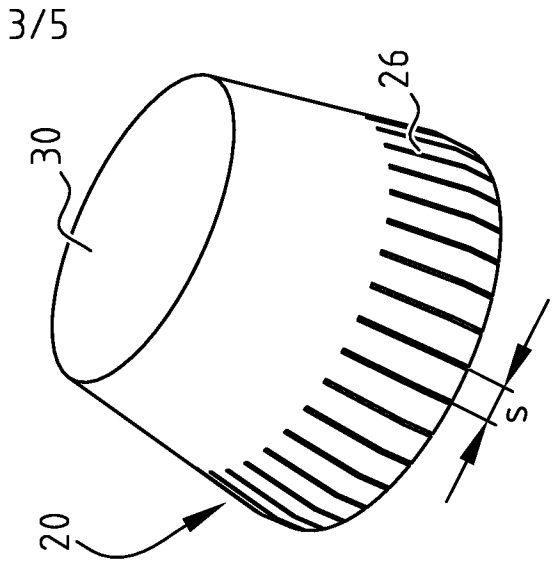
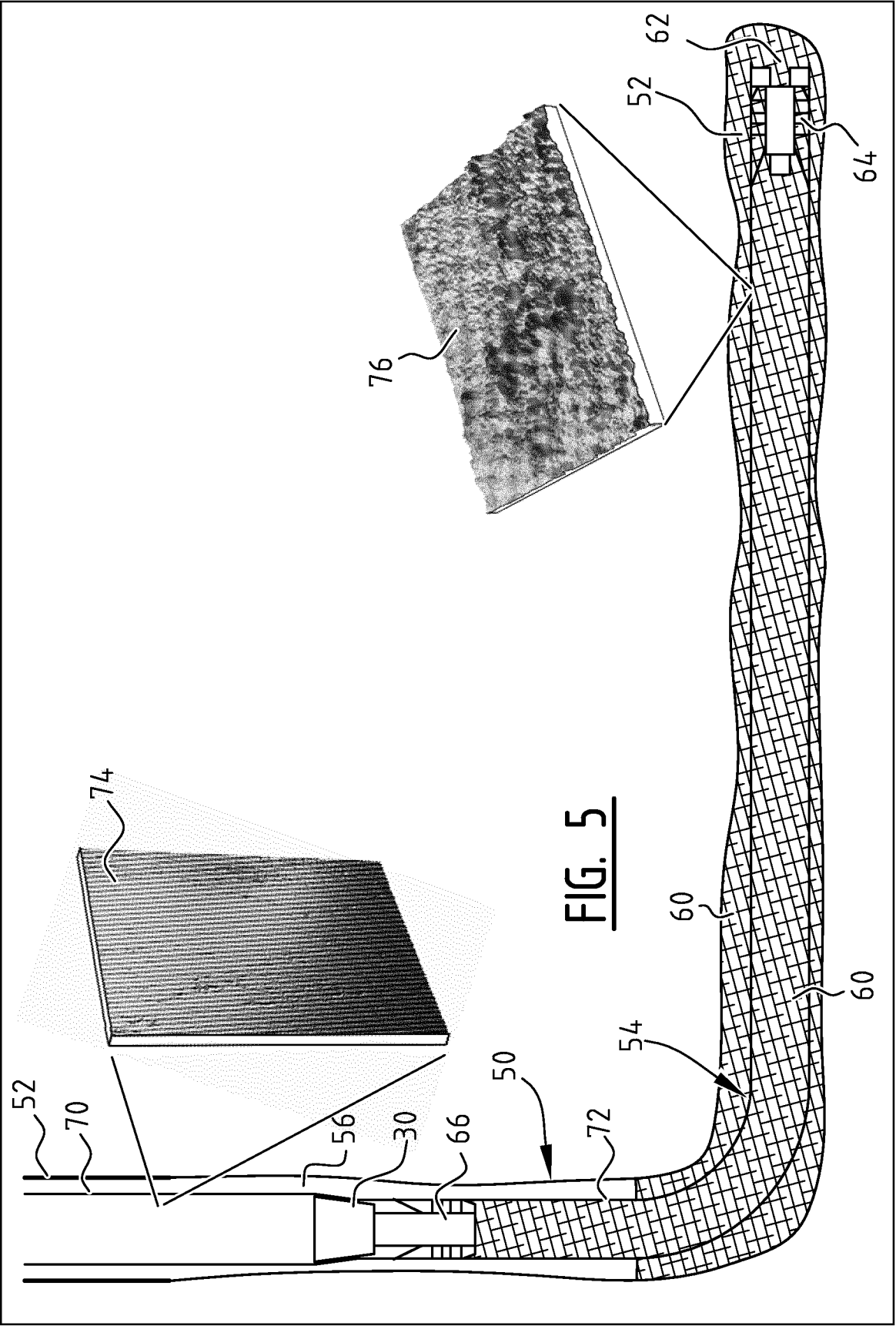


FIG. 4C



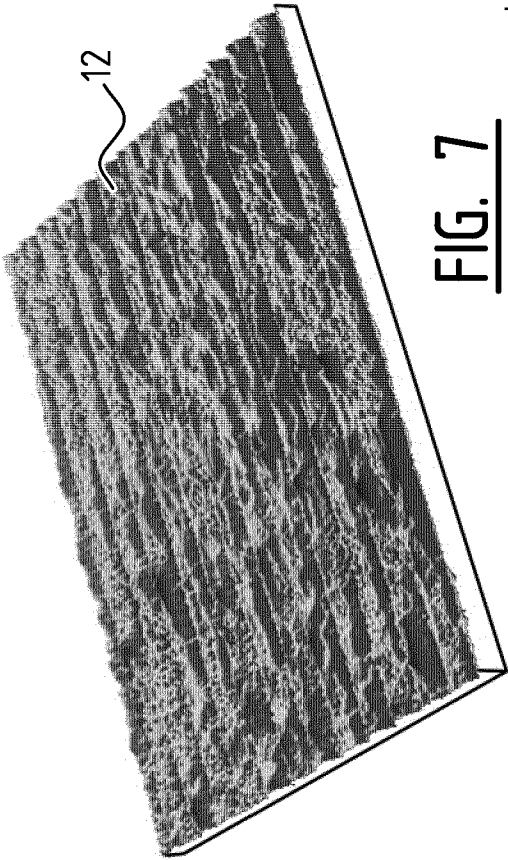


FIG. 7

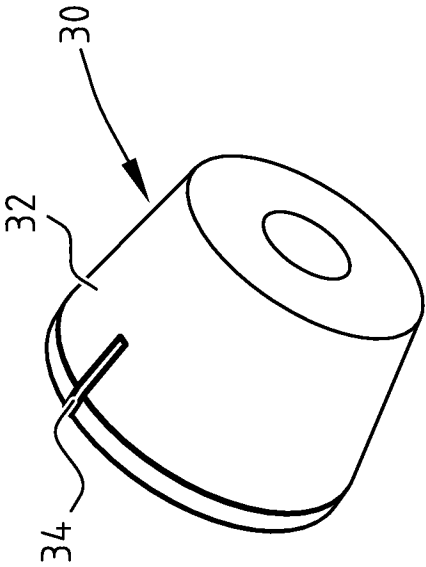


FIG. 9

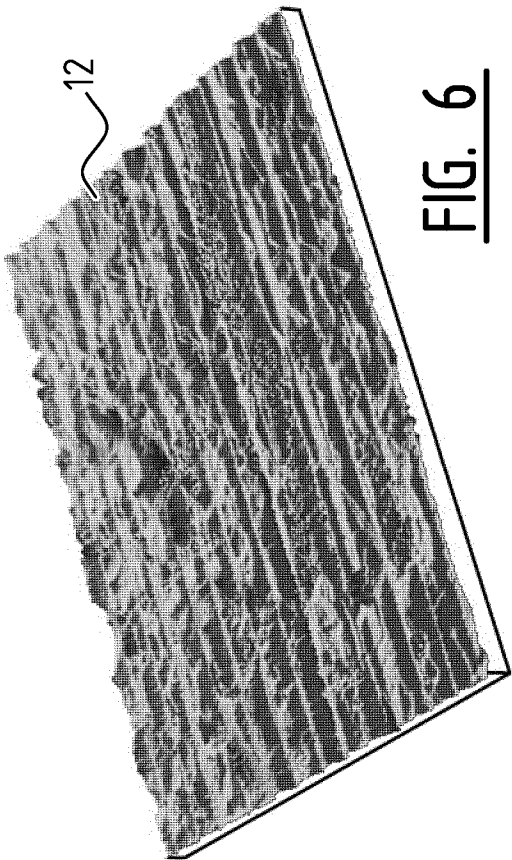


FIG. 6

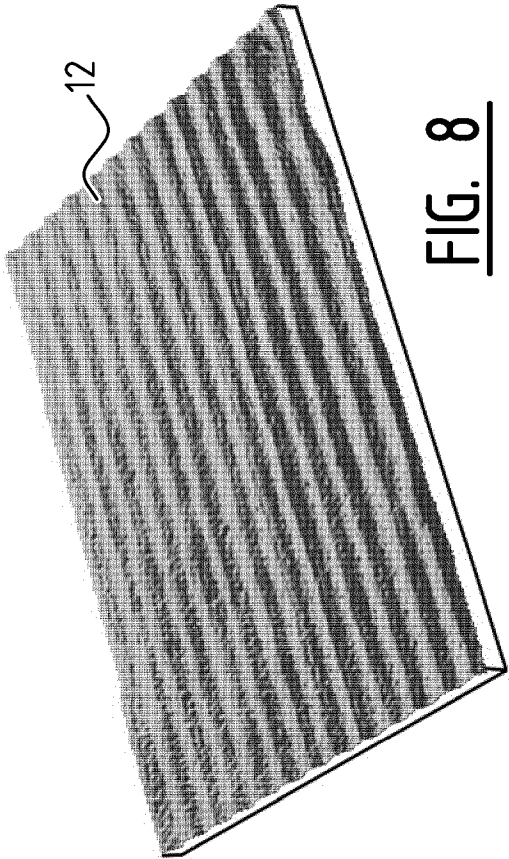


FIG. 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2014/055718

A. CLASSIFICATION OF SUBJECT MATTER
INV. E21B43/10 E21B33/16
ADD.

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)
E21B

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 practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2010/072751 A2 (SHELL INT RESEARCH [NL]; HESSELS JOHANNES LOUIS LEONARDUS [NL]; ROGGE) 1 July 2010 (2010-07-01) page 6, line 18 - line 23 page 8, line 31 - page 9, line 2 figures 1,3,4,5	1,2,6-17
A	WO 2005/005772 A1 (SHELL INT RESEARCH [NL]; SHELL CANADA LTD [CA]; LOHBECK WILHELMUS CHRI) 20 January 2005 (2005-01-20) page 1, line 14 - line 17 page 5, line 29 - page 6, line 24 figures 1-2	1-17
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See patent family annex.

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Date of the actual completion of the international search

16 June 2014

Date of mailing of the international search report

25/06/2014

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Authorized officer

Schneiderbauer, K

INTERNATIONAL SEARCH REPORT

International application No

PCT/EP2014/055718

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 2008/154388 A2 (BAKER HUGHES INC [US]; JOHNSON MICHAEL H [US]; RICHARD BENNETT M [US]) 18 December 2008 (2008-12-18) paragraphs [0004], [0008], [0009] page 5; table 1 figures 1,2 -----	1-17
A	US 6 334 351 B1 (TSUCHIYA MASAKI [JP]) 1 January 2002 (2002-01-01) column 1, line 51 - line 55 column 5, line 9 - line 36 figure 4 -----	1-17
A	WO 01/33037 A1 (SHELL OIL CO [US]; COOK ROBERT LANCE [US]; BRISCO DAVID P [US]; STEWAR) 10 May 2001 (2001-05-10) page 22, line 11 - line 28 page 23, line 19 - line 31 figures 13,14 -----	1-17
A	US 2005/194152 A1 (CAMPO DONALD B [US] CAMPO DONALD BRUCE [US]) 8 September 2005 (2005-09-08) paragraphs [0024], [0043] -----	1-17

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2014/055718

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2010072751 A2	01-07-2010	AU 2009331539 A1 CA 2748162 A1 CN 102264996 A EP 2368013 A2 US 2011259609 A1 WO 2010072751 A2	01-07-2010 01-07-2010 30-11-2011 28-09-2011 27-10-2011 01-07-2010
WO 2005005772 A1	20-01-2005	AU 2004256232 A1 BR PI0412339 A CA 2532165 A1 CN 1846041 A DE 602004002782 T2 EP 1649137 A1 MY 139451 A OA 13217 A US 2006162938 A1 WO 2005005772 A1	20-01-2005 05-09-2006 20-01-2005 11-10-2006 16-08-2007 26-04-2006 30-10-2009 13-12-2006 27-07-2006 20-01-2005
WO 2008154388 A2	18-12-2008	US 2009139725 A1 WO 2008154388 A2	04-06-2009 18-12-2008
US 6334351 B1	01-01-2002	EP 1097760 A2 JP 2001137978 A US 6334351 B1	09-05-2001 22-05-2001 01-01-2002
WO 0133037 A1	10-05-2001	AU 783245 B2 AU 1356601 A CA 2389094 A1 GB 2374622 A NO 20022048 A US 7048067 B1 WO 0133037 A1	06-10-2005 14-05-2001 10-05-2001 23-10-2002 28-06-2002 23-05-2006 10-05-2001
US 2005194152 A1	08-09-2005	BR PI0508272 A CA 2559008 A1 CN 1965147 A GB 2428060 A US 2005194152 A1 WO 2005088069 A1	07-08-2007 22-09-2005 16-05-2007 17-01-2007 08-09-2005 22-09-2005