United States Patent [19]

Hughes et al.

[11] **3,882,665**

[45] **May 13, 1975**

[54] **FLEXIBLE PUMPING STRAND AND METHOD OF MAKING**

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[22] Filed: **Feb. 19, 1974**

[21] Appl. No.: **443,930**

[52] **U.S. Cl.** **57/149;** 57/153; 57/162; 57/164

[51] **Int. Cl.** **D07b 1/16;** D07b 7/14

[58] **Field of Search** 57/149, 153, 162, 164, 57/144; 64/2; 138/125, 129

[56] **References Cited**

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2,043,401	6/1936	Wells	57/149 X
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3,800,522	4/1974	Hughes et al.	57/149
3,824,777	7/1974	Riggs	57/149

Primary Examiner—Donald E. Watkins

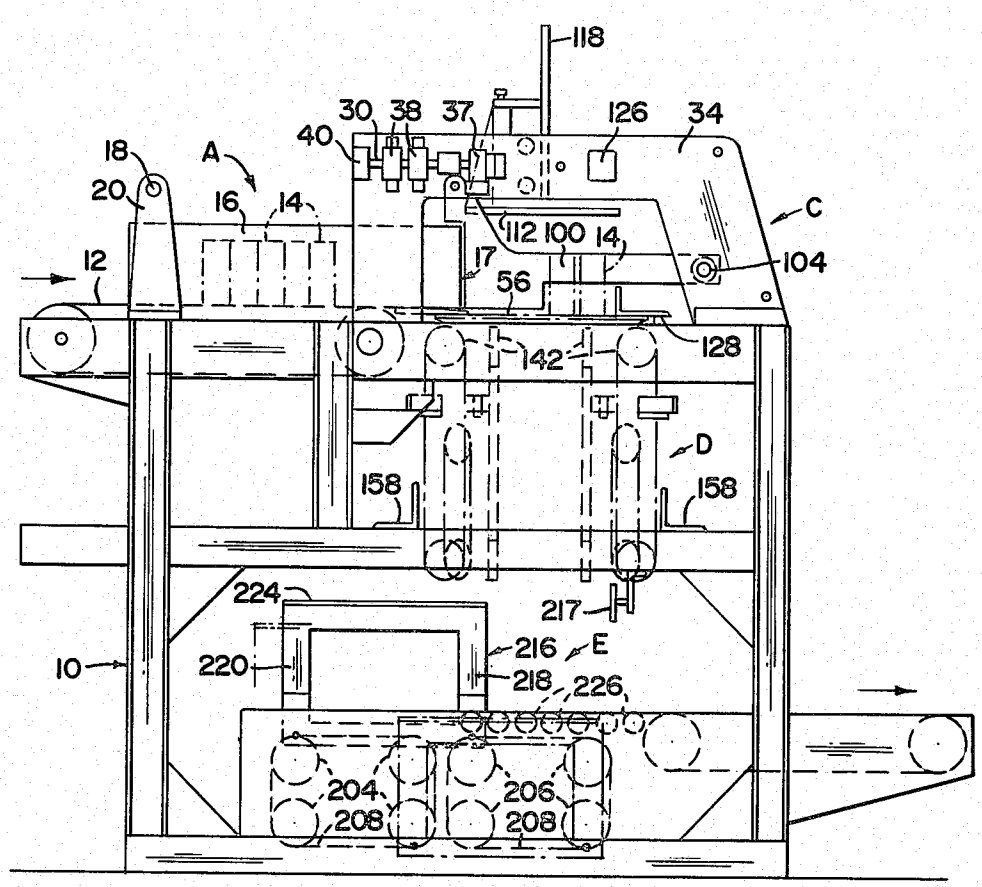
Attorney, Agent, or Firm—Joseph J. O'Keefe; Charles A. Wilkinson

[57] **ABSTRACT**

A flexible pumping strand is formed from a plurality of steel wires stranded or held together within an abrasion resistant flexible outer plastic jacket perforated at intervals along its length, each of the plurality of steel wires being coated with an imperforate corrosion resistant plastic bonded to the surface of the wire.

A method of forming the flexible pumping strand and the perforations in the outer coating of the strand involving the use of steam induced perforation during extrusion of the plastic jacket over the strand is also disclosed.

24 Claims, 5 Drawing Figures



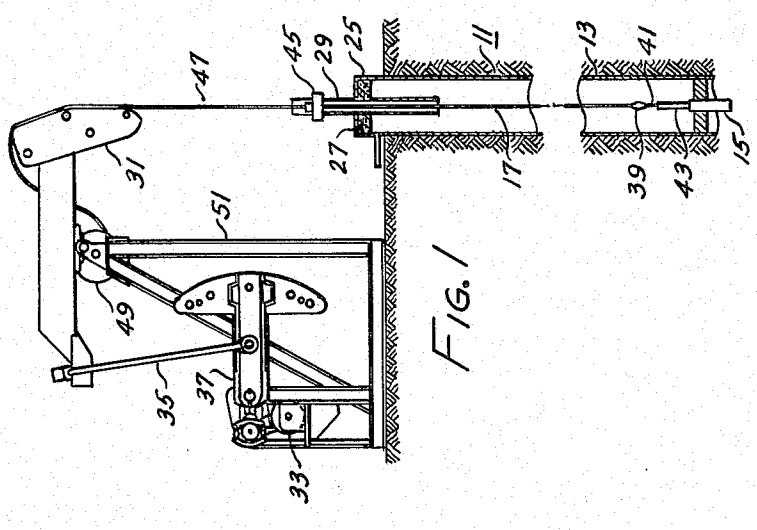


FIG. 1

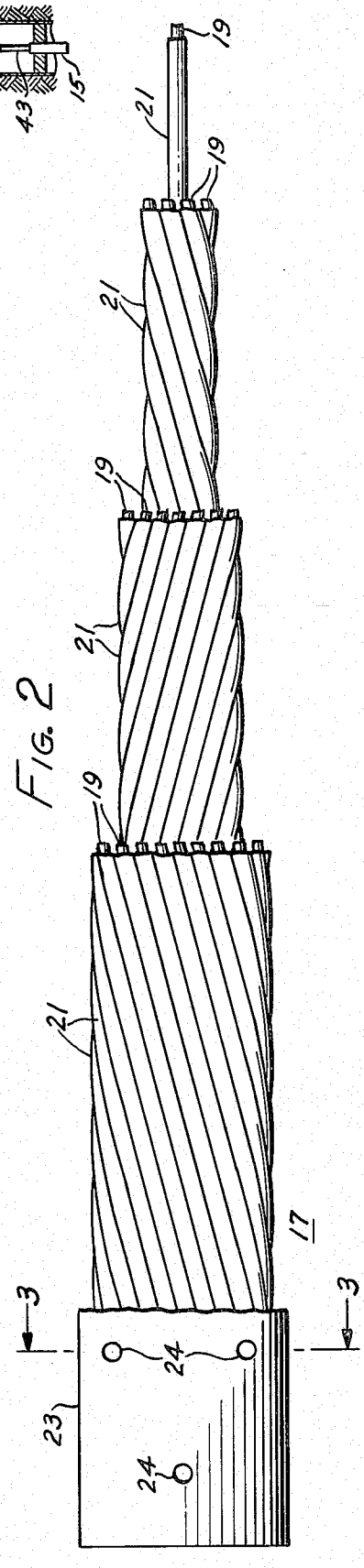


FIG. 2

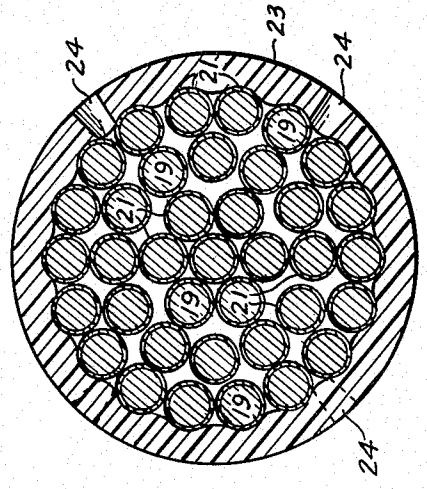


FIG. 3

FIG. 4a

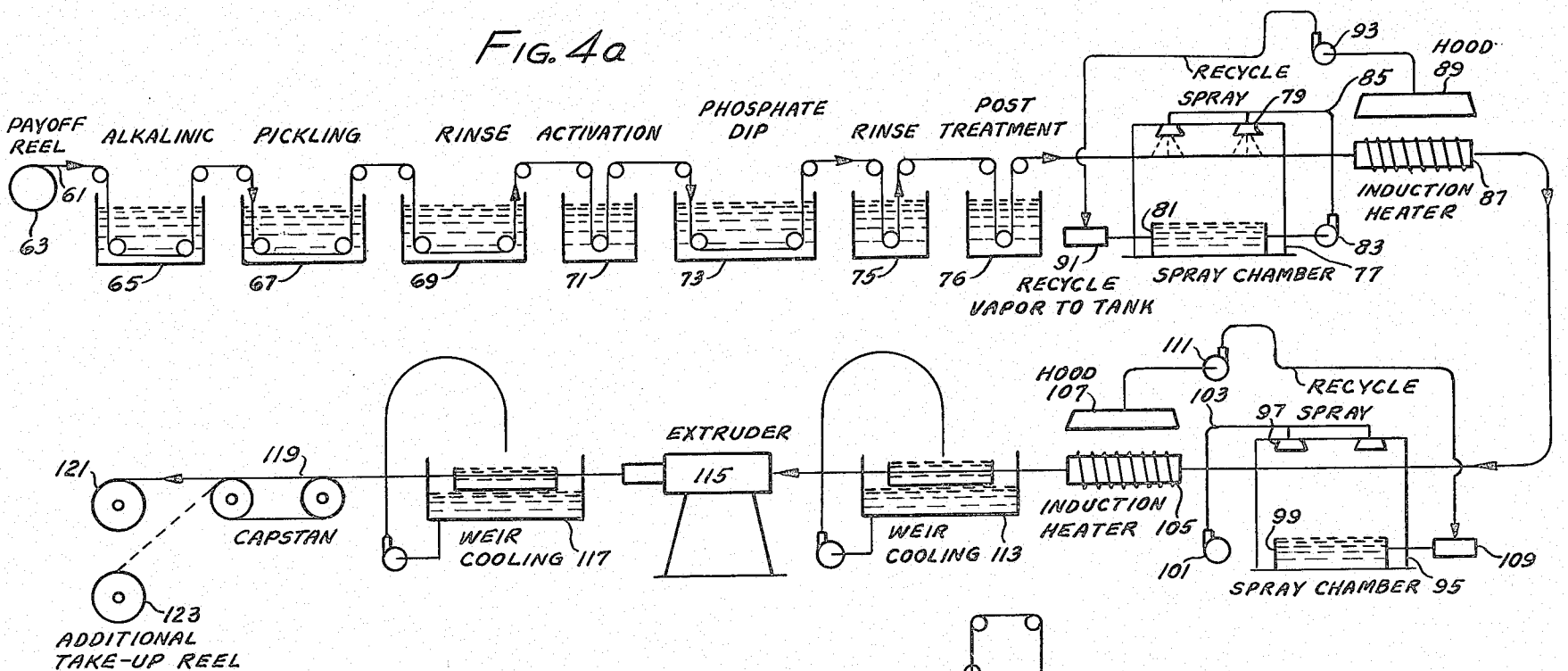
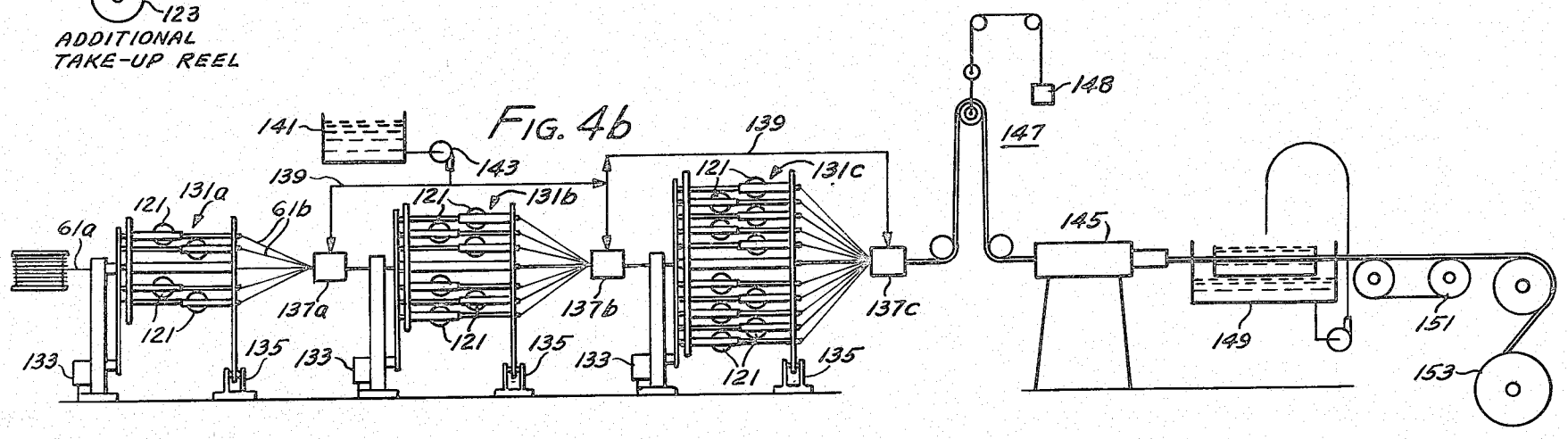

PAYOFF REEL
ALKALINIC
PICKLING
RINSE
ACTIVATION
PHOSPHATE DIP
RINSE
POST TREATMENT
RECYCLE SPRAY
HOOD
INDUCTION HEATER
RECYCLE VAPOR TO TANK
SPRAY CHAMBER
EXTRUDER
CAPSTAN
WEIR COOLING
ADDITIONAL TAKE-UP REEL
HOOD
RECYCLE SPRAY
INDUCTION HEATER
SPRAY CHAMBER

FIG. 4b



FLEXIBLE PUMPING STRAND AND METHOD OF MAKING

BACKGROUND OF THE INVENTION

The present invention relates to oil well pumping and more particularly to corrosion resistant flexible pumping strands.

In U.S. Pat. No. 3,234,723 issued Feb. 15, 1966 to K. D. Brown there is disclosed in FIGS. 6 and 7 a type of flexible pumping strand wherein a plurality of longitudinal tension wires are disposed in a so-called "bundled" arrangement within a plastic tubing. Each of the wires is preferably also individually jacketed with a plastic composition so that each wire is protected from corrosion by two jackets, an individual plastic jacket for each wire and an overall plastic jacket surrounding the entire flexible pumping strand. Thus if some corrosive substances or liquids gain entrance to the pumping strand through the outer jacket it is supposed that the inner jackets will provide a second line of defense against corrosion of the wires of the strand by the corrosive substances. The outer jacket of the U.S. Pat. No. 3,234,723 patent jacket also serves to "bundle" or confine the plurality of wires which comprise the strand together since according to the disclosure of the patent the individual wires are disposed in a somewhat loose bundle within the jacket and are substantially straight or parallel to each other in order to attain the maximum strength in the strand per metal cross section. The individual plastic jacketing of the wires not only provides a secondary line of defense against corrosive substances, but also serves to facilitate movement and adjustment between the individual wires with a minimum friction and abrasion between the wires. The invention of the U.S. Pat. No. 3,234,723 has been tried experimentally in strands having an overall outer plastic jacket extruded over the strand and individual plastic jackets extruded over the wires as disclosed in the patent, but in which the individual wires, rather than being bundled together loosely within the jacket to facilitate individual movement and adjustment of the wires, are instead stranded together into a helical wire strand having a fairly long helix or lay, the length of which falls somewhere between the customary lay which is provided in most helical wire strands both to hold the strands together and to facilitate bending of the strands about a radius, and the parallel wire arrangement of a conventional parallel wire strand in which the wires are not stranded together in a helix. Since a flexible pumping strand conventionally operates while disposed in a straight vertical condition such strand requires only sufficient helix or twist to facilitate bending of the strand during transportation and withdrawal of the strand from the well and if the strand is additionally jacketed with an outer plastic jacket, the plastic jacket will aid somewhat in maintaining the individual wires together. The previous experimental strands were jacketed and the wires were individually coated with various types and grades of nylon. In the experimental strands referred to it was found that the strands did not successfully withstand corrosive conditions in oil wells and particularly in so-called "sour brine" oil wells containing hydrogen sulfide. The outer nylon jackets were found to suffer damage due to perforation and the like and the individual nylon jacketed wires suffered intermittent corrosion which caused failure of the strands after uneconomically short periods.

Sometimes the failure of the strands was devastatingly sudden. Various other coating substances were tried to discourage corrosion on laboratory specimens held in simulated corrosive oil well environments including Teflon, or polytetrafluorethylene, suggested as an alternative coating composition in the specification of the U.S. Pat. No. 3,234,732, but no really satisfactory solution to corrosion and damage to such strands has been found heretofore where the strand is to have the individual wires coated within an outer plastic jacket to withstand corrosion and the strand is to have a substantially static interior environment, i.e., as contrasted to the strands disclosed in U.S. Pat. No. 3,637,341 where an internal corrosion inhibitor is periodically renewed or renewable within the strand to prevent or inhibit internal corrosion of the component wires as external corrodants slowly gain entrance to the interior of the strand through the natural slight permeability of many nominally impermeable plastic resins.

SUMMARY OF THE INVENTION

The foregoing problems associated with previous double jacketed flexible pumping strands have now been obviated by the flexible pumping strand made in accordance with the present invention.

In accordance with this invention a flexible pumping strand is constructed of a plurality of wires coated with a chemically resistant plastic coating which is inert to oil well fluid, has a low permeability to water and corrosive gases and is sufficiently tough to survive stranding and interwire fretting or abrasion during service. Preferably the plastic coating is formed of a polyvinylidene fluoride composition which has been found by the inventors to be the most suitable composition for corrosive oil well environments and substantially essential along with several other similar fluoropolymers for use in severely corrosive environments in oil wells. The plastic coating is bonded to the individual wires to prevent propagation of corrosion due to migration of corrosive elements between the coating and the underlying wire starting at restricted minor defects in the coating. Over the individually coated wires there is extruded an overall outer plastic jacket formed of an abrasion resistant plastic such as nylon and particularly so-called Nylon 11. This outer plastic jacket is provided with holes or perforations through the coating at periodic intervals which are spaced with sufficient frequency with respect to the size of the perforations to allow free passage of well fluid back and forth through the perforations from the interior to the exterior of the strand and back again.

The invention also includes a method of forming the strand including the formation of perforations in the strand by means of vapor generated in the interior of the strand by vaporization of a vaporizable liquid in the core during extrusion of the plastic jacket over the body of the strand.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagrammatic elevation of an oil well using a flexible pumping strand fabricated according to the present invention.

FIG. 2 is a partially broken away longitudinal cross-section of the flexible pumping strand of the invention.

FIG. 3 is a transverse cross-section of the flexible pumping strand shown in FIG. 2 at 3—3.

FIGS. 4*a* and 4*b* respectively are elevations of a wire coating line and a strand fabricating and coating line with which the wire coating line is associated for making the flexible pumping strand of the invention.

DESCRIPTIONS OF THE PREFERRED EMBODIMENTS

In FIG. 1 there is shown a schematic view of an oil well 11 including a well casing 13, a differential pressure or other suitable pump 15 positioned at the bottom of said casing to pump the oil up to the surface through the casing or through a well tubing not shown, disposed within the casing, a flexible pumping strand 17 comprised of individual steel wires 19 each of which is coated with an individual plastic jacket 21 of polyvinylidene fluoride or other suitable corrosion resistant plastic and which wires are stranded together into a long lay strand having an outer abrasion and corrosion resistant jacket 23 covering the exterior of the strand, all as shown in greater detail in FIGS. 2 and 3. The flexible pumping strand 17 passes at the well head 25 through the usual packing 27 preferably being protected as it passes through the packing by being enclosed in a so-called hollow polished rod 29 which is secured to the strand and reciprocates in the packing 27 as the flexible pumping strand 17 is reciprocated by the movements of a horsehead 31 operated at the surface of a motor 33 through a connecting rod 35 connected to a flyweight arm 37. The reciprocation of the flexible pumping strand 17 serves to operate the pump 15 to which the flexible pumping strand is attached through a swaged fitting 39 or other suitable fitting, a shear release fitting 41 and a connecting pony rod or pumping rod 43. The hollow polished rod 29 and strand may preferably be supported from the horsehead 31 by a carrier bar 45 through bridles 47. Excess flexible pumping strand 17 is reeled as shown on a reel 49 secured to the supporting framework 51 upon which the horsehead 31 is pivotally mounted, or is coiled on the surface.

It will be readily understood that the oil well, which is for convenience of illustration shown in FIG. 1 broken in the center, may be several thousand feet deep and will be filled with crude oil which is in many cases saturated with highly corrosive substances which may be predominantly acid or alkali and may otherwise vary depending upon the nature of the surrounding geological strata and environment. Not only is the well 11 likely to be filled with highly corrosive substances, but it is also often subjected to very high pressures particularly in the lower portions of the well. The well may also be very hot in its lower reaches due to the usual approximate temperature increase of about 1° centigrade for every 100 feet or so of depth. The high pressures and high temperatures encountered in the lower reaches of the oil well quite naturally tend to aggravate the corrosive effects of corrosive substances in the well upon the metallic components of the flexible pumping strand 17 and the degradative effects of the surrounding environment upon the plastic components of the flexible pumping strand. Changes in pressure occur in the well both from time to time within any given portion of the well and also as the flexible pumping strand is lowered into and withdrawn from the oil well for inspection, repair or replacement of the pump 15 or other components of the pumping string. Such pressure changes not only tend to aggravate whatever corrosion and degradation may already be present due to a naturally detrimental deep oil well environment, but may in themselves tend to burst, rupture or otherwise damage the strand coating or jacket. In short the usual deep oil well environment is often a very rigorous environment which rather quickly damages most exposed surfaces which are subjected to it.

The flexible pumping strand of the present invention is designed to withstand the rigors of corrosive oil well environments. Durability of the strand under adverse corrosive conditions is attained by coating the individual wires with an adherent plastic resin composition which is simultaneously extremely resistant to penetration of the corrosive substances found in oil wells, resistant to degradation of the plastic by these same substances or other destructive substances found in an oil well and which is resistant to fretting and abrasion between the individual wires. The plastic coating is applied in a manner which makes the plastics very adherent to the underlying surface of the individual wires of the strand in order to discourage propagation of corrosion by any corrosive agent which may somehow gain access through the coating to a limited portion of the wire surface underneath. Such propagation of corrosion along the wires between the plastic coating and the surface of the metal wires is not only detrimental in itself, but seems to precipitously increase the rate of corrosion at the point of access through the coating as well. The wire coating will be composed of polyvinylidene fluoride which is available on the market under the name of KYNAR, a proprietary tradename of the Pennwalt Company. While polyvinylidene fluoride has been found to be the preeminent coating material for protection of the individual wires of the strand and this polymer or a comparable fluoropolymer is substantially a necessity for use in very corrosive oil well environments and particularly those which contain significant quantities of hydrogen sulfide as one of the corrodents, such as for example sour brine type wells, other corrosion resistant plastics such as nylon and polypropylene could be used in wells which are not severely corrosive and particularly those wells which are not acid in composition and do not contain hydrogen sulfide or similar compounds as a corrodent. Various fluoropolymers are in general better for corrosion protection of the individual wires in oil well environments, but all fluoropolymers, for example polytetrafluoroethylene or Teflon, are not suitable because of difficulties in application to the wire and particularly difficulties in obtaining a secure bond of the plastic to the surface of the wire.

After being individually coated with the corrosion resistant plastic and preferably a polyvinylidene fluoride composition, the wires are stranded, laid or formed into the strand 17 and an outer abrasion resistant plastic jacket is extruded over the surface of the strand. The plastic jacket is preferably composed of a nylon composition such as Nylon 11. The nylon coating is also preferably applied by a pressure type extrusion operation rather than a vacuum type extrusion operation in order to provide a thick plastic jacket with a smooth cylindrical exterior plastic surface. At frequent intervals along the strand, which intervals should normally not be greater than 30 feet and preferably considerably less, the nylon coating on the strand is perforated with small perforations about one-eighth to one-half of an inch in diameter. The perforations must extend completely through the plastic jacket in order to provide

free access for well fluids from the interior of the strand to the exterior of the strand or from the exterior well environment to the interior of the strand. The perforation may be positioned on various sides of the strand or may be placed along only one side. The size of the perforations or orifices does not seem to be critical, but the orifices should be large enough and frequent enough to provide free and unimpeded passage of well fluid back and forth through the orifices yet not so large as to allow large abrasive particles to gain access to the interior of the strand, particularly before it is placed in the well or to substantially weaken the plastic jacket due to the removal of an excessive amount of plastic from the circumference of the jacket. It has been found that much of the failure of the plastic jackets on previous experimental strands has been due to repeated and occasionally extreme pressure variations on the exterior of the strand as compared to the interior as the strand works in the well or is removed from or replaced in the well. These pressure variations are accentuated by the fact that the interior of the strand is essentially empty, or, more correctly, filled only with atmospheric gases. Even a thick plastic jacket on the exterior of the strand does not appear to be able to withstand the differential pressure between the exterior of the strand and the substantially empty center of the strand in the interstices between the component wires for long continued periods. Likewise, if well fluid should gain entrance to the strand and the strand is then removed from the well for inspection, the strand jacket may be damaged by the excess fluid in the strand. Strangely, much of this damage to the strand occasioned by pressure differentials is not evident as mechanical damage to the strand but may initially appear to be due to corrosive effects of the environment. It may be that a synergistic effect between the pressure and the corrosive or degradative substances in the well causes the damage to the strand jacket. In any event it has been found that damage to the plastic strand jacket and associated damage to the underlying wires of the strand can be avoided by providing perforations in the strand jacket which allow free access to the interior of the strand for the well fluid and free interchange of the well fluid back and forth through the outer plastic jacket.

In FIGS. **2** and **3** there is shown an enlarged partially cut away longitudinal cross section and a transverse cross section respectively of a preferred construction of the flexible pumping strand **17** shown in use in an oil-well in FIG. **1**. As shown in FIG. **3** the strand **17** is a 1 × 37 wire construction composed of 0.100 inch improved plow share steel grade wires having a tensile strength of 120 to 135 tons per square inch (240,000 to 270,000 psi.) composed of three separate operations or layers of wires, the lay of the wires in each operation being opposite to the lay of the adjacent wire operation or operations. Each wire has an outer jacket composed of polyvinylidene fluoride coated to a final coated wire diameter of 0.110 inches overall. There is about 13 percent void space in the interior of the finished strand. The opposite lays of the various operations provide a strand with minimal rotational properties. Various different lay lengths can be used in the various operations or layers to attain the particular rotational properties desired or all of the lays of the strand can be the same. It will be evident to those skilled in the art that other wire sizes and types and alternative strand constructions could be used. Other types of commercially available plastic resins such as other fluoropolymers or other compositions of plastics which (a) are inert to the particular well fluid and corrosive elements in the well fluid (b) have low permeability in water and corrosive gas and (c) are sufficiently tough to survive stranding operations and interwire fretting and abrasion during service can be used.

Over the outer circumference of the strand **17** there is applied an outer jacket **23** formed of an abrasion resistant polyamide such as Nylon 11 approximately 0.050 inches thick over the tops of the outer wires of the strand and having a smooth outer surface. The polyamide jacket has perforations **24** about three-sixteenths of an inch in diameter spaced at intervals of not greater than about thirty feet along the longitudinal extent of the strand and preferably at more frequent intervals of a few feet or less. In FIG. **3** two such perforations or orifices are shown spaced transversely from each other on the same circumference of the strand for purposes of illustration, but it will be understood that such perforations will more usually be spaced longitudinally along the length of the strand. The perforations are effective to allow free passage of well fluid back and through the strand and to allow the strand to be quickly filled with well fluid as it is being passed downwardly into the well and to allow the well fluid to drain quickly from the strand as it is being withdrawn from the well. It will be understood that other types of abrasion resistant plastics which are substantially inert to the well fluid and other thicknesses of plastic than those illustrated could be used for the outer jacket. Various types of perforations or shapes of orifices in the jacket can, furthermore, be used so long as the orifices provide free flow of well fluid back and forth through the plastic jacket, but are not so extensive that they interfere with the substantial continuity of the strand covering provided by the plastic outer jacket. The outer jacket is preferably applied to the strand by a pressure extrusion operation so that the plastic forms a fairly thick layer on the surface of the strand and has a smooth outer surface rather than an outer surface conforming generally to the contours of the individual wires which comprise the outer surface of the metallic portion of the flexible pumping strand. The plastic strand jacket may desirably have a thickness of about 0.050 inches for a polyamide or particularly a Nylon **11** jacket, but may also have other thicknesses depending upon the plastic composition used and the environment in which it is to be used.

The flexible pumping strand of the invention may be made as shown in FIGS. **4***a* and **4***b* which illlustrate an integrated production line for the initial coating of the component wires, the stranding of the coated wires together to form the body of the flexible pumping strand and the jacketing of the pumping strand with a perforated outer plastic jacket.

In FIG. **4***a* a wire **61** is initially unreeled from a payoff reel **63** and passed constructively through an alkaline cleaning bath **65** and a pickling bath **67** to remove drawing soaps and scale in a conventional manner. The wire is then passed through a rinse bath **69** to remove residues remaining from the preceding treating baths. The wire **61** then passes into a phosphate activator bath **71** where the surface of the wire is activated prior to passage into a phosphating bath **73** which applies a phosphate coating to the wire surface by treatment in

a proprietary phosphate composition in a known manner of producing an iron phosphate conversion coating on a steel surface. The proprietary phosphating compound may be Granodine 1100, produced by Amchem Products Incorporated. However, other types or brands of commercial phosphate coatings can also be used. After passing through the phosphate tank or bath **73** the phosphated wire passes through a rinse tank **75** where the phosphated wire is rinsed in water and then passes into a post treatment bath **76** where the phosphated wire is treated in an acid rinse to fix the phosphate coating and activate the surface of the wire in preparation for the next treatment. The wire then passes into a spray application chamber **77** where an epoxy type primer is applied to the surface of the wire. The epoxy primer, which serves primarily as an adhesive to aid in obtaining a tightly bonded plastic coating on the wire, may be any one of a number of commercially available primers suitable for use with the subsequently applied plastic. As an example, NUBLAR epoxy primer No. 67431 made by the Glidden Company suitably thinned by a solvent was applied to the wire in the spray chamber **77** as the wire moved through the chamber at 130 feet per minute. Overspray from the sprays **79** falls into the trough **81** within the chamber **77** and is recycled by the pump **83** back to the sprays **79** through pipe **85.**

From the spray chamber **77** the primer coated wire passes into an induction furnace **87** where the primer is baked onto the surface of the wire. The furnace **87** serves to expel the solvent from the primer as well as activate and cure the primer, and solvent vapors are caught in a hood **89** and returned to a mixing and makeup tank **91** via the suction engendered by centrifugal pump **93.** From the induction furnace **87** the wire passes to a second spray chamber **95** where a second primer coating is applied over the surface of the first primer. The second primer is comprised of a suspension of the same polymer which is to be applied by extrusion to the outer surface of wire dispersed or dissolved in a suitable organic solvent such as, for example, xylene, isopherone or diacetone alcohol. For example polyvinylidene fluoride may be dispersed in isopherone and sprayed by the sprays **97** onto the wire as the wire passes through the chamber **95.** The overspray is caught in the trough **99** and recycled via pump **101** and pipe **103** back to the sprays **97.** The second primer may consist of a proprietary primer known as Kynar dispersion No. 202 sold by the Pennwalt Corporation if the final coating on the wires is to be composed of polyvinylidene fluoride. The wire then passes through a second induction furnace **105** where the solvent is evaporated from the primer and the remaining plastic resin of the primer is fused upon the wire over the first primer. The solvent vapor escaping from the furnace **105** is caught or collected by the hood **107** and returned to make-up and mixing tank **109** via the suction induced by the centrifugal pump **111.** The wire may suitably leave the induction furnace **105** at a temperature of about 500° F. and with a total coating thickness comprised of the two primer coatings of about 0.0005 inch. From the induction furnace **105** the wire next passes through a water cooling weir **113** and then through a pressure extruder **115** where a coating of polyvinylidene plastic is extruded onto the surface of the moving wire. The polyvinylidene fluoride bonds very securely to the thin film of the second primer, which is comprised after it is fused on the surface of the wire of a very thin film of polyvinylidene fluoride, to form an overall protective plastic coating or plastic jacket which is extremely adherent to the surface of the underlying wire. The thickness of the final protective polyvinylidene fluoride protective coating may be about 0.005 inches or a total of 0.010 inches of plastic added to the diameter of the wire. After extrusion of the coating onto the wire, the wire passes through a second weir **117** where the wire with its overlying coating is thoroughly cooled before passing the wire about a pulling capstan **119** and then onto a take-up reel or spool **121,** and when that reel or spool **121** is full onto additional reels or spools designated as **123.**

The polyvinylidene fluoride plastic resin or PVF_2 may be so-called Kynar, a proprietary composition of the Pennwalt Company. However, polyvinylidene fluoride resins supplied by other sources or companies may also be used. While PVF_2 is preferred because of price and handling characteristics as the wire coating composition for sour brine type wells, i.e., oil wells having a large amount of brine and hydrogen sulfide in them, other types of fluoropolymers have also been found satisfactory though somewhat less convenient. One example of such fluoropolymers is polychlorotrifluoroethylene, often designated as PCTFE. This polymer can be purchased from the 3M Company under the brand name of Kel F. Another suitable fluoropolymer is a copolymer of tetrafluoroethylene and hexafluoropropylene sometimes designated as FEP polymer. This resin is sold by the DuPont deNemours Company under the brand name of Teflon FEP. A third suitable fluoropolymer in addition to the preferred polyvinylidene fluoride is polyethylenechlorotrifluoroethylene often designated as PECTFE. The polyethylenechlorotrifluoroethylene copolymer is sold by the Allied Chemical Corporation under the brand name of Halar. A further polymer which has been found to be suitable in a simulated sour brine oil well environment is polyethylenetetrafluoroethylene or PETFE which copolymer is sold by The DuPont deNemours Company under the brand name Tefzel. All of these fluropolymers have been found to have the required characteristics of inertness to the well fluid, low permeability to water and corrosive gases and sufficient toughness to withstand stranding and handling of the coated wires and interwire fretting and abrasion of the wires during service in an oil well. Other fluoropolymers may possibly also be suitable in sour brine or acid type oil wells and other types of polymer coatings in addition to the fluoropolymers may be suitable for sweet brine wells, i.e., brine wells which do not contain hydrogen sulfide, and alkaline type oil wells. Each polymer used should, of course, be tightly bonded to the underlying wire surface by the use of an appropriate primer or primers during the coating operations. Plastic compositions which may themselves have suitable properties, such as inertness and impermeability to corrosive substances found in oil wells, to act as protective shields against corrosion will not be suitable for use in jacketing the individual wires of the strand in a corrosive oil well environment if there is no practical manner known to securely bond the plastic to the underlying metallic surface of the wire.

After the wire or wires **61** are suitably coated and stored on the reels **121** and **123,** the spools are either transferred to the stranding line shown in FIG. *4b* or the

coated wire is removed from the reels and wound on suitable spools for use in the stranding line.

In the stranding and jacketing line shown in FIG. 4*b*, which may be a separate line or may be a continuation of the wire coating line shown in FIG. 4*a*, the spools **121** containing the coated wires **61***a* and **61***b* are placed in position with respect to or on the flyers or rotatable stranding cages **131***a*, **131***b* and **131***c*. The flexible pumping strand shown in FIGS. 2 and 3 is a 37 wire oppositely stranded wire strand and in order to make this strand as shown in FIG. 4b there are required three stranding operations or stranding machines each of which will form or lay one operation or layer of wires **61***b* about the center wire **61***a* of the strand. It will be understood that the flyer **131***a* will during the stranding operate in one direction, the flyer **131***b* will operate in the opposite direction and the flyer **131***c* will operate in the direction of the first flyer to form a cross layed strand, or a strand having opposite rotations or lays in each operation or lay of wires. If a cross layed, or opposite lay, strand is not desired the flyers would, of course, be operated in the same direction. The rotational speeds of the flyers may be varied with relation to the speed of passage of the wires or the formation of the strand to vary the lay of the various operations of wires and thus vary the characteristics and particularly the rotational characteristics of the strand as is familiar to those skilled in the art of stranding. If desired the strand could, of course, be formed by three passes through one flyer or rotatable stranding cage rather than one continuous pass through three consecutive flyers. The flyers **131** are rotatably journaled on suitable supporting and drive means **133** at their leading ends and rotatably supported on bearing roller means **135** at their opposite ends. Associated with each flyer **131** there are stranding dies **137***a*, **137***b*, and **137***c* respectively to which the wires **61***b* from the spools **131** on each flyer are directed as illustrated to strand the wires about either the center wire **61***a* or the previous operation of wires. Leading to each stranding die is a tube **139** shown for convenience as an arrow which conveys a small stream of a water base stranding lubricant to each respective stranding die, which lubricant prevents detrimental abrasion and damage to the wires or their coatings as they are forcibly drawn through the stationary stranding dies from the rotating flyers. The water base lubricant is obtained from a reservoir **141** of lubricant. The lubricant is forced through the tubing **139** by the action of the pump **143.** The stranded wires leaving the last stranding die **137***c* then pass to a pressure type extruder **145,** preferably by way of a looping tower arrangement **147** which serves to accommodate adjustments in the operating speeds of the extruder **145** and the stranders during stopping and starting of the stranding line. The stranding operation tends to require starting and stopping more frequently than the extruding operation and this starting and stopping may cause imperfect extrusion unless the speed of the extrusion line can be maintained fairly constant. Alternatively, of course, the extrusion and stranding may be done on separate lines with a separate reeling and unreeling operation between the stranding and extrusion lines. The wires of the strand will in either case retain a fair amount of the stranding lubricant clinging to the surfaces of the wires within the interstices between the wires. The particular lubricant is not critical so long as it contains a high percentage of water or other vaporizable liquid component. It is very desirable that the lubricant be a water base lubricant, however, because the lubricant, which is essentially a light lubricant having just enough lubricity to allow the wires to slip past each other in the stranding die without damage to either the wires or the coating on the wires, also serves as a coolant for the stranding operation. If there is not sufficient lubricity to the lubricant the coating on the wires may be nicked, while if the stranding operation is not cooled sufficiently the coating may again be damaged. One very suitable lubricant to use is composed of about one part of Cimperial oil, which is a soluble cutting fluid or oil combined with a corrosion inhibitor. Cimperial oil is made and distributed by the Cincinnati Milling Products Division of Cincinnati Milacron in Cincinnati, Ohio. The soluble cutting oil is diluted or combined prior to use with about 9 or 10 parts of water. Cimperial Oil is a cutting lubricant made for use primarily in thread cutting operations which is also widely used as a stranding lubricant. Other types of soluble lubricants could also be used as the stranding lubricant as well as emulsions of oil and water and the like.

As the strand passes through the pressure extruder **145** the fluoropolymer coating on the individual wires will be temporarily or momentarily compressed by the combined effects of the pressure in the extruder and the heat of the extruder. The extruder is, of course, hot enough to render the material being extruded, i.e., a polyamide such as Nylon 11 or the like, soft and plastic to facilitate its extrusion. The normal 13 percent void space between the individual wires of the strand thus drops momentarily to a very low level due to compression of the fluoropolymer wire coatings together as the strand passes through the extruder. As the outer jacket of Nylon 11 is extruded onto the outer surface of the strand the heat of the extruding operation causes the water in the water base lubricant to vaporize and since the space between the wires is momentarily very constricted the vapor has nowhere to go and cannot escape from the strand toward the entrance of the extruding die. Thus the vapor as the strand passes from the extruding die is released instead into the interior of the newly jacketed portion of the strand and, it has been discovered, quite unexpectedly, that the vapor pressure induced in the strand causes periodic perforation of the outer plastic jacket of the strand while the plastic jacket is still in a somewhat plastic condition. The amount of the water base lubricant which clings to the individual wires when a 10 to 1 water to lubricant solution is used is just sufficient to provide a perforation pattern for the finished strand which is suitable to provide free access from the interior to the exterior and vice versa in the finished strand when the strand is used in an oil well. If necessary, of course, some water or other vaporizable liquid can be placed on the wires of the strand just before the strand passes into the extruding die to provide either all of the vapor or an effective amount of additional vapor to cause proper perforation of the strand.

As an alternative to vapor perforation the strand perforations may be made by mechanical perforation with a metal die. For example, in one case a 3/16 inch cylindrical steel rod with a flat end was warmed, pressed into the soft jacket immediately after the strand exited from the extrusion die **145** and held against the strand until the rod was carried into the subsequent cooling means where the plastic hardened. After removal of the

rod from the hardened jacket a suitable perforation of the strand jacket remained. Suitable perforations may also be formed in the hardened jacket by means of small cutting dies and the like or by drilling a hole through the jacket. Such operations however, require extreme care to avoid cutting into and damaging the plastic coatings on the individual wires of the flexible pumping strand.

After the now jacketed strand leaves the extruder 145 and perforation of the still soft jacket material takes place, the strand is passed into a cooling weir 149 where a water bath cools and hardens the plastic jacket. From the weir 149 the strand passes to and about a pulling capstan 151 which serves to pull the strand through the preceding apparatus and then passes onto a take-up reel 153 for storage or shipment.

Any type of strong abrasion resistant plastic material which is substantially inert to or not substantially degraded by the well fluid will be satisfactory as the outer jacket of the strand. It is not necessary for the material of this jacket to be impermeable to water or corrosive gas so long as it is not itself seriously degraded by such substances since the outer jacket is perforated in any event specifically to allow free passage of the well fluids through the outer jacket. Various other types of nylon in addition to the preferred Nylon 1, i.e., a nylon having 11 carbon atoms on the principal di-acid, di-amine or amino-acid monomers from which the nylon polymer is polymerized, can be used if such other types are tough and abrasion resistant. Another very suitable outer jacket material is ultra-high molecular weight polyethylene or so-called UHMW polyethylene.

When the flexible pumping strand of the invention is placed in a corrosive oil-well environment the well fluid has free access to the interior of the strand through the perforations in the plastic jacket of the strand. This prevents damage of the jacket arising from pressure variations encountered in all portions of the well and particularly from the high pressures encountered in the lower portions of a deep well. The plastic outer jacket, on the other hand, effectively protects the inner components of the strand from abrasion and wear. It is important that the fluoropolymer coatings on the individual wires of the strand be protected from physical contact with the structures of the inside of the well and the general well environment and the outer jacket serves very effectively to package or protect all the individual wires from mechanical damage both in the well and during storage and transportation prior to use in the well. In the case of a pumping strand which has substantially parallel wires, furthermore, such as are shown in U.S. Pat. Nos. 3,212,582 or 3,234,723 to K. D. Brown and where individually coated wires are used as shown in U.S. Pat. No. 3,234,723, the outer plastic jacket serves effectively to maintain the wires of the strand together in a compact bundle. However, with the preferred strand shown in FIGS. 1, 2 and 3 in which the flexible pumping strand 17 has a fairly long lay to maintain the wires of the strand together and to facilitate bending of the strand while still maintaining a minimum overall diameter of the strand, the outer plastic jacket has only a minimum effect in keeping the wires together. However, if a strand such as described and claimed in U.S. Pat. No. 3,234,723 is made in the approved manner of the present invention, that is with a fluoropolymer bonded securely to the wire surface to inhibit migration of corrosion along the wire surface under the plastic coating and having an outer perforated abrasion resistant plastic jacket, then the perforated plastic jacket of the invention would serve, in addition to protecting the inner wire from damage, to, of course, also maintain the individual wires together in a compact bundled arrangement.

It has been found very important to have the fluoropolymer or other plastic covering the individual wires tightly bonded to the surfaces of the wires. The bonding blocks migration of corrosion inducing agents such as hydrogen sulfide and the like along the surface of the wire under the plastic coating and thus prevents corrosion of the wire surface. Surprisingly, when the plastic is tightly bonded to the surface of the wire in the manner of the invention, it has been found that even when the fluoropolymer has occasional pinholes or tiny holidays extending through it to the metal surface below no significant corrosion of the metal surface of the wire occurs even directly under the pinholes. Thus the bonding of the plastic to the underlying metal surface not only prevents the propagation of corrosion along the metal surface under the plastic, but actually also inhibits corrosion in an oil well environment of the metal surface in the immediate vicinity of the pinhole or tiny holiday itself. This is quite contrary to the experience with prior plastic coated wires in oil well environments in which the plastic is not tightly bonded to the surface of the wire but is instead loosely extruded over the wire perhaps with a corrosion inhibiting substance or the like deposited as an undercoating on the surface as disclosed for example in U.S. Pat. No. 3,443,982 to Kjellmark. In such cases corrosion tends to occur quickly at pinholes in the coating and spreads rapidly in spite of the corrosion inhibitor deposited between the plastic coating and the metal surface often resulting in very accelerated failure of the wire in the vicinity of the pinhole.

We claim:

1. A flexible pumping strand comprising:
   a. a plurality of wires collected together into a linear member,
   b. a polymeric coating on the exterior of each of said wires, said polymer being substantially inert to an oil well fluid, substantially impermeable to the water and gaseous corrodants and being resistant to fretting and abrasion between said wires,
   c. said polymeric coating being closely bonded to the surface of said wires through a thin film of an intermediate primer,
   d. an outer plastic jacket coating the outside of said strand,
   e. said outer plastic jacket having perforations throughout its length such that free passage of an oil well fluid through the plastic jacket is assured.

2. A flexible pumping strand according to claim 1 wherein the polymeric coating on the wires is comprised of a fluoropolymer.

3. A flexible pumping strand according to claim 2 wherein the flexible pumping strand is a helical strand.

4. A flexible pumping strand according to claim 3 wherein the flexible pumping strand has opposite rotations in different lays and the outside of the outer jacket has a smooth cylindrical surface.

5. A flexible pumping strand according to claim 3 wherein the polymeric coating on the wires is comprised essentially of a polymer selected from the group consisting of polyvinylidene fluoride, polychlorotri-

fluoroethylene, a copolymer of tetrafluoroethylene and hexafluoropropylene, polyethylenechlorotrifluoroethylene and polyethylenetetrafluoroethylene.

6. A flexible pumping strand according to claim **5** wherein the fluoropolymer is bonded to the surface of the underlying wire at least in part through an intermediate film of a fused coating of a polymer having a similar fluoropolymer composition applied initially in a dispersed condition in an organic solvent.

7. A flexible pumping strand according to claim **6** wherein the fluoropolymer is bonded to the surface of the underlying wire through an intermediate film comprised of two primary coats one of which is an epoxy base primer.

8. A flexible pumping strand according to claim **7** wherein the perforations in said outer plastic jacket are from one-eighth inch in diameter to one-half inch in diameter.

9. A flexible pumping strand according to claim **8** wherein the perforations in said outer strand jacket are spaced apart along the longitudinal extent of the strand at intervals no greater than 30 feet.

10. A flexible pumping strand according to claim **3** wherein the flexible pumping strand has opposite rotations in different layers of wires in the strand and the outside of the outer plastic jacket has a substantially smooth outer surface.

11. A flexible pumping strand comprising:

a. a plurality of wires collected together to form an extended linear member,

b. a polymeric coating on the exterior surface of said wires which is substantially inert to oil well fluid, substantially impermeable to water and corrosion inducing gases and resistant to fretting and abrasion between the wires,

c. an outer abrasion resistant plastic jacket covering the outside of said strand,

d. said outer abrasion resistant plastic jacket having perforations throughout its length such that the free passage of an oil well fluid through said plastic jacket is assured.

12. A flexible pumping strand according to claim **11** wherein said polymeric coating of (b) is a fluoropolymer.

13. A flexible pumping strand according to claim **12** wherein said fluoropolymer is comprised of polyvinylidene fluoride.

14. A flexible pumping strand according to claim **12** wherein said fluoropolymer is comprised of polychlorotrifluoroethylene.

15. A flexible pumping strand according to claim **12** wherein said fluoropolymer is comprised of a copolymer of tetrafluoroethylene and hexafluoropropylene.

16. A flexible pumping strand according to claim **12** wherein said fluoropolymer is comprised of polyethylenechlorotrifluoroethylene.

17. A flexible pumping strand according to claim **12** wherein said fluoropolymer is comprised of polyethylenetetrafluoroethylene.

18. A flexible pumping strand according to claim **12** wherein the fluoropolymer is tightly bonded to said wire surface by an intermediate film of polymer.

19. A flexible pumping strand according to claim **18** wherein the primer constitutes at least in part a fused film of a polymer similar in composition to the polymeric protective coating applied to the surface of the wire.

20. A flexible pumping strand according to claim **19** wherein the polymer is bonded to the surface of the wire through an intermediate film comprised of two primary coats one of which is an epoxy base primer.

21. A flexible pumping strand according to claim **20** wherein the perforations in said outer plastic jacket are from one-eighth inch in diameter to one-half inch in diameter and the said perforations are spaced apart on said longitudinal extent of said strand at intervals no greater than about thirty feet.

22. A method of making flexible pumping strand comprising:

a. coating a plurality of wires with a fluoropolymer,

b. stranding said plurality of wires into a wire strand,

c. contacting the wires of said strand with a vaporizable liquid, and

d. pressure extruding an outer jacket of polymer about said strand under a pressure such that the coatings on the wires are temporarily compressed during said extrusion step and the heat of the extrusion causes vaporization of said liquid and perforation of said soft jacket prior to hardening.

23. A method of making flexible pumping strand according to claim **22** additionally comprising initially applying a primer to the surfaces of the wires by contacting the surfaces of the wires with a dispersion of a polymer similar in composition to the fluoropolymer with which the wires are to be coated and fusing said polymer.

24. A method of making flexible pumping strand according to claim **23** where the primer is applied in a two step operation comprising initially contact the wire surface with a film of an epoxy base composition, heat curing the epoxy composition, applying a film of a dispersion in an organic solvent of a polymer having a composition similar to the composition of the protective fluoropolymer coating which is to be applied to the wire and fusing said film of polymer to the surface of the wire.

* * * * *

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 3,882,665

DATED May 13, 1975

INVENTOR(S) : Charles R. Hughes and James M. Doll

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

The drawing figure on the Abstract page should be deleted and the drawing figure shown on the attached sheet substituted therefor.

Col. 3, line 28, "of" should read --by--.

Col. 4, line 19, "plastics" should read --plastic--.

Col. 6, line 5, "in" should read --to--.

Col. 6, line 60, "constructively" should read --consecutively--.

Col. 7, line 7, "phosphate tank" should read --phosphate treatment tank--.

Col. 11, line 26, "Nylon 1" should read --Nylon 11--.

Signed and Sealed this

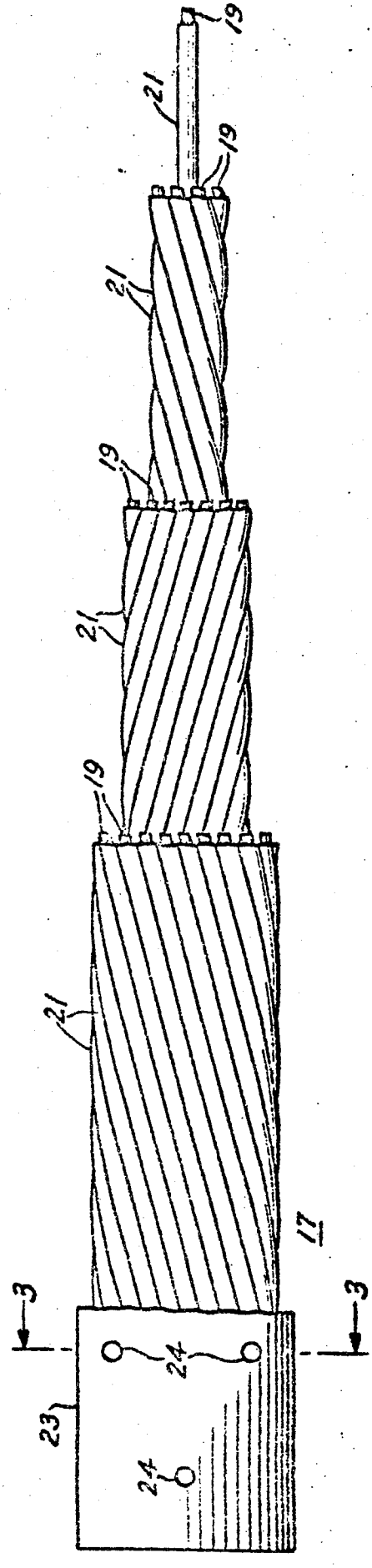
fourth Day of *November 1975*

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