US 20130287616A1

(19) **United States**
(12) **Patent Application Publication**
Guidry, JR.
(10) **Pub. No.: US 2013/0287616 A1**
(43) **Pub. Date: Oct. 31, 2013**

(54) **PROGRESSING CAVITY PUMP/MOTOR**

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(21) Appl. No.: **13/874,095**

(22) Filed: **Apr. 30, 2013**

Related U.S. Application Data

(60) Provisional application No. 61/640,280, filed on Apr. 30, 2012.

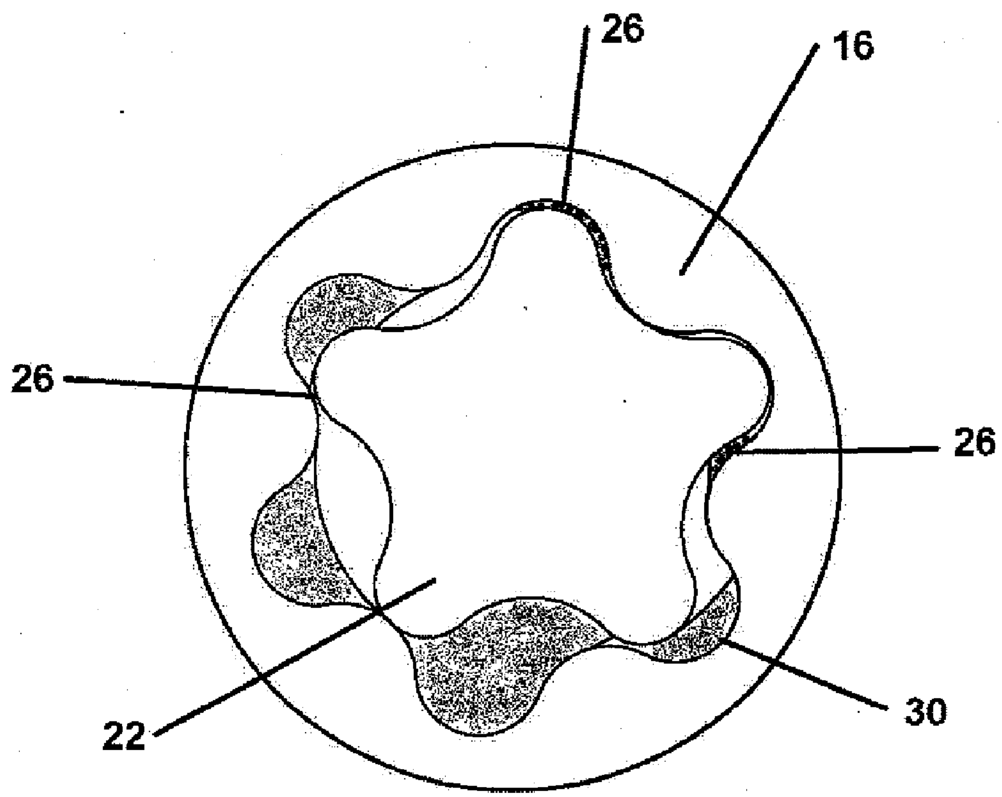
Publication Classification

(51) **Int. Cl.**
F04C 2/107 (2006.01)

(52) **U.S. Cl.**
CPC ***F04C 2/1073*** (2013.01)
USPC **418/48**

(57) **ABSTRACT**

A progressing cavity pump/motor includes a stator (**12**) having a metal interior surface (**14**) and one or more spiraling internal lobes (**16**). The rotor (**18**) has a metal exterior surface (**20**) and one or more spiraling external lobes (**22**) for cooperating with the stator to form progressing cavities between the stator and the rotor during rotation of the rotor. One or both the stator interior surface and the rotor exterior surface include a rough surface (**30**) having an Ra greater than 100 micro inches, such that fluid flowing to a gap between the stator and the rotor is disrupted by the rough surfaces to reduce fluid leakage between the stator and the rotor.



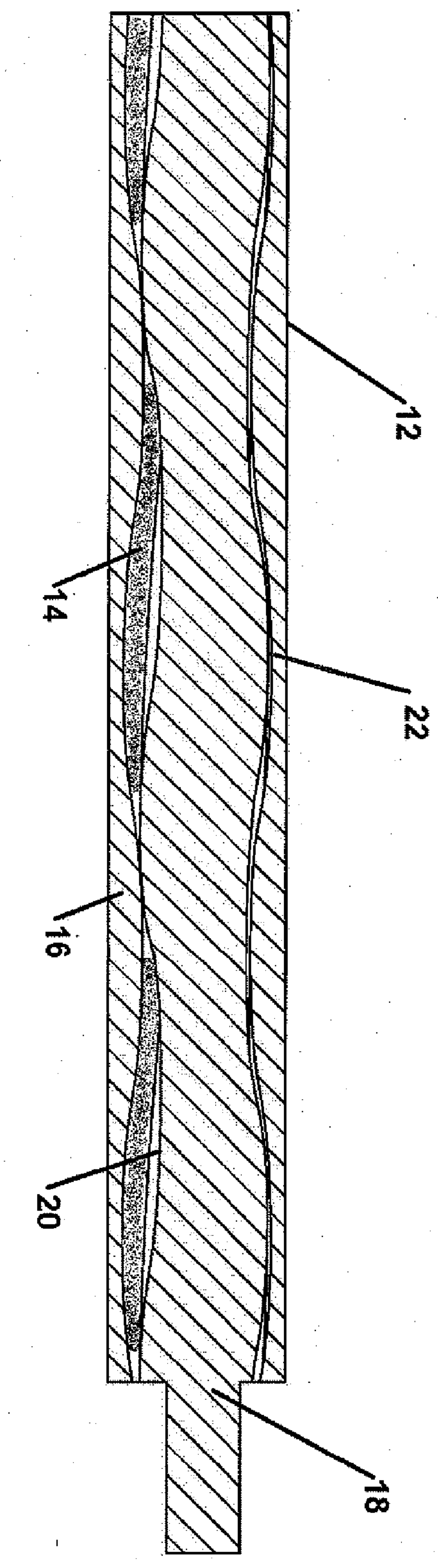


FIG. 1

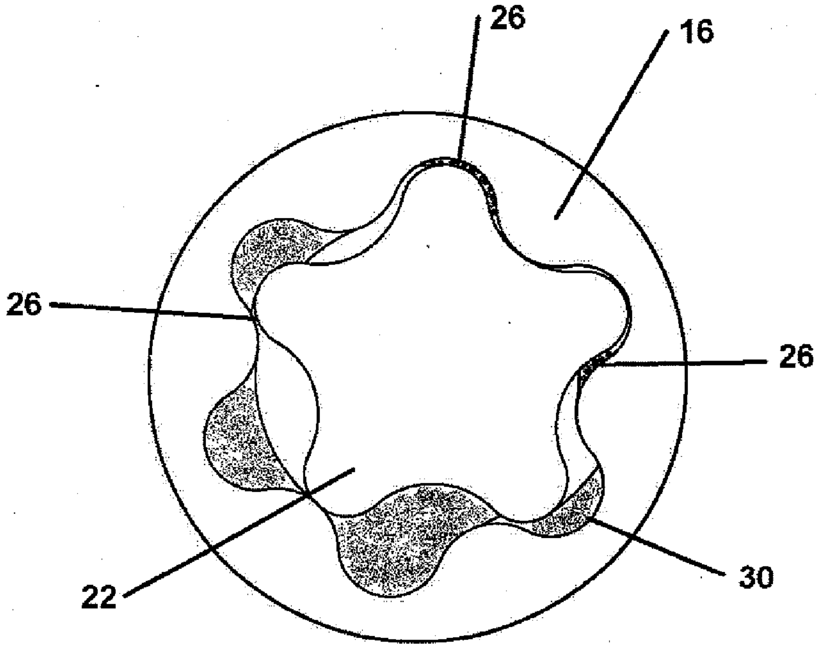


FIG. 2

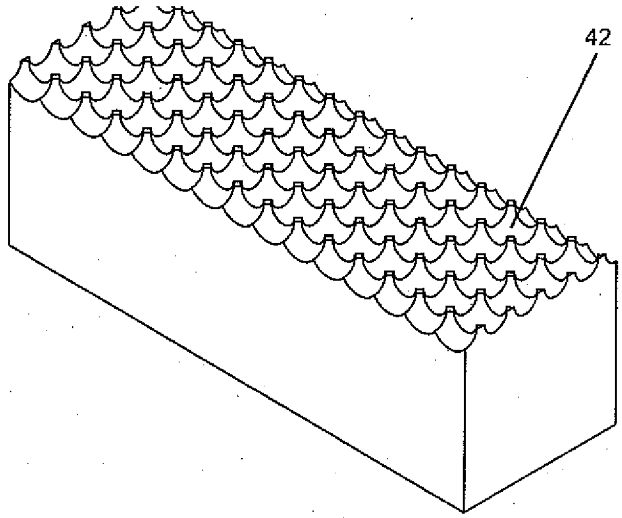


FIG. 3

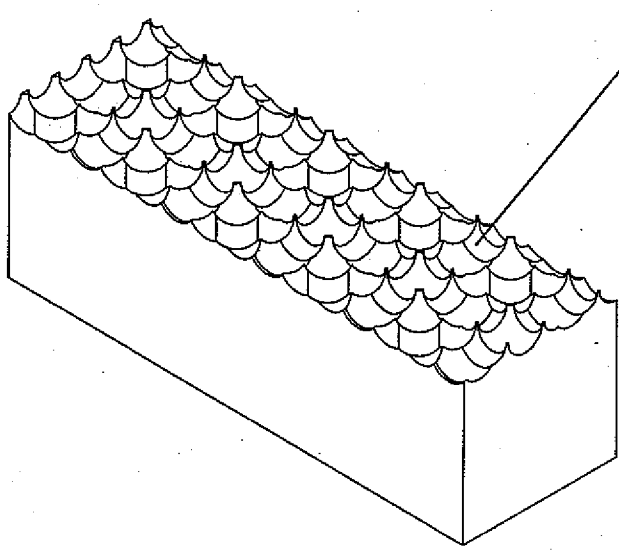


FIG. 4

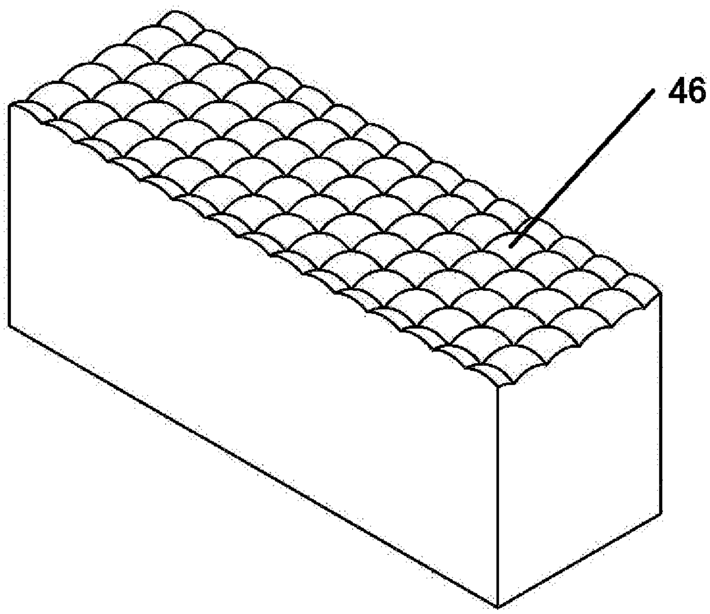


FIG. 5

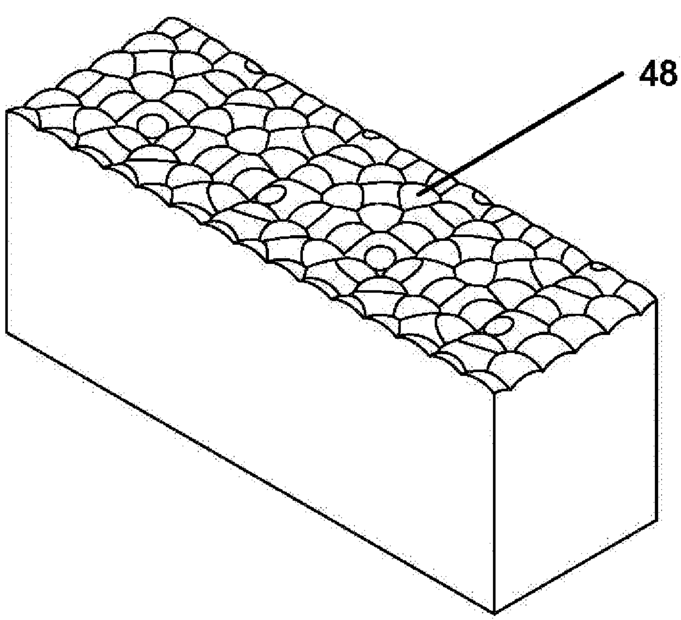


FIG. 6

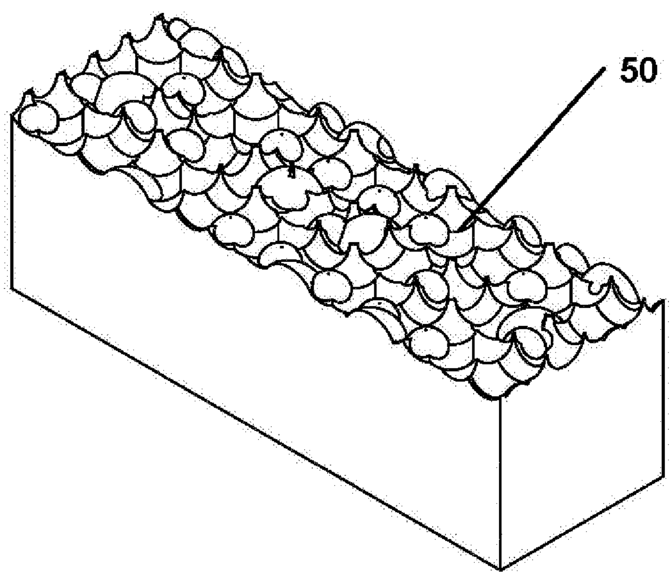


FIG. 7

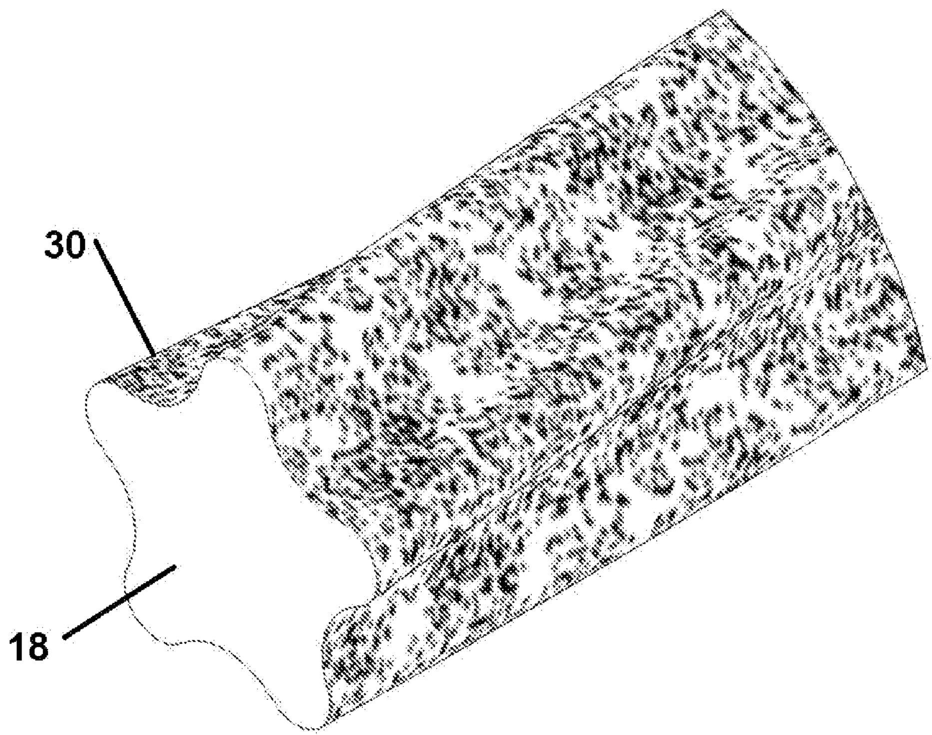


FIG. 8

PROGRESSING CAVITY PUMP/MOTOR

STATEMENT OF RELATED APPLICATIONS

[0001] This application depends from and claims priority to U.S. Provisional Application No.: 61/640,280 filed on Apr. 30, 2012.

FIELD OF THE INVENTION

[0002] The present invention relates to a progressing cavity pump/motor, and more particularly to a progressing cavity pump/motor suitable for applications wherein both the interior surface of the stator and the exterior surface of the rotor are formed from a substantially rigid material.

BACKGROUND OF THE INVENTION

[0003] Progressing cavity pumps are used in various applications, including downhole oilfield applications to pump fluids from a well bore to the surface. A progressing cavity pump uses mechanical energy provided through a shaft to turn the rotor within the stator to pressurize and fluid captured in the progressing cavity. Such a device can also be used as a progressing cavity motor to convert the hydraulic energy in pressurized fluid into mechanical energy, for example, to rotate a shaft connected to a drill bit or to some other downhole tool. The interior surface of the stator of a progressing cavity pump/motor is typically formed from an elastomeric material which acts as a contact seal with the rotor. The contact areas between the interior of the stator and the exterior of the rotor determine the perimeter of the cavities which contain the working fluid. These cavities progress, as the rotor rotates within the stator, from one end of the pump/motor towards the other end of the pump/motor.

[0004] In certain applications, the operational temperature range intended for the pump/motor exceeds the practical maximum temperature of elastomeric materials or the corresponding adhesive used to hold the elastomeric materials in place within the stator. Materials, both elastomeric and rigid, have been used in these conditions for both the exterior surface of the rotor and the interior surface of the stator. A close tolerance or low clearance between the exterior surface of the rotor and the interior surface of the stator replaces the elastomeric contact seal when non-elastomeric materials are used. The clearance between the exterior surface of the rotor and interior surface of the stator is either designed, or worn into the rotor and/or stator during operation. Such a conventional design can significantly reduce the efficiency due to the volume of the working fluid passed between the interior surface of the stator and the exterior surface of the rotor. Such conventional pump/motor designs are not favored in most applications because of their poor efficiency.

[0005] Progressing cavity pump/motors are disclosed in U.S. Pat. Nos. 6,120,267, 6,491,501, 6,695,060, 7,214,042, 7,407,372, 7,553,139, and Publications U.S. 2010/031 6518 and U.S. 2010/0322808. Such conventional pumps contain an elastomeric layer on the interior surface of the stator for deforming during rotation of the rotor to form a contact seal. U.S. Pat. No. 7,837,451 discloses a rotor with lobes and grooves in the casing for use in pulse detonation combustors (PDC's) and pulse detonation engines (PDE's). Grooves are provided on a tip portion of the lobes and presumably increase air pressure to the combustion chamber. Pumps and motors according to the present invention rely upon a working fluid, which conventionally is a mixture of liquids, solids, and often some gas, to generate energy or to transfer fluids.

[0006] The disadvantages of the prior art are overcome by the present invention, an improved pump/motor hereinafter disclosed.

SUMMARY OF THE INVENTION

[0007] In one embodiment, a progressing cavity pump/motor includes a stator having an interior surface with two or more spiraling internal lobes. The rotor within the stator has an exterior surface with one or more spiraling external lobes, with the rotor cooperating with the stator to form progressing cavities between the lobes of the stator and the lobes of the rotor during rotation of the rotor within the stator. One or both of the stator interior surface and the rotor exterior surface is a rough surface with an Ra of 100 micro inches or greater, such that fluid flowing through a gap between the interior surface of the stator and the exterior surface of the rotor is disrupted by the rough surface to reduce leakage of fluid from the progressing cavity between the stator and the rotor.

[0008] These and further features and advantages of the present invention will become apparent from the following detailed description, wherein reference is made to the figures in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] The accompanying drawings are provided to illustrate embodiments of the present invention.

[0010] FIG. **1** is a longitudinal sectional view of an embodiment of a stator and a rotor of a progressing cavity pump/motor according to the present invention.

[0011] FIG. **2** is a cross-sectional view of a portion of the stator and rotor of the embodiment of the progressing cavity pump/motor of FIG. **1** with a rough surface formed on the interior surface of the stator and a gap between the interior surface of the stator and the exterior surface of the rotor.

[0012] FIG. **3-7** are each pictorial views of a rough surface on the interior surface of the stator and/or the exterior surface of the rotor for a progressing cavity pump/motor embodiment of the present invention.

[0013] FIG. **8** illustrates a rough surface on the exterior surface of the rotor for a progressing cavity pump/motor embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0014] The substantially rigid stator interior surface and rotor exterior surface in a progressing cavity pump/motor incorporate a clearance or gap between the rotor exterior surface and the stator interior surface. This clearance or gap allows the rotor to turn inside the stator. The clearance is large enough to allow small solid particles, sometimes carried in the working fluid, to pass through without binding the rotor with the stator. Flow resistance through the non-contact seal formed by the clearance or gap between the rotor and the stator is created by choke flow wherein the fluid particles cannot move around each other. The present invention significantly increases the effective flow resistance of the non-contact seal, thereby significantly decreasing fluid leakage and loss between the rotor and the stator while there is a nominal gap between the rotor and the stator.

[0015] The seal line between the interior surface of the rotor and the exterior surface of the stator is moving in a cyclical manner as the pump/motor operates. The velocity and direction of fluid flow at any point on the rotor exterior surface or stator interior surface is therefore constantly changing in a repeating pattern. Near surface flow is substantially parallel to the stator or rotor surface but, at locations near the seal line, the fluid flow can impinge at angles approaching perpendicular. This rapid cyclical velocity offers flow resistance when the rotor and stator surfaces approach each other. In conventional progressing cavity pumps/motors, the flow resistance is minimized by smooth, contoured surfaces on both the rotor exterior and the stator interior.

[0016] Conventional progressing cavity pumps/motors have been provided with an elastomeric rotor or stator to allow contact between the two during operation. Progressing cavity pumps/motor rotors are provided with a smooth exterior surface that seals against an elastomer stator bonded to the internal surface of a structural body. Conventional progressing cavity pumps/motors having metal to metal seals are provided with a metal stator interior surface and a metal rotor exterior surface. Both metal surfaces are polished to reduce the gap between these sealing surfaces

[0017] The present invention incorporates a rough surface of either the rotor exterior surface and/or the stator interior surface to create turbulent eddies in the fluid flow occurring near to the exterior surface of the rotor and the interior surface of the stator. This increases flow turbulence along the rotor exterior surface and the stator interior surface which results in an increase in flow resistance and thus a significant decrease in fluid leakage from the progressing cavity. Eddies are created by substantially disrupting the fluid flow along the rough surfaces, or by redirecting fluid flow from oblique angles.

[0018] Referring now to FIG. **1**, a longitudinal section view of an embodiment of a progressing cavity pump/motor of the present invention, a rotor **18** is rotatable within the interior of a stator **12** having an internal surface **14** and two or more spiraling lobes **16**. The rotor **18** includes an exterior surface **20** and one less lobe **22** than the stator **12**, thereby forming progressing cavities between the rotor **18** and the stator **12** as the rotor **18** rotates within the stator **12**. The rotor **18** of a progressing cavity pump as shown in FIG. **1** may be rotated within the stator **12** by rotation of a work string extending from the Earth's surface to the pump. Well bore fluids entering the pump are therefore moved to the surface for recovery. Alternately the rotor **18** and stator **12** of FIG. **1** may be used as a progressing cavity motor which is powered by pressurized fluid pumped from the Earth's surface down a well to the progressing cavity motor. The pressurized fluid forces the rotor **18** to turn within the interior of the stator **12** and can be used to, for example, rotate a shaft connected to the rotor **18** to rotate a drill bit to extend a drilled well bore.

[0019] As suggested above, the vast majority of downhole progressing cavity motors/pumps include a metal stator body, an elastomeric material layer on the interior surface of the stator body, and a metal rotor that rotates within the interior of the stator and forms a contact seal with the elastomeric layer as the rotor rotates relative to the stator. The same types of motor/pumps are sometimes operated, at a greatly reduced efficiency, with a clearance between the rotor and stator.

[0020] The present invention is substantially different from the conventional progressing cavity pump/motor in that the primary sealing mechanism between the exterior surface of the rotor and the interior surface of the stator is non-contact with a rough surface specifically designed to increase motor/pump efficiency. FIG. **2** illustrates a plurality of locations **26** where the rotor exterior surface approaches the stator interior surface. Each of these locations **26** is a part of the seal area including a rough surface **30** on the interior surface of the stator **12** and/or on the exterior surface of the rotor **18**, as explained further below. Some fluid will leak between the rotor **18** and the stator **12**. The amount of fluid leakage depends on the viscosity of the fluid, the velocity of the working fluid, the size of the gap, and the degree of surface roughness. A rough surface **30** provides a significant resistance to fluid flow moving toward and through the gap between the rotor **18** exterior surface and the stator **12** interior surface by generating flow disturbances along the rotor **18** exterior surface and the stator **12** interior surface which convert kinetic energy of the fluid into heat. The result is a significantly reduced amount of fluid that passes through the gap and an increase in the efficiency of the progressing cavity pump/motor. The seal location between the rotor **18** and the stator **12** is constantly changing. The rough interior surface of the stator **12** and the rough exterior surface of the rotor **18** as disclosed herein provides a significant flow disturbance to impair fluid flow through the gap and to thereby reduce fluid leakage and to increase pump/motor efficiency.

[0021] Surface roughness on a machine component takes into consideration the vertical deviation of a surface. The arithmetic mean value of the surface roughness (i.e. Ra) on the rotor exterior surface and/or the stator interior surface will typically be greater than 30 micro inches. In many embodiments of the progressing cavity pump/motor of the present invention, the surface roughness, Ra, on those surfaces may be significantly greater than 100 micro inches, and the Ra will frequently be in a range of from 200 micro inches to 400 micro inches. Surface roughness, Ra, of up to 350 micro inches may be achieved on the interior surface of a stator using grit blasting techniques. Surface roughness width is the minimum peak to peak or valley to valley distance that is typically used for surface roughness measurement of machine parts. In embodiments of the progressing cavity pump/motor of the present invention, the surface roughness width on the exterior surface of the rotor and/or the interior surface of the stator should be 0.20 inches or less.

[0022] In some applications, the interior surface of the stator may be blasted with an abrasive media using standard blasting equipment to achieve the desired surface roughness, Ra. Alternately, the exterior surface of the rotor and/or the interior surface of the stator may be chemically etched by immersion of the rotor and/or stator in an appropriate etching fluid. The etching fluid may alternately be applied using a brush or a spray nozzle. Alternately, the exterior surface of the rotor and/or the interior surface of the stator can also be roughened to the desired Ra using an electrode. More specifically, high localized current arcing between an electrode and the rotor exterior surface and/or stator interior surface will melt and/or vaporize small droplets of surface metal, resulting in a roughened surface. Electrochemical methods, such as known methods for removing plating from metal parts, may be used to roughen a metal surface. Electromechanical methods may incorporate the use of a carrier fluid to sweep or carry away the molten/vaporized material generated by the electrical arc. Chemical/mechanical methods, such as high temperature combustion of gasses in the form of a gas jet, may also be used to melt and/or vaporize a rotor/stator surface material and thereby roughen the exterior surface of the rotor and/or the interior surface of the stator of an embodiment of the improved progressive cavity pump/rotor of the present invention. These methods can also be combined to roughen the surface of a rotor and/or stator.

[0023] If a roughened surface is formed on the exterior of the rotor using a machining operation, it may be preferable for many applications that the elongate peaks of the roughened surface be oriented generally perpendicular to the centerline of the spiraling lobe on the exterior surface of the rotor. If the roughened surface is formed on the interior surface of the stator using a machining operation, the elongate peaks of the roughened surface may be oriented generally parallel to the centerline of the spiraling lobe on the interior surface of the stator. The interior surface of the stator and/or the exterior surface of the rotor could also be roughened using a milling technique or a broaching technique.

[0024] The surface roughness as discussed above may be achieved by a material subtraction, for example, by removing some material from the original exterior surface of the rotor or the interior surface of the stator to achieve a roughened surface. Alternately, surface roughness may also be achieved by material addition, for example, particle kinetic (impact) welding, electro-chemical plating or metal sprayings. The addition of material to the interior surface of the stator or the exterior surface of the rotor to form the roughened surface has the same sealing benefits as material removal. Roughness may also be achieved by a combination of material addition and material subtraction. For example, hard facing may be used to add tungsten carbide or another rigid material to the interior surface of the stator or the exterior surface of the rotor. Abrasive blasting with oxide particles or other blasting grit may result in this effect, and the abrasive material may blast a surface which is coated with an epoxy or other adhesive. In each case, the roughened surface on the interior of the stator and/or the exterior of the rotor is a substantially rigid surface.

[0025] FIG. **3** illustrates a portion of an exterior surface of a rotor or a portion of an interior surface of a stator having a uniform pitted surface **42**, illustrating the spacing between the peaks of the roughened surface. The roughened surface in FIG. **3** show roughness generated with spheres or hemispheres. Actual roughness is often angular and jagged. FIG. **4** illustrates an exterior surface of a rotor or an interior surface of a stator with a non-uniform pitted surface **44**, thus depicting an easily formed roughened surface for the interior surface of the stator and/or the exterior surface of the rotor.

[0026] FIG. **5** illustrates a roughened surface **46** which may be characterized as a uniform bumpy surface, wherein there is an addition of material to the interior surface of the stator or the exterior surface of the rotor to form the roughened surface.

[0027] FIG. **6** illustrates a non-uniform bumpy surface **48** on the rotor or the stator. FIG. **7** illustrates a combination of a non-uniform bumpy surface and a non-uniform pitted surface **50** to achieve the desired roughened surface as discussed herein.

[0028] FIG. **8** illustrates a roughened surface **30** similar to that discussed above and formed on the exterior surface of a rotor **18**. In some applications, it may be preferable to provide the roughened surface on the exterior surface of the rotor rather than on the interior surface of the stator, and in other applications the roughened surface may be provided on each of the exterior surface of the rotor and the interior surface of the stator.

[0029] A substantial portion of either the exterior surface of the rotor or the interior surface of the stator preferably includes a roughened surface, and in many embodiments the majority of the exterior surface of the rotor and the interior surface of the stator comprises a roughened surface. In some applications, substantially the entire interior surface of the stator or the entire exterior surface of the rotor comprise roughened surfaces, as disclosed herein. Whether on the exterior surface of the rotor, interior surface of the stator, or both, each roughened surface preferably circumferentially encircles the exterior surface of the rotor or the interior surface of the stator. An axially extending end, ends, or other selected areas of the rotor or stator may not be roughened, or may be less roughened than other surfaces. In other embodiments, the roughened surface as disclosed herein may be combined with the grooves in the interior surface of the stator and/or the exterior surface of the rotor, as disclosed in pending U.S. application Ser. No. 13/082,210 filed on Apr. 7, 2011 and published on Oct. 11, 2012 as U.S. Publication No. 2012/0258001 A1.

[0030] The benefits of embodiments of the present invention may be realized because downhole application systems use better filtering techniques than in decades past for recovering solid particles before a fluid enters the progressive cavity pump/motor. In some progressive cavity motor applications, for example, water may be used as a working fluid when drilling out plugs from a well. Also, some applications utilize a higher viscosity working fluid than was used in the past and, accordingly, the higher viscosity working fluid further benefits from the use of strategically roughened surfaces as disclosed herein to disrupt fluid flow to the gap between the exterior surface of the rotor and the interior surface of the stator.

[0031] A progressive cavity pump/motor can become locked by particles wedged between the exterior surface of the rotor and the interior surface of the stator if the particles passing through the pump/motor are larger than the gap between the exterior surface of the rotor and the interior surface of the stator. Decreasing the gap between the exterior surface of the rotor and the interior surface of the stator reduces the amount of "lost" fluid which passes through the gap, but decreasing the gap also increases the likelihood of solid particles becoming wedged between the exterior surface of the rotor and the interior surface of the stator. The addition of fluid flow-disrupting roughened surfaces reduces this lost fluid by impairing fluid flow into the gap, while maintaining a sufficient gap to minimize or eliminate wedging solid particles between the exterior surface of the rotor and the interior surface of the stator of a progressing cavity pump/motor of the present invention. Unlike other situations, the spacing between a roughened surface and the ever changing gap location varies as the pump/motor is operated.

[0032] The progressing cavity pump/motor of the present invention includes a stator with a substantially rigid interior surface in the form of spiraling internal lobes, and a rotor with a substantially rigid external surface and one or more spiraling external lobes. At the temperatures and pressures in which the pump/motor is operating, these surfaces are substantially rigid. As used herein, "substantially rigid" means a surface of any material with sufficient geometric stability at its operating temperature and pressure such that the flexibility of the surface does not create or contribute to sealing or to reduced loss of the working fluid between the surfaces. This includes pliable or elastic materials which "cure", "set", or "age" to meet the definition of "substantially rigid" under operating conditions.

[0033] A metal stator and rotor may be formed from steel, since it is a suitable substantially rigid material, although composite materials and some thermoset materials also have this substantially rigid feature, and also provide high chemical resistance to various types of downhole fluids. The gap between the rotor and the stator may vary from 0.000 inches to a point of maximum cavity width. Lost fluid passing through this gap is significantly reduced by the use of grooves as disclosed herein.

[0034] The roughened interior surface of the stator and/or the roughened exterior surface of the rotor reduces the flow of working fluid passing through the gap between the rotor and the stator in a progressing cavity pump/motor of the present invention, thereby increasing the overall pump or motor efficiency. In other conventional applications, the size of debris particles in the working fluid mandates a large gap between the exterior surface of the rotor and the interior surface of the stator such that the efficiency of the progressive cavity pump/motor becomes unattractive. By providing the roughened surface(s) as disclosed herein, a sufficiently large gap may be maintained in order to pass sizable debris while still maintaining a pump or motor of reasonable efficiency by impairing the leakage of fluid from the progressive.

[0035] The progressive cavity pump/motor of the present invention disclosed herein is particularly well-suited for downhole applications, for example, in oil and gas drilling and downhole fluid recovery operations. The embodiments of the progressive cavity pump/motor of the present invention have significant benefits in other applications such as, for example, applications involving high-temperature environments and/or fluids that are incompatible with elastomers.

[0036] Although specific embodiments of the present invention have been described herein in some detail, this has been done solely for the purposes of explaining the various aspects of the invention, and is not intended to limit the scope of the invention as defined in the claims which follow. Those skilled in the art will understand that the embodiment shown and described is exemplary, and various other substitutions, alterations and modifications, including but not limited to those design alternatives specifically discussed herein, may be made in the practice of the invention without departing from its scope.

I claim:

1. A progressing cavity pump/motor, comprising:

a stator having an interior surface with two or more spiraling internal lobes;

a rotor rotatably received within an interior of the stator and having an exterior surface and one or more spiraling external lobes to cooperate with the stator to form progressing cavities between the interior surface of the stator and the exterior surface of the rotor during rotation of the rotor within the interior of the stator; and

at least one of the stator interior surface and the rotor exterior surface supporting a roughened surface having a surface roughness of at least 100 micro inches Ra to impair the flow of fluid across the roughened surface and to thereby disrupt the flow of fluid from a progressive cavity through a gap between the internal surface of the stator and the exterior surface of the rotor.

2. The progressing cavity pump/motor of claim **1**, wherein the roughened surface is formed on the interior surface of the stator.

3. The progressing cavity pump/motor of claim **1**, wherein the roughened surface is formed on the exterior surface of the rotor.

4. The progressing cavity pump/motor of claim **1**, wherein roughened surfaces are formed on both the interior surface of the stator and the exterior surface of the rotor.

5. The progressing cavity pump/motor of claim **1**, wherein the roughened surface preferably has a surface roughness of between 200 micro inches and 400 micro inches Ra.

6. A progressing cavity pump, comprising:

a metal stator having an interior surrounded by an interior surface with two or more spiraling lobes;

a metal rotor having an exterior surface and at least one spiraling lobes, the rotor rotatably received within the interior of the stator to form and progressively move fluid cavities along a length of the pump by rotation of the rotor within the stator; and

a roughened surface disposed on at least one of the interior surface of the stator and the exterior surface of the rotor to impair the flow of fluid across the roughened surface and to reduce leakage of fluid from a progressive cavity through gaps between the interior surface of the stator and the exterior surface of the rotor;

wherein the roughened surface is 100 micro inches Ra or greater.

7. The progressive cavity pump of claim **6**, wherein the roughened surface is disposed on the interior surface of the stator.

8. The progressive cavity pump of claim **6**, wherein the roughened surface is disposed on the exterior surface of the rotor.

9. The progressive cavity pump of claim **8**, wherein the roughened surface is also disposed on the interior surface of the stator.

10. The progressive cavity pump of claim **6**, wherein the roughened surface is 200 micro inches or greater.

11. The progressive cavity pump of claim **6**, wherein the roughened surface is 200 to 400 micro inches.

12. The progressive cavity pump of claim **6**, wherein the rotor is connectable to a workstring to transmit torque from the workstring to the rotor of the pump.

13. A progressing cavity motor, comprising:

a metal stator having an interior surrounded by an interior surface with two or more spiraling lobes;

a metal rotor having an exterior surface and at least one spiraling lobes, the rotor rotatably received within the interior of the stator to form and progressively move fluid cavities along a length of the pump by rotation of the rotor within the stator; and

a roughened surface disposed on at least one of the interior surface of the stator and the exterior surface of the rotor to impair the flow of fluid across the roughened surface and to reduce leakage of fluid from a progressive cavity through gaps between the interior surface of the stator and the exterior surface of the rotor;

wherein the roughened surface is 100 micro inches Ra or greater.

14. The progressive cavity motor of claim **13**, wherein the roughened surface is disposed on the interior surface of the stator.

15. The progressive cavity motor of claim **13**, wherein the roughened surface is disposed on the exterior surface of the rotor.

16. The progressive cavity motor of claim **15**, wherein the roughened surface is also disposed on the interior surface of the stator.

17. The progressive cavity motor of claim **13**, wherein the roughened surface is 200 micro inches or greater.

18. The progressive cavity motor of claim **13**, wherein the roughened surface is 200 to 400 micro inches.

19. The progressive cavity motor of claim **13**, wherein the rotor is connectable to a shaft to transmit torque from the motor to a power-consuming device through the shaft.

20. The progressive cavity motor of claim **13**, wherein the a roughened surface disposed on at least one of the interior surface of the stator and the exterior surface of the rotor to impair the flow of fluid across the roughened surface and to reduce leakage of fluid from a progressive cavity through gaps between the interior surface of the stator and the exterior surface of the rotor comprises a uniformly roughened surface with a recurring geometric pattern of hemispherical indentations.

* * * * *