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3,245,471

SETTING CASING IN WELLS

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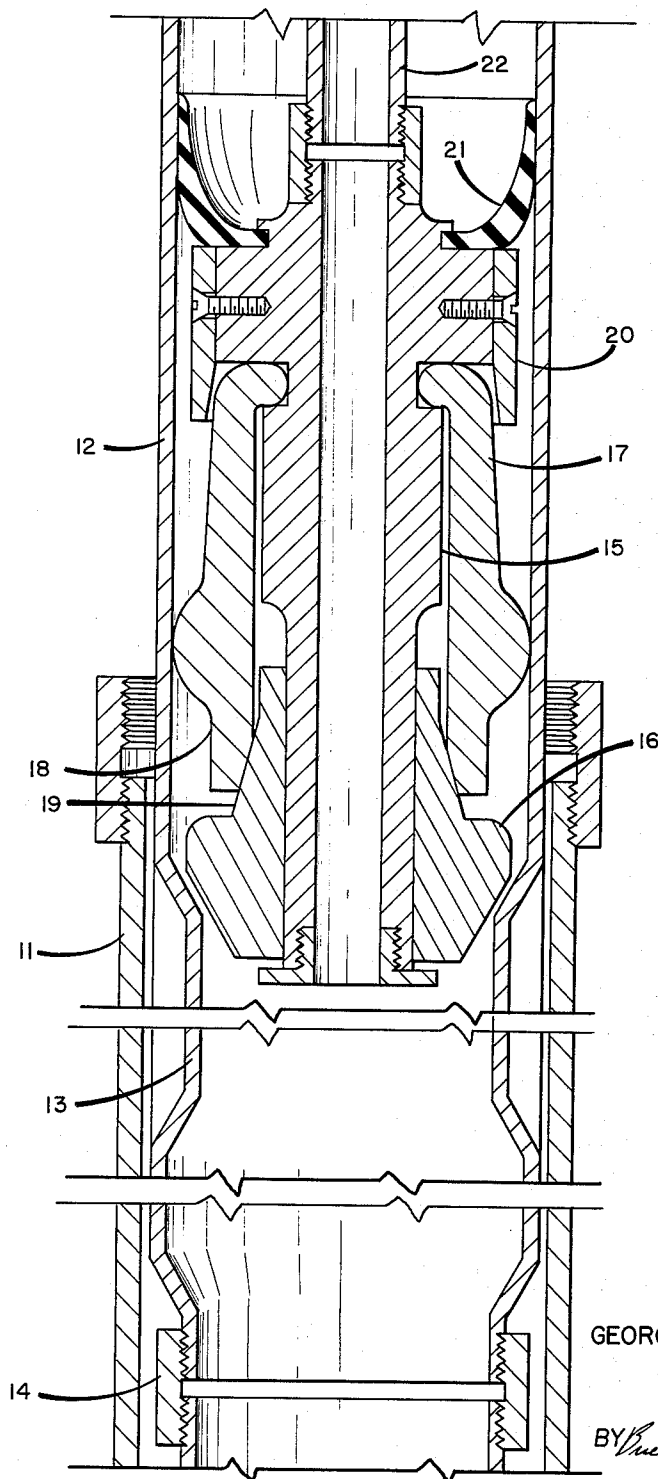


FIG. - 1

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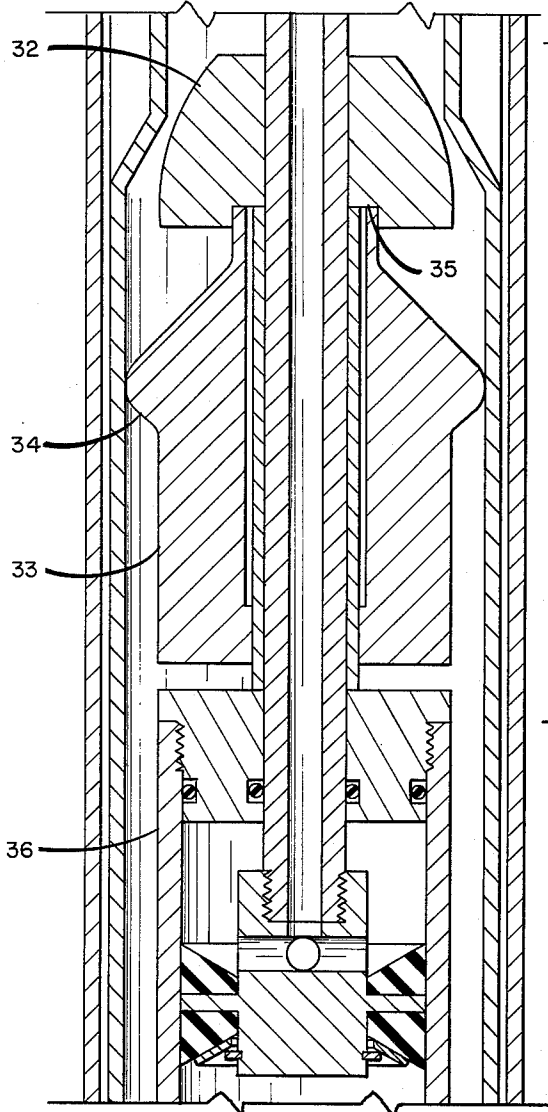
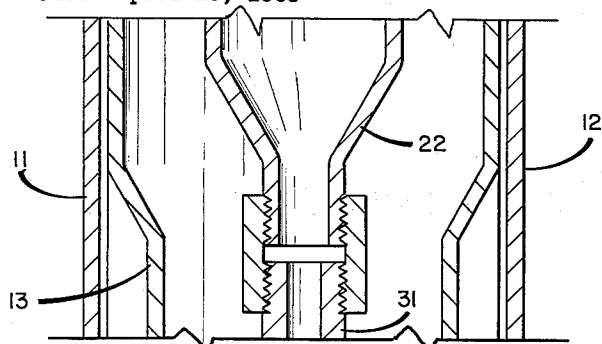


FIG.-2

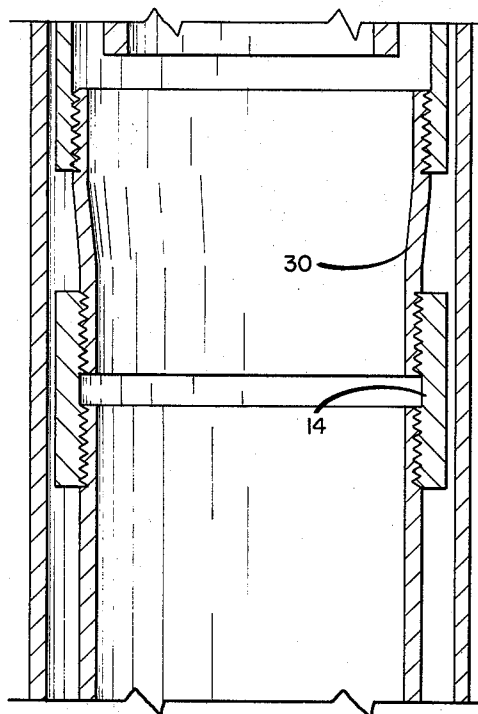


FIG.-3

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3,245,471

SETTING CASING IN WELLS

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This invention relates to setting casing in wells. More particularly it relates to forming at the top of a well a seal between strings of casing.

It is customary in drilling or completing wells to run strings of steel casing in the well to various depths. The principal purpose is to keep unwanted fluids from entering the well. A seal is ordinarily formed between the bottom of the casing and the well wall by placing cement in the space between the casing and well wall. A seal is also required at the top of the well between strings of casing. This may be provided by means of flanges and gaskets. A simpler system for forming a seal is desirable. This is particularly true in marine locations where it is considered advisable to complete the well on the marine floor, leaving nothing extending above the surface of the water. In this case, divers are ordinarily required to manipulate the flanges and gaskets, place the bolts through the flanges and tighten the bolts. A system which could be operated entirely from the surface of the water without divers would obviously be highly advantageous.

With these problems in mind, an object of this invention is to provide a method for forming a seal between the tops of casing strings in a well. An additional object is to provide a method which will produce a seal between casing strings, the seal being capable of supporting the weight of the inner string. Still other objects will be apparent to those skilled in the art.

In general, I accomplish the objects of my invention by placing a longitudinally corrugated section of casing near the top of the inner casing string and expanding this corrugated section into a substantially cylindrical shape inside the top of the outer casing string. A sealing material such as copper or a glass fiber material saturated with a settable liquid resin surrounds the inner string opposite the corrugated section.

In the drawing,

FIGURE 1 is a cross-sectional view of the corrugated section of casing together with one form of apparatus for expanding the corrugated section into substantially cylindrical form against the outer casing.

FIGURE 2 is another cross-sectional view of the corrugated casing section with another form of apparatus for expanding the corrugated section.

FIGURE 3 is a cross-sectional view of the lower part of apparatus, the top part of which is shown in FIGURE 2.

Considering the drawing in more detail, in FIGURE 1, outer casing string 11 and inner casing string 12 extend into a well. The upper portions of the strings may be in the well or above the well. Inner casing 12 includes a corrugated section 13. Immediately above and below the corrugated section the inner casing string is of a diameter which fits closely inside the outer casing. The corrugated section and the large portions immediately above and below are manufactured as one joint or length. The bottom portion of this length of casing is swaged down and threaded to fit a collar 14 on the upper end of a regular size joint of the inner string of casing.

Above the corrugated section of casing an expander tool is provided. This includes a central mandrel 15 and expander cone 16 and expander arms 17. The ends 18 of arms 17 rest on a tapered portion 19 of cone 16. The upper ends of arms 17 are held in a groove in mandrel 15 by a sleeve 20. Above sleeve 20 a flexible upwardly facing cup 21 of rubber, for example, is provided to form

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a seal between mandrel 15 and inner casing 12. Attached to the top of mandrel 15 is a length of tubing 22.

In operation the inner casing string is lowered into the well as usual until the bottom of the casing is only a few feet above the desired level. The length of pipe including the corrugated section is then attached to the top of the inner casing and the entire string is lowered until the corrugated inner casing section is inside the outer casing near the top of the outer casing string. The bottom portion of the inner string is then cemented in any of the usual ways. When the last of the cement has been displaced out the bottom of the casing by drilling fluid for example, the expander tool is then placed in the position shown in FIGURE 1. A cementing head is then placed on the top of the inner casing to seal the top of this string. The tubing 22 passes upwardly through the cementing head so that liquids may flow up the center of mandrel 15 and tubing 22 as the expander tool is forced downwardly in the casing. In high-pressure wells a back-pressure valve may be placed in tubing 22 to maintain the desired pressure within the inner casing string.

As soon as the expander tool is in place the cementing pumps are started again and a liquid such as drilling fluid is forced into the inner casing 12 above the expander tool just as it is pumped in above the top cementing plug. The pressure acting against cup 21 forces the expander tool downwardly to expand the corrugated section into substantially cylindrical shape. The function of the tool seems apparent from the drawing. It is described in more detail and claimed in U.S. patent application S.N. 179,609 filed by R. P. Vincent on March 14, 1962, now Patent 3,191,680. The expander head is forced down a distance equal to the length of the corrugated section of casing. This can be easily determined by watching the movement of the portion of tubing 22 which extends above the cementing head. After the corrugated section has been expanded, the expander tool is lifted out of the well by means of tubing 22.

In FIGURE 2 the outer and inner casing strings 11 and 12 are much the same as in FIGURE 1. Again a corrugated section 13 is provided in the inner string between enlarged portions immediately above and below. The enlarged portion immediately below the corrugated section is long enough to contain the expander tool. In FIGURE 2, however, the bottom of the length of casing which includes section 13 is not swaged down. Instead, it is internally threaded to fit a swaged nipple 30 which connects to collar 14 on the regular size casing.

The expander tool shown in FIGURE 2 is actuated by a hydraulic piston and cylinder system. The tool includes a polished rod 31 extending through expander cone 32 and collet head 33. Collet head 33 includes spring arms 34 with upper ends 35 extending up into a retaining groove in the bottom of cone 32. On the lower end of polished rod 31 is a piston and cylinder assembly 36. The top of polished rod 31 is attached to tubing 22.

In operation of the apparatus shown in FIGURE 2, an inner casing string is run and cemented as usual without the corrugated section of casing or the swaged nipple. In their place an ordinary length or joint of casing is used. After the cement has set, the top joint of the inner string is backed off and replaced by the length containing the corrugated section and the swaged nipple. It will be noted that in this in this embodiment the expander tool is placed in the enlarged portion of casing below the corrugated section before the length of casing, including both the enlarged and corrugated sections, is attached to the top of the regular casing string. When the attachment has been made, the inner casing string is again placed in tension, any previous tension having been released to remove the top standard joint of casing and replace it with the special joint. Liquid is then pumped through tubing

22 and polished rod 31 to the piston and cylinder assembly. The rising cylinder head then forces the expander cone and spring arms through the corrugated section of casing after which the expander tool is removed from the top of the casing. Apparatus of the type shown in FIGURE 2 is described in detail and is claimed in U.S. patent application S.N. 384,017, filed by R. P. Vincent on June 25, 1964, now Patent 3,203,483. U.S. application S.N. 384,017 is a division of U.S. patent application S.N. 216,949 filed on July 10, 1961, now Patent 3,179,168.

Certain limits must be observed with regard to the corrugated section of the inner casing. For example, the external cross-sectional perimeter of the corrugated section must be greater than the internal circumference of the outer casing. This insures that after the corrugated section is reformed into substantially cylindrical shape, it will be in maximum compressive stress in a circumferential direction. The purpose is to form and hold a strong seal between the two strings of casing. The outer casing must, of course, be in sufficient tensile stress to hold the inner casing in maximum compressive stress. It will be obvious then that if both strings are of the same material or alloy, which is usually the case, the inner string must be thinner than the outer one, at least in the interval of the corrugated section.

Actually, the outer casing should be considerably thicker than the inner one at the level of the corrugated section. This is because after the expander arms on the expander tool have reformed the liner into substantially cylindrical shape, these arms continue to exert radial force. Thus, the outer casing must withstand not only the stress imposed by the inner casing but also the stress imposed by the arms of the expander tool. Ordinarily the stress resulting from the expander arms is much less than that applied by the liner. In order to have some margin of safety, however, it is generally advisable to use a steel corrugated section which is not more than about $\frac{1}{2}$ as thick as the steel outer casing in which it is set.

As a practical matter, the thickness of the internal casing will ordinarily be at least slightly smaller than the thickness of the outer casing. It may be advisable, however, to form the corrugated section from pipe having an even smaller wall thickness than that of the inner casing string. It is also possible to provide an extra thick section of pipe at the top of the outer casing string opposite the interval in which the corrugated section is to be expanded. In this way it is possible to make the corrugated section of the same wall thickness as the remainder of the inner casing string.

It is also possible to make the corrugated section of a metal somewhat weaker than the metal of the outer casing string, or to make the outer casing string, opposite the corrugated section, of an extra strong metal. Either expedient permits a wider choice of wall thicknesses for either the corrugated section or the outer casing string opposite the corrugated section.

If the casing strings are made of different types of steel, they may not have the same strengths. The more general limitation on thickness can be stated, therefore, that the maximum compressive stress of the material of which the corrugated section is made times the wall thickness of this section must be less than the maximum tensile strength of the material of which the outer casing string is made times the wall thickness of the outer casing in the interval in which the corrugated section is set. Generally, a corrugated section thickness of only about $\frac{1}{2}$ the indicated value should be used to allow for a margin of safety.

The amount by which the corrugated section wall must be compressed to insure that the expanded section reaches maximum compressive stress is usually less than about $\frac{1}{4}$ of 1 percent. When a layer of glass fibers and plastic, or of a metal such as copper, aluminum or the like, is provided between the corrugated section and the outer casing, and if the external perimeter of the corrugated

section is any greater than the internal circumference of the outer casing, this requirement is satisfied. If the corrugated section external perimeter is more than about 10 percent greater than the internal circumference of the outer casing, the work required to reform the liner into cylindrical shape may be great, so a large force may be required to move the expander head through the corrugated section at a desirable rate. Therefore, the corrugated section external perimeter ordinarily should not exceed the outer casing internal circumference by more than about 10 percent.

The length of the corrugated section may be as short as a foot or two if a glass fiber mat filled with plastic is used between the casing string, and if some means other than the seal has been provided for holding the inner string in tension. If the seal is also to support at least a portion of the weight of the inner string of casing, however, a length of at least about 4 or 5 feet is recommended. A length of about 10 feet is ordinarily preferred for most circumstances when using the glass fiber mat and plastic seal. Greater lengths may, of course, be used if desired. Many glass fiber mats and satisfactory liquid resins capable of being set to a hardened state are available. In general, woven glass cloths and epoxy resins are preferred.

If a metallic sealing sleeve is used between the casing strings, the length of sealing sleeve and corrugated section should be considerably greater than when a glass mat and plastic is used. This is because the more deformable metals such as copper, aluminum, and lead, or even strong alloys of these metals, tend to creep under pressure and thus release the compressive stress in the inner casing string, at least near the end of the sealing sleeve. Thus, the length of the corrugated section and corresponding sealing metallic sleeve behind it, should ordinarily be at least about 5 to 10 feet and preferably around 15 to 20 feet in length or even longer.

When the corrugated section is reformed into substantially cylindrical form, the metal is in a condition of plastic flow. Under these circumstances the metal of the corrugated section may flow enough to make a sufficiently effective seal against the inner surface of the outer casing string. This is particularly true if the well is a low-pressure well and if the outer string of casing is new and has a smooth inner surface. Ordinarily, however, a sealing material should be used between the corrugated section and the outer string of casing. If the sealing material is a deformable metal, it will be apparent that this metal should be more deformable than the steel of which the corrugated section is made. Therefore, when reference is made to a deformable metal it will be understood that a metal or alloy more deformable than steel is intended.

The length of inner casing containing the corrugated section must be specially made. The corrugated section is made of pipe slightly larger in external circumference than the internal circumference of the outer casing. Immediately above and below the corrugated section are portions which fit as closely as possible inside the outer casing and still retain some freedom of vertical movement. On the bottom of the special length, some means, such as those previously described, must be provided to connect the special casing length to the regular internal casing string in the well. On the top of the special length, means may be provided for making the usual connections to support well tubing or the like. It is also possible, however, to cut the inner casing above the reformed corrugated section so connections can be made to the upper end of the outer casing string.

It is important that the inner string of casing be placed in tension before the seal at the upper end is made. This is to prevent buckling of casing when hot well fluids flow up through the tubing and the casing is thus heated. Ordinarily there is a relatively simple solution to the problem. The inner string is generally hung on elevators and the weight of the casing provides the necessary tension. It should be noted, however, that considerable

force is required to move the expander head through the corrugated section. Therefore, if the expander is to be moved downwardly, it may be necessary to provide sufficient support not only for the weight of the casing but also oppose the downward force of the expander tool. In the apparatus in FIGURE 1 the downward force is compensated for by the upward force on the cementing head. If a piston and cylinder arrangement is used to force the expander down, however, it may be necessary to oppose this force. If the expander tool is moved upwardly, it is generally advisable to release at least a small amount of the lift on the upper end of the inner casing to avoid any possible excessive stretching of the inner string.

The amount of tension in the inner string of casing ordinarily is not particularly critical. Therefore, it is possible simply to hang the liner string from a flange or other supporting structure resting on the top of the outer casing string or similar fixed support. This is particularly important in marine completions where the work is being carried out from a floating platform. In this case it is difficult, although not impossible, to hold a sufficiently constant tension on the inner string of casing while it is being cemented and the top seal is being formed. It is much better in such cases to support the weight of the inner string on a flange resting on the outer string of casing and make connections to the surface from the outer and inner string through slip joints, flexible hoses or the like.

The expander arms of the tools shown in FIGURES 1 and 2 are different. In FIGURE 1 the arms are pivoted at one end and are forced outwardly by inclined surfaces at the other end. In FIGURE 2 the arms are spring arms. It is possible, of course, to use the pivoted arm design in the apparatus of FIGURE 2 and the spring arm design in the apparatus of FIGURE 1. It is also possible to invert the hydraulic piston and cylinder of FIGURE 2 and use it to drive the expander cone and arms of either FIGURE 1 or FIGURE 2 downwardly through the corrugated section. Rather than using hydraulic means to force the expander head through the corrugated section, it is also possible to use the tubing to pull or push the expander head. Still other possibilities will be apparent to those skilled in the art. Some modifications will, of course, sometimes be required. For example, a spring between the trailing edge of cone 16 and the mandrel shoulder behind this end in FIGURE 1 should be used to force the cone away from the expander arms if this form of expander tool is to be pulled upwardly through the corrugated section.

Each system has its advantages and disadvantages. For example, the arrangements in which the expander tool is pulled upwardly through the corrugated section require the top joint of the inner casing to be removed and replaced with the special length containing the expander tool below the corrugated section. This is perfectly satisfactory for use on dry land and for many marine locations. It may not be easily applied, however, where a floating work platform is used. Such a system is easily adapted to use in old wells where at least the top portion of the inner casing string is removed and replaced with a new section. In this casing no cementing step is required, so the special joint of casing containing the expander tool can be run in immediately.

Any of several well-known methods can be used to remove the top joint or two of the inner casing string and replace this portion with the special length. For example, a lefthand thread may be provided in the upper part of the collar to which the special length is to be attached. It may also be possible to cause the casing to jump loose from the collar by applying tension to the casing string and using a small explosive charge opposite the collar. It is also possible to cut the inner casing string at the desired level and use a casing bowl repair tool to connect the special length to the cut end of the inner string.

Many other schemes will be apparent to those skilled in the art.

The spring arms have the disadvantage that after they have expanded the corrugated section, they may continue to press on the uncorrugated portion of the inner string as the expander tool is withdrawn from the well. The pivot arms have the disadvantage that they are released as soon as the solid cone emerges from the end of the corrugated section. A short length of the corrugated section is thus left in a partially expanded condition.

In this connection, when reference is made to expanding or reforming the corrugated section into substantially cylindrical shape or form, it will be understood that the entire length of the corrugated section need not be completely expanded, but only enough to provide the desired seal and support. The disadvantage with neither apparatus is serious for my purposes. The disadvantages can, however, be avoided by using a somewhat more complex expander tool.

The disadvantage with the spring arms can also be avoided by using an extra thick section of the outer casing string opposite the corrugated section of the inner string. This will mean that the internal diameter of the outer spring opposite the corrugated section will be smaller than the diameter immediately above this section. It will be possible, therefore, to use a section of the internal string immediately above the corrugated section, larger in diameter than the diameter of the reformed corrugated section. This will at least reduce, and may avoid, the pressure of the spring arms after the expander tool has been pulled up through the corrugated section.

In applying my method to forming top seals between casing strings in wells in marine locations, the specific technique to be used will depend to some extent on the type of working platform available and the type of well head desired. If the platform is a permanent one and the well head is to be on the platform, then any of the suggested techniques can be used. If a temporary platform is used, the well head will probably be below the surface of the water. In this case, my sealing method has the advantage of avoiding the use of divers to make underwater connections, but again any of the techniques suggested above can be used since a firm platform is available from which the position of, and tension in, the inner casing string can be controlled.

If a floating work platform such as a ship is used, a submarine well head will be used and my method again will have the advantage of avoiding the use of divers to complete the seal between casing strings. In this case, however, the rising and falling of the floating platform with waves and tides make it difficult to control the position of, and tension in, the inner casing string. Therefore, it is best in this case to hang the inner string on a supporting structure such as a flange resting on the top of the outer casing string or other support on the marine floor. An expander tool having a sealing cup as shown in FIGURE 1 can then be pumped down the internal casing string, which includes a slip joint in the interval between the floating platform and the marine floor, to expand the corrugated section of casing and form the desired seal.

Many additional embodiments and variations will occur to those skilled in the art. Those presented above are given by way of example only. I do not wish to be limited to these specific examples, but only by the terms of the following claims.

I claim:

1. In a method for casing a well in which method an inner string of casing is run inside an outer string of casing and a seal is formed between the strings at the top of the well, the improvement comprising including a longitudinally corrugated malleable metallic section near the top of said inner string at a location within said outer string, the wall thickness of said outer string, opposite said corrugated section, times the maximum tensile strength of the material of which said outer string, oppo-

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site said corrugated section, is made being greater than the wall thickness of said corrugated section times the maximum compressive strength of the material of which said corrugated section is made, the outer cross-sectional perimeter of said corrugated section being greater than the internal circumference of said outer string opposite said corrugated section, placing at least the top portion of said inner string of casing in tension, and while said inner string is in tension, expanding said corrugated section into a substantially cylindrical shape inside said outer string of casing.

2. The method of claim 1 in which the external cross-sectional perimeter of said corrugated section is no more than about 10 percent greater than the internal circumference of said said outer string of casing opposite said corrugated section.

3. The method of claim 1 in which said corrugated section is expanded by placing in said inner string of casing above said corrugated section an expander tool including an element to form a seal against the inside surface of said inner string of casing, closing the top of said inner string of casing and applying sufficient pressure inside said inner casing string above said expander tool to cause said expander tool to move through said corrugated section.

4. The method of claim 1 in which said corrugated section is surrounded with a sealing material before said corrugated section is expanded.

5. The method of claim 4 in which said sealing material is a glass fiber mat saturated with a liquid resin capable of being set to a hardened state.

6. The method of claim 4 in which said sealing material is a deformable metal.

7. A method for forming, near the top of a well, a seal between an inner string of casing and an outer string of casing in said well comprising removing at least the top portion of said inner string, replacing the removed portion with a new portion including a longitudinally corrugated malleable metallic section within said outer section, the wall thickness of said outer string, opposite said corrugated section, times the maximum tensile strength of the material of which said outer string, opposite said corrugated section, is made being greater than the wall thickness of said corrugated section times the maximum compressive strength of the material of which said corrugated section is made, the outer cross-sectional perimeter of said corrugated section being greater than the internal circumference of said outer string opposite said corrugated section, placing at least the top portion of said inner string of casing in tension, and while said inner string is in tension, expanding said corrugated section into a substantially cylindrical shape inside said outer string of casing.

8. The method of claim 7 in which said corrugated section is surrounded with a sealing material before said corrugated section is expanded.

9. A method for casing a well which already contains a string of casing comprising lowering an inner string of casing into said well, through the outer string of casing, placing cement around the bottom of said inner string to form a seal between the bottom of said inner string and the well wall, removing the top portion of said inner string from said well, replacing the removed portion with a new portion including a longitudinally corrugated malleable metallic section within said outer string, the wall thickness of said outer string, opposite said corrugated section, times the maximum tensile strength of the material of which said outer string, opposite said corrugated section, is made being greater than the wall thickness of said corrugated section times the maximum compressive strength of the material of which said corrugated section is made, the outer cross-sectional perimeter of said corrugated section being greater than the internal circumference of said outer string opposite said corrugated section, placing at least the top portion of said inner string

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of casing in tension, and while said inner string is in tension, expanding said corrugated section into a substantially cylindrical shape inside said outer string of casing.

10. The method of claim 9 in which said corrugated section is surrounded with a sealing material before said corrugated section is expanded.

11. A method for casing a well which already contains a string of casing comprising lowering an inner string of casing into said well, through the outer string of casing, said inner string including near the top a longitudinally corrugated malleable metallic section, the wall thickness of said outer string, opposite said corrugated section, times the maximum tensile strength of the material of which said outer string, opposite said corrugated section, is made being greater than the wall thickness of said corrugated section times the maximum compressive strength of the material of which said corrugated section is made, the outer cross-sectional perimeter of said corrugated section being greater than the internal circumference of said outer string opposite said corrugated section, continuing lowering said inner string until said corrugated section is within said outer casing, placing cement around the bottom of said inner string to form a seal between the bottom of said inner string and the well wall, placing at least the top portion of said inner string in tension, and while said inner string is in tension, forcing an expander tool downwardly through said corrugated section to reform said corrugated section into substantially cylindrical shape inside said outer string of casing.

12. The method of claim 11 in which said corrugated section is expanded by placing in said inner string of casing above said corrugated section an expander tool including an element to form a seal against the inside surface of said inner string of casing, closing the top of said inner string of casing and applying sufficient pressure inside said inner casing string above said expander tool to cause said expander tool to move through said corrugated section.

13. The method of claim 11 in which said corrugated section is surrounded with a sealing material before said corrugated section is expanded.

14. A method for casing a well from a floating platform in a marine location, where said well already contains a casing string, comprising lowering an inner string of casing into said well, through the outer string of casing, said inner string including near the top a longitudinally corrugated malleable metallic section, and said inner string also including a means for hanging said inner string on the top of said outer string, the wall thickness of said outer string, opposite said corrugated section, times the maximum tensile strength of the material of which said outer string, opposite said corrugated section, is made being greater than the wall thickness of said corrugated section times the maximum compressive strength of the material of which said corrugated section is made, the outer cross-sectional perimeter of said corrugated section being greater than the internal circumference of said outer string opposite said corrugated section, continuing lowering of said inner string until said corrugated section is within said outer string and said means for hanging said inner string comes to rest on the top of said outer string and supports said inner string, placing cement around the bottom of said inner string to form a seal between the bottom of said inner string and the well wall, and forcing an expander tool downwardly through said corrugated section to reform said corrugated section into substantially cylindrical shape inside said outer string of casing.

15. The method of claim 14 in which the external cross-sectional perimeter of said corrugated section is no more than about 10 percent greater than the internal circumference of said outer string of casing opposite said corrugated section.

16. The method of claim 14 in which said corrugated section is expanded by placing in said inner string of cas-

ing above said corrugated section an expander tool including an element to form a seal against the inside surface of said inner string of casing, closing the top of said inner string of casing and applying sufficient pressure inside said inner casing string above said expander tool to cause said expander tool to move through said corrugated section.

17. The method of claim 14 in which said corrugated section is surrounded with a sealing material before said corrugated section is expanded.

18. The method of claim 17 in which said sealing material is a glass fiber mat saturated with a liquid resin capable of being set to a hardened state.

19. The method of claim 17 in which said sealing material is a deformable metal.

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