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(54) **PRESSURE PERFORATED WELL CASING SYSTEMS**

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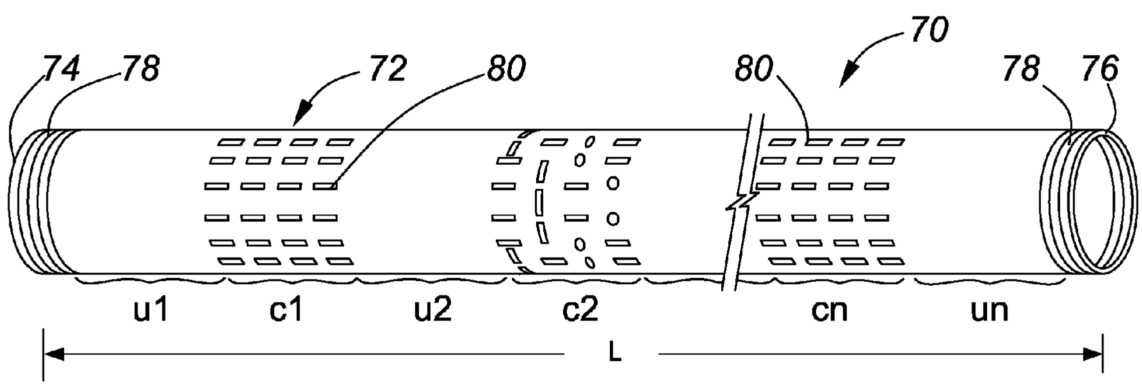
(57) **ABSTRACT**

Pressure perforated casing system has a plurality of grooves cut to an equal depth in an outer surface of a casing joint or a casing collar. Each groove has a bottom spaced from and internal surface of the casing joint or the casing collar. Sidewall bottom material in the groove ruptures at a predetermined fluid pressure below the burst pressure rating of the casing joint or casing collar.



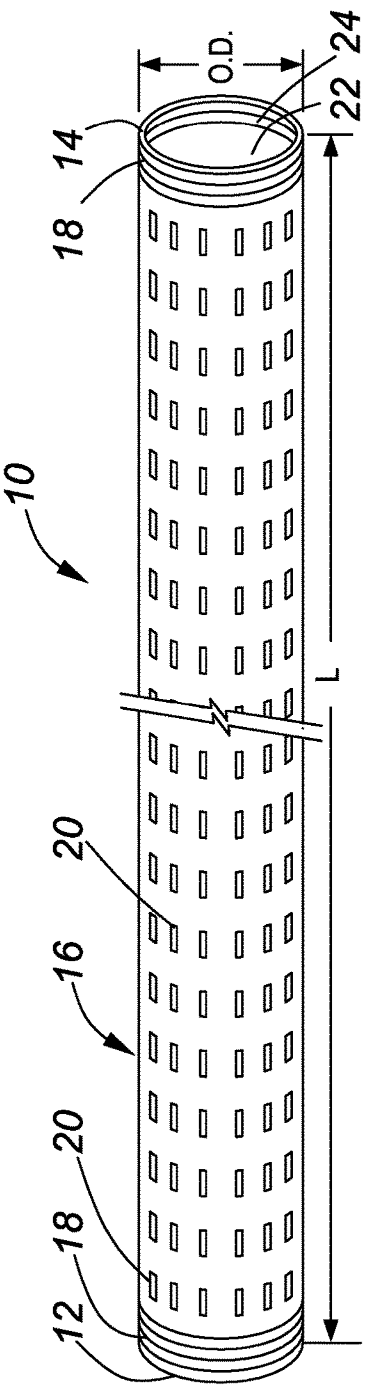


FIG. 1

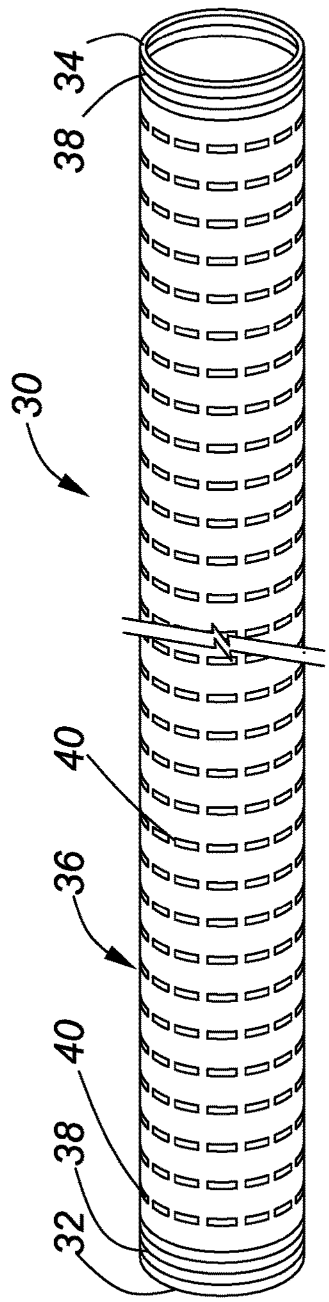


FIG. 2

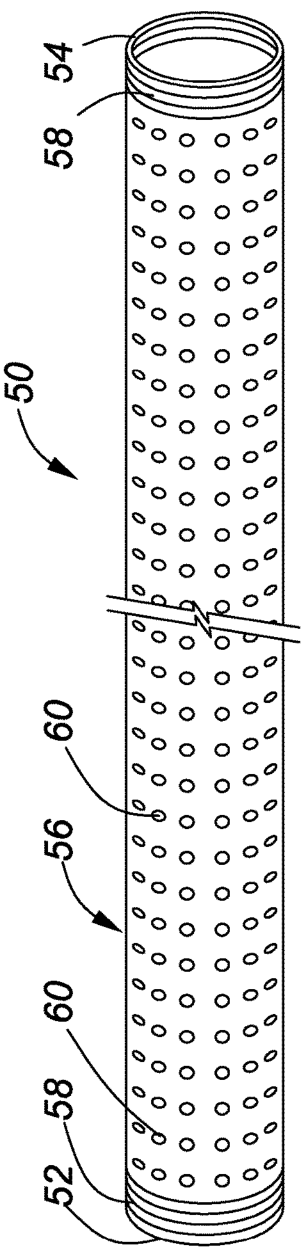


FIG. 3

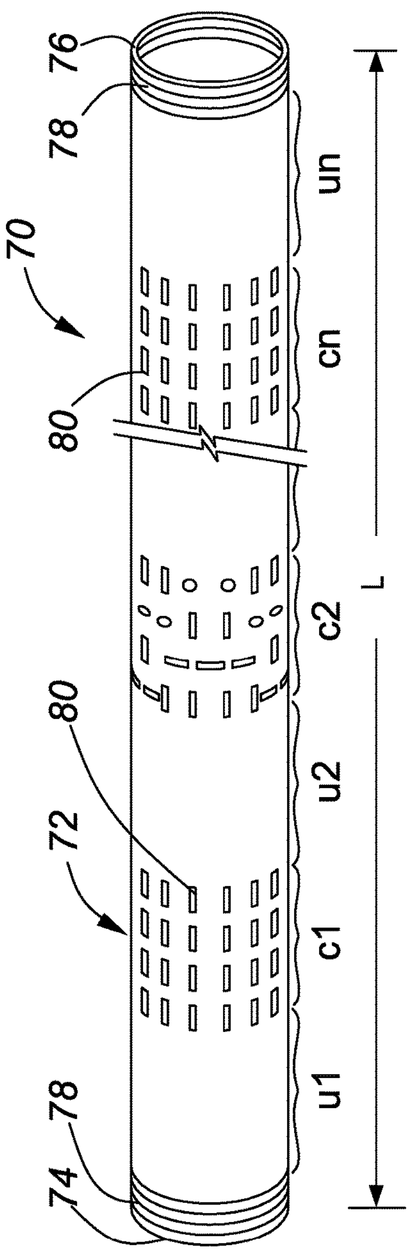


FIG. 4

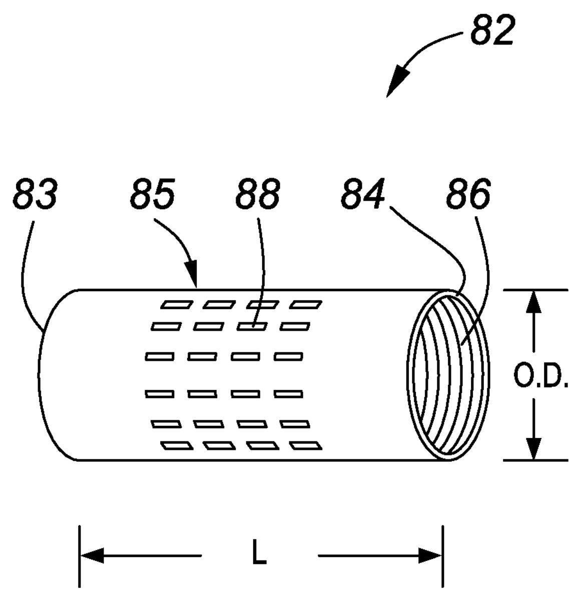


FIG. 5

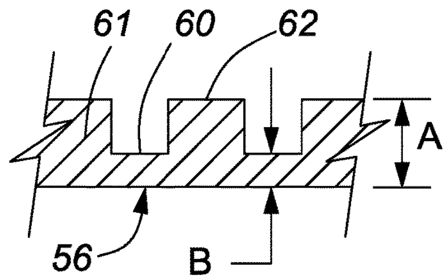


FIG. 6

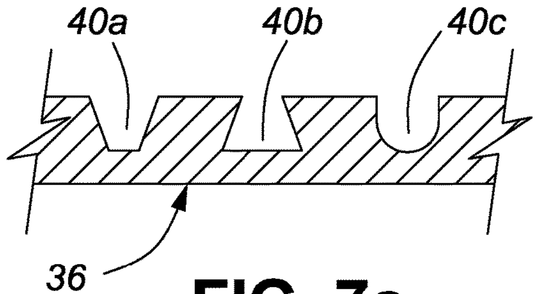


FIG. 7a

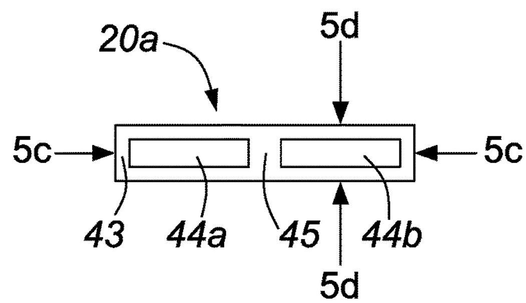


FIG. 7b

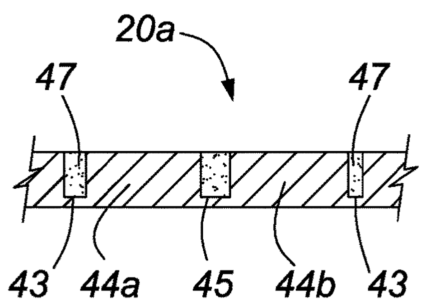


FIG. 7c

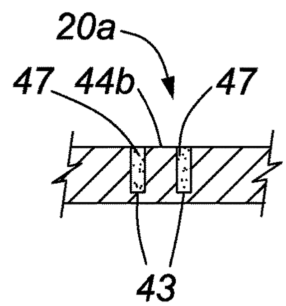


FIG. 7d

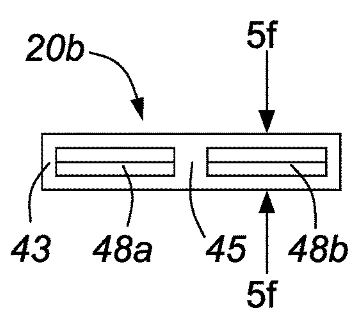


FIG. 7e

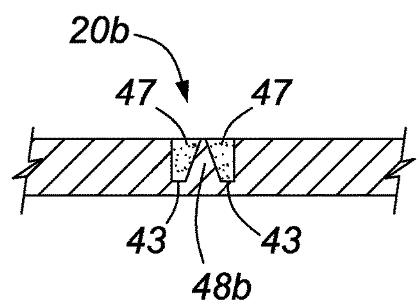


FIG. 7f

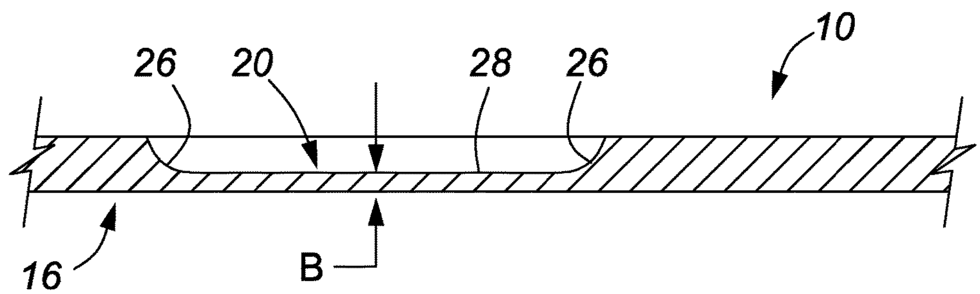


FIG. 8a

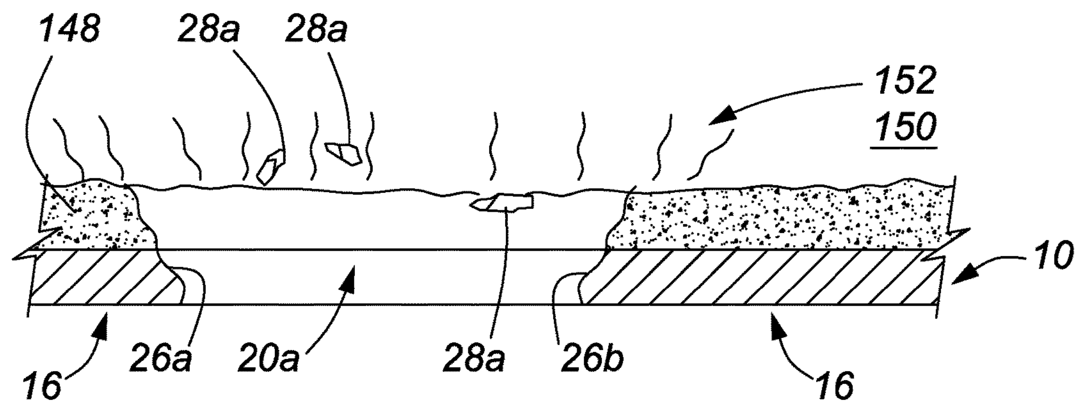


FIG. 8b

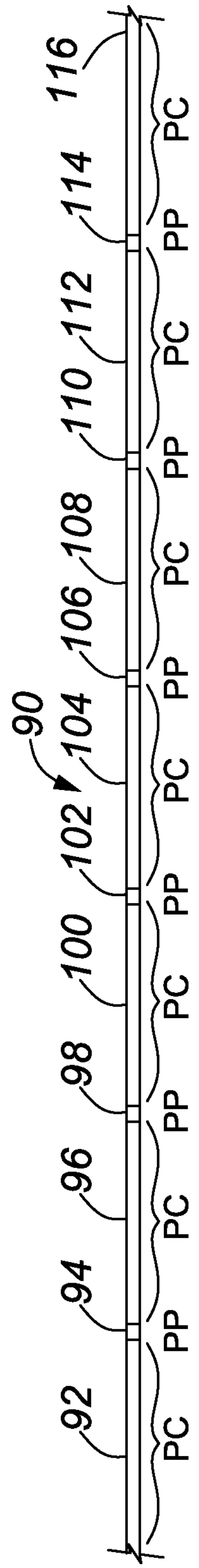

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FIG. 9

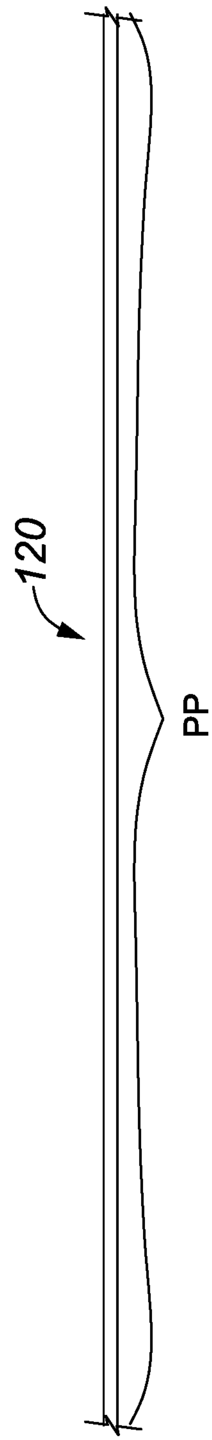
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FIG. 10

PRESSURE PERFORATED WELL CASING SYSTEMS

FIELD OF THE INVENTION

[0001] This invention relates in general to hydrocarbon well casing systems and, in particular, to a novel well casing system that is pressure perforated after a casing string is assembled, inserted and cemented into a section of a recently drilled wellbore.

BACKGROUND OF THE INVENTION

[0002] Well casing is made up of casing joints and casing collars for connecting the casing joints together to assemble a casing string. Well casing is well known in the art and used to line recently drilled hydrocarbon wellbores to prevent borehole collapse and provide a smooth conduit for inserting tools required to complete the well for production and to produce hydrocarbon from the well. Most hydrocarbon wells drilled today are vertical bores extending down to proximity of a production zone and horizontal bores within the production zone. There are two ways commonly used to complete a horizontal bore, plug-and-perf (PNP) and openhole multistage (OHMS).

[0003] The openhole multistage system has external casing packers that provide a seal between a production casing and the horizontal bore. The production casing has dropped-ball actuated sliding sleeves. The sliding sleeves open ports through the production casing. The sliding sleeves are opened in succession from the toe to the heel of the horizontal bore. The dropped balls are graduated in size to pass through each sliding sleeve until they reach the sliding sleeve to be opened next. When a ball is caught by a sliding sleeve the fracture fluid pressure opens the sliding sleeve exposing the ports, and the ball provides a seal to prevent frac fluid from going downhole past the opened sliding sleeve. The permits OHMS systems to perform multiple fracture stimulations without the need to rig up wireline or set plugs to perforate new intervals. Casing perforation is unnecessary because communication between the cased borehole and the productive formation is afforded by each set of ports opened by the balls dropped to open the respective sliding sleeves. When the entire horizontal bore has been fractured the balls are captured at the surface during flow back of the fracturing fluid.

[0004] With plug-and-perf, after assembly and insertion of the casing in the open borehole, the casing is "cemented in" by circulating a cement slurry through the inside of the casing and out into the annulus through a casing shoe at the bottom of the casing string. The cement fills the annulus around the casing and hardens to prevent the migration of fluids between zones in the wellbore. Once cemented in, the casing is perforated in sections from toe to heel using a perforating gun system that is run into the well with wireline or completion tubing. The perforating guns are triggered from the surface to fire steel projectiles that penetrate the casing to let the hydrocarbon flow into the casing. After a section of casing has been perforated, the spent perforating guns are withdrawn and fracturing fluid is pumped down the casing to fracture the formation behind the perforations. When fracturing of that section is completed, a fiber plug is run into the well with the next perforating gun system. The fiber plug is set in the casing up hole from the fractured section, before the perforating guns are fired to perforate a new section of the casing. This process is repeated until the entire horizontal bore has been plugged, perforated and fractured. Thereafter, the fiber plugs are milled out to put the horizontal bore into production.

[0005] OHMS and PNP each have their advantages and disadvantages. OHMS is more expensive to install, but fracturing proceeds more quickly because the sliding sleeves are opened in succession and fracturing can be performed with virtually no interruptions. However, OHMS is much less flexible in that once installed it cannot be reconfigured or changed. OHMS also has shorter reach because the reach is restricted by the number of sliding sleeves that can be opened using a series of different sized balls that are pumped into the well. OHMS also severely restricts fracture fluid flow rates at the toe of the lateral well bore because of the ball seat size through which fracturing fluid must be pumped. OHMS bores are likewise more difficult to re-complete, and the service life of the sliding sleeves is known to be limited. A further hazard is that sliding sleeves are sometimes skipped because a wrong sized ball is dropped, a ball shatters before it can seat in the sliding sleeve, or one or more of the openhole packers provide an incomplete seal.

[0006] PNP offers complete flexibility because casing perforations can be located at any desired interval and the location can be dynamically determined as the production zone is being fractured. PNP also offers unlimited reach because newly available completion tubing can be pushed to the furthest extent that a horizontal bore can be drilled and cased. PNP is also secure because the casing is cemented in, so fracture fluid has no place to migrate except into the formation. PNP can also provide much more drainage area than OHMS, which can be advantageous. The disadvantage of PNP is the time required to run the perforating gun strings and to set the plugs in the cased well bore. While each run is being performed the fracturing crews sit idle. This adds significantly to expense.

[0007] A disadvantage of both systems is the fracturing pump horsepower required to complete the well. The interval fractured in OHMS systems is necessarily long even though the fracture fluid ports are concentrated in a very small area opened by the sliding sleeve, and the interval fractured in PNP is preferably long in order to minimize idle time. Consequently, both OHMS and PNP require a large number of high powered pump trucks, about 25,000 total horsepower, each with attendant crew. Those trucks must be scheduled, congregated and maintained onsite throughout the well completion. This requires long term planning, complex scheduling and significant expense.

[0008] Perforated casing is also known and is used for openhole completions in certain heavy oil reservoirs. However, perforated casing does not permit cementing or well stimulation and its use is therefore limited.

[0009] There therefore exists a need for a novel well casing system that is pressure perforated after it is assembled, inserted and cemented into a section of a recently drilled wellbore.

SUMMARY OF THE INVENTION

[0010] It is therefore an object of the invention to overcome the disadvantages of prior art hydrocarbon well casing systems and provide a novel well casing system that is pressure perforated after it is assembled, inserted and cemented into a section of a recently drilled wellbore.

[0011] The invention therefore provides a pressure perforated well casing joint, comprising: a pipe having a sidewall with a first end, a second end, an inner surface, an outer surface and a burst pressure rating; an external tread on each of the first and second ends adapted to threadedly engage a casing collar, and a plurality of grooves cut in the outer surface, each groove extending inwardly from the outer surface to an extent less than a thickness of the sidewall, so there remains sidewall bottom material in each groove; whereby fluid pressure applied within the pressure perforated well casing will cause the sidewall bottom material in the grooves to rupture before the burst pressure rating of the pipe is reached, thereby opening a slot through the sidewall at each of the plurality of grooves subjected to the fluid pressure.

[0012] The invention further provides a pressure perforated well casing collar, comprising: a pipe having a sidewall with a first end, a second end, an inner surface, an outer surface and a burst pressure rating; an internal tread on each of the first and second ends adapted to threadedly engage an external thread on a casing joint; a plurality of grooves cut in the outer surface, each groove extending inwardly from the outer surface to an extent less than a thickness of the sidewall, so there remains sidewall bottom material in each groove; whereby fluid pressure applied within the pressure perforated well casing collar will cause the sidewall bottom material in the grooves to rupture before the burst pressure rating of the casing collar is reached, thereby opening a slot through the sidewall at each of the plurality of grooves.

[0013] The invention yet further provides a pressure perforated well casing system, comprising: a well casing joint and a well casing collar respectively having a plurality of grooves cut in an outer surface thereof, the grooves being cut to an equal depth in the outer surface, each groove having sidewall bottom material remaining in a bottom of the groove; whereby sufficient fluid pressure applied to the grooves cause the sidewall bottom material in the respective grooves to rupture before a burst pressure rating of the well casing joint or the well casing collar is reached, thereby opening slots through the sidewalls at each of the respective grooves under sufficient fluid pressure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Having thus generally described the nature of the invention, reference will now be made to the accompanying drawings, in which:

[0015] FIG. **1** is a schematic view of an embodiment of a pressure perforated casing joint of the well casing system in accordance with the invention;

[0016] FIG. **2** is a schematic view of another embodiment of a pressure perforated casing joint of the well casing system in accordance with the invention;

[0017] FIG. **3** is a schematic view of yet another embodiment of a pressure perforated casing joint of the well casing system in accordance with the invention;

[0018] FIG. **4** is a schematic view of yet a further embodiment of a pressure perforated casing joint of the well casing system in accordance with the invention;

[0019] FIG. **5** is a schematic view of a pressure perforated casing collar in accordance with the invention;

[0020] FIG. **6** is a schematic cross sectional view of a groove cut in a sidewall of the casing joint or the casing collar in accordance with the invention;

[0021] FIG. **7*a*** is a schematic cross sectional view of other grooves cut in the sidewall of a casing joint or the casing collar in accordance with the invention;

[0022] FIG. **7*b*** is a top plan view of one embodiment of another groove cut in the sidewall of a casing joint or the casing collar in accordance with the invention;

[0023] FIG. **7*c*** is a longitudinal cross sectional view taken along lines **5*c*-5*c*** of the groove shown in FIG. **7*b*;**

[0024] FIG. **7*d*** is a cross sectional view taken along lines **5*d*-5*d*** of the groove shown in FIG. **7*b*;**

[0025] FIG. **7*e*** is a top plan view of yet another embodiment of a groove cut in the sidewall of a casing joint or the casing collar in accordance with the invention;

[0026] FIG. **7*f*** is a cross sectional view taken along lines **5*f*-5*f*** of FIG. **7*e*;**

[0027] FIG. **8*a*** is a schematic cross sectional view in longitudinal section of a further embodiment of a groove cut in the sidewall of a casing joint or the casing collar in accordance with the invention;

[0028] FIG. **8*b*** is a schematic cross sectional view in longitudinal section of the groove shown in FIG. **8*a*** after the casing joint or the casing collar has been pressure perforated and a formation in which the casing is cemented has been fractured;

[0029] FIG. **9** is a schematic diagram of one embodiment of a casing string in accordance with the invention; and

[0030] FIG. **10** is a schematic diagram of another embodiment of a casing string in accordance with the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0031] The invention provides a pressure perforated well bore casing system that permits hydrocarbon wells to be completed and fractured with greater efficiency and at less expense than prior art casing and completion systems. The casing system in accordance with the invention eliminates the need for sliding sleeves, openhole packers, wirelines, perforating gun systems, plugs and plug mills. In one embodiment the casing system in accordance with the invention also reduces the pump horsepower requirement for completing a well by up to 60%, thus significantly reducing completion cost and simplifying job scheduling. The well casing system in accordance with invention also significantly reduces fracturing crew idle time while providing fracture location flexibility. The well casing system in accordance with invention may be used in vertical or horizontal well bores and is equally effective and efficient in either a vertical or a horizontal well bore.

[0032] FIG. **1** is a schematic view of an embodiment of a pressure perforated casing joint **10** of the well casing system in accordance with the invention. The casing joint **10** has a first end **12**, a second end **14** and a sidewall **16**. An external thread **18** cut on each of the first end **12** and the second end **14** is adapted to threadedly engage a casing collar (not shown but well known in the art) for connecting one casing joint **10** to another. The casing joint **10** has a length "L" and an outside diameter "OD". The outside diameter is typically 4.5" (11.4 cm), 5.5" (13.97 cm), 7.5" (19.05 cm) or 7.625" (19.37 cm), although 3" (7.62 cm), and other diameters of casing are occasionally used. The length "L" Is a matter of design choice selected by a well consultant or operator. The length "L" may be as short as 3' (91.4 cm) or as long as a drill rig can handle, typically 40' (12.19 m). A plurality of grooves **20** are cut into the sidewall **16**. The grooves **20** in this embodiment are shown to be straight axial grooves, but the shape of the grooves **20** is a matter of design choice. It is only important that the grooves **20** are spaced far enough apart that any potential erosion (known in the art as "wash") from fracturing operations will not join two or more grooves **20**, which could compromise the strength of the casing joint **10**.

[0033] In one embodiment, each groove **20** is about 0.375"-0.5" (1-1.27 cm) wide and 1"-3" (2.5-7.6 cm) long. As will be explained below with reference to FIGS. **6** and **7**, the grooves **20** are not cut through the sidewall **16**. Rather, a predetermined thickness of sidewall bottom material is left between a bottom of each groove **20** and an inner wall **22** of the casing joint **10**. The thickness of the sidewall bottom material is calculated to have a rupture pressure (yield strength) that is less than a burst pressure rating of the casing joint **16**, yet greater than the fluid pressure normally required to cement the casing in the well bore, which is typically about 3,000 psi (20,648 KPa). At the predetermined rupture pressure the sidewall bottom material will rupture, opening a slot though the casing sidewall. The rupture pressure is also far below the fluid pressure potential of modern fracturing pumps and completion tubing, which is at least 15,000 psi (103,421 KPa). Consequently, the casing joint **10** can be run into a recently bored well bore without hazard of well bore material intrusion, and it can be cemented in without danger of cement intrusion into the casing string. Once the casing **10** is installed in a recently drilled well bore and cemented in, it can be selectively perforated using a downhole fracturing tool, the description of which is beyond the scope of this disclosure. In one embodiment, a shallow groove **24** is cut in the interior wall **22** of each end **12**, **14** of the casing joint **10** when the exterior threads **18** are being cut. The groove **24** is detectable by a collar locator to provide a positive identification of any casing joint **10** in an assembled casing string, which will be described below in more detail with reference to FIG. **9**.

[0034] FIG. **2** is a schematic view of another embodiment of a pressure perforated casing joint **30** of the well casing system in accordance with the invention. The casing joint **30** has a first end **32**, a second end **34**, a sidewall **36** and an external thread **38** cut on each end of the sidewall **36**. The casing joint **30** is identical to the casing joint **10** described above with an exception that the grooves **40** cut in the sidewall **36** are radial rather than axial grooves. It should be noted that although the grooves **40** are shown to be straight radial grooves, that is a matter of design choice. It is only important that the grooves **40** are spaced far enough apart that any potential erosion from fracturing operations will not join two or more grooves **40**, which could compromise the strength of the casing joint **30**.

[0035] FIG. **3** is a schematic view of yet another embodiment of a pressure perforated casing joint **50** of the well casing system in accordance with the invention. The casing joint **50** has a first end **52**, a second end **54**, a sidewall **56** and an external thread **58** cut on each end of the sidewall **56**. The casing joint **50** is identical to the casing joint **10** described above with an exception that the grooves **60** cut in the sidewall **56** are circular trepans rather than axial grooves. It should be noted that although the grooves **60** are shown to be circular, they may be any shape in which the beginning and ending of the groove overlap. Consequently, the grooves **60** may be oval, square, rectangular, triangular, oblong, obround or irregular in shape. It is only important that the grooves **60** are spaced far enough apart that any potential erosion from fracturing operations will not join two or more grooves **60**, which could compromise the strength of the casing joint **50**.

[0036] FIG. **4** is a schematic view of yet a further embodiment of a pressure perforated casing joint **72** of the well casing system in accordance with the invention. The casing joint **72** has a first end **74**, a second end **76** and an external thread **78** on each of the first and second ends adapted to threadedly engage a casing collar. In this embodiment, grooves **80** in the casing joint **72** are arranged in clusters (cluster-**1**-cluster-n). A total area of the clusters is less than a total area of the sidewall **72**. The shape and the number of grooves in each cluster **1**-*n* is a matter of design choice, as is the number of clusters on the pressure perforated casing joint **72**. The pressure perforated casing joint **72** may have 1 cluster or several clusters. Typically, each pressure perforated casing joint has 1-3 clusters. If there is more than one cluster, the clusters **1**-*n* are spaced apart. The shape of the grooves in any cluster need not be the same, as shown in cluster **2**. In this example, cluster **1** is spaced from the first end **74** by an interval u-**1** without grooves. Cluster n is spaced from the second end **76** by an interval u-n without grooves. Each cluster **1**-*n* is spaced from any other cluster **2**-(*n*−1) by an interval u-**2**, u-**3**, etc. without grooves. The intervals without grooves u-**1**-u-n may be the same length or of different lengths. The purpose of the intervals u-**1**-u-n is to provide an area for landing packers of the downhole fracturing tool (not shown or described). In one embodiment, the casing joint **72** has a length "L" of 40' (12.19 m) and 3 clusters (cluster **1**-**3**). Each cluster **1**-**3** is about 2'-3' (0.61-0.91 m) in length and each interval without grooves (u-**1**-u-**4**) is about 7.75'-8.5' (2.29-2.59 m) in length.

[0037] In one embodiment the number of grooves and the size of each of the grooves in each cluster **1**-*n* opens slots through the sidewall **72** having a predetermined total area when the grooves in that cluster are ruptured using frac fluid pressure, that predetermined total area being an area through which fracturing fluid can be pumped at a constant rate by about 10,000 horsepower of pump capacity. This reduces the pump horsepower requirement for completing a well bore by about 60%, thus significantly reducing completion cost and simplifying job scheduling.

[0038] FIG. **5** is a schematic view of a pressure perforated casing collar **82** in accordance with the invention. The casing collar **82** has a length "L" that is longer than a standard casing collar to accommodate pressure perforated grooves that open slots as described above when the casing collar **82** is pressure perforated. The length of the casing collar **82** is typically 2'-4' (0.61-1.22 m), though the length is a matter of design choice. The casing collar **82** has a first end **83**, a second end **84**, a sidewall **85** and an internal thread **86** cut inside of each end of the sidewall **85**. The internal threads **86** mate with the external threads of a corresponding size of casing joint, in a manner well understood in the art. Consequently, the outside diameter "O.D." of the casing collar **82** is the same as the outside diameter of any casing collar of a corresponding weight and grade of casing. A plurality of grooves **88** are cut in the sidewall **85**, between the internal threads on the first end **83** and the second end **84**. The number of grooves **88** cut in the sidewall **85** is a matter of design choice. The grooves **88** may also be grouped into clusters as described above with reference to FIG. **4**, also as a matter of design choice. In one embodiment when the collar **82** is pressure perforated, the grooves **88** cut in the sidewall **85** open slots through the sidewall **85** having a predetermined total area through which fracturing fluid can be pumped at a constant rate by about 10,000 horsepower of pump capacity. The shape and size of the grooves **88** is also a matter of design choice. It is only important that the grooves **88** are spaced far enough apart that any potential erosion from fracturing operations will not join two or more grooves **88**, which could compromise the strength of the casing collar **82**.

[0039] The casing collar **82** provides further flexibility to a well operator, who can assemble casing strings with plain casing joints and the pressure perforated casing collars **82**, pressure perforated casing joints **10**, **30**, **50**, **70** and plain casing collars, or pressure perforated casing joints **10**, **30**, **50**, **70** and pressure perforated casing collars **82**, in any combination, as will be described below in more detail with reference to FIGS. **9** and **10**.

[0040] FIG. **6** is a schematic cross sectional view of a groove **60** cut in the sidewall **56** of the casing joint **50** shown in FIG. **3**. The sidewall **56** has a thickness "A". The thickness "A" is dependent on the outside diameter and the grade of the casing joint. The groove **60** is cut to a depth that leaves sidewall bottom material **61** between the bottom of the groove and the inner wall of the casing joint **56**. The sidewall bottom material **61** has a thickness "B". The thickness "B" of the sidewall bottom material is computed using methods described below to rupture at a desired rupture pressure (yield strength). Fluid pressure within the casing sidewall that exceeds the rupture pressure causes the sidewall bottom material to burst, opening a slot through the casing sidewall **56**. Any material **62** surrounded by the groove **60** need not be removed. The material **62** may be machined to a point or a wedge to facilitate well cement perforation, as will be explained below with reference to FIGS. **5*e*** and **5*f***.

[0041] The thickness "B" may be calculated, for example, using a formula (Formula 1) described on page 16 and 17 of American Petroleum Institute Bulletin 5C3, Fifth Edition, July, 1989, incorporated herein by reference. The formula is:

$$P_y = 0.7854(D^2 - d^2)Y_p \quad \text{(Formula 1)}$$

[0042] where:

[0043] P_y=pipe body yield strength in pounds rounded to nearest 1000;

[0044] Y_p=Specified minimum yield strength for pipe, psi;

[0045] D=specified outside diameter, inches;

[0046] d=specified inside diameter, inches.

[0047] Table 1 shows examples of commonly used sizes and grades of well casing, and the sidewall bottom material thickness (SBT) for each to achieve a perforation rupture pressure of 4,000 psi (27,579 KPa) and 7,000 psi (48,263 KPa).

TABLE 1

Pipe Grade Lb/FT	Outside Diameter (inches)	Inside Diameter (inches)	Burst Pressure PSI	SBT (4,000 psi)	SBT (7,500 psi)
N80 11.60	4.5	4.0	7,778	0.122"	0.240"
P110 11.60	4.5	4.0	10,694	0.087"	0.169"

TABLE 1-continued

Pipe Grade Lb/FT	Outside Diameter (inches)	Inside Diameter (inches)	Burst Pressure PSI	SBT (4,000 psi)	SBT (7,500 psi)
N80 26.30	5.5	4.5	12,727	0.137"	0.270"
P110 26.30	5.5	4.5	17,500	0.098"	0.191"
4140 38.03	5.5	4.00	28,636	0.079"	0.154"

[0048] FIG. **7*a*** is a schematic cross sectional view of other grooves **40*a***, **40*b*** and **40*c*** cut in the sidewall **36** of the casing joint **30** described above with reference to FIG. **2**. As seen, the grooves may be V-shaped as shown at **40*a***, keystone shaped as shown at **40*b*** or U-shaped as shown at **40*c***. If the groove is U-shaped, the bottom of the U is used as the measure of the thickness "B" of the sidewall bottom material described above with reference to FIG. **6**. As understood by those skilled in the art, if the casing joints **10**, **30**, **50**, **70** or the casing collars **82** are to be run into high-temperature, high-pressure production zones where they will be subject to considerable hoop stress, U-shaped grooves or grooves without right angle cuts, i.e. cuts having corners with a radius, may be preferable. In general, square or U-shaped grooves are faster to cut as they require only one machining pass, and bits for generally square grooves can be ground at the corners to provide a radius to corners in the groove. However, the shape of the groove is not material to the practice of the invention provided that all grooves **20**, **40**, **60**, **80** are cut to the same, consistent depth so the sidewall bottom material always has about the same thickness for any particular diameter and grade of casing pipe, provided that excessive hoop stress is not a significant factor.

[0049] FIG. **7*b*** is a top plan view of one embodiment of a groove **20*a*** cut in the sidewall of a casing joint **10**, **30**, **50**, **70** or a casing collar in accordance with the invention. In this embodiment, a narrow groove **43** is cut in a substantially rectangular or obround pattern to leave a sidewall bottom material thickness, computed as described above with reference to Formula 1. A cross-wise groove **45** is then optionally cut to form two narrow columns **44*a***, **44*b*** of the sidewall material, as best visualized with reference to FIG. **7*c***, which is a longitudinal cross sectional view taken along lines **5*c*-5*c*** of the groove **20*a*** shown in FIG. **7*b***, and FIG. **7*d***, which is a cross sectional view taken along lines **5*d*-5*d*** of the groove **20*a*** shown in FIG. **7*b***. The narrow columns **44*a***, **44*b*** function to break up cement surrounding a casing **10**, **30**, **50** when the casing is pressure perforated and the groove **20*a*** ruptures under fracturing fluid pressure. In one embodiment the grooves **43**, **45** are filled with a coating compound **47** designed to protect the machined surfaces while the casing **10**, **30**, **50**, **70** is in storage and while it is being run into a recently drilled well bore. The coating compound also prevents the intrusion of cement into the grooves **20**, **40**, **60**, **80**, **20*a***, etc., and remains soft to facilitate rupture of the sidewall bottom material under fluid pressure. Such coating compounds are available, for example, from Masterbond, Hackensack, N.J., U.S.A.

[0050] FIG. **7*e*** is a top plan view of another embodiment **20*b*** of a groove cut in the sidewall of a casing joint **10**, **30**, **50**, **70** or casing collar **82** in accordance with the invention. The groove **20*b*** is similar to the groove **20*a*** described above with reference to FIGS. **5*b*-5*d***, except that the narrow columns are further machined to form pointed wedges **48***a*, **48***b*. The pointed wedges **48***a*, **48***b*, best seen in FIG. **7***f*, which is a cross sectional view taken along lines **5***f*-**5***f* of FIG. **7***e*. The pointed wedges **48***a*, **48***b* slice through well cement surrounding the casing joints **10**, **30**, **50**, **70** described above when the well casing is pressure perforated. In this embodiment the grooves **43**, **45** are likewise filled with a coating compound **47** designed to protect the machined surfaces while the casing **10**, **30**, **50**, **70** is in storage and while it is being run into a recently drilled well bore.

[0051] FIG. **8***a* is a schematic cross sectional view in longitudinal section of one of the grooves cut in the sidewall **16** of the casing joint **10** described above with reference to FIG. **1**, or the sidewall **85** of the casing collar **82** described above with reference to FIG. **5**. As will be understood by those skilled in the art, the groove **20** has been cut with a wheel-type slotting cutter well known in the art. Consequently, the ends **26** are concave, reflecting the diameter of the slotting cutter. This is one fast and convenient way of cutting the grooves **20**. The same type of tool can be used to cut the grooves **40** seen in FIG. **2**. In this embodiment, the casing joint is 4140 heat-treated steel casing pipe, having an outside diameter of 4.5" (11.43 cm) and the thickness "B" of the sidewall bottom material **28** of the groove **20** is about 0.15" (3.81 mm), which will rupture at about 7,500 psi (51,711 KPa) of fluid pressure, opening a slot through the sidewall **16** (see Table 1). In one embodiment, the groove **20** is filed with a coating compound **47** designed to protect the machined surfaces while the casing **10** is in storage and while it is being run into a recently drilled well bore.

[0052] FIG. **8***b* is a schematic cross sectional view in longitudinal section of the groove **20** shown in FIG. **8***a* after the casing has been pressure perforated to open a slot through the casing **10** sidewall **16** or collar **82** sidewall **85**, and fracturing has been completed in a formation **150** in which the casing **10** or collar **82** is cemented by cement slurry **148**. As seen, fragments **28***a* of the sidewall bottom material **28** (see FIG. **8**) of the casing **10** have been driven to varying degrees into the formation **150**. The coating compound and the hardened cement slurry **148** were disintegrated by the force of the impact when the casing **10** was pressure perforated, and ground into particles by the sand-laden fracturing fluid. Fractures **152** have propagated deeply into the formation **150** and filled with sand carried by the fracturing fluid, in a manner well known in the art. The ends of the groove **26***a*, **26***b* have been eroded to some extent by the fracturing fluid pumped into the formation **150**. The amount of erosion is dependent on the concentration of sand in the fracturing fluid, and other factors well understood in the art.

[0053] FIG. **9** is a schematic diagram of a casing string **90** assembled in accordance with the invention as it is inserted into a recently bored well bore. In this embodiment the casing string **90** is made up of plain casing joints (pc) connected end-to-end between one or more joints of pressure perforated casing joints **10**, **30**, **50**, **70**, or casing collars **82** (*pp*) made from the same size and grade of pipe. Plain casing collars that are part of the casing string **90** are not shown. The number of plain casing joints in each plain casing (pc) interval **92**, **96**, **100**, **104**, **108**, **112**, **116** is a matter of design choice dependent on formation properties and other factors. The number of plain casing joints in each plain casing (pc) interval is typically 1-3 plain casing joints. The number of pressure perforated casing joints in each pressure perforated casing (pp) interval **94**, **98**, **102**, **104**, **106**, **110**, **114** is typically 1, though any number of pressure perforated casing (pp) joints may be used. The number of pressure perforated casing collars **82** in each pressure perforated casing collar (pp) interval **94**, **98**, **102**, **104**, **106**, **110**, **114** is 1. The length of each pressure perforated casing joint (pp) is also a matter of design choice, as is the length of each pressure perforated casing collar. Each pressure perforated casing joint (pp) may be as short as 3' (0.91 m) or as long as 40' (12.19 m). Each pressure perforated casing collar (pp) is typically about 2'-3' (0.61-0.91 m). Each pressure perforated casing joint or casing collar (pp) may have grooves of any size, any shape, and any number of clusters, as a matter of design choice and operative constraints described above and understood in the art.

[0054] FIG. **10** is a schematic diagram of another casing string **120** in accordance with the invention. The casing collars required in the casing string **120** may be plain casing collars or pressure perforated casing collars **82**. The casing string **120** is entirely made up of the pressure perforated (pp) casing joints **10**, **30**, **50**, **70** and plain casing collars or pressure perforated (pp) casing collars **82** in accordance with the invention. Each pressure perforated casing joint (pp) in the casing string **120** may be a casing joint **10**, **30**, **50** or **70**, or any combination of same. In one embodiment all of the casing joints in the casing string **120** are the same but this is also a matter of design choice. The casing string **120** offers more flexibility in terms of locating fracture zones during well completion.

[0055] The explicit embodiments of the invention described above have been presented by way of example only. The scope of the invention is therefore intended to be limited solely by the scope of the appended claims.

1. (canceled)

2. The pressure perforated well casing joint as claimed in claim **4**, wherein the grooves are arranged in at least one cluster, a total area of the at least one cluster being less than a total area of the outer surface between the external threads on the first and second ends of the pipe.

3. (canceled)

4. A pressure perforated well casing joint, comprising:

a pipe having a sidewall with a first end, a second end, an inner surface, an outer surface and a burst pressure rating;

an external thread on each of the first and second ends adapted to threadedly engage a casing collar; and

a plurality of spaced apart grooves cut in the outer surface, each groove extending inwardly from the outer surface to an extent less than a thickness of the sidewall, so there remains sidewall bottom material in each groove and the grooves are cuts having ends that overlap;

whereby fluid pressure applied within the pressure perforated well casing will cause the sidewall bottom material in the grooves to rupture before the burst pressure rating of the pipe is reached, thereby opening a slot through the sidewall at each of the plurality of grooves subjected to the fluid pressure.

5. The pressure perforated well casing joint as claimed in claim **4**, wherein the grooves surround a narrow column of sidewall material designed to facilitate cement penetration when the sidewall bottom material in the grooves rupture.

6. The pressure perforated well casing joint as claimed in claim **4**, wherein the grooves are filled with a coating material to protect machined surfaces while the casing joint is in storage and while the casing joint is being run into a recently drilled well bore.

7. The pressure perforated well casing joint as claimed in claim **4**, wherein the grooves are grouped in at least two spaced apart clusters between the external thread on the respective first and second ends.

8. The pressure perforated well casing joint as claimed in claim **4**, wherein the grooves are grouped in three equally spaced apart clusters between the external thread on the respective first and second ends.

9. The pressure perforated well casing joint as claimed in claim **4**, further comprising a groove cut on the inside surface of each of the respective first and second ends to positively identify the perforated well casing joint in a well casing string comprising perforated well casing joints and plain casing joints connected together.

10. A pressure perforated well casing collar, comprising:

a pipe having a sidewall with a first end, a second end, an inner surface, an outer surface and a burst pressure rating;

an internal thread on each of the first and second ends adapted to threadedly engage an external thread on a casing joint;

a plurality of spaced apart grooves respectively having overlapping ends cut in the outer surface, each groove extending inwardly from the outer surface to an extent less than a thickness of the sidewall, so there remains sidewall bottom material in each groove;

whereby fluid pressure applied within the pressure perforated well casing collar will cause the sidewall bottom material in the grooves to rupture before the burst pressure rating of the casing collar is reached, thereby opening a slot through the sidewall at each of the plurality of grooves.

11. The pressure perforated well casing collar as claimed in claim **10**, wherein the plurality of grooves are filled with a coating material to protect machined surfaces while the casing collar is in storage and while a casing string including the casing collar is being run into a recently drilled well bore.

12. (canceled)

13. The pressure perforated well casing system as claimed in claim **16** further comprising an interval on an outer surface of the well casing joint or the well casing collar without grooves.

14. The pressure perforated well casing system as claimed in claim **16** wherein the well casing joint comprises at least two clusters of grooves, each cluster of grooves being separated from the ends of the well casing joint and any other cluster of grooves by an outer surface of the well casing joint without grooves.

15. (canceled)

16. A pressure perforated well casing system, comprising:

a well casing joint and a well casing collar respectively having a plurality of spaced apart if grooves cut in an outer surface thereof, the grooves being cut to an equal depth in the outer surface, each groove having sidewall bottom material remaining in a bottom of the groove the respective grooves having ends that overlap;

whereby sufficient fluid pressure applied to the grooves cause the sidewall bottom material in the respective grooves to rupture before a burst pressure rating of the well casing joint or the well casing collar is reached, thereby opening slots through the sidewalls at each of the respective grooves under sufficient fluid pressure.

17. The pressure perforated well casing system as claimed in claim **16** wherein the grooves respectively surround a sidewall material designed to facilitate cement penetration when the sidewall bottom material in the grooves rupture.

18. The pressure perforated well casing system as claimed in claim **16**, wherein the grooves are filled with a coating material to protect machined surfaces while the casing joint or the casing collar is in storage and while the casing joint or the casing collar is in a casing string being run into a recently drilled well bore.

19. A well casing string comprising the pressure perforated well casing joints claimed in claim **16**.

20. A well casing string comprising the pressure perforated well casing collars claimed in claim **16**.

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