US012385352B2

(12) United States Patent
McWilliam

(10) Patent No.: US 12,385,352 B2
(45) Date of Patent: Aug. 12, 2025

(54) **ANNULUS REMEDIATION SYSTEM AND METHOD**

(71) Applicant: **HRG WELL SOLUTIONS LIMITED**, Aberdeenshire (GB)

(72) Inventor: **Gary McWilliam**, Aberdeenshire (GB)

(73) Assignee: **HRG WELL SOLUTIONS LIMITED**, Aberdeenshire (GB)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **18/255,074**

(22) PCT Filed: **Dec. 3, 2021**

(86) PCT No.: **PCT/GB2021/053170**
§ 371 (c)(1),
(2) Date: **May 30, 2023**

(87) PCT Pub. No.: **WO2022/118038**
PCT Pub. Date: **Jun. 9, 2022**

(65) **Prior Publication Data**

US 2024/0035354 A1 Feb. 1, 2024

(30) **Foreign Application Priority Data**

Dec. 4, 2020 (GB) 2019133

(51) **Int. Cl.**
E21B 33/13 (2006.01)
E21B 34/10 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***E21B 33/13*** (2013.01); ***E21B 34/10*** (2013.01); ***E21B 37/00*** (2013.01); ***E21B 43/112*** (2013.01)

(58) **Field of Classification Search**
CPC E21B 33/13; E21B 34/10; E21B 37/00; E21B 43/112; E21B 43/114
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

1,789,993 A *	1/1931	Switzer	....	E21B 29/00 166/55.3
9,334,712 B2	5/2016	Bakken		

(Continued)

FOREIGN PATENT DOCUMENTS

CN	11255381 A	6/2020
GB	2 499 172 A	8/2013

(Continued)

OTHER PUBLICATIONS

Holte Casing Cutter tool, Extract from The Wayback Machine https://web.archive.org/web/20101122024804/http://drilling.com/?q=node/83.

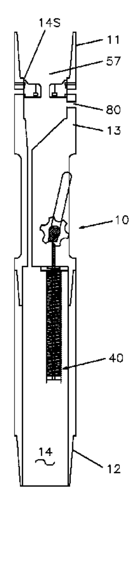
(Continued)

Primary Examiner — Nicole Coy
Assistant Examiner — Nicholas D Wlodarski
(74) *Attorney, Agent, or Firm* — Foley & Lardner LLP

(57) **ABSTRACT**

A BHA to be run into a wellbore to be plugged and abandoned comprises a slotting tool which further comprises an outer body having a throughbore and connections to permit the outer body to be included in the BHA and in a work string having a throughbore for sealed fluid communication with the throughbore of the outer body. A slotting blade is radially moveable towards and away from an inner surface of the wellbore to be slotted, and an activation mechanism is adapted to move the slotting blade between: a running in hole configuration in which the slotting blade is relatively retracted; and an activated configuration in which the slotting blade is extended and in use is capable of creating at least one slot in the inner surface of the wellbore such as the casing at a location in the wellbore to be plugged and abandoned.

37 Claims, 19 Drawing Sheets



(51) **Int. Cl.**

E21B 37/00	(2006.01)
E21B 43/112	(2006.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

2009/0071640	A1 *	3/2009	Ivanov	E21B 43/112 166/55.2
2015/0053405	A1	2/2015	Bakken	
2016/0194934	A1	7/2016	Bakken	
2016/0258257	A1 *	9/2016	Babin	E21B 29/005
2017/0030157	A1 *	2/2017	Hansen	E21B 34/08

FOREIGN PATENT DOCUMENTS

GB	2 502 504	A	11/2013	
GB	2 603 937	A	8/2022	
WO	WO-2019097259	A1 *	5/2019	E21B 17/22

OTHER PUBLICATIONS

Holte Perforators Sub-Nav, Extract from The Wayback Machine https://web.archive.org/web/20101122023401/http://drilling.com/?q=node/82.

GB Combined Search and Examination Report issued for GB App No. 2117504.7 dated May 23, 2022 (3 pages).

Notification of Grant issued for GB App No. 2117504.7 dated Feb. 7, 2023 (2 pages).

International Preliminary Report on Patentability for PCT App. PCT/GB2021/053170 dated May 30, 2023 (7 pages).

International Search Report and Written Opinion on PCT App. PCT/GB2021/053170 dated Jan. 18, 2022 (7 pages).

* cited by examiner

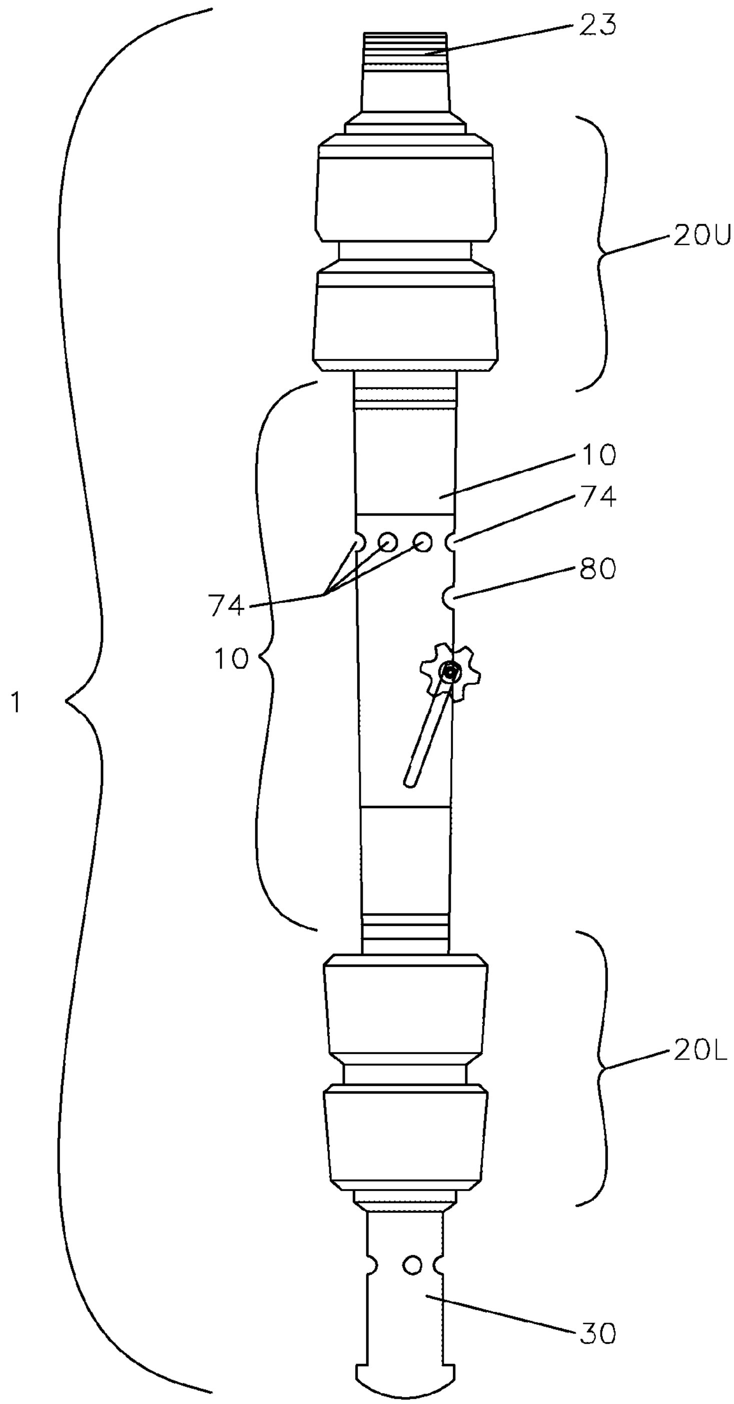


Figure 1

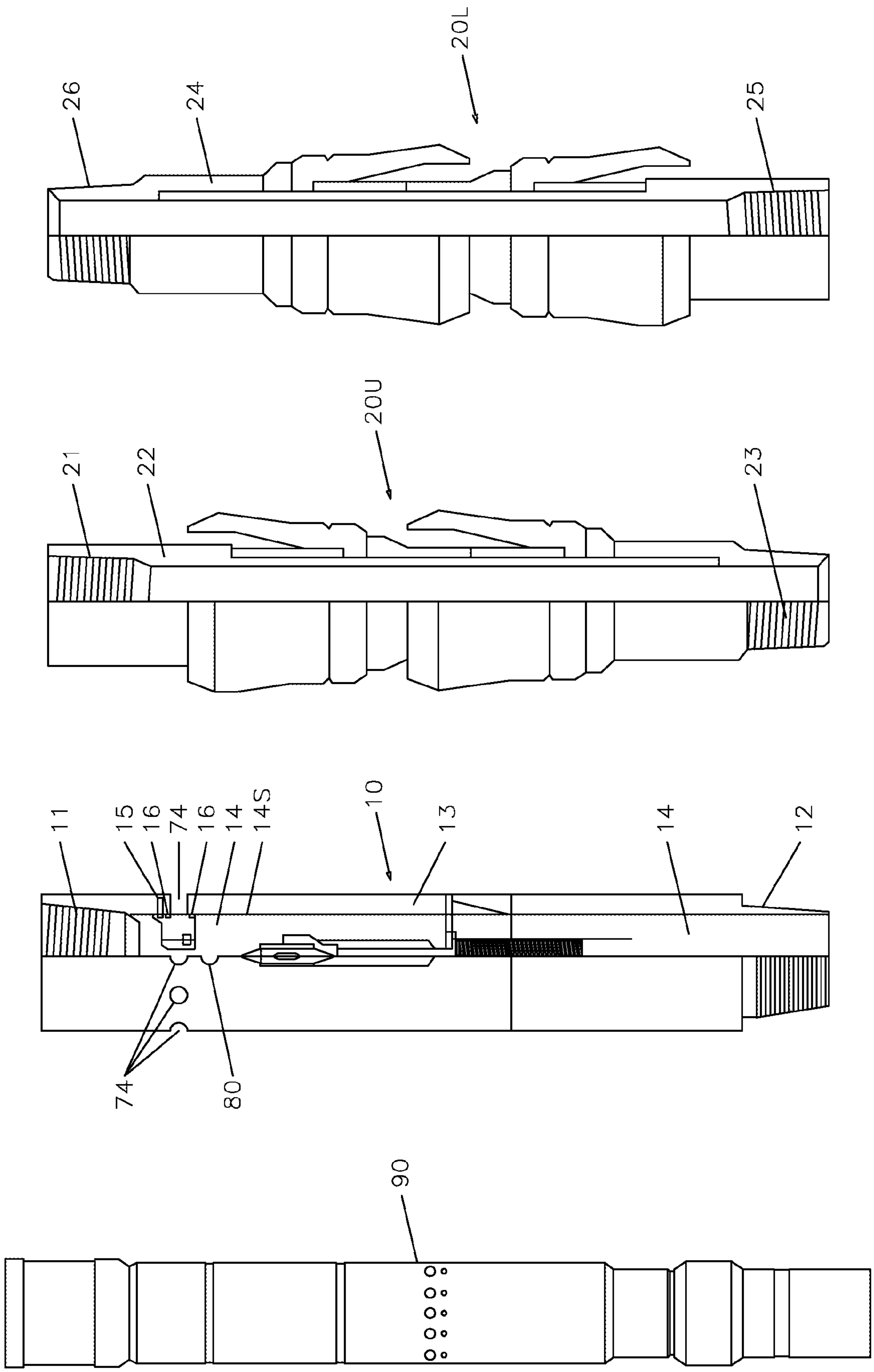


Figure 2(d)

Figure 2(c)

Figure 2(b)

Figure 2(a)

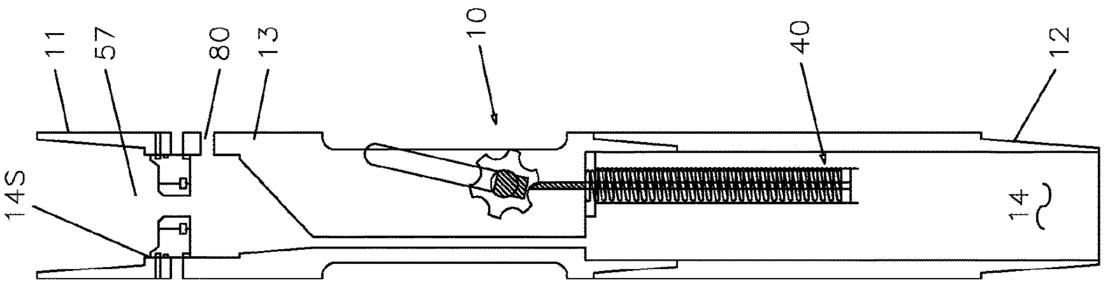


Figure 3(b)

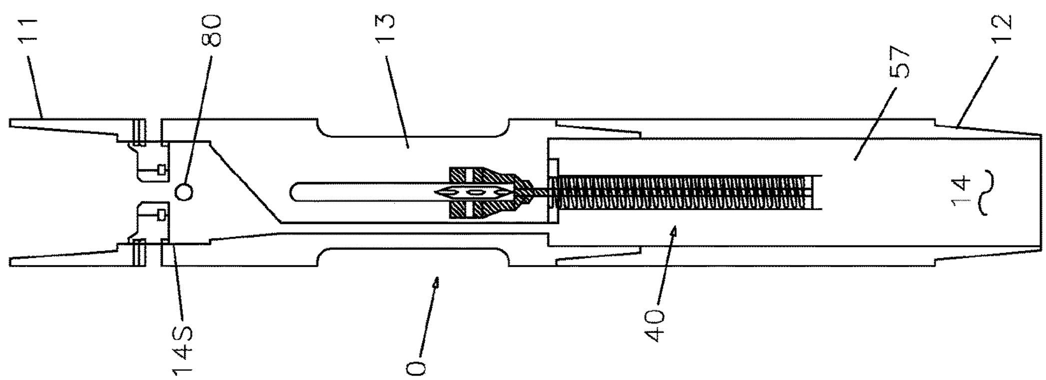


Figure 3(a)

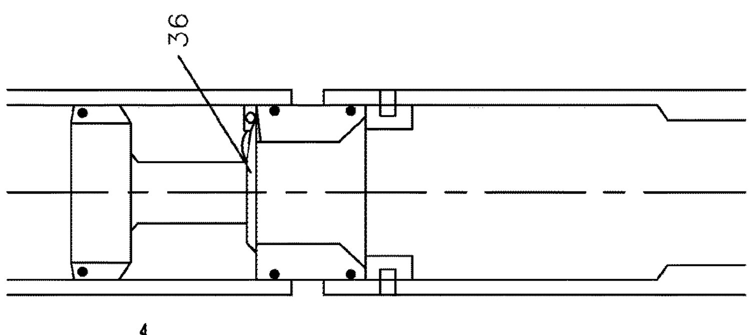


Figure 2(f)

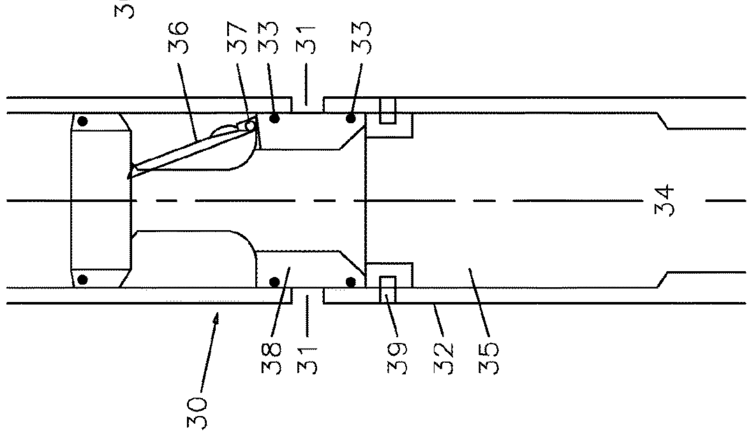


Figure 2(e)

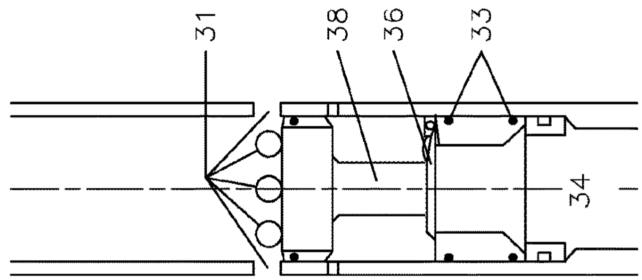


Figure 5

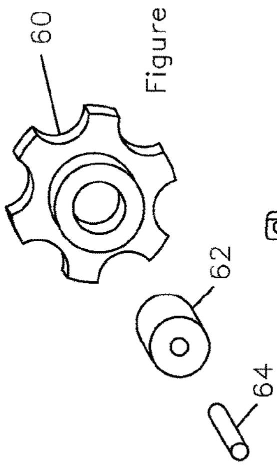


Figure 4(e)

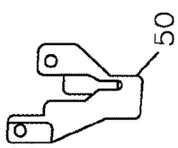


Figure 4(d)

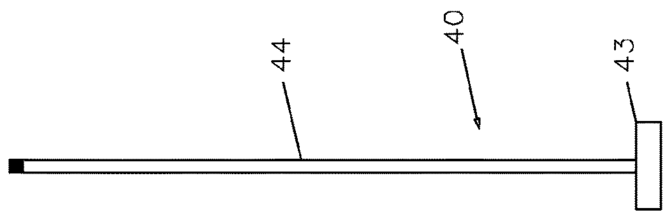


Figure 4(c)

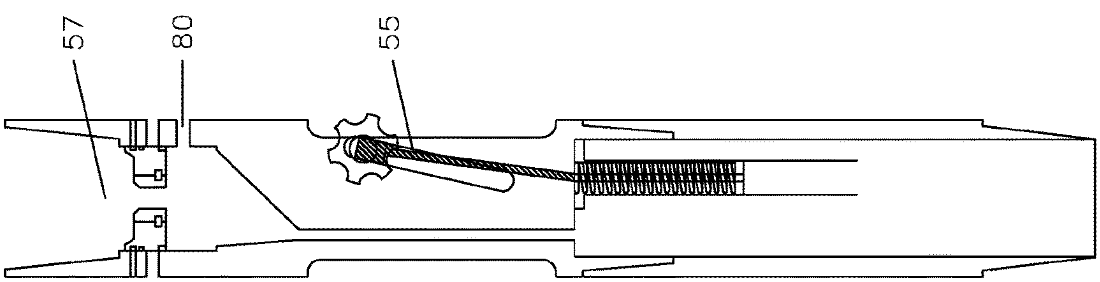


Figure 4(b)

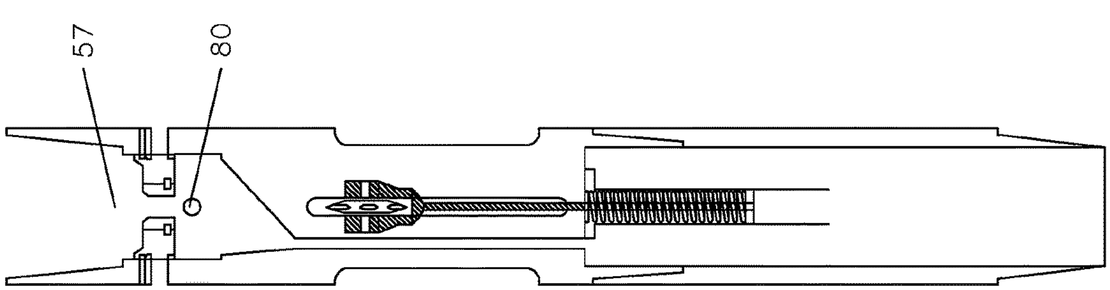


Figure 4(a)

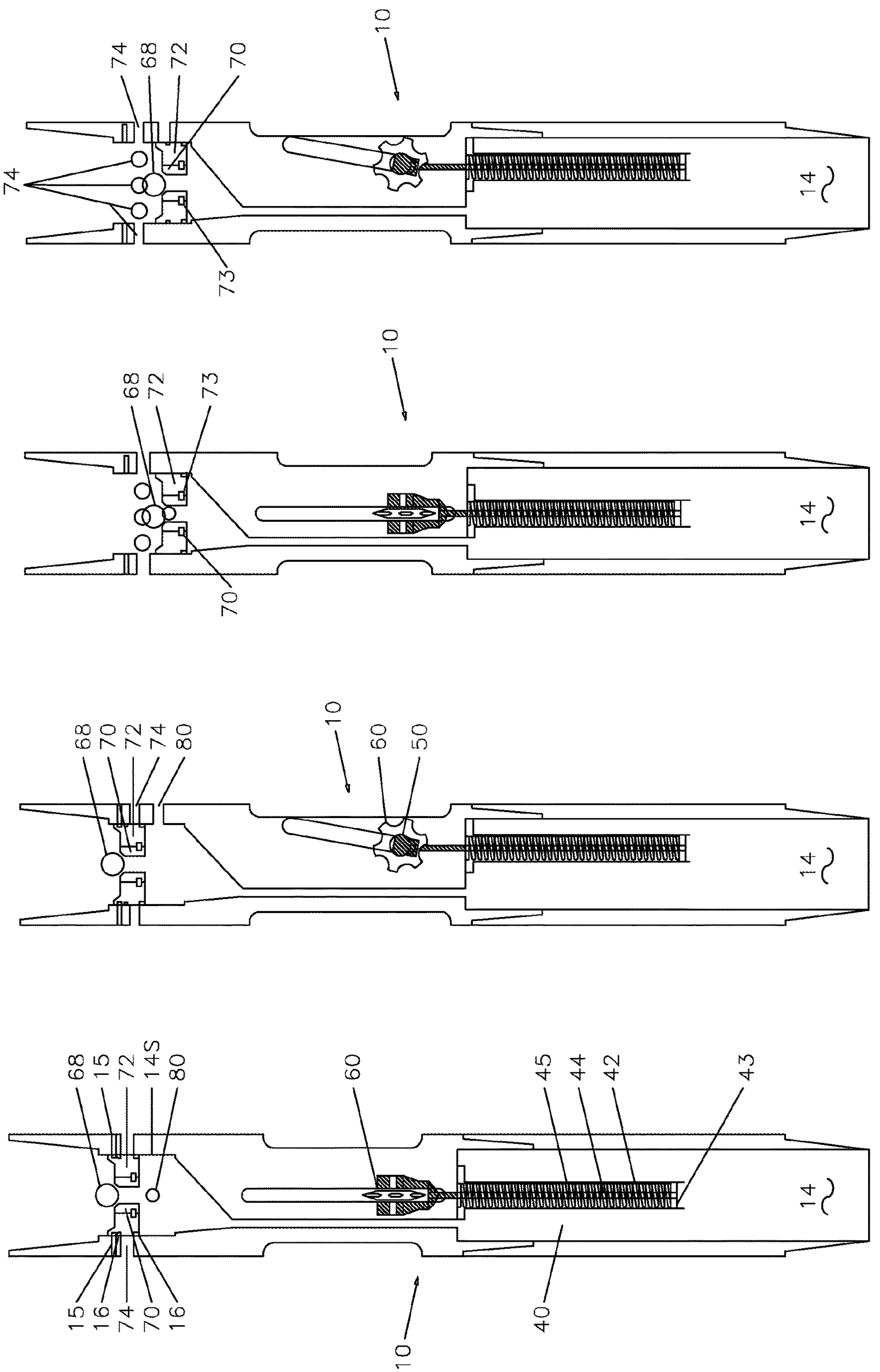


Figure 6(a)

Figure 6(b)

Figure 7(a)

Figure 7(b)

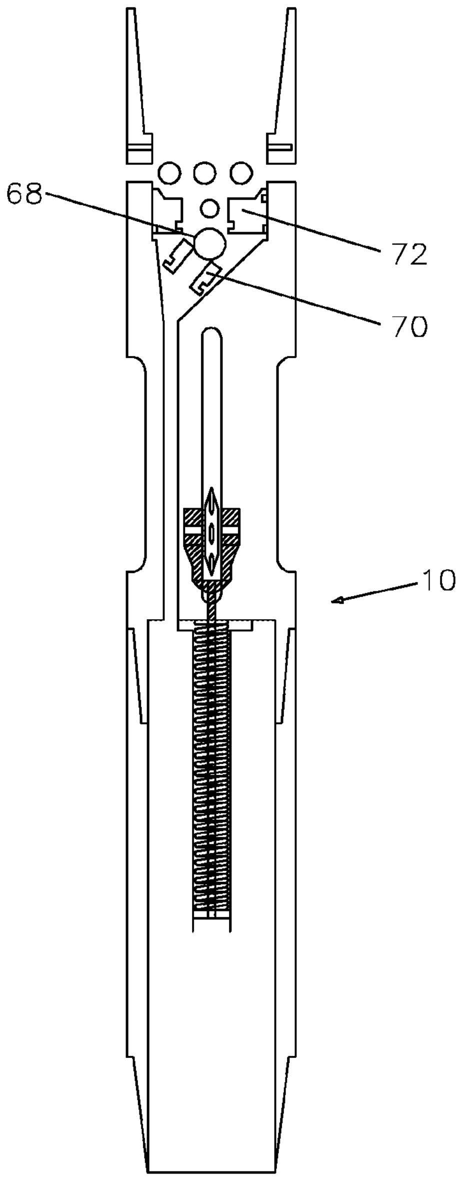


Figure 8(a)

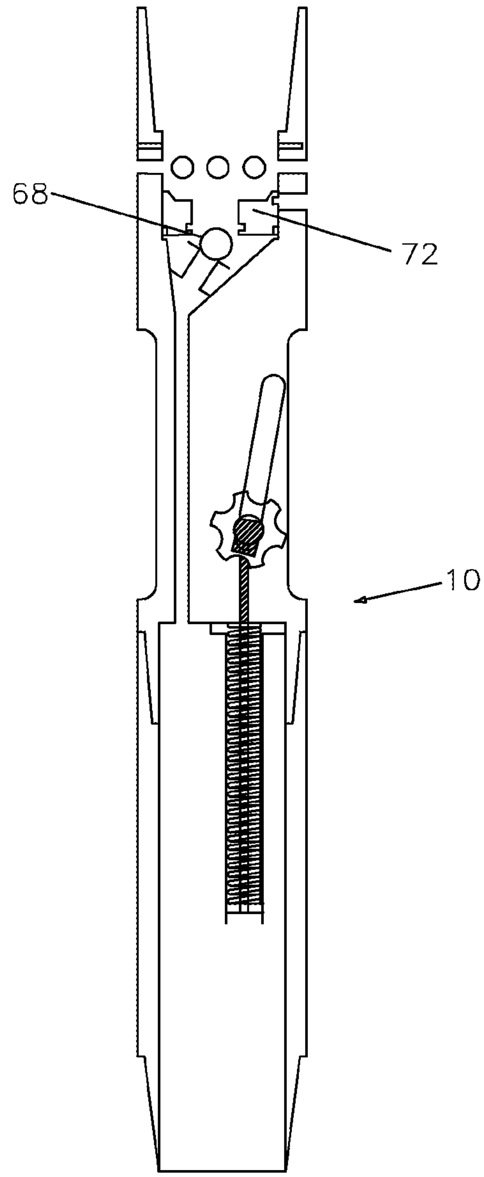


Figure 8(b)

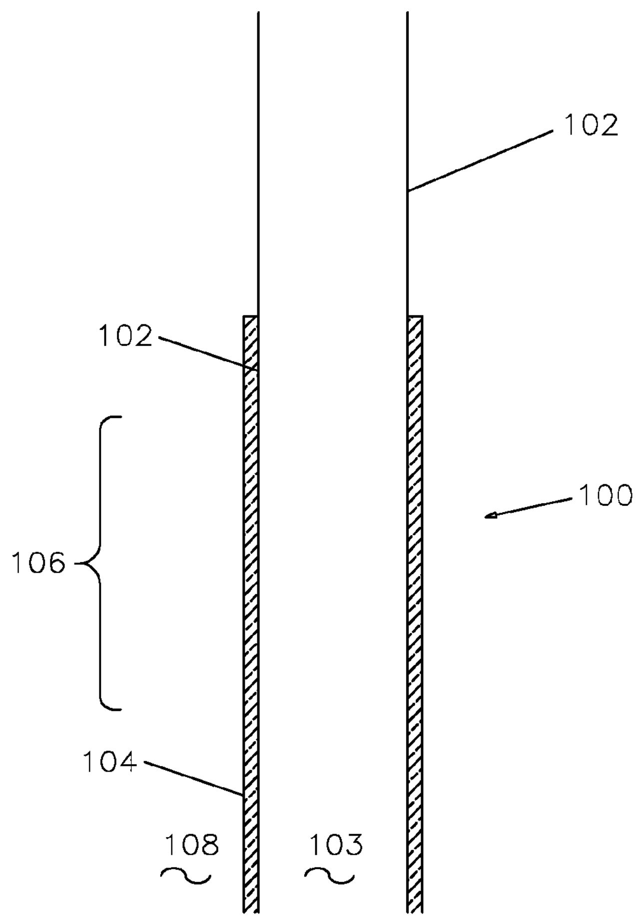


Figure 9

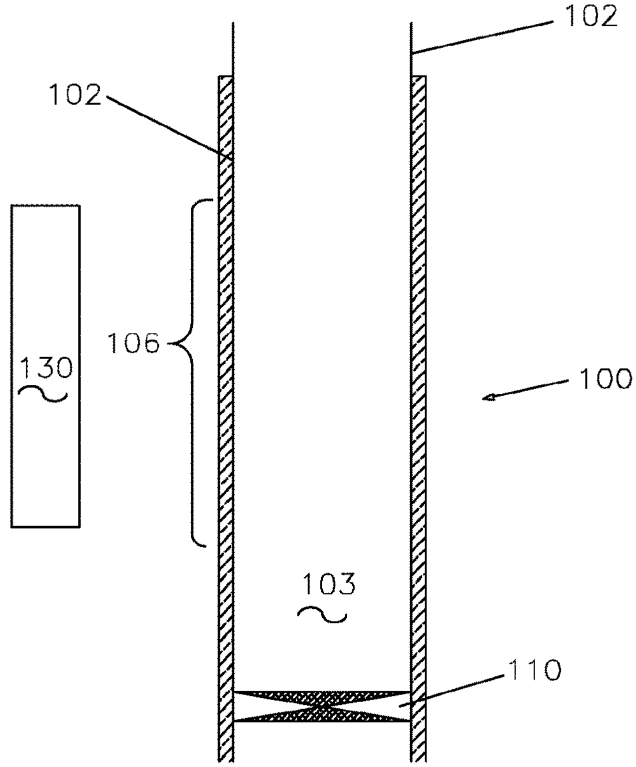


Figure 10

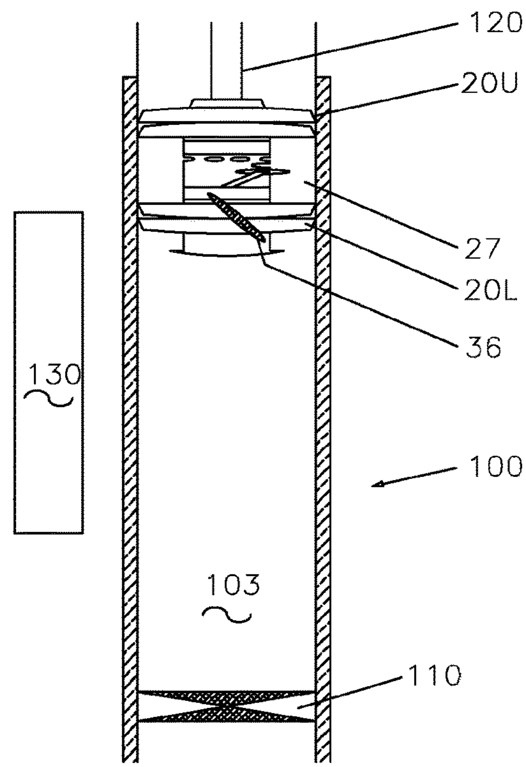


Figure 11

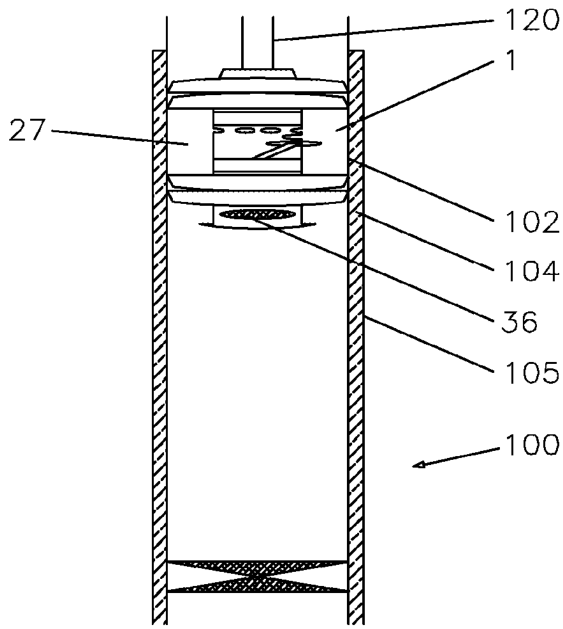


Figure 12

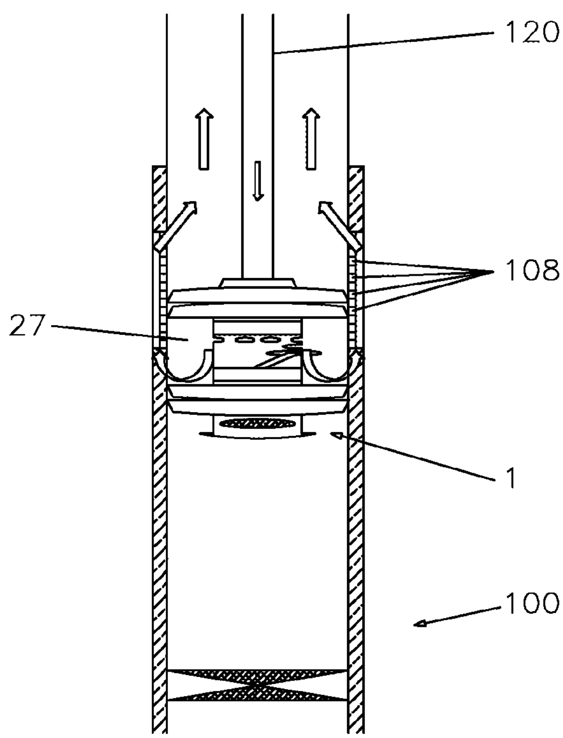


Figure 13

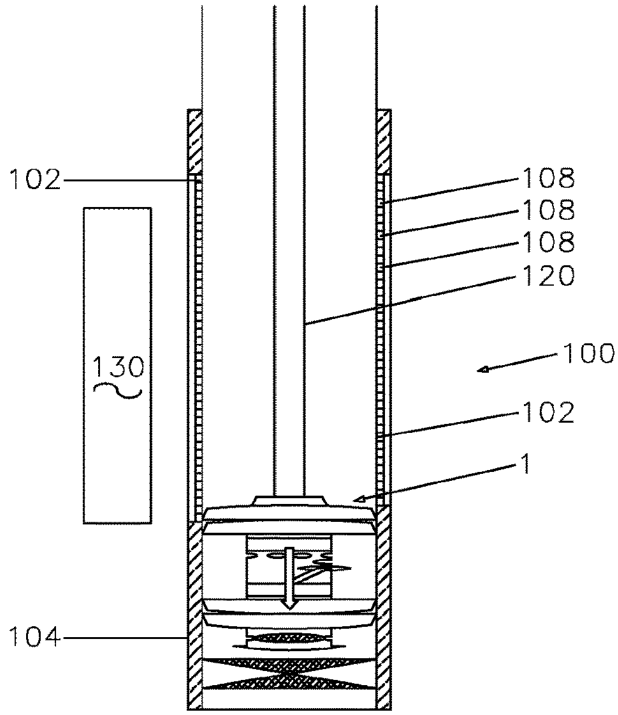


Figure 14

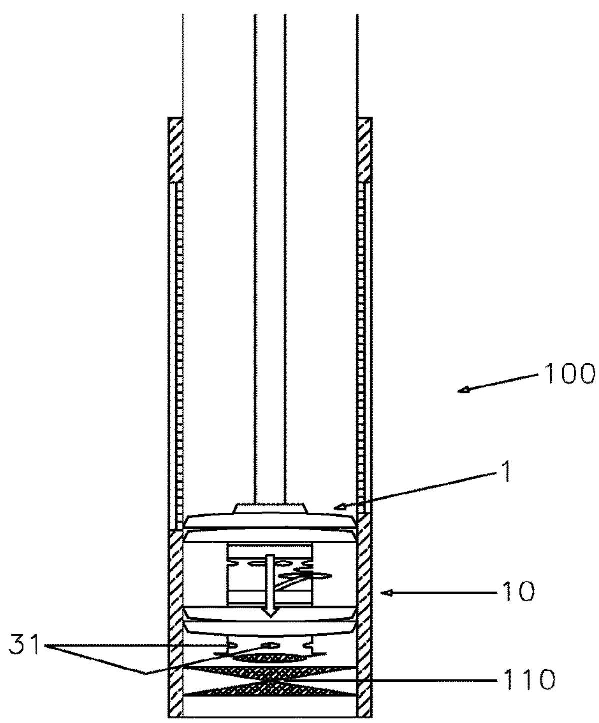


Figure 15

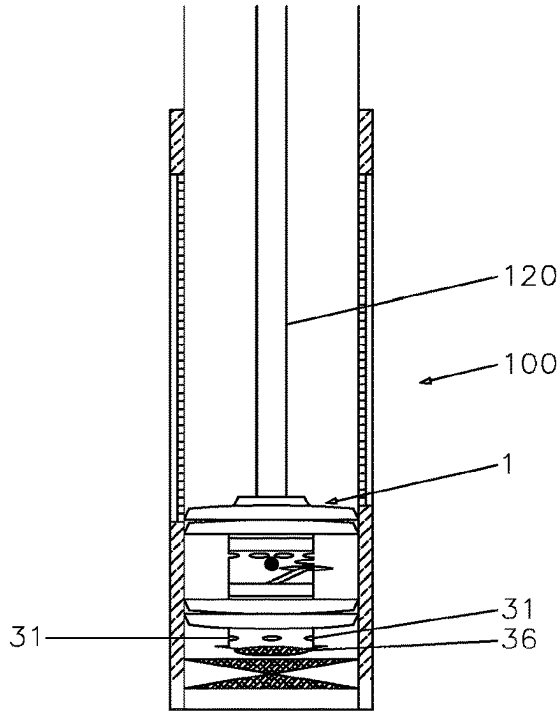


Figure 16

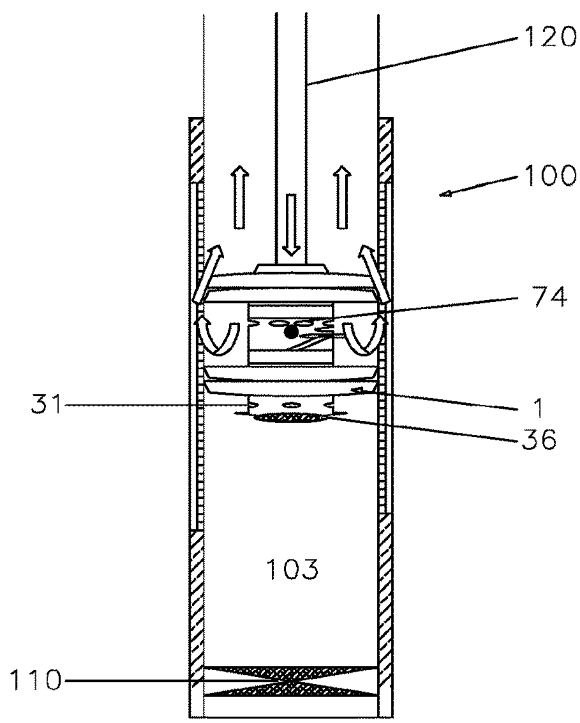


Figure 17

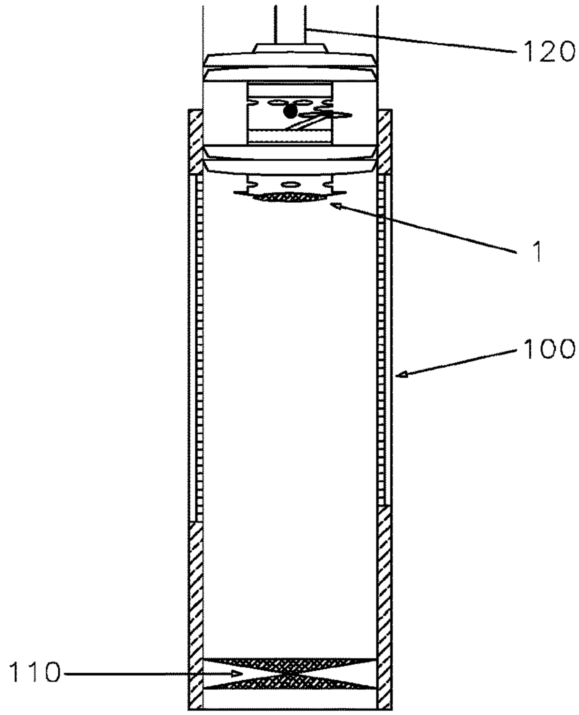


Figure 18

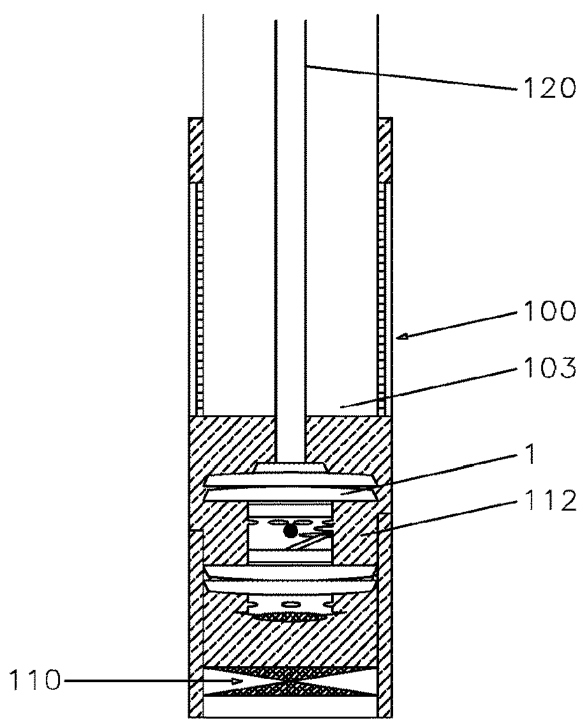


Figure 19

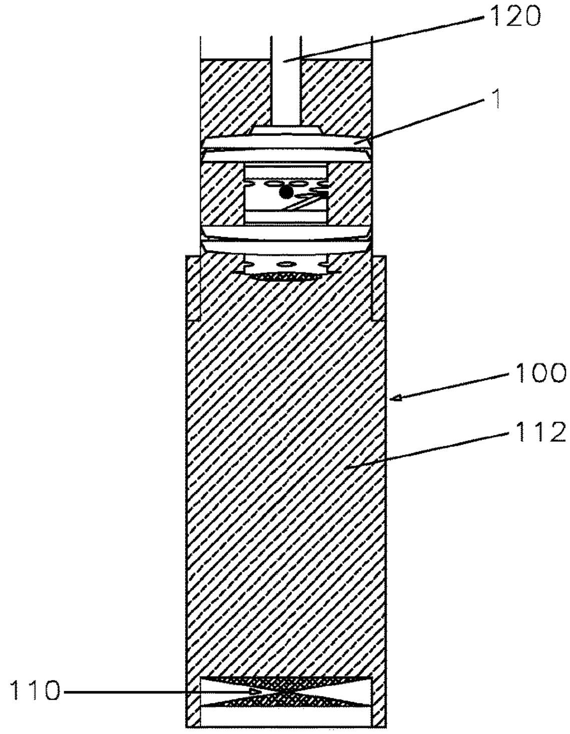


Figure 20

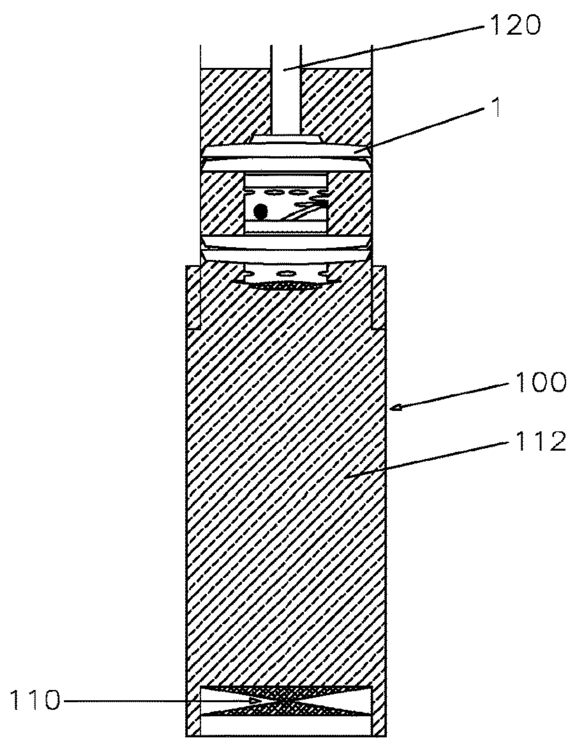


Figure 21

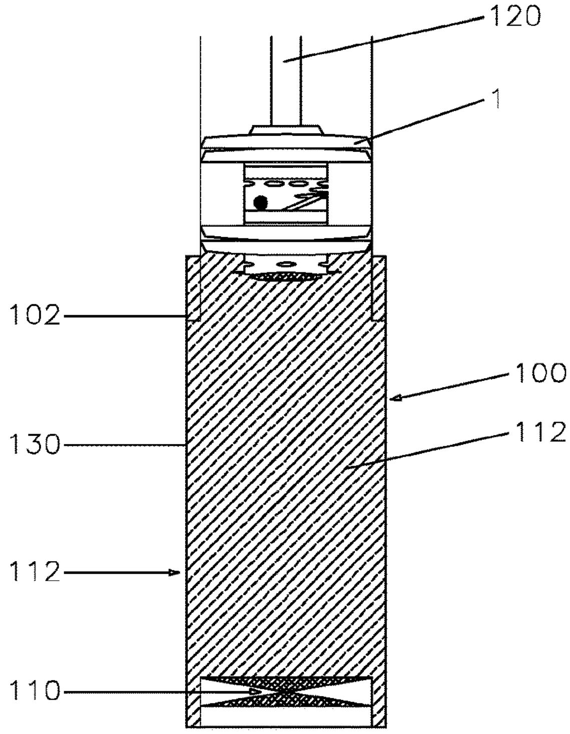


Figure 22

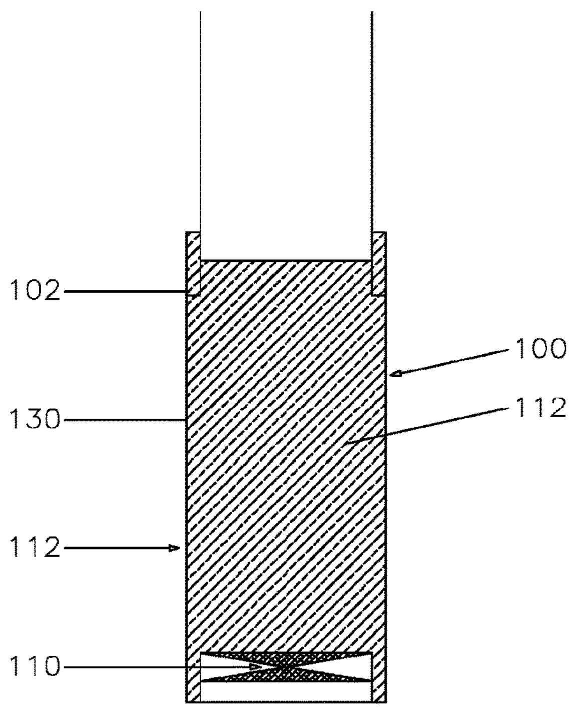


Figure 23

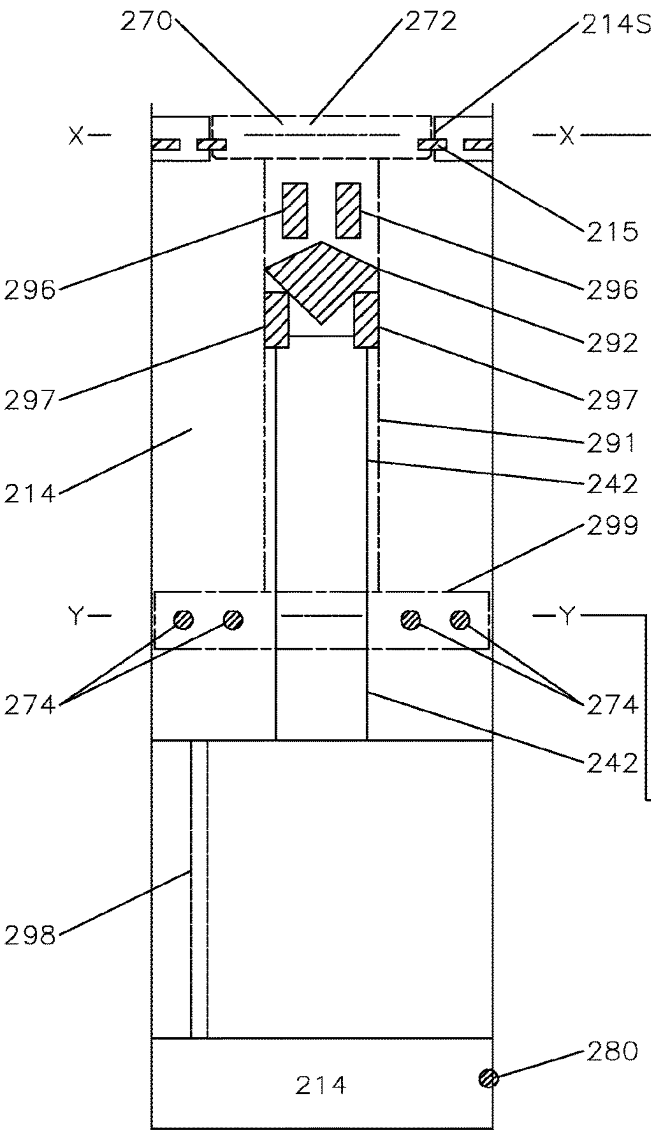


Figure 24(a)

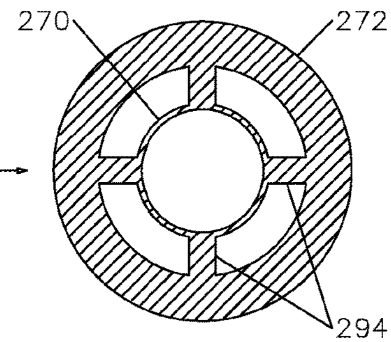


Figure 25

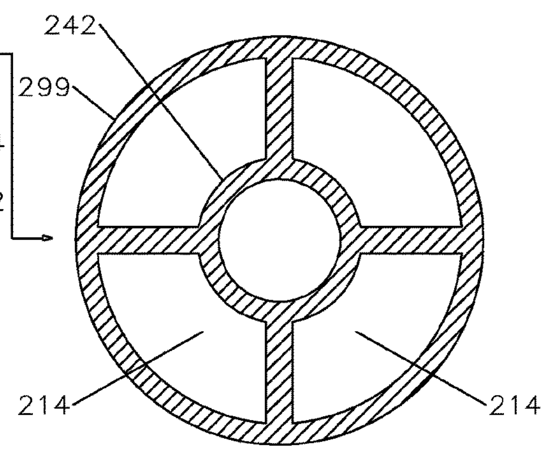


Figure 26

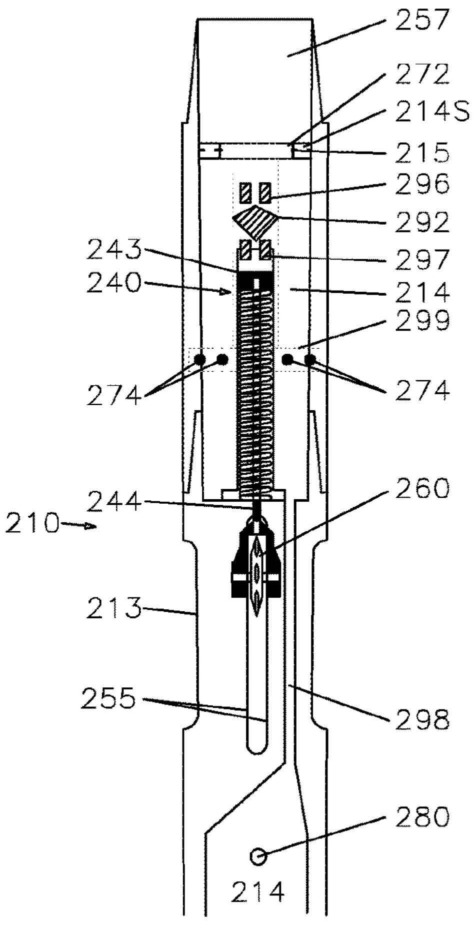


Figure 24(b)

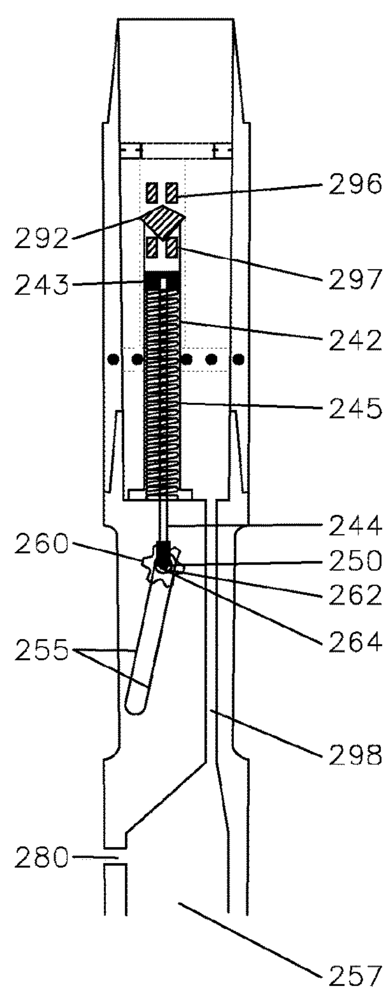


Figure 24(c)

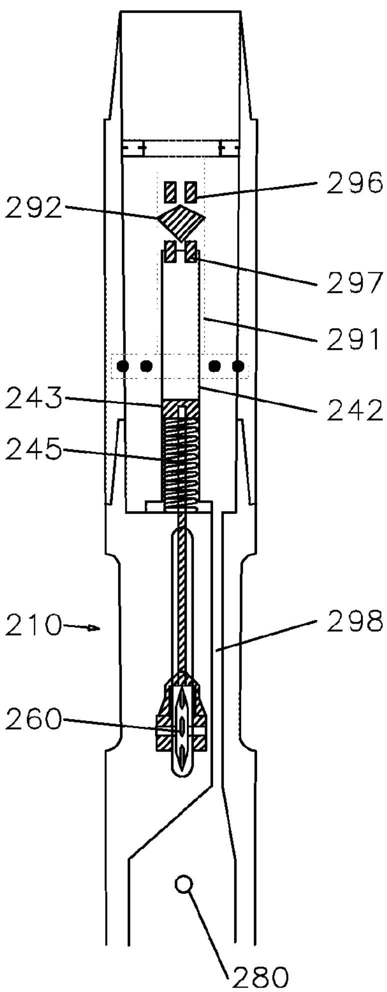


Figure 27(a)

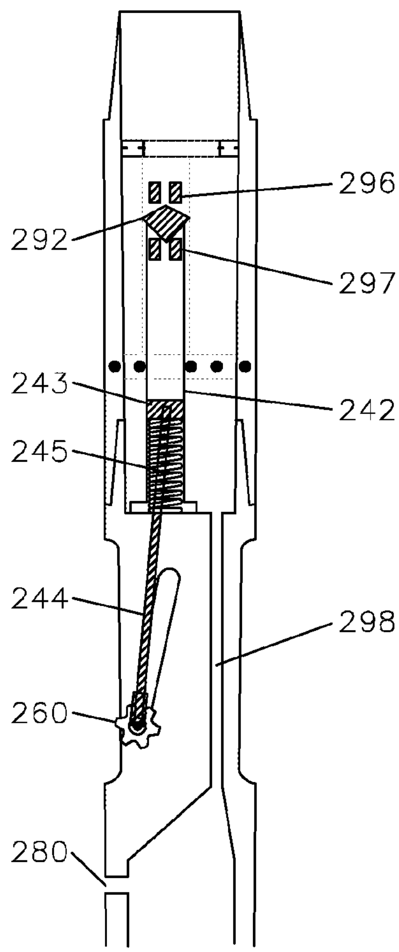


Figure 27(b)

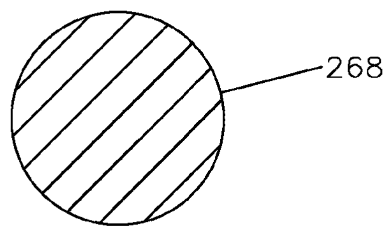


Figure 28

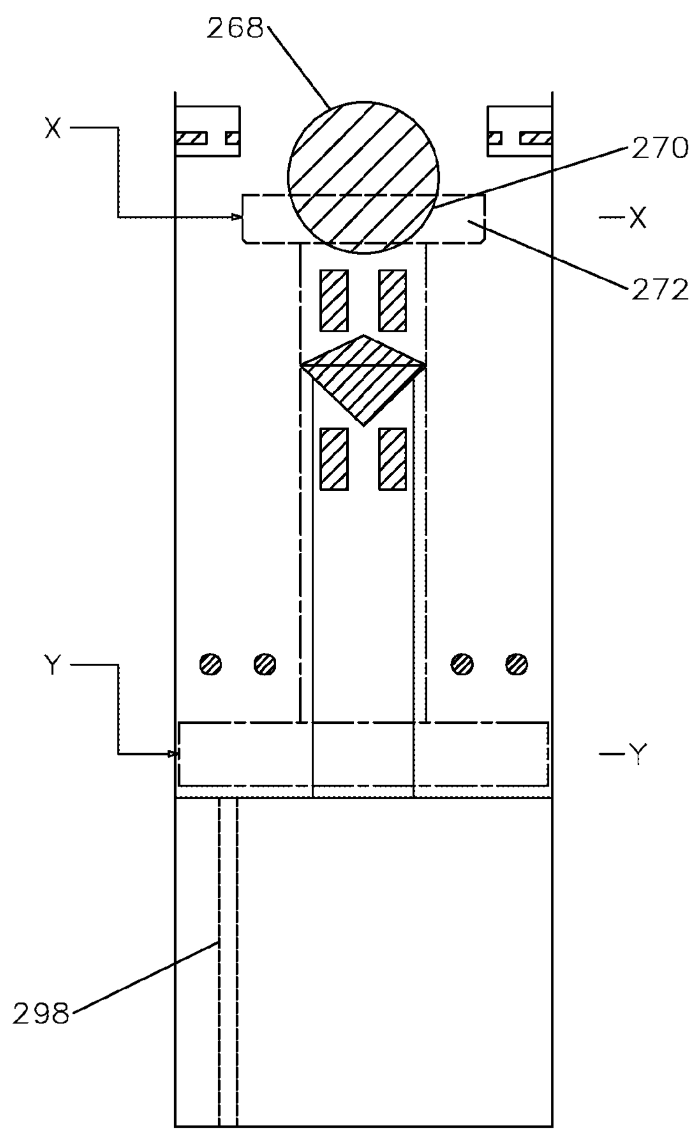


Figure 29(a)

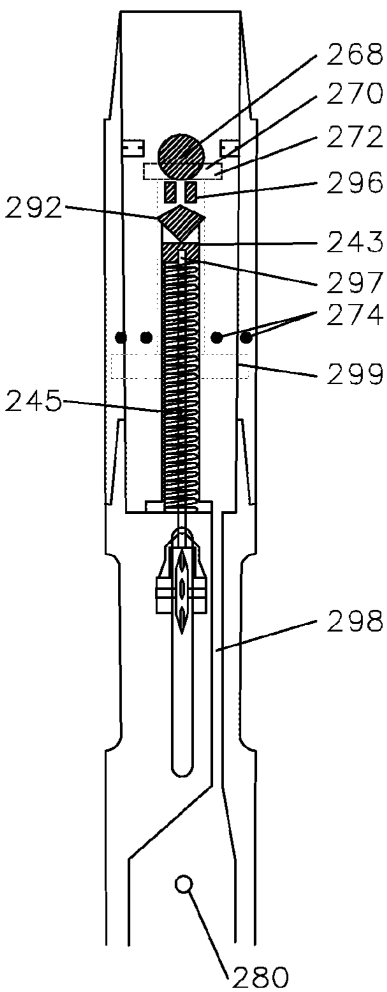


Figure 29(b)

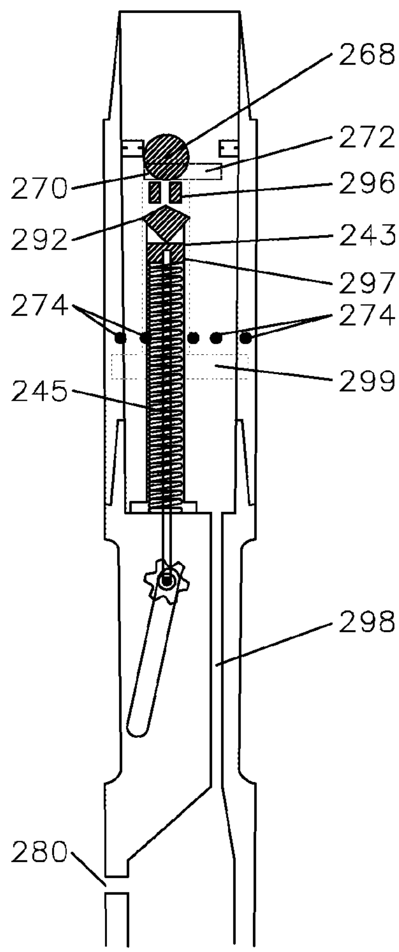


Figure 29(c)

ANNULUS REMEDIATION SYSTEM AND METHOD

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of priority to International Application No. PCT/GB2021/053170, filed on Dec. 3, 2021, which claims the benefit of Great Britain Patent Application No. 2019133.4, filed Dec. 4, 2020, all of which are hereby incorporated by reference in their entirety.

TECHNICAL FIELD OF THE INVENTION

The present invention relates to an annulus remediation system deployed into a wellbore and which can be used to place a lateral barrier (i.e. rock to rock) and in particular place isolation material such as a cement plug in a wellbore that is to be plugged with the intention of abandoning the wellbore. In particular the present invention allows a one trip annulus remediation system that may be deployed on a suitable string such as a drill pipe string and which allows placement of a lateral barrier without having to pull or section mill the casing or liner string and even more advantageously obviates the need for perforation guns.

In very broad summary, the present invention also relates to a novel method of slotting, whilst preferably jetting and isolating a wellbore during a plug and abandonment operation and which preferentially avoids and/or obviates the need for the use and actuation of perforating guns.

BACKGROUND OF THE INVENTION

When an oil and gas well has come to the end of its life, it is conventionally required to plug and abandon the well in order to make it safe and in so doing to ensure that the risk of any hydrocarbon leaking from the remnants of the well into the outer environment is minimised or completely prevented.

There are several conventional techniques known to be used to plug an abandoned well but one of the most commonly used involves the use of perforating guns in order to break through the casing/liner string that lines the wellbore and the perforations in the casing/liner string then allow pressurised cleaning or washing fluid to be pumped through the perforations in order to wash out the cement that is in the outer annulus behind the casing/liner string (i.e. in the annulus located between the outer surface of the casing/liner string and the inner surface of the borehole that was drilled when creating the wellbore) such that a new section of cement can be pumped down the well, through the perforations and into the annulus behind the casing/liner in order to provide a new cement barrier or similar material. The reason this is required is that it may be many years or many decades since the borehole was originally drilled and thus since the original cement job was performed and thus the cement job in the interim period may have been degregated such that unless it is replaced, the well will not be properly abandoned.

The conventional method of remediating the annulus behind the casing/liner string is as follows:—

Prior Art—Stage 1

A relatively long length of perforation guns, which may be in the region of 200 feet long, is run into the wellbore on the lower end of a drill pipe string, where a plug is located

in the drill string just above the perforation guns and a pair of cups are located the drill string just above the plug. The perforating guns are run into the wellbore into the region of the wellbore which has the casing/liner string to be perforated.

Prior Art—Stage 2

The perforation guns are then activated to perforate the casing/lining string.

Prior Art—Stage 3

The perforating guns are dropped down the well by releasing them from the bottom end of the drill pipe string. Accordingly, with this prior art method, the operator requires an additional section, for example 200 feet, of the wellbore below the perforated section in order to drop the perforating guns into it and that is one disadvantage of this prior art system.

Prior Art—Stage 4

Next, the plug and hence drill pipe string is moved down approximately 200 feet in order that the plug is in line with the casing/lining string just below the perforation holes.

Prior Art—Stage 5

The plug at the now lower end of the drill pipe string is then activated in order to plug the casing/lining string throughbore just below the perforation holes.

Prior Art—Stage 6

Then, the operator pumps down cleaning/washing fluid through the throughbore of the drill pipe string (or coiled tubing string if the perforation guns/plug/cups have been run in on coiled tubing instead of a drill string) and the cleaning fluid exits the drill string through holes that are provided in the drill pipe in between the pair of cups such that the pair of cups are energised in order to seal against the inside of the casing. Thus, the fluid exits through the perforation holes in the casing/lining string and washes out the broken up cement and perforation gun debris, etc. and pumps it up to the surface firstly up the outer annulus behind the casing/liner string and then, once the cups have been moved downwards into for example the middle of the area that has been perforated, the cleaning fluid can flow back into the throughbore of the casing/lining string such that it passes up the inner annulus (i.e. between the outer circumference of the coiled tubing/drill pipe string and the inner surface of the casing/lining string), such that the washing/cleaning fluid lifts the broken up cement and other debris up to the surface.

Prior Art—Stage 7

The drill pipe/coiled tubing string is then lifted and lowered in turn up and down the 200 feet of perforation holes in the casing/lining string and over time (e.g. a few or several hours), the operator will know if the cement in the outer annulus behind the casing has been cleaned out because there will be no more pressure spikes occurring as observed by the operator at the surface of the well. As background, when the cleaning process is first started (i.e. Stage 6 as described above), the operator will see pressure spikes in the pressure of the cleaning/washing fluid as pumped down the drilling string throughbore because the fluid can't pass around the various blockages caused by the cement debris. However, once the blockages begin to be and are fully cleaned out, there will be no more blockages and therefore no more pressure spikes.

The operator can then stop pumping the cleaning fluid down the throughbore of the coiled tubing/drill pipe string.

Prior Art—Stage 8

The operator will then pump down isolation material such as cement (instead of cleaning fluid) through the throughbore of the drill string/coiled tubing string and the isolation material will exit the drill pipe/coiled tubing string through the holes positioned in between the pair of cups, such that the isolation material will then flow out through the perforation holes that were formed through the casing/lining string and into the outer annulus. Accordingly, a new cap rock will be installed in the outer annulus behind the casing/lining string by virtue of the new isolation material such as cement having been installed.

Prior Art—Stage 9

The isolation material such as cement will continue to be pumped out through the holes positioned in between the pair of cups and then out through the perforation holes and the drill pipe/coiled tubing string will be pulled upwards slowly in one run so that the isolation material starts to be pumped out from the very bottom of the well at the location where the lower most perforation holes were formed but importantly the plug that was installed below the perforation holes is left in place such that the isolation will also fill up the throughbore of the casing/lining string as well as filling up the outer annulus behind the casing/lining string that was washed out. Accordingly, a long isolation material/cement plug that is greater in height than just the perforation holes will be formed so that the perforation holes and the outer annulus behind the perforation holes is completely filled in with the new isolation material/cement.

Prior Art—Stage 10

The drill pipe/coiled tubing string is pulled out of the wellbore and the new isolation material such as cement will then harden over time in order to provide placement of the new lateral barrier (rock to rock).

Such prior art systems are offered by Archer Oil Tools AS and also Hydra Systems AS, and are described in more detail in the following patents:—

US Patent Publication No US2016/0194934—Archer Oil Tools AS

U.S. Pat. No. 9,334,712—Archer Oil Tools AS

UK Patent No 2499172—Hydra Systems AS

UK Patent No 2502504—Hydra Systems AS

Such prior art systems that use perforation guns have the significant disadvantage that the perforation guns are by their very nature inherently dangerous due to the explosive material they contain and therefore they require a considerable number of personnel to operate them (typically five or six per rig). Accordingly, not only are they inherently dangerous and require to be surrounded by many safety systems but they are also very expensive to run and operate. In addition, the prior art methods involving perforation guns produce perforation gun gas just after detonation which needs to be circulated out of the hole to surface and which is typically vented to the atmosphere which is detrimental to the environment and also incurs significant additional time because the gas needs to be circulated out of the wellbore to ensure it is gun gas and not a hydrocarbon gas influx into the wellbore.

It is an object of embodiments of the present invention to provide an annulus remediation system for use in plug in abandonment of oil and gas wells which avoids the need for perforation gun systems and therefore avoids the disadvantages associated therewith.

SUMMARY OF THE INVENTION

According to a first aspect of the present invention there is provided a BHA to be run into a wellbore to be plugged and abandoned, the BHA comprising:—

- a slotting tool which further comprises:—
  - an outer body having a throughbore;
  - connections to permit the outer body to be included in the BHA and in a work string having a throughbore for sealed fluid communication with the throughbore of the outer body;
  - a slotting blade which is at least radially moveable towards and away from an inner surface of the wellbore to be slotted;
  - an activation mechanism adapted to move the slotting blade between:—
    - a running in hole configuration in which the slotting blade is relatively retracted; and
    - an activated configuration in which the slotting blade is extended and in use is capable of creating at least one slot in the inner surface of the wellbore at a location in the wellbore to be plugged and abandoned;
  - wherein application of pressure to fluid in liquid form in the throughbore of the outer body acts upon the activation mechanism to move the slotting blade from the running in hole configuration to the activated configuration;
  - wherein at least a portion of the slotting blade is forced through the inner surface of the wellbore to create the at least one slot therein by at least one of raising or lowering the BHA respectively up or down the wellbore; and
  - wherein the BHA further comprises a jetting function in order to jet liquid fluid toward the inner surface of the wellbore.

Typically, the BHA comprises one or more downhole tools suitably connected together but at a minimum, the BHA comprises the slotting tool alone. Preferably, the inner surface of the wellbore comprises an inner surface of an open hole section of the wellbore or more preferably comprises an inner surface of a casing or liner string or production tubing to be slotted.

According to a second aspect of the present invention there is provided a method of plugging and abandoning a wellbore, the method comprising the steps of:—

- running a BHA comprising a slotting tool in accordance with the first aspect of the present invention on a work string into the wellbore; and
- pressuring up at surface fluid in liquid form and pumping said fluid in liquid form down the throughbore of the work string and applying said pressurised fluid to the activation mechanism to move the slotting blade from the running in hole configuration to the activated configuration; and
- at least one of raising or lowering the BHA respectively up or down the wellbore to force at least a portion of the

slotting blade through the inner surface of the wellbore to form the at least one slot therein.

Typically, the wellbore is either a hydrocarbon wellbore such as a production oil and/or gas well or a gas storage well or a water injector wellbore that was previously used to inject water into the lowermost region of a hydrocarbon well in order to lift the hydrocarbons or any other suitable wellbore such as a geothermal well that has come to the end of its life and requires to be plugged and abandoned. The inner surface of the wellbore is hereinafter referred to as the inner surface of the casing for brevity.

The slot formed by the slotting blade may be one relatively long continuous slot (which may be a linear/longitudinally/vertically arranged slot or may be a helically formed slot) or more preferably may be a plurality of longitudinally spaced apart slots. Typically, the one or more slots formed by the slotting blade may be a puncture or cut or hole formed by the slotting blade through the inner surface of the wellbore. Preferably, the one or more slots formed by the slotting blade may be longer than they are wider and may be substantially rectangular in shape. Alternatively, the one or more slots formed by the slotting blade may be any suitable shape of hole formed through the inner surface of the wellbore (such as circular, triangular, square, or any suitable shape having 5 or more sides).

Typically, the outer body of the slotting tool further comprises a ramp formed therein wherein the ramp comprises a longitudinal axial length and is preferably further comprises an angled longitudinal axial length such that one end of the ramp is radially further inwards (with respect to the central longitudinal axis of the slotting tool) than the other end. Typically, the angle of the ramp is linear or constant along its longitudinal axial length.

Typically, the activation mechanism is selectively actuable to move the slotting blade radially:—

a) away from the central longitudinal axis of the slotting tool and towards the casing to be slotted and into the activated configuration; and
b) toward the central longitudinal axis of the slotting tool and away from the casing to be slotted and into the running in hole configuration in which the outer diameter of the slotting blade is relatively retracted towards or more preferably within the outer diameter of the outer body of the slotting tool.

Typically, the activation mechanism comprises a connecting member such as a piston rod and which is preferably coupled at one end to the slotting blade.

Typically, the activation mechanism further comprises a piston and a cylinder, wherein the piston is located in the cylinder and is sealed thereto such that the piston can be forced to move by application of pressure of liquid fluid located in the throughbore of the slotting tool. Preferably, the piston comprises two faces, a first face of which is in fluid communication with the liquid fluid located in the throughbore of the slotting tool and a second face of which is sealed from the liquid fluid located in the throughbore of the slotting tool and is preferably connected to the connecting member.

Preferably, the connecting member of the activation mechanism is coupled at its other end to the piston and more preferably is coupled to a face of the piston.

Typically, the activation mechanism is arranged such that an increase in the pressure of liquid fluid at the surface of the wellbore by the operator results in an increase in the pressure of liquid fluid in the throughbore of the slotting tool which forces the piston to move within the cylinder and which forces the slotting blade to move from said one end of the ramp to the said other end of the ramp and in so doing moves the slotting blade both vertically along the ramp in a direction parallel to the central longitudinal axis of the slotting tool and simultaneously in a direction radially outwards with respect to the central longitudinal axis of the slotting tool.

Preferably, the activation mechanism further comprises a return device to assist in return of the slotting blade from the activated configuration into the running in hole or retracted configuration, typically upon reduction of the pressure of liquid fluid at the surface of the wellbore by the operator. More preferably, the return device comprises a biasing device adapted to bias the piston away from the activated configuration into the running in hole or retracted configuration. Most preferably, the biasing device acts between the piston head and the outer body of the slotting tool such that the slotting blade is biases towards the said one end of the ramp.

The method of plugging and abandoning a wellbore may further comprise arranging the slotting tool in a pushing slotting configuration at surface prior to being run into the wellbore.

The skilled reader will understand that pushing the slotting tool downwards into the wellbore can be achieved by the operator actively pushing downwards on or letting down weight of the work string at the surface thereof.

In a first preferred embodiment, the slotting tool is arranged in a pushing slotting configuration in which the ramp is arranged such that when the BHA is run into the wellbore, the said one (radially further inwards) end of the ramp is arranged to be vertically below the said other (radially further outwards) end such that when the slotting tool is in the activated configuration, and when the slotting tool is pushed or lowered downwards within the wellbore, the slotting blade is pushed or lowered downwards within the wellbore. This has the advantage that the reaction force between the slotting blade and the inner surface of the wellbore causes the slotting blade to be forced further along the ramp in the vertically upwards direction from said one end of the ramp toward the said other end of the ramp and is thereby further forced radially outwards to thereby increase the slotting force of the said at least portion of the slotting blade against and/or through the inner surface of the wellbore.

The method of plugging and abandoning a wellbore may further comprise arranging the slotting tool in a pulling slotting configuration at surface prior to being run into the wellbore.

In a second preferred embodiment, the slotting tool is arranged in a pulling slotting configuration in which the ramp is arranged such that when the BHA is run into the wellbore, the said one (radially further inwards) end of the ramp is arranged to be vertically above the said other (radially further outwards) end such that when the slotting tool is in the activated configuration, and when the slotting tool is pulled or lifted upwards within the wellbore, the slotting blade is pulled or lifted upwards within the wellbore. This has the advantage that the reaction force between the slotting blade and the inner surface of the wellbore causes the slotting blade to be forced further along the ramp in the vertically downwards direction from said one end of the ramp toward the said other end of the ramp and is thereby further forced radially outwards to thereby increase the slotting force of the said at least portion of the slotting blade against and/or through the inner surface of the wellbore.

The skilled reader will understand that pulling the slotting tool upwards (towards the surface of the wellbore) can be achieved by the operator lifting or pulling upwards on on the work string at the surface thereof.

Typically, the slotting blade is generally disc shaped but more preferably further comprises a serrated or castellated outer circumference such that the slotting blade preferably comprises a number of cutting teeth which may be in the form of cutting tips which are preferably circumferentially equi-spaced around the circumference of the slotting blade and which are separated by gaps in order to increase the cutting force applied to the cutting teeth. The cutting teeth of the slotting blade may be suitably coated by a relatively hard material in order to provide a relatively hard cutting surface to aid cutting or slicing through the casing.

Preferably, jetting function is arranged to jet liquid fluid such as washing or cleaning fluid toward the casing and more preferably toward the slots created in the casing by the slotting blade. Preferably, the jetting function comprises at least one jetting port or orifice which is typically in the form of a jetting nozzle formed through the side wall of an outer body of the BHA and more preferably in the form of a jetting nozzle formed through the side wall of the outer body of the slotting tool and through which liquid fluid such as washing or cleaning fluid may be jetted and more preferably may be selectively jetted by the operator.

Preferably, the said at least one jetting port is circumferentially aligned with the slotting blade and more preferably the said at least one jetting port is longitudinally axially aligned with the slotting blade. Preferably in a first embodiment, the said at least one jetting port is located vertically above (typically in relatively close proximity thereto) the slotting blade which has the advantage that the jetting port will jet through the slots that have just been formed by the slotting blade as the slotting tool is moved vertically downwards within the casing in use, typically by the operator lowering the work string and thus the BHA deeper into the wellbore. Typically, the said at least one jetting port may comprise a single jetting port or may comprise two or more jetting ports in which case said two or more jetting ports are preferably located vertically above (typically in relatively close proximity thereto) the slotting blade more preferably in a longitudinal spaced apart relationship. Hereinafter, said at least one jetting port will be referred to for simplicity sake as a single jetting port but the skilled reader will understand that it may in fact comprise such two or more jetting ports located vertically above the slotting blade in a longitudinal spaced apart relationship.

Additionally and/or alternatively in a second (inverted) embodiment, the said at least one jetting port is located vertically below (typically in relatively close proximity thereto) the slotting blade which has the advantage that the jetting port will jet through the slots that have just been formed by the slotting blade as the slotting tool is moved vertically upwards within the casing in use, typically by the operator raising the work string and thus the BHA higher up the wellbore (i.e. moving towards the surface thereof). Typically, the said at least one jetting port may comprise a single jetting port or may comprise two or more jetting ports in which case said two or more jetting ports are preferably located vertically below (typically in relatively close proximity thereto) the slotting blade more preferably in a longitudinal spaced apart relationship. Hereinafter, said at least one jetting port will be referred to for simplicity sake as a single jetting port but the skilled reader will understand that it may in fact comprise such two or more jetting ports located vertically below the slotting blade in a longitudinal spaced apart relationship.

Typically, the slotting tool further comprises a plurality of jetting ports in the form of jetting nozzles formed around the circumference and preferably through the side wall of the outer body of the slotting tool (and which preferably form a second set of jetting ports in the BHA). Preferably, the second set of jetting ports are formed through the side wall of the outer body of the slotting tool are equi-spaced 360 degrees around the circumference of the slotting tool on the same plane perpendicular to the central longitudinal axis of the slotting tool such that all of the jetting ports in the second set will permit jetting of liquid fluid at the same vertical location in the wellbore (assuming the wellbore is vertical at that location).

Preferably, the second set of jetting ports are obturated when the slotting tool is in the running in hole configuration. Typically, the second set of jetting ports can be selectively opened by the operator into fluid communication with liquid fluid located in the throughbore of the slotting tool by a port opening mechanism. Preferably, the port opening mechanism comprises a drop device seat member which is secured to the outer body of the slotting tool by a frangible device and more preferably the frangible device may be broken or sheared by dropping a drop device at surface such that when the drop device lands on the seat member, application of liquid fluid pressure at surface is transmitted to the liquid fluid located in the throughbore of the slotting tool and which acts upon the drop device and the seat member to break or shear the frangible device and which results in disconnection of the seat member from the outer body of the slotting tool thereby uncovering the second set of jetting ports and permitting fluid communication with the liquid fluid located in the throughbore of the slotting tool.

Preferably, the BHA further comprises at least one upper sealing member located above the slotting tool and at least one lower sealing member located below the slotting tool, wherein the sealing members are arranged to selectively seal against the inner surface of the casing when required to do so. Preferably, the sealing members are arranged to seal the annulus at their location between the outer surface of the BHA and the inner surface of the casing. Typically, the said sealing members are arranged to provide a greater seal when the pressure of liquid fluid acting on their radially innermost faces increases. Typically, the said sealing members are cup seals and preferably, two cup seals are located above the slotting tool and at least one sealing member located below the slotting tool.

Preferably, the BHA further comprises a valve tool, preferably located below the said lower sealing member. Preferably the valve tool comprises:—

- a throughbore in sealed fluid communication with the throughbore of the rest of the BHA located above the valve tool; and
- a valve member operable within the throughbore of the valve tool.

The valve member preferably permits liquid fluid located in the wellbore to pass upwards through the throughbore of the valve tool and preferably continued passage upwards into the throughbore of the rest of the BHA and more preferably prevents fluid from flowing downwards through the throughbore of the valve tool. Typically, the valve member comprises a flapper valve, poppet valve or similar type of valve or indeed any suitable valve.

Preferably, the valve tool comprises an outer body and further preferably comprises a plurality of jetting ports or orifices in the form of jetting nozzles formed around the circumference and preferably through the side wall of the outer body of the valve tool (and which preferably forms a third set of jetting ports in the BHA). The jetting nozzles are typically arranged to break up material located in the outer annulus. However, it should be noted that the jetting nozzles may instead be circulation ports to permit fluid located downhole to pass therethrough in either direction when the said circulation ports are open. Alternatively, the said jetting nozzles may be a combination of jetting nozzles and circulation ports.

Preferably, the third set of jetting ports are formed through the side wall of the outer body of the valve tool are equi-spaced 360 degrees around the circumference of the valve tool on the same plane perpendicular to the central longitudinal axis of the valve tool such that all of the jetting ports in the third set will permit jetting of liquid fluid at the same vertical location in the wellbore (assuming the wellbore is vertical at that location).

Preferably, the third set of jetting ports are obturated when the valve tool is in the running in hole configuration and the valve member is permitted to be open to allow fluid located in the throughbore thereof to flow through the throughbore as the BHA is being run into the hole. Typically, the third set of jetting ports can be selectively opened by the operator into fluid communication with liquid fluid located in the throughbore of the valve tool by a valve tool port opening mechanism. Preferably, the valve tool port opening mechanism comprises a slidable sleeve or housing typically to which the valve member is pivotably mounted, wherein the slidable sleeve is secured to the outer body of the valve tool by at least one frangible device and more preferably the at least one frangible device may be broken or sheared by applying a force to the slidable sleeve with respect to the outer body of the valve member. Typically the force applied to the slidable sleeve is a downwardly directed force. Preferably, the downwardly directed force is applied to one face of the valve member when in its closed position and more preferably, the downwardly directed force is applied to one face of the valve member by an increase in fluid pressure in the throughbore of the valve tool against one face of the valve tool which is preferably an uppermost face and the increase in pressure of said fluid is increased at surface by the operator.

Preferably, when the valve member is closed by flow of fluid downwards through the throughbore of the valve tool and/or an increase in fluid pressure at surface which is transmitted to the liquid fluid located in the throughbore of the valve tool and which acts upon the said upper face of the valve member. Said increase in pressure applies a force to the upper end of the valve member and also the slidable sleeve which will break or shear the frangible device and which results in disconnection of the slidable sleeve from the outer body of the valve tool thereby uncovering the third set of jetting ports and permitting fluid communication to occur between the liquid fluid located in the throughbore of the valve tool and the third set of ports.

Optionally, at least one of, some of, most of or all of the (first) single jetting port, second and third sets of jetting ports contain jets which permit fluid to pass there through:—

a) in a circulation mode up to a certain pre-determined pressure; and
b) once the required pre-determined pressure has been reached, the said jetting port will jet the fluid at a disruptive forceful rate sufficient to dislodge and/or disturb old cement or formation or other material.

More preferably, only the first single jetting port permits fluid to pass therethrough in both of the aforementioned paragraphs a) and b) and most preferably the second and third sets of jetting ports are circulation ports which permit fluid to pass therethrough without restriction once they've been respectively opened.

Preferably, the method further comprises the following steps:—

a) running a BHA including a slotting tool in accordance with the first aspect of the present invention but further also comprising:—
   I. an upper cup tool;
   II. a lower cup tool; and
   III. a valve tool
   on a work string into the wellbore; and
   pressuring up at surface fluid in liquid form and pumping said fluid in liquid form down the throughbore of the work string and applying said pressurised fluid to the activation mechanism to move the slotting blade from the running in hole configuration to the activated configuration.

Preferably the method further comprises:—

b) moving the BHA downwards within the wellbore such that the activated slotting blade forms one or more slots through the side wall of the casing.

Preferably the method further comprises:—

c) pumping washing/cleaning fluid in liquid form from the surface through the throughbore of the work string at a pressure sufficient to pass through the single jetting nozzle of the slotting tool, in order to wash the washing/cleaning fluid through the one or more slots formed by the slotting tool.

Preferably the method further comprises:—

d) increasing the pressure of the liquid fluid in the throughbore of the work string to a sufficient pressure such that a downwardly directed force is applied to the closed valve member of the valve tool and the at least one frangible device is broken or sheared by said force and the slidable sleeve is moved thereby uncovering the third set of jetting ports in the valve tool, thereby permitting increased volumes of washing/cleaning fluid in liquid form to be pumped from the surface through the throughbore of the work string at a pressure sufficient to pass through the third set of jetting nozzles of the valve tool, in order to wash the washing/cleaning fluid through the one or more slots formed by the slotting tool.

Preferably the method further comprises:—

e) dropping a drop device at surface into the throughbore of the work string and landing the drop device on the drop seat of the slotting tool.

Preferably the method further comprises:—

f) increasing the pressure of the liquid fluid in the throughbore of the work string to a sufficient pressure such that a downwardly directed force is applied to the drop device and seat member whereby the at least one frangible device acting between the seat member and the outer body of the slotting tool is broken or sheared by said force and the seat member and drop device are moved thereby opening the throughbore of the slotting tool by means of uncovering the second set of jetting ports in the slotting tool, thereby permitting increased volumes of washing/cleaning fluid in liquid form to be pumped from the surface through the throughbore of the work string at a pressure sufficient to pass through the second set of jetting nozzles of the slotting tool, in order to wash the washing/cleaning fluid through the one or more slots formed by the slotting tool.

Preferably the method further comprises:—

g) pumping isolation material (which is preferably cement or the like) from surface into the throughbore of the work string to fill the required area of the wellbore (including both the throughbore of the casing and the washed clean annulus behind the casing) with said isolation material to a sufficient depth.

Preferably the method further comprises:—

h) pull the workstring upwards until the BHA is located above the uppermost slots formed by the slotting tool and increasing the pressure of said pumped isolation material at surface (which is preferably cement or the like) into the throughbore of the work string to a sufficient pressure such that a downwardly directed force is applied to the drop device and seat member until at least one frangible device acting between a ball seat and the seat member is broken or sheared by said force and the drop device and the ball seat are moved thereby opening the throughbore of the slotted tool to the throughbore of the BHA located below the slotted tool in order to open up circulation of isolation material below the slotted tool and out through the first set of circulation ports in order obtain circulation of isolation material below the slotting tool.

Preferably the method further comprises:—

i) pulling said BHA and said work string out of the hole and permitting the isolation material to set.

The accompanying drawings illustrate presently exemplary embodiments of the disclosure and together with the general description given above and the detailed description of the embodiments given below serve to explain, by way of example, the principles of the disclosure.

In the following description, like parts are marked throughout the specification and drawings with the same reference numerals, respectively. The drawings are not necessarily to scale. Certain features of the invention may be shown exaggerated in scale or in somewhat schematic form and some details of conventional elements may not be shown in the interest of clarity and conciseness. The present invention is susceptible to embodiments of different forms. Specific embodiments of the present invention are shown in the drawings and herein will be described in detail, with the understanding that the present disclosure is to be considered an exemplification of the principles of the invention, and is not intended to limit the invention to that illustrated and described herein. It is to be fully recognised that the different teachings of the embodiments discussed below may be employed separately or in any suitable combination to produce the desired results.

The following definitions will be followed in the specification. As used herein, the term "wellbore" refers to a wellbore or borehole that was drilled in a manner known to those skilled in the art. The wellbore may be 'open hole' or more typically is 'cased', being lined with a tubular string. Reference to up or down will be made for purposes of description with the terms "above", "up", "upward" or "upper" meaning away from the bottom of the wellbore along the longitudinal axis of a work string toward the surface and "below", "down", "downward" or "lower" meaning toward the bottom of the wellbore along the longitudinal axis of the work string and away from the surface and deeper into the well, whether the well being referred to is a conventional vertical well or a deviated well and therefore includes the typical situation where a rig is above a wellhead, and the well extends down from the wellhead into the formation, but also horizontal wells where the formation may not necessarily be below the wellhead. Similarly, 'work string' refers to any tubular arrangement for conveying liquid fluids and/or tools from a surface into a wellbore. In the present invention, coiled tubing and in particular a drill string is the preferred work string.

The various aspects of the present invention can be practiced alone or in combination with one or more of the other aspects, as will be appreciated by those skilled in the relevant arts. The various aspects of the invention can optionally be provided in combination with one or more of the optional features of the other aspects of the invention. Also, optional features described in relation to one embodiment can typically be combined alone or together with other features in different embodiments of the invention. Additionally, any feature disclosed in the specification can be combined alone or collectively with other features in the specification to form an invention.

Various embodiments and aspects of the invention will now be described in detail with reference to the accompanying figures. Still other aspects, features and advantages of the present invention are readily apparent from the entire description thereof, including the figures, which illustrates a number of exemplary embodiments and aspects and implementations. The invention is also capable of other and different embodiments and aspects, and its several details can be modified in various respects, all without departing from the spirit and scope of the present invention.

Any discussion of documents, acts, materials, devices, articles and the like is included in the specification solely for the purpose of providing a context for the present invention. It is not suggested or represented that any or all of these matters formed part of the prior art base or were common general knowledge in the field relevant to the present invention.

Accordingly, the drawings and descriptions are to be regarded as illustrative in nature, and not as restrictive. Furthermore, the terminology and phraseology used herein is solely used for descriptive purposes and should not be construed as limiting in scope. Language such as "including", "comprising", "having", "containing" or "involving" and variations thereof, is intended to be broad and encompass the subject matter listed thereafter, equivalents and additional subject matter not recited, and is not intended to exclude other additives, components, integers or steps. In this disclosure, whenever a composition, an element or a group of elements is preceded with the transitional phrase "comprising", it is understood that we also contemplate the same composition, element or group of elements with transitional phrases "consisting essentially of", "consisting", "selected from the group of consisting of", "including" or "is" preceding the recitation of the composition, element or group of elements and vice versa. In this disclosure, the words "typically" or "optionally" are to be understood as being intended to indicate optional or non-essential features of the invention which are present in certain examples but which can be omitted in others without departing from the scope of the invention.

All numerical values in this disclosure are understood as being modified by "about". All singular forms of elements, or any other components described herein including (without limitations) components of the apparatus described herein and/or downhole tools are understood to include plural forms thereof and vice versa.

BRIEF DESCRIPTION OF AND INTRODUCTION TO THE DRAWINGS

Embodiments of the present invention will now be described, by way of example only and with reference to the accompanying drawings, in which:—

FIG. **1** is a schematic side view of a first preferred embodiment of an as-built Bottom Hole Assembly (BHA) in accordance with the present invention for running into a well to be plugged and abandoned in accordance with a method of the present invention, where the BHA is run in on the lower end of a suitable work string such as a drill pipe string with a swivel (such as that shown in FIG. **2**(*a*)) being located above the BHA and where the BHA comprises from top to bottom:—

- an upper jetting cup tool having an upper set of jetting cups provided thereon, a slotting and jetting tool having a slotting blade/cutting wheel which is shown in the activated (extended) slotting/cutting configuration,
- a lower jetting cup tool having a lower set of jetting cups provided thereon; and
- an inverted float (shear) sub;

FIG. **2**(*a*) is a schematic side view of one example of a conventional swivel that can be placed in the drill string at a suitable location above the BHA of FIG. **1**;

FIG. **2**(*b*) is a part cross-sectional side view of a first embodiment of a slotting and jetting tool in accordance with the present invention and as shown incorporated in the BHA of FIG. **1**, where the slotting and jetting tool is shown with the slotting blade/cutting wheel in the activated (extended) slotting/cutting configuration (and which is shown in more detail in FIGS. **4**(*a*) and **4**(*b*) and referred to in the description below for Stage 7);

FIG. **2**(*c*) is a part cross-sectional view of the upper pair of jetting cups of FIG. **1** being provided on the upper jetting cup tool;

FIG. **2**(*d*) is a part cross-sectional side view of the lower pair of jetting cups of the BHA of FIG. **1** being provided on the lower jetting cup tool;

FIG. **2**(*e*) is a cross-sectional side view of the inverted float (shear) sub of FIG. **1** being shown in the run-in hole configuration (i.e. with its flapper valve in the open position);

FIG. **2**(*f*) is a cross-sectional side view of the inverted float (shear) sub of the BHA of FIG. **1** but is shown in FIG. **2**(*f*) as being in the string pressured up configuration (i.e. its flapper valve is in the closed position) and also shown in schematic form in FIG. **12** and referred to in the description below for Stage 6;

FIG. **3**(*a*) is a cross-sectional side view of the slotting and jetting tool of FIG. **1** but now being shown in the running in hole (RIH) configuration and therefore is shown as being in a prior to actuation configuration in that its activation piston has not been pressured up (i.e. the activation piston is not experiencing pressure because the liquid fluid in the throughbore of the slotting and jetting tool whilst it is being run into the hole is not pressured up);

FIG. **3**(*b*) is a cross-sectional view of the slotting and jetting tool of FIG. **3**(*a*) but being shown from a different rotational cross-section (i.e. with a 90 degrees rotational offset around the longitudinal axis) from that of FIG. **3**(*a*) but which is also shown in the RIH configuration (i.e. the activation piston is not pressured up);

FIG. **4**(*a*) is a cross-sectional side view of the slotting and jetting tool of the BHA of FIG. **1** in the same rotational cross sectional view as that of FIG. **3**(*a*) but the slotting and jetting tool is now shown in the configuration where the activation piston is experiencing fluid pressure being applied to it (due to the fluid pressure in the throughbore of the work string has been pressured up against the closed inverted float flapper of FIG. **2**(*f*)) and also shown in schematic form in FIG. **12** and referred to in the description below for Stage 7;

FIG. **4**(*b*) is a cross-sectional side view of the slotting and jetting tool of FIG. **4**(*a*) but being shown from a different rotational cross-section (i.e. with a 90 degrees rotational offset around the longitudinal axis) from that of FIG. **4**(*a*), and therefore the slotting and jetting tool of FIG. **4**(*b*) is in the same pressured up configuration as that of FIG. **4**(*a*);

FIG. **4**(*c*) is a side view of the piston head and piston rod (of the activation piston of the slotting and jetting tool of FIG. **2**(*b*)) shown in isolation for clarity;

FIG. **4**(*d*) is a side view of a slotting blade/cutting wheel mount which is used to mount the slotting blade/cutting wheel of FIG. **4**(*e*) to the in use uppermost end of the piston rod of FIG. **4**(*c*);

FIG. **4**(*e*) is an exploded view of a slotting blade/cutting wheel and cutting hub and cutting axle, and which when brought together are mounted upon and to the wheel mount of FIG. **4**(*d*);

FIG. **5** is a cross-sectional view of the inverted float (shear) sub of FIG. **2**(*f*) but after the shear pins thereof have sheared, such that the liquid fluid circulation holes formed through the side wall of the inverted float (shear) sub have been opened and the inverted float (shear) sub is now in the configuration shown in FIG. **15** at Stage 26 of the method to be described below during the final jetting procedure thereof;

FIG. **6**(*a*) is a cross-sectional side view of the slotting and jetting tool of FIG. **4**(*a*) but where the drop ball has been dropped through the throughbore of the work string and has landed on the seat within the slotting and jetting tool **10** (but prior to the shear pins that hold the seat in place as shown in FIG. **6**(*a*) having sheared) and the slotting and jetting tool is shown in the configuration described in Stage 27 of the final jetting procedure as shown in FIG. **16**;

FIG. **6**(*b*) is a cross-sectional view of the slotting and jetting tool of FIG. **6**(*a*) but being shown from a different rotational cross-section (i.e. with a 90 degrees rotational offset around the longitudinal axis) from that of FIG. **6**(*a*);

FIG. **7**(*a*) is a cross-sectional view of the slotting and jetting tool of FIG. **6**(*a*) but now shows the shear pins that hold the seat as having been sheared thus uncovering the 360 degrees jetting/washing ports and the slotting and jetting tool **10** is now in the configuration required for Stage 28 of the method;

FIG. **7**(*b*) is a cross-sectional view of the slotting and jetting tool of FIG. **7**(*a*) but being shown from a different rotational cross-section (i.e. with a 90 degrees rotational offset around the longitudinal axis) from that of FIG. **7**(*a*);

FIGS. **8** (*a*) and **8** (*b*) are cross-sectional views of the slotting and jetting tool of FIG. **7** (*a*) but is now shown with the further and final shear pins that hold the inner ball seat within the ball seat carrier as having sheared and so the ball seat and ball have moved through the ball seat carrier and circulation of fluid in liquid form through the slotting and jetting tool **10** throughbore has been opened and thus fluid flow therethrough is permitted and thus circulation of fluid in liquid form below the slotting and jetting tool **10** has been permitted, and the slotting and jetting tool is now in the configuration shown in FIG. **21** and is now in the configuration required for Stage 41 of the method during the isolation procedure;

FIG. **9** is a schematic side view of a wellbore that an operator requires to be plugged and abandoned and shows the start of the running and slotting procedure which will have the BHA of FIG. **1** run into it and will have the method of some or all of Stages 1 to 45 of the method that will be subsequently described in detail in accordance with the present invention performed upon it (Stages 1 to 23 correspond to the running and slotting procedure) and thus FIG. **9** shows the wellbore before the BHA of FIG. **1** is run into it; this FIG. **9** generally relates to Stages 1 and 2 of the method that will be subsequently described in detail;

FIG. **10** shows a subsequent Stage 3 of the method to be subsequently described in detail that will be performed on the wellbore to that of FIG. **9**, where a bridge plug has been set at a lower end of the wellbore;

FIG. **11** shows a subsequent stage of the wellbore on from that shown in FIG. **10**, where the BHA of FIG. **1** has been run into the wellbore approximately to the depth at which the casing of the wellbore requires to be slotted, where FIG. **11** largely corresponds to Stage 5 in the method to be detailed subsequently;

FIG. **12** shows a subsequent stage on from that of FIG. **11** where the BHA remains at depth and the work string has been pressured up such that the flapper valve provided within the inverted float (shear) sub has been moved from the open configuration shown in FIG. **2**(*e*) to the closed configuration shown in FIG. **2**(*f*) and the pressure built up within the throughbore of the work string activates the slotting blades/cutting wheel of the slotting and jetting tool to cut slots through the side wall of the casing—the BHA in the configuration shown in FIG. **12** corresponds to Stage 7 of the method that will be subsequently described and the slotting and jetting tool corresponds to the configuration shown in FIGS. **4**(*a*) and **4**(*b*);

FIG. **13** shows a subsequent stage on of operation of the BHA to that shown in FIG. **12**, where the BHA in FIG. **13** is moved down the wellbore, typically by the operator lowering the work string and thus the BHA deeper into the wellbore, in order for the slotting blade/cutting wheel to puncture through the casing as it is moved down the wellbore and where cleaning/washing fluid has been pumped down the throughbore of the drill pipe string at pressure and jetted out of the single jetting nozzle whilst slotting has occurred—FIG. **13** broadly corresponds to Stage 8 of the method that will be detailed subsequently;

FIG. **14** shows a subsequent stage of operation of the BHA to that of FIG. **13**, and shows the final Stage of the Running and Slotting procedure, where the BHA of FIG. **1** has been moved down (typically by the operator lowering the work string and thus the BHA deeper into the wellbore,) and then back up (typically by the operator raising or lifting the work string and thus the BHA upwards towards the surface within the wellbore), and then down the casing (again typically by the operator lowering the work string and thus the BHA deeper into the wellbore) in order to fully slot the casing/liner tubing as required whilst jetting through the single jetting nozzle at the same time as slotting and thus several passes have occurred by repeating Stages 12 to 21 of the method that will be subsequently described in detail and, once the slotting has been completed, the BHA is moved to the position shown in FIG. **14** which is an area where the test cups are located in a non-slotted area of the casing and the BHA is now at Stage 23 of the method that will be subsequently described in detail;

FIG. **15** is a subsequent stage of operation of the BHA on from that shown in FIG. **14**, and shows the first Stage of a Final Jetting procedure, where the pressure of fluid within the throughbore of the drill string has been increased by the operator at surface such that a (first) set of shear pins provided in the inverted float (shear) sub have sheared, thus opening jetting/circulation ports in the side wall of the inverted float (shear) sub in order to provide circulation of fluid from the throughbore of the drill pipe string at a position in the BHA which is below the slotting and jetting tool and, in so doing, the flapper valve has moved downwards below the location of the circulation holes such that the flapper valve is now in the position shown in FIG. **5** and the BHA is now at Stage 26 of the final jetting procedure of the method as will subsequently be described;

FIG. **16** is a subsequent stage of the BHA on from that shown in FIG. **15**, where a drop ball has been dropped at surface through the throughbore of the drill string and has landed on a ball seat provided within the throughbore of the slotting and jetting tool and fluid in the throughbore located above the drop ball has been pressured up by the operator at surface in order to shear a (second) set of shear pins that are provided in the slotting and jetting tool such that the (second) set of shear pins have sheared and the ball seat carrier has moved downwards within the slotting and jetting tool such that a set of 360 degrees jetting nozzles (which are formed through the side wall of the slotting and jetting tool at a position above the single jetting nozzle) have been uncovered such that the slotting and jetting tool has been transformed from the configuration shown in FIG. **6**(*a*) to the configuration shown in FIG. **7**(*a*) and the BHA is now at Stage 28 of the method which will be detailed subsequently;

FIG. **17** shows a subsequent stage of the operation of the BHA within the wellbore on from that shown in FIG. **16**, where the BHA is picked up by picking up the string at surface and cleaning/washing fluid is pumped down the throughbore of the drill string and is jetted out of the 360 degrees nozzles of the slotting and jetting tool in order to clean the annulus behind the slotted casing—the BHA is now between method steps 29 to 31 of the method as will be subsequently described;

FIG. **18** shows a subsequent stage of operation of the BHA on from that shown in FIG. **17**, and shows the final Stages of the final jetting procedure (albeit there may be several passes thereof), where the annulus behind the casing has been cleaned and the BHA has been moved upwards such that the pair of cups can be tested in a non-slotted section of the casing and the BHA is now between Stages 32-34 of the method as will be described subsequently;

FIG. **19** shows a subsequent stage of operation of the BHA on from that shown in FIG. **18** and shows the start of the isolation procedure where the BHA has been run further downhole (typically by the operator lowering the work string and thus the BHA deeper into the wellbore) and the operator has started to pump isolation material (such as cement or other suitable material) down the throughbore of the drill pipe string such that the cement or the like jets out of the (now uncovered) 360 degree jetting nozzles formed through the side wall of the slotting and jetting tool and the BHA has been submerged in isolation material such as cement—the BHA is now at Stage 35 of the method as will be detailed subsequently;

FIG. **20** shows a subsequent stage of operation of the BHA to that shown in FIG. **19**, where the BHA has been pulled upwards (i.e. in the direction heading out of the hole) to above the upper end of the slot jet area **130** (i.e. just above the theoretical top of the newly pumped in isolation material (cement or similar)) without the operator rotating the drill pipe and where the operation is now at Stage 40 of the method as will be described subsequently in detail;

FIG. **21** shows a subsequent stage of operation of the BHA on from that shown in FIG. **20**, where the operator has pressured up the isolation material such as cement in the throughbore of the drill pipe string and that has caused a (third) set of shear pins provided within the slotting and jetting tool to shear which has caused the ball seat to be separated from the ball seat carrier and thus has allowed the ball and ball seat to drop and thus has allowed circulation of isolation material/cement to occur through the throughbore at the bottom of the slotting and jetting tool and out through the jetting holes provided in the inverted float (shear) sub and thus the BHA is now at Stage 41 of the isolation procedure of the method as will be described in detail subsequently;

FIG. **22** shows the next stage of operation of the BHA on from that shown in FIG. **21**, where the operator circulates the well clean at the maximum loss free rate with cleaning/washing fluid pumped from the surface by the operator through the throughbore of the drill string and the BHA is now shown as being at Stage 42 of the isolation procedure of the method as will be described in detail subsequently;

FIG. **23** shows the wellbore at the end of the plug and abandonment operation performed as shown in FIGS. **9** to **22** in accordance with the present invention, where the isolation material/cement plug has been formed within the wellbore such that the wellbore is now abandoned having been plugged by the new isolation material and the BHA and drill pipe string has been pulled out of the hole with the operator laying out or laying down the drill pipe and the BHA including the slotting and jetting tool, and the operation is now at step 45 of the isolation procedure of the method as will be described in detail subsequently;

FIG. **24**(*a*) is a schematic cross-sectional side view of a second (alternative) embodiment of a slotting and jetting tool in accordance with the present invention and which can be incorporated in the BHA of FIG. **1** as an alternative to the first embodiment of the slotting and jetting tool shown in FIG. **2** (as required by the operator) and where the slotting and jetting tool of FIG. **24** is referred to as an inverted slotting and jetting tool (compared with that of FIG. **2**) and which is shown in a running in hole (RIH) configuration and therefore is shown as being in a prior to actuation configuration in that its activation piston has not been pressured up (i.e. the activation piston is not experiencing pressure because the liquid fluid in the throughbore of the slotting and jetting tool (whilst it is being run into the hole) is not pressured up);

FIG. **24**(*b*) is a cross-sectional side view of the inverted embodiment of the slotting and jetting tool of FIG. **24**(*a*) also being shown on same rotational cross section and also being shown in the running in hole (RIH) configuration and therefore is shown as being in a prior to actuation configuration;

FIG. **24**(*c*) is a cross-sectional view of the inverted embodiment of the slotting and jetting tool of FIG. **24**(*b*) but being shown from a different rotational cross-section (i.e. with a 90 degrees rotational offset around the longitudinal axis) from that of FIG. **24**(*b*) but which is also shown in the RIH configuration (i.e. the activation piston is not pressured up);

FIG. **25** is a cross sectional plan view through section X-X of a drop ball seat of the slotting and jetting tool of FIG. **24**(*a*) showing fluid bypass channels being provided and which extend downwards below the ball seat;

FIG. **26** is a cross sectional plan view through section Y-Y of a washing ports sleeve cover of the slotting and jetting tool of FIG. **24**(*a*) showing fluid bypass channels being provided therethrough and which extend downwards below the washing ports sleeve cover;

FIG. **27**(*a*) is a cross-sectional side view of the inverted (second and alternative) embodiment of the slotting and jetting tool of FIGS. **24**(*a*) and **24**(*b*) and in the same rotational cross sectional view as that of FIG. **24**(*b*) but the inverted slotting and jetting tool is now shown in the configuration where the activation piston is experiencing fluid pressure being applied to it (due to the fluid pressure in the throughbore of the work string having been pressured up at surface and which against the uppermost surface of the piston) and therefore where the inverted slotting tool can be moved upwards within the wellbore by the operator pulling up on the work string at the surface thereof in order to form slots in the inner surface and thus through the sidewall of the wellbore (such as the casing);

FIG. **27**(*b*) is a cross-sectional side view of the inverted slotting and jetting tool of FIG. **27**(*a*) but being shown from a different rotational cross-section (i.e. with a 90 degrees rotational offset around the longitudinal axis) from that of FIG. **27**(*a*), and therefore the inverted slotting and jetting tool of FIG. **27**(*b*) is in the same pressured up configuration as that of FIG. **27**(*a*);

FIG. **28** is a side view of a drop ball for use with the inverted slotting and jetting tool of FIG. **24**(*a*) and which can be dropped down through the throughbore of the work string at the surface thereof by the operator when desired by the operator;

FIG. **29**(*a*) is a schematic cross-sectional side view of the inverted embodiment of the slotting and jetting tool of FIG. **24**(*a*) and which is now shown in a washing configuration in which the ball seat having been sheared out and the slotting blade piston having been isolated and with fluid communication having been opened up through the inverted slotting and jetting tool in order to provide fluid communication from above and through to below the inverted slotting and jetting tool and which has also had its 360 degrees washing nozzles opened in order to permit washing of the inner surface of the wellbore (e.g. the casing) and in particular the annulus outside of the casing;

FIG. **29**(*b*) is a cross-sectional side view of the inverted embodiment of the slotting and jetting tool of FIG. **29**(*a*) also being shown on same rotational cross section and also being shown in the same washing configuration as that of FIG. **29**(*a*); and

FIG. **29**(*c*) is a cross-sectional view of the inverted embodiment of the slotting and jetting tool of FIG. **24**(*b*) but being shown from a different rotational cross-section (i.e. with a 90 degrees rotational offset around the longitudinal axis) from that of FIG. **29**(*b*) but which is also shown in the same washing configuration as that of FIGS. **29***a*) and (*b*).

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS OF PRESENT INVENTION

BHA **1**

FIG. **1** shows an embodiment of a Bottom Hole Assembly 1 (BHA **1**) incorporating a first embodiment of a slotting and jetting tool **10** in accordance with the present invention. The BHA **1** is to be run into a wellbore **100** to be plugged and abandoned (see FIG. **9**), the wellbore **100** having for example having produced all of the viable hydrocarbons possible and therefore has come to the end of its productive life. The BHA **1** will typically be run into the wellbore **100** at a suitable location in a work string which will typically be made up of one or more tubulars such as either coiled tubing (not shown) or a string made up of a plurality of drill pipe stands which are screwed and unscrewed together at surface to make up a work string such as a drill string **120**.

The BHA **1** comprises three main tools secured together:—

I. upper jetting cups **20**U mounted on upper jetting cup tool **22**;

II. slotting and jetting tool **10**; and

III. lower jetting cups **20**L mounted on lower jetting cup tool **24**

The BHA **1** as shown in FIG. **1** comprises at its upper most end an upper pair of jetting cups **20**U, which are typically formed of relatively durable rubber material or the like and which are mounted longitudinally spaced apart on an upper jetting cup tool **22** which comprises at its upper most end a suitably threaded pin connection **23** for connection with a suitably threaded box connection (not shown) provided at the point of inclusion in the drill pipe string **120**. The upper jetting cup tool **22** further comprises a box connection **21** (as shown in FIG. **2**(*c*)) provided at its in use lower most end and which in use is securely threadedly connected to box connection **11** provided at the upper most end of the slotting and jetting tool via a suitable sub-connector or cross-over sub (not shown) having suitable pin connections provided at both ends. Alternatively, and more preferably, the box connection **21** of the upper jetting cup tool **22** could be modified to instead be a pin connection (not shown) which would allow direct secure connection to the box connection **11** of the slotting and jetting tool **10**. The cups **20** maybe any suitable conventional cups, one example of which is manufactured by RubberAtkins Limited of Aberdeen UK but other suppliers of cups are available such as those offered under the Guiberson™ brand by Oil States Industries of Arlington, Texas, USA.

It should be noted that a bypass channel or other bypass mechanism is provided (but is not shown in the FIGS.) in either the cups **20** or in each of the upper and lower cup tools **22**, **24** in order to permit fluid to bypass the cups **20** (either around the outer edge of the cups **20** or through the cups **20** or around the inner surface of the cups **20**) particularly when the BHA **1** is being run into or pulled from the wellbore **100** in order to avoid swab surging or hydraulic locking within the annulus (between the outer surface of the drill string **120** and the inner surface of the casing **102**) particularly when the outer diameter of the cups substantially matches the inner diameter of the wellbore **100** (e.g. the casing **102**). It should also be noted that the bypass channel will be blocked or obturated when pressure is applied between the cups **20** by the operator from surface when either circulating/jetting through the single jetting port **80** and/or circulating/jetting through the second set of 360 degree jetting ports/circulation ports **74**.

It should be noted that each of the upper **22** and lower **24** jetting cup tool comprises two cups **20** but only one cup **20** is required for each of the upper **22** and lower **24** jetting cup tools but two cups **20** per tool **22**, **24** is preferred in order to provide redundancy in case one cup **20** per pair were to fail.

The cups **20** are generally arranged such that they will in use provide a seal in the annulus **27** between the outer surface of the drill string **120** and the inner surface of the casing **120** and in particular to prevent the washing/cleaning fluid that is jetted through either the single jetting nozzle **80** or the second set of 360 degree jetting nozzles/circulation ports **74** from:—

- passing further up the said annulus **27** than the upper cups **20**U (unless the washing fluid can bypass the upper cups by passing through the slots **108** first); and
- passing further down the said annulus **27** than the lower cups **20**U (unless the washing fluid can bypass the upper cups by passing through the slots **108** first).

The cups are arranged such that the higher the pressure of fluid acting upon the inner facing faces of the cups **20**, the higher the sealing force acting upon the cups **20** against the casing **102**.

A pin connection **12** is provided at the lower end of the slotting and jetting tool **10** and in use of the BHA **1**, the pin connection **12** is securely coupled to the box connection **25** provided at the upper end of the lower jetting cup tool **24**. The lower jetting cup tool **24** comprises a pair of longitudinally spaced apart pair of jetting cups **20**L provided around the outer circumference thereof and which again are formed of a suitable resilient material such as rubber or the like.

The lower end of the lower jetting cup tool **24** is provided with a pin connection for secure coupling to the upper end of the inverted float (shear) sub **30**.

It should be noted however that a swivel tool **90** is incorporated toward the lower end of the drill string **120** just above the BHA **1** in order to allow the drill string **120** to rotate with respect to the BHA **1** when the operator requires that rotation (i.e. the operator can activate the swivel tool **90** to rotationally lock or rotationally decouple the BHA **1** from the drill string **120** as required in order to permit the BHA **1** to be stationary in the wellbore **100** whilst the drill string **120** is rotating in order to aid stirring up/circulation of fluid in the wellbore **100**) as will be described subsequently. A suitable swivel **90** is shown in FIG. **2**(*a*) and a suitable example of such a swivel is a Swivel Master™ offered by Rubicon Oilfield of Aberdeen, UK but other suitable swivels could also be used such as that offered by R&D Solutions of Perth, Western Australia.

First Embodiment of Slotting and Jetting Tool **10**

The slotting and jetting tool **10** comprises an outer body or mandrel **13** having a throughbore **14** through which fluid can be pumped from the surface of the wellbore through the drill string throughbore (assuming that the throughbore **14** is not impeded by a drop ball **68** as will be subsequently described).

A ball seat carrier **72** is (at least initially) secured within the throughbore **14** of the mandrel **13** to the inner surface **14**S thereof by a first set **15** of shear pins such that whilst the first set of shear pins **15** remain intact, the ball seat carrier **72** remains in position as shown in FIG. **3**(*a*) and therefore sealingly obturates a (second) set of (a plurality of) jetting nozzles/circulation ports **74** which are equi-spaced around the circumference of the mandrel **13** formed through the side wall thereof thus providing a 360 degree coverage of fluid jetting function when they have been uncovered as will be described subsequently. However, whilst the ball seat carrier **72** is shear pinned in place by the first set of shear pins **15**, no fluid can pass from the throughbore **14** through the (second) plurality or set of jetting nozzles/circulation ports **74** due to the presence of O-ring seals located and acting in between the outer surface of the ball seat carrier **72** and the inner surface **14**S of the mandrel **13** at a location above and below the (second) set of jetting nozzles/circulation ports **74**.

However, there is further provided a single jetting nozzle **80** formed through the side wall of the mandrel **13** at a position just below the ball seat carrier **72** and which is preferably circumferentially aligned (aligned on the same longitudinal axis or plane) with a slotting blade or cutting wheel **60** and which in use will provide a jetting action to jet through the slots that are punctured through the casing **102** along the length or area of casing to be slotted **130** by the cutting wheel **60** in order to jet or wash away the old cement or formation or indeed unwanted gas or other fluid) **104** in the annulus in a slot jet area **106** between the outer surface of the casing **102** and the inner surface of the borehole **105**. Further details of the use of the single jetting nozzle **80** will be described subsequently.

It should be noted that the diameter of the single jetting nozzle **80** and also the diameter of the first set of jetting nozzles/circulation ports **31** and also the diameter of the second set of jetting nozzles/circulation ports **74** can be varied as required to permit greater or lesser flow therethrough. In addition, it should be understood that the single jetting nozzle **80** contains a jet which permits fluid to pass therethrough:—

a) in a circulation mode up to a certain pre-determined pressure (in order to move the fluid downhole in order to e.g. lift the debris out of the wellbore **100**; and

b) once the required pre-determined pressure has been reached (which as will be described subsequently, particularly during Stage 8) could be in the region of 1750 PSI in this example, the said jetting nozzle **80** will jet the fluid at a disruptive forceful rate sufficient to dislodge and/or disturb the old cement **104** or formation or other material **104** such as unwanted gas or other fluid **104** in the annulus in the slot jet area **106** between the outer surface of the casing **102** and the inner surface of the borehole **105**, and ultimately circulate such material **104** up to the surface of the wellbore **100** for disposal.

An activation mechanism in the form of an activation piston **40** is generally located in the throughbore **14** of the mandrel **13**, where the activation piston **40** comprises a downwardly projecting cylinder **42** having a piston head **43** located within the cylinder **42** at the lower most end thereof, where the piston head **43** is provided at the lower end of a piston rod **44** and where a spring **45** (which may be a coiled spring **45** or leaf washers or any other suitable spring) acts between the mandrel **13** and the upper face of the piston head **43** and wherein the spring acts to bias the piston head and thus the piston rod into the position/configuration of the slotting and jetting tool **10** shown in FIG. **3**(*a*). The lower face of the piston head **43** is in use in fluid contact with the fluid located in the throughbore **14** and the outer circumferential surface of the piston head **43** is sealed to the inner surface of the cylinder **42** by a suitable seal such as an O-ring seal or the like.

The upper end of the piston rod **44** is pivotally coupled to a wheel mount **50** upon which is mounted a slotting blade in the form of a cutting wheel **60** by means of a wheel hub **62** and a wheel axle **64**. The wheel hub **62** and wheel axle **64** can furthermore lie within an axially extending and angled slotted ramp **55**. The slotted ramp **55** is angled such that it angles (preferably linearly) outwardly from the longitudinal axis or centre line **57** of the slotting and jetting tool **10** as it axially extends upwards. Accordingly, the lower end of the slotted ramp **55** is closer to the centre line **57** of the slotting and jetting tool **10** than the upper end of the slotted ramp **55**. The wheel axle **64** is located on its rotational axis which is perpendicular to the radius of the slotting and jetting tool **10** extending from the centre line **57**. Accordingly, the activation piston **40** is arranged such that an increase in fluid pressure within the throughbore **14** acts upon the lower face of the piston head **43** and will therefore force the piston head **43** and thus the piston rod **44**, wheel mount **50** and thus the wheel axle **64**, wheel hub **62** and most importantly the cutting wheel **60** in both an axially upwards direction and also a radially outwards direction such that the cutting wheel **60** will move from the stored/inactive/running in hole configuration shown in FIGS. **3**(*a*) and **3**(*b*) to the activated/radially extended outwards and cutting or slotting configuration shown in FIGS. **4**(*a*) and **4**(*b*).

It should be noted however that the cutting wheel **60** is not reliant on the force created by the pressure of said fluid to stay engaged with the inner surface of the casing **102** or indeed is not reliant on said force created by the fluid pressure to cause the cutting/slotting action through the casing **102**. Rather, as the drill string **120** is moved downwards during operation of the method used for actuation of this first embodiment of slotting and jetting tool **10** (by the operator setting down weight (particularly in relatively vertical wellbores **100**) and/or actively pushing downwards at the surface on the drill string **120** (particularly in relatively deviated wellbores **100**) in order to lower the drill string **120** further into the wellbore **100**) and as will be described subsequently, the cutting wheel **60** is not only kept forced outwards in the activated/radially extended outwards configuration due to the ramped shape of the slotted ramp **55**, in that the slotted ramp **55** acts as a wedge to keep the cutting wheel **60** in the activated/radially extended outwards configuration, but the effect of the ramp **55** actually causes the cutting wheel **60** to be forced even further outwards and therefore to cause the slots **108** through the sidewall of the casing **102**.

Accordingly, the first embodiment of the slotting and jetting tool **10** disclosed herein can be considered to have two stages of activation:—

a) a pressure activation stage in which fluid pressure is applied down the throughbore of the drill sting **120** from the surface of the wellbore **100** in order to act upon the lower face of the piston head **43** of the activation piston **40** in order to force the piston head **43** and thus the piston rod **44**, wheel mount **50** and thus the wheel axle **64**, wheel hub **62** and most importantly the cutting wheel **60** in:—

i) an axially upwards direction and also a radially outwards direction such that the cutting wheel **60** will move from the stored/inactive/running in hole configuration shown in FIGS. **3**(*a*) and **3**(*b*) to the activated/radially extended outwards and cutting or slotting configuration shown in FIGS. **4**(*a*) and **4**(*b*) although it should be noted that it is unlikely that the force applied by the fluid pressure alone will be sufficient to force the cutting wheel's **60** cutting tips through the sidewall of the casing **102** to form the slots **108**;

AND

b) a drill string movement activation stage—in which downwards movement of the drill string **120** by the operator will further force the cutting wheel **60** further up the ramp **55** and thus will be further forced radially outwards with significant levels of force sufficient to force the cutting wheel's **60** cutting tips through the sidewall of the casing **102** to form the slots **108**.

In operation, this has a great advantage over conventional means of cutting through the sidewall of casing **102** downhole, where such conventional means typically rely on fluid pressure activated cutting means such as high speed cutting blades and the like, because much greater force can be applied to the cutting wheel **60** (and thus to the cutting tips thereof in order to form the slots **108** in the casing **102** sidewall as will be subsequently described) given the very high weight load that can be applied due to the very heavy weight of the drill string **120** (especially in relatively vertical wells).

However, reduction of the pressure of fluid within the throughbore **14** by the operator at the surface will reduce the force of that pressurised fluid acting upon the lower most face of the piston head **43** and thus the coiled spring **45** will bias the piston head **43** and thus the piston rod **44** and ultimately the cutting wheel **60** both axially downwards and also radially inwards in order to return the cutting wheel **60** to the inactive configuration shown in FIGS. **3**(*a*) and **3**(*b*) (or **6**(*a*) and **6**(*b*) if a drop ball **68** has been dropped as will be described subsequently). Moreover, the cutting wheel **60** will automatically return to the inactive configuration when the string **120** is picked up at the surface by the operator and the spring and the ramped nature of the shape of the slotted ramp will aid this return (once the pressure has been bled off).

The ball seat **70** is advantageously shear pin coupled to the ball seat carrier **72** by means of a (third) set of shear pins **73** and which have a higher shear strength than the (second) set of shear pins **15** such that the (third) set of shear pins **73** will remain intact in place after the (second) set of shear pins **15** have sheared and thus an operator can obturate the throughbore **14** until the operator is ready to start circulation of fluid below the slotting and cutting tool **10** (in particular, to circulate isolation material such as cement **112** down below the cups **20** once the cups **20** are located in a non-slotted hole section) at which point the operator can pressure up the fluid at surface which results in pressure acting upon the drop ball **68** and ball seat **70** and once the force reaches the critical point of shearing the (third) set of shear pins **73**, they **73** will shear and thus the ball seat **70** and drop ball **68** will fall through the ball seat carrier **72** and thus the fluid (such as isolation material **112**) will be able to pass through the throughbore **14** and into the inverted float (shear) sub **30** below, as will be described subsequently in more detail.

The cutting wheel **60** is generally disc shaped but further comprises a serrated or castellated outer circumference such that the cutting wheel **60** comprises a number of cutting tips circumferentially equi-spaced around its circumference and which are therefore separated by gaps in order to increase the cutting force applied to the cutting tips. The cutting tips of the cutting wheel **60** may be suitably coated (such as tungsten or diamond coated for example) to provide a very hard cutting surface to aid slotting, cutting or slicing through the casing **102** as will be subsequently described.

Inverted Float (Shear) Sub **30**

The inverted float (shear) sub **30** is shown in detail in FIGS. **2**(*e*) and **2**(*f*), and also in FIG. **5**. As particularly seen in FIG. **2**(*e*), the inverted float (shear) sub **30** comprises a tubular outer body or mandrel **32** having a throughbore **34**. A flapper valve **36** is pivotally mounted at one side to a slidable valve housing **38** by means of a pivot pin **37**. The slidable valve housing **38** is initially located axially in place within the throughbore **34** of the mandrel **32** at the position shown in FIG. **2**(*e*) by means of a (first) set of shear pins **39**. Moreover, the slidable valve housing **38** is at least initially located within the throughbore **34** at an axial position such that it sealingly obturates a circumferentially arranged (first) set (i.e. a plurality) of jetting nozzles/circulation ports **31** which are formed through a side wall of the mandrel **32** all the way (i.e. 360 degrees) around the circumference of the mandrel **32** and the slidable valve housing **38** is initially sealed to the inner surface **35** of the mandrel **32** by an upper and lower pair of O-ring seals **33**.

The inverted float (shear) sub **30** is arranged such that the flapper valve **36** can be open when the BHA **1** is running in-hole, such that the wellbore fluid can pass therethrough, allowing the running in of the BHA **1**. However, when the pressure of fluid at the surface is increased by the operator, that increase is of course transmitted to the fluid within the throughbore **34**, and the flapper **36** will shut in order to seal the throughbore **34** and thus no further fluid can pass down through the throughbore **34** past the flapper valve **36** and thus the flapper valve **36** is now in the closed flapper configuration as shown in FIG. **2**(*f*). However, if the operator wishes to open the (first) set of jetting nozzles/circulation ports **31**, the operator can increase the pressure of fluid at the surface pumped down the throughbore of the drill string **120** and as long as there is no drop ball obturating the throughbore **14** of the slotting and jetting tool **10**, the pressure acting upon the closed flapper **36** will increase up to the point (for example a pre-determined pressure of say 2500 PSI) that the (first) set of shear pins **39** fail and at that point the slidable valve housing **38** will move downwards from the configuration shown in FIG. **2**(*f*) until it reaches the position shown in FIG. **5** at which point the (first) set of jetting nozzles/circulation ports **31** have been uncovered and thus the fluid pumped down and located in the throughbore **34** will be jetted out through the (first) set of jetting holes/circulation ports **31** formed through the side wall of the mandrel **32** of the inverted float (shear) sub **30**.

Description of Method of Plugging and Abandonment of a Wellbore Using the First Embodiment of the Slotting and Jetting Tool **10**

A method of plugging and abandoning a wellbore in accordance with the present invention will now be described.

The following steps or stages of the method should generally be followed in the numerical order indicated below but some steps may be operated or performed in a different order and/or may be omitted.

Running and Slotting Procedure

Stage 1—FIG. **1** and FIG. **9**

The operating personnel responsible for the BHA **1** incorporating the first embodiment of the slotting and jetting tool **10** will visually inspect the BHA **1** at surface on the drilling rig floor prior to including the BHA **1** in the drill string **120** and in particular visually inspect the slotting and jetting tool **10** in order to ensure that it is in full working order.

Stage 2—FIG. **1** and FIG. **9**

The operating personnel will include the BHA **1** in the drill string **120** on the drill rig floor and will conduct a surface function test of the slotting blade/cutting wheel **60** and the single jetting nozzle **80** by pressuring up the fluid in the throughbore **14** to the required operating pressure (which may for example be 1750 PSI but other pressures may be used as pre-determined by the operator) to ensure they are in good working order prior to Running In Hole (RIH).

Stage 3—FIG. **9** and FIG. **10**

A conventional bridge plug **110** can be set within the wellbore **100** at a location just below the slot jet area **106** of the wellbore **100** (which is same as the area of the casing **102** to be slotted **130** with slots **108**) where the slotting and jetting tool **10** will be used to slot **108** the casing **102**, the bridge plug **110** serving to seal the throughbore **103** of the wellbore **100** at that location. The bridge plug **110** can either be run into the wellbore **100** prior to the BHA **1** being run into the wellbore **100** or the bridge plug **110** can be suitably attached to the lower end of the BHA **1** and run into the wellbore **100** with the BHA **1** and can be deployed, sealed and then detached from the BHA **1** by conventional means.

Either way, the BHA **1** incorporating the slotting and jetting tool **10** is run into the wellbore **100** until it reaches the upper end of the lateral isolation placement depth which in general is the area of the casing to be slotted **130** and (ultimately) to be filled with isolation material **112** (such as cement or the like) in the subsequent steps.

The BHA **1** should be run into the wellbore **100** at a maximum running speed of approximately 90 feet per minute inside the casing **102** particularly when the inner diameter of the casing **102** is the same size as the diverting cups **20** in order to avoid swab surging or hydraulic lock occurring due to the fluid bypass channels (hereinbefore described but not shown in the drawings) around or through the cups **20** being overwhelmed.

The slotting and jetting tool **10**, when in the running in-hole (RIH) configuration, is as shown in FIGS. **3**(*a*) and **3**(*b*) where the activation piston **40** is in the relaxed position due to it not experiencing any significant and/or sufficient fluid pressure. The inverted float (shear) sub **30** is shown in its running in-hole configuration (opened) in FIG. **2**(*e*) where the flapper valve **36** is shown in its open configuration such that the inverted float (shear) sub **30** can pass down through the wellbore fluid located in the throughbore **103** of the casing **102**. The BHA **1** and drill string **120** is now at the position in the wellbore **100** as shown in FIG. **11**.

Stage 4—FIG. **11**

The operator will, at surface, record the up and down weight of the drill string **120**, said weights typically being dictated by the:

depth;
well inclination;
fluid;
torque & drag of the wellbore **100** geometry; and
string configuration; etc. etc.

Stage 5—FIG. **11**

Prior to functioning the BHA **1** and in particular the slotting and jetting tool **10** and inverted float (shear) sub **30**, the operator will likely run the BHA **1** to its maximum in use depth (i.e. just above the bridge plug **110**) and will then pick the drill string **120** back up such that the BHA **1** is pulled back up to be aligned with the top of the lateral isolation placement depth (i.e. the uppermost end or top of the slot jet area **106**) and therefore the top of the area of the casing to be slotted **130**. By performing this step, the operator will therefore know how many stands of drill pipe are required to make up that depth and also the operator will then install an open conventional TIW/Kelly valve (not shown) in the drill pipe string **120** at the drill pipe floor level, the number of TIW/kelly valves required being dictated by the depth or length of the slot jet area **106**.

Stage 6—FIG. **12**

The operator will pressure up the drill string **120** to an appropriate pressure such as 1,250 psi in order to close the inverted float flapper valve **36** (as shown in the closed position in FIG. **12** and in more detail in FIG. **2**(*f*)) such that the flapper valve **36** moves from the open position shown in FIG. **2**(*e*) to the closed position shown in FIG. **2**(*f*).

Stage 7—FIG. **12**

The operator can now activate the slotting blade or cutting wheel **60** by pressuring up the throughbore of the drill string **120** to an appropriate pressure such as 1,500 psi and that fluid pressure will act against the upper surface of the now closed flapper valve **36**. That increased pressure is calculated or pre-determined to be sufficient to now act on the activation piston **40** such that it will move the piston head **43** and thus the piston rod **44** upwards such that the slotting blade or cutting wheel **60** is moved both upwards and radially outwards along the slotted ramp **55** from the configuration shown in FIGS. **3**(*a*) and **3**(*b*) to the extended configuration shown in FIGS. **4**(*a*) and **4**(*b*) such that the slotting blade/cutting wheel **60** extends radially outwards firstly beyond the outer diameter of the mandrel **13** and then secondly is forced against the inner surface of the casing **102** and then thirdly, due to the wedge action provided by the slotted ramp **55** as the BHA **1** is moved downwards, punctures, cuts or slots through the side wall of the casing **102** in order to form a slot **108** therein. In addition, the slotting blade/cutting wheel **60** will further extend and puncture, cut and slot into and through the old cement **104** (and potentially the formation itself) located in the annulus between the outer surface of the casing and the borehole wall **105**.

Stage 8—FIG. **12**

After the operator has confirmation of the blades **60** full travel upward and outwards and that casing **102** has begun to be slotted **108**, the operator will continue to pressure up the string further to, for example, 1,750 psi pressure and in so doing will cause significant jetting of fluid through the single jetting nozzle **80** located directly vertically above and longitudinally aligned above the extended slotting blade/cutting wheel **60**.

The pressurised fluid in the throughbore **14** of the mandrel **13** of the slotting and jetting tool **10** will therefore be forced out through the single jetting nozzle **80** in order to ensure that the washing fluid will wash through the slots that have just been formed through the casing **102** as the slotting and jetting tool **10** is moved downwards in subsequent steps (for example in step 9) because the single jetting nozzle **80** is circumferentially and longitudinally aligned with the slotting blades/cutting wheel **60**, and because it is located vertically above the cutting wheel **60** it will permit the pressurised cleaning/washing fluid to be jetted through the slots **108** that have just been formed.

Stage 9—FIG. **13**

The operator will now set down weight on the drill string **120** such that the BHA **1** and more importantly the slotting and jetting tool **10** are moved downwards for example by 3 feet such that the slotting blades/cutting wheel **60** forms a number of longitudinally spaced apart slots **108** through the side wall of the casing **102** with its cutting tips as previously described.

Furthermore, the upper **20**U and lower **20**L pair of jetting cups ensure that the washing fluid which is highly pressurised to, for example 1,750 psi, is directed out through those slots **108** because the outer surfaces of the cups **20** are in sealed and sliding engagement with the inner surface of the casing **102**.

Stage 10

The operator can then, if desired, perform an optional flow check by performing the next three stages. They can initiate this by shutting down the pumps at surface which supply the pressurised washing fluid down the throughbore of the drill string **120** in order to bleed the washing fluid pressure off.

Stage 11

The operator can then pick up the drill string **120** by for example 5 feet such that the BHA **1** is now located above the slot jet area **130** and therefore above the slots **108**.

Stage 12

The operator can then apply an increased washing fluid pressure by initiating pumps again at surface and supply for example 2,000 psi (but other pressures may be used as pre-determined by the operator) of pressure down the throughbore of the drill string **120** and can test the integrity of the cups **20**.

Importantly, the pressure at which the integrity check of the cups **20** is performed is arranged to be lower than the slotting blade/cutting wheel **60** activation pressure of the activation piston **40**.

Accordingly, because the cups are arranged in a non-slotted area (i.e. they are positioned above the slot jet area **130**), the integrity of the cups **20** can be tested in that there should be no washing fluid loss because all of the washing fluid should be retained within the area defined by the upper **20**U and lower **20**L jetting cups and therefore there should be no loss of washing fluid if the integrity of the cups **20** is in place.

Stage 13—FIG. **14**

The operator will move the drill string **120** downwards and will observe washing fluid pressure bleed off when the cups **20** pass over the slots **108**. The operator will then shut down the washing fluid pumps at surface. This stage 13 ensures that the casing **102** has been slotted **108** and stage 12 has also confirmed that the integrity of the cups **20** is in good condition.

Stage 14—FIG. **14**

The operator will then start to commence further slotting by activating the activation piston **40** by pressuring up the drill string to for example 1,500 psi again against the inverted closed flapper valve **36**.

Stage 15—FIG. **14**

After the operator has confirmation of the slotting blade/cutting wheel **60** full travel upwards and radially outwards along the axially extending angled slotted ramp **55**, and has confirmation that the casing **102** is being slotted **108**, the operator will continue to pressure up the drill string **120** to 1,750 psi pressure again to start jetting from the single jetting nozzle **80** again.

Stage 16—FIG. **14**

The operator will again move the BHA **1** and therefore the slotting and jetting tool **10** downwards within the slot jet area **130** of the wellbore **100** and will monitor the stand pipe pressure of the washing fluid at surface for any fluctuation in that pressure—fluctuation of the pressure will indicate to the operator that the old cement or formation **104** is bridging the slots **108** and has therefore not yet been washed out. If such fluctuation of pressure is observed, the operator will continue to wash the cement for a longer period of time until no fluctuation of such pressure is observed.

Stage 17—FIG. **14**

Once the operator has lowered the BHA **1** down 200 feet of travel and has therefore caused 200 feet of slot jet area **130** to be slotted **108**, the operator will shut down the washing fluid pumps and will bleed off the washing fluid pressure.

The operator will check the tally of drill pipe stands inserted into the drill string **120** to ensure that the correct depth has been reached.

Stage 18—FIG. **14**

If for example the slot jet areas **130** is to be 200 feet, the operator will pick up the drill string **120** by 205 feet such that the BHA **1** is located 5 feet above the slot jet area **130** and therefore the cups **20** are compressed against the inner surface of the casing **102** at a location at which there are no slots therein.

Stage 19—FIG. **14**

The operator will then apply a suitable pressure such as 2,000 psi to the washing fluid that is pumped down through the drill string **120** in order to check the integrity of the cups **20** and again that pressure is to be below the slotting blade/cutting wheel **60** activation pressure.

The operator does that by ensuring that the cups **20** are placed in a non-slotted area of the casing **102**.

Stage 20

The operator will move the BHA **1** and therefore the slotting and jetting tool **10** five feet down into the wellbore.

Stage 21

The operator will then rotate the drill string by any suitable number of degrees between 45 to 90 degrees of phasing (which will be confirmed on location during execution of the plugging and abandonment operation depending upon if the operator wishes for example four to 8 vertically extending lines of slots **108** formed through the casing **102**). The skilled person will understand however that greater or fewer longitudinally extending columns of slots **108** may be formed by varying the degrees of rotation imparted to the BHA **1**.

It should be noted that the operator can rotationally lock and unlock the BHA **1** from the rest of the work string **120** by operating the swivel **90** (which can be achieved by different methods depending upon what type of locking mechanism is incorporated in the swivel tool **90**, such as rotating the work string **120** with lefthand turn rotation of the work string **120** at surface by the operator or the other way round. Alternately, there are swivel tools **90** that are pressure activated i.e. when pressure is applied, the swivel tool **90** allows the work string **120** to rotate with respect to the BHA **1** etc.).

Stage 22

The operator will then repeat steps 12-21 in order to provide another vertically extending and vertically spaced apart column of slots **108** through the side wall of the casing **102** and will wash out the old cement or formation **104** in the annulus behind those slots **108**.

Stage 23—FIG. **14**

After the operator has confirmation of one or more repeated stage 22, the operator will run the drill pipe string **120** down to the bottom and place the slotting and jetting tool **10** in line with the bottom slot **108**.

Final Jetting Procedure

Stage 24

The operator will, at surface, record the up and down weight of the drill string **120**, said weights typically being dictated by the:

depth;
well inclination;
fluid;
torque & drag of the wellbore **100** geometry; and
string configuration; etc. etc.

Stage 25

The operator will place the cups **20** against the inner surface of the casing **102** below the lower most slots **108** and therefore below the slot jet area **130**.

Stage 26—FIG. **15**

The operator will then pressure up the fluid in the throughbore of the string **120** to a suitable pressure, such as for example 2,500 psi and in so doing will shear the first set of shear pins **39** in the BHA **1**, those being the set of shear pins **39** provided in the inverted float (shear) sub **30**. The shearing of the shear pins **39** will cause the slideable valve housing **38** to drop downwards, thus uncovering the (first) set of circulation ports **31** and therefore providing circulation of washing fluid out of the throughbore **34** through the (first) set of jetting nozzles/circulation ports **31** and therefore providing for a 360 degrees of fluid circulation below the slotting and jetting tool **10**. The inverted float (shear) sub **30** is now in the configuration shown in FIG. **5** and the rest of the BHA **1** is shown in the configuration shown in FIG. **15**, where the inverted flapper valve **36** has been moved below the (first) set of jetting nozzles/circulation ports **31**.

Stage 27—FIG. **16** and FIGS. **6**(*a*) and (**6***b*)

The operator will then drop a drop ball **68** down the throughbore of the drill string **120** and will allow gravity to pull the drop ball **68** to depth until it lands on the ball seat **70**, and the pumping of fluid down the throughbore of the drill string **120** will of course greatly aid and speed the landing of the drop ball **68** on the ball seat **70**. The throughbore of the drill string **120** above the ball seat **70** and drop ball **68** is therefore blocked and fluid pressure applied at surface by the operator can therefore increase thereon.

Stage 28—FIGS. **7**(*a*), **7**(*b*) and FIG. **17**

The operator will then pressure up the washing fluid pumped into the throughbore of the drill string **120** to a suitable pressure such as 2,000 or even 2,500 psi and in so doing will shear the second set of shear pins **15** provided in the BHA **1**, namely the set of shear pins **15** provided in the slotting and jetting tool **10** which are sheared because the fluid pressure builds up due to the drop ball **68** obturating the throughbore **14**. The ball seat carrier **72** thus drops to the position shown in FIGS. **7**(*a*) and **7**(*b*) and in so doing uncovers the 360 degree and second set of jetting nozzles/circulation ports **74**. Accordingly, the washing fluid flow is changed such that it will also and/or mainly flow out of the 360 degree (second) set of jetting nozzles/circulation ports **74**.

Stage 29—FIG. **17**

The operator will pressure up the string **120** to a suitable pressure such as 2000 psi (or any other suitable pressure as pre-determined by the operator) and will start to rotate the string **120** above the slotting and jetting tool **10** to a maximum of 120 RPM if required, although if the wellbore **120** is shallow then no rotation may be required (for example if the wellbore is above a depth of 3,000 feet, then no rotation may be required). The swivel tool **90** located above the slotting and jetting tool **10** will therefore rotationally decouple the slotting and jetting tool **10** and indeed the rest of the BHA **1** such that they will not experience that rotation. The operator may well wish to rotate the string **120** in order to create velocity (i.e. turbulent force) in the wellbore fluid surrounding the string **120**, where this velocity assists in the lifting of any cuttings **104** from the annulus between the outer surface of the string **120** and the inner surface of the casing **102**, thereby assisting the lifting of such material **104** such as the cuttings to the surface.

Stage 30—FIG. **17**

The operator will then pick up the drill string **120** and will jet washing fluid between the cups **20** via the 360 degrees (second) set of jetting nozzles/circulation ports **74** and will monitor the standpipe pressure at surface for any bridging occurring in the annulus **104**.

Stage 31

After the operator has obtained confirmation of 360 degrees of jetting fluid being pumped through the (second) set of jetting nozzles/circulation ports **74** and has noted 200 feet of clean annulus **104** (i.e. with no old cement left in the annulus **104**), the operator will shut down the fluid pumps and will stop rotation of the drill string **120**.

Stage 32—FIG. **18**

The operator will know that he has a clean annulus **104** due to that being indicated by no fluctuations of spikes in the standpipe pressure at surface and instead the operator will observe a consistent pressure at surface during the final jetting procedure. If so, the operator will proceed to stage 33. If not, the operator can repeat Stages 29 to 31.

Stage 33

The operator will run the drill string **120** back in hole such that the BHA **1** and slotting and jetting tool **1** are located in line with the bottom slots **108**.

Stage 34

The operator will conduct a flow check to ensure that everything is ready for the isolation/cementing procedure to follow.

Isolation/Cementing Procedure

Stage 35

The operator will mix and then pump whatever mix of suitable isolation material is desired, as determined by the cementing specialist on the drilling rig, such as:—

a) spacer fluid material, followed by;

b) isolation material **112** (such as cement or similar); and

c) spacer material;

with an appropriate cementing unit (not shown) at surface (e.g. on the drilling rig floor (not shown)).

Stage 36—FIG. **19**

The operator will then pump that spacer material followed by the isolation material **112** followed by the next batch of spacer material at a reduced rate down through the throughbore of the drill string **120** until it arrives at and passes through the (second) set of 360 degree jetting nozzles/circulation ports **74** and until the BHA **1** has been submerged in isolation material/cement—see FIG. **19**. Accordingly, such pumping will result in the isolation/cement material **112** filling the throughbore **103** of the casing **102** from above the bridge plug **110** until the isolation material/cement **112** is located above the upper cup **20**U. This ensures that the entire slotting and jetting tool **10** is submerged in isolation material such as cement or similar **112**.

Stage 37

The operator starts to pull the drill string **120** out of the wellbore **100** whilst pumping isolation material **112** down through the throughbore of the drill string **120** in order to jet the isolation material **112** through the second set of 360 degrees jetting nozzles/circulation ports **74**, such that the slotting and jetting tool **10** is always submerged by the isolation material **112** as it is being pulled out of the wellbore **100**.

The operator will continue to rotate the drill pipe string **120** whilst pulling it out of the wellbore **100** until the operator has pulled enough drill string **120** out of the wellbore **100** such that he can remove one stand of drill pipe.

Stage 38

The operator will stop pumping the isolation material **112** and will instead breakout that one stand of drill pipe.

Stage 39

The operator will continue to pull out the drill pipe string **120** out of the wellbore **100** and will alternatively stop pumping the isolation material **112** and will break out the stands of drill pipe.

Stage 40—FIG. **20**

The operator will continue to pull the drill pipe string **120** out of the wellbore **100** until, importantly, the BHA **1** is located above the theoretical top of the isolation material and above the top (shallowest) slots **112** W/O (WithOut) the operator rotating the drill pipe string **120** at the surface; the operator may wish to do this because stopping rotation will limit the contamination of pump fluid, spacer and the isolation material such as cement **112** (i.e. no turbulent force to mix everything together).

Stage 41—FIG. **21**

The operator will pressure up the isolation material **112** in the drill string **120** to a pre-determined pressure such as for example 3000 psi (although the pressure could be different as decided by the operator) and in so doing will shear the third set of shear pins **73** which act between the ball seat **70** and ball seat carrier **72** which will then open up circulation of fluid through the throughbore **14** and thus the jetting and cutting tool **10** is now in the configuration shown on FIG. **8**(*a*) and FIG. **8**(*b*). Accordingly, the isolation material **112** such as cement can be now pumped down into the throughbore **34** of the inverted float (shear) tool **30** and out through the (first) set of 360 degree jetting nozzles/circulation ports **31** in order to obtain circulation of isolation material **112** below the jetting and cutting tool **10**. In other words, the operator is able to change the flow path of the isolation material:—

a) from down the throughbore of the string **120** and out of the string **120** through the single jetting nozzle **80** and more importantly the 360 degree set of jetting nozzles **74** in between the upper **20**U and lower **20**L sets of cups **20** and through the slots **108**;

b) to down the throughbore of the string **120**, down the throughbore **14** of the slotting and jetting tool **10** and into the throughbore of the inverted float (shear) sub **30** and out through the second set of jetting nozzles/circulation ports **31** (i.e. below the lower most cups **20**L.

Stage 42—FIG. **22**

The operator will then circulate the wellbore **100** clean at the maximum loss free rate with cleaning fluid.

Stage 43

The operator will space out (i.e. place the string at the correct place at the surface to ensure nothing is preventing the BOP(s) (not shown) from shutting) and clean up the wellbore **100** with appropriate cleaning fluid and close the annular BOP at the surface of the wellbore **100**.

Stage 44

The operator will wait on isolation material **112** to set and if needs be will pressure up the wellbore **100** as required to aid the setting of the isolation material **112**. This Stage 44 can be swapped with Stage 45 if desired.

Stage 45—FIG. **23**

Once the isolation material **112** is set, the operator will pull the entire drill string **120** and BHA **1** out of the hole and lay down or layout drill pipe and slotting and jetting tool **10**.

Technical Benefits Realised which Result from Embodiments of the Present Invention Compared with Current Technology

The BHA **1** and in particular the inverted float (shear) sub **30** and the slotting and jetting tool **10** provide the advantage of enabling a one trip annulus remediation system deployed on drill pipe **120** at considerably lower cost and risk compared with current techniques (particularly those that utilise perforating gun systems).

The BHA **1** allows placement of a lateral barrier (rock to rock) in the form of the isolation material such as cement **112** which is particularly useful in hydrocarbon wellbores **100** (which are considerably more complex than e.g. water wellbores) without having to pull or section mill the casing **102** or liner string **102**.

The embodiments of BHA **1** allow for slotting of casing between 4.5 inch diameter up to 20 inch diameter casing **102**.

Moreover, the cutting wheel **60** design permits perforation of a casing string **102** and can provide for example a one inch length by 0.25 inch width slot size for each slot **108** and can provide a gap in the region of 1.5 inches between each slot **108**.

The BHA **1** therefore enables a repeatable mechanical multiuse slotting system and moreover provides two different jetting systems in the slotting and jetting tool **10** within the one tool **10** and provides a further jetting system within the inverted float sub **30**.

In an alternative embodiment of the BHA **1**, the cups **20** and associated cup tools **22**, **24** could be omitted and whilst that has the disadvantage of not providing the captured volume through which the second set of jetting ports/circulation holes **74** can flow into, in such an embodiment, the rest of the BHA **1** can be modified to suit other applications (for example by using a second larger drop ball (not shown) to knock against the first drop ball **68** and shear the third shear pins **73** in order to open up the circulation through the throughbore **14** again).

Embodiments of the present invention allow a bypass of fluid when running the BHA **1** into the wellbore **100** and also when pulling out of the hole by virtue of the fluid bypass channels around, through or within the cups **20**.

In addition, the BHA **1** enables 360 degree jetting of fluid (whether washing fluid or cement/isolation material **112**) after the slotting **108** has occurred.

In addition, there are various key performance indicators available to the operator at the surface during the operation of the method hereinbefore described such as pressure, weight and fluid returns.

There are many advantages and benefits obtained by performing embodiments of the present invention such as:—

- Less/no permitting by safety authorities required due to the system not using any perforation guns.
- no perforation gun re-stocking charge required as the embodiments are explosive free.
- the method enables a single trip system with no sump required.
- the method enables the ability to remove and wash ratty or poorly formed cement or other suitable materials **104**.
- the embodiments provide standoff after the slots **108** have been formed and as such elevates the casing **102** off of the low side and this is beneficial if the casing **102** is actually a liner located within a casing and is lying on the casing of if the casing **102** is lying on a more horizontal section of the wellbore **100**—the stand off can allow fluid to pass through the gap or annulus provided by the standoff. the embodiments of the present invention will ensure clean slots **108** are provided due to the ability to jet whilst slotting.
- the slotted length can be changed when in hole. Moreover, there is no waiting for final interpretation of log results before running in hole. This provides major benefits whilst conducting the operation because the operation can be changed if log results show differences to the anticipated well profile, whereas perforation guns need to be set up in advance and can't be changed during running in hole.
- the embodiments of the present invention minimise the man power that is required on location, due to the avoidance of perforation guns.
- embodiments of the present invention can be adapted for different casing sizes whilst on location, such as a drilling rig.

Safety factor of not handling explosives with stored energy.

No requirement to dispose of harmful gases produced from explosives which add additional time to the execution timings and furthermore, significant environmental benefits are achieved by not having to capture potentially harmful gasses.

Example Pressure Applied for Shear Values:

1^{st} set of shear pins 39 (in the Inverted Float (shear) sub 30) -	2500 psi
2^{nd} set of shear pins 15 (in the slotting and jetting tool 10) -	2500 psi
3^{rd} set of shear pins 73 (in the slotting and jetting tool 10) -	3000 psi

Second Embodiment of (Inverted) Slotting and Jetting Tool **210**

A second embodiment of slotting and jetting tool **210** is also provided as an alternative to the first embodiment, albeit in some circumstances and particularly with differently sized drop balls and/or differently assigned activation pressures, the skilled person could envisage running both the first embodiment of slotting and jetting tool **10** and the second (inverted) embodiment of slotting and jetting tool **210** into the wellbore **100** spaced apart on the same work string **120** wherein the skilled person could operate either slotting and jetting tool **10**; **210** in turn as per their requirements.

Overall, the second (inverted) embodiment of the slotting and jetting tool **210** is particularly useful when an operator wishes to form the slots **80** in the casing **102** by pulling up on the work string in order to apply upwards directed force to the inverted slotting and jetting tool **210** (as opposed to pushing down on the drill string **120** in order to apply downwards directed force to the first embodiment of the slotting and jetting tool **10**).

The second (inverted) embodiment of slotting and jetting tool **210** is relatively similar to the first embodiment of slotting tool (and where that is the case, the same reference numeral has been used but with the addition of 200 in relation to the same/similar component/function and for such components/functions, their further operation will not be repeated again).

However, the main difference between the two embodiments is that the second embodiment of the slotting and jetting tool **210** is inverted (i.e. it can basically be considered by a skilled person to be an upside down version (in concept) when compared to the first embodiment of slotting and jetting tool **10**), in that for example:—

i) the ball seat carrier **272** is (at least initially) secured within the throughbore **214** of the mandrel **213** to the inner surface **214**S thereof by a set **215** of shear pins such that whilst the set of shear pins **215** remain intact, the ball seat carrier **272** remains in position as shown in FIG. **24**(*a*) to **24** (*c*) and therefore by means of the ball seat carrier **272** being connected to a sleeve cover **299** (which in the configuration and position shown in FIGS. **24** (*a*) to (*c*) covers over and therefore obturates the set of (a plurality of) 360 degrees jetting nozzles/circulation ports/washing ports **274** which are equi-spaced around the circumference of the mandrel **213** formed through the side wall thereof thus providing a 360 degree coverage of fluid jetting function when they have been uncovered (when the sleeve cover **299** is moved downwards) as will be described subsequently. However, whilst the ball seat carrier **272** is shear pinned in place by the set of shear pins **215**, no fluid can pass from the throughbore **214** through the (second) plurality or set of jetting nozzles/circulation ports/washing ports **274** due to the presence of one or more suitable seals such as O-ring seals (not shown) located and acting in between the outer surface of the ball seat carrier **272** and the inner surface **214**S of the mandrel **213** at a location above and below the (second) set of jetting nozzles/circulation ports **274**;

ii) there is further provided a single jetting nozzle **280** formed through the side wall of the mandrel **213** at a position some way below the ball seat carrier **272** and is moreover and importantly now also located below the cutting wheel **260** and which is preferably circumferentially aligned (aligned on the same longitudinal axis or plane) with the slotting blade or cutting wheel **260** and which in use will provide a jetting action to jet through the slots **108** that are punctured through the casing **102** along the length or area of casing to be slotted **130** by the cutting wheel **260** in order to jet or wash away the old cement or formation or indeed unwanted gas or other fluid) **104** in the annulus in a slot jet area **106** between the outer surface of the casing **102** and the inner surface of the borehole **105**. Further details of the use of the single jetting nozzle **280** will be described subsequently;

iii) the activation piston **240** comprises an upwardly projecting cylinder **242** having a piston head **243** located within the cylinder **242** at the uppermost end thereof, where the piston head **243** is provided at the upper end of the piston rod **244** and where the spring **245** (which may be a coiled spring **245** or leaf washers or any other suitable spring) acts between an upper surface of the mandrel **213** and the lower face of the piston head **243** and wherein the spring **245** acts to bias the piston head **243** and thus the piston rod **244** into the non-activated position/configuration of the slotting and jetting tool **210** shown in FIG. **24**(*b*) (due to it not experiencing any significant and/or sufficient fluid pressure). The upper face of the piston head **243** is in use in fluid contact with the fluid located in the throughbore **214** and the outer circumferential surface of the piston head **243** is sealed to the inner surface of the cylinder **242** by a suitable seal such as an O-ring seal (not shown) or the like;

iv) the lower end of the piston rod **244** is pivotally coupled to the wheel mount **250** upon which is mounted the slotting blade in the form of the cutting wheel **260** by means of the wheel hub **262** and the wheel axle **264**. The wheel hub **262** and wheel axle **264** can furthermore lie within the axially extending and angled slotted ramp **255**. The slotted ramp **255** is angled such that it angles (preferably linearly) outwardly from the longitudinal axis or centre line **257** of the slotting and jetting tool **210** as it axially extends downwards (i.e. the ramp **255** is inverted with respect to the first embodiment's ramp **55**). Accordingly, the upper end of the slotted ramp **255** is closer to the centre line **257** of the slotting and jetting tool **210** than the lower end of the slotted ramp **255**. The wheel axle **264** is located on its rotational axis which is perpendicular to the radius of the slotting and jetting tool **210** extending from the centre line **257**. Accordingly, the activation piston **240** is arranged such that an increase in fluid pressure within the throughbore **214** acts upon the upper face of the piston head **243** and will therefore force the piston head **243** and thus the piston rod **244**, wheel mount **250** and thus the wheel axle **264**, wheel hub **262** and most importantly the cutting wheel

260 in both an axially downwards direction and also a radially outwards direction such that the cutting wheel 260 will move from the stored/inactive/running in hole/non-activated configuration shown in FIGS. 24(*a*) to 24(*c*) to the activated/radially extended outwards and cutting or slotting configuration shown in FIGS. 27(*a*) and 27(*b*);

v) the inverted slotting and jetting tool is further provided with a selectively slidable piston cylinder sleeve 291 (shown in dotted lines in FIGS. 24(*a*) to (*c*)) as being in the form of a cylinder and which is arranged in a co-axial manner around the outside of the upwardly projecting cylinder 242. The upper most end of the piston cylinder sleeve 291 is secured to the lower face of the drop ball seat carrier 272 and the lower most end of the piston cylinder sleeve 291 is secured to the upper face of the sleeve cover 299, such that when the drop ball seat carrier 272 is shear pinned 215 to the inner surface 214S of the mandrel 214, the piston cylinder sleeve 291 and the sleeve cover 299 are fixed in position (with the latter sealing the set of jetting nozzles/circulation ports/washing ports 274).

An upper 296 and a lower 297 set of bypass ports are formed through the side wall of the piston cylinder sleeve 291 towards its upper end, where the upper 296 and lower 297 ports are spaced apart about a blade piston back pressure valve 292 (which is shown in the shape of a solid cone but could be any other suitable shape such as a flat disc of ball or the like suitably shaped that firstly provides a blockage in the throughbore of the piston cylinder sleeve 291 and secondly can cover over the upper face of the piston head 243 when required, as will be detailed subsequently). The blade piston back pressure valve 292 is arranged to provide a blockage or obturation in the throughbore of the piston cylinder sleeve 291 at that location between the upper and lower 297 set of bypass ports. Accordingly, whilst the shear pins 215 remain in place and thus the piston cylinder sleeve 291 remains fixed in the position shown in FIGS. 24 (*a*) to (*c*), fluid flowing from the surface down through the throughbore of the work string will pass through the ball seat 270, down into the throughbore of the piston cylinder sleeve 291, out through the upper set of bypass ports 296 into the throughbore 214 of the mandrel 213 and can then flow back into the throughbore of the piston cylinder sleeve 291 and can thus then act upon the upper face of the piston head 243; in doing so, the fluid was able to bypass the blade piston back pressure valve 292 and can, if the pressure of the fluid is increased sufficiently, can move the piston head 243 and thus the cutting wheel 260 into the activated configuration to allow slotting to be commenced by pulling up on the inverted slotting and jetting tool 210.

However, when the shear pins 215 are sheared (due to pressure build up above the drop ball 268 when it is seated), the drop ball seat carrier 272, piston cylinder sleeve 291 and the sleeve cover 299 are moved downwards:—

i) firstly uncovering the set of jetting nozzles/circulation ports/washing ports 274 to permit washing (of the inner surface of the casing 102 and more importantly the annulus outside the casing through the slots 108 formed therein by the cutting wheel 260) therethrough; and

ii) secondly the lower set of bypass ports 297 have moved down below the level of the upper face of the piston head 243 and thus fluid within the throughbore 214 of the mandrel 213 of the slotting and jetting tool 210 is prevented from re-entering the throughbore of the piston cylinder sleeve 291 and thus pressure cannot start building up against the upper face of the piston head 243 and therefore the piston rod 244 and thus the cutting blade/wheel 260 are essentially prevented from moving from the retracted (i.e. the running in hole configuration) to the extended position (i.e. the activated configuration) and therefore the cutting blade/wheel 260 is held or restrained in the retracted position.

Accordingly, whilst the seating of the drop ball 268 will prevent fluid from flowing into the throughbore of the piston cylinder sleeve 291 and onto the upper face of the piston head 243, if the drop ball 268 were to be removed therefrom (e.g. by falling off the seat 270 particularly in a highly deviated wellbore 100), the cutting wheel 260 is still prevented from slotting once the washing procedure has commenced (with the dropping and seating of the drop ball 268).

It should importantly again be noted that the cutting wheel 260 is not reliant on the force created by the pressure of said fluid to stay engaged with the inner surface of the casing 102 or indeed is not reliant on said force created by the fluid pressure to cause the cutting/slotting action through the casing 102. Rather, in use, as the drill string 120 or other work string such as coiled tubing is moved upwards during operation of the method used for actuation of this second (inverted) embodiment of slotting and jetting tool 210 (by the operator picking up weight in order to actively pull the upper end of the work string 120 such as the coiled tubing string upwards at the surface (either for relatively deviated or relatively non-deviated wellbores 100) in order to lift the work string 120 and thus the slotting and jetting tool 210 up the wellbore 100) and as will be described subsequently, the cutting wheel 260 is not only kept forced outwards in the activated/radially extended outwards configuration due to the ramped shape of the slotted ramp 255, in that the slotted ramp 255 acts as a wedge to keep the cutting wheel 260 in the activated/radially extended outwards configuration, but the effect of the ramp 255 actually causes the cutting wheel 260 to be forced even further outwards and therefore to cause the slots 108 through the sidewall of the casing 102.

Accordingly, the inverted second embodiment of the slotting and jetting tool 210 disclosed herein can be considered to have two stages of activation:—

a) a pressure activation stage in which fluid pressure is applied down the throughbore of the work string 120 from the surface of the wellbore 100 in order to act upon the upper face of the piston head 243 of the activation piston 240 in order to force the piston head 243 and thus the piston rod 244, wheel mount 250 and thus the wheel axle 264, wheel hub 262 and most importantly the cutting wheel 260 in an axially downwards direction and also a radially outwards direction such that the cutting wheel 260 will move from the stored/inactive/running in hole configuration shown in in FIGS. 24(*a*) to (*c*) to the activated/radially extended outwards and cutting or slotting configuration shown in FIGS. 27(*a*) and 27(*b*) although it should be noted that it is unlikely that the force applied by the fluid pressure alone will be sufficient to force the cutting wheel's 260 cutting tips through the sidewall of the casing 102 to form the slots 108;

AND

b) a work string 120 movement activation stage—in which upwards movement due to lifting or pulling of the work string 120 by the operator at the surface will further force the cutting wheel 260 further down the ramp 255 and thus will be further forced radially outwards with significant levels of force sufficient to force the cutting wheel's 260 cutting tips through the sidewall of the casing 102 to form the slots 108.

In operation, this has a great advantage over conventional means of cutting through the sidewall of casing **102** downhole, where such conventional means typically rely on fluid pressure activated cutting means such as high speed cutting blades and the like, because much greater force can be applied to the cutting wheel **260** (and thus to the cutting tips thereof in order to form the slots in the casing **102** sidewall as previously described) given the very high pulling load that can be applied by the operator at the surface to e.g. a coiled tubing string.

The particular advantage of the inverted embodiment of the slotting and jetting tool **210** is that it can be used within both a drill string **120** but also particularly on the end of a coiled tubing string (not shown) which is particularly advantageous because it is much easier for an operator to apply a certain amount of pulling force to a coiled tubing string than it is to apply the same pushing force to a coiled tubing string (because coiled tubing is prone to buckling when pushed)—and coiled tubing run BHA's are attractive to operators due to their much lower running cost compared with drill string run BHA's.

The Slotting and Jetting Tool **210**

Operation of the Second (Inverted) Embodiment of the Slotting and Jetting Tool **210**

The second (inverted) embodiment of the slotting and jetting tool **210** may be incorporated into a BHA **1** instead of or in addition to (particularly if the two embodiments are arranged to have different activation pressures) the first embodiment of the slotting and jetting tool **10** and the skilled person will understand that it is operated in a similar manner thereto as hereinbefore described with the exception for the differences required given its inverted arrangement and therefore, whilst similarities will not be described, notable differences between the stages 1 to 45 hereinbefore described with reference to the first embodiment of the slotting and jetting tool **10** will now be described for ease of reference of the skilled person.

For example:—

Stage 3—FIG. **9** and FIG. **10**

The BHA **1** incorporating the inverted slotting and jetting tool **210** is run into the wellbore **100** until it reaches the lower end of the lateral isolation placement depth which in general is the area of the casing to be slotted **130** and (ultimately) to be filled with isolation material **112** (such as cement or the like) in the subsequent steps.

The inverted slotting and jetting tool **210**, when in the running in-hole (RIH) configuration, is as shown in FIGS. **24**(*b*) and **24**(*c*) where the activation piston **240** is in the non-activated position due to it not experiencing any significant and/or sufficient fluid pressure. The inverted slotting and jetting tool **210** can pass down through the wellbore fluid located in the throughbore **103** of the casing **102** and said fluid can pass through a bypass channel **298** (around the cutting wheel **260**) formed in the mandrel **213** and out of the throughbore at the upper end of the inverted slotting and jetting tool **210**.

Stage 5—FIG. **11**

Prior to functioning the BHA **1** and in particular the slotting and jetting tool **210**, the operator will likely run the BHA **1** to its maximum in use depth (i.e. just above the bridge plug **110**) and will then pick the work string **120** back up such that the BHA **1** is pulled back up to be aligned with the bottom of the lateral isolation placement depth (i.e. the lowermost end or bottom of the slot jet area **106**) and therefore the bottom of the area of the casing to be slotted **130**.

Stage 7—FIG. **12**

The operator can now activate the slotting blade or cutting wheel **260** by pressuring up the throughbore of the work string **120** to an appropriate pressure such as 1,500 psi and that fluid pressure will bypass the blade piston back pressure valve **292** and will act against the upper surface of the piston head **243**. That increased pressure is calculated or predetermined to be sufficient to now act on the activation piston **240** such that it will move the piston head **243** and thus the piston rod **244** downwards (against the biasing force of the spring **245**) such that the slotting blade or cutting wheel **260** is moved both downwards and radially outwards along the slotted ramp **255** from the configuration shown in FIGS. **24** (*b*) and **24** (*c*) to the extended configuration shown in FIGS. **27** (*a*) and **27**(*b*) such that the slotting blade/cutting wheel **260** extends radially outwards firstly beyond the outer diameter of the mandrel **213** and then secondly is forced against the inner surface of the casing **102** and then thirdly, due to the wedge action provided by the slotted ramp **255** as the BHA **1** is moved upwards, punctures, cuts or slots through the side wall of the casing **102** in order to form a slot **108** therein due to the force being provided by the operator pulling up on the work string **120** at the surface of the wellbore. In addition, the slotting blade/cutting wheel **260** will further extend and puncture, cut and slot into and through the old cement **104** (and potentially the formation itself) located in the annulus between the outer surface of the casing and the borehole wall **105**.

Stage 8—FIG. **12**

After the operator has confirmation of the blades **260** full travel downwards and outwards and that casing **102** has begun to be slotted **108**, the operator will continue to pressure up the string further to, for example, 1,750 psi pressure and in so doing will cause significant jetting of fluid through the single jetting nozzle **280** located directly vertically below and longitudinally aligned below the extended slotting blade/cutting wheel **260**.

The pressurised fluid in the throughbore **214** of the mandrel **213** of the slotting and jetting tool **210** will therefore be forced out through the single jetting nozzle **280** in order to ensure that the washing fluid will wash through the slots **108** that have just been formed through the casing **102** as the slotting and jetting tool **210** is moved upwards in subsequent steps (for example in step 9) because the single jetting nozzle **280** is circumferentially and longitudinally aligned with the slotting blades/cutting wheel **260**, and because it is located vertically below the cutting wheel **260** it will permit the pressurised cleaning/washing fluid to be jetted through the slots **108** that have just been formed.

Stage 9—FIG. **13**

The operator will now pick up weight from the work string **120** such that the BHA **1** and more importantly the slotting and jetting tool **210** are moved upwards for example by 3 feet such that the slotting blades/cutting wheel **260** forms a number of longitudinally spaced apart slots **108** through the side wall of the casing **102** with its cutting tips as previously described.

Furthermore, the upper **20**U and lower **20**L pair of jetting cups (not shown in FIGS. **24** to **29** but which are preferably present in the BHA **1**) ensure that the washing fluid which is highly pressurised to, for example 1,750 psi, is directed out through those slots **108** because the outer surfaces of the cups **20** are in sealed and sliding engagement with the inner surface of the casing **102**.

Stage 15—FIG. **14**

After the operator has confirmation of the slotting blade/cutting wheel **260** full travel downwards and radially outwards along the axially extending angled slotted ramp **255**, and has confirmation that the casing **102** is being slotted **108**, the operator will continue to pressure up the drill string **120** to 1,750 psi pressure again to start jetting from the single jetting nozzle **280** again.

Stage 16—FIG. **14**

The operator will again move the BHA **1** and therefore the slotting and jetting tool **210** upwards within the slot jet area **130** of the wellbore **100** and will monitor the pressure of the washing fluid at surface for any fluctuation in that pressure for the same reasons as before.

Stage 17—FIG. **14**

Once the operator has lifted the BHA **1** up 200 feet (or more if required) of travel and has therefore caused 200 feet of slot jet area **130** to be slotted **108**, the operator will shut down the washing fluid pumps and will bleed off the washing fluid pressure.

Stage 18—FIG. **14**

If for example the slot jet areas **130** is to be 200 feet, the operator will lower the work string **120** by 205 feet such that the BHA **1** is located 5 feet below the slot jet area **130** and therefore the cups **20** are compressed against the inner surface of the casing **102** at a location at which there are no slots therein.

Stage 20

The operator will move the BHA **1** and therefore the slotting and jetting tool **210** five feet up into the wellbore.

Final Jetting/Washing Procedure

Stage 27—FIG. **16**—and FIGS. **29**(*a*) and **29**(*b*)

The operator will then drop a drop ball **268** down the throughbore of the drill string **120** and will allow gravity to pull the drop ball **268** to depth until it lands on the ball seat **270** held within the drop ball seat carrier **272** by means of centralising fins **294** (which permit fluid to flow from the surface down the throughbore of the work string and further flow therebetween and down into the throughbore **214** of the mandrel **213** when the ball **268** is not sitting upon the seat **270**), and the pumping of fluid down the throughbore of the drill string **120** will of course greatly aid and speed the landing of the drop ball **268** on the ball seat **270**. The throughbore of the work string **120** above the ball seat **270** and drop ball **268** is therefore blocked and fluid pressure applied at surface by the operator can therefore increase thereon.

Stage 28—FIGS. **29**(*a*) and **29**(*b*) and FIG. **17**

The operator will then pressure up the washing fluid pumped into the throughbore of the work string **120** to a suitable pressure such as 2,000 or even 2,500 psi and in so doing will shear the set of shear pins **215** provided in the BHA **1**, namely the set of shear pins **215** provided at the upper end of the slotting and jetting tool **210** holding the drop ball seat carrier **272** and thus the ball seat **270** and which are sheared because the fluid pressure builds up due to the drop ball **268** obturating the throughbore **214**. The drop ball seat carrier **272** and thus the ball seat **270** drop to the position shown in FIGS. **29**(*a*), (*b*) and (*c*) and in so doing the piston cylinder sleeve **291** moves downwards along with the sleeve cover **299** to thereby uncover the 360 degree set of jetting nozzles/circulation/washing ports **274** because it moves the sleeve cover **299** downwards thus uncovering the jetting nozzles/circulation/washing ports **274**. Accordingly, the washing fluid flow is changed such that it will also and/or mainly flow through the throughbore **214** and out of the 360 degree set of jetting nozzles/circulation/washing ports **274** (and can't act upon the upper face of the piston head **243** due to the blade piston back pressure valve **292** blocking the fluid from acting upon the upper face of the piston head **243**).

The rest of stages 29 to 34 of the washing procedure are largely the same for the inverted slotting and jetting tool **210** as hereinbefore described with reference to the first embodiment of the slotting and jetting tool **10**.

Isolation/Cementing Procedure

This is largely the same for the inverted slotting and jetting tool **210** as hereinbefore described with reference to the first embodiment of the slotting and jetting tool **10**, with the isolation material/cement **112** being pumped from surface down through the throughbore of the work string and if can exit the throughbore **214** of the mandrel **213** firstly and mainly through the jetting nozzles/circulation/washing ports **274** and also via the bypass channel out exit via the single jetting nozzle **280**.

Embodiments of the present invention can be modified or improved without departing from the scope of the invention.

For example, both embodiments of the slotting and jetting tool **10**; **210** have hereinbefore been described with having conventional suitable jetting cups **20** as being typically formed of relatively durable rubber material or the like. Such conventional cups **20** can be considered to be static jetting cups **20** in that they have a fixed outer diameter which is notably greater than the outer diameter of the widest portion of the mandrel **13**; **213** of the slotting and jetting tool **10**; **210** and which is also slightly greater than the inner diameter of the throughbore of the wellbore **100** and therefore the casing **102** into which the slotting and jetting tool **10**; **210** and thus in use are designed to be squeezed into the inner throughbore of the casing **102** during running in and which will therefore always be in sealing contact with the inner throughbore of the casing **102** whilst the slotting and jetting tool **10**; **210** is located therein. Accordingly, such static jetting cups do have the risk that hydraulic clock could occur if bridging (i.e. the fluid cannot pass up through the annulus **104**) were to occur when the slotting and jetting tool **10**; **210** is located within a slot jet area **130** of the casing **102** and it is jetting through the single jetting port **80**; **280**; and/or during washing with the 360 degree circulation/washing ports **74**; **274** into the annulus **104** through the slots **108**.

However, a preferred modification of either or both embodiments of slotting and jetting tool **10**; **210** utilises an improved set of cups (not shown) which are available from RubberAtkins Limited of Aberdeen, UK (but other suppliers of cups are available such as those offered under the Guiberson™ brand by Oil States Industries of Arlington, Texas, USA.) where each of the improved cups is an active or actuable cup and which comprises an outer diameter which is no greater than the outer diameter of the widest portion of the mandrel **13**; **213** of the slotting and jetting tool **10**; **210** and therefore which is also notably less than the inner diameter of the throughbore of the wellbore **100** and therefore the casing **102** and thus in use are designed to be clear of the inner throughbore of the casing **102** during running in, slotting and jetting and which are arranged not to provide a seal with the inner surface of the casing **102** and this ensures that the preferred embodiments of slotting and jetting tool **10**; **210** will not be able to experience hydraulic locking which could otherwise be caused if the jetting/cleaning/washing fluid cannot flow within the annulus **104** because e.g. bridging of the old cement therein has occurred.

However, the improved set of active or actuable cups are also arranged to be activated by a fluid pressure build up against them but only when the preferred embodiments of slotting and jetting tool **10**; **210** are located within a blank (i.e. non-slotted section), in that the operator can increase the pressure of the fluid within the throughbore and that increase in pressure increases the fluid pressure in the annulus **27** (due to the fluid pressure being communicated through either or both of the 360 degree circulation/washing ports **74**; **274** and/or the single jetting nozzle **80**; **280** depending upon which stage of operation the tool **10**; **210** is at).

That increase of the pressure of the fluid within the annulus **27** can't escape through e.g. slots **108** because the tool **10**; **210** is in the blank section of the casing **102** and so the increase in fluid pressure acts upon said improved actuable cups piston area and:—

i) firstly moves the cups to close the bypass channel around the inner surface (i.e. underneath) of the cups); and secondly

ii) moves and/or expands the cups outwards such that the cups have an increasing outer diameter and which results in the outer diameter of the cups closing the annular gap between the outer surface of the mandrel **13**; **213** and the inner surface of the casing **102**; and

iii) such expansion of the cups continues until the cups make contact with and thus seal against the inner surface of the casing **102**, such that the annular gap between the outer surface of the mandrel **13**; **213** and the inner surface of the casing **102** is now sealed.

Accordingly, said expansion and sealing of the cups when such preferred embodiments of slotting and jetting tool **10**; **210** are located within a blank (i.e. non-slotted) section of the casing **102** now allows further pressure of fluid to be built up and the fluid that is exiting:—

a) first the single jetting nozzle **80**; **280**; and possibly also

b) secondly the (first) set of jetting nozzles/circulation ports **31**; and possibly also

c) thirdly the (second) set of 360 degrees jetting nozzles/circulation ports/washing ports **274 74**; **274**

allows the fluid pressure to quickly build up within the throughbore of the tool **10**; **210** and thus causes the shearing of the respective shear pins **39** (if the tool **20**; **210** is at stage 26—FIG. **15**) or shear pins **15**; **215** (if the tool **20**; **210** is at Stage 28—FIGS. **7**(*a*), **7**(*b*), or FIGS. **29**(*a*) and **29**(*b*) and FIG. **17**).

In other words, the said preferred embodiments of the slotting and jetting tool **10**; **210** with the improved active cups requires to be moved into a blank (i.e. non-slotted) section of the casing **102** when the operator requires to move the tool **10**; **210** to the appropriate stage as hereinbefore described in order to shear the respective shear pins **39** (if the tool **20**; **210** is at stage 26—FIG. **15**) or shear pins **15**; **215** (if the tool **20**; **210** is at Stage 28—FIGS. **7**(*a*), **7**(*b*), or FIGS. **29**(*a*) and **29**(*b*) and FIG. **17**).

The invention claimed is:

1. A bottom hole assembly (BHA) to be run into a wellbore to be plugged and abandoned, the BHA comprising:

a slotting tool which further comprises:

an outer body having a throughbore;

connections to permit the outer body to be included in the BHA and in a work string having a through bore for sealed fluid communication with the throughbore of the outer body;

a slotting blade which is at least radially moveable towards and away from an inner surface of the well bore to be slotted; and

an activation mechanism adapted to move the slotting blade between:

a running in hole configuration in which the slotting blade is relatively retracted; and

an activated configuration in which the slotting blade is extended and in use is capable of creating at least one slot in the inner surface of the wellbore at a location in the wellbore to be plugged and abandoned;

wherein application of pressure to fluid in liquid form in the throughbore of the outer body is configured to act upon the activation mechanism to move the slotting blade from the running in hole configuration to the activated configuration;

wherein at least a portion of the slotting blade is configured to be forced through the inner surface of the wellbore to create the at least one slot therein by lowering the BHA down the wellbore by means of lowering the work string at the surface of the wellbore; and

wherein the slotting tool is configured such that said lowering the BHA down the wellbore via the work string at the surface thereof also pushes the slotting blade downwards within the wellbore, and thereby further forces the slotting tool radially outwards, to thereby increase the slotting force of the said at least portion of the slotting blade against and/or through the inner surface of the wellbore; and

wherein the BHA further comprises a jetting function in order to jet liquid fluid toward the inner surface of the wellbore;

wherein the outer body of the slotting tool further comprises a ramp formed therein wherein the ramp comprises an angled longitudinal axial length such that one end of the ramp is radially further inwards, with respect to the central longitudinal axis of the slotting tool, than the other end; and

wherein the slotting tool is configured to be in a pushing slotting configuration in which the ramp is configured such that when the BHA is run into the wellbore, the said one radially further inwards end of the ramp is configured to be vertically below the said other radially further outwards end such that when the slotting tool is in the activated configuration, and when the slotting tool is pushed or lowered downwards within the wellbore, the slotting blade is also pushed or lowered downwards within the wellbore, and is thereby further forced radially outwards due to movement of the slotting blade along the ramp to thereby increase the slotting force of the said at least portion of the slotting blade against and/or through the inner surface of the wellbore.

2. A BHA according to claim **1**, wherein the activation mechanism is selectively actuable to move the slotting blade radially:

a) away from the central longitudinal axis of the slotting tool and towards the casing to be slotted and into the activated configuration; and

b) toward the central longitudinal axis of the slotting tool and away from the casing to be slotted and into the running in hole configuration in which the outer diameter of the slotting blade is relatively retracted towards or within the outer diameter of the outer body of the slotting tool.

3. A BHA according to claim **1**, wherein the activation mechanism further comprises a piston and a cylinder, wherein the piston is located in the cylinder and is sealed thereto such that the piston can be forced to move by application of pressure of liquid fluid located in the through bore of the slotting tool.

4. A BHA according to claim **3**, wherein the activation mechanism is configured such that an increase in the pressure of liquid fluid at the surface of the well bore by the operator results in an increase in the pressure of liquid fluid in the through bore of the slotting tool which forces the piston to move within the cylinder and which forces the slotting blade to move from said one end of the ramp to the said other end of the ramp and in so doing moves the slotting blade both vertically along the ramp in a direction parallel to the central longitudinal axis of the slotting tool and simultaneously in a direction radially outwards with respect to the central longitudinal axis of the slotting tool.

5. A BHA according to claim **1**, wherein the activation mechanism further comprises a return device to assist in return of the slotting blade from the activated configuration into the running in hole or retracted configuration, upon reduction of the pressure of liquid fluid at the surface of the well bore by the operator.

6. A BHA according to claim **1**, wherein the jetting function is configured to jet liquid fluid toward the slots created in the casing by the slotting blade.

7. A BHA according to claim **1**, wherein the jetting function comprises at least one jetting port or orifice in the form of a jetting nozzle formed through the side wall of an outer body of the BHA and through which liquid fluid is selectively jetted by the operator.

8. A BHA according to claim **7**, wherein the said at least one jetting port is longitudinally axially aligned with the slotting blade, such that the said at least one jetting port is located one of vertically above or below the slotting blade such that it is configured to jet washing fluid through the slots that have just been formed by the slotting blade as the slotting tool is moved vertically respectively downwards or upwards within the casing in use.

9. A BHA according to claim **7**, wherein the slotting tool further comprises a plurality of jetting ports in the form of jetting nozzles formed around the circumference through the side wall of the outer body of the BHA such that they form a second set of jetting ports in the BHA.

10. A BHA according to claim **9**, wherein the second set of jetting ports formed through the side wall of the outer body of the BHA are equi-spaced 360 degrees around the circumference of the slotting tool on the same plane perpendicular to the central longitudinal axis of the slotting tool such that all of the jetting ports in the second set will permit jetting of liquid fluid at the same vertical location in the well bore.

11. A BHA according to claim **9**, wherein the second set of jetting ports are obturated when the slotting tool is in the running in hole configuration and can be selectively opened by the operator into fluid communication with liquid fluid located in the throughbore of the BHA by a port opening mechanism.

12. A BHA according to claim **11**, wherein the port opening mechanism comprises a drop device seat member which is secured to the outer body of the slotting tool by a frangible device adapted to be sheared by dropping a drop device at surface such that when the drop device lands on the seat member, application of liquid fluid pressure at surface is transmitted to the liquid fluid located in the throughbore of the slotting tool and which acts upon the drop device and the seat member to shear the frangible device and which results in disconnection of the seat member from the outer body of the slotting tool thereby uncovering the second set of jetting ports and permitting fluid communication with the liquid fluid located in the throughbore of the slotting tool.

13. A BHA according to claim **1**, wherein the BHA further comprises at least one upper sealing member located above the slotting tool and at least one lower sealing member located below the slotting tool, wherein the sealing members are configured to selectively seal against the inner surface of the casing when required to do so, and wherein the sealing members are configured to seal the annulus at their location between the outer surface of the BHA and the inner surface of the casing, and wherein the said sealing members are configured to provide a greater seal when the pressure of liquid fluid acting on their radially innermost faces increases.

14. A BHA according to claim **13**, wherein the BHA further comprises a valve tool, located below the said lower sealing member, wherein the valve tool comprises:

- a throughbore in sealed fluid communication with the throughbore of the rest of the BHA located above the valve tool; and
- a valve member operable within the throughbore of the valve tool.

15. A BHA according to claim **14**, wherein the valve member permits liquid fluid located in the wellbore to pass upwards through the throughbore of the valve tool and continued passage upwards into the throughbore of the rest of the BHA and prevents fluid from flowing downwards through the throughbore of the valve tool.

16. A BHA according to claim **14**, wherein the jetting function comprises at least one jetting port or orifice in the form of a jetting nozzle formed through the side wall of an outer body of the BHA and through which liquid fluid is selectively jetted by the operator, wherein the slotting tool further comprises a plurality of jetting ports in the form of jetting nozzles formed around the circumference through the side wall of the outer body of the BHA such that they form a first set of jetting ports in the BHA, wherein the valve tool comprises an outer body and a plurality of jetting ports or orifices in the form of jetting nozzles formed around the circumference and through the side wall of the outer body of the valve tool and which forms a second set of jetting ports in the BHA, wherein the jetting nozzles are configured in use to break up material located in the outer annulus.

17. A bottom hole assembly (BHA) according to claim **16**, wherein the second set of jetting ports are formed through the side wall of the outer body of the valve tool and are equi-spaced 360 degrees around the circumference of the valve tool on the same plane perpendicular to the central longitudinal axis of the valve tool such that all of the jetting ports in the second set will permit jetting of liquid fluid at the same vertical location in the well bore, and

- wherein the second set of jetting ports are obturated when the valve tool is in the running in hole configuration and the valve member is permitted to be open to allow fluid located in the throughbore thereof to flow through the throughbore as the BHA is being run into the hole; and
- wherein the second set of jetting ports can be selectively opened by the operator into fluid communication with liquid fluid located in the throughbore of the valve tool by a valve tool port opening mechanism which comprises a slidable sleeve or housing to which the valve member is pivotably mounted,
- wherein the slidable sleeve is secured to the outer body of the valve tool by at least one frangible device which is selectively broken or sheared by applying a force to the slidable sleeve with respect to the outer body of the valve member.

18. A BHA according to claim **17**, wherein when the valve member is closed by flow of fluid downwards through the throughbore of the valve tool and/or an increase in fluid pressure at surface which is transmitted to the liquid fluid located in the throughbore of the valve tool and which acts upon the said upper face of the valve member, and said increase in pressure applies a force to the upper end of the valve member and also the slidable sleeve which will break or shear the frangible device and which results in disconnection of the slidable sleeve from the outer body of the valve tool thereby uncovering the second set of jetting ports and permitting fluid communication to occur between the liquid fluid located in the throughbore of the valve tool and the second set of jetting ports.

19. A BHA according to claim **16**, wherein at least one of, some of, most of or all of the single jetting port, first and second sets of jetting ports contain jets which permit fluid to pass therethrough:

a) in a circulation mode up to a certain pre-determined pressure; and

b) once the required pre-determined pressure has been reached, the said jetting port will jet the fluid at a disruptive forceful rate sufficient to dislodge and/or disturb old cement or formation or other material;

wherein only the single jetting port permits fluid to pass therethrough in both of the aforementioned paragraphs a) and b) and the first and second sets of jetting ports are circulation ports which permit fluid to pass therethrough without restriction once they've been respectively opened.

20. A bottom hole assembly (BHA) according to claim **1**, wherein the angle of the ramp is linear or constant along its longitudinal axial length.

21. A bottom hole assembly (BHA) according to claim **1**, wherein the reaction force between the slotting blade and the inner surface of the wellbore causes the slotting blade to be forced further along the ramp in the vertically upwards direction from said one end of the ramp toward the said other end of the ramp and is thereby further forced radially outwards to thereby increase the slotting force of the said at least portion of the slotting blade against and/or through the inner surface of the wellbore.

22. A bottom hole assembly (BHA) according to claim **1**, wherein the slotting blade is generally disc shaped and further comprises a castellated outer circumference such that the slotting blade comprises a number of cutting teeth in the form of cutting tips which are circumferentially equi-spaced around the circumference of the slotting blade and which are separated by gaps in order to increase the cutting force applied to the cutting teeth.

23. A method of forming slots in a wellbore suitable for plugging and abandoning the wellbore, the method comprising the steps of:

running a bottom hole assembly (BHA) comprising a slotting tool on a work string into the wellbore, the slotting tool comprising:

an outer body having a throughbore and a ramp formed in the outer body wherein the ramp comprises an angled longitudinal axial length such that one end of the ramp is radially further inwards, with respect to the central longitudinal axis of the slotting tool, than the other end; and

connections to permit the outer body to be included in the BHA and in a work string having a throughbore for sealed fluid communication with the through bore of the outer body;

a slotting blade which is at least radially moveable towards and away from an inner surface of the wellbore to be slotted; and

an activation mechanism adapted to move the slotting blade between:

a running in hole configuration in which the slotting blade is relatively retracted; and

an activated configuration in which the slotting blade is extended and in use is capable of creating at least one slot in the inner surface of the well bore at a location in the wellbore to be plugged and abandoned;

wherein application of pressure to fluid in liquid form in the throughbore of the outer body is configured to act upon the activation mechanism to move the slotting blade from the running in hole configuration to the activated configuration,

wherein at least a portion of the slotting blade is configured to be forced through the inner surface of the wellbore to create the at least one slot therein by at least one of raising or lowering the BHA respectively up or down the wellbore by means of respectively raising or lowering the work string at the surface of the wellbore, and

wherein the BHA further comprises a jetting function in order to jet liquid fluid toward the inner surface of the wellbore; and

pressuring up at surface fluid in liquid form and pumping said fluid in liquid form down the throughbore of the work string and applying said pressurised fluid to the activation mechanism to move the slotting blade along the ramp from the running in hole configuration to the activated configuration; and

at least one of raising or lowering the BHA respectively up or down the wellbore via the work string at the surface thereof to force at least a portion of the slotting blade through the inner surface of the wellbore to form the at least one slot therein; and

wherein said raising or lowering the BHA respectively up or down the wellbore via the work string at the surface thereof, pulls or pushes the slotting blade respectively upwards or downwards within the wellbore, and thereby moves the slotting blade further along the ramp and thereby further forces the slotting tool radially outwards, to thereby increase the slotting force of the said at least portion of the slotting blade against and/or through the inner surface of the wellbore.

24. A method of plugging and abandoning a wellbore according to claim **23**, wherein the slotting tool further comprises:

an upper cup tool; and a lower cup tool.

25. A method of plugging and abandoning a wellbore according to claim **23**, wherein the slotting tool is configured in one of a pulling or pushing slotting configuration at surface prior to being run into the wellbore.

26. A method of plugging and abandoning a wellbore according to claim **23**, wherein the method further comprises:

pumping washing/cleaning fluid in liquid form from the surface through the throughbore of the work string at a pressure sufficient to pass through a single jetting nozzle of the slotting tool, in order to wash the washing/cleaning fluid through the one or more slots formed by the slotting tool.

27. A method of plugging and abandoning a wellbore according to claim **23**, wherein the slotting tool further comprises a valve tool, and wherein the method further comprises:

increasing the pressure of the liquid fluid in the throughbore of the work string to a sufficient pressure such that a downwardly directed force is applied to a closed valve member of the valve tool and at least one frangible device is broken or sheared by said force and a slidable sleeve is moved thereby uncovering a set of jetting ports in the valve tool, thereby permitting increased volumes of washing/cleaning fluid in liquid form to be pumped from the surface through the throughbore of the work string at a pressure sufficient to pass through said set of jetting ports of the valve tool, in order to wash the washing/cleaning fluid through the one or more slots formed by the slotting tool.

28. A method of plugging and abandoning a wellbore according to claim **23**, wherein the method further comprises:

dropping a drop device at surface into the throughbore of the work string and landing the drop device on a drop device seat member of the slotting tool.

29. A method of plugging and abandoning a wellbore according to claim **28**, wherein the method further comprises:

increasing the pressure of the liquid fluid in the throughbore of the work string to a sufficient pressure such that a downwardly directed force is applied to the drop device and drop device seat member whereby at least one frangible device acting between the drop device seat member and the outer body of the slotting tool is broken or sheared by said force and the drop device seat member and drop device are moved thereby opening the throughbore of the slotting tool by means of uncovering a set of jetting ports in the slotting tool, thereby permitting increased volumes of washing/cleaning fluid in liquid form to be pumped from the surface through the throughbore of the work string at a pressure sufficient to pass through said set of jetting ports of the slotting tool, in order to wash the washing/cleaning fluid through the one or more slots formed by the slotting tool.

30. A method of plugging and abandoning a wellbore according to claim **23**, wherein the method further comprises:

pumping isolation material from surface into the throughbore of the work string to fill the required area of the wellbore including both the throughbore of the casing and the washed clean annulus behind the casing with said isolation material to a sufficient depth.

31. A method of plugging and abandoning a wellbore according to claim **30**, wherein the method further comprises:

pull the workstring upwards until the BHA is located above the uppermost slots formed by the slotting tool and increasing the pressure of said pumped isolation material at surface into the throughbore of the work string to a sufficient pressure such that a downwardly directed force is applied to the drop device and seat member until at least one frangible device acting between a ball seat and the seat member is broken or sheared by said force and the drop device and the ball seat are moved thereby opening the throughbore of the slotted tool to the throughbore of the BHA located below the slotted tool in order to open up circulation of isolation material below the slotted tool and out through the first set of circulation ports in order obtain circulation of isolation material below the slotting tool.

32. A method of plugging and abandoning a wellbore according to claim **30**, wherein the method further comprises:

pulling said BHA and said work string out of the hole and permitting the isolation material to set.

33. A bottom hole assembly (BHA) to be run into a wellbore to be plugged and abandoned, the BHA comprising:

a slotting tool which further comprises:

an outer body having a throughbore;

connections to permit the outer body to be included in the BHA and in a work string having a throughbore for sealed fluid communication with the throughbore of the outer body;

a slotting blade which is at least radially moveable towards and away from an inner surface of the wellbore to be slotted; and

an activation mechanism adapted to move the slotting blade between:

a running in hole configuration in which the slotting blade is relatively retracted; and

an activated configuration in which the slotting blade is extended and in use is capable of creating at least one slot in the inner surface of the wellbore at a location in the wellbore to be plugged and abandoned;

wherein application of pressure to fluid in liquid form in the throughbore of the outer body acts upon the activation mechanism to move the slotting blade from the running in hole configuration to the activated configuration;

wherein at least a portion of the slotting blade is forced through the inner surface of the wellbore to create the at least one slot therein by raising the BHA up the wellbore; and

wherein the slotting tool is configured such that said raising the BHA up the wellbore pulls the slotting blade upwards within the wellbore, and thereby further forces the slotting tool radially outwards, to thereby increase the slotting force of the said at least portion of the slotting blade against and/or through the inner surface of the wellbore;

wherein the BHA further comprises a jetting function in order to jet liquid fluid toward the inner surface of the wellbore;

wherein the outer body of the slotting tool further comprises a ramp formed therein wherein the ramp comprises an angled longitudinal axial length such that one end of the ramp is radially further inwards, with respect to the central longitudinal axis of the slotting tool, than the other end; and

wherein the slotting tool is configured to be in a pulling slotting configuration in which the ramp is configured such that when the BHA is run into the wellbore, the said one radially further inwards end of the ramp is configured to be vertically above the said other radially further outwards end such that when the slotting tool is in the activated configuration, and when the slotting tool is pulled or lifted upwards within the wellbore, the slotting blade is also pulled or lifted upwards within the wellbore, and is thereby further forced radially outwards to thereby increase the slotting force of the said at least portion of the slotting blade against and/or through the inner surface of the wellbore.

34. A bottom hole assembly (BHA) according to claim **33**, wherein the angle of the ramp is linear or constant along its longitudinal axial length.

35. A bottom hole assembly (BHA) according to claim **33**, wherein the reaction force between the slotting blade and the inner surface of the wellbore causes the slotting blade to be forced further along the ramp in the vertically downwards direction from said one end of the ramp toward the said other end of the ramp and is thereby further forced radially outwards to thereby increase the slotting force of the said at least portion of the slotting blade against and/or through the inner surface of the wellbore.

36. A bottom hole assembly (BHA) according to claim **33**, wherein the slotting blade is generally disc shaped and further comprises a castellated outer circumference such that the slotting blade comprises a number of cutting teeth in the form of cutting tips which are circumferentially equi-spaced around the circumference of the slotting blade and which are separated by gaps in order to increase the cutting force applied to the cutting teeth.

37. A bottom hole assembly (BHA) to be run into a wellbore to be plugged and abandoned, the BHA comprising:

a slotting tool which further comprises:

an outer body having a throughbore;

connections to permit the outer body to be included in the BHA and in a work string having a throughbore for sealed fluid communication with the throughbore of the outer body;

a slotting blade which is at least radially moveable towards and away from an inner surface of the wellbore to be slotted; and

an activation mechanism adapted to move the slotting blade between:

a running in hole configuration in which the slotting blade is relatively retracted; and

an activated configuration in which the slotting blade is extended and in use is capable of creating at least one slot in the inner surface of the wellbore at a location in the wellbore to be plugged and abandoned;

wherein application of pressure to fluid in liquid form in the throughbore of the outer body acts upon the activation mechanism to move the slotting blade from the running in hole configuration to the activated configuration;

wherein at least a portion of the slotting blade is forced through the inner surface of the wellbore to create the at least one slot therein by at least one of raising or lowering the BHA respectively up or down the wellbore; and

wherein the slotting tool is configured such that said raising or lowering the BHA respectively up or down the wellbore, pulls or pushes the slotting blade respectively upwards or downwards within the wellbore, and thereby further forces the slotting tool radially outwards, to thereby increase the slotting force of the said at least portion of the slotting blade against and/or through the inner surface of the wellbore;

wherein the BHA further comprises a jetting function in order to jet liquid fluid toward the inner surface of the wellbore;

wherein the BHA further comprises at least one upper sealing member located above the slotting tool and at least one lower sealing member located below the slotting tool, wherein the sealing members are configured to selectively seal against the inner surface of the casing when required to do so, and wherein the sealing members are configured to seal the annulus at their location between the outer surface of the BHA and the inner surface of the casing, and wherein the said sealing members are configured to provide a greater seal when the pressure of liquid fluid acting on their radially innermost faces increases;

wherein the BHA further comprises a valve tool, located below the said lower sealing member, wherein the valve tool comprises:

a throughbore in sealed fluid communication with the throughbore of the rest of the BHA located above the valve tool; and

a valve member operable within the throughbore of the valve tool;

wherein the jetting function comprises at least one jetting port or orifice in the form of a jetting nozzle formed through the side wall of an outer body of the BHA and through which liquid fluid is selectively jetted by the operator, wherein the slotting tool further comprises a plurality of jetting ports in the form of jetting nozzles formed around the circumference through the side wall of the outer body of the BHA such that they form a first set of jetting ports in the BHA;

wherein the valve tool comprises an outer body and a plurality of jetting ports or orifices in the form of jetting nozzles formed around the circumference and through the side wall of the outer body of the valve tool and which forms a second set of jetting ports in the BHA, wherein the jetting nozzles are configured in use to break up material located in the outer annulus;

wherein the second set of jetting ports are formed through the side wall of the outer body of the valve tool are equi-spaced 360 degrees around the circumference of the valve tool on the same plane perpendicular to the central longitudinal axis of the valve tool such that all of the jetting ports in the second set will permit jetting of liquid fluid at the same vertical location in the wellbore, and wherein the second set of jetting ports are obturated when the valve tool is in the running in hole configuration and the valve member is permitted to be open to allow fluid located in the throughbore thereof to flow through the throughbore as the BHA is being run into the hole;

wherein the second set of jetting ports can be selectively opened by the operator into fluid communication with liquid fluid located in the throughbore of the valve tool by a valve tool port opening mechanism which comprises a slidable sleeve or housing to which the valve member is pivotably mounted, and

wherein the slidable sleeve is secured to the outer body of the valve tool by at least one frangible device which is selectively broken or sheared by applying a force to the slidable sleeve with respect to the outer body of the valve member.

* * * * *