WELLBORE PRODUCTION STRING AND METHOD

BACKGROUND

In petroleum producing zones, wellbores may be drilled into a petroleum-containing formation and a tubing string is installed through which petroleum from the formation is produced to surface.

In some operations, after some time, water will begin to be produced from the formation. The production of water is not of interest and such production must be controlled.

SUMMARY

In accordance with another broad aspect of the present invention, there is provided a wellbore tubing string including a first port and a second port, a ball-actuated closure for each of the first port and the second port, the ball-actuated closure being configurable to move from a port closed position to a port openable position by actuation with an actuating ball, a ball-actuated seal configurable to seal off production from a lower port when the ball-actuated closure opens a port above.

A method for producing a well, the method comprising: producing fluids from a formation through a first port of a tubing string; passing an actuating ball through the tubing string past a third port to a second port of the tubing string above the first port, the actuating ball opening the second port and stopping production from the first port through the tubing string; producing fluids from the formation through the second port of a tubing string; and passing a second actuating ball through the tubing string to open the third port and to stop production from the second port through the tubing string.

It is to be understood that other aspects of the present invention will become readily apparent to those skilled in the art from the following detailed description, wherein various embodiments of the invention are shown and described by way of illustration. As will be realized, the invention is capable for other and different embodiments and its several details are capable of modification in various other respects, all without departing
from the spirit and scope of the present invention. Accordingly the drawings and detailed
description are to be regarded as illustrative in nature and not as restrictive.

BRIEF DESCRIPTION OF THE DRAWINGS

Several aspects of the present invention are illustrated by way of example, and not by
way of limitation, in detail in the drawings.

The drawings include:

Figures 1, 2 and 3 are schematic sectional views through a wellbore illustrating a method
for producing hydrocarbons.

Figure 4 is a schematic sectional view of one embodiment of a ball-actuated tool
assembly;

Figure 5 is a schematic sectional view of another embodiment of a ball-actuated tool
assembly; and

Figures 6, 7 and 8 are sectional views of another embodiment of a ball-actuated tool.

DETAILED DESCRIPTION OF VARIOUS EMBODIMENTS

The description that follows and the embodiments described therein are provided by way
of illustration of an example, or examples, of particular embodiments of the principles of
various aspects of the present invention. These examples are provided for the purposes of
explanation, and not of limitation, of those principles and of the invention in its various
aspects. In the description, similar parts are marked throughout the specification and the
drawings with the same respective reference numerals. The drawings are not necessarily
to scale and in some instances proportions may have been exaggerated in order more
clearly to depict certain features.

A staged production system may be useful in a hydrocarbon producing wellbore that is at
risk of producing water. In such a system, the wellbore is produced in stages wherein
production is permitted from a first zone in the wellbore until it is desired to shut off that
first zone and open and produce from a second zone that is uphole (closer to surface) from the first zone. A ball-actuation is employed to shut off the first zone and open the second zone, thereby avoiding the need to run in with a tethered tool to manipulate the ports to the zones. Avoiding run-in intervention, such as with a coiled tubing, a rod, a jointed tubing string or a line, provides savings in terms of cost and time.

In one embodiment, a single ball-actuation shuts and opens the respective zones. For example, an actuating ball may be launched from above the first zone to close first ports that provide communication to the first zone and open second ports that provide communication to the second zone. In one embodiment, the actuating ball remains in the tubing string to close off the tubing string below the second ports such that fluid cannot pass upwardly or downwardly through the tubing string between the first ports and the second ports.

The production may be inflow controlled, as by screening, pressure controlled, flow controlled, etc.

The wellbore may be open hole or cased in horizontal or other orientations. The tubing string through which production occurs may be cemented in or open annulus. Packers may be carried on the tubing string and may be actuated to form a plurality of annularly separated zones within the wellbore.

With reference to Figures 1 to 3, there is shown a tubing string 10 installed in a wellbore defined by wellbore wall 12. The wellbore is separated into a plurality of zones a, b, c by packers 14 carried on the outer diameter of tubing string 10 and expanded to seal an annular area 16 between the tubing string and the wellbore wall.

Tubing string 10 includes at least one port 18a, 18b, 18c between each set of adjacent packers which, when open, permits communication between the inner diameter ID of string and the annular area.

Tubing string 10 also includes a closure 20a, 20b, 20c for each port 18a, 18b, 18c. Each closure controls the open and closed condition of its port. Each closure is ball-actuated to permit remote actuation from an untethered ball launched from above, also termed uphole
of, of the closure.

Each closure 20 can be specifically actuated by a particular sized ball by selection of a seat size that catches an intended ball but allows smaller balls to pass through. As such, in the illustrated tubing string, the seat of closure 20a, which is the most downhole, is smaller than the seats of other closures 20b, 20c and the seat of closure 20c, which is uphole of the other two closures, has the largest diameter and stops, and is actuated by, only a ball larger than the balls for closures 20a and 20b. In particular, the seat sizes of the closures are as follows: closure 20a has the smallest seat, with the seat of closure 20b being larger than that of closure 20a and the seat of the closure 20c being larger than those of both closures 20a and 20b.

While not shown here, there may be additional ports and closures that are actuated by the same ball as one used for one of the closures. In such an embodiment, the closures may access the same zone or two or more zones may be opened.

There may be other tools in the tubing string for other purposes and operated by other means. For example, the toe 10a of the string, which is the distal end, may include a port open to production from the toe of the well. While there may be a closure for that port, that closure may be hydraulically actuated such as by pressuring up the string to open. With such a tool, a ball need not be run to open the toe to production.

It is intended that fluids produced by the formation in each zone a, b, c pass into the annular area between packers and then through the port in that zone to enter the tubing string. The fluids entering tubing string 10 inner diameter ID then flow or are pumped to surface. The port accessing a zone can remain open until a selected time when it is desired to close it. In one embodiment, for example, when problematic levels of water begin to be produced, it may be desired to close that zone and open a zone above. This process is repeated by closing a zone when production therefrom is no longer desired and opening a zone above until all zones of interest are produced.

The closing of one zone and the opening of a zone above may occur via the same actuation, for example, by launching one ball to close a lower zone and also to permit
opening of a zone above the lower zone. The one ball may permit opening of a zone, in that it may either perform an operation that permits the zone to be opened later or it may open the zone directly.

In any event, when the tubing string is run in and installed in a wellbore (Figure 1), the tubing string is employed to allow production from the formation. Generally, the string is run in will all ports 18a, 18b, 18c closed. The toe 10a may be manipulated to provide or close circulation and to open production from zones accessed by the toe.

When desired, a first zone, such as zone a, will be opened for production. To produce from zone a, port 18a is opened by dropping a ball 22 to move through string 10 past closure 20c and then past closure 20b to arrive at closure 20a. The seats of closures 20c and 20b each have a larger diameter than the seat of closure 20a such that ball 22 can pass through the uphole seats to arrive at its target seat in closure 20a.

When ball 22 lands at the seat of closure 20a, it moves that closure to an open port position (Figure 2) so that fluids from zone a may be produced Pa through port 18a. Ball 22 may also close off production from the toe. In the illustrated embodiment, for example, ball 22 remains captured in closure 20a even after port 18a is opened to seal off production from the toe.

If production Pa from zone a becomes problematic, for example, water begins to be produced in undesirable quantities, a second ball 24 is launched to both (i) permit opening of a zone, such as zone b, above the zone a and (ii) to close off production from zone a (Figure 3). Second ball 24 is launched from uphole of closure 20b, such as from surface. Second ball 24 moves through string 10 past closure 20c to arrive at closure 20b. The seat of closure 20c has a larger diameter than the seat of closure 20b such that ball 24 can pass through the uphole seat at closure 20c to arrive at its target seat in closure 20b.

When ball 24 lands at the seat of closure 20b, it creates a pressure differential above and below the seat to axially move closure 20b to an open port position such that fluids from zone b may be produced Pb through port 18b. Ball 24 may also close off production from the zone a. In the illustrated embodiment, for example, ball 24 remains captured in
closure 20b even after port 18b is opened and ball 24 seals off production from zone a. As such, if water was problematically being produced from zone a, that water production can be stopped.

If production from zone b becomes problematic, for example, water begins to be produced in undesirable quantities, a further ball is launched to both (i) permit opening of zone c and (ii) close off production from zone b. In particular, the process of dropping balls may be repeated to both (i) open an uphole zone and (ii) seal off a zone below.

If stimulation processes are of interest, when the balls land and open the ports, stimulation fluids may be injected out through the opened ports first before permitting production. The ports may be open or have inflow control such as screens or nozzles.

The closures may take various forms to permit such operation. In one embodiment, an uphole port is opened by a ball and the same ball closes a port below. In a second embodiment, an uphole port is triggered by a ball to permit later opening of its port while the same ball closes a port below. In a third embodiment, an uphole port is opened or triggered to open by a ball, while the ball is captured in the tubing string between the uphole port and a port below to close the tubing string to flow upwardly and downwardly therepast. In the third embodiment, the port below may not actually be closed to communication between the annular area and the tubing string inner diameter, but fluids flowing through that port cannot be produced to surface due to the ball being captured in the wellbore.

With reference to Figures 4 and 5, for example, two options are shown for a closure assembly, wherein the tools each include a plurality of sleeves to control the open and closed condition of associated ports. In these closure assemblies, a first sleeve with a collapsible seat is used that is actuated by passage of a first ball, but that first ball can proceed through the first sleeve and land in a second sleeve further down. For example, the actuation may permit opening of a first port, by later pressuring up or delayed opening. In particular, the port is not immediately opened by seating or passage of the ball. That same ball, being released from the first sleeve, can continue to travel to land in and close off a sleeve further down.
Thus, with reference to Figure 4, a closure assembly is shown which is used at each zone. The closure assembly works with a production port (flow port) that is delayed opening and includes two seats: a lower, smaller diameter port opening seat on a sleeve (DEH lower sleeve) that covers the production port and an upper, larger diameter, port-closing seat (DCFP upper housing). Where a series of these closure assemblies are employed in a string 110 to control production through a number of zones, the closure assembly of a lower zone has an upper seat that is the same size (i.e. actuated by the same diameter ball) as the lower seat of the closure assembly in the zone uphole of it.

The lower, smaller diameter port opening seat is on an inner sleeve that covers the production port. The inner sleeve normally overlies and closes the production port, but the sleeve can be moved to expose the port to tubing pressure that can be employed to open it. In particular, the port is delayed opening and, thereby, has a secondary closure (outer sleeve DEH) that holds the port closed after the inner sleeve is moved until a second procedure actually opens the port to flow between the inner diameter and the outer surface.

The inner sleeve includes a collapsible seat at quick port key that allows it to be actuated (axially moved) by a ball, but thereafter, when the inner sleeve moves to align the quick port key with quick port key lock, the key expands out of the way and ball can pass through and travel down in the tubing string. The upper seat is formed to retain and create a seal with a suitably sized ball that lands therein.

In operation, if the illustrated closure assembly was employed for the lowest zone, a first, smaller diameter ball may be launched to pass through the string 110 and move through the closure assembly. That ball passes through the upper seat without acting on it, but lands in the lower seat. When that ball lands in the seat, it causes the inner sleeve to move and expose ports to tubing pressure. The ball can then pass through the seat and move further down the tubing string to actuate other tools, be caught, dissolve, etc.

The port, now exposed to tubing pressure is configured to open only after a delay. Because there is a delay, the ball continues to be pushed along and driven by fluid pressure. After the delay, however, the port can be opened to fluid flow outwardly or
inwardly. In the illustrated embodiment, the port will be opened by pressuring up the tubing string to a pressure suitable for shearing the outer sleeve.

When it is desired to close the production port, a second ball is launched that has a diameter suitable to land and create a seal in the upper seat. That second ball has a diameter greater than the first ball. That ball becomes captured in the upper seat and closes off the tubing string to any production from the flow ports.

In operation, recall that there is a closure assembly uphole with a similar design and particularly, a lower seat with a configuration similar to this illustrated lower seat but having a seat size actuated by the second ball. As such, launching of the second ball to close off the ports, also actuates the uphole closure assembly to begin the opening process for its production port. Thus, the process to close a port in a zone below opens or allows opening of a port uphole for production (with or without production) without running in with a line or tethered tool, which is commonly called intervention.

When the staged production is deemed complete, if desired, a milling string can be run to remove the seats and the inner sleeves can be shifted by a shifting tool.

The closure assembly can be part of a screen tool that screens production fluids. For example, a screen can be installed in or about production ports.

With reference to Figure 5, the tool is a combination of a ported tool (Quick Port V) with an inner isolation sleeve 6 over the tool's port 5 and a hydraulically actuated hydraulic piston (DBH) which acts as a secondary closure for the port. The inner isolation sleeve has a collapsible seat. A ball can land in the seat and generate a force to slide the sleeve 6 open, but the seat eventually collapses (i.e. expands) when the seat keys reach recess 7 to permit the ball to pass.

Above that ported tool, there is a sliding closing sleeve (DCFP). That closing sleeve includes a slidable sleeve with a ball seat 2. Ball seat 2 is sized larger than the ball seat on sleeve 6, such that a ball sized for the seat of sleeve 6 can pass through the seat 2 without actuation thereof. Locks 3 hold sleeve with seat 2 in the run in position. Locks 4 are also provided to hold the sleeve in a final position after it moves.
There may be a screen for the port 5 in the ported sub.

In this tool, an initial ball is passed to move the inner sleeve of the ported sub to expose the hydraulic piston. The initial ball will pass through and may be used below, for example, to land out on another seat. Then the tubing string may be pressured up to move the hydraulic piston and open ports 5 to fluid flow, for example, for stimulation of the well or for flow back production. When desired, a second ball of a larger size is dropped and lands on seat 2. When the ball lands, the sleeve carrying seat 2 shears out from locks 3 and slides to close the ports 5. Seals on the sleeve seal off flow through the ports 5. The ball may stay on the sleeve or lift off.

As the system of Figure 5 is likely to be used in series in a tubing string, there may be a similar system uphole of the system of Figure 5 in the tubing string. In such a case, the second ball, when moving through the string to arrive at seat 2, would have moved through a sleeve 6 on the tool above and shifted it to open ports 5 of that uphole tool. Thereafter, since the ports 5 of the lower tool are closed, the tubing string may be pressured up to open the hydraulic piston accessed through ports 5 in the tool above.

The sleeve used to close the lower port could be attached to the same sleeve to open the next production port.

These tools may be run in series with a selection for varying ball sizes using smaller balls first and introducing successively larger balls. The tools may be used to produce wells in stages from the toe until each stage waters out. Once a zone is producing water, it is closed off by sliding sleeve 2 and the stage above is opened until the well is produced to the degree desired. This will allow the operator to close off water production without needing to mobilize a rig or coiled tubing unit. This again eliminates intervention.

With reference to Figures 6 and 7, another closure assembly is shown that combines a port opening and port closing features into one structure. In this embodiment, the closure that is moveable by ball-actuation to open a port also includes a catcher operable to hold the actuating ball after actuation of the ball-actuated closure, the catcher configured to hold the actuating ball and to seal against fluid flow therepast upwardly and downwardly
below the port. Thus, landing of a ball to open the ports of a closure immediately also captures that ball in the same closure below the opened port to seal off production from a zone below.

The illustrated tool 10 includes a housing 12 and a piston structure 14 in a bore 12a of the housing. The piston structure is axially moveable within the housing from a run-in position (Figure 6) to a port-open and lower zone closed position (Figures 7 and 8). In the port-open position, the piston is moved axially down against a shoulder 12b in the inner bore of the housing. The shoulder acts as a stop wall for the piston in the bore of the housing.

A bore 16 extends through the piston. When open, bore 16 defines a fluid flow path, arrows F, extending axially through the piston structure from an upper surface 14a to a lower surface 14b thereof. Bore 16 extends the full length of piston structure 14 and is continuously parallel along its full length with the long axis x of the piston structure.

Housing 12 may include an upper end 12c and a lower end 12d formed to be connected to a liner 2. The upper end may be configured to secure the tool in a position with axis x of the tool coaxial with long axis of the liner. The connection to liner places a portion of the housing and the piston structure exposed to the inner diameter of the liner.

A port 17 extends through the wall of housing providing communication between bore 12a and the outer surface of the housing. Piston 14 covers port 17 run-in position (Figure 6). However, port 17 is open to bore when piston 14 is moved to the port-open position (Figure 7).

A ball seat 18 is located in the bore. The position of ball seat 18 in the bore defines a uphole portion 16a of the bore uphole of the ball seat. Uphole portion 16a is that portion of bore 16 between ball seat 18 and upper surface 14a of the piston structure. It is noted that the ball seat 18 may be in other positions along the length of the bore.

A ball 22 works with the tool and is selected with regard to the ball seat to be sized to enter the chamber but unable to pass ball seat 18. The ball is sized to become sealed up against the ball seat to block the flow path through the bore. The landing of the ball in
the ball seat of the bore alone closes flow through the tool. The tool remains closed to flow downwardly past the piston as long as the ball remains in the bore. While the term "ball" is used, the ball may not have the exact characteristics of a spherical ball. For example, the ball may be more of a dart, with fins or an elongated form.

Uphole portion 16a of the bore may have an inner diameter ID just larger than the diameter D of ball 22 such that the ball can enter the bore but the ball restricts flow through the bore. Alternately, ball 22 or the material of the piston structure about uphole portion 16a, may be somewhat deformable to allow the ball to seal about its diameter with the uphole portion. For example, in one embodiment, ball 22 is deformable such that it can deform to squeeze into the uphole portion of the bore and completely restrict flow through the bore past the ball. Although being deformable in such an embodiment, the ball cannot pass the ball seat, but instead seals against it to block fluid flow therepast. In such an embodiment, flow past the ball downwardly is stopped by ball landing against seat 18 and as shown in Figure 5, reverse flow upwardly, arrows U, past ball 22 is also stopped as long as the ball remains in bore 16. In one embodiment, once the ball is in place the tubing string pressure can be raised to levels associated with hydraulic tool setting and fracturing.

A ball retainer 24 is positioned at the open, upper end of bore 16 above the ball seat and is actuable between an inactive position (Figure 6: where the ball retainer isn't in a position to act against a ball moving therepast) and an active position (Figure 7 and 8: where the ball retainer resists passage of a ball therepast). The ball retainer in this embodiment, is actuable between the inactive position and the active position by movement of piston structure 14, which is driven by the landing of the ball 22 in the ball seat 18. In this embodiment, the ball retainer 24 is carried on the piston structure and moves therewith through bore 12a. In this embodiment, the ball retainer 24 includes a plurality of collet fingers 26 that are initially positioned in a large diameter section 12a' of the housing bore, where fingers 26 can expand into the large diameter region and do not protrude across the opening to bore 16. However, fingers 26 are compressed inwardly when the collet fingers are moved to a smaller diameter region 12a" of the housing bore. When compressed inwardly (Figure 7), fingers 26 have a close spacing S less than the
inner diameter ID across uphole portion 16a of the bore. Fingers 26, thus, protrude across the opening to bore 16 and occlude the bore such that the ball cannot pass out of the bore. The inactive position of the ball retainer corresponds with the run-in condition of the piston structure and the active position of the ball retainer corresponds with the closed position of the piston structure.

Ball seat 18 and ball retainer 24 are positioned such that sufficient space is provided therebetween such that once ball 22 lands in the ball seat, ball retainer 24 can move into an active position and hold ball 22 in the bore. Depending on the desired action of ball 22 after actuating the piston to move down, the ball retainer may provide space for ball to move out of a sealing position in the bore or, as shown ball retainer 24 may be configured to hold the ball in the bore and thereby continue to hold ball 22 in a position restricting or sealing against flow through bore 16 in both directions. It is to be noted, however, that the bore shape and size at uphole portion 16a and the shape of the ball retainer can be formed in many ways to allow the ball to act in bore 16 as a permanent plug, stopping or resisting flow in both directions.

The tool may further include locking structures to control operation. For example, the tool may include a releasable lock 28 to hold the piston structure in the run-in position. Releasable lock 28 may include shear pins as shown or other means such as a snap ring, detents, etc. Piston structure 14 can only move when the pressure builds up to apply a sufficient force to overcome the releasable lock.

The tool may additionally or alternatively include a final position lock 30 to hold the piston structure in the closed position. Final position lock 30 may include a ratchet, as shown, or other means such as a snap ring, detents, etc. Piston structure 14 once moved, cannot return to an uphole position due to the holding force of lock 30. This ensures that ball retainer 24 continues to hold ball 22 in bore 16.

A funnel can be provided to direct ball 22 toward ball seat 18. In one embodiment, the bore can have a diverging upper end to facilitate entry of ball 22 to bore 16. In the illustrated embodiment, housing 12 includes, as a part of its inner facing surface, an upper end funnel surface 32 that narrows toward the upper surface of piston 14. For
example, the upper end funnel surface 32 forms guiding walls that converge towards bore 16.

Piston structure 14 and ball retainer 24 may be formed of durable materials that can withstand the rigors of downhole use. However, in one embodiment, at least some portion of piston structure 14 and possibly portions of ball retainer 24 are formed of drillable materials such that they can be milled out to open up the liner to the wellbore, if desired. If desired, there may be structures to prevent the piston structure from spinning about axis x to facilitate drilling removal.

In operation, a plurality of tools 10 with successively larger seats 18 are attached in series in a liner 2. The liner with the tools 10 installed and in the run-in condition each with bore 16 open (Figure 6), is then run into the well.

Once the liner is in position and it is time to begin production from a zone of the formation accessed by the lowest tool 10, a ball is introduced to the liner and moved as by pumping or gravity to the tool. This ball flows into uphole portion 16a of the bore and lands against the seat 18 (Figure 7). The piston structure is moved axially through bore 12a toward shoulder 12b by fluid pressure from above when a ball lands in seat 18 and creates a piston effect across piston structure 14. In particular, when ball 22 lands in the piston structure, the flow is stopped through the bore from the liner to the annulus and a piston face is formed across the ball and piston structure 14. Piston structure 14 is then pushed down by applied fluid pressure against the created piston face once releasable lock 28 is overcome. Movement of piston 14 opens ports 17 so that fluids produced in the annular area about the tool may flow into the inner diameter of the tool and be produced to surface. Additionally, if desired, before production, stimulation fluid may be injected outwardly through ports 17.

As also shown in Figures 7 and 8, the ball retainer is moved with the piston structure. When ball 22 lands and piston structure 14 moves, fingers 26 move with the piston structure and are pulled from their initial position in larger diameter section 12a' to smaller diameter region 12a". When the collet moves into the smaller diameter region, the collet fingers move inwardly trapping the ball in bore 16.
The piston structure may be locked in place by lock 30 after moving by fluid pressure, such that the ball remains trapped in the flow path. Ball 22, then remains in bore 16 providing flow control. In particular, the ball is sized to seal against the bore walls (i.e. for example, the diameter OD of the ball is the same as or slightly larger than the inner diameter ID of the bore) and the ball retainer is formed to hold the ball in a sealing position against the bore walls, flow through the tool will be stopped in both directions (i) downwardly and (ii) upwardly, arrow U (Figure 8). As such, fluids produced below the tool are stopped from being produced past the tool.

If desired, the tool can be drilled out to open the liner to its full inner diameter and to open it to flow.

The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to those embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments. Thus, the present invention is not intended to be limited to the embodiments shown herein, but is to be accorded the full scope consistent with the claims, wherein reference to an element in the singular, such as by use of the article "a" or "an" is not intended to mean "one and only one" unless specifically so stated, but rather "one or more". All structural and functional equivalents to the elements of the various embodiments described throughout the disclosure that are known or later come to be known to those of ordinary skill in the art are intended to be encompassed by the elements of the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims. No claim element is to be construed under the provisions of 35 USC 112, sixth paragraph, unless the element is expressly recited using the phrase "means for" or "step for".
Claims:

1. A wellbore tubing string including a first port and a second port, a ball-actuated closure for each of the first port and the second port, the ball-actuated closure being configurable to move from a port closed position to a port openable position by actuation with an actuating ball, a ball-actuated seal configurable to seal off production from a lower port when the ball-actuated closure opens a port above.

2. A method for producing a well, the method comprising: producing fluids from a formation through a first port of a tubing string; passing an actuating ball through the tubing string past a third port to a second port of the tubing string above the first port, the actuating ball opening the second port and stopping production from the first port through the tubing string; producing fluids from the formation through the second port of a tubing string; and passing a second actuating ball through the tubing string to open the third port and to stop production from the second port through the tubing string.