ABSTRACT

A perforating gun of unique port and port plug architecture. The gun may include ports with separate guide channel and engagement regions for receiving a port plug. Once more, the engagement region may be offset from the central axis of the guide channel and overall port. Thus, the engagement region of the port as well as the matching engaging mechanism of the port plug may be out of the direct line of fire when a perforating application takes place. The same may be true of a seal for the port plug. Therefore, achieving adequate engagement and sealing of the port with such plugs may be more effective, for example, in spite of the guide channel and other portions of the gun carrier beginning to exhibit post-perforation bulging.
FIG. 2
REUSABLE PERFORATING GUN AND PORT PLUG

PRIORITY CLAIM/CROSS REFERENCE TO RELATED APPLICATION(S)


BACKGROUND

[0002] Exploring, drilling and completing hydrocarbon wells are generally complicated, time consuming and ultimately very expensive endeavors. As a result, over the years, well architecture has become more sophisticated where appropriate in order to help enhance access to underground hydrocarbon reserves. For example, as opposed to wells of limited depth, it is not uncommon to find hydrocarbon wells exceeding 30,000 feet in depth. Furthermore, today’s hydrocarbon wells often include deviated or horizontal sections aimed at targeting particular underground reserves. Indeed, at targeted formation locations, it is quite common for a host of lateral legs and perforations to stem from the main wellbore of the well toward a hydrocarbon reservoir into the surrounding formation.

[0003] The above described perforations are formed and effectively completed by a series of applications that begin with perforating the well wall. So, for example, a casing defining the well may be perforated with use of a perforating gun. The gun itself may be equipped with conventional shaped charges that are detonated within the gun such that explosive forces are directed out of the gun and toward the well wall or casing in order to form the noted perforations. More specifically, explosive gasses from the charge detonation will form a jet that creates the perforations.

[0004] The gun is sealed off from the downhole environment in advance of firing. That is, to allow for proper functionality, the shaped charges and other internal components of the gun are isolated from fluids within the well. However, rather than blowing holes through the gun wall when fired, the shaped charges are generally retained within a carrier of the gun that is outfitted with replaceable port plugs. The plugs themselves may screw into guide ports or holes of the carrier and include a weakpoint or breakaway location that is blown through when the shaped charge is fired. Thus in theory, the damaged portion of the gun due to the perforating is limited to a plug which may be replaced once the gun is removed back to the oilfield surface.

[0005] Unfortunately, the effects of perforating are not limited to a damaged plug that may be replaced. Notably, with each firing of the gun, the carrier will bulge and deform a bit. Indeed, over the natural course of 10-20 firings, as is common with a conventional reusable gun, it is quite likely that the guide port will be ovaly deformed. As a result, sealed retention of the plug within the guide port becomes unreliable.

[0006] Failure of the plug to remain securely and sealably engaged with the guide port may result in leakage of well fluids into the gun. This may result in significant damage to the gun when fired. Alternatively, as is more often the case, the detonator for each shaped charge is of a fluid desensitized character. Thus, exposure to fluids will result in the inability of the gun to fire. That is to say, the solution to fluid exposure is to render the gun non-functional as opposed to allow for malfunction. However, in either case, a significant amount of time is lost to gun retrieval from the well followed by replacement and redeployment.

[0007] The problem of the deforming port or guide port may be exacerbated even further as the retention of the shaped charge is called into question. That is, as the carrier begins to bulge around the location of the shaped charge, it is not only the guide port that is deformed. Rather, the structure of the carrier bulges in a manner that results in less secure retention of future shaped charges. For example, upon initial uses of the gun, the shaped charges may be snugly retained adjacent each guide port location. However, after several uses, with the carrier bulging more and more in the areas of the shaped charges, they may no longer be securely held in place. The result is that the shaped charge may be off-center relative the guide port. Thus, firing of the shaped charge may be angled or otherwise directed more at the threads of the guide port, as opposed to the intended weakpoint of the adjacent port plug. When this occurs, the guide port is not only becoming less effective at plug retention due to the noted oval widening, but also due to the fact that it is effectively being shot at by the shaped charge.

[0008] The damaged guide port due to oval widening and/or off-center shaped charge retention means that the ability of the gun to be reused via port plug replacement is compromised. As indicated above, port plugs that are used later in the life of the gun are less likely to be sealably retained within the guide port. As a result, well fluid leakage into the gun becomes increasingly more likely over the life of the gun. However, fluid leakage is not the extent of the issue as described below.

[0009] Irrespective of fluids leaking into the gun, the insecure retention of a port plug may result in downhole problems beyond the gun. For example, when the gun is fired, an insecurely retained plug is more prone to being shot out of the guide port and carrier entirely. The result may be that plugs become projectile chunks of debris that are undesirably left in the well, perhaps accumulating at an elbow of a deviated well section. Even worse, the shot plug projectile may become stuck between the gun and the well wall leading to the requirement of a dedicated intervention in order to retrieve the gun.

[0010] As a practical matter, a reusable perforating gun is only so reusable due to the limitations resulting from the deforming regions around the shaped charge location. Indeed, as indicated above, as a matter of operator preference, it is unlikely that a gun will be used more than about twenty times before being pulled from service.

SUMMARY

[0011] Embodiments of a reusable perforating gun are described. The gun may include a carrier that accommodates a shaped charge. Additionally, the carrier may be outfitted with a particularly configured guide passage or port. More specifically, the port may include an inner channel proximate an accommodated charge along with an engaging region. The engaging region is substantially isolated from the inner channel during secured engagement with a port plug that occludes the guide port. Additionally, the port plug itself may include a seal that provides both the noted occluding of the port as well as the isolating of the engaging region from the inner channel.
BRIEF DESCRIPTION OF THE DRAWINGS

[0012] FIG. 1 is a side view of an embodiment of a reusable perforating gun with a guide port of separated inner channel and engaging region for retention of a port plug.

[0013] FIG. 2 is an overview of an oilfield with a well accommodating the gun of FIG. 1 to form perforations into a surrounding formation.

[0014] FIG. 3 is an enlarged top cross-sectional view of the gun of FIG. 1 revealing the configuration of the guide port for engagement with the port plug.

[0015] FIG. 4 is a side view of an alternate embodiment of the gun with the guide port and plug configured for twist-lock engagement.

[0016] FIG. 5A is a side view of an alternate embodiment of the gun and port plug configured with a latching engagement interior of the inner channel.

[0017] FIG. 5B is a side view of an alternate embodiment of the gun and port plug configured with plastically deformable engagement.

DETAILED DESCRIPTION

[0018] Embodiments are described with reference to certain types of downhole perforating applications. For example, perforating via a wireline deployed gun in a deviated well is shown. However, other types of perforating applications in wells of varying architecture may take advantage of embodiments detailed herein. For example, slickline deployment may be utilized in vertical wells or any other number of different combinations. Regardless, as long a carrier of the gun is be outfitted with a particularly configured guide port, certain port plug materials are utilized, or even an internal charge sleeve is employed, unique perforating gun advantages may be realized.

[0019] Referring now to FIG. 1, a side, partially sectional, view of an embodiment of a reusable perforating gun 100 is shown. The gun 100 is made up of a durable carrier 110, generally of stainless, alloy and/or mild steel or other suitable material for downhole deployment and firing. Additionally, the gun 100 includes guide ports 175 of unique architecture. More specifically, the ports 175 are shaped to receive replaceable port plugs 101 that are of a substantially matching architecture relative the ports 175. So, for example, with added reference to FIG. 2, the ports 175 of the gun 100 may be sealably plugged with the plugs 101, the gun 100 deployed into a well 280 and fired to form perforations 297. Thus, firing damage may be largely limited to the replaceable plugs 101, thereby allowing the gun 100 to be removed and the plugs 101 replaced to allow gun use in subsequent perforating applications.

[0020] In the embodiment shown, loading of the gun 100 with shaped charges 375 may be aided with the use of a charge sleeve 125, generally of foam construction, that helps keep the charges 375 in place and aligned with the ports 175 as detailed further below (see also FIG. 3). Indeed, after each use of the gun 100, plug remnants and the entire sleeve/charge assembly may be removed and replaced with new unused versions of the same for later gun use.

[0021] In the embodiment of FIG. 1, the gun 100 has previously been fired in the manner described above, perhaps several times. As a result, a degree of bulging is apparent in the axial vicinity of each guide port 175. That is, with added reference to FIG. 3, the structure of the carrier 110 is slightly deformed near detonation (e.g. see cord 350) in response to the firing shaped charges 375 adjacent the ports 175 (see FIG. 3). Indeed, the outward bulging that results is accompanied by an internal widening of the space within the carrier 110. With reference to guide spaces 150 that begin to emerge between the replaceable charge sleeve 125 and the carrier structure defining each port 175, this internal widening may be seen with some clarity.

[0022] Continuing with reference to FIG. 1, the engagement between each plug 101 and port 175 is of an architectural configuration that enhances the security of the sealing therebetween, in spite of the noted widening and bulging of the carrier 110. More specifically, with added reference to FIG. 3, the plug 101 and/or the guide neck 167 thereof is not configured to directly interface structure of the internal guide channel 301 of the port 175 in order to achieve a sealable engagement between the plug 101 and port 175. Thus, even with bulging at one side of the carrier 110 or emerging ovality at the port 175 over successive uses of the gun 100, a sealed engagement between the plug 101 and port 175 may not be substantially compromised.

[0023] Instead of reliance on direct engagement with the structure of the guide channel 301 of FIG. 3, each plug 101 is provided with a separate engaging mechanism 160 adjacent the guide neck 167. For example, in the embodiment of FIG. 1, a threaded cap may serve as the engaging mechanism 160 and be sized to engage with an engaging region 177 of the more external carrier structure that defines the port 175. Indeed, a seal member 165 may be provided below the cap engaging mechanism 160 to further aid in maintaining a sealed off port 175. In this manner, the engaging and sealing functions of the plug 101 are removed from sole reliance on the guide channel 301 maintaining a substantially unchanging stable shape in order to ensure functionality. In fact, as detailed further below with respect to FIG. 3, the engaging mechanism 160, seal member 165 and corresponding port architecture may be offset to a degree relative the neck 167, channel 301 and the direct line of perforating fire. Thus, bulging and other port deformation may have a notably less immediate impact on engaging and sealing functionality.

[0024] Referring now to FIG. 2, an overview of an oilfield 205 is shown with a well 280 accommodating the gun 100 of FIG. 1. Thus, perforations 297 may be formed into a surrounding formation 290, for example, as a manner of enhancing hydrocarbon recovery therefrom. That is, the well 280 may be of sophisticated architecture, specifically tailored for the surrounding environment. For example, in the embodiment shown, the well 280 is lined with a casing 285, traverses multiple formation layers 290, 295, and even terminates in a deviated section 287. However, at another oilfield or location, the well 280 may be of an entirely different architecture. Regardless, as part of the overall architectural design, perforations 297 are to be formed in a cased region of the depicted well 280. Thus, a perforating gun 100 as detailed above may be utilized.

[0025] In the embodiment shown, the deployment line 210 used to deliver the gun 100 downhole is wireline provided to the oilfield 205 via a reel 240 at a mobile truck 225. However, other types of conveyance line may be utilized and the reel 240 need not be inherently mobile. Regardless, with added reference to FIGS. 1 and 3, the gun 100 may be outfitted with plugs 101 at each port 175. Thus, the line 210 and gun 100 may be deployed from a rig 260 or other supportive structure to pass a well head 270 and begin to traverse the well 280 in a manner that keeps underlying shaped charges 375 sealably
isolated and free of exposure to downhole fluids. As a result, the gun 100 may be reliably fired upon reaching the depicted location for the perforating application.

[0026] Continuing with reference to FIG. 2, with added reference to FIGS. 1 and 3, once shaped charges 375 of the gun 100 are fired, the guide channel 301 may begin to deform and the carrier 110 begin to bulge to a degree along the axis of each port region as detailed above. Additionally, plug 101 adjacent a fired shaped charge 375 is destroyed. Nevertheless, upon retrieval of the gun 100 from the well 280 it may be outfitted with new shaped charges 375, plugs 101 and other components as needed for subsequent use as also detailed above. Once more, the plug 101 or any large chunks thereof are unlikely to become wedged between the gun 100 and the well wall, potentially damaging the casing 285 or leaving the gun 100 stuck in the well 280. This is due to the fact that a sealed secure fit of the plug 101 in the port 175 means that the firing of an adjacent shaped charge 375 is likely to destroy the plug 101 as intended. That is, as opposed to dislodging an insecurely retained plug 101 from its port 175 and firing it as a projectile into the well 280, the plug 101 is securely held in place throughout the firing application.

[0027] In one embodiment, even the disintegrated material of the plug 101 is kept from accumulating in the well 280. That is, not only is the plug 101 unlikely to take on the form of a shot projectile as noted above, even the remnants of the fully destroyed plug 101 are rendered largely inconsequential. Along these lines, the plug 101 may be constructed of zinc or other readily disintegartable and/or dissolvable material. Thus, spent plug material is unlikely to impede future applications, for example by accumulation at the bend 289 toward the deviated section 287 in the embodiment shown.

[0028] Referring specifically now to FIG. 3, an enlarged top cross-sectional view of the gun 100 of FIG. 1 is shown. In this view, the mating architecture of the guide port 175 and plug 101 are more evident. The plug 101 is hollowed out to a degree at the guide neck 167 and kept in alignment with the shaped charge 375 via the guide channel 301 and further by a sleeve guide 327 of the charge sleeve 125. Thus, the weaker central portion of the plug 101 is blown out as the shaped charge 375 is fired via the depicted detonating cord 350.

[0029] Effective firing results are further assured by the maintaining of proper alignment as noted. That is, prior gun usage may have changed the morphology of the guide channel 301 to a degree. However, the charge sleeve 125 and guide 327 may nevertheless, help ensure proper aligned orientation of shaped charge 375 and plug 101. For example, as shown, prior use has led to an emerging bulge of the carrier 110 at the port location (see guide space 150). Yet, the charge sleeve 125 is a tubular structure that is steadily held centrally within the carrier 110 due to the un-deformed majority of the carrier body (see FIG. 1).

[0030] In one embodiment, the charge sleeve 125 is of a foam based construction and serves as a charge holder with individual pockets to hold shaped charges 375 in place as the loaded sleeve 125 is inserted into the gun 100. This may save time during loading the gun 100 at surface where the tubular sleeve 125 is readily slid into a previously used but newly cleaned carrier 110. Regardless, the result is centralized proper locating of the shaped charge 375 in spite of the emerging bulge. Indeed, this also assures proper alignment of the plug 101 relative the charge 375 due to the interfacing guide neck 167 and sleeve guide 327 as noted above.

[0031] Proper alignment of the charge 375 and plug 101 helps prevent misfiring or jetting directed at the engaging region 177 or other off-center location of the port 175 or plug 101. Indeed, with this in mind, the architectural matching of the plug 101 and port 175 is tailored to take advantage of off-center, more hidden locations relative the noted jetting. For example, the seal member 165 may be of o-ring configuration, disposed within a recessed chamber 300 that is offset from the central axis of the guide channel 301 and the firing that takes place therethrough. Similar to the engaging region 177 and mechanism 160 (e.g. threads) are offset from the central line of fire. For example, note the larger diameter of the engaging region 177 as compared to the guide channel 301. Thus, while the guide channel 301 is quite prone to the effects of jetting, the offset sealing and engaging features of the plug 101 and port 175 are less susceptible to such effects.

In fact, in the embodiment shown, the entirety of the engaging features (160, 177) may be spared any direct effects of the fired charge 375 where the seal is held in tact. The end result may be to extend the serviceable life of the gun 100 to beyond about 20 firings due to the fact that sealing and engaging features may remain effective well beyond such usage. This is in sharp contrast to a conventional embodiment where such engagement and/or sealing takes place centrally within the guide channel 301.

[0032] Referring now to FIG. 4, a perspective side view of an alternate embodiment of the gun 400 is shown. In this embodiment, the guide port 475 and plug 401 are configured for twist-lock engagement. That is, while the guide channel 301 and neck 467 remain similar to the embodiment depicted in FIG. 3, the engagement between these components is not of a threaded configuration. Rather, the engaging region 477 of the carrier 110 and the engaging mechanism 460 of the plug 401 are architecturally configured for twist-lock engagement. More specifically, the engaging mechanism 460 includes extending tabs that are received by the matchingly shaped engaging region 477.

[0033] Use of a twist lock engagement as depicted in FIG. 4 may allow for the securing engagement between the plug 401 and port 475 to be readily distanced from the central area of concern during perforating (e.g. along the axis of the guide channel 301). For example, from a manufacturability standpoint regarding the plug 401, achieving such distancing may require no more than ensuring adequate size or length of the tabs of the engaging mechanism 460. Once more, tabs in place of threads may prove to be particularly robust for general handling, storage, transport, etc. when the plug 401 is not in use in an application. Further, outfitting the carrier 110 with plugs 401 as depicted may reduce assembly time given that a twist-lock engagement may require no more than pressing into the port 475 and turning the plug 401 about ¼ of a rotation.

[0034] The embodiment of FIG. 4 may also incorporate other features as detailed hereinabove. For example, a zinc-based plug 401 may be utilized along with a seal member in the form of an elastic o-ring. Further, an underlying charge sleeve 125 with guide 327 may be utilized to help ensure maintaining proper alignment of the plug 401 relative the internally disposed charge 375 (see FIG. 3).

[0035] Referring now to FIGS. 5A and 5B, side views of other alternative embodiments of the gun 100 are shown. Specifically, FIG. 5A depicts a port plug 500 configured with a latching engagement 525 interior of the guide channel 301.
FIG. 5B, on the other hand reveals a port plug 501 that utilizes a plastically deformable engagement.

[0036] With respect to the embodiment of FIG. 5A, the latching engagement 525 is a traditional "clip pawl" type of latch that is located interior of the guide channel 301 and secures to the inside surface of the carrier 110. That is, as opposed to an engaging region 377, 477 as shown in FIGS. 3 and 4, the engagement is achieved at a different location. Nevertheless, engagement is again achieved without reliance on the threading or other features at the surface of the guide channel 301. Thus again, as the guide channel 301 becomes plastically deformed over successive perforating applications as described hereinabove, the impact on engagement may be minimized. As a consequence, sealing with the seal member 165 may be rendered more reliable in a reused gun 100 due to the avoidance of engagement via the guide channel 301 itself.

[0037] FIG. 5B, on the other hand reveals an embodiment where engagement with any portion of the interior of the port 175 is substantially unaffected by changing morphology thereof. Specifically, irrespective of bulging as a result of prior perforating, the port plug 501 may be constructed of a manually shapable and/or curable material. So, for example, a plug 501 may be pressed into the port 175 and moldably take on a matching morphological shape thereof, whether at an irregular guide channel 301, more symmetrical engaging region 177 or elsewhere. The material of the plug 501 may then be expansively cured and hardened over a period of time via conventional techniques. Thus, the engagement between the plug 501 and port 175 may be rendered sealably secure.

[0038] Note that in the embodiment of FIG. 5B, the material of the plug 501 may be selected such that use of a separate seal member 165 as depicted in FIG. 5A may be avoided, thereby saving assembly time. Rather, the plug material serves as its own seal member. Further, in this particular embodiment a degree of engagement between the plug 501 and the guide channel 301 may take place in spite of the likely deformation thereof when the gun 100 is not new. Further, in this particular embodiment, the material choices for the initially soft plug 501 may be readily disintegratable. This may include materials that are selected due to post-cure fractureable properties as well as those that are readily fragmentable, dissolvable and/or degradable upon exposure to well fluids. Thus against perforating, plug 501 may be reduced in size, sticking of the gun 100 in the well 280 or accumulation of debris therein may be reduced (see FIG. 2).

[0039] Embodiments described hereinabove provide a perforating gun and plugs therefor which take account of port deformation over time. The nature of the port, engagement with the port plug, and other features such as an internal charge sleeve may allow for a degree of deformation without substantially compromising gun performance. More specifically, the gun may be utilized 10-20 times or more in different successive downhole perforating applications without undue concern over reliability or effectiveness. Furthermore, such applications may also be undertaken without significant concern over port plug related debris buildup, either in a general sense within the well, or as a potential obstruction to gun and/or other tool removal from the well.

[0040] The preceding description has been presented with reference to presently preferred embodiments. Persons skilled in the art and technology to which these embodiments pertain will appreciate that alterations and changes in the described structures and methods of operation may be practiced without meaningfully departing from the principle, and scope of these embodiments. Furthermore, the foregoing description should not be read as pertaining only to the precise structures described and shown in the accompanying drawings, but rather should be read as consistent with and as support for the following claims, which are to have their fullest and fairest scope.

We claim:

1. A reusable perforating gun comprising:
   a carrier for accommodating a shaped charge at an interior thereof;
   a defined guide port of said carrier adjacent the charge, said guide port having an inner guide channel adjacent the charge to receive a guide neck of a port plug for sealing off the interior relative said port, said guide port further having an engaging region offset from a central axis of the guide channel for secured engagement with the plug.

2. The gun of claim 1 wherein the port plug comprises an engaging mechanism for interface with the engaging region to achieve the secured engagement.

3. The gun of claim 2 wherein the guide channel is proximately aligned with the shaped charge at the interior of said carrier and the engaging region interfaces the engaging mechanism at an offset location therebetween.

4. The gun of claim 3 wherein the port plug comprises a seal member for sealing off of the interior at an offset location between the engaging region and the guide channel of said port.

5. The gun of claim 2 wherein the engaging mechanism is one of a threaded engagement, a twist-lock engagement, a latching engagement and a plastically deformable engagement.

6. The gun of claim 5 wherein the engaging mechanism is the latching engagement for interfacing the engaging region at an offset location more proximately aligned with the shaped charge at the interior of said carrier than the guide channel.

7. A single use replaceable port plug for a reusable perforating gun, the plug comprising:
   a guide neck for reception by a carrier of the gun at a port guide channel aligned with a shaped charge disposed within the carrier; and
   an engaging mechanism for securely interfacing an engaging region of the carrier at a location offset from a central axis of the guide channel and said neck.

8. The plug of claim 7 constructed of a zinc-based material.

9. The plug of claim 7 constructed of a fragmentable material.

10. The plug of claim 7 constructed of a material that is one of a dissolvable and degradable upon exposure to well fluid.

11. The plug of claim 7 wherein at least a portion of said neck is hollowed out.

12. The plug of claim 7 wherein the engaging mechanism is one of a threaded engagement, a twist-lock engagement, a latching engagement and a plastically deformable engagement.

13. The plug of claim 12 wherein the plastically deformable engagement is manually shapable to moldably match morphology of the port.

14. The plug of claim 12 wherein the plastically deformable engagement is of a curable material.

15. The plug of claim 12 further comprising a seal member for sealing off the port of the carrier during the secure interfacing of said mechanism and the engaging region.
16. The plug of claim 15 wherein the seal member is an o-ring at a location offset from a central axis of the guide channel and said neck.

17. The plug of claim 15 wherein the engaging mechanism is the plastically deformable engagement, the plastically deformable engagement serving as the seal member.

18. A charge sleeve for disposal in a carrier of a perforating gun, said sleeve comprising:
   a tubular body for retaining at least one shaped charge therein; and
   a sleeve guide defined by said body and adjacent the shaped charge for alignment of the charge with a port of the carrier.

19. The charge sleeve of claim 18 wherein the carrier at the location of the port bulgingly forms a guide space and said tubular body retains a substantially uniform shape including adjacent the location.

20. The charge sleeve of claim 18 constructed of a foam-based material.

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