

Description

[0001] The present invention is concerned with explosive shaped-charges, and more particularly to an improved liner for use in such shaped-charges, an improved shape charge which is especially useful in a well pipe perforating gun, and a method for making them.

[0002] The use of shaped-charges for perforating the tubing, pipes, or casings used to line wells such as oil and natural gas wells and the like, is well-known in the art. For example, U.S. Pat. No. 3,128,701, issued Apr. 14, 1964 to J. S. Rinehart et al, discloses a shaped-charge perforating apparatus for perforating oil well casings and well bore holes.

[0003] Generally, shaped-charges utilized as well perforating charges include a generally cylindrical or cup-shaped housing having an open end and within which is mounted a shaped explosive which is configured generally as a hollow cone having its concave side facing the open end of the housing. The concave surface of the explosive is lined with a thin metal liner which, as is well-known in the art, is explosively driven to hydrodynamically form a jet of material with fluid-like properties upon detonation of the explosive and this jet of viscous material exhibits a good penetrating power to pierce the well pipe, its concrete liner and the surrounding earth formation. Typically, the shaped-charges are configured so that the liners along the concave surfaces thereof define simple conical liners with a small radius apex at a radius angle of from about 55 degrees to about 60 degrees. Other charges have a hemispherical apex fitted with a liner of uniform thickness.

[0004] Generally, explosive materials such as HMX, RDX, PYX, or HNS are coated or blended with binders such as wax or synthetic polymeric reactive binders such as that sold under the trademark KEL-F. The resultant mixture is cold- or hot-pressed to approximately 90% of its theoretical maximum density directly into the shaped-charge case. The resulting shaped-charges are initiated by means of a booster or priming charge positioned at or near the apex of the shaped-charge and located so that a detonating fuse, detonating cord or electrical detonator may be positioned in close proximity to the priming charge.

[0005] The known prior art shaped-charges are typically designed as either deep-penetrating charges or large-diameter hole charges. Generally, shaped-charges designed for use in perforating guns contain 5 to 60 grams of high explosive and those designed as deep-penetrating charges will typically penetrate concrete from 10 inches (0.25m) to over 50 inches (1.3m). Large-diameter hole shaped-charges for perforating guns create holes on the order of about one inch (25.4mm) in diameter and display concrete penetration of up to about 9 inches (0.23m). Such data have been established using API RP43, Section I test methods.

[0006] The present invention relates to a liner for a shaped-charge made up of two liner components and a

method for making a shaped-charge using such a liner. In the preferred embodiments, each liner component has a convex outer surface, a concave inner surface, an apex having a center, a mouth portion of the liner component opposite the apex of the liner component, and a skirt portion terminating in a circular skirt edge at the mouth portion of the liner component. The first liner component is made of a first material and has an opening at the center of its apex. The second component is made of a second material and a portion of the second component is within the opening at the center of the apex of the first component.

[0007] The first material and the second material include different materials. In one embodiment, the first material has a greater density than the second material. In another embodiment the second material has a greater sound speed than the first material. In the more preferred embodiments, the first material comprises a metal and most commonly the first material is selected from the group of copper, copper alloy, aluminum, aluminum alloy, tin, tin alloy, lead, lead alloy, powdered metal, powdered metal within a polymeric base, and sintered metal. By comparison, the second material is may be made from a similar set of materials or compacted or hardened explosive, but more preferably comprises aluminum or copper alloy or powdered metal in a polymeric base. In the most preferred embodiment the first material comprises copper alloy and the second material comprises aluminum.

[0008] In the described embodiments, each of the first and second components has a liner angle. In the more preferred embodiment the second component has a liner angle which is no more than about 15 degrees greater than the liner angle of the first component. Preferably the second component has a liner angle within about 15 degrees of the liner angle of the first component. In alternative embodiments, the liner angle of the second component is less than the liner angle of the first component.

[0009] The first and second components each also have a liner height. In the preferred embodiments, liner height of the second component is no more than about the liner height of the first component, and preferably the liner height of the second component is less than about two thirds of the liner height of the first component.

[0010] In an embodiment, the liner height for the second component is between about 1/3 and 2/3 of the liner height for the first component.

[0011] In an embodiment, the liner height for the second component is less than about 1/2 of the liner height for the first component.

[0012] In an embodiment, the liner height for the second component is between about 1/4 and 1/2 of the liner height of the first component.

[0013] The circular skirt edges of first and second components each have a diameter. In the presently most preferred embodiment the circular skirt edge of the second component has a diameter of between about

0.30 inches (7.6mm) and about 0.45 inches (11.4mm). It is also preferred that the ratio of the diameter of the circular skirt edge of the second component to the diameter of the circular skirt edge of the first component is between about 0.05 and about 0.35 and more preferably between about 0.10 and about 0.25.

[0014] The more preferred shape for the second component is an approximately conical shape. The more preferred approximate shapes for the first component are selected from the group consisting of hemispherical, parabolic, ellipsoidal, flattened parabolic, and hyperbolic. For both it is highly preferred that each component be radially symmetric about the central axis passing through the apex.

[0015] The present disclosure also addresses a method for making a shaped-charge. The preferred method starts by forming a first liner component of a first material wherein the first liner component has an apex and an opening at the center of the apex. A second liner component is formed of a second material wherein the second material is not identical to the first material. A housing is provided which contains explosive material. The first component and the second component are assembled into the housing acting together to line the explosive material. The components are assembled so that a portion of the second component is within the opening at the center of the apex of the first component.

[0016] In various embodiments, the action of forming the liner components may comprise drawing or molding the liner components among a number of possible forming methods - thus, it is possible for each liner component to be either drawn or molded. In the most preferred embodiments, the two liner components are joined, although they may be joined before, during, or even after assembly into the housing.

[0017] The action of joining may include fitting a portion of the second component within the opening in the apex of the first component. This may involve pressing the second component into the opening of the apex of the first component until an interference fit is attained between the two components. In an embodiment, the second component could have a lip around its mouth, in which case the action of fitting would include inserting the second component into the opening of the apex of the first component until the lip of the second component catches the edge of the opening of the first component. In an embodiment, the first component could also have a recess around the opening and the lip of the second component could fit into the recess around the opening in the apex of the first component.

[0018] Finally, in the preferred embodiments the two components may be attached at the intersection of the opening of the apex and the portion of the second component. Attaching could be accomplished by applying an adhesive coating, by soldering, by welding, or by other methods disclosed herein. These forms of attachment could be accomplished alone or in combination with each other and could occur before, during, or after

assembly into the shaped-charge.

[0019] Reference is now made to the accompanying drawings, in which:

Figure 1 is a cross-sectional diagram illustrating an embodiment of an assembled shaped-charge including a primary liner having a flattened parabolic apex with a conical precursor liner;

Figure 2 is a cross-sectional diagram illustrating an embodiment of an assembled shaped-charge including a primary liner having a hemispherical apex with a conical precursor liner;

Figure 3 is a cross-sectional diagram illustrating an embodiment of a flat-bottom cone primary liner having a flattened parabolic apex with a conical precursor liner;

Figure 4 is a cross-sectional diagram illustrating an embodiment of a hemi-cone primary liner having a hemispherical apex with a conical precursor liner;

Figure 5 is a cross-sectional diagram illustrating an embodiment of an assembled shaped-charge including a primary liner having a hemispherical apex with a larger conical precursor liner;

Figure 6 is a cross-sectional diagram illustrating an embodiment of an ellipsoidal primary liner with a conical precursor liner; and

Figure 7 is a cross-sectional diagram illustrating an embodiment of an assembled shaped-charge including a flat-bottom cone primary liner having a flattened parabolic apex with a hemispherical precursor liner.

[0020] One factor influencing performance of shaped-charges in large well bores is the presence of fluid in the annulus between the perforating gun carrying the charges and the casing. The presence of fluid in this area significantly affects the formation of the jet tip, particularly in "big hole" perforators, but also in perforators in general (where shaped-charges are the perforators or perforating devices carried on the perforating guns). The fluid has a mushrooming effect on the jet tip which causes it to create a large entry hole in the first string of casing. While this may be desirable for single string completions where big holes are sought, there are situations where wells are completed in zones with multiple strings of casings, or it is necessary to establish fluid communication through multiple strings. When this situation occurs, it is desirable to obtain a large hole in all of the casing strings. Having fluid in the annulus makes this more difficult, because the mushroomed jet tip expends most of its energy getting through the fluid and creating a large hole in the first string, and there is very little energy left to perforate subsequent strings.

[0021] The present disclosure suggests a method to remove well bore fluid from the path of a shaped-charge jet in order to reduce the effect it has on the jet tip. The reduction of the mushrooming effect caused by the fluid enables the shaped-charge designer to spread out the

jet's energy so that it can be used more effectively to create large holes through multiple strings of casing when shooting across fluid gaps. The shaped-charge designer may alternatively be able to create a larger hole in a single string when shooting across fluid gaps or even a deeper penetration of the formation after shooting across fluid gaps. This is most preferably accomplished by using a precursor liner and a primary liner both pressed in the same housing. In the most preferred embodiment, the primary liner is similar or equivalent to a standard big hole shaped charge liner. The precursor liner is pressed into the booster end (or apex end) of the primary liner to form an initial very fast moving jet to open a path through the fluid of the well bore annulus. The jet from the primary liner moves at a slower rate of speed and thus follows the path made through the fluid by the precursor resulting in reduced effects from the well bore fluid.

[0022] A particular class of big hole liner incorporates the use of an opening, preferably circular, at the center of the apex of the liner. The opening at the apex is especially useful in "big hole" applications, as it enhances entrance hole performance, although there typically is a trade off in terms of loss of penetration. When assembled in a shaped-charge under the present disclosure, the primary liner has the apex opening, and the precursor liner is fit within the apex opening. The precursor liner and primary liner may also be viewed as components of a single overall shaped-charge liner which are joined together by any of a number of means. The liners are in theory usable separately, but when placed together in the shaped-charge act together to line the explosive charge. The two liners (or liner components as they are also referred to herein) most typically interact at the apex opening of the primary liner.

[0023] A number of potential approaches may be used to join the two liner components at the apex opening. One preferred method involves the use of an interference fit between the mouth of the precursor liner and the walls of the opening in the primary liner. Another method could involve the addition of a lip to the mouth of the precursor liner such that the lip is too large to pass through the apex opening in the primary liner, while the rest of the precursor liner is able to pass through. The precursor liner could also sit atop the primary liner. This could be done by forming a recess in the top of the convex outer portion of the main liner and setting the precursor liner in the recess. In this instance, "glue" could again be used to keep the precursor liner in place or the confinement/compression between the explosive powder and the primary liner could be the fixing mechanism. An additional alternative could employ welding or soldering the border between the precursor liner and the primary liner.

[0024] In an alternative embodiment, the precursor liner may not be pressed all the way onto the primary liner, leaving a portion of the precursor liner extending above the opening in the primary liner. One approach to

this alternative would be to have an interference fit where the mouth of the precursor liner is somewhat larger than the opening in the apex of the primary liner such that as the precursor liner is pressed in the two are interference fit at a circumference of the precursor liner below the mouth of the precursor liner. Alternatively the precursor liner could be inserted to the desired point and one of the other attachment methods described above or below could be used to join the two components together into the overall liner.

[0025] The most preferred approach is to have a close fit (without being an interference fit) and applying an adhesive coating to keep the two components of the overall liner (individually the primary liner and the precursor liner) together. The coating is most preferably an adhesive/paint sold under the trademark Glyptol, preferably an adhesive selected from an epoxy material compatible with the explosive material, and generally comprises an adhesive. The coating may be a single layer either of adhesive alone or adhesive in combination with graphite. The coating may also be more than one layer, with a layer as described above and additional layers contributing to other properties, such as improving the moisture barrier characteristics, or improving the slight amount of time the coating acts as to dynamically confine the explosive gases which are the product of detonation. The coating as a whole is preferably no more than twice the thickness of the liner around the opening in the apex, more preferably less than or about the thickness of the liner around the opening of the apex, and most preferably between about 5-10% of the thickness of the liner around the opening of the apex. This tends to place the thickness of the coating within the range of about 0.002 inches (0.05mm) to about 0.05 inches (1.3mm). The coating may also be employed even when other methods should maintain relative position (such as the use of a lip or interference fit or other methods understood by those of skill in the art). In this case the adhesive properties of the coating may provide additional assistance, and the coating may also help to improve the seal between the liners, preventing potential salting out of explosive material through the component interface (the interface between the primary liner component and the precursor liner component).

[0026] The primary liner component is preferably made from a metal strip or sheet, more preferably from a metal selected from the group of copper, copper alloy, aluminum, aluminum alloy, tin, tin alloy, lead, and lead alloy, and most preferably made of copper alloy. In alternative processes, the liner may be made from a powdered metal within a polymeric base which is molded (for example injection molded) into the form of a liner. The liner could also be made from a sintered metal, possibly with other material components, which is cast or molded into a desired shape. These alternative processes would typically be manufactured using a molding or casting process.

[0027] The precursor liner component may be made

from similar materials and using similar processes. However, in the preferred embodiment, the precursor liner is made from a material which is less dense than the material used in the primary liner component. Alternatively, the precursor liner component may be made from a material with a greater sound speed, where the sound speed is the speed at which an acoustic shock-wave travels through the liner material. In either event, these properties assist the precursor liner in traveling more quickly than the primary liner following the detonation of the charge. This helps to promote the travel of the jet formed by the precursor liner into the fluid preceding the jet formed by the primary liner. A preferred material for the precursor liner component is aluminum, but a lighter brass or even a CLG-80 powdered metal are preferred alternative materials. Another less preferred alternative would involve making the precursor liner out of a hardened or compacted explosive. This could create an exploding precursor jet to push a path through the fluid. It might also have a lower density or higher sound speed than the primary liner component. For either liner component, when the word material is used in the present disclosure it is intended to refer to blends and composites as well as more simple elemental materials. Basically, it represents the stuff out of which a liner component is formed.

[0028] The preferred method for making the liner components calls for drawing the chosen material (preferably from a flat state) into a concave shape radially symmetric about a central axis passing through and perpendicular to the center of the apex, where radial symmetry about an axis is intended to describe concentricity about such axis within any plane defined perpendicular to such axis and intersecting such axis. In this process the center of the material is drawn down to form the apex while the perimeter of the material forms a skirt portion terminating in a circular skirt edge at the mouth of the liner. Depending on the desired apex shape and other factors, the draw may be done in a single step or may be done in several steps. For a hemispherical apex, a single step draw is preferable. The drawing process may result in creation of a slight necking point in the material, where the thickness is slightly reduced generally in the area near the transition from the skirt portion to the apex portion of the liner. Multiple step draws tend to leave several necking points near each radial transition, but these are generally smaller and less well defined. Multiple step draws are preferable when the desired apex profile is parabolic such as the more complex flattened parabolic apex described in this disclosure.

[0029] The primary liner component will typically use an opening in the apex to locate and/or hold the precursor liner component. Preferably, a punch is used to punch the opening in the apex centered on the central axis. This preferably occurs in the same sequence as the drawing process to increase reliability of the central axis for the punch being identical to the central axis for the draw. Other alternatives to the use of a punch to cre-

ate the hole include drilling, honing, sawing, or chemically etching.

[0030] The draw is preferably done from a sheet of material, but may also be performed on pre-cut and sized discs or other shaped blanks. At the conclusion of the draw, either preferably as a final step in the drawing process using the drawing tools, or as a separate step, any excess flat material from the sheet or blank outside of the circular skirt edge forming the mouth of the liner must be removed. Additionally, in some embodiments, following removal of any excess flat material, an additional step may be undertaken to trim the height of the liner to a desired size.

[0031] In an alternative method of manufacture, the liner components of the present invention may be manufactured by spinning a sheet of material into a concave shape radially symmetric about a central axis, having an apex centered on the central axis and a mouth at the opposite end from the apex, wherein a portion of the material forms the apex and a portion of the material forms a skirt portion terminating in a circular skirt edge at the mouth of the liner. Following the spinning process there must be a removal of any excess material outside the circular skirt edge forming the mouth. Where an opening in the apex is desired, this may be accomplished by the use of a punch or drill, after the completion of the spinning process. Other methods of manufacture may also be contemplated by those of skill in the art as appropriate to the material of choice, such as sintering, casting, molding, compositing, and the like.

[0032] Figure 1 is a cross-sectional diagram illustrating one specific embodiment of the present invention. Figure 1 is a cross-section of a shaped-charge 10 having a primary liner 50 with a flattened parabolic apex 54 and a precursor liner 70 with a conical apex 74. The shaped-charge 10 includes a housing 12 having an outer wall 14, an inner wall 16, a base 18, and a mouth 20 opposite the base 18. Within the housing is contained a shaped explosive 28 mounted on the inner wall 16 of the housing 12 and having an open concave side facing the mouth 20 (or mouth portion) of the housing.

[0033] The housing 12 also contains a chamber 22 to hold an initiation charge 24. The initiation charge 24 preferably is actually larger than chamber 22 and flows into the area housing the main shaped explosive 28. In the illustrated embodiment, the initiation charge actually overlaps the precursor liner. One alternative may modify the shape of the standard shaped-charge housing to allow sufficient initiation charge without having the charge overlap the precursor liner.

[0034] One of the simpler approaches to change the position of the initiation charge is to angle the cavity where the initiation charge generally sits while preserving the minimum diameter. This would bring the initiation charge line away from the precursor liner. In addition increasing the angle of the inner wall of the case above the cavity by increasing the minimum diameter would also lower the initiation charge line. Another way to

change the level is by manipulating how much powder is actually poured into the charge. Finally, a two-step pressing process could be employed in which the initiation charge is shaped to reflect the conical (or other) shape of the precursor liner. During this pressing the shape could potentially be offset to allow some amount of air or preferably some amount of the main explosive to be between the initiation charge and the precursor liner. While an alternative, it may be less desirable to pre-form the initiation charge after it was poured into the case due to the additional process steps and complexity of manufacture.

[0035] The initiation charge 24 is triggered by an explosive member, preferably a linear explosive member linking and initiating several shaped-charges, contained at least in part within primer container 26 attached to the base 18 of housing 12.

[0036] The primary shaped-charge liner component 50 (also referred to as the primary liner) has a concave inner surface 51, a convex outer surface 52, an apex 54 (or apex portion), and a mouth opposite the apex 54 (illustrated here contiguous to mouth 20 of housing 12). The apex 54 has a center at a point where the apex 54 intersects the central axis 53 about which the shaped-charge liner is radially symmetric. The embodiment illustrated in Figure 1 further includes an opening 56 at the center of the apex 54. The liner 50 also includes a skirt portion 60 terminating in a circular skirt edge 62 at the mouth of the liner on the opposite end of the liner from the apex 54. The liner 50 lines the concave side of the shaped explosive 28 leaving an open space 30 between the concave inner surface 51 of the liner and the mouth 20 of the housing.

[0037] The precursor shaped-charge liner component 70 (also referred to as the precursor liner) has a concave inner surface 71, a convex outer surface 72, an apex 74 (or apex portion), and a mouth opposite the apex 74 (illustrated here contiguous to opening 56 of primary liner 50). The apex 74 has a center at a point where the apex 74 intersects the central axis 53 about which both the primary liner 50 and the precursor liner 70 are radially symmetric. The precursor liner 70 also includes a skirt portion 80 terminating in a circular skirt edge 82 at the mouth of the liner on the opposite end of the liner from the apex 74. The combined liner components 50 and 70 work together to line the concave side of the shaped explosive 28 leaving an open space 30 between the concave inner surface 51 of the primary liner and the mouth 20 of the housing.

[0038] The main shaped explosive 28 is bounded by the housing inner wall 16, the initiation charge 24, the convex outer surface 52 of the primary liner 50, and the convex outer surface 72 of the precursor liner 70.

[0039] In the embodiment illustrated in Figure 1, the primary liner 50 is drawn multiple steps. The transition between the skirt portion 60 and the apex portion 54 of the liner 50 is roughly defined as the transition from a straighter, although not necessarily completely straight,

skirt section 60 from the skirt edge 62 of the liner 50 to the more curved (having a shorter radius of curvature) apex portion 54 of the liner 50. With the more complex curve of this embodiment, the transition is a transition region of gradually decreasing radius of curvature, which may decrease stepwise or in an approximately curvilinear fashion. In a simpler curved liner such as Figure 2 below, the primary liner may be drawn in a single step and have a necking point near the transition between the skirt portion and the apex portion of the liner. For the embodiment of Figure 1, the transition between the skirt portion 60 and the apex portion 54 of the liner 50 is roughly defined as the transition from a straighter, although not necessarily completely straight, skirt section 60 from the skirt edge 62 of the liner 50 to the more curved (having a shorter radius of curvature) apex portion 54 of the liner 50. With a more complex curve, the transition is a transition region of gradually decreasing radius of curvature, which may decrease stepwise or ideally in a curvilinear fashion. The transition point 64 identified in the drawing of Figure 1 is illustrative, but is not intended to be correct to scale.

[0040] For the purposes of this disclosure a "liner angle" may be defined for a liner component. If a section is taken on a plane through a liner or liner component which includes the central axis and intersects the apex of the liner and a straight line is drawn tangential to the skirt portion of the liner on each side. The lines should intersect at a point below the apex of the liner (or exactly at the apex of the liner in the case of a perfect cone) and define an angle between them. This angle represents the liner angle for the liner or liner component.

[0041] For the embodiment described in Figure 1, the liner angle for the primary component is preferably within the range of 10 degrees to 150 degrees, more preferably within the range of 35 degrees to 75 degrees, and most preferably within the range of 50 degrees to 55 degrees. For the embodiment described in Figure 1, the liner angle for the precursor component is preferably within the range of 10 degrees to 150 degrees, more preferably within the range of 20 degrees to 75 degrees, and most preferably within the range of 35 degrees to 55 degrees. It is also preferable that the liner angle for the precursor liner be no more than 15 degrees more than the liner angle for the primary liner. It is more preferable that the liner angle for the precursor liner be between about 15 degrees less and about 5 degrees more than the liner angle for the primary liner. In the present described embodiment, it is most preferable that the liner angle for the precursor liner be less than the liner angle for the primary liner. Similar to the deep-penetrating advantages provided by conical liners over the more curvilinear big hole liners, it is believed that steeper liners (smaller liner angles) for the precursor liners will travel faster thus helping to promote the travel of the jet formed by the precursor liner into the fluid preceding the jet formed by the primary liner.

[0042] For the purposes of this disclosure a "liner

height" may be defined for a liner component. If measurement is taken along the central axis from the opening or lowest apex of the liner component to the point on the axis where a plane defined by the circular skirt edge of the liner intersects the axis, this measurement represents the liner height for the liner or liner component.

[0043] For the embodiment described in Figure 1, the liner height for the primary component is preferably within the range of 0.25 inches (6.4mm) to 3.0 inches (76mm), more preferably within the range of 0.5 inches (13mm) to 2.0 inches (51mm), and most preferably within the range of 0.75 inches (19mm) to 1.25 inches (32mm). For the embodiment described in Figure 1, the liner height for the precursor component is preferably within the range of 0.125 inches (3.2mm) to 1.5 inches (38mm), more preferably within the range of 0.125 inches (3.2mm) to 0.5 inches (13mm), and most preferably within the range of 0.2 inches (5.1mm) to 0.4 inches (10.2mm). These represent specific heights for a specific embodiment, but as is understood by those of skill in the art, charges may be scaled up or down depending on the proposed or desired end use. There are also preferred ratios for the height of the liners. It is preferable that the liner height for the precursor liner be less than $\frac{1}{2}$ the liner height for the primary liner. It is more preferable that the liner height for the precursor liner be less than about $\frac{1}{3}$ of the liner height for the primary liner, and most preferable that the liner height for the precursor liner be between $\frac{1}{5}$ and $\frac{1}{3}$ of the liner height for the primary liner.

[0044] Figure 2 is a cross-sectional diagram illustrating a distinct specific embodiment of the present invention. Figure 2 is a cross-section of a shaped-charge 110 having a primary liner 150 with a hemispherical apex 154 and a precursor liner 170 having a conical apex 174. The shaped-charge 110 includes a housing 112 having an outer wall 114, an inner wall 116, a base 118, and a mouth 120 opposite the base 118. Within the housing is contained a shaped explosive 128 mounted on the inner wall 116 of the housing 112 and having an open concave side facing the mouth 120 (or mouth portion) of the housing.

[0045] The housing 112 also contains a chamber 122 to hold an initiation charge 124. The initiation charge 124 is triggered by an explosive member contained at least in part within primer container 126 attached to the base 118 of housing 112.

[0046] The primary shaped-charge liner 150 has a concave inner surface 151, a convex outer surface 152, an apex 154 (or apex portion), and a mouth opposite the apex 154 (illustrated here contiguous to mouth 120 of housing 112). The apex 154 has a center at a point where the apex 154 intersects the central axis 153 about which the shaped-charge liner is radially symmetric. The embodiment illustrated in Figure 2 further includes an opening 156 at the center of the apex 154. The liner 150 also includes a skirt portion 160 terminating in a circular skirt edge 162 at the mouth of the liner on the opposite

end of the liner from the apex 154. The liner 150 lines the concave side of the shaped explosive 128 leaving an open space 130 between the concave inner surface 151 of the liner and the mouth 120 of the housing.

[0047] The precursor shaped-charge liner 170 has a concave inner surface 171, a convex outer surface 172, an apex 174 (or apex portion), and a mouth opposite the apex 174 (illustrated here contiguous to opening 156 of primary liner 150). The apex 174 has a center at a point where the apex 174 intersects the central axis 153 about which both the primary liner 150 and the precursor liner 170 are radially symmetric. The precursor liner 170 also includes a skirt portion 180 terminating in a circular skirt edge 182 at the mouth of the liner on the opposite end of the liner from the apex 174. The combined liner components 150 and 170 line the concave side of the shaped explosive 128 leaving an open space 130 between the concave inner surface 151 of the primary liner and the mouth 120 of the housing.

[0048] The shaped explosive 128 is bounded by the housing inner wall 116, the initiation charge 124, the convex outer surface 152 of the primary liner 150, and the convex outer surface 172 of the precursor liner 170.

[0049] For the embodiment described in Figure 2, the liner angle for the primary component is preferably within the range of 10 degrees to 150 degrees, more preferably within the range of 35 degrees to 65 degrees, and most preferably within the range of 42 degrees to 47 degrees. For the embodiment described in Figure 2, the liner angle for the precursor component is preferably within the range of 10 degrees to 150 degrees, more preferably within the range of 20 degrees to 90 degrees, and most preferably within the range of 20 degrees to 50 degrees. For this embodiment and some other embodiments, it is also preferable that the liner angle for the precursor liner be no more than 15 degrees more than the liner angle for the primary liner. It is more preferable that the liner angle for the precursor liner be between about 15 degrees less and about 10 degrees more than the liner angle for the primary liner.

[0050] For the embodiment described in Figure 2, the liner height for the primary component is preferably within the range of 0.25 inches (6.4mm) to 3.0 inches (76mm), more preferably within the range of 0.5 inches (13mm) to 2.0 inches (51mm), and most preferably within the range of 1.0 inches (25.4mm) to 1.35 inches (34mm). For the embodiment described in Figure 2, the liner height for the precursor component is preferably within the range of 0.125 inches (3.2mm) to 1.5 inches (38mm), more preferably within the range of 0.125 inches (3.2mm) to 0.5 inches (13mm), and most preferably within the range of 0.2 inches (5.1mm) to 0.4 inches (10.2mm). These represent specific heights for a specific embodiment, but as is understood by those of skill in the art, charges may be scaled up or down depending on the proposed or desired end use. There are also preferred ratios for the height of the liners. With the embodiment of Figure 2 in mind, it is preferable that the liner

height for the precursor liner be less than $\frac{2}{3}$ the liner height for the primary liner. It is more preferable that the liner height for the precursor liner be less than $\frac{1}{2}$ of the liner height for the primary liner, and most preferable that the liner height for the precursor liner be between $\frac{1}{4}$ and $\frac{1}{2}$ of the liner height for the primary liner.

[0051] The liner illustrated in Figure 3 is made up of a relatively straight conical section in the skirt transitioning into a flattened parabolic apex, where the apex comprises a flattened parabola that is radially symmetric about the central axis passing through the center of the apex. The parabolic apex is blended in a curvilinear fashion to a simple truncated conical section that extends to the opening of the case. This type of liner allows an increased standoff for the parabolic section while minimizing the amount of explosive material necessary to fill the case. The conical section allows this standoff while maintaining a solid boundary between the explosive and the cavity within the shaped-charge. The precursor liner illustrated is approximately a simple cone where the mouth of the precursor liner is contiguous to the opening in the apex of the primary liner. The various methods of coupling the two liner components at or about the opening in the primary liner are addressed above and equally apply for this embodiment.

[0052] In the described example of Figure 3, the opening at the center of the apex of the primary liner has a diameter of about 0.375 inches (9.5mm) and the circular skirt edge has a diameter of about 1.9 inches (48mm). In this example the ratio of the diameter of the opening to the diameter of the circular skirt edge is about 0.2. Preferably the ratio of the diameter of the opening to the diameter of the circular skirt edge is between about 0.05 and about 0.35 and more preferably the ratio of the diameter of the opening to the diameter of the circular skirt edge is between about 0.10 and about 0.25. In the specific examples disclosed herein the opening at the center of the apex preferably has a diameter of between about 0.30 inches (7.6mm) and about 0.45 inches (11.4mm). In the preferred embodiment, this ratio equally applies to the ratio of the diameter of the circular skirt edge of the mouth of the precursor liner to the circular skirt edge of the mouth of the primary liner.

[0053] In the described example of Figure 4, the opening at the center of the apex of the primary liner has a diameter of about 0.36 inches (9.1mm) and the circular skirt edge has a diameter of about 2.45 inches (62mm). In this example the ratio of the diameter of the opening to the diameter of the circular skirt edge is about 0.15. Similarly the ratio of the diameter of the circular skirt edge of the mouth of the precursor liner to the circular skirt edge of the mouth of the primary liner is about 0.15. In both Figure 3 and Figure 4, the size of the opening in the apex also approximates the size of the mouth of the precursor liner and thus the ratio of the mouth of the primary liner to the apex opening of the primary liner approximates the ratio of the mouth of the primary liner to the mouth of the precursor liner.

[0054] The hemi-cone primary liner illustrated in Figure 4 allows a larger apex and tends to distribute more explosive material directly behind the apex section. Again, the embodiment illustrated in Figure 4 incorporates a simple cone for the precursor liner.

[0055] In one alternative embodiment illustrated in Figure 5, it may be desirable to have a more substantial precursor component resulting in a larger apex opening in the primary liner and corresponding larger mouth in the precursor liner. Similarly, the relative liner heights of the two liners may also approach one end of the most preferred spectrum.

[0056] For the embodiment described in Figure 5, the liner angle for the primary component is preferably within the range of 10 degrees to 150 degrees, more preferably within the range of 35 degrees to 65 degrees, and most preferably within the range of 42 degrees to 47 degrees. For the embodiment described in Figure 5, the liner angle for the precursor component is preferably within the range of 10 degrees to 150 degrees, more preferably within the range of 30 degrees to 100 degrees, and most preferably within the range of 40 degrees to 60 degrees. For this embodiment and some other embodiments, it is also preferable that the liner angle for the precursor liner be no more than 15 degrees more than the liner angle for the primary liner. It is more preferable that the liner angle for the precursor liner be between about 15 degrees less and about 15 degrees more than the liner angle for the primary liner (within about 15 degrees of the liner angle for the primary liner).

[0057] For the embodiment described in Figure 5, the liner height for the primary component is preferably within the range of 0.25 inches (6.4mm) to 3.0 inches (76mm), more preferably within the range of 0.5 inches (13mm) to 2.0 inches (51mm), and most preferably within the range of 1.0 inches (25.4mm) to 1.35 inches (34mm). For the embodiment described in Figure 5, the liner height for the precursor component is preferably within the range of 0.125 inches (3.2mm) to 1.5 inches (38mm), more preferably within the range of 0.25 inches (6.4mm) to 1.0 inches (25.4mm), and most preferably within the range of 0.6 inches (15mm) to 0.8 inches (20mm). These represent specific heights for a specific embodiment, but as is understood by those of skill in the art, charges may be scaled up or down depending on the proposed or desired end use. There are also preferred ratios for the height of the liners. With the embodiment of Figure 5 in mind, it is preferable that the liner height for the precursor liner be less than the liner height for the primary liner. It is more preferable that the liner height for the precursor liner be less than $\frac{2}{3}$ of the liner height for the primary liner, and most preferable that the liner height for the precursor liner be between $\frac{1}{3}$ and $\frac{2}{3}$ of the liner height for the primary liner.

[0058] In the described example of Figure 5, the opening at the center of the apex of the primary liner has a diameter of about 0.675 inches (17mm) and the circular skirt edge has a diameter of about 2.45 inches (62mm).

In this example the ratio of the diameter of the opening to the diameter of the circular skirt edge is about 0.275. Similarly the ratio of the diameter of the circular skirt edge of the mouth of the precursor liner to the circular skirt edge of the mouth of the primary liner is about 0.275. Preferably the ratio of the diameter of the opening to the diameter of the circular skirt edge is between about 0.10 and about 0.45 and more preferably the ratio of the diameter of the opening to the diameter of the circular skirt edge is between about 0.20 and about 0.35.

[0059] While the embodiments particularly addressed above reflect the use of an approximately hemispherical apex liner and of a flattened parabolic apex liner as primary liners, one of skill in the art will recognize that the benefits of the proposed invention could also apply in other shapes of liners, for example simple conical liners, slightly modified conical liners which take the form of ellipsoids (partial 3-dimensional ellipses) or have ellipsoidal apexes (for example the primary and precursor liner illustrated in Figure 6), liners with hyperbolic apexes, liners with truncated apexes, other shapes familiar to those of skill in the art. For any of the shapes described herein, when an apex is described as having a particular shape it is recognized that the shape is approximate and may involve some degree of eccentricity, deviation, or transitioning, both as a matter of design and as a matter of manufacture. The shape is intended to provide insight into the basic pattern being followed and is not intended to be a precise description of the physical outcome. In any event, the liners are preferably radially symmetric about the central axis passing through the center of the apex. While the disclosure herein refers to concave and convex surfaces to describe the general orientation of the surface within the context of the object, the use of convex and concave are not intended to imply a requirement that the surface be smooth or curvilinear.

[0060] Returning to the embodiment described in Figure 6, (briefly introduced above) the liner angle for the primary component is preferably within the range of 10 degrees to 150 degrees, more preferably within the range of 25 degrees to 55 degrees, and most preferably within the range of 37 degrees to 43 degrees. For the embodiment described in Figure 6, the liner angle for the precursor component is preferably within the range of 10 degrees to 150 degrees, more preferably within the range of 20 degrees to 75 degrees, and most preferably within the range of 35 degrees to 55 degrees. For this embodiment and some other embodiments, it is also preferable that the liner angle for the precursor liner be no more than 15 degrees more than the liner angle for the primary liner. It is more preferable that the liner angle for the precursor liner be within about 15 degrees of the liner angle for the primary liner.

[0061] For the embodiment described in Figure 6, the liner height for the primary component is preferably within the range of 0.25 inches (6.4mm) to 3.0 inches (76mm), more preferably within the range of 0.75 inches

(19mm) to 2.0 inches (51mm), and most preferably within the range of 1.20 inches (30mm) to 1.50 inches (38mm). For the embodiment described in Figure 6, the liner height for the precursor component is preferably within the range of 0.125 inches ((3.2mm) to 1.5 inches (38mm), more preferably within the range of 0.125 inches (3.2mm) to 0.5 inches (13mm), and most preferably within the range of 0.2 inches (5.1mm) to 0.4 inches (10.2mm). These represent specific heights for a specific embodiment, but as is understood by those of skill in the art, charges may be scaled up or down depending on the proposed or desired end use. There are also preferred ratios for the height of the liners. With the embodiment of Figure 6 in mind, it is preferable that the liner height for the precursor liner be less than $\frac{1}{2}$ the liner height for the primary liner. It is more preferable that the liner height for the precursor liner be less than about $\frac{1}{3}$ of the liner height for the primary liner, and most preferable that the liner height for the precursor liner be between $\frac{1}{5}$ and $\frac{1}{3}$ of the liner height for the primary liner.

[0062] In the described example of Figure 6, the opening at the center of the apex of the primary liner has a diameter of about 0.375 inches (9.5mm) and the circular skirt edge has a diameter of about 2.50 inches (64mm). In this example the ratio of the diameter of the opening to the diameter of the circular skirt edge is about 0.15. Similarly the ratio of the diameter of the circular skirt edge of the mouth of the precursor liner to the circular skirt edge of the mouth of the primary liner is about 0.15. Preferably the ratio of the diameter of the opening to the diameter of the circular skirt edge is between about 0.05 and about 0.35 and more preferably the ratio of the diameter of the opening to the diameter of the circular skirt edge is between about 0.10 and about 0.25.

[0063] While the precursor liners shown in the examples have been simple cones, more complex shapes could be employed as described above or as illustrated in Figure 7. Alternatively, even a simple button or disk could be employed for the precursor liner, however, such an instance makes particularly favorable the choice of a material for such liner which is less dense or has a greater sound speed than the material making up the primary liner.

[0064] The embodiments addressed above involve an open shaped-charge, i.e. one without a cover. This type of shaped-charge is typically used within a perforating gun or tubing, which provides protection from direct exposure to the downhole pressure and environment. Alternative shaped-charges have covers that cooperate with the housing to protect each individual charge from direct exposure to the downhole environment. While not specifically addressed here, the benefits of the present invention would equally apply to such covered charges, as would be recognized by one of skill in the art.

[0065] Although only a few embodiments of the present invention have been described, it should be understood that the present invention may be embodied

in many other specific forms without departing from the scope of the present invention. Therefore, the present examples are to be considered as illustrative and not restrictive, and the invention is not to be limited to the details given herein, but may be modified within the scope of the appended claims.

Claims

1. A liner for a shaped-charge having two liner components, each component having a convex outer surface, a concave inner surface, an apex having a center, a mouth portion of the liner component opposite the apex of the liner component, and a skirt portion terminating in a circular skirt edge at the mouth portion of the liner component, the liner comprising: a first component made of a first material and having an opening at the center of the apex of the first component; a second component made of a second material wherein a portion of the second component is within the opening at the center of the apex of the first component; wherein the first material and the second material comprise different materials.

2. A liner according to claim 1, wherein the first material has a greater density than the second material.

3. A liner according to claim 1 or 2, wherein the second material has a greater sound speed than the first material.

4. A liner according to claim 1, 2 or 3, wherein each of the first and second components has a liner angle and wherein the second component has a liner angle which is no more than about 15 degrees greater than the liner angle of the first component.

5. A liner according to any preceding claim, wherein each of the first and second components has a liner height and wherein the liner height of the second component is no more than about the liner height of the first component.

6. A liner according to any preceding claim, wherein the ratio of the diameter of the circular skirt edge of the second component to the diameter of the circular skirt edge of the first component is between about 0.05 and about 0.35.

7. A method for making a shaped-charge, comprising forming a first liner component of a first material wherein the first liner component has an apex and an opening at the center of the apex; forming a second liner component of a second material wherein the second material is not identical to the first material; and assembling the first component and the

second component into a housing, containing explosive material, acting together to line the explosive material wherein a portion of the second component is within the opening at the center of the apex of the first component.

8. A method according to claim 7, wherein the first and second components are joined.

9. A method according to claim 7 or 8, wherein the first and second components are joined during assembly of the components into the housing.

10. A method according to claim 7, 8 or 9, wherein the action of joining the first and second components comprises fitting a portion of the second component within the opening in the apex of the first component.

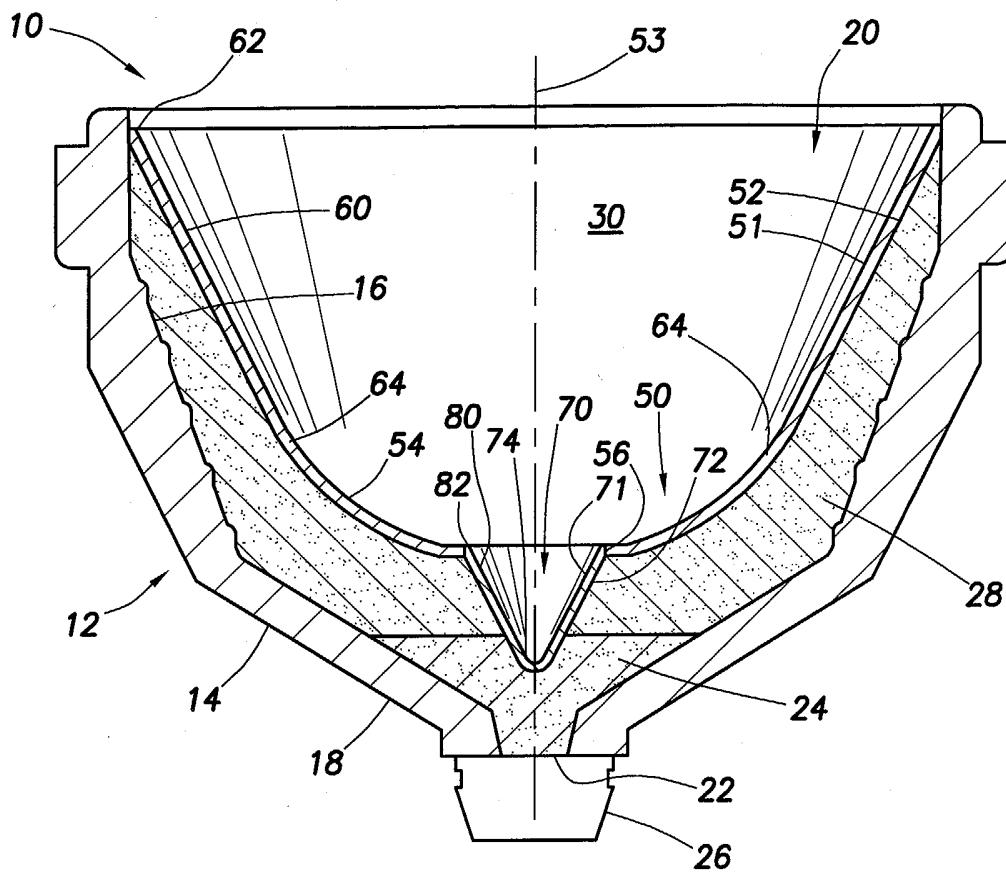


FIG. 1

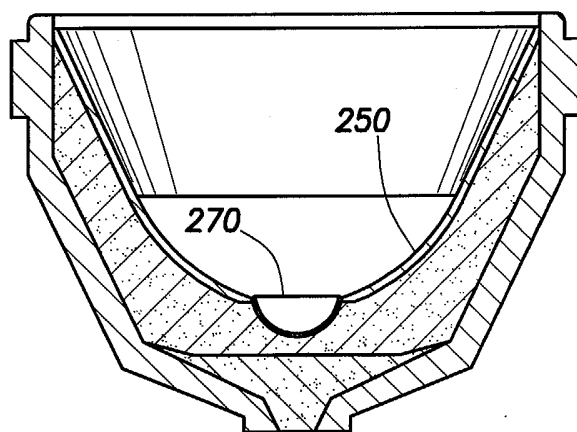


FIG. 7

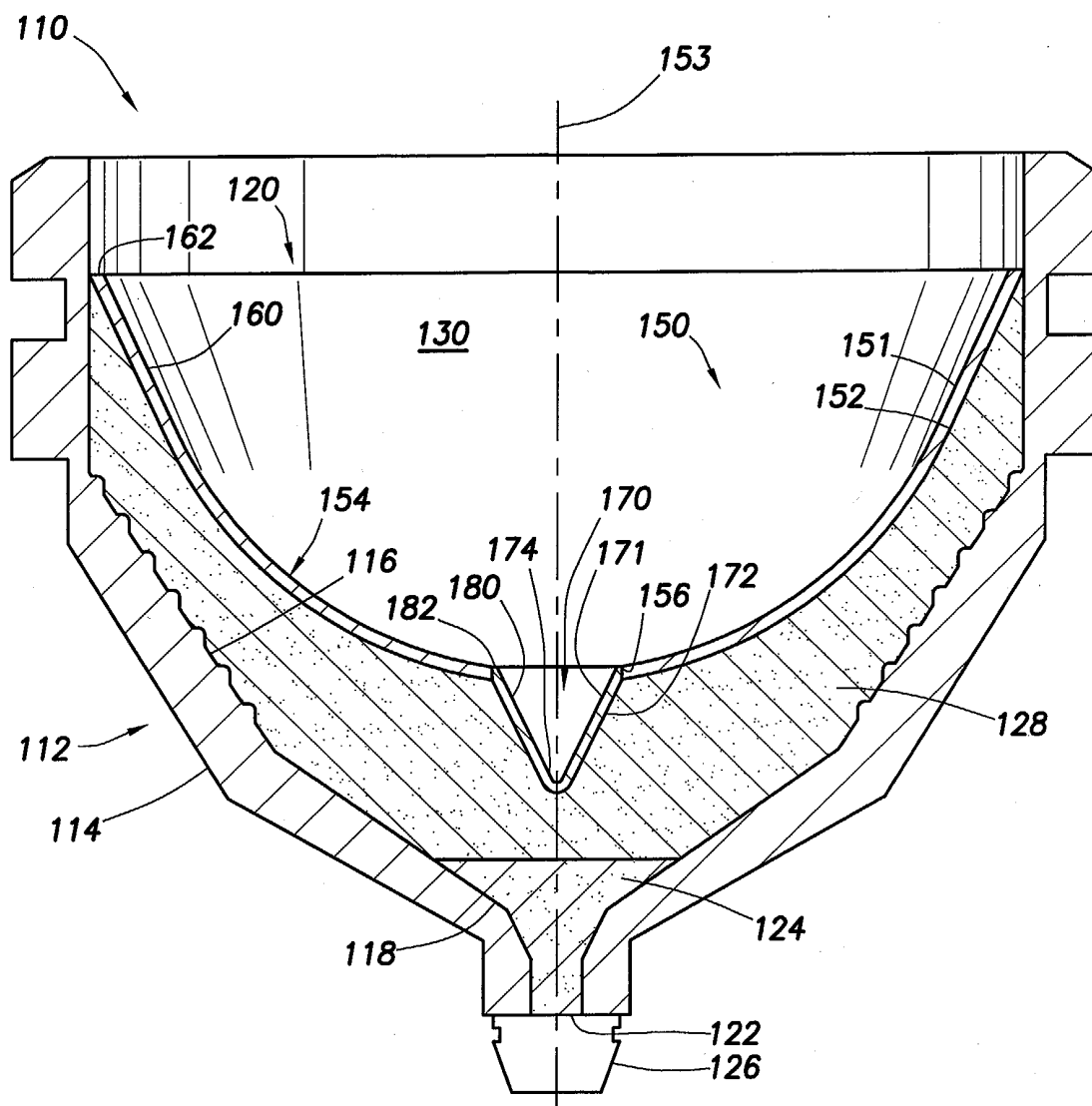


FIG.2

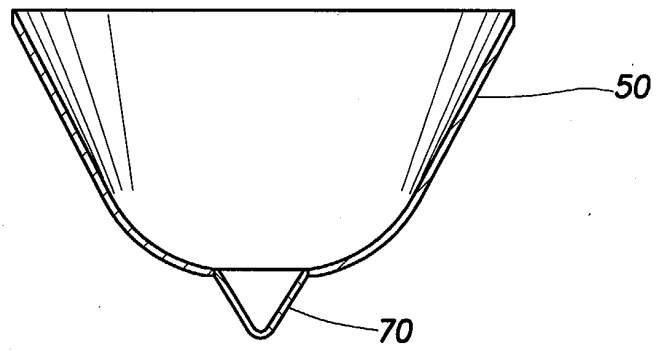


FIG. 3

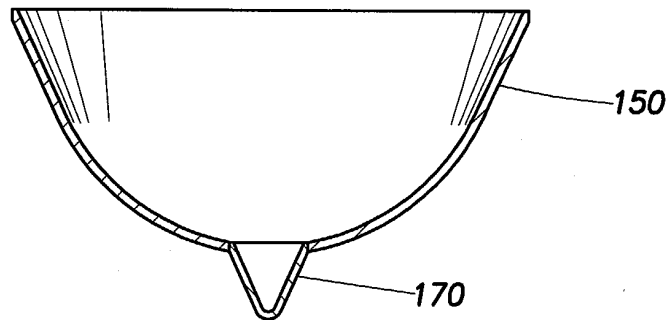


FIG. 4

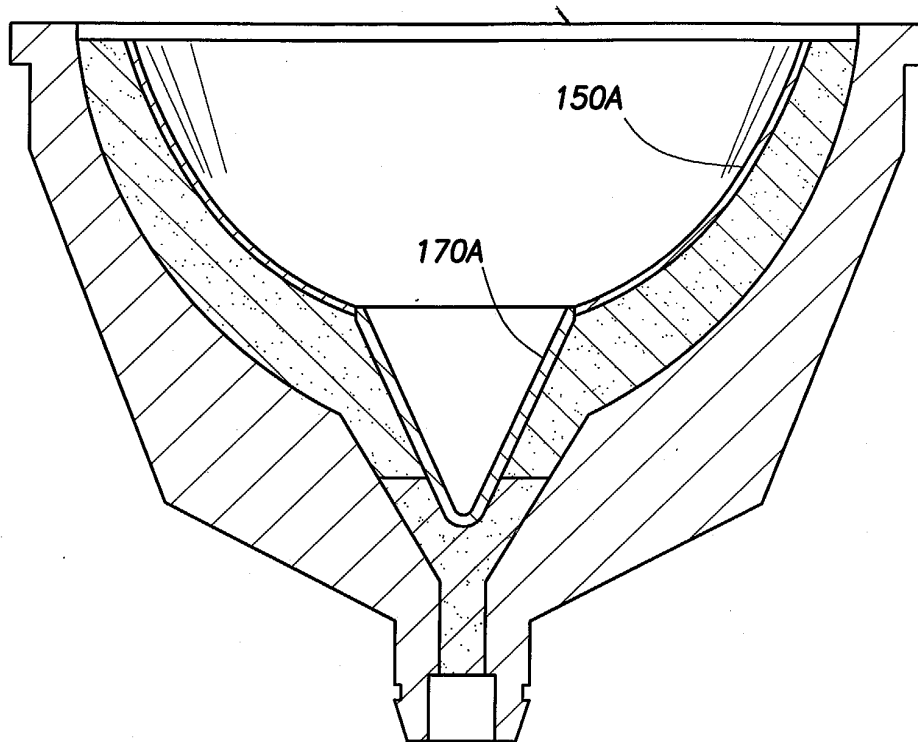


FIG. 5

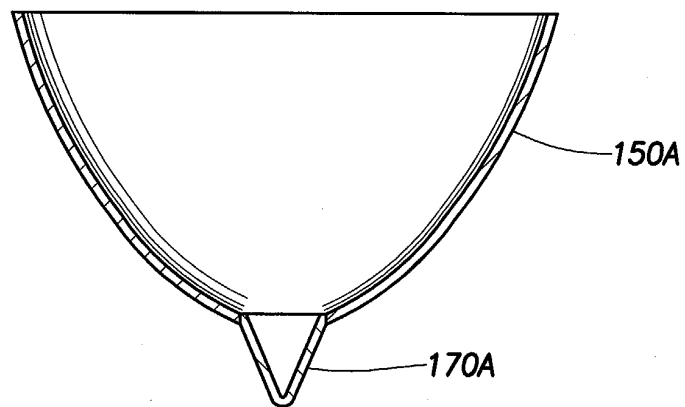


FIG. 6