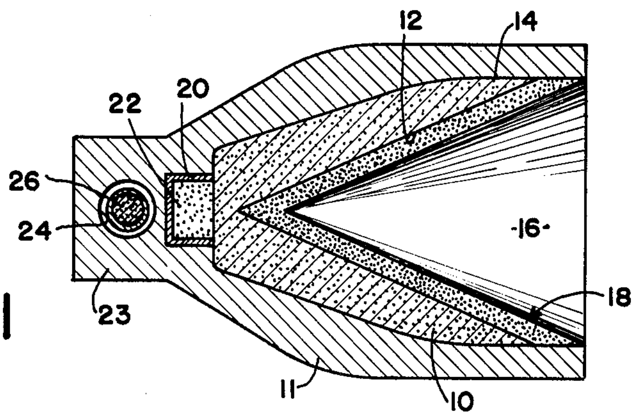

FIG. 1

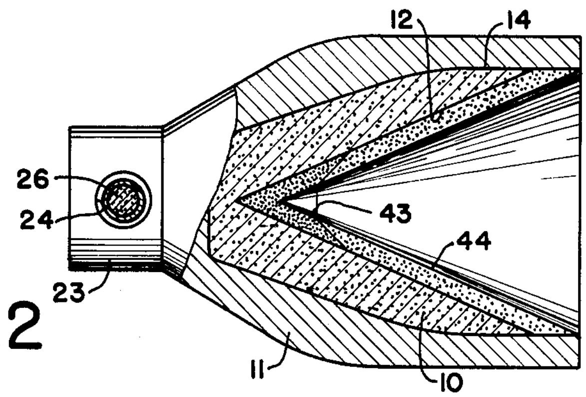

FIG. 2

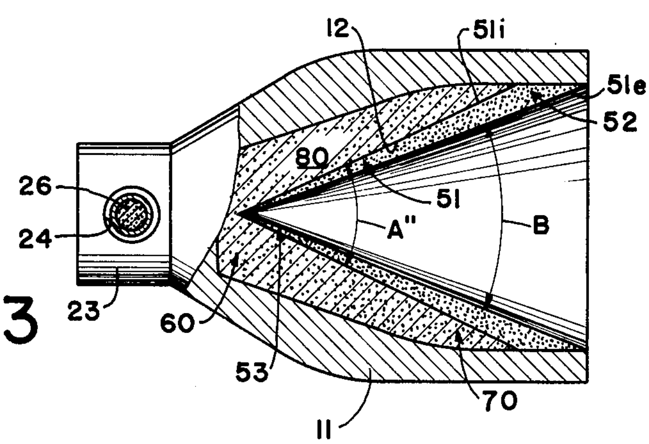

FIG. 3

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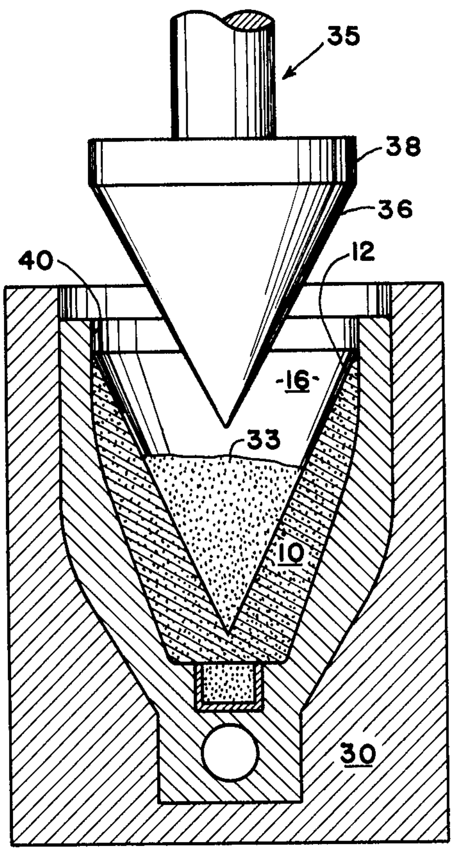

FIG. 4

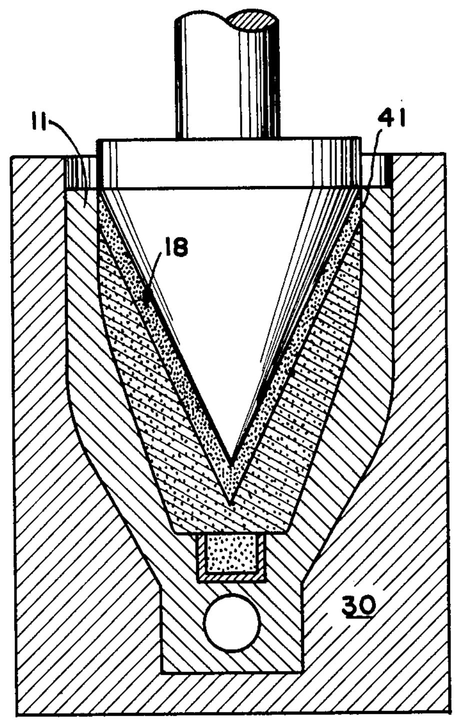

FIG. 5

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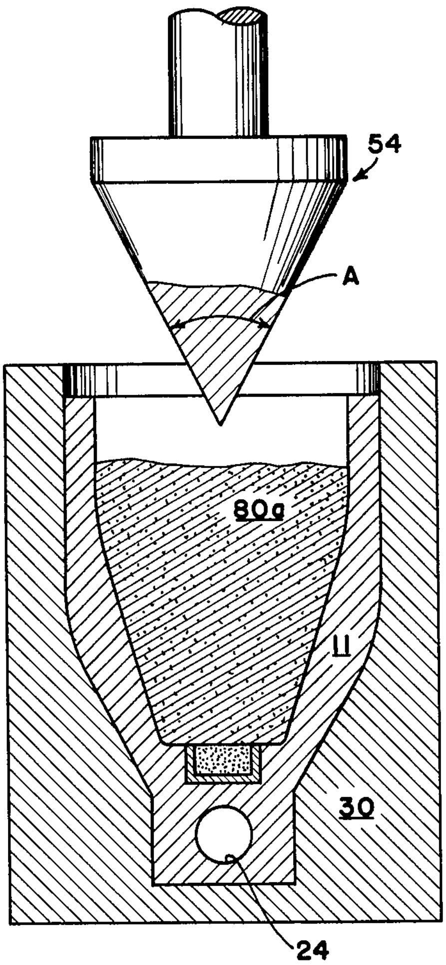

FIG. 6

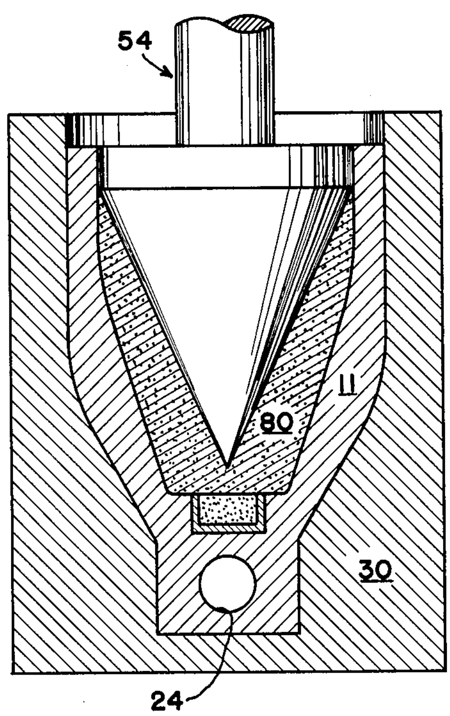

FIG. 7

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June 14, 1966 A. VENGHIATTIS 3,255,659
METHOD OF MANUFACTURING SHAPED CHARGE EXPLOSIVE WITH
POWDERED METAL LINER
Filed Dec. 13, 1961 4 Sheets-Sheet 4

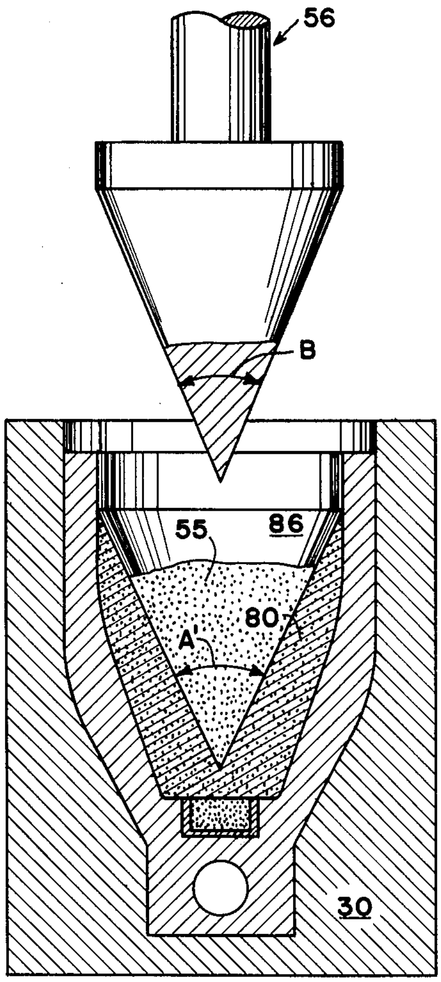

FIG. 8

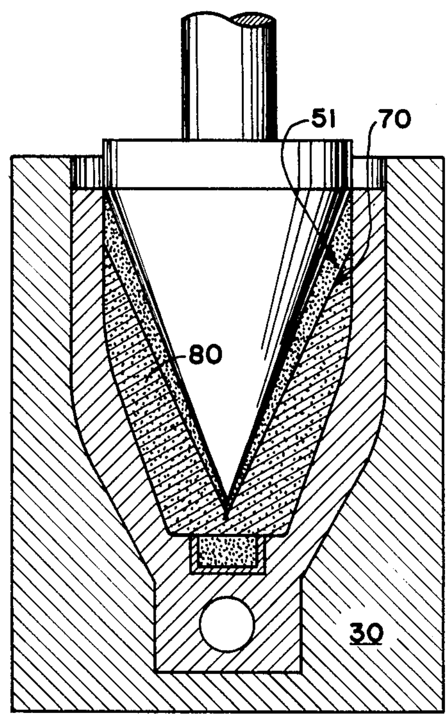

FIG. 9

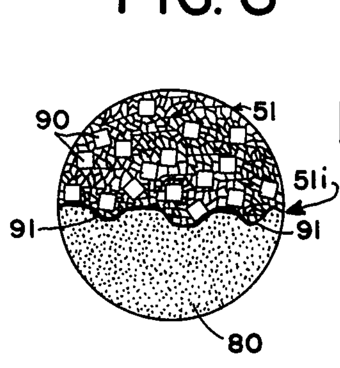

FIG. 10

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United States Patent Office

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Patented June 14, 1966

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3,255,659

METHOD OF MANUFACTURING SHAPED CHARGE EXPLOSIVE WITH POWDERED METAL LINER

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Filed Dec. 13, 1961, Ser. No. 159,092
7 Claims. (Cl. 86—20)

This application is a continuation-in-part of the co-pending application entitled "Shaped Charge Perforator," Serial No. 717,876, filed February 27, 1958, now abandoned.

This invention relates generally to shaped explosive charges and to a method of making them, and more particularly to improvements in explosive shaped charges for perforating well casing and surrounding earth formation in well boreholes, and to an improved method of manufacturing such charges.

In the employment of shaped explosive charges for making one or more perforations into earth formations surrounding an earth borehole or through fluid-filled well casings and thence into the surrounding earth formations, it has become accepted practice to mount one or more shaped charges either inside a suitable retrievable, fluid-tight, thick-walled, cylindrical steel housing which is adapted to be lowered into the fluid-containing well borehole to be perforated, or to mount such shaped charges within individual, expendable, fluid-tight containers adapted to prevent entrance of well fluid into the space surrounding the explosive charge and into the perforating jet-forming cavity therein. In either such apparatus where a plurality of such shaped charges are employed, they are usually positioned or linked together at suitable, longitudinally-spaced apart intervals suitable for lowering into a well borehole, with the axes of the shaped charges directed radially thereof. In the case of the thick-walled, retrievable, cylindrical container construction, the axes of the shaped charges are directed laterally in alignment with suitable ports formed in the housing wall, the ports usually being initially closed prior to firing the shaped charges by suitable relatively thin, replaceable, fluid-tight port seals. In the case of the individual expendable shaped charge units, as before mentioned, the axes of the shaped charges are likewise directed radially but through relatively thin portions of the individual housings covering the jet-forming cavities in the shaped charge explosive bodies.

Shaped charges for the hereinbefore-described purposes are usually constructed of a body of high explosive material which is formed in outwardly-facing concavity which may take various predetermined shapes for different purposes, but for the usual well perforating service is normally of conical form, and the outwardly-facing surface of such concavity is usually provided with a relatively thin liner formed from a sheet of suitable metal. Copper sheet has been found to be a preferred and commonly used material for this purpose, but sheet forms of metals such as aluminum, steel, zinc and the like materials, or combinations or alloys thereof, have been more or less successfully employed.

Upon detonation of a shaped charge, for example, one having a conically shaped concavity lined with sheet metal, an extremely high velocity jet is projected axially outward of said cavity, such jet comprising gaseous products resulting from the detonation of the explosive body of material together with portions of the metal liner, some of which portions are gasified, some of which are atomized. The main part of the sheet metal liner, however, is usually formed by the explosive force into a relatively solid metal missile or slug which moves along with the jet into any perforation which is formed by the piercing action of the jet. The shaped charge slug is usually found to have an elongated form generally described in the industry as carrot-shaped, and having a diameter or lateral dimension relative to its axial length, along which it travels, equal to, if not slightly exceeding, that of at least a portion of the perforation formed by the jet.

Thus, in the application of shaped charges to the perforating of casing and earth formations surrounding a well borehole, the metal slug heretofore usually formed of the liner material, as beforementioned, lodges within the perforation formed in the formation, and it has been found that such lodgement of the shaped charge slug and associated debris within the perforation acts as an obstruction which may substantially plug or at least offer considerable resistance to the subsequent flow of fluids from the thus-perforated formation into the well. The presence of shaped charge slugs and associated debris within the earth perforations formed by such shaped charges is therefore undesirable from a well fluid production standpoint, and the elimination of the presence of such slugs in connection with such perforation operations is highly desirable.

The substantial elimination of the beforementioned shaped charge slugs has been found to be possible in certain ways and under certain conditions. For example, it has been found that if the shaped charge liners or cones are made from a solid body or sheet of a relatively soft metal such as aluminum, lead, zinc and the like, the resulting perforating jets are substantially free from slugs, but with such materials the perforation efficiency of the charge suffers with respect to perforation hole diameter and penetration depth, and also, in some cases, the apparent or effective permeability of the formation immediately surrounding the perforation, and the subsequent production of fluid therefrom also appears to have been impaired, for some reason not entirely understood.

As beforementioned the generally preferred material for the fabrication of the shaped charge cavity liners or cones has heretofore been sheet copper. Sheet steel or other relatively hard metals have also been found to be preferable for this purpose over the beforementioned softer metals, because of the superior perforating efficiency and effective permeabilities obtained. By the use of these harder metals, including copper, the size of the slug has been found to be minimized if the liner thickness is sufficiently limited, but, if this is done, the perforating efficiency and effectiveness of the shaped charge is likewise limited with respect to both perforation hole diameter and depth. In other words, it has not seemed possible, heretofore, to attain at the same time both an optimum condition with respect to perforating efficiencies and freedom from slug formation, when employing shaped charge cavity liners formed of the most desirable sheet metals.

It has also been found that the fabrication of shaped charge cavity liners of the most desirable sheet material such as, for example, sheet steel and copper, makes it necessary to employ relatively complicated and expensive forming tools including multi-stage forming, and in some cases expensive and time-consuming annealing processes, otherwise erratic and inefficient perforating results were obtained.

Extensive research on this subject has established that superior performance is obtained from shaped charges having conical liners with a wall thickness greater adjacent the base or large diameter end of the liner than adjacent the apex or small diameter end thereof. Fabrication of shaped charge liners of this type from sheet metal is so difficult and expensive as to make sheet metal liners with tapering wall thickness too expensive for commercial application. Indeed, the expense of such sheet metal forming makes it economically impractical to provide any type of commercial sheet metal liner having other than walls of a uniform thickness. A related disadvantage of using sheet metal for shaped charge liners is the impracticability of making a conical liner having other than a rounded apex end.

It is, therefore, a primary object of this invention to provide a shaped charge perforator which is free of the hereinbefore-described disadvantages and undesirable effects.

It is another object of this invention to furnish a shaped charge unit including a shaped charge cavity liner which results in improved perforating effectiveness and efficiency.

It is another object of this invention to provide a shaped charge perforating device employing a cavity liner or cone which does not result in the formation of a metal slug.

Another object of this invention is to provide a shaped charge unit which avoids the formation of a metal slug while at the same time does not result in the impairment of the effectiveness of the shaped charge perforating action.

It is a still further object of this invention to provide a method of forming shaped charges which permits the fabrication of liners of a wide variety of shapes and configurations not otherwise capable of economic production.

It is a still further object of this invention to provide a method of shaped charge manufacture incorporating advantages of flexibility and economy heretofore unattainable.

The objects of this invention are accomplished, broadly, by employing shaped charge cavity liners which are composed of powdered materials, preferably powdered metals, which have been formed and consolidated in the required shapes, such formation and consolidation being preferably accomplished in situ in the shaped charge unit by pressing the powdered material between the surface of the previously formed explosive body cavity and a suitably formed ram at high pressure without the use of binding material and without subsequent sintering. The cavity in the explosive body is thus utilized, in effect, as the forming die against which the powdered material is compacted, and in which the resulting compacted layer intimately fits and adheres. Such in situ formation of the compacted layer imparts superior performance characteristics to the shaped charge units. In one embodiment of this invention, the compacted layer is in the form of a liner having walls having a predetermined thickness variation therealong. In a particularly preferred embodiment, the liner is generally conical and the wall is of tapering thickness being thicker adjacent the base end of the cone than adjacent the apex end thereof. Shaped charges including liners of this configuration have been found to possess perforating characteristics very much superior to other shaped charges. One method of forming a shaped charge unit with this type of liner is to initially compact the explosive body from particulate material by means of a conical ram of one apex angularity and subsequently compacting the metal powder forming the liner withiin the cavity of the explosive by means of another conical ram of smaller apex angularity.

Other objects, advantages and features of novelty of this invention will be evident hereinafter.

In the drawings which illustrate the preferred embodiments of the invention and wherein the same or similar reference characters illustrate the same or similar parts;

FIG. 1 is a view in longitudinal section of a typical well perforator shaped charge unit emboding certain features of this invention;

FIG. 2 is a view partially in longitudinal section and partially in elevation of a typical well perforator shaped charge unit similar to that of FIG. 1 embodying certain alternative features of this invention;

FIG. 3 is a view partially in longitudinal section and partially in elevation of a typical well perforator made in accordance with a different embodiment of this invention;

FIGS. 4 and 5 are views partially in longitudinal section and partially in elevation of apparatus illustrating certain steps in the method of this invention according to one embodiment thereof;

FIGS. 6, 7, 8 and 9 are views partially in longitudinal section and partially in elevation of apparatus illustrating certain steps in the manufacture of shaped charge units in accordance with another embodiment of this invention; and

FIG. 10 is an enlarged schematic view depicting the interface between the explosive body and liner surfaces of a shaped charge made by the steps illustrated in FIGS. 6–9.

Referring first primarily to FIG. 1, in which a typical well perforator shaped charge unit is illustrated, **10** is a body or charge of high explosive material which is enclosed within a protective shell or casing **11** which may be composed of metal, plastic, rubber or the like suitable material. The body of explosive material **10** may have different shapes for different purposes and for producing different effects, as is more or less well known in the art, but by way of illustration of this invention, the explosive body has a generally cup-shaped truncated, hollow, conical form, having inner and outer coaxial approximately conical surfaces **12** and **14** respectively, the inner surface **12** forming in the forward end thereof a forwardly-facing concavity **16** which, as beforesaid, in the particular form of perforation unit herein illustrated for forming substantially round perforations, is usually conical in general shape. The surface **12** of the concavity **16** is covered or lined with a relatively thin layer or coating of material **18** in the general form of a hollow cone, the particular features or characteristics of which are hereinafter more fully descibed.

A cylindrical booster cup **20** containing a suitable explosive booster charge **22** is located coaxially adjacent the rear end portion of the shaped charge body **10** within the case **11**, and the rearwardly-extending neck portion **23** of the case **11** is provided with a transverse bore or passage **24** adjacent the rear end of the booster charge cup **20** through which a suitable detonating fuse may be threaded, as shown at **26**, for detonating the shaped charge unit.

Where a plurality of shaped charge units are employed and are to be substantially simultaneously fired, as is conventional in oil well perforation practice, the detonating fuse employed, as shown at **26**, is preferably of an explosive or detonating type such as, for example, that known commercially as "P.E.T.N. Reinforced Primacord." The shaped explosive body **10** is cast, pressed or otherwise pelletized, as is well known in the art, to form a relatively firm self-supporting body, and is preferably although not necessarily, composed of a high explosive known as "R.D.X.," which is the trade name of a high explosive material (cyclotrimethylene trinitramine).

Referring again to FIG. 1, the shaped charge cavity liner or cone **18**, which is a particular feature of this invention is composed of a body of finely-divided metal particles of powdered metal which has been consolidated by suitable means into a relatively solid, rigid but friable body. The formation of the liner is accomplished in a manner, in part, similar to the well known powdered metallurgy manufacturing technique. In accordance with this latter method, a previously-formed body of explosive **10** contained within the case **11** (within which booster charge **22** has been positioned) is placed in a metal die **30**, as shown in FIG. 4, which may be the same one, or a similar one, in which the explosive body **10** was originally formed or compacted. A quantity of a selected powdered metal **32** is then poured into the upturned cavity **16** of the explosive body **10** to a suitable level, as shown at **33**, the amount of such powdered metal being dependent upon a predetermined desired thickness of the finished liner.

A ram 35 which likewise may be the same one or similar to the one originally used in forming the explosive body 10 is lowered into the die 30 and into the quantity of powdered metal 32 contained within the upturned cavity 16 formed by explosive body 10 to a position illustrated in FIG. 5, and pressure applied to the entrapped powdered metal between the downwardly directed conical face 36 of the ram and the upwardly facing conical surface 12 of the charge body 10, charge body 10 thus acting, in part, as a die against which the material forming the liner 18 (FIG. 1) is compacted and formed.

The upper cylindrical base portion 38 of the ram 35 makes a close-sliding fit within the upper cylindrical entrance portion 40 of the charge case 11 such that at a point near the downwardly bottoming travel of the ram within the case, the powdered metal 32 which is thereby displaced and flows up through the clearance between the ram 35 and the shaped charge body 10, is trapped therein as shown in FIG. 5 at 41. Further downward movement of the ram within the case under sufficient pressure results in compaction and consolidation of the powdered metal into a self-sustaining but frangible or friable layer made up of individual particles cohering to one another and adhering to the surface 12 of the explosive body cavity solely by pressure or compaction. The liner 18, being unsintered, may be referred to as "green" throughout this specification and in the appended claims, although it is recognized that as this term is employed in the powder metallurgy art it usually refers to unsintered, compacted bodies which have been subjected to pressures in the order of 50,000–100,000 p.s.i. This is somewhat greater than the pressure normally employed in the practice of this invention.

Usually if the cavity 16 is filled substantially to the top with metal powder, upon compaction the thickness of the resultant finished liner 18 will be approximately the correct finished thickness. For example, in the case of a conical cavity having a maximum diameter of about 1¼ inches, the finished, compacted liner or layer will have a thickness of approximately 3/32 of an inch.

As a more specific example of this process, a quantity of non-spherical, substantially pure powdered copper having a grain size of —150 mesh, was placed in the conical cavity of the explosive body 10, as hereinbefore described, and subjected to a forming or consolidating pressure between the ram and explosive body cavity surface of approximately 25,000 pounds per square inch. The resultant compacted conical liner body, which was approximately 3/32 of an inch thick and which had a form substantially as shown at 18 in the hereinbefore described drawings, had a good mechanical strength and conformed precisely and intimately and adhered firmly to the surface 12 of the shaped charge cavity.

Upon firing of the thus-assembled shaped charge unit through a steel casing and into an earth formation, a clean straight perforation was formed having improved hole diameter and depth of penetration as compared to similar shaped charge units having conventional cavity liners, and the perforation was free of any metal slug or so-called carrot.

As an alternative construction of the powdered metal cavity liner, and utilizing the method and apparatus illustrated in FIGS. 4 and 5, a quantity of powdered iron of approximately —150 mesh was first carefully poured into the bottom of the upturned cavity of the explosive body 10 and carefully leveled, followed by a layer of powdered copper of approximately —150 mesh, the proportion of powdered iron to powdered copper being approximately one part to three parts respectively, and sufficient to fill the cavity. The ram was then lowered into the cavity to a position similar to that shown in FIG. 5 and the powdered metal therein thereby formed, under high pressure as hereinbefore described, into a liner body having a thickness of approximately 3/32 of an inch, and in which the apex portion of the conical liner comprised mainly iron, as shown at 43 in FIG. 2 but the sides or outwardly diverting wall portion thereof comprising mainly copper, as shown at 44. This arrangement of cavity liner constituents was found to have the advantage over the liner composed entirely of copper of producing a perforation of increased diameter and penetration when fired under the same conditions.

A preferred embodiment of the present invention is illustrated in FIG. 3. This charge illustrated differs from those of FIGS. 1 and 2 in that the liner 51 is provided with a wall of tapering thickness; that is, the wall is thicker at the portion 52 adjacent the base end of the conical liner than in the portion 53 adjacent the apex end thereof. Shaped charge containing a liner of this configuration has substantially superior penetrating power as compared with otherwise identical charges having liners of uniform thickness of the type shown in FIG. 1. Improvement of penetration depth of as much as 25%, for example, has been found attainable in certain types of geological formations by the substitution of the tapered wall liner such as 51. While all the reasons for this improvement in performance are not fully understood, it is believed that the provision of the thinner liner portion 53 adjacent the rearward part of the explosive body 10 wherein the jet is believed to initiate permits the production of a jet of enhanced penetrating power when combined with a liner of greater thickness adjacent the forward portion of the explosive body. This increase in penetrating power is believed to result from a difference in velocity between the material forming the forward portion of the jet and that forming the rearward portion. The forward portion, being formed adjacent the thinner apex end of the liner, is of higher velocity than that forming the rearward portion of the jet which originates adjacent the thicker base end of the liner. Hence, the jet becomes relatively elongated, as compared with jets formed by shaped charges having liners of uniform thickness, and its penetrating power is correspondingly increased.

At least two factors contribute to the elongation of the penetrating jet produced in detonation of the charge embodying this invention. First, the mass of metal included in the forward part of the jet is relatively small since it is made up of the thinnest portion of the liner. A given explosive force will produce a greater acceleration of the smaller metal mass at the apex end of the liner than of the larger metal mass at the base end thereof. Second (as will be pointed out subsequently), the explosive body is denser adjacent the apex end of the liner than it is adjacent the base end so the mass of explosive adjacent the apex is greater than that adjacent the base. Thus, the accelerating force applied to the metal in the forward part of the jet is greater than that applied to the rearward part.

FIGS. 6–9 illustrate successive steps in the method of making the improved shaped charge shown in FIG. 3. This method is similar to that illustrated in FIGS 4 and 5 but differs in certain important particulars.

In FIG. 6 an open-ended, cup-shaped charge case 11 is shown positioned in the die 30 with a quantity of powdered explosive 80*a* contained in the cavity formed by the case. The conical die 54 is shown as having an apex angle designated as angle A. The term "apex angle" as used herein means the angle formed by two diametrically opposed generatrices of the cone. In accordance with one preferred embodiment of this invention, the angle A is 60°.

FIG. 7 shows the die 54 at the limit of its downward travel and the explosive powder formed into a consolidated body 80 similar in shape to body 10 shown in FIGS. 1 and 2. As shown in FIG. 8, explosive body 80 defines a conical concavity 86 which has an apex angle designated as A′ which is equal to the corresponding apex angle A of the ram **54**; in the embodiment described, 60°. A quantity of powdered metal **55** is introduced into the cavity **86** as powdered metal was introduced into cavity **16** in the embodiment illustrated in FIG. 4.

While in the embodiments described in connection with FIGS. 4 and 5 the ram used to form the compacted metal liner could be the same ram that was used to compact the explosive body **10** (if body **10** was formed by compaction); in this embodiment the liner forming ram **56** has an apex angle B which is smaller than the corresponding apex angle A of explosive forming ram **54**. In the particular embodiment described angle B is 50°. As shown in FIG. 9, the pressing of the ram **56** toward the bottom of the concavity **86** and the difference in acuteness between the apex angle A of explosive forming ram **54** and the apex angle B of liner forming ram **56** results in the formation of conical liner **51**, the wall of which is of tapering thickness decreasing from the large diameter end thereof toward the apex or small diameter end thereof. The pressure applied by the ram **56** is approximately 25,000 pounds per square inch or about the same pressure applied forming the consolidated explosive body **80** by the use of ram **54**.

It will be readily appreciated that, while a conical liner such as **51** with a wall of tapering thickness is formed easily, quickly, and economically by the method just described, the fabrication of a conical liner of similar configuration from sheet metal would be both difficult and costly. In addition to making the formation of the fabrication of a liner for the wall of tapered thickness practical, the preferred method of this invention has the additional advantage of providing additional compaction to the consolidated explosive body **80** in a manner improving the performance of the shaped charge of which it is a part. It has been found that the portion generally indicated at **60** in FIGS. 3 and 9, i.e., the rearward portion of the explosive body adjacent the apex of the liner is of greater density than the forward portion, generally indicated at **70**, i.e., the portion located adjacent the base of the conical liner **51**. This increase in density is evidently the result of deformation of the explosive body **80** during compaction of the metal powder into liner **51**. The extent of such deformation is such that while the apex angle A' (FIG. 8) formed by the sides of the explosive body **80** before the liner **51** is formed is 60°, the apex angle A'' (FIG. 3) formed by the walls of the explosive body **80** after the liner has been pressed into place is approximately 55°. The difference between angle A' and angle A'' depends upon the difference between the apex angles of the explosive-forming and liner-forming rams and on the forming pressures so it will be understood the angels specified herein are exemplary only.

The improved performance of shaped charges such as that shown in FIG. 3 testifies to the benefits obtained by such further compaction. It is believed that increased density of explosive in the portion **60** of body **80** wherein the jet is initiated substantially increases the perforating power of the jet by increasing the initial detonation velocity of the explosive. This provides a velocity differential between the forward and rearward portions of the jet. As previously explained, the resulting elongation of the jet increases the perforating power thereof. The perforating power of the jet is further enhanced by using an explosive body of this type in conjunction with a liner such as **51** characterized by walls of tapering thickness and wherein the angle formed by diametrically opposed generatrices of the conical inner surface **51*i*** thereof (angle A'') is greater than the angle formed by diametrically opposed generatrices of conical exterior surface **51*e*** (angle B).

The fabrication of shaped charges in accordance with the foregoing method has also been found to increase the density of the explosive body **80** in that portion immediately adjacent the liner **51** as compared with the density of the explosive in portions closer to the case **11**. This density differential is believed to contribute further to the velocity differential along the jet.

Another advantage of this invention arising out of deformation of the explosive body during compaction of the powdered metal liner is illustrated in FIG. 10. This figure is a very much enlarged view taken at the interface between explosive body **80** and liner **51** (FIG. 3). The scale of the drawing is such as to show that the liner **51** is made up of a plurality of coherent individual metal particles **90** which, as previously explained, are held together solely by compaction.

The conical surface **51*i*** of the explosive body **80** is shown in FIG. 3 as a smooth surface but, in fact, the deformation caused by the compaction of the metal powder particles **90** into liner **51** produces a plurality of secondary concavities, such as **91**, on this concave surface. The secondary concavities **91** are shown as being lined or substantially filled with metal particles **90**. Thus, in effect, a multitude of very small individual shaped charges formed by secondary concavities **91** are distributed all along the concave surface **51*i*** of explosive body **80**. It is believed that these very small shaped charge units each produce tiny jets which are cumulative in effect with that of the principal jet formed because of the presence of the concave surface **51*i*** and of the liner **51**. The additive effect of the many very small jets is believed to enhance the perforating power that a jet produced by this invention has compared to a jet produced by a shaped charge in which the concave surface of the explosive body is substantially smooth. In addition, the intimate contact between body **80** and liner **51**, which is evident from FIG. 10, is believed to contribute to perforating effectiveness.

While a principal advantage of the preferred method of this invention is the ease with which the improved charge illustrated in FIG. 3 may be formed, that is a charge having a liner with a wall of tapering thickness and an explosive body of higher density adjacent the apex of such liner, it will be apparent that there are other substantial advantages to such method. The in situ formation of the metal of the shaped charge liner from powdered material enables liners of an almost infinite variety of configurations to be formed. For example, the sides of the explosive body and the liner need not be straight in section as shown but may be curved. Also, the wall thickness throughout the liner may be predetermined and accurately controlled by use of the method of this invention. Thus, charges capable of producing a great variety of particular effects can be made simply by providing rams of appropriate shape.

Another advantage of the process of this invention is that materials not readily fabricated into sheet may be used as the liner of a shaped charge. Such materials may include metal oxides, materials lacking ductility such as tungsten or silicon carbide, or a wide variety of materials capable of being formed into a self-sustaining mass by the application of pressure alone.

It will be understood, of course, that while embodiment of the invention illustrated in FIGS. 6–9 is a particularly preferred form thereof, the invention may be practiced using an explosive body cast or otherwise fabricated by means other than pressing so as to provide a concavity such as **16**, within which powdered materials may be placed in situ compaction into a liner such as liner **18**, liner **51** or liners of other configuration. Also, the illustration of the shaped charge units as having conical cavities and liners will be understood to be exemplary only and other configurations such as hemispherical or prismatic may be employed in the practice of this invention.

What is claimed is:

1. A method of forming a shaped charge comprising:

placing a quantity of powdered high explosive material in a cavity formed by an open-ended cup-shaped case;

inserting a ram member into said case and said cavity;

pressing said powdered explosive material between said ram member and said case to form a consolidated body of high explosive material having an outwardly facing concavity therein;

placing a quantity of metal powder in said concavity;

inserting a ram member into said concavity; and

pressing said metal powder between said ram and said consolidated body at sufficient pressure to form a compacted metal powder layer adhering to said consolidated body.

2. A method of forming a shaped charge comprising:

forming a consolidated body of high explosive material with an outwardly facing concavity therein having a surface of predetermined contour;

introducing a quantity of metal powder into said concavity;

inserting a ram member into said concavity, said ram having a surface of predetermined contour different from that of said concavity and bearing a predetermined relation thereto; and

pressing said metal powder between said concavity surface and said ram surface at sufficient pressure to form a compacted layer adhering to said surface of said concavity and having a predetermined thickness variation therealong.

3. A method of making a shaped charge comprising:

compacting particles of explosive material by pressure to form an explosive body having a generally conical cavity formed in one surface thereof, the sides of said body defining said cavity forming a first predetermined apex angle;

introducing a quantity of metal powder into said cavity; and

compacting said metal powder to form a self-sustaining generally conical liner with inner and outer surfaces, said outer surface forming a second predetermined apex angle less than said first predetermined apex angle.

4. A method of forming a shaped charge comprising:

placing a quantity of powdered high explosive material in a cavity formed by an open-ended, cup-shaped case;

inserting a first ram member into said case and said cavity, said first ram member being of generally conical form and having a predetermined apex angle;

pressing said powdered explosive material between said first ram member and said case to form a consolidated body of high explosive material having an outwardly facing generally conical concavity therein;

placing a quantity of metal powder in said concavity;

inserting a second ram member into said concavity, said second ram member being of generally conical form and having a predetermined apex angle less than the apex angle of said first ram member; and

pressing said metal powder between said second ram member and said consolidated body at sufficient pressure to form a compacted metal powder layer adhering to said consolidated body.

5. A method of forming a shaped charge comprising:

placing a quantity of powdered high explosive material in a cavity formed by an open-ended, cup-shaped case;

subjecting said explosive material to pressure to form a consolidated body of high explosive material having an outwardly facing concavity therein;

placing a quantity of metal powder in said concavity; and

subjecting said metal powder and said body to pressure sufficient to form a compacted metal powder layer adhering to said body and to deform said body with respect to the form it took due to the first named pressure application.

6. A method of forming a shaped charge comprising: placing a quantity of powdered high explosive material in a cavity formed by an open-ended, cup-shaped case; inserting a first ram member into said case and said cavity, said first ram member being of generally conical form and having a predetermined apex angle; pressing said powdered explosive material between said first ram member and said case to form a consolidated body of high explosive material having an outwardly facing generally conical concavity therein; placing a quantity of metal powder in said concavity; inserting a second ram member into said concavity, said second ram member being of generally conical form and having a predetermined apex angle less than the apex angle of said first ram member; and pressing said metal powder between said second ram member and said consolidated body at a pressure to form a compacted metal powder layer adhering to said consolidated body, the pressure further compacting the explosive material.

7. A method of forming a shaped charge comprising: placing a quantity of powdered high explosive material in a cavity formed by an open-ended, cup shaped case; inserting a first ram member into said case and said cavity, said first ram member being of generally conical form and having a predetermined apex angle of approximately 60°; pressing said powdered explosive material between said first ram member and said case to form a consolidated body of high explosive material having an outwardly facing generally conical concavity having an apex angle of approximately 60° therein; placing a quantity of metal powder of —150 mesh in said concavity; inserting a second ram member into said concavity, said second ram member being of generally conical form and having a predetermined apex angle less than the apex angle of said first ram member and having an apex angle of approximately 50°; and pressing said metal powder between said second ram member and said consolidated body at a pressure of approximately 25,000 p.s.i. to form a compacted metal powder layer adhering to said consolidated body, the pressure further compacting the explosive material whereby the apex angle of the explosive material is now approximately 55°.

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