May 29, 1951 | T. C. POULTER | 2,554,499

HIGH-PRESSURE APPARATUS

Filed Sept. 8, 1947 | 2 Sheets-Sheet 1

Fig. 1

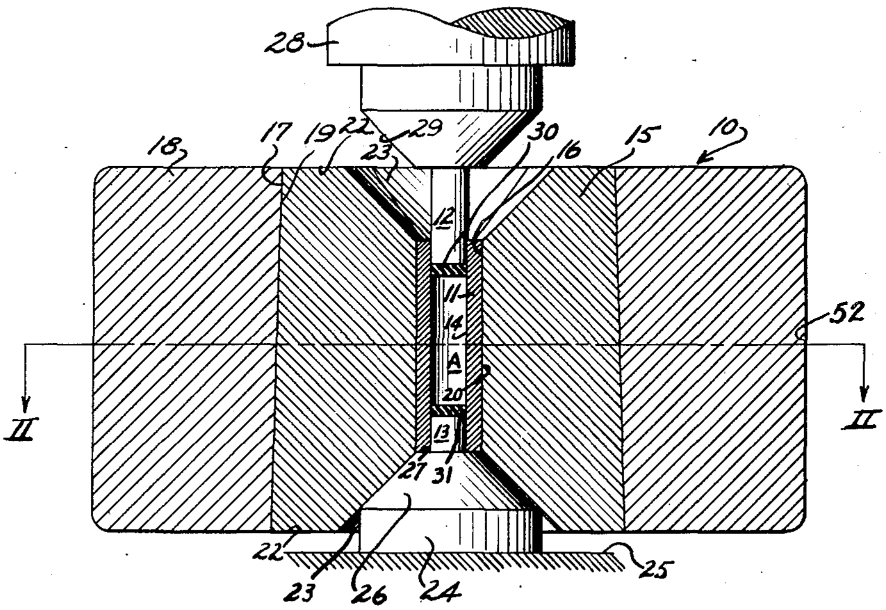
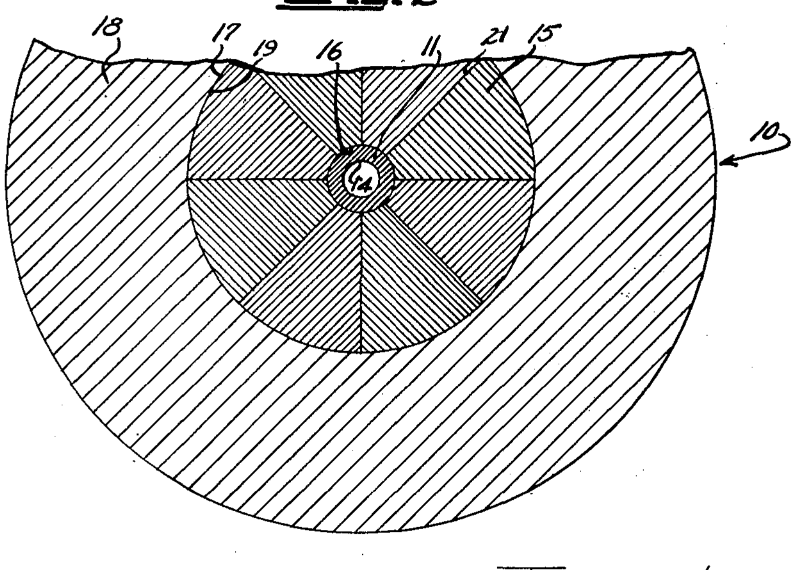


Fig. 2



Inventor
THOMAS C. POULTER

by The Firm of Charles W. Hills Attys.

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HIGH-PRESSURE APPARATUS

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Fig. 3

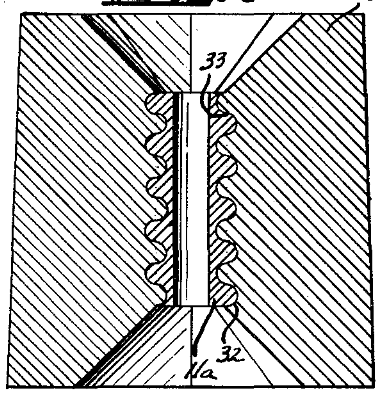
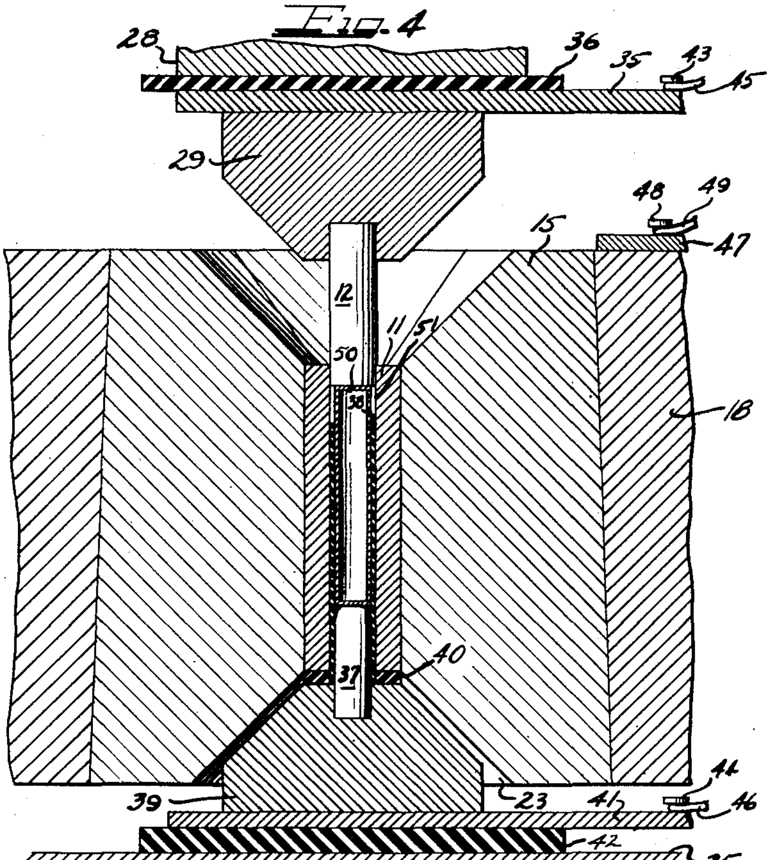


Fig. 4



Inventor
THOMAS C. POULTER

by The Firm of Charles W. Hills Attys.

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UNITED STATES PATENT OFFICE

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HIGH-PRESSURE APPARATUS

Thomas C. Poulter, La Grange, Ill., assignor to Armour Research Foundation of Illinois Institute of Technology, Chicago, Ill., a corporation of Illinois

Application September 8, 1947, Serial No. 772,645

12 Claims. (Cl. 18—34)

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This invention relates to a high pressure apparatus for the obtaining of very high pressures, such as those of the order of one million pounds per square inch and over. Such apparatus is frequently referred to as a "pressure bomb."

Heretofore, for extra high pressure work, pressure bombs have often been constructed as a tube, simple or composite, open at both ends and defining a cylindrical bore running axially for the full length of the tube. Cylindrical "pistons," one of which may be stationary and the other movable with respect to the bomb, are arranged for introduction into the open ends of the bore in opposed position. Pressure is applied externally and axially to the two pistons as by means of a hydraulic press or other suitable means, to create the desired pressure within the bomb bore between the adjacent ends of the two pistons.

The pistons, as heretofore employed, are usually made of high grade steel or sintered carbide, tempered glass-hard, and are generally capable of withstanding pressures greater than those which can be sustained by the bomb. The piston strength increases as the unsupported length decreases and as the diameter decreases. Values of one-half million pounds per square inch are obtainable with pistons of one-half inch in diameter and pressures of even a few million pounds per square inch are attainable with one-eigth to one thirty-second inch diameter pistons.

In the past, bombs have often been constructed as single thick-walled tubes or a nest of two or more such tubes shrunk or taper-fitted and pressed together. Calculation and control of stresses in such bombs are difficult. Usually "creep" is involved, and the permissible pressures which can be utilized are empirically determined by the length of time and number of repetitions of applied pressure, and by the temperature and nature of contents compressed in the bomb. If the bomb does not burst, often the central bore is stretched and deformed, requiring reboring, grinding, and lapping to a new truly cylindrical form. This is a time-consuming and expensive process. Other limitations and disadvantages of heretofore constructed bombs are well known to those skilled in the art and efforts to overcome them have only been partially successful.

I have devised an entirely novel and improved

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bomb construction which avoids the above mentioned difficulties and which has additional advantages not heretofore realized. In general, the bomb of my present invention comprises a relatively thin-walled inner tubular member defining a working volume to be subjected to high pressure, an outer ring-like member, and a plurality of sector-shaped blocks in mutual laterally supporting relationship compressively confined between the inner tubular member and the outer ring-like member. In the bomb of my invention, extremely high stresses produced near the center are transmitted radially outwardly by essentially pure compression to outer members, including the outer annular ring and the sector-shaped blocks, which serve to restrain these extremely high stresses with the imposition of relatively moderate stresses upon the outer ring-like member. The intermediate sector-shaped block elements cannot fail since they are subjected to practically pure compression with lateral and mutual support.

Furthermore, the bomb of my invention can be readily assembled and disassembled so that the central tubular liner can be removed and replaced and any other parts readily interchanged. This feature of construction is of particular convenience not only in the replacing of liners with corroded or worn out bores but also in the accommodation of liners with different bore diameters and correspondingly sized pistons as desired. The major components of my bomb seldom or never require renewal, a factor which is an obvious advantage.

The construction of my bomb also makes it feasible and convenient to introduce electrical insulation, under compression, in a manner such that the contents of the bomb may be heated electrically while under pressure.

It is therefore an important object of this invention to provide high pressure apparatus of improved and novel construction embodying the features of construction and advantages above mentioned.

It is a further important object of my invention to provide apparatus for achieving very high pressure, wherein a relatively thin-walled tubular liner defines the working volume of the bomb and such liner can be placed under a predetermined initial radial pressure to absorb a portion of the pressure developed within such working volume of the bomb.

It is a further important object of this invention to provide a high pressure bomb capable of withstanding pressures of the order of over a million pounds per square inch, and wherein the stresses therein set up near the center of the bomb are properly controlled and restrained by the outer members of the bomb construction at relatively moderate stresses.

It is a still further important object of this invention to provide a high pressure bomb in which a relatively thin-walled tubular liner is confined within an outer annular member by means of sector-shaped blocks initially placed under compressive stress by said outer annular member to withstand the pressures radially transmitted outwardly.

Other and further important objects of this invention will be apparent from the disclosures in the specification and the accompanying drawings.

On the drawings:

Figure 1 is a vertical cross-sectional view, with parts shown in elevation, of a high pressure apparatus made in accordance with my present invention, the apparatus being shown as positioned upon the floor or bed of a hydraulic press between a lower stationary bed and an upper movable ram of the press.

Figure 2 is a partial sectional view taken substantially along the line II—II of Figure 1.

Figure 3 is a vertical sectional view of a modified form of the inner bomb construction.

Figure 4 is a broken, vertical sectional view, with parts shown in elevation, of a modified construction of the bomb shown in Figure 1, the modified bomb being adapted for electrical heating of the pressure chamber.

As shown on the drawings:

The reference numeral **10** (Figs. 1 and 2), indicates generally a high pressure apparatus, or pressure bomb, embodying the principles of my invention. Said apparatus **10** includes an inner tubular member, or liner **11**, which is of relatively thin-walled construction and which is open at both of its ends for the reception of relatively movable pistons **12** and **13** to be described in greater detail later on. Said pistons **12** and **13** serve to produce the desired high pressure in "working volume" A within the bore **14** of the tubular liner **11**.

A plurality of sector-shaped blocks **15** confine and laterally support the tubular liner **11**. When assembled in place about said tubular liner **11**, the assembled blocks **15** define an inner cylindrical surface **16** for conforming contact with the outer cylindrical surface **20** of the tubular liner **11**. As will be later explained, the outer diameter of the tubular liner **11** may be of the exact size of the diameter of the inner cylindrical surface **16**, or it may be undersized or oversized, depending upon the results desired.

The outer surface of the assembled blocks **15** is preferably slightly tapered, as indicated by the surface **17**, to facilitate the mounting of said assembled blocks within an outer, annular retaining member **18** having a similarly tapered inner surface **19**. The outer annular retaining member **18** may be of a solid piece of metal, or alloy, or may be of composite construction. The tapered surfaces **17** and **19** are preferably conical surfaces of the same small axial taper so as to permit a press fit. The sector-shaped blocks **15** are first assembled about the tubular liner **11**

and the outer annular retaining member **18** then pressed axially onto the liner-block assembly. In the final assembled relationship, as shown in Figure 1, the blocks **15** are under predetermined circumferential-radial compression, as in the case of very thick staves of a barrel bound together by hoops. With a definitely undersized tubular liner **11**, the sector-shaped blocks **15** alone, by virtue of the keystone or barrel stave action that results, would support the entire compressive forces exerted by the outer annular retaining member **18** and no radially compressive force would be exerted on the outer surface **20** of the tubular liner **11**.

On the other hand, if the tubular liner **11** were definitely oversized, the entire compressive forces exerted by the outer annular retaining member **18** would be transmitted to the outer surface **20** of the tubular liner **11**. Therefore, by a proper selection of the outer diameter of the tubular liner **11** with respect to the inside diameter of the cylindrical surface **16** defined by the inside ends of the sector-shaped blocks **15**, it is possible to control the initial radial compression on the liner **11** across the surface **20** thereof to any desired fraction of the total initial radial compression exerted by the outer ring **18**.

This is a great advantage since it permits the use of an inner tubular liner **11** of a comparatively thin-walled section without crushing of the liner by initial external radial pressure set up upon assembly of the apparatus. The large initial compression produced by the outer restraining annular member **18** is initially carried largely by a circumferential pressure between the contacting lateral surfaces **21** of the sector-shaped blocks. As hydrostatic pressure is built up within the working volume A within the bore **14** of the tubular liner **11** under the action of the pistons **12** and **13**, this pressure is transmitted radially outwardly, first through the sector-shaped blocks **15** and then to the outer annular retaining member **18**. The sector-shaped blocks **15** themselves provide mutual lateral support circumferencewise and have longitudinal and radial dimensions both large compared to the corresponding dimensions of the high pressure working face **14**. Therefore, at all times the sector-shaped blocks **15** are stressed in virtually pure compression with adequate lateral support so that their failure is virtually impossible. Moreover, the outer annular retaining member **18** is of a size and accessibility that, without overstressing, it will readily support any pressure which it is feasible to develop in the space A. Consequently, the major outer parts of the bomb such as the sector-shaped blocks **15** and the annular retaining member **18**, have indefinitely long life.

The end faces of the assembled blocks **15** provide an outer annular plane surface **22** (Fig. 1) and an inwardly directed conical recess **23**. The tubular liner **11** is of such length as to terminate at the bottoms of said conical recesses **23**. A stationary base block **24**, supported upon the floor or bed **25** of a hydraulic press (not shown), extends into one of said recesses **23** and is provided with a conformingly tapered conical end portion **26**. The piston **13** projects from the end of said base block **24** to leave an annular plane shoulder **27** for supporting the adjacent end of the tubular liner **11**. The movable ram, indicated by the reference numeral **28** is similarly provided with a conically shaped block **29** which extends into the corresponding conical recess **23**. The piston **12** projects from the conical end of block

29 into the tubular liner 11 in opposed relationship to the piston 13. The end portions of said pistons 12 and 13 are preferably carefully lapped to fit exactly the bore 14 of the tubular liner 11.

For some applications, a pressure tight fit between the pistons 12 and 13 and the wall of the bore 14 may be insured by providing seals 30 and 31, respectively, on the ends of said pistons. Said seals may be formed of any suitable plastic or resilient material, such as a soft vulcanized rubber, either natural or synthetic, a silicone resin, or the like, capable of withstanding the temperatures employed. Said seals 30 and 31 may initially be somewhat oversize to effect a tight seal, and need not be secured in any manner to the ends of said pistons. These seals 30 and 31 are more conveniently merely pushed ahead of the active ends of the pistons 12 and 13.

In assembling the apparatus, the sector-shaped blocks 15 are first assembled in place around the tubular liner 11, and the outer annular retaining member 18 is then pressed or shrunk in place about the assembled blocks to clamp the blocks together by virtue of the conical surface of contact between the outer surfaces 17 of the blocks 15 and the inner surface 19 of the member 18. The pistons 12 and 13 are inserted into the ends of the upper block 29 and the lower base block 24, which may be of hard steel or sintered carbide. The lower, stationary piston 13 is inserted into the lower end of the tubular liner 11, and the entire bomb and lower piston assembly placed on the floor 25 of a hydraulic press. The desired charge is then placed in the cavity A, the upper piston 12 inserted, and pressure applied by the ram 28 to the upper block 29 and piston 12.

In the specific form of my apparatus illustrated in Figures 1 and 2, the sector-shaped blocks 15 are shown provided with plane lateral faces and the dihedral angle between these plane faces exactly $360/n°$, where n is the number of sectors around the liner. For optimum control of the extremely high stresses which may be produced in the central regions of the bomb, it may be desirable to depart from such geometric accuracy and the opportunity to do so in the bomb of my invention is one of the major advantages of the design. It may not be desirable that the lateral faces of the blocks be exactly plane or that the dihedral angles between the lateral faces of the sector blocks be exactly $360/n°$. Instead of the lateral faces being flat, they may be slightly convex, or in general, of compound curvature. In such case, after the outer annular member 18 has been pressed over the slightly tapered outer conical surface 19 of the blocks 15, a predetermined circumferential compressive stress can be established throughout the sector-shaped blocks, with initial radial and longitudinal gradation of this circumferential stress pre-controlled as desired.

Alternatively, the sector-shaped blocks may be machined or ground as geometrically perfect as feasible, both with respect to dihedral angles and the flatness of the lateral faces. Before assembly, however, thin shims of metal foil, flake mica, or the like, of desired thickness and contour may be inserted between the sector-shaped blocks, and the blocks then assembled and the outer annular member pressed into place. The additional thickness, when compressed between the blocks, creates additional circumferential pressure, with resultant radial and circumferential pressure profiles accurately predetermined at will. Shims of different thickness and thickness profiles can be included for different bombs or for different pressure runs of the same bomb, thus making the initial pressure distribution different, as desired, for different internal liners, operating pressures, and different temperature profiles (with resultant different thermal dilation and distortion which will exist under the different temperature gradients) for particular heating and external cooling conditions of various tests. Such graded shims, therefore, make possible the grading of circumferential pressure over the faces of the sector-shaped blocks adjustable at will to compensate for the conditions of any given pressure run of any bomb.

As a still further essential refinement in the control of stresses in the crucial central high-stress region made possible by the bomb of my invention, a controlled longitudinal beam action can be introduced into the block sectors 15. This may be accomplished in either or both of two ways. First, when internal pressure is developed in the working space A (Fig. 1), as pressure is applied to the pistons 12 and 13, then, due to the fact that the axial length of A is much shorter than the length of the sectors 15 and outer ring 18, the stretching or radial dilation will be greatest at and near the central plane II—II. This action may be accentuated by purposely reducing the thickness of the outer ring 18 at its central section by making its outer surface 52 spool or capstan shaped. Secondly, instead of making the inner surface 19 of outer ring 18 and outer surface 17 of assembled sectors 15 both truly straight mating conical surfaces, either or both of these surfaces may be intentionally ground with an axially extending concavity to fit tighter at the ends than at the center. Practically, it is convenient to make the inner surface 19 of the outer ring 18 truly conical and to grind the outer conical surface 17 of the assembled sectors 15 slightly more at the center than is represented by a true cone.

Using either or both of these expedients in combination, hydrostatic pressure applied in the working volume A will cause the sectors 15 to dilate or "bulge" radially outward more at their centers than at their ends, i. e., to bend slightly along their length like the lengthwise bend in wooden barrel staves. This will produce nominal tensile stresses axialwise in the outer wide sections of the blocks 15 where areas are large and other stresses comparatively small. However, more important, it will create large axial compressive stresses in the narrow inner portions of the block sectors 15 adjacent to liner 11, these axial stresses being greatest, in a lengthwise direction, in the region surrounding working volume A.

In the preceding exposition, descriptive terms have been used such as "blending like barrel staves," etc. It must be realized, however, that all dilations, bending, intended departures from true geometric flat surfaces and angles or conical surfaces actually are matters of a few mils at most either initially or during pressure application and are, therefore, far too small to indicate in the figures.

It is well known that with equal triaxial compressive stresses, i. e., three equal compressive stresses in mutually orthogonal directions which is equivalent to hydrostatic pressure, any homogeneous metal can withstand any hydrostatic pressure whatever, no matter how large, without plastic distortion. Now, although it is not possible to design my bomb so that (a) the circumferential pressure stresses produced in blocks 15 by non-flat or slightly off-angled faces or shims between faces, and (b) axial stresses in the inner portions of the sectors 15 due to lengthwise bending will, at all times of a pressure cycle from zero to full hydrostatic pressure in space A, both be equal to each other and to (c) the radial pressure exerted by liner 11 itself, plus the hydrostatic pressure internal to A, yet in the crucial central region of the sectors, these three triaxial compressive stresses can be controlled in my bomb, never to become unequal to a sufficiently large amount to cause permanent distortion of the sectors 15 or outer ring 18.

As internal pressure is created in the bomb, the additional radial compression combines with and alters the initial circumferential and axial bending stresses in such a manner that at no time and at no place in the sector-shaped blocks do the resultant combined triaxial stresses cause plastic deformation of the sector blocks 15. This is a distinctly superior result, made possible by my invention, unobtainable heretofore with the use of the ordinary, thick-walled tube bomb construction where the metal immediately surrounding the pressure cavity is plastically deformed in tension each time the tube is loaded and in compression each time the tube is unloaded. Under those conditions, a few repetitions of such cyclic plastic deformations causes failure after a limited number of times of use. While the thin-walled inner tubular liner 11 of my bomb may, of course, be plastically deformed upon application and release of pressure, it can be made of a softer alloy which is capable of appreciable deformation, since the stresses which it is called upon to withstand are nominal, just like an inner tube in a tire casing. Indeed, for some applications, I find it desirable to replace liner 11 by a soft rubber tube (or the like) closed at both ends and containing the charge to be compressed. In this case, pistons 12 and 13 (Fig. 1), are made to accurately fit the inner cylindrical surface 16 of the sector blocks 15, which pistons then longitudinally compress such soft rubber or metal capsule together with its contents.

Moreover, the high unit radial stresses at the central ends of the sector-shaped blocks are fanned out and become nominal pressures at the inside surface 19 of the outer annular member 18. Since the annular member 18 is of comparatively large inside diameter, the ratio of its outer to inner radii is not far from unity. Therefore, the metal in the outer annular member 18 is nearly uniformly stressed over its cross-section in hoop tension, so that the required cross-section need not be excessive, nor the alloy used in making the member 18 so critical as with usual high pressure bomb constructions.

External radial support for the tubular liner 11 in the construction of Figures 1 and 2 is adequate under all circumstances. Because of the thin-walled section of the liner and the friction along the surface 20, axial support of the liner may not be required under ordinary circumstances. However, should the liner wall be comparatively thick and the temperature and pressure of operation extreme, there is a possibility that the tubular liner 11 may be squeezed in two parts near its center by internal hydrostatic pressure and the two parts extruded axially endwise out of the bomb.

In order to prevent this possibility, the alternative construction illustrated in Figure 3 may be employed. As there shown, the inner tubular liner 11a is provided with an outer circumferentially fluted surface 32. The fluting may be helically arranged, in a manner similar to threads on a screw, or may be arranged annularly. The inner surfaces of the blocks 15 are similarly contoured as at 33. This arrangement effectively prevents failure of the liner by extrusion. There is adequate axial strength in the sector-shaped blocks 15 to provide this additional function of longitudinal or axial support for the tubular liner 11, or 11a.

One great advantage of the bomb of my invention is the convenience with which it may be modified for electrical heating of the charge while such charge is under extreme pressure. A preferred embodiment of this modification is shown in Figure 4.

In Figure 4, similar reference numerals are used to indicate the tubular liner 11, the sector-shaped blocks 15 and the outer annular retaining member 18. The upper piston 12 is mounted as previously described in a block 29, but an electrically conductive plate 35 is positioned in place against the top of said block 29 and a layer of insulation 36 inserted between said plate 35 and the upper movable ram 28.

The lower piston 37 is made of slightly less diameter than the inside of the tubular liner 11 to permit a thin tube, or sleeve 38, formed of mica or other suitable insulating material, to fit snugly around the piston 37 and extend upwardly from the block 39 into the tubular liner 11. Said insulating sleeve 38 extends from the end surface of the block 39 to a point somewhat short of the working end of the piston 12 in its initial position.

An insulating washer 40 lies against the end of said block 39 about the piston 37 and insulating sleeve 38. This insulating washer 40 prevents the conical face of block 39 from completely seating in the conical recess 23 in the ends of segments 15, the conical air gap so formed electrically insulating the respective members from each other. A plate 41 of electrically conductive material is inserted between the block 39 and a plate 42 of insulating material that rests upon the floor 25 of the hydraulic press. The electrically conductive plates 35 and 41 are provided with contacts 43 and 44, respectively, for connection with a source of electrical current including wires 45 and 46. In addition, an electrical contact, including an electrically conductive plate 47 and a contact post 48, may be provided for the outer annular ring 18, with a wire 49 for connection to the source of electrical current in parallel with or as an alternative to wire 45.

In assembling the apparatus illustrated in Figure 4, the piston 37 is secured in the end of the block 39 and the insulating sleeve 38 slipped over the projecting end of the piston. The insulating washer 40 is then inserted in place against the end of the block 39. The entire sub-assembly including the piston 37, block 39, insulating sleeve 38 and insulating washer 40 may then be chilled, if desired, and the insulating sleeve 38 and piston 37 inserted into the end of the tubular liner 11, the latter having been heated just prior to such insertion.

By careful selection of dimensions, such as the diameters of the parts and the thickness of the insulating sleeve 38, and by proper choice of assembly temperature of parts, the thermal shrink fit may be made to strongly compress the insulating sleeve 38 between the stationary piston 37 and the lower end of the tubular liner 11. Pressure is still further increased by the external compression on the liner 11 produced by the sector-shaped blocks 15 and the outer annular member 18, which are next assembled in place in that order. The upper edge of the lower piston 37 and the lower internal edge of the tubular liner 11 may be slightly rounded off to prevent cutting through the insulating sleeve 38 under the conditions of extreme radial compression to which the sleeve is subjected.

The active charge is next inserted in the cavity provided by the liner 11 and insulating sleeve 38. If the charge is electrically non-conductive, or it may be desirable to do so for other reasons, it may be enclosed in a thin-walled metal capsule 50. Said capsule 50 may be closed at both ends and formed with such thin walls and of suitable metal so as to be easily collapsible. The capsule fits snugly inside of the insulating sleeve 38 to rest against the end of the piston 37, but extends about one diameter beyond the end of the sleeve 38 toward the piston 12. When the upper movable piston 12 is inserted into the tubular liner 11 and pressure is applied, the piston will cause the upper end of the capsule 50 to collapse, or "mushroom," and make electrical contact with the tubular liner 11 along the end cylindrical surface thereof, as indicated at 51.

Electrical contact with the capsule 50 is made at each end by the pistons 12 and 37. (Elastic fluid seals 30 and 31 of Figure 1 are omitted, or, if included in Figure 4, the lower one 31 at least must be made of electrical conducting material.) If the charge itself is electrically conductive, the metallic capsule 50 may be omitted, in which case, the charge itself makes electrical contact with the ends of the pistons 12 and 37 and with the exposed inner surface of the tubular liner 11 at 51.

The bomb and piston assembly is insulated from the floor 25 and from the ram 28 by means of the plates or sheets 42 and 36 of insulating material. Electrical current may thus be supplied through the wire 46 and contact post 44 to the plate 41, for passage through the block 39 and piston 37 to enter the capsule 50 and thence flow through the piston 12, block 29 and plate 35 to the terminal post 43 and wire 45. Useful heating can thus be produced by the flow of the electrical current lengthwise in the thin wall of the metal capsule 50. If the charge itself is electrically conductive, or if the capsule is omitted, then the electrical current would flow entirely or in part endwise through the charge itself.

In the latter case, the electrical current required for effective heating might be large. In order to avoid danger of overheating the moving piston 12, it is desirable to provide the outer annular retaining member 18 with an electrical connection through the terminal 48 and wire 49, the electrical circuit being completed through the blocks 15, liner 11 and contact at 51 with the capsule 50 in its mushroomed state. Both the wires 45 and 49 may be used in parallel as one side of the electrical circuit, or either one may be used as a potential lead. The important point is that the capsule 50 is insulated for almost its entire length from the containing tubular liner 11 and electrical contact provided only at or near each end of the capsule. The heating currents required are relatively large and the voltage is small due to low resistance of the circuit. Insulation problems are, therefore, almost entirely mechanical.

The insulating sleeve 38 may be collapsed or telescoped at its end adjacent the upper piston 12 as said piston advances during compression. Likewise, the capsule 50, if used, may also crumple and collapse during application of pressure. It is feasible, however, to preserve the integrity of the insulation provided by the sleeve 38 despite such pressure.

As an alternative construction, the tubular liner 11 may be insulated from the sector-shaped blocks 15 by insulating the inner face surface at 20 (Fig. 1), or inter-surface 32—33 (Fig. 3) by enamel or the like, in which case the liner may be heated by heavy electrical current flow lengthwise of the liner after provision of suitable end terminals. When using the liner itself as the electrical heating element, I have found that concentration of heat liberation at the center of the bomb can be achieved by reducing the wall thickness of the tubular liner at its mid region. This reduction may take the form of an internal or external annular groove in the tube wall. In the latter case, the space between the liner and the sector-shaped blocks so formed must be filled with insulation, or the longitudinal contour of the inner ends of the sector-shaped blocks 15 must be made to correspond to the outer contour of the liner as modified.

If shims of graded thickness are used between the lateral faces of the sector-shaped blocks 15 in order to grade circumferential compression at will over the faces of the blocks, these same shims, if made of electrical insulating material such as mica flake, could also be made to serve as part of an electrical heating system using the individual sectors as current elements. It is possible to insulate all or desired parts of the surfaces of each sector so that electrical contact is, or is not made, between the sectors, or between the sectors and the tubular liner, or between the sectors and the outer annular member 18. Many combinations are thus feasible for heating the liner by electrical current flow in series or multiple, long or short, circumferential and/or longitudinal paths by suitable contact with part areas of the sectors, to which sectors electrical current is introduced by a suitable electrical terminal fixed to the sectors. Location of applied heat, in and to the liner, is also of considerable importance and the bomb construction here disclosed makes for great flexibility and convenience in achieving the desired heating conditions.

It will, of course, be understood that various details of construction may be varied through a wide range without departing from the principles of this invention, and it is, therefore, not the purpose to limit the patent granted hereon otherwise than necessitated by the scope of the appended claims.

I claim as my invention:

1. In a high pressure apparatus, an outer annular member having a tapered inner surface, an inner tubular liner having an outer circumferentially fluted surface, and a plurality of sector-shaped blocks defining an inner surface conforming with the outer surface of said tubular liner and defining an outer surface generally conforming with the tapered inner surface of said outer annular member, the dimensions of said liner, blocks and annular member being such that upon assembly said blocks are placed under initial radial compression.

2. High pressure apparatus comprising a relatively thin-walled tubular member defining a working volume to be subjected to high pressure, an outer ring-like member concentric with and

surrounding said tubular member, and a plurality of sector-shaped blocks in mutual laterally supporting relationship interposed between said members upon assembly, said blocks collectively having a greater total effective volume than that volume lying between said tubular member and said ring-like member, and said blocks being compressed within said outer member upon assembly to subject said tubular member to an initial inwardly acting radial compression.

3. High pressure apparatus comprising a relatively thin-walled tubular member defining a working volume to be subjected to high pressure, an outer ring-like member and a plurality of sector-shaped blocks in mutual laterally supporting relationship compressively confined between said members to subject said tubular member to initial radial compression upon assembly of said apparatus, said blocks having longitudinal and radial dimensions at the surfaces of contact with said outer member that are both large in comparison with the corresponding dimensions of said working volume, and said blocks in combination normally occupying a volume greater than that occupied by the blocks upon assembly of said appartus, whereby compression stresses set up in said blocks upon assembly are transmitted directly to said working volume.

4. High pressure apparatus comprising a relatively thin-walled tubular member defining a working volume to be subjected to high pressure and formed of material that is plastically deformable under the pressures to which it may be subjected and an outer ring-like member and a plurality of sector-shaped blocks formed of a material relatively harder than said plastically deformable material and arranged in mutual laterally supporting relationship compressively confined between said members to subject said tubular member to initial radial compression upon assembly of said apparatus.

5. High pressure apparatus comprising a relatively thin-walled tubular member having an outer circumferentially fluted surface and an inner cylindrical surface defining a working volume to be subjected to high pressure, an outer ring-like member and a plurality of sector-shaped blocks in mutual laterally supporting relationship compressively confined between said members and having surfaces conforming to and in contact with said fluted surface and the inner surface of said ring-like member to subject said tubular member to initial radial compression upon assembly of said apparatus.

6. High pressure apparatus comprising an outer annular member having an inner tapered surface, an open-ended inner tubular liner providing a cylindrical inner working surface, a plurality of sector-shaped blocks providing when assembled an outer tapered surface for pressure contact with said inner tapered surface and an inner surface in conforming contact with said tubular liner and inwardly tapered end recesses coaxial with said inner working surface, said blocks serving to transmit radial compression forces created upon assembly of the apparatus to said tubular liner, and relatively movable rams having pistons for insertion into the open ends of said liner and having tapered end faces for insertion into said tapered end recesses, said pistons having end portions lapped within said cylindrical inner working surface.

7. High pressure apparatus comprising an outer annular member having an inner tapered surface, an open-ended inner tubular liner providing a cylindrical inner working surface, a plurality of sector-shaped blocks providing when assembled an outer tapered surface for pressure contact with said inner tapered surface and an inner surface in conforming contact with said tubular liner and inwardly tapered end recesses coaxial with said inner working surface and in surface contact with said liner, and relatively movable rams having pistons for insertion into the open ends of said liner and having tapered end faces for insertion into said tapered end recesses, said pistons having end portions lapped within said cylindrical inner working surface and having end seals of plastic sealing material.

8. In a high pressure apparatus having a pair of opposed force-generating elements, a charge confining and retaining structure comprising sector-shaped blocks defining when assembled a central cavity for receiving said elements and having a tapered outer surface, and an annular member for enclosing said assembled blocks and having a similarly tapered inner surface for cooperation with said assembled blocks to hold the same under radially inwardly directed initial compression upon assembly of said member about said blocks, said compression being transmitted directly through said assembled blocks to the area lying between said elements.

9. High pressure apparatus comprising an outer annular member, an open-ended inner tubular member, relatively movable piston elements extending into and closing the open ends of said tubular member to define a high pressure working chamber, and sector-shaped blocks confined between said outer annular member and said inner tubular member, said blocks presenting lateral surfaces of initially curved contour to establish a predetermined circumferential stress throughout said sector-shaped blocks when said outer annular member is in assembled position confining said sector-shaped blocks.

10. High pressure apparatus comprising an outer annular member, an open-ended inner tubular member, relatively movable piston elements extending into and closing the open ends of said tubular member to define a high pressure working chamber, sector-shaped blocks confined between said outer annular member and said inner tubular member, and shims between the lateral faces of said blocks to establish a predetermined circumferential stress throughout said sector-shaped blocks when said outer annular member is in assembled position confining said sector-shaped blocks.

11. High pressure apparatus comprising an outer annular member, an open-ended inner tubular member, relatively movable piston elements extending into and closing the open ends of said tubular member to define a high pressure working chamber, and sector-shaped blocks confined between said outer annular member and said inner tubular member, said blocks presenting lateral surfaces of initially convex contour to establish a predetermined circumferential stress throughout said sector-shaped blocks when said outer annular member is in assembled position confining said sector-shaped blocks.

12. High pressure apparatus comprising an outer annular member having an inner generally conical surface, an open-ended inner tubular member, relatively movable piston elements extending into and closing the open ends of said tubular member to define therein a high pressure working space, and sector-shaped blocks

confined between said outer annular member and said inner tubular member, said blocks when assembled about said tubular member presenting a generally conical-shaped outer surface for contact with the inner generally conical surface of said outer member, one of said generally conical surfaces being concave axially to provide a tighter fit at the ends than at the center and thereby create axial compressive stresses in the narrow inner portions of said blocks adjacent said inner tubular member, the axial stresses being greatest in the region surrounding said working space.

THOMAS C. POULTER.

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