May 14, 1963 B. GILBERT 3,089,416

METHODS OF AND MEANS FOR FRACTURING EARTH FORMATIONS

Filed Oct. 5, 1959 4 Sheets-Sheet 1

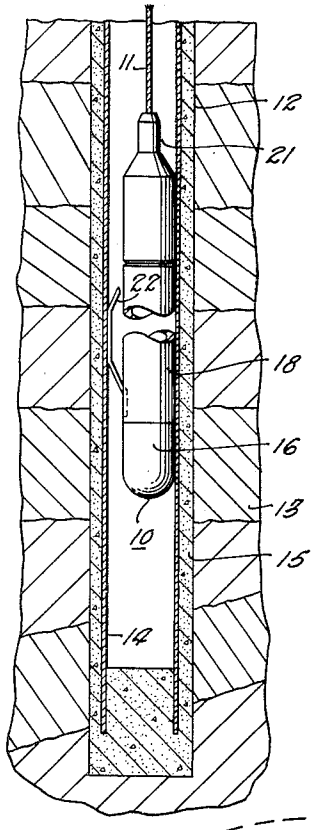


Fig. 1

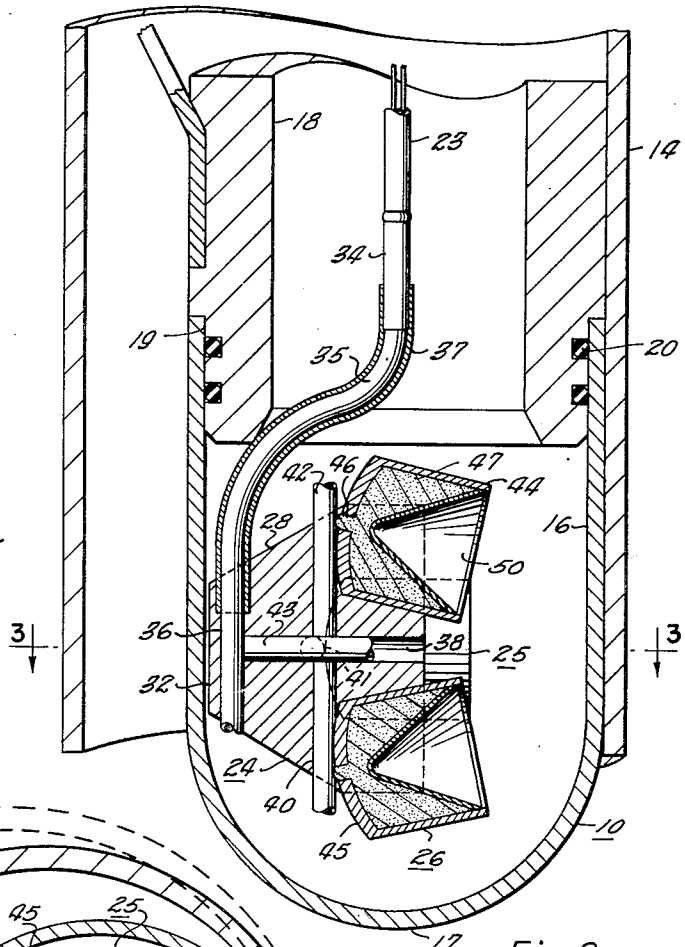


Fig. 2

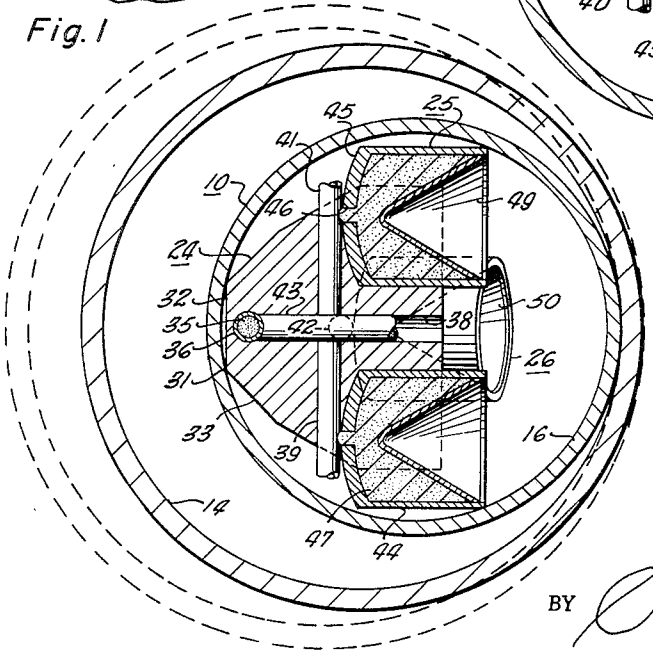


Fig. 3

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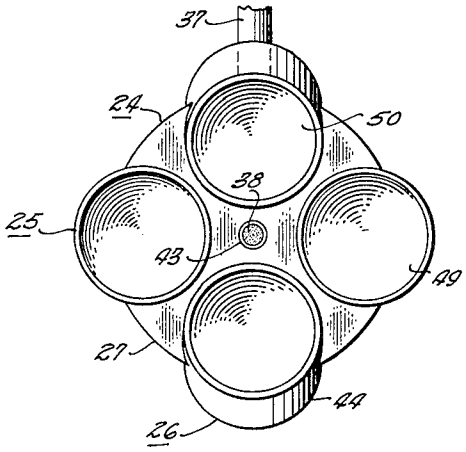


Fig. 4

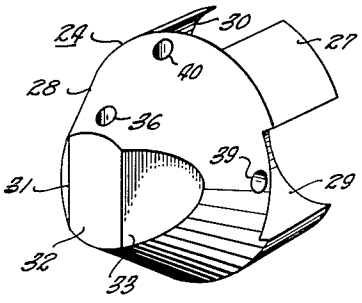


Fig. 5

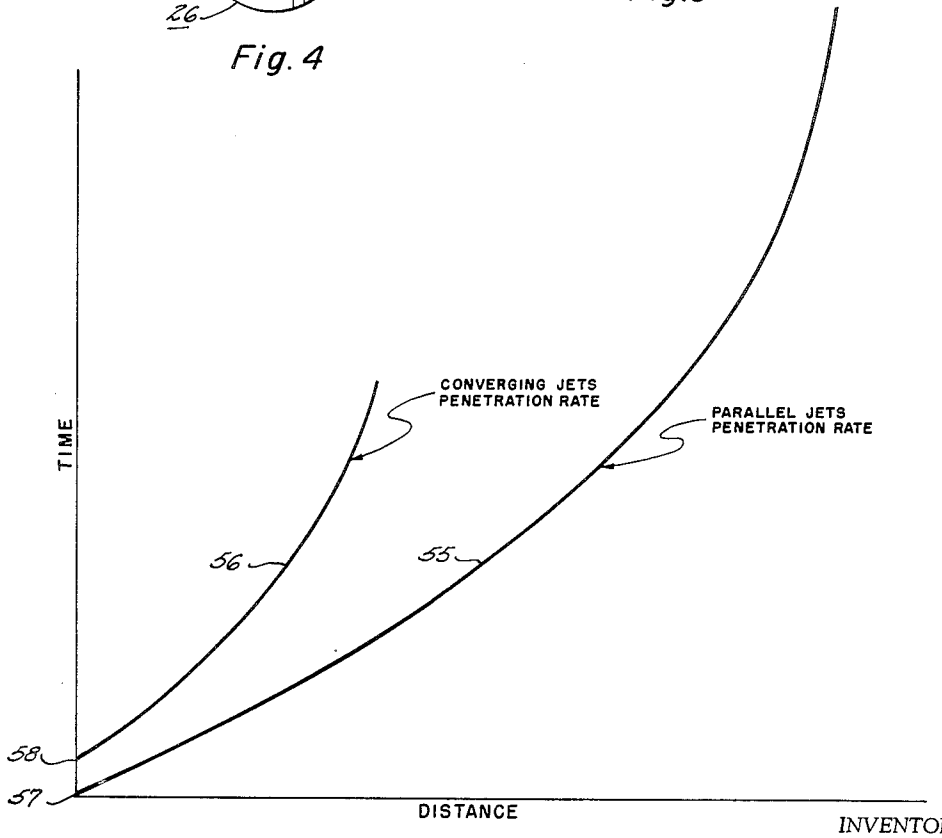


Fig. 6

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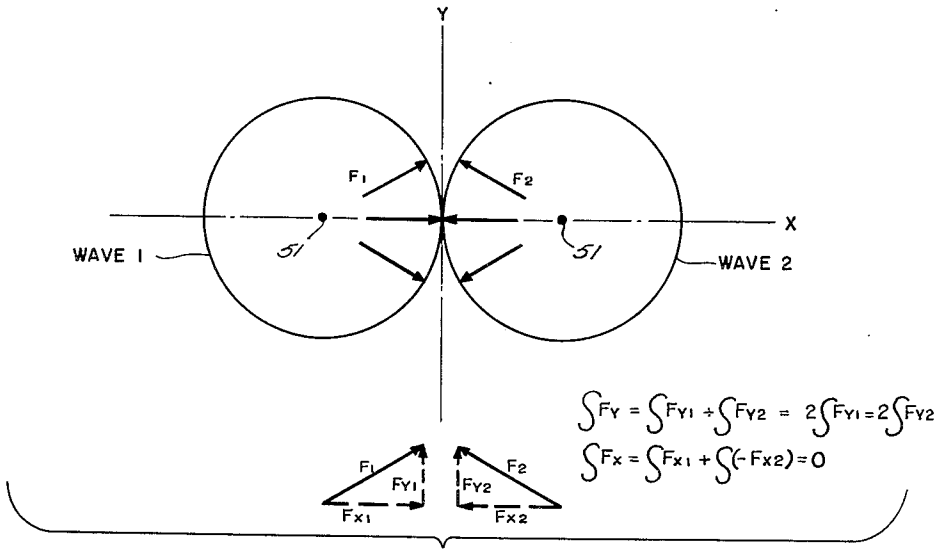


Fig. 7

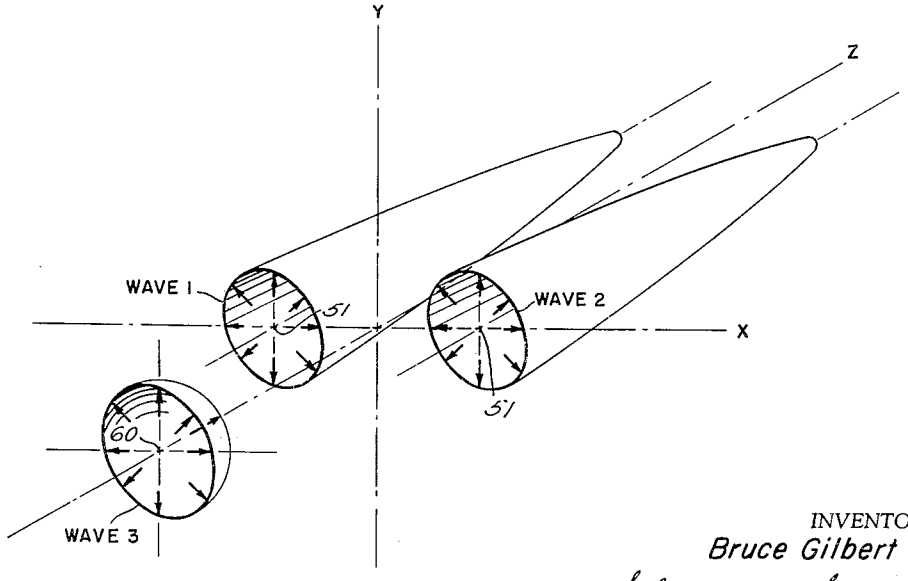


Fig. 8

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METHODS OF AND MEANS FOR FRACTURING EARTH FORMATIONS

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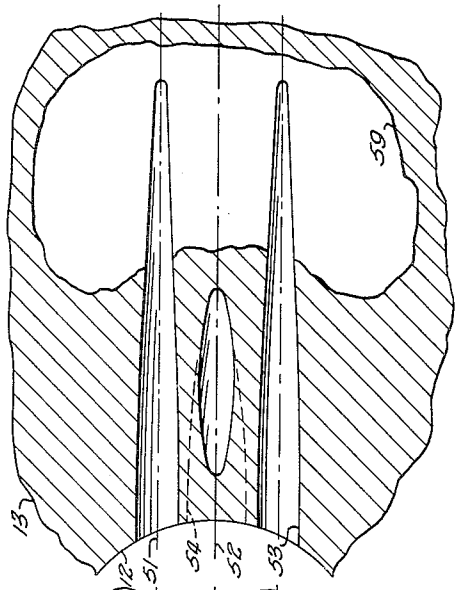


Fig. 13

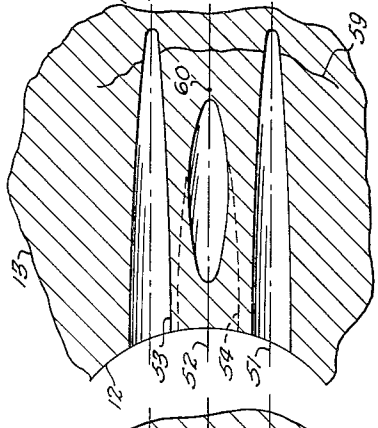


Fig. 11

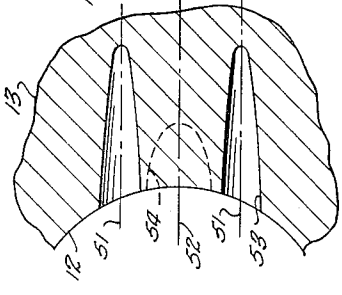


Fig. 9

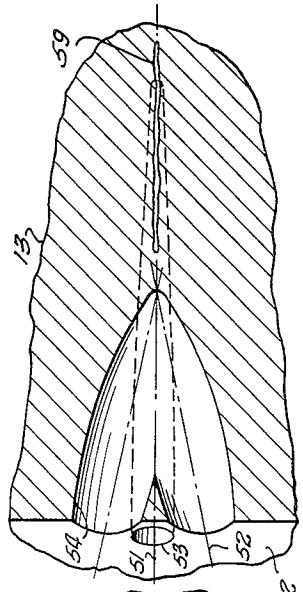


Fig. 14

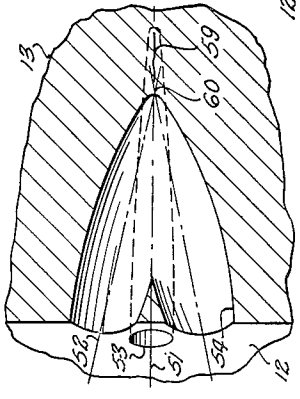


Fig. 12

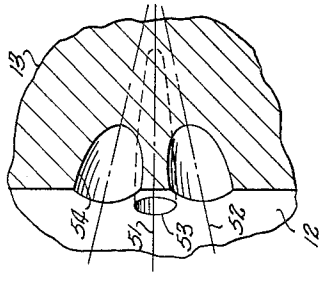


Fig. 10

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United States Patent Office 3,089,416 Patented May 14, 1963

3,089,416

METHODS OF AND MEANS FOR FRACTURING EARTH FORMATIONS

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Filed Oct. 5, 1959, Ser. No. 844,536
4 Claims. (Cl. 102—20)

This invention relates to new and useful improvements in methods of and means for fracturing earth formations.

As is well known, it is common practice to increase the productivity of oil bearing and similar earth formations by creating artifical fractures therein so as to provide passages for facilitating flow from the formations into well bores from which the fluids can be recovered. Hydraulic fracturing, i.e., the injection of fluids under high pressure, is in general use for this purpose and has been relatively successful; however, there is no control over the direction or plane of the fracture which may extend into a barren or undesirable zone, such as a gas or water bearing formation instead of the desired oil bearing formation. Also, some formations tend to "break down" or crush and form a multiplicity of minute fissures only in the vicinity of the well bore or the point of initiation rather than fracturing in a single plane which deeply penetrates the reservoir. Accordingly, it is readily apparent that it is most desirable to orient the plane of the fracture whereby it is disposed wholly within the selected formation and that said fracture be of sufficient magnitude to accommodate an adequate flow of fluid from said formation to an adjacent well bore.

Therefore, one object of the invention is to provide an improved method of fracturing an earth formation adjacent a well bore or other cavity in a predetermined plane, such as parallel to the horizon or at any angle thereto.

Another object of the invention is to provide an improved method of creating a fracture having a predetermined orientation in an earth formation so that the fracture can be confined to the selected formation and directed and/or extended so as to increase the flow of fluid from said formation.

A particular object of the invention is to provide an improved fracturing method, of the character described, wherein a fracture having a predetermined orientation is created by the interaction of shock waves in the earth formation which coact to produce a combined force sufficient to fracture the formation in the desired plane.

An important object of the invention is to provide an improved fracturing method, of the character described, wherein the orientation of the fracture is controlled by the intersection of a pair of shock waves having spaced sources moving along substantially parallel axes in the desired plane and which coact with a subsequent third shock wave radiating from a point source intermediate and in the plane of the two moving sources whereby the forces of the waves combine to part the formation in said plane.

A further object of the invention is to provide an improved method, of the character described, wherein a pair of jets are directed along substantially parallel axes in the desired plane of fracture to generate the pair of shock waves which initially intersect in said plane of fracture whereby the components of force of said pair of waves perpendicular to said fracture plane increase relative to the components of force of said waves parallel to said fracture plane and coact with the components of force of the third shock wave perpendicular to said fracture plane to produce a combined force sufficient to part the formation in the desired plane.

Another particular object of the invention is to provide an improved fracturing method, of the character described, wherein the third shock wave results from the delayed collision in the desired plane of fracture of a pair of jets having convergent axes in a plane substantially perpendicular to the plane of the fracture and between the pair of substantially parallel jets whereby said third wave is of greater magnitude than the wave produced by either of the colliding jets.

An object of the invention is to provide improved means for fracturing an earth formation adjacent a well bore or other cavity by explosive jet charges which penetrate the formation and produce shock waves which coact in such manner that the plane of the fracture may be accurately controlled.

A further object of the invention is to provide an improved apparatus for fracturing an earth formation by a pair of explosive jet charges having substantially parallel axes for generating a pair of shock waves which initially intersect in the desired plane of fracture, and by explosive jet charge means which generates a subsequent third shock wave from a point source between and in the plane of the substantially parallel axes whereby the waves coact to produce a combined force sufficient to fracture the formation in the desired plane.

Another object of the invention is to provide an improved apparatus, of the character described, wherein the explosive jet charge means has less penetrating capacity than the substantially parallel jet charges so that the third shock wave emanates from a point source adjacent the terminus of the penetration of said means.

A particular object of the invention is to provide an improved apparatus, of the character described, wherein the point source of the third shock wave is produced by the collision in the plane of desired fracture of a pair of jets which emanate from a pair of explosive jet charges having convergent axes in a plane substantially perpendicular to said fracture plane and between the substantially parallel explosive jet charges.

In essence, this invention involves creating a fracture in a desired plane in an earth formation by the intersection of a pair of shock waves, which emanate from moving sources having substantially parallel axes in the plane, in coaction with a subsequent third shock wave having a point source in said plane and between the substantially parallel axes so as to produce a combined force sufficient to part the formation in said plane. More specifically, the pair of shock waves are generated by a pair of substantially parallel jets which penetrate the formation in the desired plane and the third shock wave emanates from the collision in said desired plane of a pair of jets having convergent axes in a plane substantially perpendicular to the plane of and between the substantially parallel jets whereby the forces of all three shock waves coact to fracture the formation in said desired plane. It has been found that the shock waves have a combined force sufficient to fracture the formation when the jets are formed by pairs of substantially parallel and convergent explosive jet charges. In addition to providing a third shock wave of ample magnitude, the convergent changes may overlap the substantially parallel charges and permit the positioning of the latter charges in relatively close proximity whereby the apparatus may be of minimum width or diameter for use in small bores. Since the substantially parallel jets control the orientation of the plane of the fracture, it is essential that the pair of shock waves be initiated prior to the initiation of the third shock wave, such as by detonating the convergent charges subsequent to the detonation of the parallel charges.

The pair of shock waves generated by the substantially parallel jets are substantially conical or paraboloidal and intersect in the plane of fracture whereby the components of force of said waves parallel to said plane offset or nullify one another and the components of force of said

waves perpendicular to said plane combine and coact to produce a perpendicular force which tends to part the earth formation in said plane. The third shock wave is substantially spherical or hemispherical, since it is generated from a stationary point, and has its center or point source in the plane of the fracture between the substantially parallel axes of the pair of shock waves. Preferably, the point source is disposed medially of the substantially parallel axes whereby the third shock wave has an identical relationship to each of the pair of shock waves. The components of force of the third shock perpendicular to the plane of fracture combined with the aforesaid perpendicular components of force of the pair of shock waves to produce a perpendicular force which is sufficient to part the earth formation in said plane, the components of force of said third wave parallel to said plane radiating in directions opposed to one another and being insufficient to create fracture in the perpendicular plane.

Methods of carrying out the invention will be hereinafter described, together with an apparatus for performing the methods.

The invention will be more readily understood from a reading of the following specification and by reference to the accompanying drawings, wherein examples of the invention and methods thereof are shown, and wherein:

FIG. 1 is a transverse, vertical sectional view of a well bore having a casing cemented therein and an apparatus constructed in accordance with the invention suspended therein on an electrical cable for performing the methods,

FIG. 2 is an enlarged, transverse, vertical, sectional view of the lower portion of the apparatus and a portion of the casing,

FIG. 3 is a horizontal, cross-sectional view, taken on the line 3—3 of FIG. 2, a casing of larger diameter being shown in broken lines,

FIG. 4 is a front elevational view of the apparatus,

FIG. 5 is a rear perspective view of the mounting block with the explosive jet charges and fuse cords removed therefrom,

FIG. 6 is a graph showing the relative penetration and timing of the jets,

FIG. 7 is a diagrammatic view showing the relationship of the pair of parallel shock waves and their components of force,

FIG. 8 is a diagrammatic view showing the relationship of the shock waves in exploded perspective,

FIGS. 9, 11 and 13 are diagrammatic, horizontal, cross-sectional views illustrating the penetration of the formation by the jets for generating the shock waves,

FIGS. 10, 12 and 14 are diagrammatic, transverse, vertical, sectional views showing the penetration of the jets at right angles to FIGS. 9, 11 and 13, respectively.

In the drawings, the numeral **10** designates an apparatus for carrying out the method of the invention and adapted to be lowered by a cable **11** into a well bore **12** to a point adjacent the earth formation **13** in which it is desired to create a fracture. Although the well bore **12** may be open or uncased, usually, a well casing **14** extends throughout the same and is secured against displacement by cement **15**. The apparatus includes a cylindrical, thin-wall body **16** which may have a hemispherical bottom or lower end **17** and which is suspended from a tubular, thick-wall sub or housing **18**. As shown by the numeral **19** in FIG. 2, the lower end of the sub **18** is reduced externally for receiving the upper end of the body **16**. Suitable packing **20**, such as O-rings, are carried by the reduced portion **19** for frictional, sealing engagement with the inner surface of the body. The interior of the sub, which has its upper end connected to the cable **11** by a cable head **21**, provides a shock chamber for the apparatus. A drag spring **22** is attached to the sub **18** and extends longitudinally thereof for maintaining the opposite portion of the apparatus in contact with the casing **14**. As shown by the broken lines **14'** in FIG. 3, the casing may be of much greater diameter than the apparatus. The cable contains an insulated core or conductor **23** for transmitting electrical impulses to the apparatus from the surface.

A mounting block **24** of suitable material is adapted to be inserted in the body **16** for supporting two pairs of explosive jet charges **25** and **26** in predetermined positions. As shown most clearly in FIGS. 4 and 5, the block **24** has a cylindrical front end portion **27** and a substantially conical or frusto-conical rear end portion **28**. Complementary, longitudinal chambers or sockets **29** and **30** are formed in the cylindrical portion **27** for confining the charges **25** and **26** in spaced relationship with portions thereof projecting laterally beyond the margin of said portion as well as forwardly thereof. The pair of charges **25** and their sockets **29** have substantially parallel axes in a transverse or substantially horizontal plane, while the pair of charges **26** and their sockets **30** have convergent axes in a plane substantially perpendicular to the plane of the substantially parallel axes. As shown in FIG. 3, the lateral portions of the front ends of the parallel charges **25** are adapted to bear against the inner surface of the body **16** for positioning the block **24** therein in coaction with the upright margins **31** of the flat, rear face **32** of said block. The orientation of the face margins **31** is determined by the bevelling of the frusto-conical portion **28** to provide a pair of flat, upright surfaces **33** in opposed relationship, whereby the plane of the parallel charges may be horizontal, as shown, or at an angle to the horizon. Preferably, the convergent charges **26** are spaced equally from the parallel charges and have equal angularity, such as 12°, whereby the perpendicular plane of said convergent charges bisects the transverse plane of said parallel charges and this intersection may be in alinement with the longitudinal axis of the block **24**.

A detonator **34**, such as an electrical blasing cap, is secured to the lower end of the electrical conductor **23** for connection with the upper end of a fuse cord **35** which extends through an upright port **36** in the rear portion **28** of the block adjacent its rear face **32**. The exposed portion of the fuse cord **35** between the detonator **34** and port **36** is encased in and protected by a tube **37** of suitable material. An axial passage **38** extends from the port to the front face of the block **24** and has its intermediate portion intersected by a pair of transverse passages **39** and **40** which are substantially perpendicular to each other and communicate with the inner ends of the sockets **29** and **30** at their respective axes. The passages **39** and **40** contain fuse cords **41** and **42** which contact a fuse cord **43** in the passage **39** and engaging the fuse cord **35**. As shown in FIGS. 2 and 3, the passage **39** is disposed rearwardly of the passage **40** whereby the cords **41** are detonated prior to the detonation of the cords **42**. Also, due to the divergence of the axes of the convergent charges **26** at their inner ends, the cords **42** have a greater effective length than the cords **41**. As a result, the parallel charges **25** are detonated prior to the detonation of the convergent charges **26** whereby the jets generated by said parallel charges penetrate the earth formation before the jets generated by convergent charges.

The explosive jet charges **25** and **26** are shown as being of conventional construction and as including cylindrical cases **44** of dense metal, such as lead or zinc, having thick concave bases **45** formed with axial apertures **46** for communicating with the passages **39** and **40**. A mass of highly compacted explosive **47** is contained within each of the cases **44** and may be shaped by conical liners or cones **49** and **50** of suitable metal having inwardly-directed apices. Since the apertures **46** communicate with the passages, the explosive **47** is in contact with the fuse cords **41** and **42**. Satisfactory results have been obtained when the cones **49** of the substantially parallel charges **25** are formed of copper, the cones **50** of the convergent charges **26** are formed of aluminum and all

of the cones are of 60°. All of the charges may have equal diameters and lengths of about 1⅛ inches and contain approximately 11 grams of high explosive. The substantially parallel axes of the charges 25 may be spaced apart a distance of about 1⅝ inches, while the spacing between the convergent axes of the charges **26** may be greater than this distance at their inner end and less than said distance at their outer ends. Due to this convergence, the charges 26 project forwardly of the charges **25** a short distance, such as ¼ inch. These specifications represent a preferred embodiment of the invention which has produced satisfactory results in typical earth formations; however, it is noted that said specifications are subject to variation in accordance with the characteristics of the particular formation in which it is desired to create a fracture, some formations being more difficult to fracture than others. Different sizes and types of explosive jet charges may be employed, the quantity and/or strength of the explosive may be varied, the angles and materials of the cones may be changed, and the charges may be spaced differently.

It is emphasized that the convergent charges **26** are highly desirable for two reasons. These charges may overlap the substantially parallel charges **25** and permit closer spacing thereof whereby the apparatus **10** may be of minimum width or diameter for use in small bores. For example, the external diameter of the apparatus may be as small as 3¼ inches so as to be capable of being lowered through and used in well casing having an internal diameter 3½ inches. The converging jets initiated by the charges **26** collide outwardly of the casing wall and combine to provide a shock wave **3** of sufficient force to fracture the earth formation **13** in coaction with a pair of shock waves **1** and **2** generated by the substantially parallel jets initiated by the charges **25** (FIGS. 7 and 8). Manifestly, it would require a much stronger and/or larger single charge to produce a force equal to the combined force derived from the convergent charges and such charge would necessitate more space, i.e., width or diameter. Accordingly, it is readily apparent that the utilization of convergent charges is most advantageous.

Irrespective of the construction and relationship of the charges, it is essential that the charges **25** produce a pair of subsantially parallel jets **51** which penetrate the earth formation **13** to a greater depth than the converging jets **52** produced by the charges **26**. As shown in FIGS 9–14, the jets **51** form perforations **53** of greater penetration and less diameter than the perforations **54** formed by the jets **52** due to the different characteristics of their respective charges. For example, the perforations **53** of the jets **51** may be approximately one-half the diameter and twice the penetration of the perforations **54** of the jets **52**. It is noted that the relative dimensions of the perforations may vary from formation to formation and in accordance with other factors, such as the nature of the charges and whether the well bore is cased or uncased. In FIG. 6, the curved lines **55** and **56** of the graph illustrate the relative rates of penetration of the substantially parallel and converging jets **51** and **52**, respectively, and the time interval between the initiation of said jets is shown by the distance between the points **57** and **58**. The greater length of the line **55** indicates the deeper penetration of the parallel jets and the longer time required for such penetration. The prior initiation of the parallel jets or the delay in the initiation of the converging jets is due to the greater effective length of the fuse cords **42** and the positioning of the same forward of the fuse cords **41**. Due to the velocity of the jets being much greater than the detonation rate of the fuse cords, the time interval between initiations need be of only brief duration and, as an example, may be of the order of 0.91 micro-second. It is pointed out that the delayed initiation of the convergent jets **52** provides convenient means for insuring that the parallel jets **51** commence to penetrate the formation and commence to generate the pair of shock waves **1** and **2** prior to the collision of said converging jets and the generation of a third shock wave **3**. The desired time interval between the initiation of the shock waves is of primary importance and may be obtained by other means, such as varying the source of the third wave. In other words, the charges may be detonated simultaneously if the initiation of the third shock wave is subsequent to the initiation of the pair of shock waves.

Upon initial penetration of the converging jets **52**, the substantially parallel jets **51** have penetrated the earth formation **13** and are advancing as shown in FIGS. 9 and 10. The collision of the jets **52** and the continued travel of the jets **51** is shown in FIGS. 11 and 12, wherein the line **59** indicates the commencement of the desired fracture at a point slightly deeper than the penetration and collision of said jets **51**. The total penetration of the jets **52** and the completion of the fracture **59** is shown in FIGS. 13 and 14, it being noted that the well casing **14** and cement **15** are omitted for simplicity of illustration. The fracture is in the plane of the parallel jets which controls the orientation of said fracture due to the coaction of the pair of shock waves **1** and **2** generated by said jets. As shown, the converging jets collide in this plane, preferably, midway between the parallel jets, and the point of this collision determines the origin or initiation of the third shock wave **3**. From the results of numerous tests, it appears that the shock wave **3** emanates from a point source **60** which is spaced a slight distance from the actual point of collision of the converging jets. As shown in FIG. 8, the point source **60** is stationary whereby the shock wave **3** is substantially spherical or hemispherical, while the pair of shock waves **1** and **2** are paraboloidal or substantially conical due to the moving sources provided by the continued travel of the jets **51**.

The coaction of the pair of shock waves **1** and **2** is illustrated diagrammatically in FIG. 7 wherein the axes of said waves are shown as being substantially parallel and disposed in the desired plane of fracture of the earth formation, represented by the line *x*. These waves collide in the plane, indicated by the line *y*, which is substantially perpendicular to the plane *x* and intersects said plane medially of the axes of said waves due to the same being of equal velocity and being initiated simultaneously. The components of force F*x*1 and F*x*2 of the waves which are parallel to the plane *x* offset or cancel one another, while the components of force F*y*1 and F*y*2 of said waves which are perpendicular to said plane *x* or parallel to the plane *y* are additive and combine to produce a perpendicular force which tends to part the formation in said plane *x*. In other words, the sum of the perpendicular components of force F*y* equals the sum of the perpendicular components of force F*y*1 and F*y*2, or two times F*y*1, or two times F*y*2, whereas the sum of the parallel components of force F*x* equals the parallel components of force F*x*1 minus the parallel components of force F*x*2 or zero. Accordingly, the only effective parting force is provided by the components of force F*y* which are perpendicular to the desired plane *x* of fracture.

In FIG. 8, the shock waves are shown in exploded perspective to more clearly illustrate the relationship of the same. Although the shock wave **3** radiates in all directions, its stationary center or point source **60** is disposed in a plane *y*—*z* which intersects the plane *x*—*z* between the axes of the shock waves **1** and **2**. The components of force of the shock wave **3** which are perpendicular to the plane *x*—*z* or parallel to the plane *y*—*z* are additive and combine with the perpendicular components of force of the shock waves **1** and **2** to increase the force perpendicular to said plane *x*—*z* sufficiently to fracture the formation in said plane. The components of force of the shock wave 3 which are parallel to the plane *x*—*z* are ineffective because the parallel components of force of the shock waves **1** and **2** have nullified one another and are not available for combined coaction therewith. It is noted that the third shock wave is of greater magnitude than the shock waves generated by the converging jets

52 and that the collision of said jets in the plane x—z locates its point source 60 in said plane to permit utilization of its perpendicular components. As set forth hereinbefore, the coaction of all three shock waves is essential to the method of this invention. The orientation of the fracture is determined by the plane x—z of the substantially parallel axes of the pair of waves 1 and 2. Due to the intersection of these waves in the substantially perpendicular plane y—z and the location of the point source 60 of the third wave 3 at the intersection of the planes x—z and y—z, the combined components of force perpendicular to said plane x—z is of such magnitude that the formation is fractured in said plane x—z. The longitudinal movement of the jets 51 and their waves 1 and 2 cause the fracture 59 to progress in the plane of said jets and said fracture may extend beyond the penetration of said jets (FIGS. 13 and 14). The third shock wave 3 generated by the collision of the converging jets 52 provides sufficient additional force to insure the creation of the fracture. Insofar as the method is concerned, the shock waves may be initiated by any suitable means capable of producing the necessary force and controlling the orientation of the plane of fracture.

Various changes and modifications in the methods and apparatus disclosed herein may be made within the scope of the appended claims without departing from the spirit of the invention.

What I claim and desire to secure by Letters Patent is:

1. An apparatus for fracturing an earth formation in a predetermined plane at a location spaced from a surface of said formation, said apparatus including: mounting means; a first pair of explosive jet charges secured to said mounting means and having substantially parallel spaced axes lying in a common plane for directing a first pair of jets into the formation from the surface thereof toward said location when the apparatus is disposed adjacent said surface with said common plane coplanar with said predetermined plane to penetrate the formation and generate a pair of shock waves in the formation having parallel spaced axes lying in said predetermined plane whereby said pair of shock waves intersect initially in said predetermined plane in said formation; a second pair of explosive jet charges secured to said mounting means having converging axes lying in a plane substantially perpendicular to said common plane and intersecting in said common plane and between the axes of said first pair of jet charges for directing into the formation from the surface thereof, when the apparatus is disposed adjacent said surface with said common plane coplanar with said predetermined plane, a second pair of jets having convergent axes intersecting at said predetermined plane in said formation and colliding in said predetermined plane for generating a third shock wave in said formation; and means for detonating said first pair of charges and said second pair of charges, said mounting means and said detonating means cooperating to hold said two pairs of jet charges in predetermined relationship to each other and the surface of the formation when the apparatus is disposed adjacent said surface and to detonate said charges to cause said second pair of jets to penetrate into said formation at said surface subsequent to the penetration of said first pair of jets into said formation at said surface whereby said second pair of jets collide and generate said third shock wave subsequent to the initiation of generation of said first pair of shock waves by said first pair of jets.

2. The apparatus of claim 1 wherein said second pair of explosive jet charges have less penetrating capacity than said first pair of jet charges whereby the penetration of the second pair of jets into said formation is substantially less than the penetration of said first pair of jets, the point of collision of said second pair of jets being disposed in said common plane between the point of greatest penetration of said first pair of jets and said surface of the formation when the apparatus is disposed adjacent the surface of the formation.

3. The apparatus of claim 2 wherein said means for detonating the two pairs of charges causes the detonation of said second pair of charges a predetermined period of time after the detonation of said first pair of charges.

4. The apparatus of claim 1 wherein said means for detonating the two pairs of charges causes the detonation of said second pair of charges a predetermined period of time after the detonation of said first pair of charges.

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2,928,658	Miner	Mar. 15, 1960
2,984,307	Barnes	May 16, 1961