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[11] 3,587,743

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[54] **EXPLOSIVELY FRACTURING FORMATIONS IN WELLS**
8 Claims, 5 Drawing Figs.

[52] **U.S. Cl.** **166/299,** 102/23, 166/308, 175/61
[51] **Int. Cl.** **E21b 43/26**
[50] **Field of Search** 166/271, 299, 308; 175/61; 102/20, 21, 21.4, 21.6, 22, 23

[56] **References Cited**

UNITED STATES PATENTS

3,002,454	10/1961	Chesnut	166/299
3,141,504	7/1964	Sarapuu	166/299X
3,291,215	12/1966	Nichols	166/299X
3,336,982	8/1967	Woodward et al.	166/299

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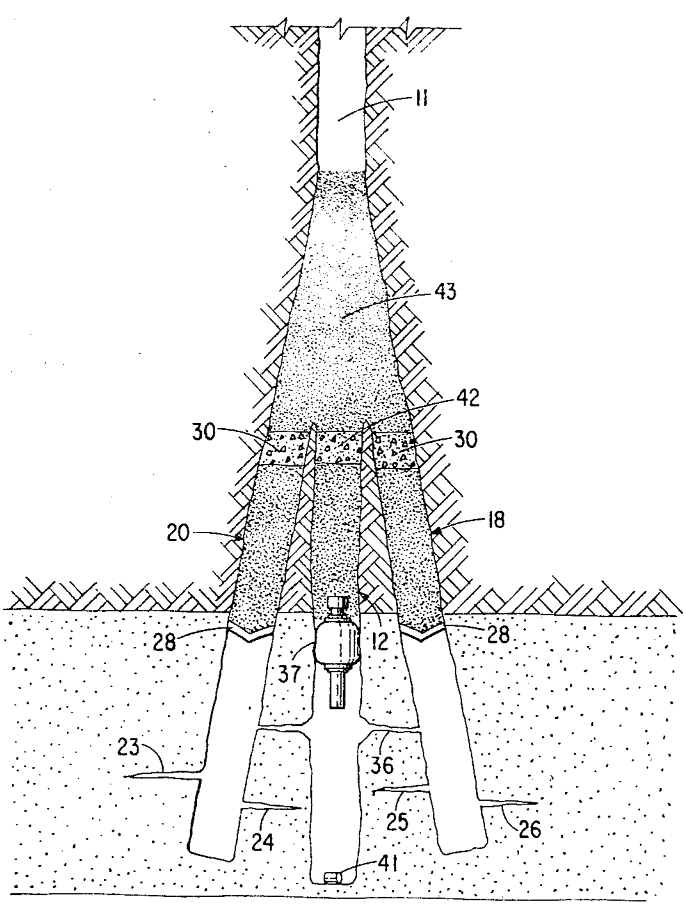
ABSTRACT: In order to increase drainage from a porous but low permeability reservoir rock into wells, a plurality of wells are drilled into the reservoir rock. Hydraulic fracturing is employed to fracture between wells in the pay formation. A low fluid loss liquid explosive is placed in all wells. It also fills the fracture. Preferably each well is stemmed by placing a long mechanical obstruction immediately above the liquid explosive. Detonation of the explosive in the central well causes explosion of the liquid in the fracture, which in turn detonates the explosive in the surrounding wells. This creates a zone of large drainage area for production from the formation, or injection into it. Preferably the neighboring wells surrounding the central well are drilled by deviation or side-tracking from the central bore.



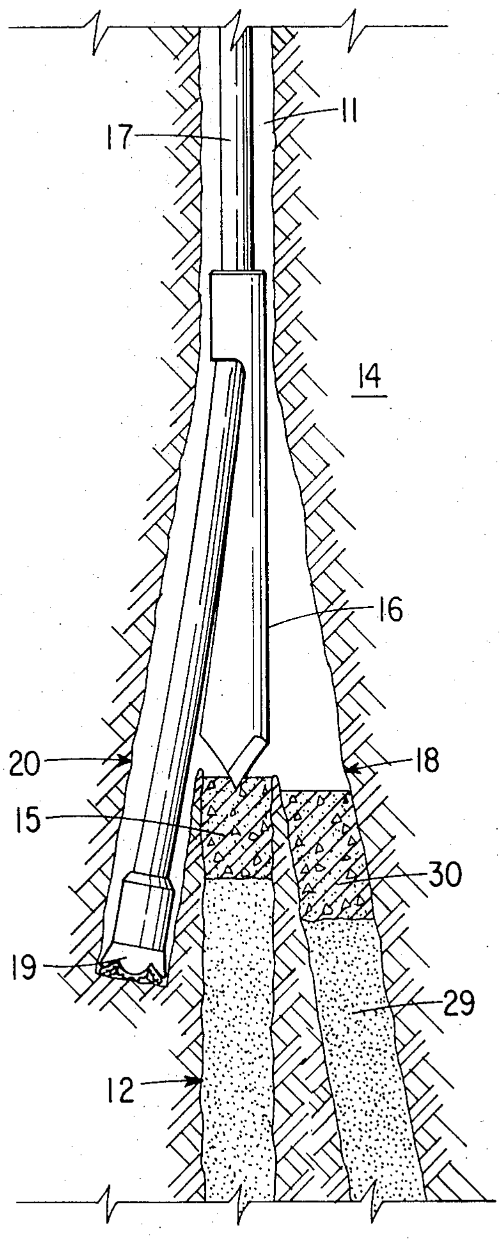


FIG. 1

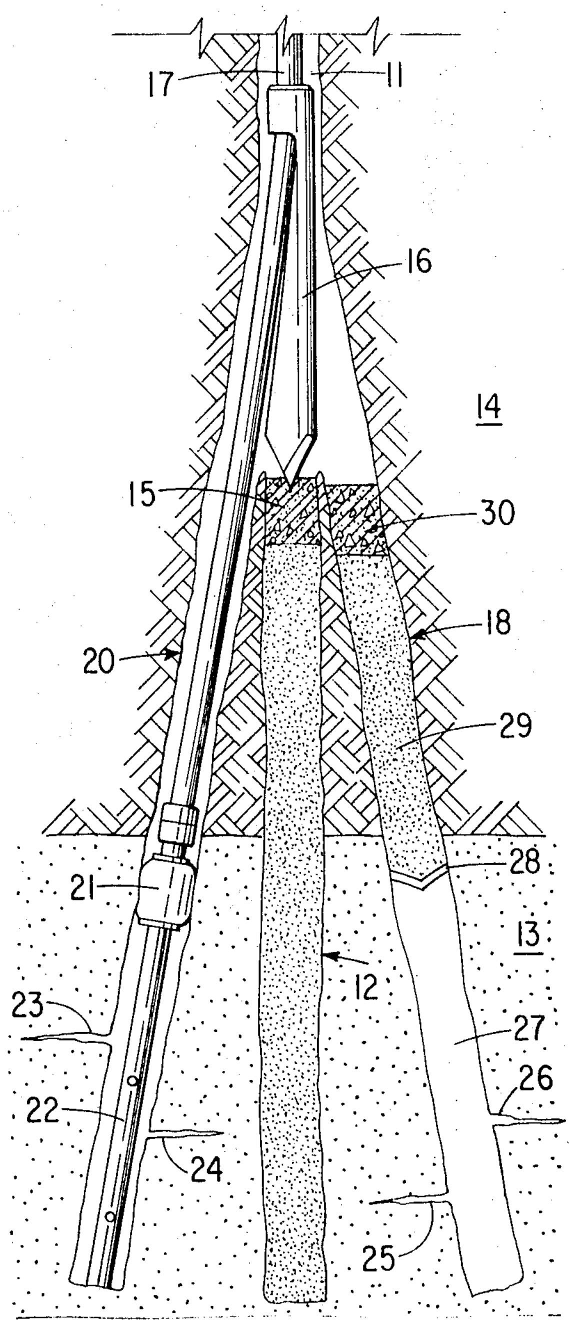


FIG. 2

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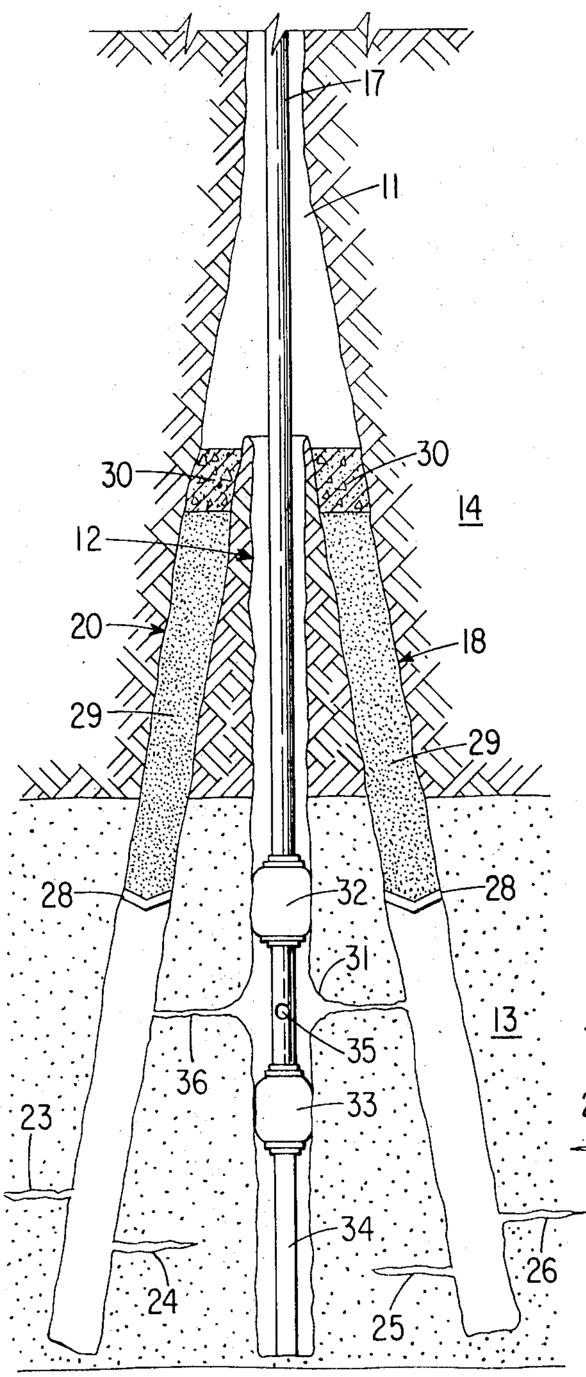

FIG. 3

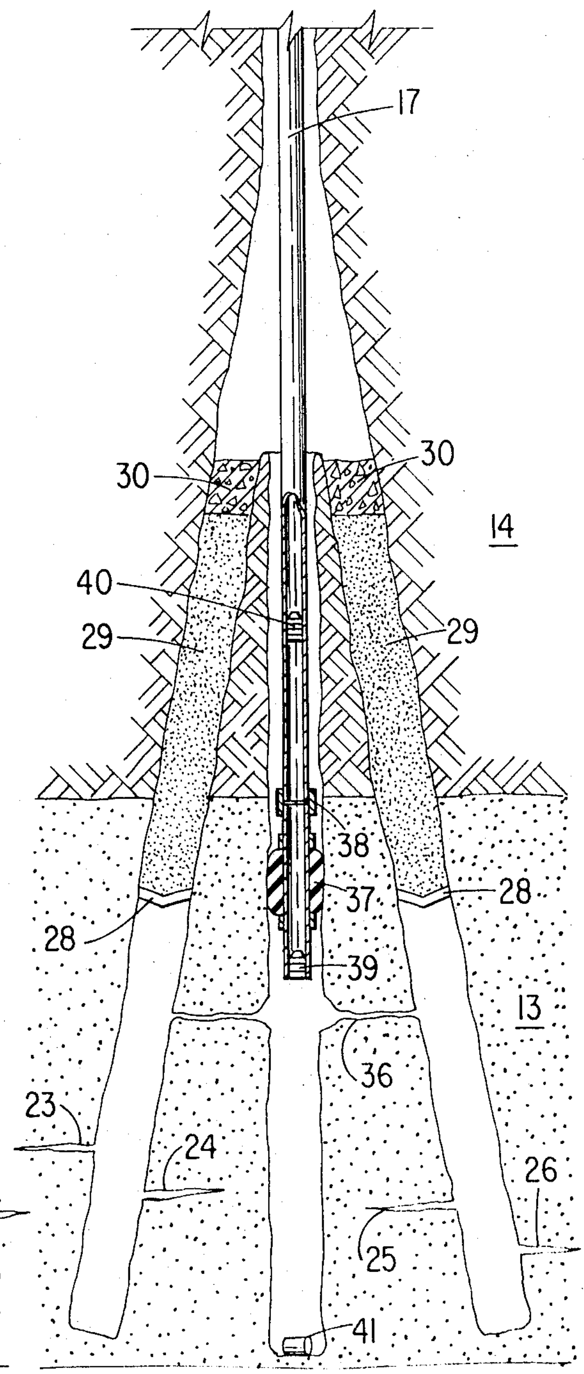

FIG. 4

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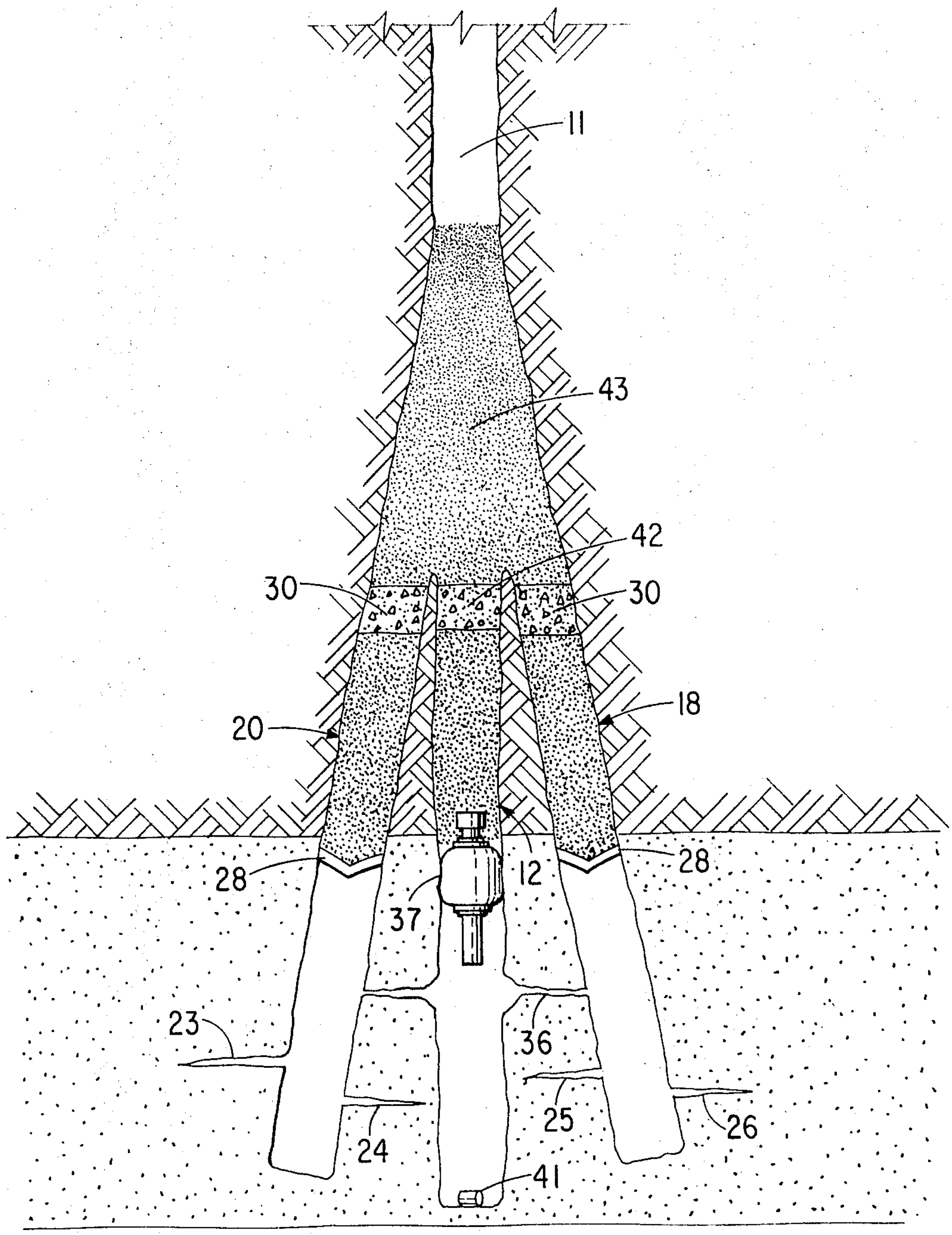

FIG. 5

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EXPLOSIVELY FRACTURING FORMATIONS IN WELLS

CROSS REFERENCE TO RELATED APPLICATIONS

A liquid explosive composition well suited for use in this method is disclosed in the U.S. Pat. application of Clarence R. Fast, Ser. No. 3,511, filed in the U.S. Patent Office Jan. 16, 1970.

BACKGROUND OF THE INVENTION

1. Field of the Invention

In the production of liquids from reservoir formations (frequently called pay zones) in the earth, it has been common practice for many years to increase the productivity from a well by altering the formation adjacent the well. Usually this formation has insufficient permeability, or put another way, there is insufficient reservoir energy for the drainage area. The resistance to flow under the available pressure gradient is too great. Such alteration can be carried out in a number of ways, such as the now obsolete procedure of "shooting" the well with a canister of liquid nitroglycerin, which causes local shattering of the rock. A popular procedure in carbonate reservoirs is acidization, by which connecting channels are enlarged by chemical solution using an acidizing solution. More recently, hydraulic fracturing has been very widely employed for this purpose, in both sandstone and carbonate reservoirs.

In very tight (low permeability) reservoirs, single fracturing using hydraulic fracturing processes is frequently ineffective, even when carried out in large volume treatments using high capacity, high injection pressure pumps. Also such procedures can be quite expensive. The procedure described below provides adequate drainage in conditions which ordinary simple hydraulic fracturing processes are inadequate.

Another major problem associated with effective conduction of secondary recovery operations is obtaining adequate injection of fluids into the exposed reservoir to increase the reservoir energy and displace reservoir fluids (ordinarily petroleum) into recovery wells. Injectivity is decreased by damage to the reservoir formation during completion operations, subsequent plugging of the well bore face by injected fluids, the normal streaking encountered in a pay formation by shale layers, and wide variation in permeability of the exposed rock.

These difficulties can also be overcome by the procedure described below in which the area available for injection of driving fluids can be greatly increased without profound penetration of a few fractures deep into the reservoir.

2. Description of the Prior Art

Explosive fracturing of subsurface formations has never to my knowledge been taught in a multiple well operation. Especially is this true when explosions in the neighboring wells are due to an explosion in a central well.

A number of articles and patents have disclosed the explosive fracturing of a single well. For example, the Bureau of Mines has carried out shallow well experiments at orders of 600 feet below the surface, injecting and subsequently detonating desensitized liquid nitroglycerin. Such material has a viscosity under field conditions essentially that of water and can leak away into the formation.

U.S. Pat. No. 2,892,405 of John Chesnut discloses injection of sensitized nitromethane into cracks and fissures adjacent a well. This liquid explosive is detonated in the fractures by detonation of the explosive still present in the well. Again, the material has very low viscosity, so it can leak into the surrounding rock matrix in a short period of time. Chesnut contemplates operations only in a single well.

A series of patents assigned to Dow Chemical Company disclose various explosives considered suitable for use in a single well, in a procedure rather like the earlier well shooting. Some of the materials taught are slurries of a solid, granulated explosive in a carrier liquid, such as in U.S. Pat. Nos. 2,867,172 Hradel and 2,992,912 Hradel and Staadt. Two-liquid explosives used in a single well are taught in U.S. Pat. Nos. 3,104,706 Eilers and Park, 3,075,463 Eilers et al., 3,336,981 Barron et al., and 3,336,982 Woodward et al. All of these systems involve low viscosity materials permitting rapid leak away, and are also subject to the difficulty that detonation at depths common for oil wells involves either difficult or hazardous procedures.

The U.S. Pat. No. 2,991,046 of Yahn attacks the problem in a different way, but still uses only a single well. In this case a liquid plastic embedding an explosive charge is solidified within the bore at the reservoir formation prior to detonation. There is no indication whatever of a unitary procedure permitting essentially simultaneous detonation of explosive in a plurality of adjacent wells. The Rachford U.S. Pat. No. 2,766,828 teaches another single well technique in which explosive is placed in the bore to apply a temporary high pressure to an ordinary fracturing liquid, rather than employing pumps in the more conventional hydraulic fracturing procedure.

In summary, none of this art discloses a procedure for causing increased drainage area in the reservoir formation beyond that which can be achieved by explosion of solid or liquid explosive in the bore plus any adjacent fractures.

SUMMARY OF THE INVENTION

A number of wells are bottomed in a producing formation at a medium distance apart (of the order of 50 to 100 feet). These wells are connected at some point in the procedure by a fracture in the productive zone. Each well is filled with liquid explosive in the producing zone. The central well is similarly packed with liquid explosive which, through the connecting fracture, communicates with explosive in the surrounding wells. Preferably all wells are stemmed, i.e., mechanically sealed above the producing zone. An explosion is created in the central well, which through propagation through the fractured zone, detonates the explosive in the surrounding wells. This produces massive fracturing of a large portion of the interwell area, permitting increase in production from the zone, or increased injectivity.

Preferably all wells are drilled from the center well by whipstocking or the like.

BRIEF DESCRIPTION OF THE DRAWINGS

All the following drawings are diagrammatic only, showing cross sections through a producing formation in the earth penetrated by one or more wells.

FIG. 1 shows a method of drilling an offset well from a center bore, using a system advantageous for this invention.

FIG. 2 shows a cross section of the earth, including three wells penetrating the producing formation, illustrating a second step in my method of well treatment.

FIG. 3 shows another step in the procedure, in which fracturing of the central well is being accomplished.

FIG. 4 illustrates the next step in this process, with explosive being packed into the central well.

FIG. 5 shows the last step in the process, in which explosive has been placed in each well bore and suitable packing or stemming has been employed to produce a mechanical obstruction above the explosive in the bores.

DESCRIPTION THE PREFERRED EMBODIMENT

In FIG. 1 a central bore **11** has been drilled into the earth. The lower part of this bore **12** penetrates the producing formation **13** (see FIG. **2**) as well as the above formation **14**. The driller starts to employ my invention by filling the bore **12** up to a level considerably above the producing formation **13** (ordinarily several hundred feet) with sand or other easily removable solid, and spots a small cement cap **15** above this, to take the chisel end of a whipstock **16**. This whipstock is lowered from the surface on a drill stem **17**, as is well known in this art, and the whipstock **16** is oriented each time that it is set, again as is well known in the art. The driller then proceeds to drill a slant hole by this side-tracking technique which, by the time that it enters the producing formation **13**, is of the order of 50 to 100 feet away from the central bore **12**. When this offset hole has been drilled as far as desired into the reservoir rock of the pay formation **13**, the operator is ready for the next step in the procedure.

In FIG. **1** the stage is shown at which one offset well **18** has already been drilled, the whipstock **16** has been reoriented and reset on the cement plug **15**, and the bit **19** is drilling a second offset well **20**.

FIG. **2** shows the preferred procedure after a well has been drilled to the desired depth in the pay formation. The whipstock **16** has been removed from the well, and on the lower end of the string **17** a retrievable packer **21** with a perforated tail pipe **22** has been installed. This assembly is set up on the whipstock **16**, which is then replaced in the bore **11** and reoriented to set on the cement plug **15**, after which, by extension of string **17**, the packer **21** is set preferably in the top of the producing formation **13**, or at least near it.

At this point a liquid explosive is pumped through the drill string **17** and out through perforations in tail pipe **22**, into the zone below the packer **21** in the well **20**.

Numerous examples of liquid explosives have been proposed for well fracturing. Most of these have the disadvantage of either being sufficiently sensitive so as to be dangerous in handling, or are so liquid that they can leak off into the formation **13**. I prefer to employ a liquid explosive which, in the language of the Farris Patent Reissue 23,733, is a low-penetrating liquid. Such liquid has an apparent viscosity of preferably at least 30 centipoises at the formation temperature, or a fluid loss of not over 50 ml. in 30 minutes, using the procedure of API test 29. One such satisfactory liquid explosive has already been disclosed in U.S. application Ser. No. 3,511 of Clarence R. Fast.

The amount of liquid which is spotted on the bottom of the offset well **20** should be at least that calculated to fill the bore of this well up to the level of the packer. Preferably an excess is used. In either case, an elastic wiper plug or equivalent should be inserted in the string **17** after the last of the thick liquid explosive has been introduced into the string, and a fluid used to force the liquid explosive into the bottom of well **20**. If an excess of the liquid explosive has been used, it is possible to apply high hydraulic pressure to this, to produce fracture a few feet into the formation, such as those shown diagrammatically at **23** and **24**, **25** and **26**.

Whether or not a hydraulic fracturing process is used at this point, after the process of spotting the liquid explosive has been completed, the string **17** is withdrawn and a bridge plug is set by wireline or drill pipe manipulation (as is well known) immediately above the explosive. Such a set bridge plug **28** is shown in offset well **18** in FIG. **2**. Now the well is stemmed above the bridge plug by introducing a mechanical obstruction in the well. The presence of such stemming increases the effectiveness of the explosion by minimizing gas venting through the well, thus raising the mean effective pressure in the well itself. In FIG. **2** a preferable arrangement for forming this mechanical obstruction is shown. After the ridge plug **28** has been set, an open pipe is run into the offset well and sand, or similar material, preferably angular, is spotted to form a layer **29**. If this layer **29** is sufficiently long, it will adequately stem the subsequent explosion simply by itself. The stemming is made more effective and further sealing (considered desirable) is furnished by spotting immediately above the sand or the like a short layer of cement slurry to form a cement plug **30**. The volume of the cement slurry is normally 10 percent of the volume of sand employed. If the cement plug is employed, the length of the mechanical obstruction should be at least 100 feet. If the plug is not employed, it is desirable to stem with sand or the like at least twice this length.

After one offset well has been drilled, loaded with liquid explosive, and stemmed, all as discussed above, another offset well can be formed using the same side-tracking technique. I prefer to have a minimum of at least two offset wells, and preferably three or four. In FIG. **3** the offset wells have been drilled, filled with explosive, and stemmed.

After this has been accomplished, the central bore **12** of the well is cleaned out by drilling out the cement plug **15** and the sand below it. Preferably this is followed by directing against the wall of well **12** a stream of highly abrasive particles in a concentrated jet of liquid, the tool being rotated so that a notch or ring **31** is cut into the formation in a substantially horizontal plane. This notching technique has been employed with considerable success in creating a weakened zone favorable for horizontal fracturing. This notch is, of course, created in the reservoir formation **13**.

Next a string **17** is lowered into the well, the string containing near the lower end at least one settable packer **32**, which will isolate the bottom part of the well **12**, including the notch **31**. In FIG. **3** I have shown a second settable packer **33** below the first settable packer **32**, which is the preferable arrangement in that when the two of them are set by allowing the weight of the string **17** to act against the tail pipe **34**, the fluid pumped through string **17** and hence through aperture **35** between the packers is essentially applied at the notch **31**. The liquid employed for this fracture should be relatively highly penetrating, and, in fact, crude oil is preferred. The pump rate should be quite slow so that the pressure that builds up on the notch **31** will not reach fracturing pressure until at least the order of 2 to 5 minutes or more. These precautions tend to cause a roughly horizontal fracture **36** to be formed, and as pumping proceeds, this fracture extends until ultimately it breaks into the neighboring wells, such as wells **18** and **20**. If desired, the latter part of the fluid pumped, i.e., after the fracture has been started, may be any of the low penetrating liquids, such as napalm gels, available from fracturing companies. In passing, it should be stated that packer **33** may be eliminated; its use, however, does tend to make a horizontal fracture easier to achieve.

The central well **12** is now ready for loading with liquid explosive. The packer arrangement of FIG. **3** is withdrawn and a string **17** is run into the well having near its lower end a settable packer **37**, shown in FIG. **4**. Above this packer is an anchor seal nipple **38**, which upon suitable manipulation releases the string **17** from the packer **37**.

In operation the string **17** is lowered until the packer **37** can be set near the top of reservoir formation **13**, and above the fracture **36**. The packer originally is not set, so there is circulation of fluid from inside of the string **17** and up the annular space. The liquid explosive is then lubricated into the string **17** between elastic wiper plugs **39** and **40** in sufficient volume to more than fill the zone in well **12** below the packer **37**. When the lower plug **39** is near the bottom of the string **17**, the packer **37** is set and the liquid, essentially the explosive liquid, fills the zone below the packer and the fracture **36**.

I prefer to detonate the liquid explosive by the use of a time bomb, i.e., clockwork arrangement in a sealed container, which ultimately ignites caps or fuses. Such time bomb **41** may be injected just ahead of wiper plug **39**, or after this plug and before plug **40**, so that it ultimately is in the confined zone below packer **37**. The string **17** is then manipulated to free it from anchor seal nipple **38**, for example by rotating string **17** to the left, and this string is then pulled up above packer **37**, which is left in the well. Stemming is then accomplished in well **12** by pumping sand-laden fluid in through string **17**, the sand settling on top of the packer **37**. If desired (and as shown in FIG. **5**), this sand zone is capped with another cement plug **42**, of the order of 10 percent of the length of the sane column in well **12**. This stemming should be at least about 100 feet long. If desired, further stemming can be then accomplished by raising the bottom end of string **17** still farther and pumping a sand-laden fluid into well **11**, causing the sand to settle in a zone **43** above the cement plugs in all of the wells. The string **17** is then withdrawn from the well.

Ultimately the time bomb **41** detonates the liquid explosive in well **12**. This explosion is propagated through the explosive liquid in fracture **36** into the liquid explosive in the neighboring wells, such as wells **18** and **20**, to detonate this and create an extensively fractured zone between and outside all of these wells. This greatly increases the area of the fracture system created by the explosive. Customary drilling-out procedures are then employed to clear the central well **12**. It is obvious that one should employ for the packer **37** one made of easily drillable materials. This well is then completed in any of the well-known techniques customarily employed.

I have found by this procedure that it is possible in the case of very low permeability reservoir formations to achieve a sufficiently great drainage area so that it is possible to produce the well much easier or to secure higher injectivity than if the extensive fracturing inherent in this method were not employed.

If desired, particularly in the case of shallow reservoir zones of very low permeability, the neighboring wells equivalent to wells **18** and **20** may be drilled directly from the surface rather than offset from a center bore, as long as these offset wells are of the order of 50 to 100 feet only from the central well. Analogous techniques are then employed to fill the reservoir zone of such neighboring wells with liquid explosive, stem them by the use of a mechanical obstruction as already discussed, fracture from the central well into these offset wells, and carry out central well filling with explosive, and detonation, all as discussed above. Extra expense in cleaning out these wells is offset by the increasing interwell permeability.

It should be emphasized again that the liquid explosive employed should have a very low fluid loss so that during the necessary time taking procedures following the filling of one neighboring well with explosive until time of detonation, this liquid will not substantially leak away into the surrounding formation.

It should also be mentioned that there are a number of variations in the technique for drilling a multiplicity of offset wells from a central bore. This is discussed, for example, in the article "Lateral Drain Hole Drilling" by H. John Eastman, Petroleum Engineer, 1954, page B—57 and following, and in a series of U.S. Pat. Nos., for example to Granville (1,367,042 and 1,865,853), Lee (1,816,260; 1,850,403; 1,886,820, and **2,118,650**), Zublin (2,336,333; 2,336,334; 2,336,338, and 2,344,277), and Bielstein (2,709,070).

I claim:

1. A method of increasing the flow capacity of a plurality of neighboring wells penetrating a subsurface liquid-containing reservoir rock comprising the steps of:

1. forming a fracture from a centrally located one of said neighboring wells to the offset wells;
2. placing liquid explosive in said centrally located well and in the offset wells in at least the zone penetrating said reservoir, and in said fracture; and
3. detonating said explosive in said centrally located well, whereby the resultant explosion detonates the liquid explosive in said offset wells.

2. A method in accordance with claim **1** including the step of stemming said wells with a mechanical obstruction at least about 100 feet long in each of said wells above the liquid explosive in that well.

3. A method in accordance with claim **2** characterized by the fact that said liquid explosive as placed in any of said wells has an apparent viscosity of at least about 30 centipoises and a fluid loss of not more than about 50 ml. at the temperature of said reservoir rock, and thus has a reduced tendency to filter through said reservoir rock.

4. A method in accordance with claim **3** characterized by the fact that the spacing between said centrally located well and said offset wells at the level of said reservoir rock is in the range of approximately 50 to 100 feet.

5. A method in accordance with claim **4** characterized by the fact that each of said neighboring wells other than said centrally located well is loaded in turn with said liquid explosive and stemmed with said mechanical obstruction prior to placement of said liquid explosive in said centrally located well.

6. A method in accordance with claim **5**, including the step of forming a fracture in at least a majority of said neighboring wells prior to detonation of liquid explosive therein.

7. A method in accordance with claim **4**, said offset wells having been drilled by side-tracking from one common bore reaching the surface of the earth.

8. A method in accordance with claim **2** characterized by the fact that the fracture formed form said centrally located well is created by hydraulic fracturing following notching of said reservoir rock in said centrally located well in substantially a horizontal plane.