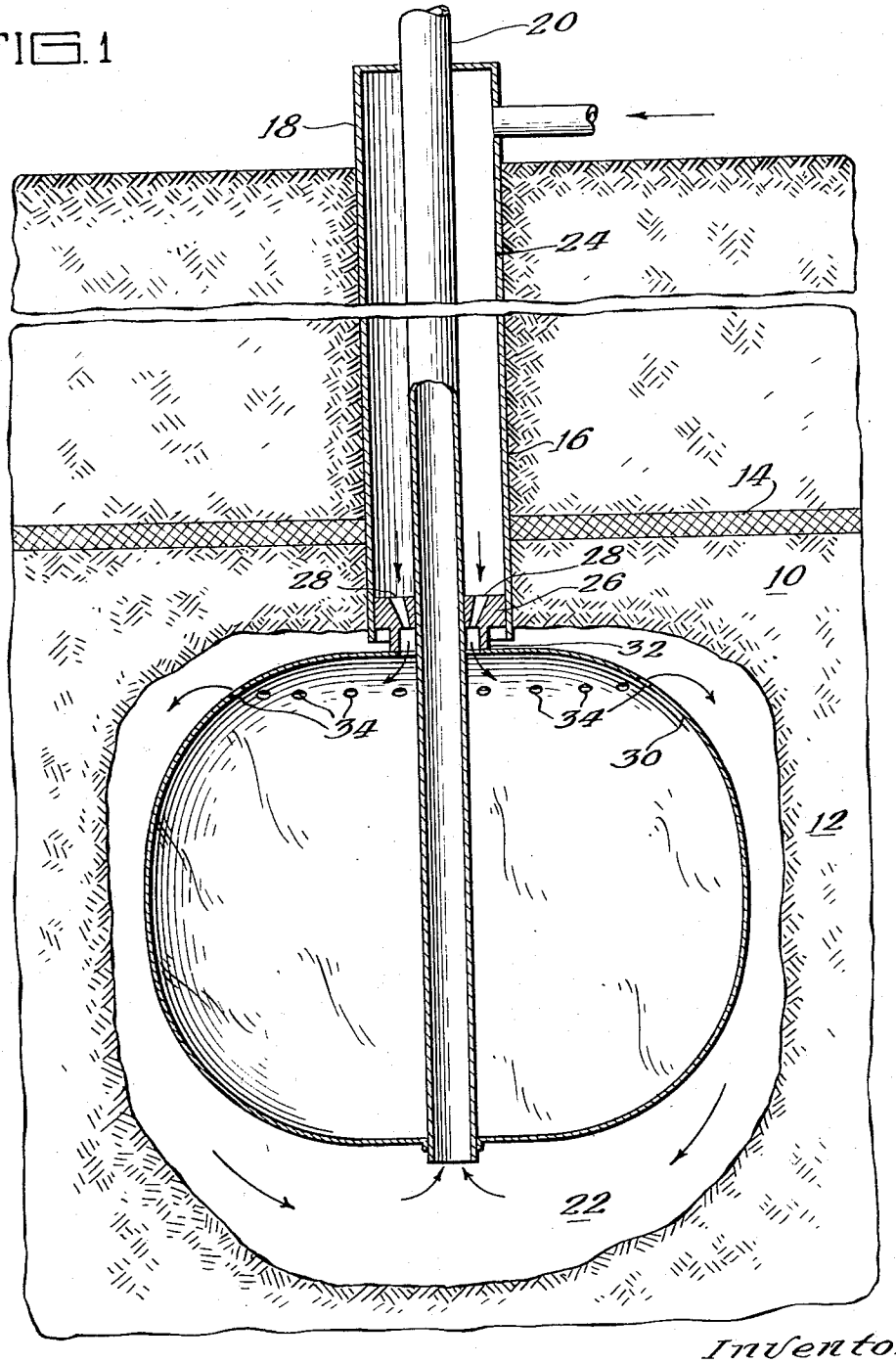
Jan. 10, 1967 J. W. CURRIER 3,297,362

METHOD AND APPARATUS FOR SOLUTION MINING

Filed June 24, 1963 2 Sheets-Sheet 1

FIG. 1



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METHOD AND APPARATUS FOR SOLUTION MINING

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FIG. 2

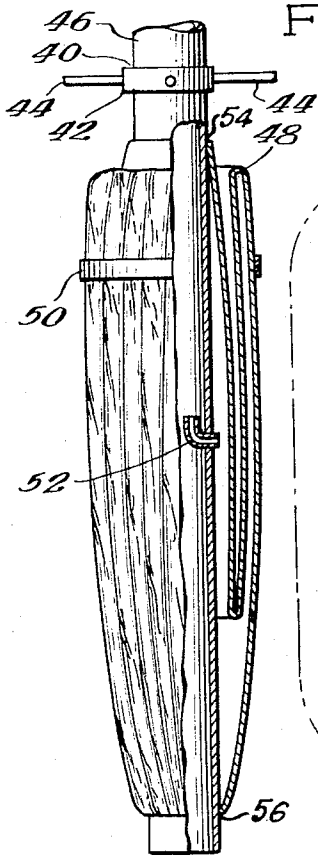


FIG. 3

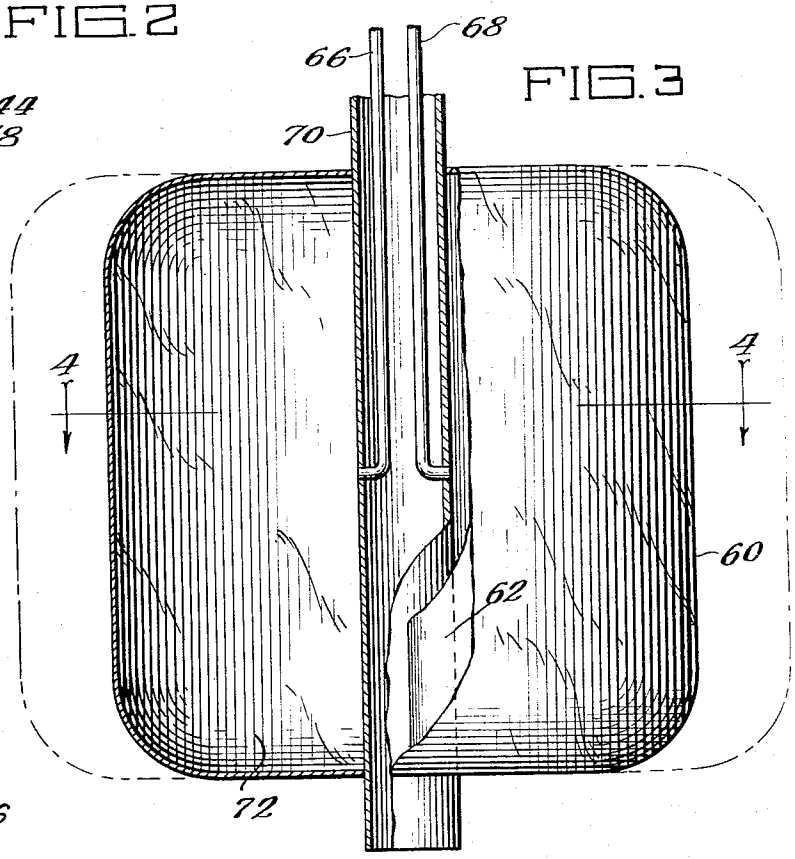
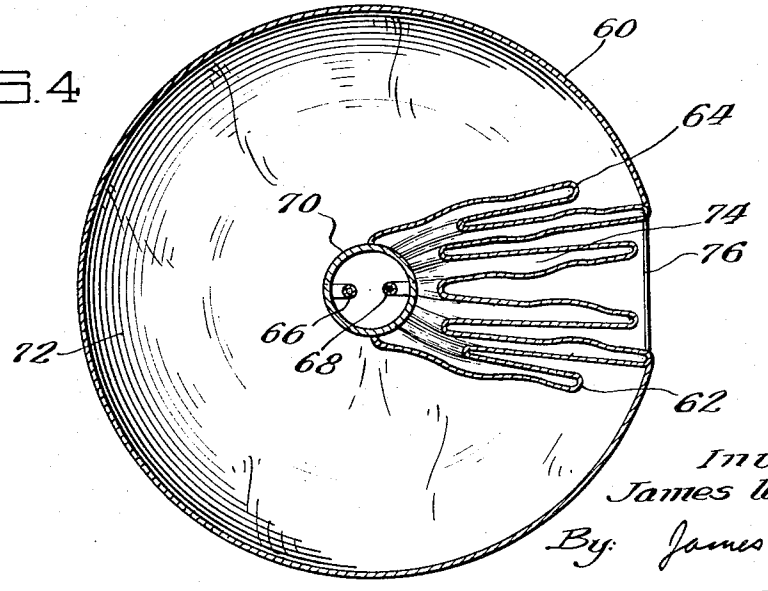


FIG. 4



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3,297,362

METHOD AND APPARATUS FOR SOLUTION MINING

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7 Claims. (Cl. 299—5)

This invention relates to a method and apparatus for the solution mining of soluble minerals. More particularly, this invention relates to a method and apparatus for which improved fluid distribution in a subterranean cavity is obtained. In another aspect, this invention relates to an improved method and apparatus for forming subterranean caverns for the storage of fluid materials by the removal of soluble formation constituents.

It has been proposed to recover valuable minerals from deeply buried deposits by dissolving the mineral in a solvent, usually water, which is circulated through a well-bore from the surface of the earth into the mineral-bearing deposit, and thence upward through the same or different well-bore to the surface of the earth. It has usually been preferred to drill a single well into the mineral-bearing deposit, and equip the well to provide two conduits which terminate at vertically spaced points within the formation. An unsaturated solvent is pumped downward through the well to dissolve soluble minerals from the formation, and more highly concentrated solvent is pumped from the formation to the surface of the earth. A portion of the dissolved mineral content of the solvent is then recovered, usually by reducing the temperature of the solvent.

As the material is dissolved and removed from the subterranean formation, a cavern or cavity is formed. As the size of the cavity increases unsatisfactory circulation of solvent within the cavity has been found to exist. Flow rates adjacent the wall of the cavity are too low, the bulk of the fresh solvent tending to follow the shortest path between the outlet of the input conduit and the inlet of the output conduit.

It is an object of this invention to provide a method and apparatus whereby improved circulating efficiency is obtained in cavities formed by solution mining.

Another object of this invention is to provide a method and apparatus for solution mining whereby flow of solvent is directed in a path closely paralleling the walls of a subterranean cavity.

Another object of this invention is to provide a method and apparatus for solution mining whereby increased fluid velocities are obtained in solution mining cavities adjacent the walls thereof.

Still another object of this invention is to provide a method for controlling the shape of solution mining cavities.

Briefly, the invention resides in utilizing a large bladder or balloon fabricated of a foldable, flexible material which can be inserted through a well casing and into a cavity formed by solution mining. The bladder is disposed between the inlet and outlet of the solvent distribution system and is inflated until it occupies a major portion of the volume of the cavity, whereby the flow of solvent is directed over a course adjacent to the walls of the cavity.

The invention is described in detail with reference to the drawings of which:

FIGURE 1 is a vertical section showing a solution mining assembly in which the apparatus of this invention is incorporated,

FIGURE 2 shows an alternate embodiment of the apparatus of this invention,

FIGURE 3 shows a second alternate embodiment of the apparatus of this invention, and

FIGURE 4 is a view of the apparatus shown in FIGURE 3 taken in the direction 4—4.

Referring to FIGURE 1, a subterranean formation **10** includes a mineral-bearing stratum **12** which lies below an impermeable stratum **14**. A well-bore **16**, which communicates the mineral-bearing stratum **12** with the surface of the earth, is provided with a conventional well casing **18** and a tubing string **20**. The well casing terminates just below impermeable stratum **14**, which is to say, adjacent the top of the mineral-bearing formation **12**. Tubing string **20** extends to a greater depth in formation **12**, and a salt cavity **22** has developed through the removal of soluble formation constituents. The salt cavity is typical of that formed by circulating a solvent, such as hot water, downward through annulus **24** which lies between the interior of casing **18** and the exterior of tubing string **20**. The hot water dissolves a mineral, such as potassium chloride, and the mineral-laden water is removed from cavity **22** upward through tubing string **20**.

In accordance with this invention, when the salt cavity has reached such dimensions that solvent circulation is found to follow a course downward from casing **18** to tubing string **20**, without adequately contacting the walls of the subterranean formation, the solution mining system is modified in accordance with this invention. A packer **26** is secured to tubing string **20** at a suitable distance above the low end thereof. The packer **26** is provided with a plurality of apertures **28**. A bladder **30**, which is fabricated of a foldable, flexible material is secured to the tubing string intermediate packer **26** and the lower end of the tubing string. Fluid communication is provided between the apertures **28** and the bladder interior by securing the bladder to the packer outwardly of the apertures. This can be conveniently done by providing the packer with a tubular shoulder **32** and securing the upper end of the bladder to the shoulder, as shown. The bladder is provided with a plurality of openings such as openings **34** which are preferably spaced circumferentially around the upper portion of the bladder, or in any event are positioned in a portion of the bladder remote from the inlet to tubing string **20**.

The bladder may be fabricated of any of a number of thin, substantially fluid impermeable, flexible materials capable of withstanding temperatures normally encountered in solution mining, i.e., temperatures up to about 200° F. Polyethylene films are suitable, and polyethylene terephthalate films are preferred. Especially preferred are polyethylene terephthalate films reinforced with nylon web. The nylon web greatly improves the strength and tear resistance of the film, which is preferably bonded to the web.

In operation, when the cavity has reached a size such that the circulation efficiency in the cavity is considered unsatisfactory, tubing string **20** is removed from the well-bore and equipped with a packer and bladded as shown in FIGURE 1. The bladder is, however, initially folded into a compact cylindrical form as illustrated, for example, in FIGURE 2. Thus the entire bladder and packer are insertable within the casing, and the diameter of the bladder when folded is preferably sufficiently smaller than the diameter of the packer so that the packer serves as a guide to prevent damage to the bladder as the assembly is run downward through the casing. After tubing string **20** has been returned to position packer **26** is expanded to provide fluid-tight seal between casing **18** and tubing string **20** adjacent the lower extremity of casing **18**. It will be understood that packer **26** is merely illustrated schematically, such packers and their oper-

ation being well known and understood in the well arts. Bladder **30** is inflated by the circulation of solvent downward through annulus **24**, through apertures **28** in packer **26** and into the interior of the bladder. After the bladder has expanded to its maximum diameter the solvent flows outwardly through openings **34** and circulates as indicated in FIGURE 1. The circulation is thus directed to place the solvent in intimate contact with the walls of the cavity, whereby greater quantities of valuable mineral are dissolved. A further advantage is obtained in that the velocity of the solvent adjacent to the walls of the cavity is maintained at a high level, whereby the rate of solution of salt in the solvent is increased.

Referring now to FIGURE 2 an alternate embodiment of the apparatus is shown. The packer has been eliminated and guide **40**, which comprises a ring **42** and a plurality of spokes **44**, has been secured to tubing string **46** above folded bladder **48**. The function of guide **40** is to prevent contact between folded bladder **48** and the well casing as the tubing string is run downward through the well. A strap **50** is provided to retain the bladder in folded condition and at minimum diameter. In practice a number of such straps will generally be employed. The strap is fragible and may be fabricated of some easily broken material, such as, a very thin plastic film. Internal pressure within the bladder breaks strap **50** and permits the bladder to inflate. A small, bent pipe **52** having an opening directed axially of the tubing string and communicating with the interior of the bladder is provided. The bladder is sealed at **54** and **56** in a fluid-type relationship with the tubing string. In operation, the velocity of fluid flow downward through the tubing string creates a velocity head which is communicated to the interior of the bladder. At high rates of solvent flow this kinetic head is sufficient to create a pressure differential between the interior of the bladder and the interior of the cavity. Thus the bladder is forced outwardly by this pressure differential and retained in expanded condition as long as fluid is pumped downward through the tubing string.

Referring to FIGURES 3 and 4, an alternate embodiment of the apparatus is illustrated. In this embodiment the bladder **60** is provided with two radial, vertical, fluid-tight partitions **62** and **64** which together divide the bladder into two hemispherical segments. Two separate fluid inlet conduits **66** and **68** extend internally of tubing string section **70**, and communicate with bladder segments **72** and **74**, respectively. In use, the bladder segments are folded separately and one of the bladder segments is secured by a fragible strap such as strap **76**. After the bladder has been positioned in a subterranean cavity, fluid pressure is applied through conduit **66** to inflate segment **72** of bladder **60**. Segment **74** of bladder **60** remains in a collapsed condition, but unfolds sufficiently to permit expansion of segment **72**, as illustrated in FIGURE 4. After further production of soluble minerals from the subterranean formation the cavity will eventually again increase in size to the point at which circulation becomes unsatisfactory because of the excess radial distance between the wall of the partially inflated bladder and the wall of the cavity. Bladder segment **74** is then inflated by applying fluid pressure through conduit **68**. The fluid pressure causes strap **76** to rupture and segment **74** becomes inflated, whereby the bladder is expanded to its maximum extent.

It will be understood that an operative device of somewhat more simple construction than is shown in FIGURES 3 and 4 can be made by merely eliminating the two radial, vertical fluid-tight partitions **62** and **64**, and fluid inlet conduit **68**. In this case, the bladder can be inflated by applying to conduit **66** a pressure great enough to inflate the bladder, but insufficient to cause rupture of strap **76**. When required, the thus partially inflated bladder can be increased in size to its full dimensions by applying an increased pressure sufficient in magnitude to rupture strap **76**, whereby the bladder is inflated to its maximum dimensions. It is, however, desirable to incorporate in the device the vertical partitions **62** and **64** since this eliminates necessity for controlling the magnitude of the pressure applied to inflate the bladder. Such control can be difficult where the bladder is disposed at great depths due to hydrostatic head considerations. Also, the partitions serve a useful function as restaining members in cylindrically shaped bladders. It will be understood that where the top and bottom panels of the bladder are substantially flat or disc-like in shape, internal pressure will tend to bulge these panels to produce a more nearly spherical shape. The partitions **62** and **64** serve to restrain against such deforming of the bladder.

The bladder can be fabricated to any desired shape to meet the needs of a particular mining operation. For example, where the stratum mined is of limited depth, it will generally be preferred to employ a bladder of greater diameter than height. By the use of a bladder of suitable shape, and particularly by the use of bladders which may be inflated in steps to provide a variety of shapes of increasing volume, the growth of the cavity can be controlled to provide optimum removal of valuable ore between the limiting dimensions of the ore-containing stratum. Thus, in a stratum of shallow depth, a bladder as aforedescribed capable of controlled expansion in a radial direction can be employed to control the growth of the cavity to provide a final cavity shape compatible with the limited depth of the stratum, but of substantial diameer. Further, the bladder is useful in controlling cavity shape to produce a more nearly cylindrical cavity and to avoid the formation of a cavity of substantially inverted-triangular, vertical cross-section, as frequently otherwise occurs.

While any suitable fluid may be used to expand the bladder to the desired size, it is preferred to employ a liquid having approximately the same density of the solvent used in the solution mining operation. In this way any tendency of the bladder to rise or sag due to differential density effects is avoided.

The invention has been described with reference to a single well solution mining operation for the recovery of valuable minerals. It will be apparent to those skilled in the art that the method and apparatus of this invention are equally applicable to the removal of soluble minerals from subterranean formations to form cavities for the storage of volatile material such as natural gas and LPG, or for the safe disposal of radioactive waste material.

While the invention has been described in detail with reference to the several preferred embodiments thereof, it will be understood that within the scope of the appended claims the invention can be practiced otherwise than as specifically described.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In the removal of soluble minerals from a subterranean formation by providing an input conduit having an outlet within said formation and an output conduit having an inlet within said formation and spaced from said outlet, and circulating a solvent through said formation between said outlet and inlet, whereby a cavity is formed, the improvement comprising disposing a collapsed, flexible bladder within said cavity between said inlet and outlet and inflating said bladder to a size smaller than said cavity to provide a substantial bulk between said outlet and inlet, and continuing the circulation of solvent from said outlet to said inlet over a course defined as lying between said bladder and the periphery of said cavity.

2. The method in accordance with claim **1** wherein said bladder is secured in collapsed condition adjacent the end of one said conduit, and said bladder is disposed in the cavity by passing the one said conduit and bladder

through the other said conduit and into the cavity, prior to inflating the bladder.

3. The method in accordance with claim 2 in which the one said conduit is said output conduit and the other said conduit is said input conduit.

4. The method in accordance with claim 3 in which said bladder is inflated to occupy a major portion of the volume of said cavity.

5. The method in accordance with claim 3 in which the outlet of said input conduit is connected to the interior of said bladder, said bladder is provided with a plurality of fluid openings disposed remotely with respect to said inlet, and solvent is circulated from said input conduit into said bladder, and out of said fluid openings and through the cavity to said inlet.

6. A manufacture comprising a rigid, substantially straight tube section, a bladder fabricated of a foldable, flexible material encompassing a portion of said tube section intermediate the ends thereof, said bladder being secured to said tube section in fluid-tight relationship therewith adjacent one end thereof, a packer secured to said tube section at a point remote from said one end said packer having a greater diameter than the diameter of said bladder when folded, said bladder being secured to said packer in fluid-tight relationship therewith, an opening extending axially through said packer and communicating with the interior of said bladder, said bladder being provided with a plurality of openings therein spaced remotely with respect to the said one end of said tube section.

7. In a system for the removal of soluble minerals from a subterranean formation, a subterranean cavity, fluid distribution means comprising an open casing extending between the surface of the earth and said cavity, said casing terminating a substantial distance above the bottom of said cavity, an open tubing string of smaller diameter than said casing extending through said casing and terminating below the lower end of said casing and within said cavity, a bladder fabricated of a foldable, flexible, substantially fluid impervious material encompassing a portion of said tubing string intermediate the cavity adjacent terminus thereof and said casing, a fluid-tight packer disposed between said casing and said tubing string to form a seal therebetween, said bladder being secured to said packer in fluid-tight relationship therewith, an aperture in said packer connecting the interior of said bladder with the interior of said casing above said packer, said bladder being provided with a plurality of openings located remotely with respect to said terminus of said tubing string.

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