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SEALING UNDERGROUND CAVITIES

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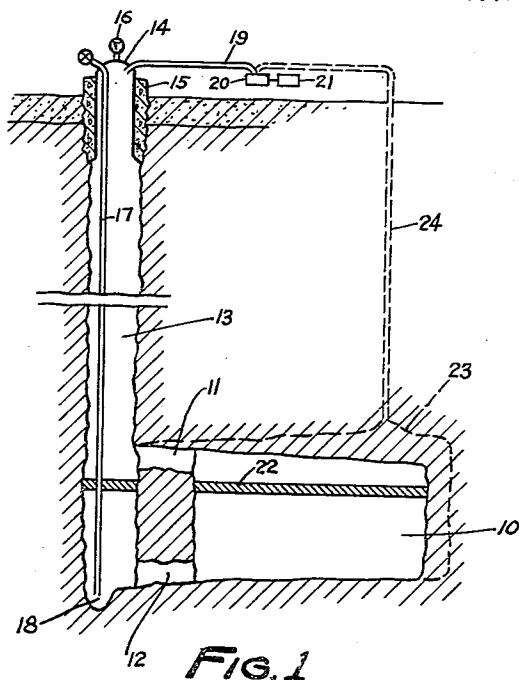


FIG. 1

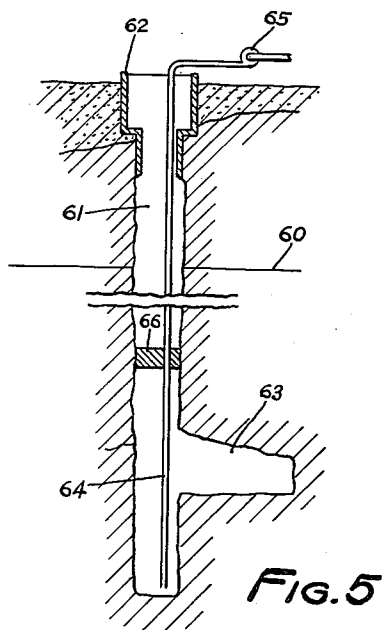


FIG. 5

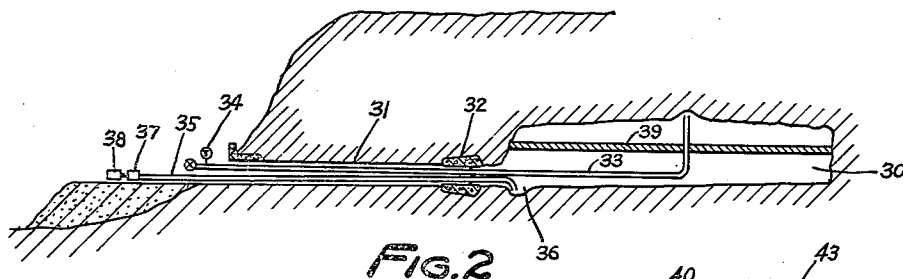


FIG. 2

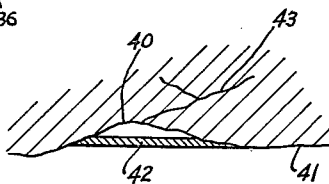


FIG. 3

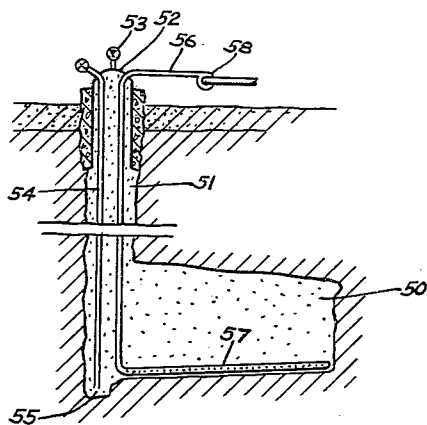


FIG. 4

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3,064,436

## SEALING UNDERGROUND CAVITIES

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6 Claims. (Cl. 61—5)

This invention relates to a method of sealing underground cavities against leakage, both against leakage of ground fluids into underground chambers and interconnecting tunnels and shafts, and against leakage of stored products from underground storage systems into surrounding earth structure.

Ever increasing demand and production of liquid or liquifiable petroleum products such as liquid propane, butane, gasoline, fuel oils and the like, and other materials such as anhydrous ammonia, has created problems in providing extensive and suitable storage facilities for such materials. Because of the high vapor pressure of liquified hydrocarbons and the like, the cost of surface storage equipment, such as steel tanks, becomes excessive due to the pressure resistant construction required to safely withstand the pressure of the stored material. The problem becomes acute where it is necessary to store large quantities of such materials during off seasons.

In addition to expense, there are additional disadvantages arising out of the necessity of maintenance to prevent corrosion and fire hazards. Evaporation losses are great when petroleum products having volatile fractions at ordinary temperatures are stored in open or vented tanks. Surface storage facilities are vulnerable to air attack, sabotage, contamination from radiation in the event of attack by atomic or thermonuclear weapons and like extraordinary hazards present during wartime and periods of national emergency.

It has been proposed to store liquid and liquifiable products in porous water bearing formations, in water leached caverns and salt formations or in abandoned mines in impermeable shale or limestone formations.

It is desirable that underground storage of liquified petroleum or natural gas and like products be located at or reasonably near the place of consumption rather than the place or origin so as to relieve the peak loads on transportation and production equipment. However, due to the differing earth formations in different parts of the country, desirable locations for construction of underground storage chambers are not always present at terminals adjacent points of consumption of the products. The available sites for construction of underground vaults or chambers for the storage of gas liquid and liquifiable petroleum products may therefore be less than ideal in many locations.

Because the earth formations available for construction of underground storage systems may present less than ideal conditions a frequent problem encountered is one of leakage. The stored fluid may permeate the surrounding earth formation contaminating wells and streams and resulting in waste of the valuable fluid. Where the storage vault is in water bearing strata the seepage of water into the vault may gradually fill up the vault reducing its capacity and in many cases absorbing or reacting with the stored fluid. For example, the underground storage of anhydrous ammonia is impossible unless water may be excluded from the storage cell.

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Equally important is the problem of preventing flow of ground fluids into the workings of underground mines. Seepage of ground water into mines results in rusting and corrosion of equipment, rotting of timbers, difficulties in ventilating the workings and, at times, almost intolerable working conditions for the miners.

In addition to the storage of petroleum products, natural gas, jet fuel, ammonia and the like, an ever more burdensome problem is that of disposing of radioactive wastes. While underground storage of such materials has been suggested, such storage is not feasible so long as seepage or outflow of these dangerous materials from the storage cavities is possible.

It is the principal object of this invention to provide a method for sealing underground cavities against leakage.

Other objects of the invention will become apparent as the description proceeds.

To the accomplishment of the foregoing and related ends, this invention then comprises the features hereinafter fully described and particularly pointed out in the claims, the following description setting forth in detail certain illustrative embodiments of the invention, these being indicative, however, of but a few of the various ways in which the principles of the invention may be employed.

The invention is illustrated by the drawings wherein corresponding numerals refer to the same parts and in which:

FIGURE 1 is a simplified and diagrammatic sectional view of an underground cavity having communication with the surface through a shaft fitted for practice of this invention;

FIGURE 2 is a similar simplified and diagrammatic view of an underground cavity having communication with the surface through a tunnel or drift;

FIGURE 3 is a detailed sectional view of an irregularity in the ceiling or roof of a storage chamber or tunnel showing how such an irregular surface is sealed;

FIGURE 4 is a simplified and diagrammatic sectional view of an underground cavity to be sealed by a dispersion of sealant, either in a gas or in a liquid; and

FIGURE 5 is a simplified and diagrammatic sectional view of an open underground cavity to be sealed with the use of only hydrostatic pressure.

Broadly stated, this invention contemplates the sealing of fractures, joints, pores or other openings in the rock roof, walls or floor of underground excavations so as to prevent the entrance of water or the exit of any fluid stored in the excavation. The sealant may be applied both above and below the level of ground water. Although in usual practice the excavation is sealed before being put into use, under favorable circumstances, as will be explained in detail hereinafter, a storage system may be sealed while in use. Under some circumstances the sealant may be formed in situ in storage and act as a perpetual self-sealant.

Either new or old excavations of virtually any shape may be sealed, whether in sedimentary, igneous or metamorphic rock. Sealing is accomplished without the necessity of workmen entering the excavation and without the necessity for tediously cleaning or concreting floors. The sealant is forced at depth in the walls of the excavation rather than applied as a superficial surface coating.

To accomplish sealing according to this invention, it is necessary that the pressure within the excavation shall be greater than the pressure of rock fluid (usually water

or air) in the fractures, joints or pores to be sealed. This differential pressure may be from 20-40 p.s.i. gauge to as high as several hundred pounds. A sealant is introduced to the excavation and is forced by the greater pressure in the excavation to travel into the defects which it is desired to seal. Over surfaces where no defects exist obviously no sealant will be used up filling leaks, and, dependent upon the sealant used, only a thin surface layer or none at all will be deposited on the excavation surface.

The sealant is introduced as an emulsion, a suspension or a solution completely filling the excavation, or, more economically, as a layer of emulsified, suspended or dissolved material floating on a fluid of greater density. A single sealant may be applied in one or in several successive applications, or, where conditions require it, a plurality of different sealants may be used. For example, a first sealant is used to plug fractures with discrete particles by bridging them and a second is then used to cement the particles together.

In most instances, pressure is applied by closing the entrance to an excavation and pumping fluid into it. In shafts or downwardly inclined tunnels pressure may optionally be applied by maintaining an abnormally high fluid level with respect to the water table, or by the use of heavy or weighted fluids.

Where the excavation to be sealed contains any large openings, fractures, crevices or the like, it is desirable to prepare the walls of the excavation by partially stopping these large openings by concreting or grouting. It is desirable that these large openings be closed in order that the required pressure can more easily be maintained during the sealing process and to prevent waste of the sealant. No other special trimming, brushing, digging, washing or cleaning is necessary nor is it necessary to build scaffolds or provide movable staging to gain access to walls and roofs.

The sealant must be a material which is stable with respect to the rock walls and ground fluids. In the case of storage excavations, it must also be compatible with the material to be stored by being non-reactive with it and by not introducing any contaminant into the stored product. The setting of the sealant in place in the fractures, joints and pores within the excavation must be controllable in some fashion. Dependent upon the particular sealant used setting may take place by change of temperature, by change of pressure, by aging, by addition of a reagent or the like. To make sealing economical, the sealant must also be of reasonable cost.

If the sealant is to be floated, then it must have a density intermediate of the densities of the fluids between which it is to float, or be capable of admixture with another agent such that the mixture will float between the two fluids. For example, a finely powdered solid like silica or alumina has a density greater than water and will not ordinarily float on water. However, if mixed with a dispersant in a hydrocarbon oil or the like, these higher density solids will readily form a floating layer on water. Obviously, the fluids between which the floating layer is supported must be compatible with the excavation surfaces. In many instances, however, the fluids used in sealing cavities will be different from those subsequently stored in the sealed chambers.

A wide variety of materials may be used as sealants, and, depending upon the particular sealant employed, they may be applied from suspensions in gases, suspensions in liquids or solutions. Certain of the materials, either as solids, suspensions or solutions may be applied from a floating layer as will be explained in detail hereinafter.

Exemplary of those materials which may be applied as suspensions in air or other gas are Portland cements, plaster of Paris, bentonite, powdered limestone, clays and the like. These materials in finely divided form are introduced into a sealed excavation under pressure and

are maintained in suspension by agitation to insure contact with all of the excavation surfaces. The pressure upon the excavation is sufficient to reverse the flow of groundwater. The suspended particles are driven deep into the fractures, joints and pores. The hydratable particles become hydrated in contact with any moisture present in the leaks and form a cemented plug. Where the excavation or part of it is dry, the suspended particles are forced into the defects forming a dry plug. In this event, if desired to form a hydrated cemented seal, the excavation can be filled with water to hydrate the sealant particles exposed at the mouths of any leakage points, and the water is then pumped out. Under ordinary circumstances, this expedient should seldom be necessary.

The sealant may likewise be applied from a suspension in water or other liquid. The sealant may be any inert powdered solid, for example, silica, alumina, clays, powdered metals or the like. These solids are introduced into the excavation maintained under pressure either by externally applied pressure or hydrostatic pressure exerted by the column of liquid suspending the solids. The solids are kept in suspension by means of suitable dispersing agents (fatty alcohol sulfates, fatty acid partial esters of hexitol anhydrides ("Span"), quaternary ammonium compounds, silica aerogels, sodium alginates, etc.) or by mechanical agitation. The suspension may be a dispersion or emulsion of a rubber latex or resin applied in the same manner. Suitable materials include, for example, water emulsions of alkyd resins, dispersions of modified vinyl copolymers, dispersions of styrene copolymers, polyvinyl acetate copolymer emulsion, styrene modified polyester type resins, neoprene and Buna-N synthetic rubber latices, polyvinyl chloride latices and the like. From the economic standpoint these resinous dispersions and emulsions are desirably applied from a floating layer.

As an example of a hydratable solid applied from suspension, bentonite is dispersed throughout a light oil, using a suitable dispersing agent if necessary to maintain the suspension. This material is then introduced into the bottom of the excavation which is then pressurized. Water is introduced under the oil-bentonite suspension which then rises floating upon the rising water. The bentonite particles are forced from the suspension into the leakages. As these particles are subsequently contacted by the rising water they expand and become locked in place in the pores and fractures. The oil acts initially to inhibit expansion of the bentonite in the floating layer and after the bentonite seal is in place permits a slower regulated expansion than normally takes place when water contacts bentonite. Although some expansion may take place at the interface during the upward course of the water and floating layer, this expanded layer serves as a barrier to further insulate the oil-bentonite suspension floating above.

A variety of solutions of material are useful as sealants. One group of substances which may be mentioned as useful in many instances for forming a fluid tight seal are aqueous solutions of soluble alginates, for example, sodium alginate and ammonium alginate. These materials are useful when the exposed rock surfaces of the excavation contain calcium in a form available for reaction to form a seal of insoluble calcium alginate in the points of leakage, such as in limestone. The soluble alginate solution is simply introduced under pressure into contact with the rock surfaces and then pumped out.

As another example of a similar reacting solution there may be mentioned acid solutions of metals such as iron and aluminum which precipitate as gels upon neutralizing in contact with a basic rock surface. A solution of ferric chloride, ferric sulfate, aluminum chloride or the like upon contact with basic rocks precipitate in the leakages as insoluble hydroxides. Where the rock is not basic a first application of the acid salt solution

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may be followed by the application of a basic solution to form the sealing precipitate.

Solutions of materials which set upon heating or cooling are applied in their unset state and forced into the points of leakage. Thereafter a hot or cold fluid is applied to set the sealant. For example, an emulsion of tar or asphalt in hot water is first applied to the excavation walls and thereafter the walls are cooled to solidify the sealant, or a low temperature thermosetting resin is first applied from solution or suspension. Thereafter, a hot fluid, liquid or gaseous, is applied under pressure to the resin to set it in the fractures and pores. In some instances the rock temperature itself is sufficient to set the sealant. In still other instances an initial application of resinous sealant is followed by application of a setting catalyst or similar reacting substances are applied in successive stages so as to react in situ. As an example, a solution of sodium silicate is first applied to the excavation under pressure and followed by an application of brine to set the silicate in the leaks. Or, the liquid coal tar-epoxy resin material sold by Pittsburgh Coke and Chemical Co. under the trade mark "Tarset" is first applied to the cavity walls and subsequently the walls are contacted with "Tarset" catalyst to set the resin in situ. If this expedient is followed, preferably some catalyst is incorporated into the resin before it is applied to the leaks, but this amount is insufficient to cause setting of the resin. In some large excavations, several days' time may be required to fill or empty the cavity. It is imperative that premature setting of the sealant be prevented.

Another material well suited as a sealant is composed of plastic bubbles or hollow spheres of minute size. Phenolic nitrogen filled spheres ranging in size from about 0.0002 inch to 0.0036 inch (average 0.0013) are available as "Micro Balloons" from the Bakelite Co. This material has a bulk density of 8.7 pounds per cubic foot. The particle density is 20.6 pounds per cubic foot. The bubbles are stable in hydrocarbons. Because of the particle size range smaller spheres fit in the interstices between larger spheres forming a virtually impenetrable barrier.

The spheres are applied to the excavation surfaces from suspension in a gas or liquid or preferably from a floating layer passed through the excavation. When applied as a suspension from a gas or liquid these spheres tend to migrate under pressure only to the points of leakage so that little or no surface coating is deposited on the walls where no sealing is necessary. When applied from a floating layer the spheres are desirably intermixed with a binder, such as a solution or suspension of a resin or rubber material, whereby the particles are firmly cemented in place in the pores and crevices of the excavation walls.

A paint-like phenol-formaldehyde resinous base sealant having the property of setting at a predetermined time is available commercially under the name "Dowell." This material is well suited to use as a floating sealant. The "Tarset" coal tar-epoxy resin mentioned previously is likewise controllably settable. The setting rate is inversely proportional to the temperature and to the amount of catalyst incorporated into the resin. Thus, the setting rate of the sealant in place can be extended by cooling the excavation surfaces and/or decreasing the proportion of catalyst in the resin. Cooling may be accomplished, for example, by using a cold liquid as the supporting fluid for the sealant.

Where conditions permit, a more tenacious seal may be created by initially cooling the rock of the excavation surfaces to enlarge the pores and fractures. The sealant is then forced into these enlarged openings under pressure according to the teachings of this invention. Thereafter, the rock is allowed to assume its ordinary temperature, reducing the fractures and pores so that they tightly grip the sealant.

The method of application of the sealant according to this invention is described with reference to the draw-

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ings. Referring to FIGURE 1, there is shown diagrammatically one form of storage cavity 10 communicating through an upper tunnel 11 and a lower tunnel 12 with an inclined or vertical shaft 13 leading to the earth's surface. A closed casing 14 is concreted at 15 into the mouth of shaft 13 extending down to below bedrock. The pressure dome at the top of casing 14 is fitted with a pressure gauge 16 and at least two inlet-outlets, one for a pipe 17 for pumping fluid to or withdrawing fluid from the bottom of the storage system. A sump hole 18 at the bottom of the shaft 13 facilitates withdrawal of fluid from the system. Pipe 19 is connected to a pump 20 driven by a motor 21 for pumping air or other fluid into the excavation to pressurize the system. A floating layer of sealant is shown at 22 between two fluids in the system. For example, layer 22 may be composed of a dispersion or emulsion of a resinous sealant floating upon water with air occupying the space above.

The sealant is applied to the walls of the excavation in one of two ways. The sealant may be pumped to the bottom of the excavation to a depth sufficient to provide at least a thin surface coating of predetermined thickness over the entire excavation walls. The sealant is then floated upwardly by pumping a liquid heavier than the sealant through pipe 17 to the bottom of the shaft. As the level of this liquid rises the floating layer of sealant contacts the excavation wall surfaces and spreads out into a thin surface coating. The pressure within the excavation is kept above the pressure of the rock fluid in the fractures, joints and pores by means of the pump, to force the sealant into these points of leakage. Even though the cavity contains leakages in the form of fractures, joints and pores, these areas of leakage constitute a relatively minor portion of the total area of the cavity. Thus, even though some of the pressurizing fluid may be lost through the leakages, it is possible to readily build up the pressure within the cavity by introducing the pressurizing fluid at a rate substantially greater than that by which the fluid is lost through the points of leakage. Since the sealant migrates towards the points of leakage with the escaping flow of pressurizing fluid, the sealant is deposited in the points of leakage and gradually closes them off. As this takes place the rate of escape of the pressurizing fluid gradually diminishes to zero so that the maintenance of pressure within the cavity becomes easier. When the sealant layer reaches the top of the shaft the remaining sealant is withdrawn and the excavation is pumped dry. Thereafter, depending upon the particular sealant used, the excavation may be filled with a setting reagent, it may be repressurized until the sealant sets or the like.

In the event the excavation contains high spots or domes such as indicated at 23 which are above the level of the top of upper tunnel 11 sealing is accomplished by tapping the highest point of the excavation with an auxiliary pipe 24 through which the air or other gas above the floating sealant layer can be withdrawn permitting the sealant to rise and contact all points of the excavation surfaces. Thereafter, pipe 24 may be sealed off.

Instead of introducing the floating sealant layer from the bottom of the excavation, it may alternatively be applied from the top by first filling the excavation with a heavier supporting liquid, pouring the sealant material on top of this liquid and then spreading the sealant by lowering the level of the supporting liquid by pumping it from the bottom of the excavation. Pressure above the falling sealant layer is maintained by pump 20. Desirably the floating layer may be raised and lowered with an undulating movement to insure intimate contact of all portions of the excavation by the sealant.

FIGURE 2 shows a storage chamber 30 communicating with the surface by means of a drift or tunnel 31. The tunnel is closed by means of a bulkhead 32 concreted in place. The bulkhead is provided with means

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for passing at least two pipes. Pipe 33 is fitted with a pressure gauge 34 and is in communication with the uppermost point in chamber 30 for maintaining pressure within the chamber and withdrawing fluid as necessary. Pipe 36 is in communication with the lowest point in chamber 30, namely sump hole 36. Pipe 36 is connected to a pump 37 driven by a motor 38 for pumping liquid into the storage chamber.

As in the case of the example of FIGURE 1, the floating sealant layer 39 is formed by first pumping the sealant into the bottom of the chamber 30 and pumping a heavier fluid under it to cause it to float or alternatively by first filling the storage chamber with the heavier liquid and pumping the sealant into it so as to form a floating layer at the top. In either event, the level of the floating layer is moved so that the entire surface of the excavation is contacted with the sealant layer while it is maintained under pressure. Here too, the pressure is maintained by pumping the fluid supporting the sealant layer 39 into the cavity at a rate faster than the rate of escape of fluid from the cavity. Since any leakages present soon become plugged, escape of fluid from the cavity is soon cut off and maintenance of pressure is stabilized.

As shown in FIGURE 3 separate means need not be provided for withdrawing the fluid from above the floating sealant layer in the case of every small dome or irregularity in the roof of an excavation. Where a dome 40 exists in the roof 41 of a chamber the sealant layer 42 floats up over the highest point at the base of the dome. If the dome contains a fracture 43 or other leak, the gas trapped by the dome leaks out through the fracture permitting the floating sealant to raise up into contact with the entire dome surface forced by the pressure from below and sealing off the fracture. On the other hand, if the dome contains no leaks to permit escape of the entrapped gas, then the dome is already storage tight and need be of no concern.

In FIGURE 4 there is shown means for applying the sealant from a fluid suspension in either gas or liquid. A chamber 50 communicates through shaft 51 with the surface. The shaft is provided with a domed casing 52 fitted with a pressure gauge 53, a pipe 54 to sump hole 55 and a second pipe 56 to a perforated agitator tube 57 at the bottom of chamber 50. A pump 58 is provided to maintain the sealant in suspension, whether it be a solid suspended in a gas or a solid or liquid suspended in a liquid. If the fluid suspending the sealant is a gas it may be recirculated, maintaining the pressure within the excavation above the pressure of the ground fluids at all times. Similarly, if the suspending fluid is liquid it may be recirculated. It is only necessary that pressure be maintained and that all surfaces of the excavation be contacted by the sealant. In the embodiment of FIGURE 4, pressure is also maintained by means of pump 58 by introducing the fluid suspending the sealant at a rate greater than the rate of escape of fluid from the cavity until the points of leakage are closed off. Pressure is then permitted to build up to the desired level and is maintained until a permanent seal of the leakages is effected.

FIGURE 5 shows a method for sealing open excavations, such as mine shafts and workings, wherein hydrostatic pressure alone is used to force the sealant into the fractures, joints and pores of the excavation. In this instance the principal concern is to seal off the flow of ground fluids below the water table level, indicated at 60, into the excavation. The excavation comprises an open shaft 61 cased at 62 at its mouth. One or more drifts or tunnels 63 communicate with the shaft. A pipe 64 to the bottom of the shaft is provided. Pipe 64 is connected to a pump 65.

To seal the excavation sealant material 66 is introduced to the bottom of the excavation and a heavier supporting liquid is pumped under it. As the floating layer

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is raised a surface coating of the sealant is applied over the walls, floors and roofs of the excavated parts. The hydrostatic pressure created by the column of liquid in the shaft forces the sealant into any pores or crevices. The height of the column of liquid above the water table level is in most instances sufficient to create pressure adequate to seal off all of the exposed excavation surfaces below the water table level. If it is not adequate, a weighted liquid may be used.

In many instances, to produce a column of height sufficient to exert the necessary hydrostatic pressure would require an excessive amount of sealant material. Where this is true the several layers are so chosen that a column of a liquid, such as water, can be used to exert the hydrostatic pressure. For example, a heavy supporting fluid such as drilling mud may be used under a sealant layer having a density intermediate that of the mud and water. Then the space above the sealant in the excavation is occupied by water.

If the mine being treated is an operating mine, all fixtures and equipment, timbers, cables, etc. will receive a coating of the sealant compound. This is not a disadvantage, however, because of the preservative effect on the equipment. Humidity control is greatly facilitated and working conditions are vastly improved by sealing the walls against entrance of water. The strength of rock in walls and roof is improved.

Where the float method of treatment is used to apply the sealant to excavation walls much of the surface of the floating layer is not in use except when contacting the floor or sealing of the excavation. The only function of the bulk of the layer most of the time is to insure that an adequate supply of the sealant is available at the periphery of the floating layer to make good contact with the walls. The effectiveness of the floating layer can be increased by interposing floating objects such as logs, planks, drums, etc. in the sealant layer so as to increase its effective thickness at its periphery. Even though the floating objects might contact the walls, the irregular nature of the wall itself would insure that these objects did not interfere with the application of the sealant.

Control over the application of the sealant can be exercised from the surface. The surface area of the excavation is known approximately. The average thickness of the sealant layer which will be deposited depending upon the sealant used and the rock structure can readily be predetermined by experimentation. From this, the approximate amount of sealant required can readily be calculated. Spot checks can readily be made at different depths during the application of the sealant to insure that the sealant has not become exhausted. For example, the thickness of the floating sealant layer, its progress and its properties can be gauged through cased holes drilled for this purpose.

If a leak develops in a storage system already in use, it can be sealed by use of a sealant properly selected with respect to the stored product without substantial disruption of use of the storage. Assuming a storage as shown in FIGURE 4, an inert solid sealant such as "Micro-balloons" could be readily dispersed through the stored product, whether gaseous or liquid, while the system was adequately pressurized. Part of the sealant would migrate to the leak and seal it. Thereafter, the unused sealant would simply settle to the floor of the excavation where it would not interfere with the stored product, or in the case of the hollow spheres, rise to the roof of the excavation, out of the way. If the location of the leak is known, the sealant can be introduced and placed through a carefully cased hole drilled especially for that purpose to the immediate vicinity of the leak.

A desirable expedient in the case of many storage systems is to provide a permanent self-sealing layer which will remain in place upon the top of the liquid in storage. This material would then be available to immediately seal

leaks upon contact with them in the course of rising and falling with the level of the stored product. Where this product is one, such as a liquified hydrocarbon, which is stored on a seasonal basis, so that periodically it covers the cycle from substantially full to virtually empty, most all of the excavation surface will be contacted by the sealant from time to time. In this way, any newly developed leakages will be sealed before any substantial loss can occur.

The pressures exerted upon the excavation during sealing must be at least sufficient to reverse the flow of ground fluids and the excavation may be pressurized up to the maximum anticipated storage pressure. In general, this may be up to 5000 pounds gauge and in extreme cases up to 10,000 pounds gauge. In most instances pressures in the range of 100 to 500 pounds gauge will be more than adequate to effect a tight seal.

This application is related to an earlier application of Robert L. Loofbrourow, Serial No. 497,070, filed March 28, 1955 for Sealing Method for Underground Cavities and to the extent applicable, the disclosure of that application is incorporated herein by reference.

It is apparent that many modifications and variations of this invention as hereinbefore set forth may be made without departing from the spirit and scope thereof. The specific embodiments described are given by way of example only and the invention is limited only by the terms of the appended claims.

What is claimed is:

1. A method for sealing underground storage cavities against leakage and maintaining the seal therein which method comprises closing the mouth of an underground cavity to render the cavity pressure-tight, applying a pore and fracture filling sealant over the surfaces of the cavity, said sealant being inert to the material to be stored in the cavity and applied to the cavity surfaces by passing it through the cavity as a floating layer supported upon a liquid disposed in said cavity, said liquid being heavier than the sealant and inert to the sealant and the cavity surfaces, application of the sealant to the cavity surfaces being accomplished by varying the level of the supporting liquid within the cavity, simultaneously pressurizing the cavity to a pressure greater than the pressure of inflowing ground fluids between about 40 and 5000 pounds gauge to force the sealant into points of leakage, maintaining the cavity under pressure until a tight seal is effected, withdrawing the inert liquid supporting the sealant, charging the storage cavity with a fluid to be stored under pressure and applying a further layer of sealant material lighter than the stored fluid floating upon the stored fluid to assist in maintaining the storage cavity leakproof.

2. A method for sealing underground storage cavities against leakage and maintaining the seal therein, which method comprises closing the mouth of an underground cavity to render the cavity pressure tight, applying a pore and fracture filling sealant over the surfaces of the cavity, said sealant being inert to the material to be stored in the cavity and applied to the cavity surfaces by passing it through the cavity as a floating layer supported upon a liquid disposed in said cavity, said liquid being heavier than the sealant and inert to the sealant and the cavity surfaces, application of the sealant to the cavity surfaces being accomplished by varying the level of the supporting liquid within the cavity, simultaneously pressurizing the cavity to a pressure greater than the pressure of inflowing ground fluids between about 40 and 5,000 pound gauge to force the sealant into points of leakage, maintaining the cavity under pressure until a tight seal is effected, withdrawing the inert liquid supporting the sealant and charging the storage cavity with a fluid to be stored under pressure.

3. A method of sealing the wall surfaces of deep underground excavated cavities against leakage, both from within and from without, while maintaining the inside dimensions and contours of the cavities, which method com-

prises introducing a liquid to a cavity to be sealed, said liquid being inert to the cavity surfaces, introducing a suspension of a pore and fracture filling sealant to said cavity, said sealant being non-reactive with said liquid and less dense than said liquid so as to float as a layer supported upon the liquid, introducing a further fluid to the cavity, said further fluid being less dense than said sealant and said liquid and non-reactive therewith and inert to the cavity surfaces, said further fluid being introduced under pressure to exert a fluid pressure against all of the wall surfaces of the cavity greater than the pressure of any inflowing ground fluids, contacting the wall surfaces of the underground cavity with said sealant while the cavity is maintained under said applied fluid pressure by varying the level of the supporting liquid within the cavity, forcing the sealant into points of leakage by means of said applied fluid pressure, and, after application of the sealant, maintaining the cavity under said applied fluid pressure until a tight seal is effected.

4. A method of sealing underground storage cavities against leakage which comprises introducing a pore and fracture filling sealant into an underground cavity, said sealant being heavier than inflowing ground fluids, introducing a supporting liquid for said sealant, said supporting liquid being heavier than the sealant and inflowing ground fluids and inert to the sealant and the cavity surfaces, contacting the wall surfaces of the cavity with said sealant by varying the level of the sealant and supporting liquid within the cavity, permitting inflowing ground fluids to accumulate above said sealant, maintaining a head of inflowing ground fluids on top of said sealant to exert pressure upon the sealant layer to force it into points of leakages, and maintaining said applied fluid pressure until a tight seal is effected.

5. A method of sealing the wall surfaces of deep underground excavated cavities against leakage, both from within and from without, while maintaining the inside dimensions and contours of the cavity, which method comprises closing the mouth of a deep underground excavated cavity with a pressure tight closure, subjecting the thusly closed cavity to applied fluid pressure by pumping a fluid therein under pressure to exert a fluid pressure against the cavity wall surfaces between about 40 and 5,000 pounds gauge, said pressure being greater than the pressure of any inflowing ground fluid, simultaneously contacting the wall surfaces of the cavity with a pore and fracture filling sealant, said sealant being contacted with the cavity walls from fluid suspension, introducing a liquid more dense than said sealant and non-reactive with the sealant and cavity walls to the cavity whereby said suspension of sealant is floated as a layer supported upon said liquid, said sealant being contacted with the cavity walls by varying the level of said supporting liquid within the cavity, said sealant being forced into points of leakage by means of said applied fluid pressure, and thereafter, after application of the sealant, maintaining the cavity under said applied fluid pressure until a tight seal is effected.

6. A method of sealing the wall surfaces of deep underground excavated cavities against leakage, both from within and from without, while maintaining the inside dimensions and contours of the cavity, which method comprises closing the mouth of a deep underground excavated cavity with a pressure tight closure, initially artificially cooling the cavity walls to contract the rock and expand any fractures therein to facilitate entry of a sealant, subjecting the closed cavity to applied fluid pressure by pumping a fluid therein under pressure to exert a fluid pressure against the cavity wall surfaces between about 40 and 5,000 pounds gauge, said pressure being greater than the pressure of any inflowing ground fluid, simultaneously contacting the wall surfaces of the cavity with a pore and fracture filling sealant, said sealant being forced into points of leakage by means of said applied fluid pressure, and thereafter, after application of the sealant, maintaining the cavity under said applied fluid pressure until a

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tight seal is effected and permitting the cavity walls to resume their normal temperature, whereby a tight gripping seal is obtained.

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