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[54] **CONSTRUCTING BROKEN ROCK SUPPORTS FOR ROOFS OF CAVITIES STORING LIQUIFIED HYDROCARBON GASES**

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[51] **Int. Cl.**.....**B65g 5/00**

[58] **Field of Search** 61/.5, 35; 62/4

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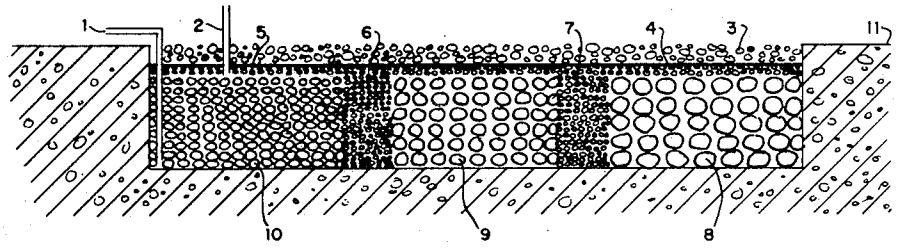
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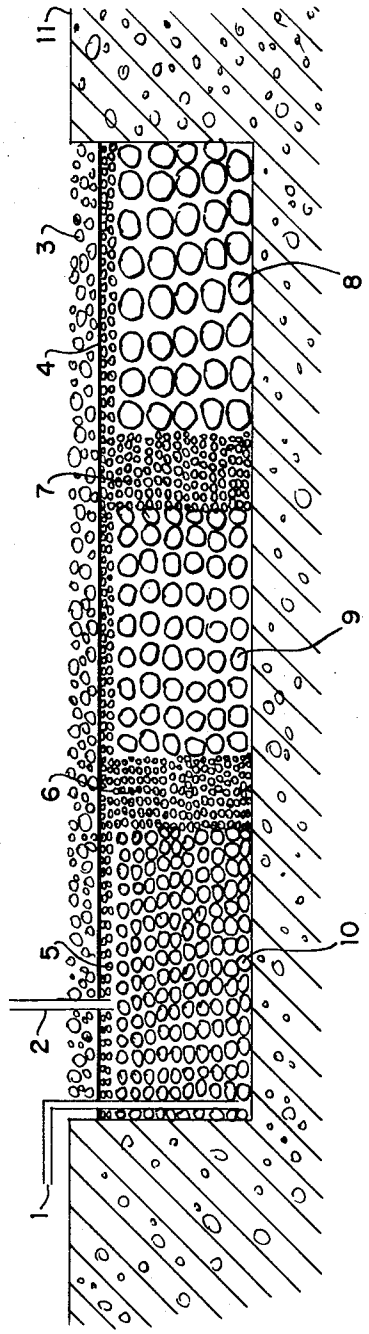
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[57] **ABSTRACT**

Liquified natural gas, ethane or propane is stored in a cavity in which the roof is supported on broken rock placed in the lake. Very cheap broken rock containing a large volume of voids,when piled,is provided by building the cavity on a rock formation, breaking the rock formation into small pieces by rippers or giant teeth pulled by giant tractors, sieving the broken rock into fractions with each fraction having rock pieces with a minimum to maximum size ratio of 0.5, and piling the rock fractions without substantial mixing in the cavity. This allows storage cavities to be built at a fraction of the former cost and that also can not be damaged by sabotage and riots like former storage can be.

8 Claims, 1 Drawing Figure




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CONSTRUCTING BROKEN ROCK SUPPORTS FOR ROOFS OF CAVITIES STORING LIQUIFIED HYDROCARBON GASES

Natural gas(which is a mixture of methane with some ethane) and much of propane gas are mostly used in the winter time for the heating of houses. However it is very desirable to keep the facilities producing and transporting the preceding hydrocarbons operating at a constant rate the year around. Also, with the importation of liquified natural gas by ship on the east coast from countries that have not been noted for political stability, it is highly desirable to keep as large a supply of natural gas on hand as possible in case a distant country supplying the liquified natural gas should suspend deliveries in case of political unrest. As a result there has been a large amount of work by numerous companies on the storage of normally gaseous hydrocarbons as liquids in cavities.

When normally gaseous hydrocarbons are liquified by cooling to low temperatures they occupy a very small volume in the liquid form as compared with the volume they occupy in the gaseous form. When a liquified gaseous hydrocarbon with a boiling point lower than the freezing point of water is stored in a cavity at atmospheric pressure the hydrocarbon will evaporate and cool the sides and the bottom of the cavity to below the freezing point of water. If the cavity is made so that water tends to flow into the cavity, when a crack occurs in earth or rock of the sides or bottom of the cavity water will flow into the crack. But since the sides of the crack are below the freezing point of water the water flowing into the crack will freeze and stop up the leaking crack.

The use of cavities to store liquified propane gas and liquified natural gas has been long practiced in this country. It has been found a cavity can be built very cheaply in large sizes. However for large cavities the cost for supporting an insulated roof for covering the cavity is high. Also all prior cavities are very easy to destroy by homemade dynamite bombs thrown on their roofs.

The drawing shows one form of the invention as would be preferred when a roof is provided for a small storage cavity. The drawing is taken up in detail at nearly the last of the specification.

In my invention I support the insulated roof of a cavity on top of broken rock placed in and filling the cavity. In this case the insulation may just be 3 or 4 feet of leaves, chopped weeds, hay or straw placed on top of the broken rock. Or more preferably, where sabotage by home made dynamite bombs is feared, the insulation may be at least 6 to 8 feet of 0.5 inch maximum size rock on top of the regular liquid storage section rock of the storage cavity. Then a layer of polyethylene sheet is placed on top the insulation. Then the top of the polyethylene sheet is covered with at least 2 feet of small broken rock to protect the roof from stray bullets and home made bombs. The roof is sloped into gutters that drain off rain water.

I supply the broken rock to fill the cavity by first picking a site for the storage cavity that is over a rock formation or very near to one. I also first see that the rock formation is rippable by rippers pulled by tractors.

Breaking up rock by ripping is a practice that has been used widely in recent years in the construction of highways and in mining. In ripping, giant teeth are pulled by big crawler type tractors through the rock. It is normally best to use the biggest tractor available. It is also practical to use one enormous tractor pulling the ripper and as many as six enormous tractors in a line pushing the tractor pulling the ripper.

As available tractors have gotten larger it has become possible to rip all but the hardest rocks. Even the hardest rocks can frequently be ripped if they are weathered or are first slightly broken by a small charge of explosive. Ripping is a well developed art and the cost of a specific ripping job is about always possible to estimate in advance. About all the ripping done in highway construction is done by bids submitted in advance. Equipment has long been available to measure the seismic velocity, or the velocity of sound through the rock, which gives a good indication of whether a rock is rippable. Further details on ripping can easily be obtained from the Kelly Products Division of CRC-Crose International, Inc., P.O. Box 3227, Houston, Tex., The American Tractor Equipment Corp., 9131 San Leandro St., Oakland, Calif. or other manufacturers of rippers. For the hardest rock I prefer to use the patented ripper, with an adjustable ripper point angle, of the Kelly Products Division above mentioned.

I use rippers to break up the rock in all cases because of two reasons. First, breaking up rock by rippers costs 50 percent and sometimes 75 percent less than breaking rock by drilling holes and blasting. Second, and of much more importance, is the fact that breaking a rock formation by ripping produces rock pieces of a much more uniform size than blasting.

It is important that the mass of broken rock filling the storage cavity have a high percentage of voids between the pieces of rock. This is because a lake of a given volume will hold more liquified natural gas or other hydrocarbon liquid if there is a higher percentage of voids in the mass of broken rock. Also the amount of rock required per cubic foot of liquified gaseous hydrocarbon varies greatly with possible percentages of voids in the mass of broken rock. For instance dropping the percentage of voids from 50 percent to 33 percent doubles the amount of rock that must be used to store a given volume of liquified gaseous hydrocarbon. A decrease to 20 percent voids multiplies the amount of rock required by four.

The volume of broken rock required to store a given volume of liquified hydrocarbon gas is of importance since it determines the amount of refrigeration required to cool the broken rock filling a storage cavity down to the temperature at which the cavity will operate in final operation. In case of liquified hydrocarbon gases boiling at temperatures not so far below the freezing point of water, as for example liquid propane, the refrigeration required to cool the broken rock down to operating temperatures is of minor importance. Also in the case where liquified natural gas is imported by ship the liquified natural gas has to be vaporized and heated anyway and the refrigeration thus obtained is very conveniently used to cool the broken rock filling the cavity. In this latter case for a broken rock mass containing 50 voids it will take the evaporation of about half of the storage capacity between the voids of a cavity to cool the broken rock down to operating temperatures. In the case of liquified natural

gas storage used to store natural gas, during the summer, from a gas pipe line, cooling the broken rock is more expensive. However, it is not as expensive as first thought. In this latter case there will have to be refrigeration equipment at the cavity to cool the pipe line gas and liquify it from the pipe line that is used only part of the time. This equipment can be used the rest of the time to liquify natural gas that is evaporated in cooling the broken rock in the cavity the electric power used will be generated by the electric power company with the portion of boiler and generating equipment that has to be kept in reserve for supplying electricity to the motors at the storage cavity. Or in the language of electric power companies the amount of electricity used in the initial cooling of the cavity increases the amount of electricity used but does not increase the maximum demand of electricity during any second of time. Therefore the only additional expense for the electric power company is the use of more fuel for boilers that are kept operating more steadily. Electric power companies greatly like this and always give much cheaper rates for the additional electricity used.

However it is emphasized that the total amount of refrigeration per cubic foot of liquid stored required to cool a cavity containing broken rock prepared according to my invention will normally be less than that for storage cavities that have been constructed by prior methods. These cavities now in use made by prior methods are limited in diameter because of the necessity of supporting the roofs from the sides. However the diameter of my cavity containing broken rock is only limited by the amount of storage needed at a given location and this is normally very large.As a result my cavities containing broken rock usually will be built in diameters of over 1,000 feet as compared with the storage cavities of perhaps 200 feet diameter now built. Therefore my storage cavities will have heat pick up from the sides of only a small fraction of the heat pick up from the sides that a smaller diameter storage cavity will have that must support the roof from the sides. Therefore a broken rock filled cavity will normally require less total refrigeration per cubic foot of liquid stored as compared with presently used storage cavities through the refrigeration required by a rock filled cavity will have a greater percentage of the refrigeration needed at the start.

It is the essence of this invention that the rock pieces made not only be made cheaply but more particularly they must provide in the cavity a mass that contains a large percentage of voids.

I have found that the way to increase the percentage of voids is to increase the ratio of the size of the minimum sized pieces of rock to that of the maximum sized pieces of rock in any given part of the piled rock filling the cavity. This fact has been taken from the book entitled Micromeritics by J.M.Dallavalle, Pitman Publishing Co., N.Y., 2nd edition, pages 135–143. While the interest of other workers has been in getting mixtures of broken rock with the minimum volume of voids, which is of extreme value in making strong and cheap concrete from a maximum of broken rock and sand and a minimum of cement, the same data can be used to determine what size ranges mixed together give the most voids. The data show that increasing the ratio of the maximum dimension, of the minimum sized pieces of a sieved fraction, to the maximum dimension of the maximum sized pieces in the same fraction always increases the volume of voids. However increasing the preceding ratio to above 0.5 is rarely necessary and increasing the ratio above 0.4 will usually do. However in all cases the used of ripped rock, which the ripping process produces in somewhat even sizes of rock pieces, and sieving the ripped rock into at least two fractions that are piled separately in the cavity is necessary.

In predicting the actual void volume that will be obtained in actual practice it is known that the fractions of voids in a pile that are possible by mixing spheres of the same diameter are between 26.95 percent and 47.64 percent voids depending on how much shaking and tamping are applied on the mass of spheres. (See reference by Dallavalle previously quoted page 127.) However with broken rock the individual pieces are not spherical but have angular corners that stick out and prevent the individual pieces from coming together as closely as spheres. This increases the volume of voids in a pile of broken rock pieces. The exact voidage on breaking a rock and sieving it to sized fractions will not only depend much on the range of sizes in each fraction(as can be predicted from Dallavalle's Data) but also on the amount of corners on each rock piece and the amount of tamping. An example of the voids in piles of broken rock is given by J. J. Barker, Industrial Engineering Chemistry, Vol. 57, pages 46–47 where for piles of granular broken basalt pieces ranging from 0.08 to 0.24 inches in size the voidage was measured as ranging between 41.3 percent and 44.5 percent. Since this rock mixture has a ratio of minimum sized pieces to maximum sized pieces of 0.33 it can be easily estimated from Dallavalle's Data that limiting the ratio,of the dimensions of the minimum sized pieces to the maximum sized pieces, to 0.5 that the voidage will be increased by about 4 percent or the total voidage will be in the range of 45 percent to 49 percent. Dallavalle on page 144 shows that for rock pieces of this size and larger it is only the relative size to each other of the rock pieces in a fraction and not the size of the rock pieces themselves that causes variation in voidage, assuming a constant amount of tamping. Therefore the above example is applicable in calculating what voidage fractions of larger rock pieces will have. It may be pointed out that Dallavale on page 137 shows that with very small ratios of minimum sized rock pieces to that of the maximum sized pieces(as for example 0.001 which is not uncommon in ordinary mixtures that are not sieved) that the voidage may go down to as low as 10 percent which would make the use of it impractical to use to fill a storage cavity with.

In making the broken rock pieces filling a storage cavity it is about always possible to examine a large number of prospective sites for any given cavity. Natural gas or liquid propane or other liquified hydrocarbons can be very cheaply transported as much as 25 to 50 miles and sometimes more from a storage place to where they are to be used. As a result areas of over several thousand square miles can be carefully looked over for the best site for a cavity. In my case the best location will also mean close proximity to a formation of rock that can be conveniently broken by ripping into pieces that can be used to fill the cavity and act as supports for the roof.

The ripping of the rock will be done by tractors pulling giant teeth through the rock formation. A bulldozer with a blade in front will push the broken rock to a transportable set of sieves where the broken rock will be sieved into sized fractions. The number of fractions, that can be sieved economically, is large and as many as ten different sized fractions can be made. This allows size ratios, of the maximum sized pieces to the minimum sized pieces in a fraction, to be maintained easily over 0.5 though this is not necessary. The sized fraction with the smallest rock pieces is reserved for building roads, over the partially filled cavity, for hauling the broken rock to where it is dumped. Since cavities of at least 75 feet depth to a maximum of 200 feet depth will usually be built the roads will not have to be built very close together for broken rock when dumped will roll quite a distance when dumped down a slope. However it is highly desirable to build roads of finer material since it allows large dump trucks with rubber tires to be used without heavy wear on the tires. In all cases the different-sized fractions of rock are placed in separate and different positions in the storage lake. Intermixing of touching different-sized fractions is easily avoided as can be seen from work done in the petroleum field using gravel at the bottom of oil wells to keep sand from being pumped up with the oil. There it has been found that gravel that is not over eight times the size of the 10 percent size of the sand will hold the sand back. The 10 percent size of a sand is the size of the sand in which exactly 10 percent of the total sand has a greater diameter than the 10 percent size. (See Petroleum Production Engineering, Oil Field Development, by L.C. Uren, 4th Ed., 1956, McGraw-Hill Book Co., New York City, page 718.)

In the final stage of filling a storage cavity with broken rock, a very small bulldozer pushing a blade is used to grade the top of the pile of rock. If leaves, chopped weeds or hay or straw are used for insulation they are put on. The roof itself is very conveniently made out of a sheet of polyethylene plastic covered with a layer of broken rock or earth to protect against stray rifle bullets or home made bombs.

Referring to the drawing, a cavity has been dug out of rock or earth of the original location as shown at **11**. The rock that has been broken by ripping and is used to support the roof has been sieved into four fractions. The first of the four fractions is the largest fraction and has been placed at **8** on the right side of the cavity in the drawing. The second largest fraction of the broken rock has been placed at **9** in the center of the cavity as shown in the drawing. The next smallest fraction of the broken rock has been placed at **10** as shown in the drawing. The smallest fraction of the broken rock, or the fines, has been placed at **6** and **7** as shown in the drawing. As has been described previously the fines **6** and **7** have been used to slowly build up roads during construction on which trucks can haul the other fractions of broken rock and can dump these other fractions from. Insulation, in this case, consists of a layer of rock fines **5** placed on top of the fractions of rock **6, 7, 8, 9,** and **10**. On top of the insulation **5** is placed a plastic sheet **4**. On top of the plastic sheet **4** is placed a layer of unsieved rock to prevent damage to the plastic sheet **4** by stray bullets or from actual intentional sabotage. The liquified hydrocarbon gas is introduced or removed by pipe **1** with the aid if required of a pump not shown. The storage cavity is vented by vent pipe **2** which is connected if need be to means not shown for recovering hydrocarbon gases in the vented gases if required. Drainage of rainwater from the top of plastic sheet **4** may be preformed by means previously described but in the drawing rain water is removed by occassionally sucking it off by inserting a hose down to the accumulated water.

In conclusion I may say that this application discloses a method for supporting the roof of a storage cavity for liquified hydrocarbon gases whose boiling points, at any possible barometric pressure at the location of the storage cavity, are lower than the freezing point of pure water, that costs only a fraction of prior means. Moreover the final storage cavities made possible by this patent are so much safer. In these days when arson, riots and sabotage have been so frequently occurring the possibility of some saboteur throwing a homemade bomb of dynamite on the roof of a storage cavity storing liquified natural gas is frightening. With former methods of supporting roofs for such storage the roofs must be made light and would offer little resistance to a dynamite blast. The blast would start off a fire and only extreme luck would prevent all the liquified natural gas from burning with a very spectacular fire.

By timing the sabotage and burning of a city's supply of stored natural gas just before the coldest time of the winter the city would only have about a third of the needed gas per day to keep the houses of the people warm. This would not be enough gas to keep the water pipes of all the homes in the city from freezing and bursting. The amount of suffering that can be caused by a few home made dynamite bombs on the roofs of prior types of liquified natural gas storage cavities is frightening.

However with my method of supporting a roof for a storage cavity, a roof can be covered with a thick layer of rock or earth and be made completely resistant to home made dynamite bombs. If the saboteurs made and used a super bomb only the natural gas at the top of the storage cavity would burn and the great amount of the liquified gas stored would stay cold and not burn because of the protection of the broken rock about it.

I claim:

1. A method for constructing the supports for the roof for a storage cavity storing a liquified hydrocarbon gas with a boiling point, at the lowest possible barometric pressure of the locality where the cavity is located, lower than the freezing point of pure water which comprises: ripping rock into smaller pieces, sieving the broken rock into at least two different sized fractions, piling the mentioned rock fractions in the storage cavity but with each fraction in different places from the other rock fraction, so that liquified hydrocarbons may be stored in the voids between the pieces of broken rock, and supporting the roof of the storage cavity on top of the broken rock placed in the cavity.

2. A method according to claim **1** in which the rock is ripped at a location less than 5 miles from a border of the completed cavity.

3. A method according to claim **1** in which the rock is ripped at a location less than one mile from a border of the completed cavity.

4. A method according to claim **1** in which the rock is ripped from a location over which the completed cavity is finally built.

5. A method according to claim 1 in which, for a rock fraction, the average maximum dimension on a weight basis of the minimum sized pieces is over 0.4 times the size of the average maximum dimension of the maximum sized pieces taken on a weight basis.

6. A method according to claim 5 in which the rock is ripped at a location less than 5 miles from a border of the completed cavity.

7. A method according to claim 5 in which the rock is ripped at a location less than one mile from a border of the completed cavity.

8. A method according to claim 5 in which the rock is ripped from a location over which the completed cavity is finally built.

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