Sept. 2, 1958 B. DYKSTRA 2,850,271

METHOD OF MINING SULFUR LOCATED UNDERNEATH BODIES OF WATER

Filed April 2, 1956 2 Sheets-Sheet 1

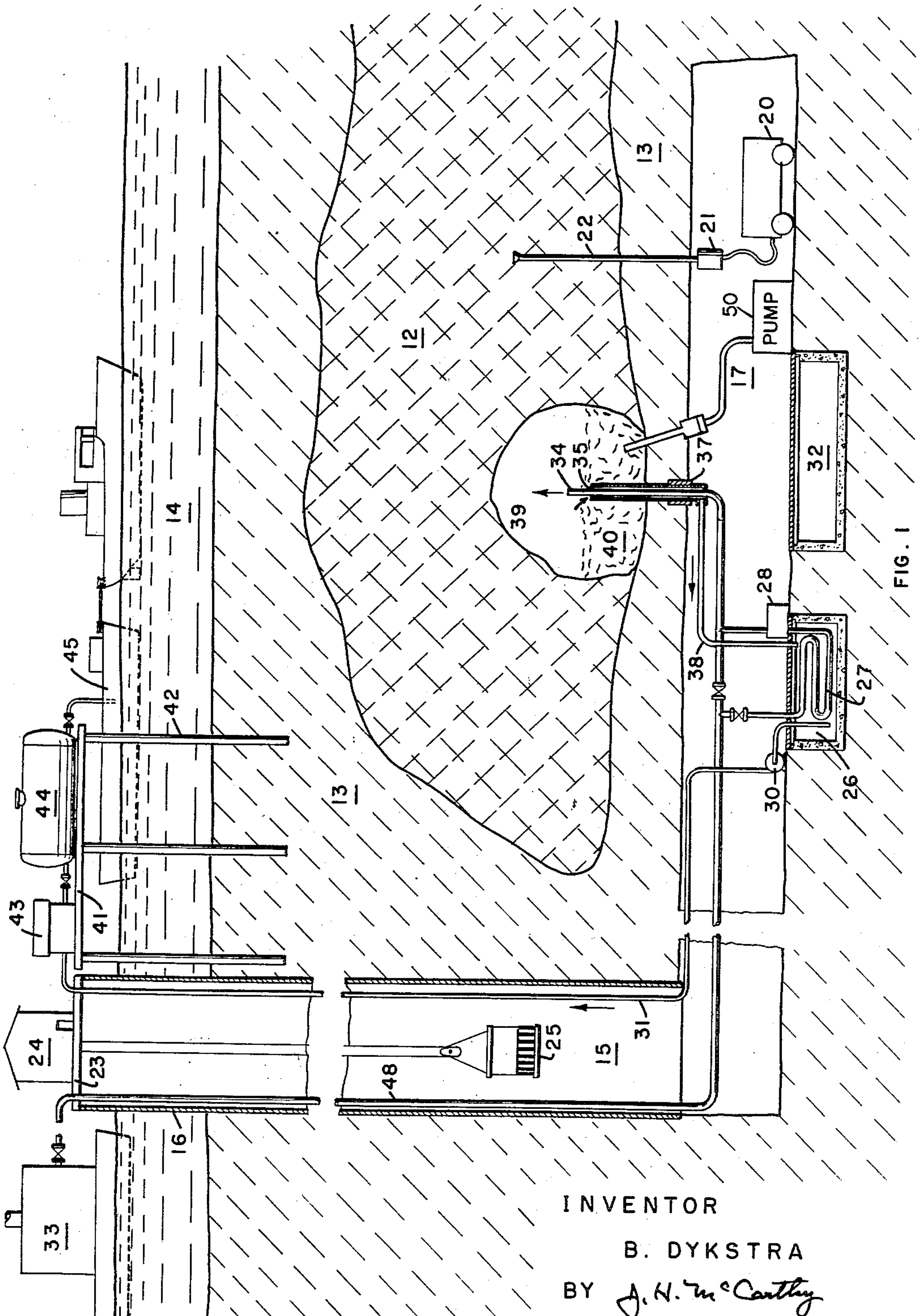

FIG. 1

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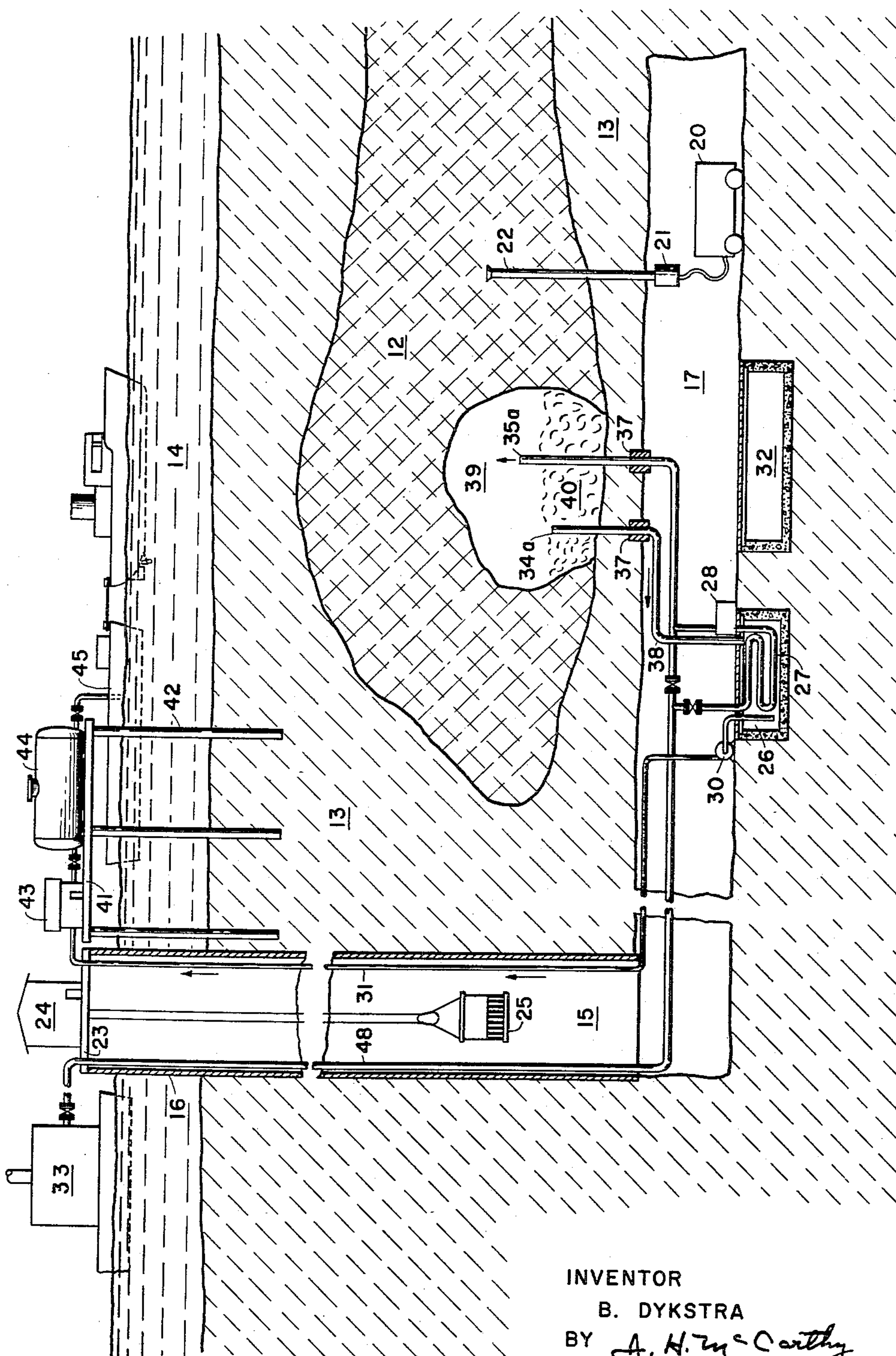

FIG. 2

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METHOD OF MINING SULFUR LOCATED UNDERNEATH BODIES OF WATER

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4 Claims. (Cl. 262—3)

This invention relates to the recovery of sulfur from earth formations and pertains more particularly to a novel method for separating and/or recovering sulfur from deposits located at considerable distances from the shore underneath bodies of water of relatively great depth.

Sulfur deposits of considerable size are believed to exist in many off-shore locations, such for example, as in the Gulf of Mexico, off the coast of Texas and Louisiana. The sulfur normally does not occur in continuous beds, but is found in the cavities, crevices and openings of limestone beds, from which it may be extracted by melting.

At present, sulfur is recovered from its underground deposits in the Texas-Louisiana area by employing the well known Frasch method. In this method, three or four concentric pipes are sunk through the earth and into the sulfur-limestone bed. Compressed air and high pressure steam are forced down the innermost pipes whereby the sulfur is melted from the limestone by the steam and then air-lifted up the outer concentric pipes. As the sulfur is removed from the limestone, the limestone takes on the appearance of honey-combed rock which has little structural strength and which is subject to periodic caving.

This method of mining sulfur has several serious drawbacks. Some of the defects inherent in seeking to conduct sulfur operations in the open waters are the lack of space for the type of machinery required, the lack of storage space and the fact that the operations are exposed to the elements. A companion to the last-named defect is the danger to personnel on an exposed platform.

To some extent, these defects are encountered by offshore oil and gas operators, but the drilling of oil and gas wells is sufficiently different to keep them from being serious obstacles in connection with oil and gas production, whereas, on the other hand, due to nature of operations for the production of sulfur, which require large steam plants together with heavy machinery and other equipment as well as storage space for produced sulfur, the difficulties encountered by the exposure to the elements while operating on the open water become a serious obstacle. One of the chief things accomplished by the subject invention is to provide ample working space in a subterranean cavity which is protected from the elements and from the danger inherent to operating in the open water. Ample room is afforded for the installation of all necessary machinery, living quarters for the men and storage space for tools and supplies as well as for sulfur which is produced.

It is therefore a primary object of the present invention to provide a method for recovering the sulfur from underground sulfur formations which are positioned offshore underneath a large body of water.

Another difficulty with the presently known method of mining sulfur is that after a portion of the sulfur has been removed from its bed, the weakened honey-combed limestone from which the sulfur has been removed, caves in and shears off the concentric pipes which have been sunk into the bed for removing the sulfur therefrom.

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After the bottom ends of the concentric pipes have been sheared off, it is necessary to re-drill the bed and to set new concentric pipes in the bed down to a lower level. Also, the continuous caving in of the limestone ore bed causes a gradual surface subsidence around the sulfur extraction pipes, which subsidence often takes the form of cracks in the formation and around the extraction pipes, through which much of the air, steam, and molten sulfur may be lost. The loss of these and other substances such as oil, gas, and mud probably present in the sub-soil strata may cause contamination of the sea water to the extent that marine life is endangered and beaches are spoiled. Subsidence of the underwater surface of the earth prohibits the drilling of additional wells since the water becomes deeper and destroys surface as well as sub-surface installations resulting in loss of investment and sulfur left unrecovered.

Therefore, another object of this invention is to provide a method for melting and recovering sulfur from an ore bed wherein the collapse of the surrounding limestone bed does not interfere with the extraction of the sulfur and does not necessitate the drilling of a new extraction borehole or the installation of new extraction equipment.

A further object of the present invention is to provide a method for recovering sulfur from underwater formations whereby the subsidence and cracking of adjacent formations are minimized.

It is another object of this invention to provide a method for obtaining samples of the sulfur as it exists without contaminating the sulfur or changing its physical state.

A further object is to minimize danger of contamination of surface waters by preserving the natural seal of the formations overlying the sulfur bearing limestone.

A still further object of this invention is to provide a method for filling cavities from which sulfur has been removed without interfering with the extraction of sulfur in the area.

These and other objects of this invention will be understood from the following description of the invention taken with reference to the drawings wherein:

Figure 1 is a sectional elevation of an offshore sulfur deposit from which sulfur is being removed in accordance with the method of the present invention; and

Figure 2 is a view similar to Fig. 1, showing a modification wherein the hot water is introduced and the molten sulfur withdrawn through separate pipes.

Referring to the drawings, an underground offshore sulfur deposit 12 is shown surrounded by competent formation 13 known as caprock. The caprock 13, formed predominantly by carbonates and sulfates, is the matrix in which the sulfur occurs.

While the water 14 may have any depth, the caprock may be covered with several hundred feet of sediment and mud (not shown). The caprock itself may extend several hundreds of feet in thickness above and below the sulfur deposit 12. It normally rests on the salt body of a salt dome (not shown). The commercial surful deposit 12 may vary greatly in thickness and in depth. It may cover only part of the areal extent of the salt dome which might be more than one square mile. The method of the present invention for recovering sulfur from underground offshore ore beds consists primarily in sinking one or more vertical shafts 15 into the ocean floor by any suitable means, as by sinking of caissons deep into the ocean floor and then mining or drilling the vertical shafts 15 to depth below the lowest point of the richest part of the sulful deposit 12. The vertical shaft 15 is appropriately lined either with metal or cement, so that the caissons nad the lining form a continuous well casing 16 which extends from well above the wave level of the ocean to the bottom of the shaft, which may be from 10 to 50 feet in diameter. It is essential that the shaft be terminated in competent formation, such as a caprock or salt.

One or more horizontal galleries or tunnels 17 are mined so as to extend from the vertical shaft 15 in a direction which will bring them below the sulfur bed 12. If desired, the roof, and sides of these horizontal galleries or tunnels 17 may be reinforced in any suitable manner, as with cement. All equipment to be used in the recovery of sulfur by the present method is lowered down the vertical shaft 15 and transported along the horizontal gallery or tunney 17.

In sampling the sulfur deposit 12, a compressor 20 may be positioned in the horizontal tunnel 17 for supplying air which may be used with a drilling apparatus 21 which is operated pneumatically, electrically, etc., and which is adapted to drive a bit or core barrel 22 up into the sulfur formation 12.

Since the bit or core barrel 22 is driven substantially vertically up into the sulfur deposit 12 and the compressed air is used to cool the bit or core barrel and remove the cuttings, the samples of the sulfur or sulfur containing ore may be readily recovered in gallery 17. Thus it is possible by the present method to sample a sulfur ore body and obtain representative samples of the ore by penetrating the deposit upwards from below. In this manner the drill stays in the caprock formation. It does not have to penetrate the porous sedimentary beds overlying the caprock which contain fluids that contaminate the samples.

The top of the well casing 16 is provided with an operating platform 23 on which a suitable housing 24 is positioned for equipment needed for mining operations.

Hoisting equipment is provided in the housing 24 for lowering a hoist cage 25 in the vertical shaft 15. All of the equipment necessary for the sulfur production is lowered through the vertical shaft 15 and is preferably positioned in recessed portions of the horizontal tunnel 17. For example, one or more of the sulfur storage bins 26 are cut in the tunnel floor. The bins 26 may be lined, if desired, as by cement or any metallic lining and are preferably provided with heating coils 27 for melting the sulfur if it becomes solidified in the bin.

The reheating coils 27 may be of the hot water circulating type and are operatively connected to distributor 28. One or more pumps 30 are provided for withdrawing molten sulfur from its storage bin 26 and pumping it up a discharge line 31 to the surface. Fresh water storage bins 32 are cut in the floor of the horizontal gallery 17 and are lined for containing the water to be used in the operations. Facilities to heat the water to be introduced in the formation are provided on pile-supported or floating surface equipment 33, or may be installed underground. If surface equipment is used, the heated water is pumped down shaft 15 through conduit 48 and forced into the formation melting the sulfur. Shaft 15 or other shafts connecting with the underground galleries are available to carry the pipe to circulate fresh or cooled air underground and exhaust used or heated air from below. Sulfur is recovered from the deposits by drilling vertically up through the roof of the horizontal gallery 17 into the sulfur deposit 12. Two concentric pipes 34 and 35 are sealed in a fluid-tight manner in the shaft by a suitable seal 37, which may be made of any suitable material such as a thermo-setting resin. The innermost pipe 34 carries the hot water to the sulfur bearing formation, while the outer pipe 35 is connected by means of a discharge conduit 38 with the sulfur storage bin 26.

As hot water is pumped into the sulfur bed 12, the sulfur is melted and separated from other matter, such as limestone and flows in a molten condition through conduits 35 and 38 to the storage bin 26. Since the mining is done from below, no air is needed to force the sulfur out of the mining cavity 39. A bed of collapsed limestone 40 is shown in the bottom of the cavity 39. This crumbled limestone is formed when the honeycombed limestone, from which the sulfur has been extracted, collapses under its own weight. However, in collapsing it does not shear pipes 34 nor does it plug these pipes in any manner since it is still sufficiently porous for molten sulfur to flow through. Thus, at this stage of the mining from cavity 39 in the sulfur bed 12, the concentric pipes 34 and 35 may remain in the position illustrated while sulfur removal is continued, or the innermost hot-water pipe 34 may be extended to a higher level in the cavity 39, if so desired. Alternatively, both of the concentric pipes 34 and 35 may be raised to a higher level before continuing operations. In some sulfur beds it will be found more desirable to extend the concentric pipes 34 and 35 to a level near the top of the sulfur bed 12 before starting sulfur recovery operations, and then gradually to lower said pipes as the top portion of the bed becomes melted and collapses.

At the time the limestone within the cavity 39 collapses to the position 40 shown in the drawing, the thickness of the competent formation or caprock 13 below the sulfur bin is sufficient to prevent any cracks forming in the formation around the pipes 34 and 35 so that no water or molten sulfur is lost down into the horizontal tunnel 17. At times, it is often desired to fill a cavity or a portion of a cavity from which sulfur has been extracted with a material adapted to lessen the subsidence of adjacent formations. This may be done in the present method by pumping a suitable slurry, such for example as a water and sand slurry, into the cavity by means of a pump 50. Sand used for this operation may be lowered down shaft 15 and may be obtained by dredging.

A platform 41 or platforms are preferably positioned on piles 42 adjacent to and over the shaft casing 16. Auxiliary equipment for the recovery of sulfur by the present method may be positioned on this platform 41, such for example as a pump house 43 and a heated storage tank 44. The hoisting equipment will be set on a large platform mounted over the top of the shaft casing 16. From time to time, the molten sulfur that accumulates in the storage bins 26 underground, or in the storage tanks 44 above the ground, is transported by means of a suitable barge 45 to its destination. Means can also be provided to pump the molten sulfur directly to the surface storage or barges.

While hot water could be introduced into cavity 39 and molten sulfur withdrawn therefrom through separate pipes 34*a* and 35*a*, as illustrated in Figure 2, which might separately extend into the cavity 39, the use of concentric pipes 34 and 35, as illustrated in Figure 1 of the drawing, is preferred as it reduces the cost of drilling additional holes up into the sulfur body 12. At the same time the steam pipe 34 mounted within the sulfur discharge pipe 35 furnishes sufficient heat to maintain the flowing sulfur in pipe 35 in a liquid condition.

I claim as my invention:

1. The method of extracting and recovering sulfur from a sulfur deposit surrounded by a competent formation submerged under water, said method comprising the steps of sinking a substantially vertical shaft into said competent formation to a point below the bottom of the sulfur deposit, installing a watertight casing from at least the top of said shaft to a point above the wave level of the water, forming at least one substantially horizontal tunnel from a point near the lower end of said shaft to the boundaries of said sulfur deposit at a level below said sulfur deposit in the competent formation, extending at least one small-diameter shaft upwards through said competent formation into sulfur body thereabove, installing a pair of pipes in said shaft in communication between said tunnel and said sulfur deposit, pumping hot fluid up one of said pipes into said sulfur deposit to melt the sulfur therein, flowing the molten sulfur down the other pipe to said tunnel

and removing the sulfur from the tunnel up said shaft to storage means at the surface.

2. The method of extracting and recovering sulfur from a sulfur deposit surrounded by a competent formation submerged under water, said method comprising the steps of sinking a substantially vertical shaft into said competent formation to a point below the bottom of the sulfur deposit, installing a watertight casing from at least the top of said shaft to a point above the wave level of the water, forming at least one substantially horizontal tunnel from a point near the lower end of said shaft to the boundaries of said sulfur deposit at a level below said sulfur deposit in the competent formation, extending at least one small-diameter shaft upwards through said competent formation into sulfur body thereabove, installing concentric pipes in said shaft in communication between said tunnel and said sulfur deposit, pumping hot fluid up one of said concentric pipes into said sulfur deposit to melt the sulfur therein, flowing the molten sulfur down the other concentric pipe to said tunnel, and removing the sulfur from the tunnel up said shaft to storage means at the surface.

3. The method of extracting and recovering sulfur from a sulfur deposit surrounded by a competent formation submerged under water, said method comprising the steps of sinking a substantially vertical shaft into said competent formation to a point below the bottom of the sulfur deposit, installing a watertight casing from at least the top of said shaft to a point above the wave level of the water, forming at least one substantially horizontal tunnel from a point near the lower end of said shaft to the boundaries of said sulfur deposit at a level below said sulfur deposit in the competent formation, drilling a sample core barrel through the roof of said tunnel into said sulfur deposit, sampling said sulfur deposit by gravity-removal of a sample through said core barrel, extending a small-diameter shaft upwards through said competent formation into sulfur body

thereabove, installing concentric pipes in said shaft in communication between said tunnel and said sulfur deposit, pumping hot fluid up one of said concentric pipes into said sulfur deposit to melt the sulfur therein, flowing the molten sulfur down the other concentric pipe to said tunnel, and removing the sulfur from the tunnel up said shaft to storage means at the surface.

4. The method of extracting and recovering sulfur from a sulfur deposit surrounded by a competent formation submerged under water, said method comprising the steps of sinking a substantially vertical shaft into said competent formation to a point below the bottom of the sulfur deposit, installing a watertight casing from at least the top of said shaft to a point above the wave level of the water, forming at least one substantially horizontal tunnel from a point near the lower end of said shaft to the boundaries of said sulfur deposit at a level below said sulfur deposit in the competent formation, extending a small-diameter shaft upwards through said competent formation into sulfur body thereabove, installing concentric pipes in said shaft in communication between said tunnel and said sulfur deposit, pumping hot fluid up one of said concentric pipes into said sulfur deposit to melt the sulfur therein, flowing the molten sulfur down the other concentric pipe to said tunnel, removing the sulfur from the tunnel up said shaft to storage means at the surface, and periodically filling the voids in the sulfur deposit with inert solid matter after the sulfur has been removed therefrom.

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