July 28, 1959 U. C. MARQUIS 2,896,931

MINING OF SULFUR BY LIQUEFACTION OF THE SULFUR

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FIG. 1.

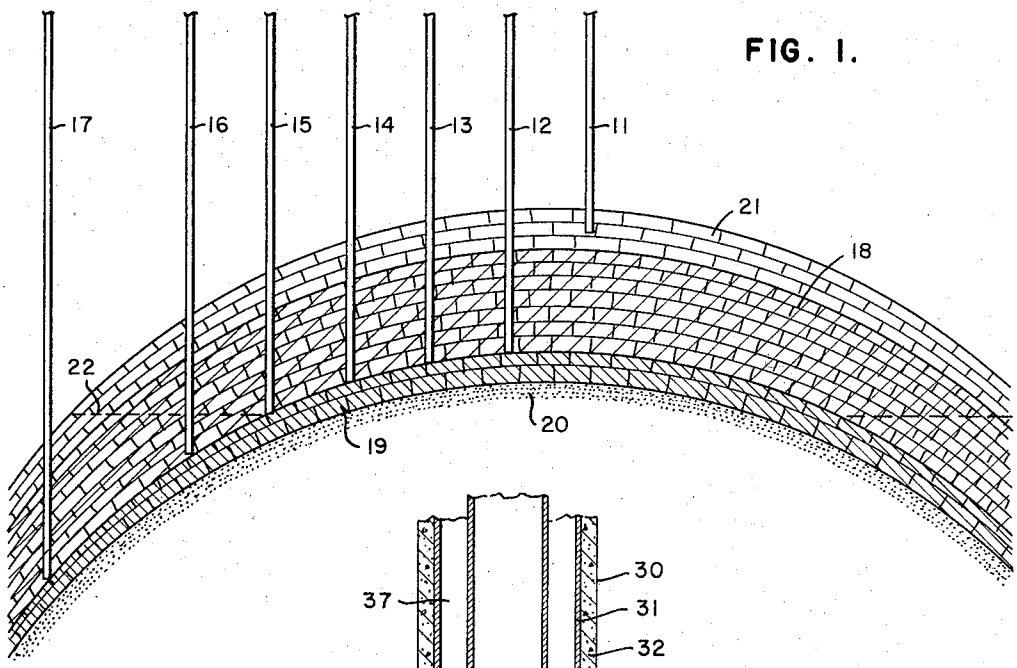
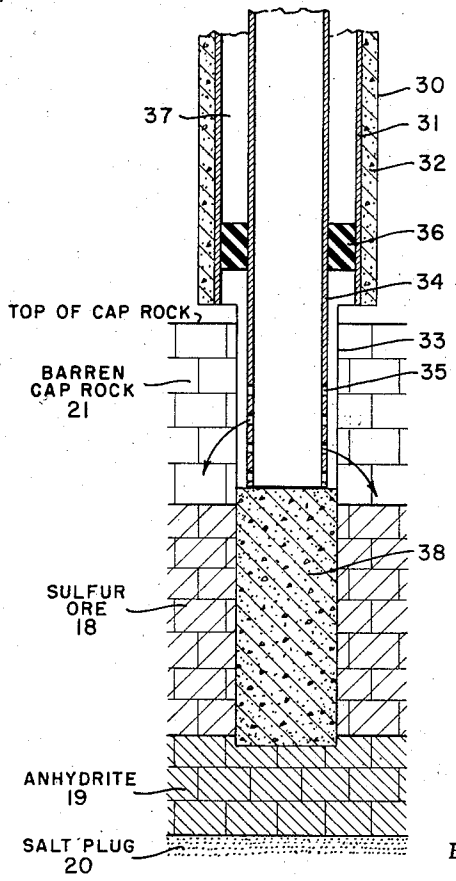


FIG. 2.



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FIG. 3.

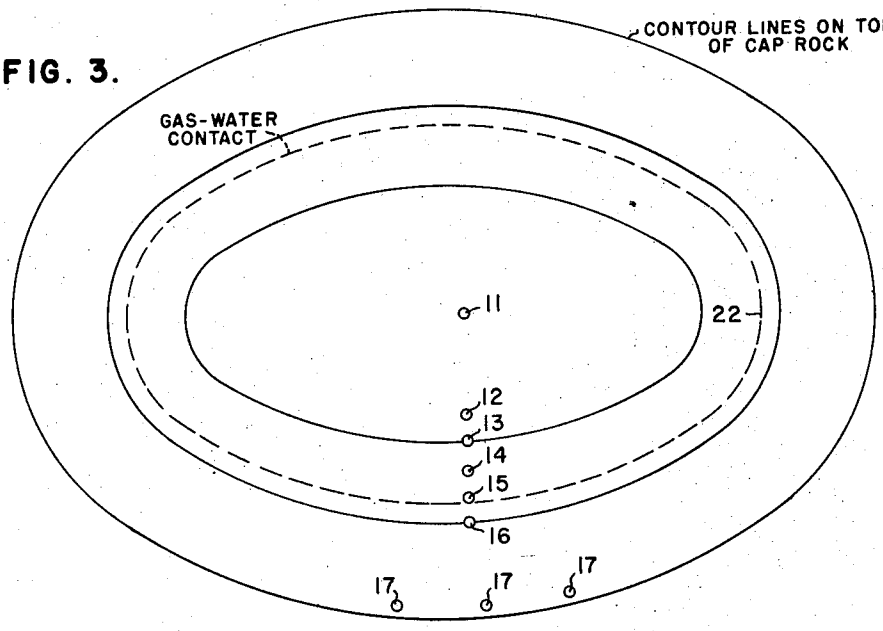
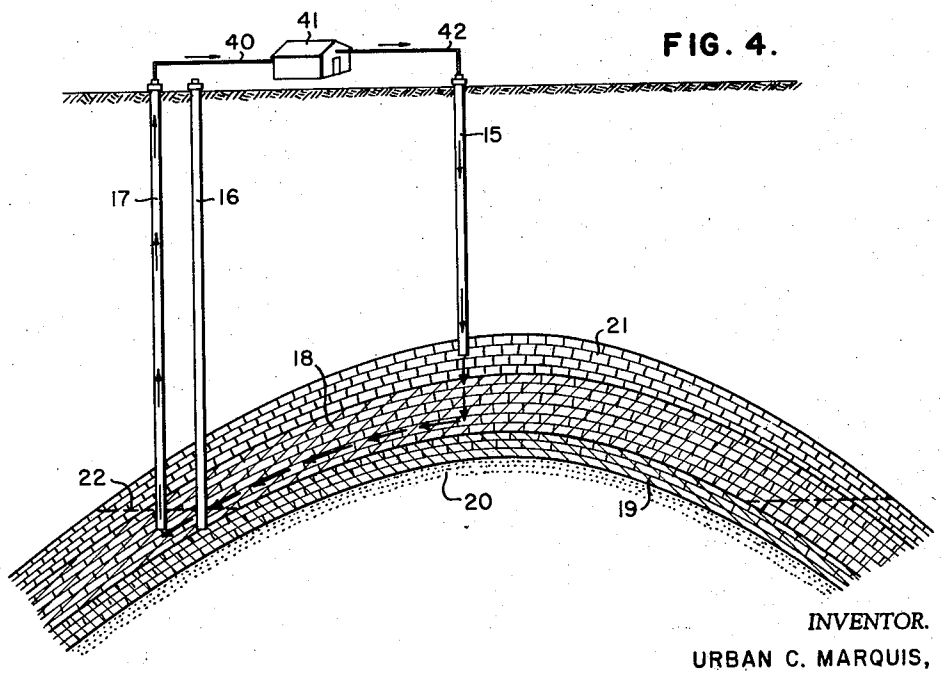


FIG. 4.



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MINING OF SULFUR BY LIQUEFACTION OF THE SULFUR

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Application January 22, 1958, Serial No. 710,516

4 Claims. (Cl. 262—3)

The present invention is directed to a method for mining sulfur. More particularly, the invention is directed to a method for mining sulfur in which substantially all of the sulfur available in a porous deposit is mined. In its more specific aspects the invention is concerned with the selective removal of sulfur from a porous sulfur deposit.

The present invention may be briefly described as a method for mining sulfur in which a sufficient amount of gas is introduced into the porous spaces of a cap rock and the underlying sulfur-containing formation of a porous sulfur deposit to displace substantially all of the water contained in said cap rock and in the sulfur-containing formation. Thereafter, the displaced water is removed from the cap rock and the sulfur-containing formation and hot water is injected at a temperature sufficient to melt sulfur in the gas-containing cap rock above the sulfur-containing formation such that the hot water drains down through the sulfur-containing formation liquefying the sulfur, and thereafter the liquefied sulfur is removed from the sulfur-containing formation.

Thus, the present invention comprises filling with gas or gases the pore space of both the barren limestone and the sulfur ore zone to be mined of a pressurable porous sulfur deposit. A gas-water level is established and maintained immediately below a horizon from which it is desired to mine sulfur, or immediately above a horizon from which it is desired to withdraw liquefied sulfur from the cap rock. This gas cap is formed by injecting gas into the porous cap rock at any desired point that permits movement of the gas to the crest of the cap rock structure and at the same time withdrawing cap rock water to provide space for the gas cap.

The present invention is of considerable advantage in that it provides control for distributing hot water to desired portions of the cap rock and may be applied directly to a localized area without appreciable loss of heat to undesired areas.

Moreover, the present invention dispenses with heating the cold formation water in the sulfur zone and the barren zone of the porous limestone cap rock. Porosities of the porous limestone cap rock approximate about 15 percent. As a result, with the practice of the present invention, less hot water is required to heat the gas filled cap rock to the desired temperature than is required in the prior art to heat the same cap rock filled with cold formation water. In short, the amount of hot water required and the number of B.t.u.'s required to liquefy a ton of sulfur in the formation is greatly reduced. Another advantage of the present invention is that initial sulfur production may be obtained in less time than that in conventional operations.

In the practice of the present invention four types of wells are drilled. One type is a gas injection well, another type is a hot water injection well, a third type is a sulfur production well, and a fourth type of well is a cold water bleed well. The gas injection well is drilled

for the purpose of injecting or withdrawing gas as required to maintain or control the desired mine pressure gas-water level. The hot water injection wells are suitably drilled up structure from the sulfur producing wells. The sulfur production wells are drill and completed down structure from the hot water injection wells and just below the gas-water level. The cold water bleed wells are located down structure from the sulfur production wells. These wells drain cold water from the lower part of the cap rock formation and when the production wells are at an intermediate level in the sulfur ore body, the warm water from the producing area preheats the lower sulfur zone for later production as it moves down structure towards the bleed wells.

The sulfur production wells may be drilled vertically or directionally, if desired, from beyond the subsidence area. Directional drilling from beyond the subsidence area and entering the sulfur zone at a low angle may be desirable since these wells would not be affected detrimentally by sloughing within the cap rock. As a result, the directionally drilled wells drain sulfur from a large area and may not be affected by sloughing of the cap rock and production from them may be obtained over a long period of time.

The practice of the present invention is especially applicable to recovering sulfur from shoulder and flank deposits where there is a large amount of porous barren cap rock above the sulfur deposit because, in the practice of the present invention, hot water is not lost up structure to the barren cap rock and cold water does not migrate into the mining area. In other words, the hot water is applied directly to the sulfur ore. Furthermore, the drainage pattern on the steep flank of the dome may be used to advantage by the improved method of producing sulfur to drain sulfur from a large area.

Inasmuch as the hot water employed in the practice of the present invention is used efficiently and contacts directly the rock containing the sulfur, the hot water need not be at the temperature usually employed in conventional sulfur mining. In other words, where a temperature heretofore from about 315° to 340° F. has been required, in the practice of the present invention a temperature in a lower range may be used. For example, a temperature from about the melting point of sulfur up to about 315° F. may be employed and may be preferred in the practice of the present invention with efficient mining of the sulfur, although I do not preclude the use of temperatures up to 340° F.

Another great advantage of the present invention is that essentially all of the sulfur in the ore body is recovered. In the prior art practice, residual splines of sulfur between sulfur wells are not recovered. In the practice of the present invention, with gas filling the cap rock pore space and with hot water heating the base of the sulfur ore body and the top of the underlying formation, the result is that all of the sulfur in the ore body is liquefied and essentially all of it drains to the production wells. Thus, a gas cap is introduced into the cap rock to liquefy sulfur in a gaseous rather than in a liquid medium so that the hot water is introduced into the top of the sulfur formation and gravitates down through the sulfur formation liquefying the sulfur as it penetrates the formation. The sulfur liquefies and drains down structure to the production well to be lifted to the earth's surface. Hot water is utilized effectively and efficiently in heating a desired or localized portion of the cap rock without requiring the heating of other or undesired areas.

The present invention will be further described by reference to the drawing in which:

Fig. 1 is a sectional view of a sulfur deposit over a salt dome penetrated by a plurality of wells;

Fig. 2 is a cross-sectional view of the hot water injection wells;

Fig. 3 is a view showing the arrangement of the wells of Fig. 1; and

Fig. 4 is a view illustrating the reuse of the hot injected water.

Referring now to the drawing, numerals **11**, **12**, **13**, **14**, **15**, **16** and **17** designate a plurality of wells drilled from the earth's surface, not shown. These wells are drilled to penetrate a sulfur-containing formation generally indicated by the numeral **18**. By sulfur-containing formation, it is understood that the barren cap rock and the actual sulfur-containing formation is designated. It will be noted that gas injection well **11** is drilled into the barren cap rock, while hot water injection wells **12** to **15** are drilled to the substantial base of the sulfur containing formation **18**, just above the layer of anhydrite **19** and are then plugged back to a desired depth above the sulfur-containing formation. The bleed well **17** is also drilled to just above the anhydrite formation **19**. The anhydrite and the sulfur-containing formation **18** overlie a salt plug **20**.

In the practice of the present invention, gas is introduced by well **11** to fill the barren cap rock designated by the numeral **21** and to fill the pores of the sulfur-containing formation **18**. This gas may suitably be a hydrocarbon gas, such as methane, ethane, or propane. However, other gases may be employed, such as air, nitrogen, and the like. It will be preferred to use a hydrocarbon gas, since the porous barren cap rock **21** and the sulfur-containing formation **18** may be used as a storage space for the hydrocarbon gas besides performing its function in the present invention. After the gas has been introduced, or as it is being introduced, cold water is withdrawn from the bleed well **17** to remove substantially all of the cold water from the cap rock **21** and the sulfur-containing formation **18** down to a gas-water interface generally indicated by the numeral **22**.

The gas-water interface is suitably maintained by regulating the rate at which the bleedwater is withdrawn at the bleed wells. The mine pressure within the gas filled portion of the cap rock is controlled by withdrawing or injecting gas through the gas injection well. At this point it is to be noted that the gas injection well is up structure to the hot water injection well and also that the hot water injection wells are up structure to the sulfur producing well, while the bleed water well is down structure from the remainder of the wells. Hot water is then introduced through one or more of the plurality of the wells to cause the sulfur to be liquefied and flow to the bottom of the porous formation and drain down structure on top of the impermeable anhydrite to sulfur production wells **16** where the liquefied sulfur is raised to the earth's surface. These sulfur production wells are completed in the conventional manner using three concentric strings of pipe which flow hot water downward through the large outer pipe and flow liquefied sulfur upward through the intermediate string and pumps compressed gas downward through the small inner string of pipe to jet the liquefied sulfur upward through the intermediate or production string. Wells **12**, **13**, **14**, and **15** illustrate wells which have been used as hot water injection wells to exhaust substantially all of the sulfur from the sulfur-containing formation **18**, while well **16** illustrates a well from which sulfur is being produced while injecting hot water therein, it being noted that the hot water causes the selective melting out of the sulfur within a limited radius of the well, but only below the gas-water interface and does not remove sulfur from the gas filled sulfur formation above the gas-water interface. By leaving the sulfur in the gas filled cap rock above this well, the formation remains strong and does not tend to slough as it would do if the sulfur were removed. Sloughing would damage the well equipment and consequently shorten the life of the well.

Referring now particularly to Fig. 2, numeral **30** designates a well bore of a hot water injection well, such as **12** to **15** of Fig. 1, in which a casing **31** is arranged and cemented in place with cement **32**. The well bore **30** is drilled to the top of the cap rock **21** and thereafter an open hole **33** is drilled to penetrate to the layer of anhydrite **19**. Arranged within the open hole **33** is a perforated liner **34** provided with perforations **35**. The liner **34** is arranged in a packer **36** which seals the annular space **37** between the casing **31** and the liner **34**. The open hole **33** below the liner **34** may suitably be plugged with cement **38**.

By virtue of providing an arrangement such as shown in Fig. 2, the liner **34** is free to move upwardly and downwardly within the packer **36** and yet maintain a seal, the hot water being injected into the cap rock **21** through the perforations **35** and trickling downwardly into the ore body **18**.

These hot water wells require no inner strings of tubing or complex wellheads such as currently used in sulfur production wells. If sloughing shears the liner, the well may be reworked and placed in use again because only the liner is involved and this may be replaced after cleaning out the hole. The liner may be divided into sections to strengthen it.

Referring now to Fig. 4, hot water introduced through well **15** causes sulfur production as has been described through well **16** with bleed water being removed through well **17**. This bleed water contains heat and may be returned by insulated line **40** to heating plant **41** and returned to well **15** by insulated line **42** for reuse as described. Thus, the temperature of the bleed water may be such that only sufficient heat in plant **41** may be required to raise its temperature by 50° to 70° F. for reinjection and reuse. In this particular embodiment, sulfur production wells **16** may be located adjacent bleed wells **17** to utilize the heat contained in the water for melting the sulfur and make it available for reuse. Also, as shown in Fig. 4, wells **16** and **17** are completed at approximately the same depth and the less dense hot water will circulate over the denser cooler water to well **17** for return to the surface as has been described.

It will be noted in the practice of the present invention that substantially all of the sulfur is depleted from the formation by employing the practice of the present invention without requiring the heating up of all the cold water originally in the formation.

The present invention is of considerable advantage and utility by virtue of the savings allowed in the mining of sulfur by using the particular technique described and claimed here.

The nature and objects of the present invention having been fully described and illustrated, what I wish to claim as new and useful and secure by Letters Patent is:

1. A method for mining sulfur which comprises injecting a sufficient amount of gas into the pore spaces of the cap rock and the underlying sulfur-containing formation of a porous sulfur deposit to displace substantially all of the water contained in said cap rock and the sulfur-containing formation, removing the displaced water from the cap rock and the sulfur-containing formation, injecting hot water at a temperature sufficient to melt sulfur into the gas-containing cap rock above the sulfur-containing formation whereby the hot water drains down through the sulfur-containing formation liquefying same, and removing liquefied sulfur from the sulfur-containing formation.

2. A method for mining sulfur which comprises injecting a sufficient amount of gas into the pore spaces of the cap rock and the underlying sulfur-containing formation of a porous sulfur deposit to displace substantially all of the water contained in said cap rock and

the sulfur-containing formation and to form a gas-water interface immediately below a horizon from which sulfur is to be mined, removing the displaced water from the cap rock and the sulfur-containing formation, injecting a sufficient amount of hot water at a temperature sufficient to melt sulfur into the gas-containing cap rock above the sulfur-containing formation whereby the hot water drains down through the sulfur-containing formation liquefying same, and removing liquefied sulfur from the sulfur-containing formation, said gas-water interface being maintained by controlling the amount of gas and water in said cap rock and said sulfur-containing formation.

3. A method for mining sulfur which comprises drilling a plurality of at least 4 wells into a porous sulfur deposit, at least a first of said wells being drilled into the cap rock, at least a second of said wells being drilled into the sulfur-containing formation of said deposit down structure from the first well, at least a third of said wells being drilled into said deposit down structure from the second well, and at least a fourth of said wells being drilled into said deposit down structure from the third well, injecting a sufficient amount of gas into the pore spaces of the cap rock and the underlying sulfur-containing formation of the porous sulfur

deposit through the first well to displace substantially all of the water contained in said cap rock and the sulfur-containing formation and to form a gas-water interface below a horizon from which sulfur is to be mined, removing the displaced water from the cap rock and the sulfur-containing formation through the fourth well, injecting a sufficient amount of hot water at a temperature sufficient to melt sulfur into the gas-containing cap rock above the sulfur-containing formation through the second well whereby the hot water drains down through the sulfur-containing formation liquefying same, and removing liquefied sulfur from the sulfur-containing formation through the third well, said gas-water interface being maintained by controlling the amount of gas and water in said cap rock and sulfur-containing formation.

4. A method in accordance with claim 3 in which the hot water is at a temperature in the range between the melting point of sulfur and about 315° F.

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