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[54] METHOD OF WITHDRAWING HAZARDOUS GASES FROM SUBTERRANEAN FORMATIONS

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[58] **Field of Search** 299/2, 12; 98/50; 166/268, 314

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[57] ABSTRACT

Disclosed herein is a method for withdrawing hazardous gases from a water saturated subterranean formation containing a minable mineral deposit. In the method, wells are drilled through the subterranean formation and water is withdrawn from the subterranean formation to establish permeability to gas within the subterranean formation. Gas is then withdrawn from the formation by means of the wells. This method has particular applicability in reducing the influx of radon into a mine contained in a mineral deposit.

6 Claims, No Drawings

METHOD OF WITHDRAWING HAZARDOUS GASES FROM SUBTERRANEAN FORMATIONS

BACKGROUND OF THE INVENTION

1. Field of the Invention

This invention relates to the use of wells to withdraw fluids from a subterranean formation. More particularly, this invention relates to a method for reducing the influx of hazardous gases into mine workings in a water saturated subterranean formation by withdrawing water from the subterranean formation until permeability to gas is established within the formation.

2. Description of the Prior Art

Many naturally occurring substances such as coal, metal ores, and the like, are obtained from subterranean formations by mining which can present a variety of problems. One problem of wide occurrence in mining these mineral deposits is the influx of gases into the mine shafts and drifts within the subsurface formation. Gases such as methane, hydrogen sulfide, and radon can be particularly hazardous to the mine workers. They can lead to explosions, asphyxiation of the miners, and poisoning, including radiological poisoning.

Radon gas can be a serious problem. While radon itself is relatively harmless, it is naturally radioactive and its decay products are believed to be cancer producers. It has been noted that there is a high incidence of lung and bronchial cancer in miners working in environments containing radon gas. As a result of these studies of the effects of radon gas, it is now required that the concentration of this gas and its decay products in the mines be reduced to permissible levels or the period of exposure by miners be shortened. Although radon is generally associated with the mining of radioactive ores, such as uranium deposits, it can also be associated with the mining of other minerals. In other words, this problem is not limited solely to the mining of radioactive ores but can be more widespread.

A number of methods have been used or suggested to combat the problem of hazardous gases, including radioactive gases such as radon, in mine workings. One such method is forced air circulation. In this method ventilation shafts are sunk to the mine drifts; air is drawn in one or more inlet shafts, circulates through the mine workings, and discharges through one or more exit shafts. The means employed for circulation of air in such a method are generally fans which are employed as a means of suction or discharge for the circulating air. This method simply reduces the concentration of the gases within the mine. It does nothing to prevent the initial entering. Moreover, the method has detrimental side effects; it increases the problem of airborne particles or dust within the mine drifts. This in itself can be a health hazard. Also, where the forced air circulation system employs only discharge fans, the influx of gases into the mine workings can actually be increased. In such a system, the pressure within the mine is reduced which increases the tendency of the gases to diffuse from the subterranean formation into the mine working.

It has also been suggested that a positive pressure be maintained within the mine working to reduce the influx of hazardous gases. It has been shown that moderate increases in the air pressure within the mine can reduce the quantity of gas that will enter the mine by diffusion. However, this method presents the very practical problem of maintaining an adequate pressure seal within the mine. In addition, positive pressure maintenance can be a short-term benefit. As the air which is introduced into the mine diffuses into the matrix of the minable deposit, the pressure between the mine and deposit will tend to equalize. Once these pressures are equalized, the gas will once again diffuse into the mine.

Another suggestion that has received some attention is the use of core holes around the minable deposit to create a pressure sink and thereby establish a pressure gradient within the formation to cause the flow of gas away from the mine and toward the core holes. In the suggested method, suction would be applied at the core holes to lower the pressure at these locations and thereby increase the differential pressure between the mine and the core holes. While the suggested method appears to have some merit in dewatered subterranean formations having a high permeability to gas, it would be generally inapplicable to the more common situation where the subterranean formation has a high water saturation and a corresponding low permeability to gas.

DESCRIPTION OF THE INVENTION

This invention has general applicability to the problem of gas influx into mines which have been sunk into mineral deposits within subterranean formations. However, for convenience, and to assist in the understanding of the invention, it will be described in terms of a specific problem — radon gas influx into a mine in a uranium deposit.

Prior to discussing the invention in detail, it may be helpful to discuss the problems associated with radon gas. Radon is an inert gas which is produced by the natural disintegration or decay of radioactive substances. Its most commonly occurring isotope, Radon–222, is produced in the earth as the result of a very slow radioactive decay in a series of isotopes beginning with Uranium–238, the principal isotopic component of natural uranium. The radioactive decay series begins with Uranium–238 and proceeds ultimately to the formation of stable (non-radioactive) Lead–206. For the purposes of this discussion, the portion of the uranium decay series of interest begins with Radium–226 and continues through Polonium–214. This portion of the uranium disintegration series including the common name of the decay products, the name of the isotope, the principal radiations of the decay, and the half life of each of the decay products is shown below in Table I.

TABLE I

Common Name	Isotope	Principal Radiations	Half Life
Radium	Radium–226	Alpha	1,622 years
Radon	Radon–222	Alpha	3.825 days
Radium A	Polonium–218	Alpha	3.05 minutes
Radium B	Lead–214	Beta and Gamma	26.8 minutes
Radium C	Bismuth–214	Beta and Gamma	19.7 minutes
Radium C′	Polonium–214	Alpha	2.73×10^{-6} min.

It is recognized that from a health standpoint the short-lived alpha energy emitters in the uranium decay series are of primary concern. As was previously stated, Radon–222 is not particularly hazardous in and of itself. Radon is chemically inert and is gaseous under ordinary conditions. Because of these characteristics and its relatively long half life, radon can be inhaled and exhaled before it is able to emit any appreciable amounts of alpha energy. The decay products of radon, the so-called radon daughters, are clearly more hazardous. These substances have the tendency to interact with dust particles within a mine. When the mine air is breathed, a portion of the dust is trapped in the respiratory system and when the attached radon daughters decay, the soft lung tissue is irradiated by the alpha particles emitted. Of the radon daughters, Radium A and Radium C′ are particularly hazardous since they are alpha particle emitters and have relatively short half lives.

Because of the chemically reactive nature of the radon daughter products, they are unlikely to travel through the matrix of the mineral deposit and into the mine atmosphere. Radon–222 being gaseous and chemically inert is much more likely to reach the atmosphere of the mine workings than its daughter products. The radon then decays within the mine atmosphere to form the more hazardous radon daughters.

There are three principal mechanisms by which radon can enter the open working spaces of a mine. These mechanisms include gaseous diffusion, dissolved gas contained in water flowing through the mineral deposits and into the mine, and emanation from freshly exposed mine wall surfaces and crushed ore.

Where the mineral deposit is porous and permeable to gas, the chemically inert and relatively long-lived radon gas has the ability to diffuse through the interstices of the mineral deposit and into the mine working. The rate of radon influx is dependent among other things on the permeability of the deposit to gas, the concentration of radon existing within the mineral deposit, the concentration existing within the open atmosphere of the mine, and the pressure differential existing between the mine atmosphere and the mineral deposit.

In additon, radon enters the mine by emanation from freshly exposed mine surfaces and broken ore. When a mine wall has been exposed to the atmosphere of the mine for an appreciable period of time, the radon concentration within the mineral deposit will be low near the wall of the mine and will increase with distance away from the wall. When a new wall is formed by mining into the mineral deposit, the portion of the deposit containing a higher concentration of radon is exposed to the mine atmosphere. Thus, the newly exposed mine wall will have a higher tendency to emanate radon into the mine atmosphere.

Radon can also enter the mine in solution in water flowing into the mine. If the pore spaces of the mineral deposit are filled with water, radon gas emanating from the host crystal will go into solution in the water and its concentration in this water will be approximately equal to the concentration which would be present if the void had been filled with air. Because the flow of water toward and into the mine may be more rapid than the diffusion process which occurs in the dry deposit, the net transport of radon into a wet mine may be greater than into a dry mine where the major transport mechanism for radon is gaseous diffusion.

Radon carried into the mine workings by water is released almost completely to the air in the workings. By application of Henry's Law for the solubility of gases in liquids and Dalton's Law of partial pressure of gases, it can be shown that the distribution coefficient ratio for radon between air and water is approximately 3.0 for the temperatures normally prevailing in mine workings. As the radon-ladened water flows into and through the mine, it can release radon until the concentration in the air above the water is about three times the radon concentration in the water. Since the equilibrium concentration of randon in water within the pore spaces of the deposit can be several thousand times greater than a tolerable concentration level in the mine atmosphere, the percentage of the radon carried by the water that is released to the air within the mine at equilibrium is very nearly 100 percent. At this point it should be noted that the transport of radon gas by water flowing into a mine can be a severe problem, even though the mineral deposit being mined is not radioactive. A high incidence of lung cancer has been noted in miners in a fluorspar mine in Newfoundland and has been attributed to radon and its decay products. However, no appreciable quantities of radioactive substances were present in the deposit being mined; the radon was apparently carried into the mine in ground water.

The influx of hazardous gases including radon into a mine can be radically reduced through the practice of this invention. In the practice of this invention, a plurality of wells are drilled from the surface of the earth to a point below the subsurface formation containing the mineral deposit. These wells and their operation serve a number of purposes, all of which are directed to the primary function of reducing the influx of hazardous gases into a mine working. The wells are used to withdraw water from the formation to establish permeability to gas between the location of the mine and the wells. The withdrawal of this water from the subterranean formation also reduces the quantity of water containing dissolved gas which might otherwise enter the mine. A vacuum is also applied to the wells to cause the flow of gas from the location of the mine workings to the wells once permeability to gas has been established. Flow of the gas in this direction will of course reduce the quantity of gaseous influx into the mine workings.

The wells used in the practice of this invention may be of a conventional type having a bore hole which is lined with a large diameter metal conduit or casing and a string of smaller diameter pipe or tubing disposed within the casing string. Preferably the tubing hangs free in the hole. That is to say, no packer would be employed in the annular space between the casing and the tubing, thus there would be fluid communication between the subterranean formation and the surface of the earth by means of the annular space between the tubing and the casing as well as through the tubing string itself. The tubing string should extend to a point below the bottom of the subterranean formation to permit depression of the fluid level in the well to a point below the bottom of the subterranean formation, if desired.

The wells employed in the practice of this invention will be spaced around the periphery of the area to be mined within the mineral deposit. The location of the mineral deposit is generally determined by coring from the surface of the earth to determine the concentration of the ore at that location. Taking into consideration such economic factors as the depth of the subterranean formation, transportation costs, processing costs and the like, an economic limit is established for the minimum concentration of ore which is considered to be minable. Taking these factors into consideration as well as known principles of mining engineering, the expected location of the mine workings within the deposit can be determined. Where the minable deposit is small and the expected mine workings are not extensive, withdrawal wells can be drilled which will substantially surround the area to be mined. Where the deposit is more extensive and the mining is to be done in stages, it may be preferable and more economical to drill the withdrawal well in stages. That is, an initial set of withdrawal wells would be drilled around the periphery of the initial area to be mined and additional withdrawal wells would be drilled as the mine workings are extended.

The number of wells to be drilled around the periphery of any area to be mined can be determined using known principles of fluid hydraulics and the flow of fluid through porous media. Naturally, the maximum benefit could be attained by surrounding the area to be mined with wells which are spaced as closely to one another as possible. However as a practical matter fewer wells are employed in the practice of this invention. It has been estimated that **16** wells evenly spaced on the circumference of a circle having a radius of 3,500 feet will withdraw two-thirds of the theoretical maximum amount of fluid which could be withdrawn from a subterranean formation by an infinite number of wells on the circumference of this circle.

In the operations of the wells, water is withdrawn from the wells by suitable means such as pumping through the tubing. The tubing of course is in fluid communication with the mineral bearing deposit by means of perforations through the casing, setting the casing above the mineral bearing deposit, the use of a slotted liner at the location of the mineral deposit or the like. The tubing should extend beneath the bottom of the mineral bearing deposit and the pump will be set within the tubing at or near its bottom. This will permit the pumping fluid level within the well to be depressed beneath the bottom of the deposit to expose the entire deposit interval to air within the tubing-casing annulus.

It will of course be preferred to expose the entire deposit to air during the pumping-dewatering operation. However, it should be understood that this is not absolutely necessary to the practice of this invention. Some benefit can be realized if only a portion of the deposit is exposed to air.

During the preliminary pumping, the tubing-casing annulus at the surface is preferably open to the atmosphere. This will permit air to travel down the tubing-casing annulus and enter the mineral deposit as it is being dewatered by the pumping operation. At this point it should be noted that a porous and permeable formation which is saturated with water, as is the instance in many deeply buried mineral deposits, is not permeable to gas. Until the gas saturation within the formation reaches some finite value, gas cannot flow through the formation. However, in the preferred manner of practicing this invention, water is withdrawn from the formation by means of the wells and simultaneously air is introduced into the formation by means of the tubing-casing annulus of the well. After operating in this manner for a period of time, permeability to gas can be established within the area of interest in the subterranean formation.

Preferably, the dewatering-pumping operation should start prior to opening the mine shaft within the deposit. If it is possible to pump for a sufficient period of time prior to opening the mine drift, the formation will have permeability to gas between the mine locations and the wells at the time the mine drift is opened. This initial permeability to gas will permit the flow of air from the mine atmosphere, through the deposit, and to the wells when the drift is first opened. In this manner the quantity of hazardous gases which would enter the mine when it was first opened would be reduced since there would be an immediate counterflow of air through the deposit which would reduce the diffusion of gas into the mine. Also since the flow path for the gas would be dewatered, less water would flow into the mine with entrained or dissolved gases.

This preliminary pumping is of course determined by conditions existing at the time the pumping is initiated and economics. For example, preliminary pumping quite naturally could not be accomplished where the mine existed prior to drilling the withdrawal wells. This condition would prevail in many older mines. In those mines where permeability to gas cannot be established prior to opening the drift, the quantity of air used for ventilating the mines will be initially at a higher level to reduce the concentration of hazardous gases within the mine atmosphere. Once permeability to gas is established between the mine and the wells, however, the quantity of ventilation air within the mine can generally be reduced.

In those cases where the mine drift is opened within the deposit prior to establishing gas permeability between the mine and the wells, the mine itself can serve as a source of air to establish gas permeability. This air from the mine can be used in supplement to or in lieu of air which is introduced through the wells.

Once permeability to gas has been established within the subterranean formation between the wells and the mine location, a vacuum is applied to the tubing-casing annulus. The purpose of establishing the vacuum within the tubing-casing annulus is to create a differential pressure in the gas phase within the subterranean formation between the mine location and the wells. This differential pressure will cause the gas to flow from the mine to the wells and thereby reduce the influx of hazardous gases into the mine atmosphere.

The vacuum can also be applied prior to establishing gas permeability within the formation; however, in such a case no appreciable amount of gas will flow from the formation until there is a continuous gas phase existing between the mine and the wells which will thereby establish permeability to gas between these locations.

The magnitude of the vacuum which is applied to the annulus may vary depending upon the number of wells employed around the minable deposit and the pressure within the atmosphere of the mine. Water will continue to be withdrawn from the well during the periods the vacuum is applied to further dewater the formation and reduce its influx into the mine.

It is interesting to note that there can be a substantial reduction in the total influx of hazardous gases into a mine working with a relatively small countercurrent flow of air at the mine wall. For example, with air moving at a velocity of 2 feet per day the flux of radon into a mine can be reduced to approximately one-third of the level which would exist with no countercurrent air flow. With this countercurrent air velocity increased to 4 feet per day, the flux of radon can be reduced to approximately 20 percent of the level which would otherwise exist. Further increases in the countercurrent air flow produce lesser results; the diffusional flux of radon into the well would still be at five percent of the level which would otherwise exist with a countercurrent air flow velocity of 14 feet per day.

EXAMPLE

The benefits of the practice of this invention can perhaps best be shown by considering an example mine working within a subterranean formation. The mineral deposit in this instance is uranium ore contained in four sand bodies separated by impermeable shale barriers. The top of the uppermost of the four sand bodies is 400 feet below the surface of the earth and the bottom of the lowermost sand lies approximately 600 feet below the surface. The water table at the location of the minable deposit is approximately 270 feet below the earth's surface and each of the uranium bearing sands is initially saturated with water. The average porosity of the sands is approximately 30 percent and the sands have an average horizontal permeability to water of 460 millidarcies.

It has been determined that the minimum concentration of uranium which can be economically mined is approximately 0.05 weight percent U_3O_8. (U_3O_8 is a conventional expression used to describe a mixture of uranium oxides.) From cores taken from these subterranean deposits, it has been determined that the ore body is roughly circular in horizontal cross section, and that the minable ore containing at least 0.05 weight percent U_3O_8 is in an annular ring within this circle. The innermost limit of minable ore is approximately 1,750 feet from the center of the deposit and the outermost limit is approximately 3,500 feet from this center.

Sixteen wells are drilled around the deposit at approximately uniform spacing and at distance of approximately 3,500 feet from the center of the deposit. The wells are drilled to a depth of 675 feet and completed in a conventional manner with the casing set at 650 feet. The tubing string extends to a depth of 625 feet and the casing is perforated opposite each of the sand bodies to establish fluid communication between these sands and the interior of the casing.

Using known principles of mining engineering it is determined that the optimum method of mining the annular deposit is to sink a shaft at the center of the deposit and extend drifts from the shaft to the minable ore. Lateral shafts would then be used to withdraw the high-grade ore from the sand bodies.

Pumping of the withdrawal wells is started two years prior to developing the lateral drifts within the minable ore deposits. After two years of withdrawing water from the ore bearing sand bodies, permeability to gas has been established in these sand bodies throughout the circular deposit. At this time a lateral drift having a length of 1,400 feet and a rectangular cross section of 10 feet by 6 feet is opened at atmospheric pressure in the high-grade ore deposit. Table II shows the estimated radon influx in curies per day into this mine working under various conditions.

TABLE II

	Radon Influx, Curies/Day	
	By Solution in Water	By Gaseous Diffusion
After 1 Year of Mining		
Without Wells	0.294	0.107
Wells at Atmospheric Pressure	0.181	0.104
Wells with 4 psi Vacuum in Annulus	0.164	0.035
After 5 Years of Mining		
Without Wells	0.221	0.141
Wells at Atmospheric Pressure	0.082	0.115
Wells with 4 psi Vacuum in Annulus	0.057	0.020

As can be seen from Table II, the practice of this invention can result in radical decrease in radon influx into a mine. After 1 year of mining, the rate of radon influx into a mine by solution and gaseous diffusion is approximately one-half of the influx which would exist in the absence of the withdrawal wells with vacuum. After 5 years of mining, the radon influx of wells operating with the 4 psi vacuum in the annulus is less than one-fourth of the radon influx in the absence of such wells. Moreover, there is an even more pronounced reduction in the radon influx due to gaseous diffusion by the practice of this invention. As can be seen from Table II, after 5 years of mining without wells the radon influx by gaseous diffusion has actually increased. However, with the wells operating at a vacuum the rate of gaseous diffusion into the mine decreases to a level which is less than 15 percent of the amount diffusing into the mine in the absence of withdrawal wells.

The principle of the invention and the best mode in which it is contemplated to apply that principle have been described. It is to be understood that the foregoing is illustrative only and that other means and techniques can be employed without departing from the true scope of the invention as defined in the following claims.

What is claimed is:

1. A method of reducing the hazard to miners from the danger of hazardous gases which are produced from a water saturated subterranean formation containing a mineable mineral deposit and which is penetrated by a plurality of wells, said wells being in pressure communication with said mineral deposit through said subterranean formation, which comprises withdrawing water from and injecting air into said subterranean formation by means of said wells to establish permeability to gas within said mineral deposit, and withdrawing hazardous gases from said mineral deposit by means of said wells.

2. A method as defined in claim **1** in which air is introduced into said subterranean formation by means of said wells while water is withdrawn from said formation.

3. A method as defined by claim **1** wherein water is withdrawn from said subterranean formation while said hazardous gas is being withdrawn from said subterranean formation.

4. A method as defined in claim **1** further comprising opening a mine working within said mineral deposit subsequent to establishing permeability to gas within said subterranean formation and introducing air into said mine working at a pressure greater than the pressure existing at said wells to cause the flow of air and hazardous gases from the mine to said wells.

5. A method of ventilating a mine in a mineral deposit contained in a water saturated subterranean formation comprising drilling a plurality of wells into said subterranean formation in locations which are offset from said mine, said wells being in pressure communication with said mine by means of said subterranean formation, withdrawing water from said subterranean formation by means of said wells to establish permeability to gas within said subterranean formation between said mine and said wells, introducing air into said formation, withdrawing hazardous gas from said formation by means of said wells, and introducing air into said mine working at a pressure greater than the pressure existing at said wells to cause the flow of air and hazardous gases from the mine to the wells.

6. A method of reducing the influx of radon into a water saturated mineral deposit within a subterranean formation which comprises drilling a plurality of wells into said subterranean formation at locations which are spaced from a mine location within the mineral deposit, said wells being drilled to a depth below the subterranean formation and having a casing string, a tubing string extending below the bottom of the subterranean formation, an annular space defined by the tubing strings and casing strings which is in fluid communication with the subterranean formation, and pumping means disposed within the tubing string, withdrawing water from the formation by means of the pumping means and tubing, introducing air into the formation until permeability to gas is established within the water saturated mineral deposit, withdrawing gas containing radon from the formation by applying a vacuum to the annular space, and continuing to withdraw water from the formation through the tubing to maintain a pumping fluid level within the annular space which is below the top of the formation.

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