PROCESS FOR MINING SULPHUR

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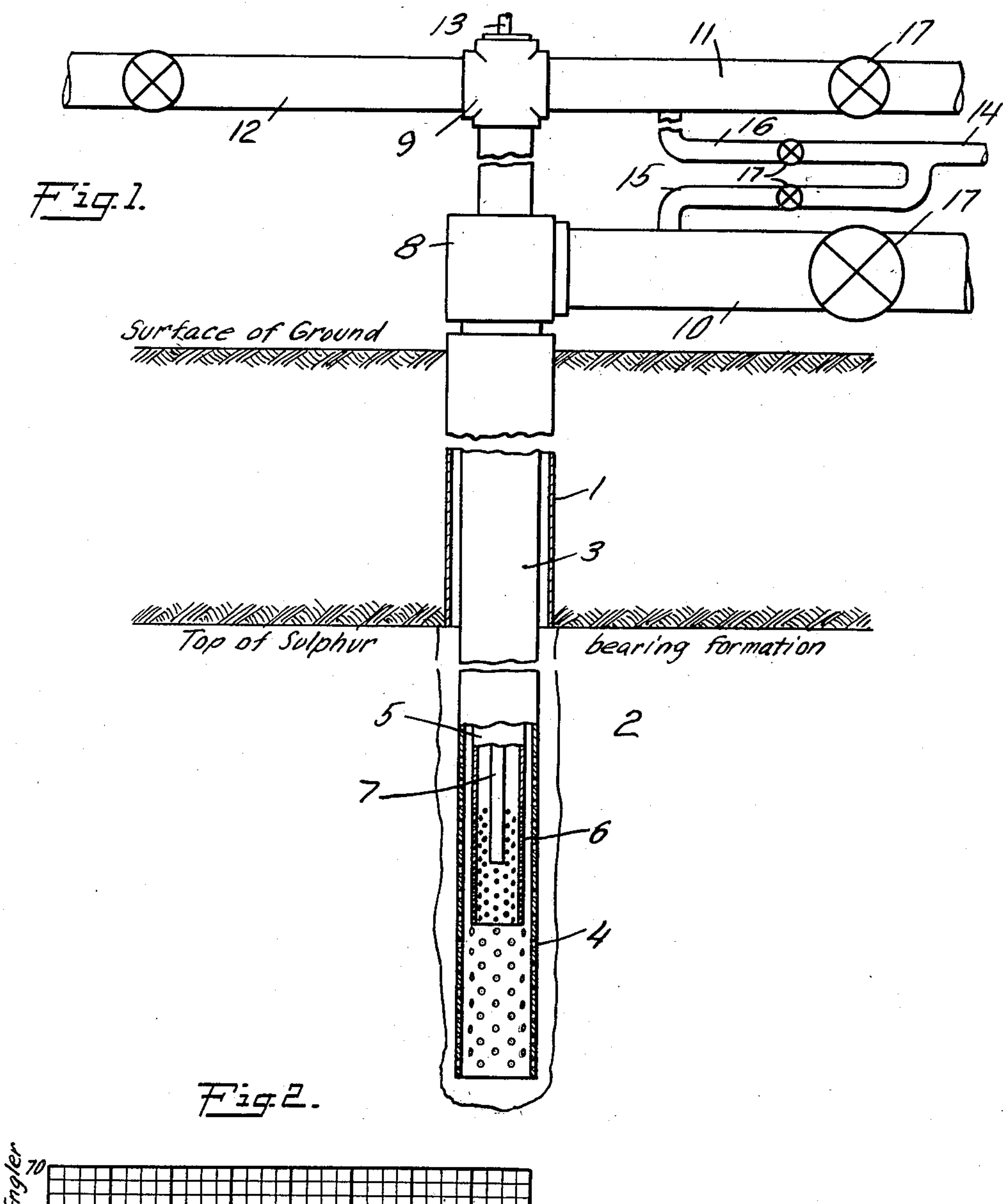

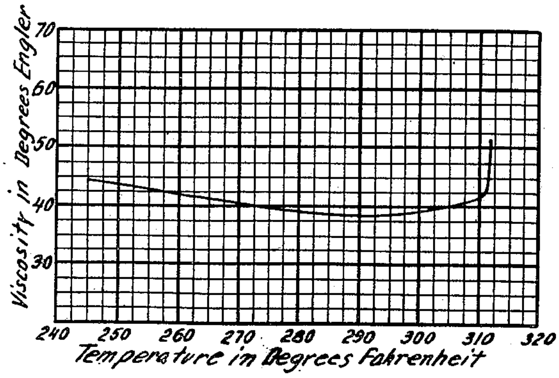

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PROCESS FOR MINING SULPHUR

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Our invention relates to the method of mining sulphur by what is known as the Frasch, or underground fusion process, and is an improvement thereon.

The purposes of the invention are manyfold. To control the viscosity of the molten sulphur as it is lifted from the well, to increase the rate of production of sulphur from the well, to increase the amount of hot water which may be pumped into the well while it is producing, to enable a number of wells, each requiring a different temperature for maximum production, to be operated simultaneously from one source of hot water supply, and to increase the efficiency, output and convenience of operation of the power-and-water-heating plant which serves the mining area.

In the drawing Fig. 1 represents one form of application of our invention and Fig. 2 shows graphically the relation existing between the viscosity and the temperature of molten sulphur.

In the mining of sulphur by the Frasch process it is customary to drill a hole from the surface of the ground to the top of the rock containing or covering the sulphur-bearing formation. Within this hole is set a liner or casing (1) for the purpose of preventing the caving-in of the earthy material surrounding the hole. Below the surface of the rock on which this liner or casing is set the hole is continued into and through the sulphur-bearing formation (2) and into the rock underlying the sulphur-bearing formation. Within this hole through the sulphur-bearing strata and within the casing which lines the upper portion of the hole, a smaller pipe (3), which we will call the hot-water pipe, is set. This pipe (3) extends from the bottom of the hole up to the surface of the ground, or it may extend up into the casing and be sealed off with a packer placed between the said pipe and the casing. This hot water pipe which extends to the bottom of the hole is perforated in that portion (4) which extends through the sulphur-bearing formation. The size, number and location of the perforations in the hot water pipe vary with conditions found to exist in the sulphur-bearing formation during the process of drilling of the hole, and is subject to the judgment of those in charge of equipping the well. Within the hot water pipe is set a smaller pipe (5), which we will call the sulphur discharge pipe. This pipe is usually 3½ or 4 inches in diameter and extends from the surface of the ground to or near the bottom of the well. It is perforated in its lower portion with holes (6) of a size, number and location deemed best suited to the conditions of the particular well in which it is placed. Within the sulphur discharge pipe is set a smaller pipe (7), usually 1 inch or 1¼ inches in size, which we will call the air line, and which extends from the surface of the ground to or near the bottom of the well. At the surface of the ground each of these pipes is connected by a system of valves and fittings to pipes through which hot water and compressed air may be supplied to the appropriate pipe or pipes within the well, and through which molten sulphur from the well may be conducted to a suitable point of discharge.

In the drawing, Fig. 1, these fittings are represented by 8 and 9; the pipe line (10) supplies hot water to the hot water pipe; the pipe line (11) supplies hot water to the sulphur discharge pipe; the pipe line (12) is the pipe through which the molten sulphur is conveyed away from the well; and the pipe line (13) is the pipe through which compressed air is injected into the sulphur pipe to lift the molten sulphur to the top of the well.

The above described example of the usual equipment of a sulphur well is not by any means fixed or unvarying. Many modifications and variations are practiced but in all cases there are at least three essential elements, to wit: (*a*) a hot water line, (*b*) a sulphur discharge line and (*c*) an air line. It is also universal practice to have the hot water line surrounding the sulphur discharge line and the air line within the sulphur discharge line.

In starting a new well hot water at suitable temperature and pressure is admitted to both the hot water line (3) and the sulphur discharge line (5) and is pumped into the well continuously for a period varying usually from 24 to 48 hours. This period is called the "preliminary steaming period." The hot water so pumped into the well passes through the two pipes named and through the perforations near the lower ends of these pipes, and so out into the porous sulphur-bearing formation surrounding the well. As the temperature of the water is considerably higher than the melting temperature of sulphur, there is melted about the lower end of the pipes a quantity of sulphur which fills the cavities in the porous sulphur-bearing formation adjacent to the bottom of the well and enters the lower portions of the pipes within the well through the perforations mentioned above. When, in the judgment of the operator, the heating and fusing process, commonly called "steaming" the well, has progressed sufficiently the hot water supply to the sulphur discharge pipe is shut off, leaving the supply of hot water still flowing into the well through the hot water pipe surrounding the sulphur discharge pipe. The sulphur discharge pipe is then opened at the surface of the ground to the atmosphere, whereupon the hot water within it is vaporized to steam partly by the heat within its mass and partly by heat transmitted through the walls of the sulphur discharge pipe from the hot water within the hot water pipe. As this water is evaporated and the steam is blown out into the atmosphere the weight of the column of water within the sulphur discharge line is removed and molten sulphur, if present, rises from the lower portion of the well up into the sulphur discharge pipe, sealing the perforations near its bottom and preventing the entry of hot water from the surrounding hot water pipe into the sulphur discharge pipe. The well is then said to have "sealed". When the well has sealed and all the water evaporated from within the sulphur discharge pipe, as is evidenced by the cessation of emergence of steam from the open end of the pipe at the surface of the ground, compressed air at suitable pressure is admitted to the air line in the well and the molten sulphur is elevated to the surface of the ground by the well known principle of the air lift. This is called the "pumping period."

The hot water used in this process is heated in a specially designed heating plant provided with high pressure heaters of what are known as the "mixing type", that is, the type in which the steam for heating and the water to be heated are mixed together in a receptacle of suitable design. It is important in heaters of this type that there shall always be maintained an excess quantity of steam over and above the maximum amount which the water present can absorb or condense. If this condition of excess of available steam should ever fail to exist the water would condense all of the steam present and serious water hammer would result. Heaters of this type are and have been the universal practice in all plants in America using the Frasch process for mining sulphur. Since for safety there must always be an excess of steam available within the heaters, it follows that the water introduced into such a heater will be heated to a temperature approximately equal to the temperature of the steam under the pressure at which the heater is operated. For example, if the pressure of the steam and water within the mixing heater is maintained at 100 pounds per square inch, gauge, then the temperature of the steam will be approximately 338° F. and the water will automatically be heated to that temperature, since it is mixed with an excess of steam. Likewise, if the pressure of the steam and water within the heater is maintained at 90-pounds gauge, the temperature will be that corresponding to the temperature of steam at 90 pounds which is about 331° F., and if 110 pounds pressure is maintained the resulting temperature of the water will be about 344° F. This method offers a very convenient and effective means for automatically heating to any desired temperature the water passing through these heaters since by varying the pressure of the steam maintained in excess within the heaters the resulting temperature of the water is varied correspondingly. This method of heating water for mining sulphur by the Frasch method is the one in universal use in all American plants.

This method, however, has one serious drawback which is overcome by our invention. As has been stated, the temperature of the water when heated by this method is approximately equal to the temperature of the steam at the pressure carried in the heaters and in the boilers. This temperature varies, as stated, from about 331° F. to about 344° F. and is quite suitable for use in the wells during the "preliminary steaming period" and during the "boosting period", but is hotter than is desirable during the pumping period for reasons which will now be explained.

Pure sulphur has a melting point of 235° F. when crystallized in the rhombic form and 246.7° F. when in the monoclinic form. Commercial sulphur has a melting point varying from 230.4° F. to 246.7° F., depending on conditions. Above the melting point the liquid sulphur has a viscosity which varies with the temperature. In the drawing, Fig. 2 shows the relation between the viscosity of molten sulphur as measured by the standard Saybolt viscosimeter and the temperature of the liquid. In this chart the viscosity-to-temperature relation of sulphur over the temperature range from a few degrees above its melting point to 312° F. is shown. With the same instrument water shows a viscosity of 30. It will be noted that the viscosity of the liquid sulphur at a temperature but a few degrees above its melting point is about 45 and that the viscosity gradually decreases as the temperature rises until at about 290° F. the viscosity is at its minimum or lowest point. Above 290° F. the viscosity slightly increases until at about 310° F. the viscosity curve abruptly turns upward and at 312° F. the viscosity is very much higher than at any lower temperature above the melting point. Above 312° F. the increase in viscosity is so great that it is difficult to accurately measure. At about 324° F. the molten sulphur thickens to a tough rubber-like mass of dark brown color known as plastic sulphur. If the temperature of sulphur is still further increased to about 365° F. the viscosity of sulphur becomes more than 50,000 times the viscosity of water.

In the practice of the Frasch process it has been the universal custom to heat the water which is injected into the sulphur-bearing formation to melt the sulphur to the temperature corresponding to that of steam at approximately 100 pounds, gauge, pressure per square inch; or, in other words, to about 335° F. There has been some variation in this temperature for reasons which will be explained, but in general the pressure carried in the boilers generating the steam for heating mine water and consequently the pressures carried in the mixing heaters, has been between 90 pounds and 110 pounds, gauge, corresponding to water temperatures between 331° F. and 344° F. It will be noted that these temperatures to which it is customary to heat the fusion fluid are many degrees above the temperature at which molten sulphur becomes viscous. If during the pumping period fusion fluid at these temperatures is pumped into the well through the hot water line which surrounds the sulphur through which molten sulphur is being pumped to the surface of the ground there will be a heating of this sulphur by transfer of heat from the hot fusion fluid in the outer pipe through the wall of the sulphur discharge line to the sulphur within. If the temperature of the fusion fluid is too high there results an overheating of the sulphur which increases its viscosity and results in a marked decrease in the pumping rate of the well. When this occurs with the present commonly used method it is necessary to reduce the temperature of the fusion fluid in the pipe surrounding the sulphur discharge line by reducing its pressure to a point at which its temperature corresponding to its pressure is not high enough to overheat the sulphur passing through the sulphur discharge line. As stated above, molten sulphur increases rapidly in viscosity as its temperature is raised above 312° F. and it is essential therefore that the temperature of the sulphur being pumped shall not exceed 312° F. This temperature corresponds to the temperature of steam at about 67 pounds gauge. To prevent the overheating of the sulphur it is customary with the method now in common use to reduce the quantity of fusion fluid being pumped into the well during the pumping period to a point at which the pressure in the well is not higher than corresponds to a safe temperature for the fusion fluid. This pressure is about 68 pounds gauge which corresponds to a temperature of 315° F. It is not practical to carry a steam pressure in the boilers of the water heating plant as low as 68 pounds for various obvious reasons, among which are the following. Such a pressure is too low for the economical operation of steam driven apparatus, the temperature corresponding to this pressure is lower than is desired for use in wells during the preliminary steaming period and during the boosting period, and since a number of wells are served simultaneously from the same plant, it is not expedient to carry so low a temperature and pressure as 315° and 68 pounds. The practice therefore has been and is to carry a steam pressure of 90 to 120 pounds and corresponding temperature of 331 to 350° F. in the fusion fluid and reduce this temperature in the well during the pumping period by permitting the pressure on the fusion fluid to reduce to about 68 pounds gauge. This reduction in pressure is now accomplished by reducing the rate at which the fluid is injected into the well to such a point that the resistance of the porous sulphur bearing formation is balanced by the pressure of 68 pounds on the fusion fluid. The porosity of the sulphur bearing formation varies in different parts and the quantity of fusion fluid which can be injected during the pumping period without maintaining a pressure above 68 pounds varies with the porosity of the formation. With a very open, porous formation large quantities may be injected. With very close, dense formations very little fluid can be injected at this pressure. By the use of our invention the temperature may be regulated and adjusted to the desired point without any necessary change in the pressure and a safe temperature, just about the point at which the sulphur has its minimum viscosity or its maximum fluidity, without reducing the pressure correspondingly as is the present custom. The reasons for these variations in steam pressure and mine water temperatures are as follows. It is desirable, of course, to carry as high temperature in the mine water as possible since the quantity of heat which is carried into the sulphur-bearing formation by each gallon of water pumped into said formation is greater at the higher temperatures and so more effective in melting sulphur. But the peculiar relation between the viscosity of sulphur and its temperature which has been described above makes it impractical to use water which will overheat the sulphur to a point which will transform it to the stiff rubbery or "plastic" state. It is the practice, therefore, to vary the pressure of the steam supplied to the heaters and by that means vary the temperature of the mine water to suit field conditions. When the sulphur wells are located at long distances from the water heating plant and consequently the hot water pipes leading from the plant to the wells are long, there is considerable loss of heat from radiation and consequently the mine water may be heated to a higher temperature at the plant than when the sulphur wells are located close to the plant.

In winter the loss of heat due to radiation is greater than in summer and consequently the temperature of the water as it leaves the heaters must be higher for any given temperature at the sulphur well. Since a change in the temperature to which the water is heated involves a corresponding change in the pressure of the steam used to heat it, it follows that the steam boilers are operated at varying pressures at different times.

The sulphur-bearing formation frequently varies widely in its characteristics. Some parts are much more dense than others. The porosity varies greatly from place to place. Large caverns are frequently encountered in some formations. These variations have made it expedient to treat the formation in different ways to produce the best results. One of the variations made in the method of treatment is a change in the temperature and volume of the hot water injected into the wells. Some formations have been found to respond better or to yield better production of sulphur when the hot mine water has a temperature as low as 315° F. corresponding to a steam pressure in the boilers and heaters of 65 pounds while other wells have given best results at temperatures as high as 344° F., corresponding at 110 pounds pressure, or at even higher temperatures. Sometimes these various conditions exist at the same time in working the same sulphur deposit, that is, in the same water heating plant it is desirable to furnish water for some wells at one temperature and for other wells at other temperatures, but under the present method of operation this would mean the carrying of different steam pressures on different boilers and mixing heaters which is highly inconvenient and impractical, and is therefore not practiced.

Another difficulty inherent in the present commonly used method of mining sulphur by the Frasch process and which is overcome by the use of our invention may be described as follows. As outlined above, when a new well is started up hot water is pumped through the hot water pipe and also through the sulphur discharge pipe into the sulphur-bearing formation for a period of time, or until the well is "sealed" with molten sulphur. During the period of this "preliminary steaming" of the new well the mine water may be quite hot. The new region into which this hot water is being injected is cool to begin with and there is little danger of overheating it to a degree which would be detrimental. The hotter the water injected at this period the greater the number of heat units carried into the formation, which is desirable. However, after the well has "sealed", the injection of hot water through the sulphur discharge pipe is discontinued, and compressed air is admitted to the air line, and the molten sulphur is elevated to the surface of the ground through the sulphur discharge pipe. This sulphur discharge pipe is surrounded by and inclosed within the hot water pipe so that as the melted sulphur rises in this pipe it is in contact with the inside of a pipe which in turn is in contact on its outside surface with the hot mine water entering the well. There follows an interchange of heat from the hot mine water to the sulphur and if the temperature of the hot mine water is too high there will follow, and in practice actually does follow, an overheating of the sulphur to the point at which its viscosity is so greatly increased that the pumping rate of sulphur from the well is materially reduced and the rate of production of the well curtailed. It is desirable therefore to be able to supply very hot water to a well before it has sealed and to supply a cooler water while the well is pumping, so as to avoid overheating the sulphur as it rises through the sulphur discharge pipe. The present method commonly employed to avoid overheating the sulphur rising through the sulphur discharge pipe while the well is pumping to limit the amount of hot water passing down the hot water pipe into the well so that the sulphur will not become overheated. This curtailment of the hot water entering the well during pumping period in order to avoid overheating the sulphur greatly reduces the amount of heat going into the sulphur-bearing formation to melt more sulphur, and consequently sulphur is not melted at a rate equal to the rate at which the melted sulphur is being ejected from the well. The result is that sooner or later the pool of melted sulphur at the bottom of the well is exhausted, the well is no longer "sealed", hot water passes through the perforations in the sulphur discharge pipe and the well "blows". When this occurs it is customary and necessary to close off the compressed air from the air line and to close the discharge valve in the sulphur line and inject hot water into the well through both the hot water pipe and the sulphur discharge pipe, and to continue this injection of hot water until sufficient sulphur is again melted to seal the well so that pumping may again be resumed. This operation is called "boosting" the well. During this "boosting" period no sulphur is being lifted through the sulphur discharge pipe and consequently the temperature of the hot water injected may be considerably higher than is permissible while the well is being pumped since there is no danger of overheating the sulphur during what is called the "boosting" period.

If means were available for conveniently varying the temperature of the hot water injected into each well at the different periods of operation without the necessity, as is at present the case, of varying the steam pressure of the boilers there would result a larger output of sulphur from certain wells under certain conditions.

As outlined above, it is advantageous to use hotter water during the original steaming period of a new well and during the boosting period of an operating well than it is desirable to use during the pumping period because of the adverse effect of the hotter water upon the viscosity of the sulphur coming up through the sulphur discharge pipe, and the consequent reduction of the pumping rate due to the high viscosity of the hotter sulphur.

Our invention makes this variation in temperature possible and practicable without the inconvenience or necessity of varying the steam pressure in the boilers. Our new process consists in furnishing to the wells two sources of supply of water under suitable pressures and at different temperatures.

In the drawing, Fig. 1, we have indicated one method of carrying out our invention, and while there are other ways of putting our invention into practice, some of which we describe herein, the method indicated in the drawing is our preferred method.

We provide at each sulphur well a supply of water under pressure and we connect this supply (14) to the hot water pipe through the pipe shown at 15 and we also connect this supply to the sulphur discharge line through the pipe shown at 16.

The supply pipes which convey water which has the higher temperature we will call the "hot lines", and the other supply which has the lower temperature we will call the "cold line". The temperature of the water in the hot line may be maintained at any point which is as high or higher than the maximum temperature which may be required in the operation of the well or wells supplied by it. The temperature of the water in the cold line may be at any point which is as low or lower than the minimum temperature which may be required in the operation of the well or wells supplied by it. By having these two sources of supply of hot and cold water available at the well and both connected to the pipes within the well and provided with suitable arrangement of valves (17) under the control of the operator, it is possible for the operator to inject into the well pipes such a mixture of the hot and cold waters as will have a resulting temperature which is best suited to produce maximum efficiency in the operation of the well and the maximum output of sulphur. For example, when a new well is being steamed for the first time and before it has produced any sulphur, it may be supplied solely with water from the hot line and this may be continued until the well has sealed. Then, since this water would heat the sulphur to such a temperature that its viscosity would be too high for pumping, a suitable mixture of waters from the hot line and the cold line may be injected into the well at a temperature which would keep the molten sulphur at or near its minimum viscosity with the resulting gain in pumping rate.

Our invention consists in the improvement in the process of mining sulphur by the underground fusion method whereby the fusion fluid is heated at the heating plant to a temperature as high as or higher than the highest temperature desired in any well at any time and reducing the temperature of the fusion fluid at or near the well to the temperature desired at the time in each well as stated above. This may be accomplished by several methods. One method we have described, namely, by the use of a hot line and a cold line delivering fluid at different temperatures and mixing them in proper proportion to secure the desired temperature. Another method is to cool the hot fusion fluid to the desired temperature by means of cooler water in contact with the pipe through which the fusion fluid is delivered to the well. Or any of a number of forms of heat interchanger may be used to cool the hot fusion fluid to the desired temperature before it enters the well.

The benefits to be derived from the use of this process are not confined to the increased output of the sulphur from a particular well. The use also increases the efficiency and convenience of operation of the water heating plant. Under the process heretofore in common use it is the universal practice to effect any desired variation in the temperature of the hot mine water by raising or lowering the pressure of the steam carried in the boilers as described in detail above. This change in steam pressure not only affects the temperature of all of the hot water heated by the steam, but it also affects the operation of all the steam-driven equipment in the plant which is supplied from the same boilers. These plants have turbo-generators for supplying electric power for use in the various operations incident to the mining of sulphur; pumps for pumping water, air compressors and other steam-driven apparatus. Varying the steam pressure on the boilers in order to deliver water at suitable temperature to the sulphur wells also varies the steam pressure applied to the steam-driven apparatus in the plant. This means that turbines, engines, pumps, compressors, etc., may at times be supplied with steam at, say, 90 pounds pressure while at other times when hotter water is required for the sulphur wells, they may be supplied with steam at, say, 110 pounds or even higher. This variation in the steam pressure obviously results in inefficient and at times difficult operation of this apparatus. Steam-driven machinery of the types enumerated, designed for efficient operation at, say, 110 pounds, is working under a disadvantage when the steam pressure is reduced to 90 pounds. As the steam pressure is lowered the amount of steam required to do a given amount of work is proportionately increased and steam-driven apparatus designed to do a certain amount of work when supplied with steam at 110 pounds, it is unable to perform its required amount of work when supplied with steam at only 90 pounds pressure. By the use of our new process the steam pressure in the boilers supplying steam both to the water heaters and to the steam-driven apparatus may be maintained constantly and continuously at or above the pressure corresponding to the temperature of the water in what we term the hot line, and thus the operation of the power and water heating plant is made more efficient and convenient.

But perhaps the greatest benefit to be derived in the plant from the application of our invention is that resulting from the ability to operate the plant at higher rating and more constant load, since the plant boilers may be operated continuously at high pressure and high efficiency instead of at varying pressures and loads as is at present the custom. The resulting economies in fuel costs are decidedly advantageous.

Our invention places the plant supplying the hot fusion fluid in a position practically independent of the requirements of the sulphur wells, and permits the plant to be operated steadily at a uniform steam pressure and temperature and at its highest efficiency and at the same time any well in operation may be supplied with fusion fluid at a temperature and pressure best suited to the maximum production of sulphur, however much those conditions of temperature and pressure may vary in different wells or in the same well at different times.

In this description of the process of mining sulphur by the underground fusion method, we have frequently referred to the fusion fluid as being hot water. This is now universally true but we do not wish to limit our process to use with pure water. Other fluids may be used, such, for example, as a solution of salt in water, and our process would be equally useful if fusion fluids other than relatively pure water are used.

Having described in detail our invention and the manner of its application to the mining of sulphur, so that one versed in the art may apply it, we now state what we believe to be new and novel and for which we pray that Letters Patent be granted,

1. The improvement in the process of mining sulphur by the underground fusion method which consists in heating the hot fusion fluid to a temperature equal to the highest temperature required in a sulphur well and reducing said temperature of the fusion fluid to the temperature desired by adding thereto a fluid having a lower temperature.

2. The improvement in the process of mining sulphur by the underground fusion method which consists in injecting hot fusion fluid into the well during the preliminary steaming period and during boosting periods and reducing the temperature of the hot fusion fluid during the pumping periods by adding thereto a fusion fluid having a lower temperature.

3. The improvement in the process of mining sulphur by the underground fusion method which consists in supplying from a common source to all the sulphur wells served from said common source a hot fusion fluid at a temperature at least equal to the highest temperature required by any of the wells at any time and reducing said temperature of the hot fusion when desired by adding thereto a cooler fluid in proper quantity to produce the temperature desired at each well.

Signed at Freeport, in the county of Brazoria and State of Texas.

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