April 11, 1961 C. A. BAYS 2,979,317

SOLUTION MINING OF TRONA

Filed Aug. 12, 1959 2 Sheets-Sheet 1

Fig. 1

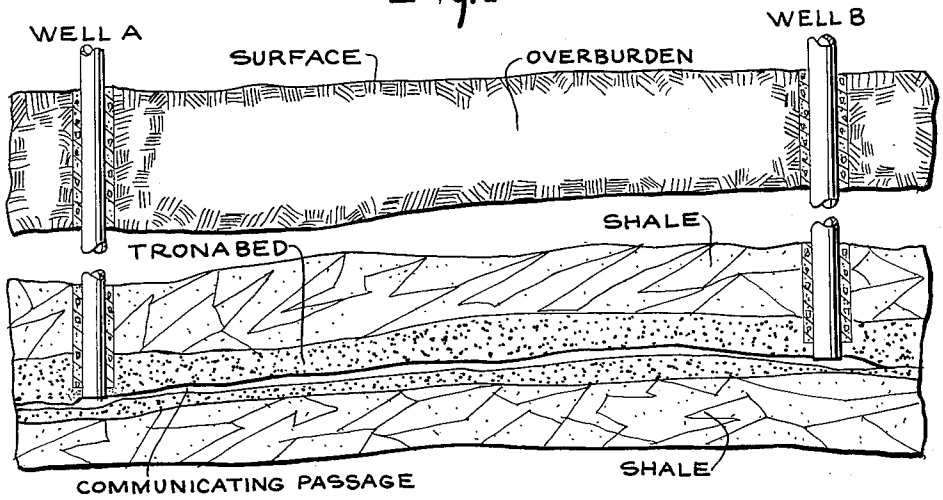
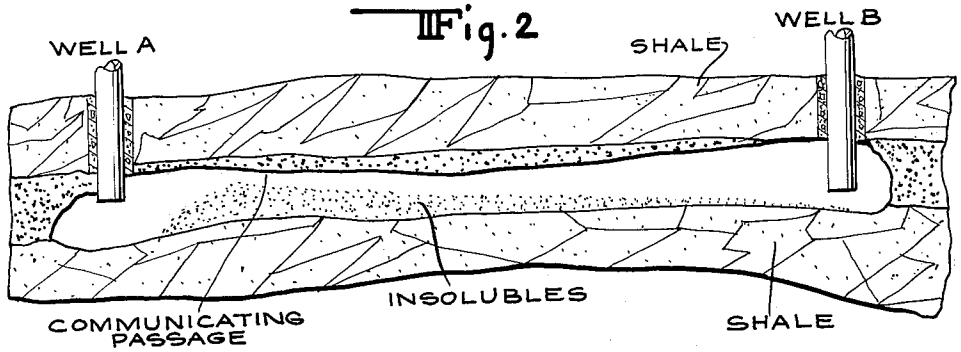


Fig. 2



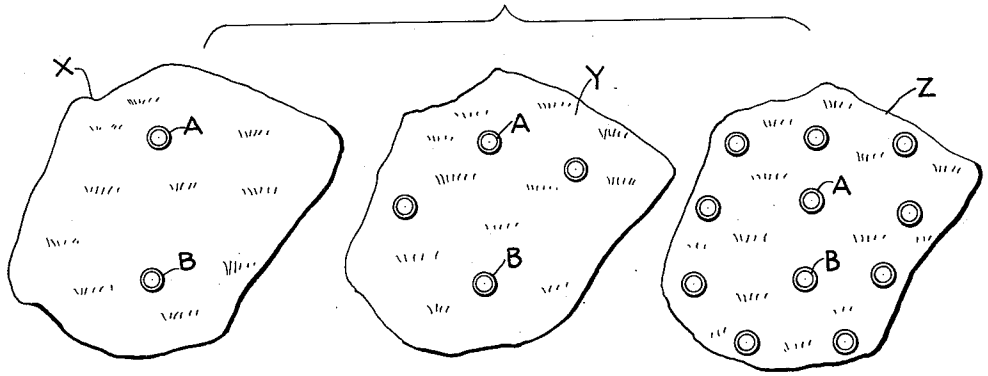


Fig. 3

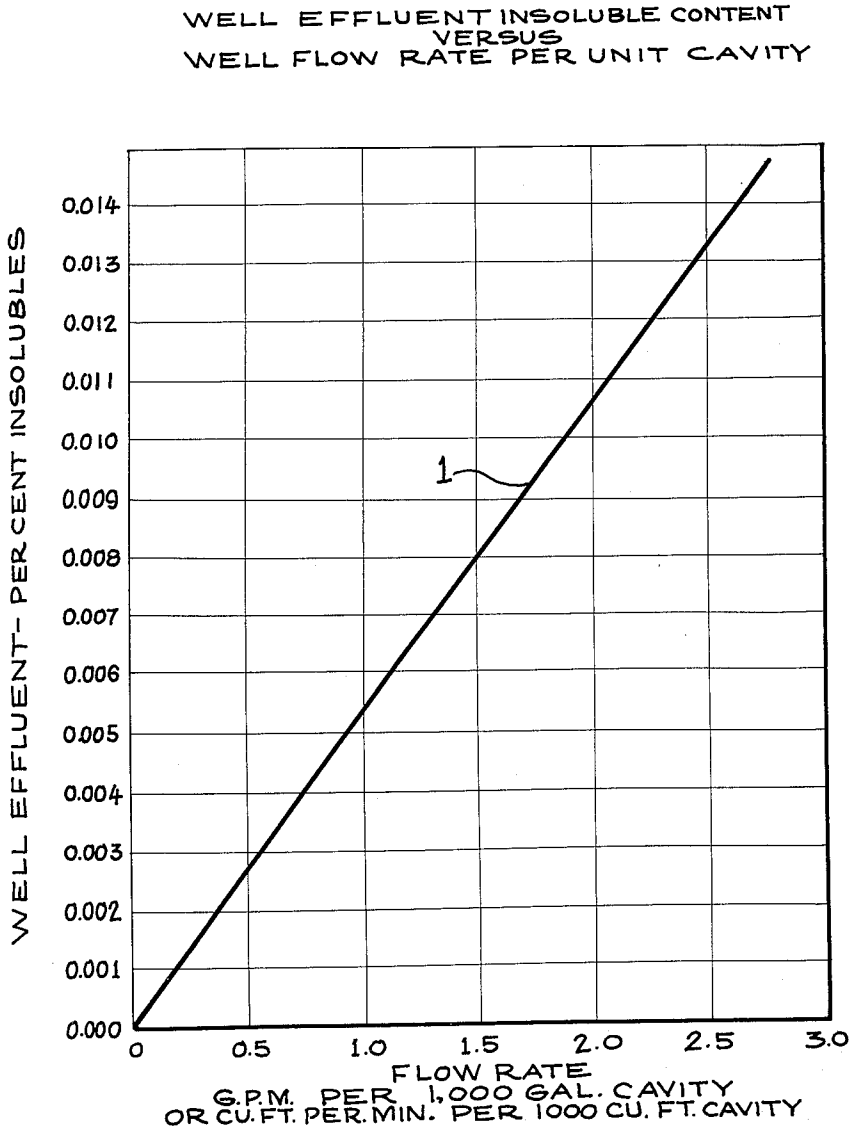
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April 11, 1961 C. A. BAYS 2,979,317

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Filed Aug. 12, 1959 2 Sheets-Sheet 2

Fig. 4



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Patented Apr. 11, 1961

2,979,317

SOLUTION MINING OF TRONA

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7 Claims. (Cl. 262—3)

This invention relates to solution mining of underground deposits of trona, particularly in areas where trona has not been previously dry mined.

In the vicinity of Green River, Wyoming, there is a large bed of crude trona at a depth of approximately 1500 feet below the ground surface. The crude trona deposit is essentially sodium sesquicarbonate, represented by the empirical formula $Na_2CO_3.NaHCO_3.2H_2O$. In addition, the trona bed has insoluble inclusions distributed throughout, as well as contaminating organic matter.

The percent insolubles varies from area to area in the trona deposit. An average analysis of Green River trona shows at least a five percent insoluble content.

When employing the dry-mined method of recovering trona or the solution mining method of the prior art, the presence of insolubles necessitates an elaborate system of clarifying, thickening and filtering, in order to remove the objectionable insolubles from the crude trona solutions.

For example, ground dry-mined trona is placed in dissolving tanks where in the presence of rapid agitation, it dissolves in the cycling mother liquors. As a result of the dissolving action a substantial portion of the insolubles is suspended in the dissolving liquors and must be removed by settling and filtration.

Normal commercial specifications for soda ash permit not more than 0.5% of insolubles, and in producing soda ash from trona there is about a 10 fold concentration of impurities from the trona liquor into the soda ash in the crystallizer mother liquor process and in the complete evaporative process about a 4 fold concentration of impurities in the finished soda ash. Thus a trona liquor containing 0.005% insolubles will produce soda ash containing 0.05% insolubles in the crystallizer mother liquor process and 0.02% insolubles in a completely evaporative process. Therefore the percentage insolubles which can be tolerated in the trona solutions is strictly limited.

It is the object of this invention to provide a process for solution mining of previously unmined underground trona deposits by which vast areas of the underground deposit may be opened with sufficient rapidity to solution mining methods and a trona liquor sufficiently low in insolubles produced therefrom to permit economical production of soda ash therefrom with no clarification and a minimum amount of filtration.

Another object of this invention is to provide a process for the solution mining of underground deposits of trona, not previously dry-mined, in which a substantial portion of the insolubles are deposited in the underground formation and only relatively clear solutions of trona are brought to the surface for further processing into soda ash or other sodium products produced from crude trona.

Another object of this invention is to facilitate the opening of large underground areas in the trona bed at low cost whereby the solution mining operations herein described may be readily and economically carried out.

Another object of this invention is to provide a method

for rapidly opening large separated underground areas in the trona bed for solution mining without danger of one area accidentally merging into another area whereby solution from one mining area may be lost to another area, thereby increasing the amount of underground solution required and the mining costs.

Other objects and advantages will appear as the description of the invention proceeds.

In the drawings which show diagrammatic illustrations of one method of practicing the process, Figure 1 is a cross-sectional view of a typical portion of the trona formation showing two wells sunk into the trona bed with interconnections established between the wells, Figure 2 is an enlarged detail illustrating diagrammatically the operation of the underground solution and deposition of insolubles, Figure 3 is an outline plan view showing how separate areas may be solution mined by the methods herein described without danger of one area becoming accidentally merged with another area, and Figure 4 is a diagram illustrating the rate of underground solution flow to produce trona solutions of a given clarity from a solution mining cavity.

In general, the invention comprises sinking two or more wells into the trona formation and interconnecting these wells so as to permit flow of a dissolving liquid between the wells, forming a solution mining cavity therein, pumping a dissolving liquid down one well, circulating the solvent through the trona bed and removing a trona rich solution from the adjacent well or wells and controlling the rate of flow through the solution cavity so as to produce a trona solution having a low insoluble content. The trona rich liquor may then be treated to recover the sodium values therein having a low insoluble content.

The main trona bed found at Green River, Wyoming, is of the order of 12 to 15 feet in thickness and overlies a bed of relatively water impervious oil shale. Above the trona bed is another layer of oil shale and above this is an overburden of various constitution to a thickness of about 1500 feet.

A typical analysis shows trona 92.76%, NaCl 0.08%, Na_2SO_4 0.02%, Fe_2O_3 0.14%, insolubles 7.00%. The insolubles are distributed throughout the main trona bed and form a slimy precipitate in a trona solution. Additional thinner beds of trona are found above the main trona bed and separated therefrom and from each other by alternate layers of shale.

After drilling the two or more wells, intercommunication between the wells is established by any suitable method such as cross drilling, radial drilling from the ground surface, explosive charges or underground hydraulic fracturing. Preferably the cross connection between the two wells is established as near the interface between the bottom of the trona bed and the top of the underlying oil shale layer as possible. When established by hydraulic fracturing a connection can be formed between the base of two wells by subjecting the formation to a pressure concentrated adjacent the lower interface of the trona-shale layer and sufficiently in excess of the parting pressure of the overburden to cause the formation of a fracture or fissure between the two or more adjacent wells. Fractures of this nature can be established over distances of about 400 feet to 1200 feet or more between wells, whereas interconnections between wells by radial or cross drilling or by the use of explosive charges is confined to wells more closely spaced than 400 feet.

While a fracture caused by hydraulic fracturing might tend to follow any natural crack or fault in the trona bed, the formation is essentially a dense well consolidated formation and the rapidity with which the formation

can be opened by the methods herein described will tend to overcome any irregularities in the orignal fracture.

After the fracture or fissure, or other communications between the wells are established, regardless of the method by which it is established, a suitable solution may be pumped into one well and removed through the adjacent well or wells to open a mining cavity between the wells. This solution circulates in contact with the trona formation and dissolves trona from the formation thereby increasing the area of the underground void as more and more trona is dissolved and removed from the formation. After a suitable size cavity has been opened a solvent for trona is circulated at a given rate through the cavity to dissolve trona therefrom and deposit most of the insolubles underground.

The size of the solution cavity, however, does not always increase, as subsidence or caving into the cavity from time to time will decrease the volume of the cavity and also changes the shape of the cavity and alter the flow characteristics through the cavity. For these reasons, in order to dissolve and remove trona solutions substantially free from insolubles from the cavity it is necessary to adjust the flow rate of the solution through the cavity, as conditions of the cavity change.

Water or mother liquor compositions containing carbonate and bicarbonate may be used to dissolve the formation. When employing a mother liquor containing excess normal carbonate over bicarbonate, it is preferable to pass the mother liquor into the formation at a temperature of about 130° C. and to recover the trona rich solution at a temperature of 95 to 100° C., the flow rate being adjusted to maintain these temperatures and to produce a substantially insoluble free solution.

The dissolving liquor entering the underground fracture or channel has a tendency to rise as it passes through the underground fracture since it is less dense than the trona rich liquor. Due to this phenomenon, constant mixing and reintroduction of fresh unsaturated liquor to the trona surfaces takes place and the trona is dissolved mainly from the exposed bottom and side walls of the trona cavity.

As the trona rich liquors pass toward the outlet well, if the rate of solution flow is kept sufficiently low, the insolubles found in the crude trona formation settle out by gravitating toward the base of the underground cavity resulting in an exiting liquor having substantially less suspended solids than when the crude trona is dissolved as taught by the prior art.

The clarity of the exiting liquors is further enhanced by an underground filtration brought about by the settling out and depositing on the floor of the underground cavity of insolubles in the form of a porous layer. Thus, as the trona rich liquors gravitate toward the bottom of the cavity they must pass through the porous medium formed by the deposited insolubles and are further clarified thereby.

The specific gravity of a solution saturated with trona at 100° C. is 1.26 and the density of the insolubles is about 2.11.

According to this invention, the wells A and B indicated on the enclosed drawings are drilled sufficiently far apart to expose a vast area of the underground formation to solution mining and the solution is flowed through the underground cavity at a rate to allow the production from an outlet well of a substantially clear solution. The interconnection whether formed by explosion, cross drilling, hydraulic fracturing or any other method of interconnecting wells is preferably as near as possible to the bottom of the trona bed and along the top of the underlying oil shale bed.

Following is set forth an embodiment of the subject invention. Two wells A and B were drilled into and through the trona formation at a distance of 400 feet apart.

The depths of wells A and B were 1787 feet and 1581, respectively. The difference in depth between the two wells was because of the slope of the trona bed and the differences in ground surface elevation of the trona wells.

A 7 inch outside diameter (O.D.) casing was run into one well A and cemented to the trona formation by conventional cementing practices in oil well drilling. The well was perforated at the interface between the main trona bed and the shale bed immediately below for a distance of three feet. An 8 inch O.D. casing was run into the other well B and cemented to the trona formation. This well was perforated at the interface between the main trona bed and the shale bed immediately below for a distance of three feet.

After these steps had been taken, the formation adjacent the bottom of well A was subjected to a fracturing pressure of 1600 p.s.i. measured at the ground surface by pumping cold water into the casing in well A. After about two minutes the pressure dropped to 1020 p.s.i. and then gradually decreased to 920 p.s.i. nine minutes after application of pressure began. Pumping was continued at the rate of 200 gallons per minute and a pressure of 920 p.s.i. for a period of 42 hours with no evidence of an interconnecting fracture from well A to well B. During this period 480,450 gallons of 0° C. water had been pumped into the formation. At this point the valve in the casing of well A was closed and the pressure on the formation maintained at 900 p.s.i., to keep the fracture adjacent well A from closing.

After a period of 3.5 hours during which period no liquor was injected into the underground formation, the valve on well A was cracked and pumping into well B commenced. While pumping at a rate of 200 gallons per minute, the pressure on well B rose to 1,000 p.s.i. for about 10 seconds then dropped to 950 p.s.i. and after 3 minutes dropped to 20 p.s.i. After pumping at the rate of 200 gallons per minute for a period of two hours, the pressure at well A had dropped to 280 p.s.i. At this point the valve in well A was opened wide. This resulted in an increased flow rate, with the pressure as measured at well A, dropping to 2 p.s.i. This clearly indicated that a connection between wells A and B had been made.

Following the above-described breaking in period, the formation was solution mined by pumping water down one well and removing from the other well a liquor which was rich in trona.

Figure 4 illustrates the rate of solvent flow through the formation in gallons per minute for each 1000 gallons of cavity space, or in cubic feet per minute for each 1000 cubic feet of cavity space, to produce a solution of a given clarity or percent insolubles at the head of the outlet well.

Thus, as shown by the line 1, to produce a well solution containing only 0.005% insolubles it is necessary to circulate the solution through the underground cavity at a rate of slightly less than 1 gallon per minute for each 1000 gallons of cavity space. Such a solution can be processed directly, without further clarification or filtration by the crystallizer and recirculating mother liquor process described, for example, in the patent to Robert D. Pike, No. 2,639,217, granted May 19, 1953, to produce soda ash containing less than 0.05% insolubles or by the process of complete evaporation to produce soda ash containing 0.02% insolubles.

Where a clean up filtration by the use of a filter and activated carbon is used, which is sometimes necessary to reduce organics and soluble coloring matter in the solution, a solution having an insoluble content of 0.011% can be used. Such a solution will be obtained when the circulation rate is approximately 2.2 gallons per minute for each 1000 gallons of cavity space. A solution containing 0.011% of insolubles can be filtered directly and without difficulty to reduce the insoluble content of the liquor to below 0.005% without the use of clarifiers or settling basins. However, solutions containing in excess of

0.011% insolubles cannot be satisfactorily filtered in a simple filtration and require substantial additional expense for clarifiers or settling basins or additional filter capacity. They also present additional waste disposal problems and other complications all of which are solved by limiting the rate of circulation of the dissolving liquid to approximately 2.2 gallons per minute for each 1000 gallons of cavity space.

The size of an underground cavity space is easily ascertained by determining the tons of trona removed in solution from the formation. The number of tons multiplied by 14.5 cubic feet per ton gives the cavity volume in cubic feet. The number of tons multiplied by 108.5 gallons per ton gives the cavity volume in gallons. To take into account the trona which is dissolved but remains underground in the solvent in the cavity space, these values should be multiplied by a factor of 1.08 to 1.20. The smaller factor is used for a mother liquor solvent and the larger factor for water solvent. When there is no subsidence, the well exit volume is 1.04 times the inlet volume due to the trona dissolved therein. When subsidence occurs, the exit volume will be more than 1.04 times the inlet volume by the amount of solution forced out of the cavity by the subsidence. To calculate the cavity space after subsidence it is necessary to subtract the excess volume from the cavity volume calculated from the tons of trona dissolved before subsidence. Other methods of measuring cavity space, such as sonar surveys or electronic surveys may be used, but are more complicated and less reliable than the method described.

As illustrated in Figure 2, when the rate of circulation is below approximately 2.2 g.p.m. per 1000 gallons of cavity space the insoluble material deposits at the bottom of the communicating passage between the wells A and B or clings as a porous slimy layer to the roof and walls of the solution cavity and the formation adjacent the inlet and outlet wells is relatively free of insoluble material so that relatively little of the insoluble material is carried out of the formation with the trona solution.

However, increased agitation of the slimy layer of insolubles by increased flow rates or from subsidence or substantial caving which decreases the cavity volume will result in the carrying of more insolubles out of the formation and the further processing difficulties described above.

Table I shows a comparison of the amount of suspended solids present in trona mother liquor where the crude trona is dissolved in an aboveground dissolver as compared with the trona mother liquor exiting from the underground trona formation when solution mined according to the teachings of this invention.

Dry-mined trona is dissolved by agitating the crushed trona ore in the presence of a cycling mother liquor containing about 19 percent sodium carbonate and 5.5 percent sodium bicarbonate at about 100° C. to yield a solution containing about 21.5 percent carbonate and 9 percent bicarbonate. From the dissolver the solution passes to a clarifier where some of the suspended insolubles found in the crude trona settle out. In Table I, sample A represents the average percent insolubles found in clarifier overflow taken over the course of several years period.

A mother liquor at 130° C. and of similar composition as that fed to the dissolver was passed to an underground solution mining operation having a cavity space of approximately 480,450 gallons at the rate of approximately 200 gallons per minute, giving an initial flow rate of approximately 0.42 gallon per minute for each 1000 gallons of cavity space. The use of amother liquor of this approximate composition dissolves the trona congruently so that all of the less soluble bicarbonate is removed along with the normal carbonate and only the insolubles are left underground.

The solution produced at the outlet well was sampled on several different days with the results shown by samples B, C, D, E and F of Table I.

TABLE I

Solids suspended in trona mother liquors

Samples:	Insolubles (percent)
A	0.009
B	0.0011
C	0.0012
D	0.0006
E	0.0001
F	0.0000

Table I clearly illustrates the substantial decrease in percent insolubles when mining trona according to the teachings of this invention and illustrates how mining solutions can be produced which are sufficiently free of insolubles to be processed directly into soda ash, with or without filtration and entirely without the use of clarifiers or settling basins.

The trona rich liquors exiting from the outlet well may be processed by passing the solution to a series of crystallizers to crystallize sodium sesquicarbonate therefrom. The mother liquor from the crystallizers may be recirculated as the underground solvent. The sesquicarbonate crystals produced in the crystallizers may be calcined to produce soda ash.

As illustrated in Figure 3 when an area such as X, Y or Z has been completely worked, a new section of the formation may be readily opened by the methods herein described and brought into production with a minimum of expense.

Additional wells can be drilled into any formation which has already been opened by solution mining as described above, but by opening spaced separated areas as illustrated in Figure 3 the size of the areas can be kept under better control and accidental communication between one area and another with possible loss of the solvent liquor underground may be avoided.

The unmarked circles found within the larger circles X, Y and Z represent wells drilled into the earth formation and horizontally connected to the underground void created by solution mining between wells A and B so as to expand the area of recovery of crude trona.

When a given area has been mined to the desired degree, the solvent remaining in the cavity may be recovered by pumping the solution from the underground formation. As an aid to the recovery of the residual liquor in the underground cavity, it may be desirable to displace the liquor by pumping into the cavity an inert gas.

Pursuant to the requirements of the patent statutes, the principle of this invention has been explained and exemplified in a manner so that it can be readily practiced by those skilled in the art, such exemplification including what is considered to represent the best embodiment of the invention. However, it should be clearly understood that, within the scope of the appended claims, the invention may be practiced by those skilled in the art, and having the benefit of this disclosure, otherwise than as specifically described and exemplified herein.

This application is a continuation-in-part of my copending application Serial No. 627,413 filed December 10, 1956, now abandoned.

That which is claimed as patentably novel is:

1. The method or recovering a clarified trona solution from an underground body of trona approximately twelve feet in thickness and containing insoluble inclusions therein, in the amount of about 5%, which comprises sinking a plurality of wells into the trona formation, interconnecting said wells through the trona formation, forming a cavity in the trona formation and circulating a dissolving liquid into one well and out of another at a rate of less than 2.2 gallons per minute for each 1000 gallons of cavity space to dissolive and remove trona from the formation and separate and deposit the insolu-

ble material from the trona solution within the formation and remove only a clarified trona solution therefrom.

2. The method of claim 1 in which the solvent is circulated through the formation at a rate, in gallons per minute, which is less than $\frac{1}{2400}$ of the void space in the formation through which the solvent circulates.

3. The method or recovering a clarified trona solution from an underground body of trona containing insoluble inclusions therein in the amount of about 5%, which comprises sinking a plurality of wells into the trona formation spaced from 400 to 1200 feet apart to expose a large area of the trona formation to solution mining and allow the production from an outlet of a substantially clear solution of trona, interconnecting said wells through the trona formation forming a cavity therein and circulating a dissolving fluid into one well and out of another to dissolve and remove trona from the formation and separating and depositing the insoluble material from the trona solution within the formation and removing only clarified trona solutions therefrom by maintaining a rate of circulation of the solvent through the formation of less than 2.2 gallons per minute for each 1000 gallons of the cavity space in the formation, whereby the solids in the trona solution settle out and deposit within the formation.

4. The method of recovering a clarified trona solution from an underground body of trona containing insoluble inclusions therein in the amount of about 5%, which comprises sinking a plurality of wells into the trona formation spaced from 400 to 1200 feet apart to expose a large area of the trona formation to solution mining and allow the production from an outlet well of a substantially clear solution of trona, interconnecting said wells through the trona formation forming a cavity therein and circulating a dissolving fluid into one well and out of another to dissolve and remove trona from the formation and removing a clarified solution from the formation which can be processed directly into soda ash containing less than 0.05% insolubles by circulating the solvent through the trona formation at a rate of less than 1 gallon per minute for each 1000 gallons of cavity space in the trona formation.

5. The method of recovering a clarified trona solution containing less than 0.011% of insolubles from an underground body of trona containing insoluble inclusions therein in amounts of about 5% which comprises sinking a plurality of wells into the trona formation, interconnecting said wells at substantially the base thereof, forming an underground cavity of substantial size in the trona formation and then circulating a dissolving fluid through the formation from one well to the other at a rate of less than 2.2 gallons per minute for each 1000 gallons of cavity space to dissolve and remove trona from the formation and deposit substantially all of the trona insolubles underground.

6. The method of claim 5 in which the solvent is an unsaturated solution of sodium carbonate and sodium bicarbonate containing more normal carbonate than bicarbonate so as to dissolve trona congruently.

7. The method of claim 5 in which the solvent is pumped into the formation at a temperature in excess of 130° C. and removed at a temperature in excess of 90° C.

References Cited in the file of this patent

UNITED STATES PATENTS

2,388,009	Pike	Oct. 30, 1945
2,847,202	Pullen	Aug. 12, 1958

UNITED STATES PATENT OFFICE

CERTIFICATE OF CORRECTION

Patent No. 2,979,317 April 11, 1961

Carl A. Bays

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 1, line 41, for "0.5%" read -- 0.05% --; column 6, line 64, for "or" read -- of --; line 74, for "dissolive" read -- dissolve --; column 7, line 7, for "or" read -- of --.

Signed and sealed this 3rd day of October 1961.

(SEAL)
Attest:

ERNEST W. SWIDER
Attesting Officer

DAVID L. LADD
Commissioner of Patents

USCOMM-DC