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[54] METHOD OF FILLING SUBTERRANEAN VOIDS WITH A PARTICULATE MATERIAL

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 86,755, Nov. 4, 1970, Pat. No. 3,817,039.

[52] **U.S. Cl.** **61/35**
[51] **Int. Cl.** **E21f 15/08**
[58] **Field of Search** 61/35, 36; 169/2

[56] **References Cited**

UNITED STATES PATENTS

2,710,232	6/1955	Schmidt et al.	61/35 UX
3,440,824	4/1969	Doolin	61/35
3,459,003	8/1969	O'Neal	61/35
3,500,934	3/1970	Magnuson	61/35 X

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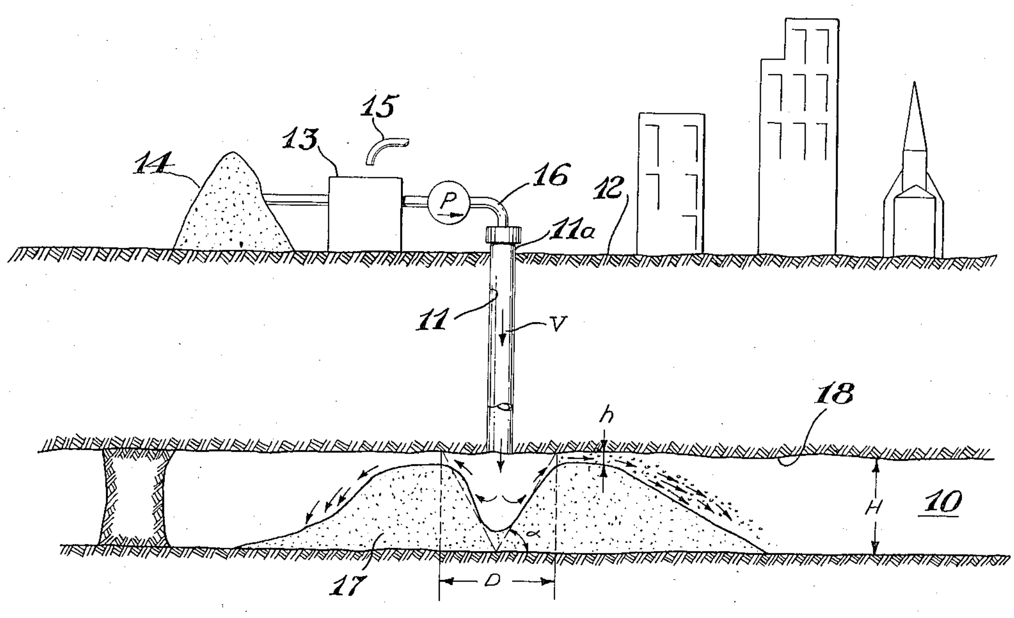
[57] **ABSTRACT**

A method is provided for backfilling a subterranean void, e.g. a mined out cavity such as a tunnel, etc. An aqueous suspension of solid particles (fill material) is injected through a conduit which connects the void with a suitable work surface (said conduit and void consisting of a closed pressurized system during injection) and into the void at a certain critical minimum rate.

1 Claim, 1 Drawing Figure



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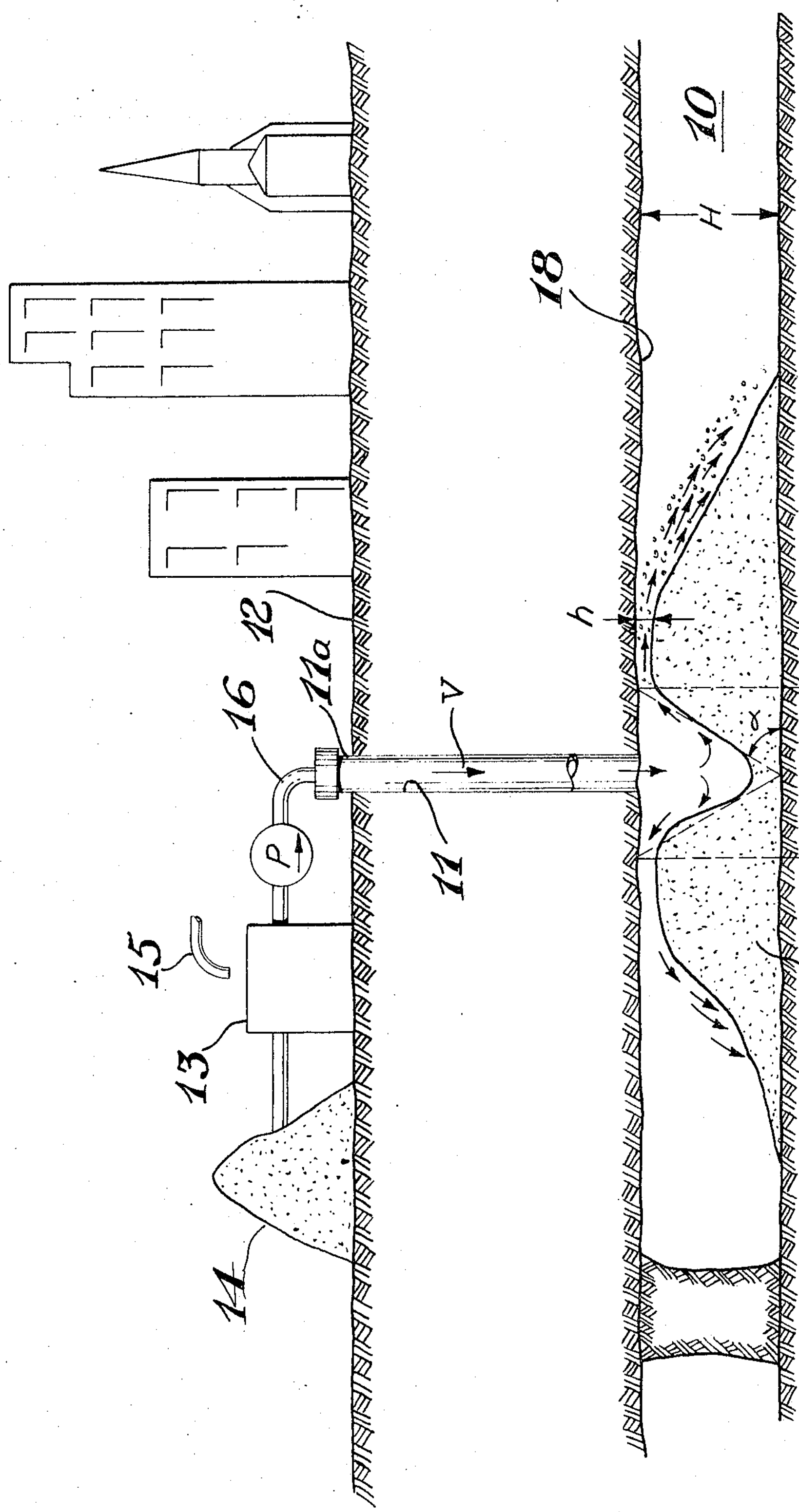

METHOD OF FILLING SUBTERRANEAN VOIDS WITH A PARTICULATE MATERIAL

CROSS REFERENCE TO RELATED APPLICATION

The present application is a continuation-in-part of patent application Ser. No. 86,755, filed Nov. 4, 1970 now Pat. No. 3,817,039.

BACKGROUND OF THE INVENTION

The problem of surface subsidence due to the collapse of underground voids is as old as the mining industry itself. The magnitude of the problems associated with mine collapse, including a digest of some of the methods which have been employed in an attempt to alleviate the problem, and immediate apparent needs have been recently reported by the United States Bureau of Mines in a report entitled "Investigation of Subsidence in Rock Springs, Sweet Water County, Wyoming" by Donner and Whaite.

Earth strata overlying mine voids are subjected to collapse at some point in time following the actual rock or mineral removal. The general understanding is that once the natural support is removed by mining, the weight of the overburdened is redistributed. Pillars of unmined material, if insufficiently strong, eventually disintegrate and allow overlying strata to break and fall into the voids. Excessive extraction widths between pillars can cause the roof over the mine area to collapse even through the pillars may be of sufficient strength to support the additional weight. The height of the mine void is an important factor and influences the distance above the void that breakage occurs. If this height is great enough caving may extend upward through the total overburden and cause subsidence at the surface.

The time which elapses between the creation of the void and the subsidence at the surface may vary from a few days to several years depending on such factors as the nature of the overburden, the depth below the surface of the mining operation, the size of the voids created.

If a sufficient height of the void is reduced by filling the void with a filler, e.g., sand, gravel, cement, fly ash, crushed slag, limestone, etc., then an equilibrium of the stresses in an overlying strata can occur before breakage reaches the surface. Complete filling of the voids can substantially eliminate surface subsidence.

Several methods have been developed in an attempt to fill mine voids. These methods are generally broken down into two general classes. One is called controlled back filling. This method can only be employed where the underground void is accessible to workmen which in many instances is impossible or at least highly impractical because of cave-ins, flooding and the like.

Blind flushing in the second general method employed. In this method several techniques have been proposed to fill a void. The most common method has been to drill an injection hole from the surface of the ground to connect with the void and then sluicing a slurry of particulate material into the void by gravity flow. By sluicing, a conical shaped bed of material is emplaced directly under the borehole and for a very limited distance therefrom. The area of support generally depends on the natural angle of repose of the material in air or water, the size of the void, and the depth of the bed. Several materials are employed in these sluicing methods. Generally sand, gravel and fly ash are chosen. A variation of this method is disclosed in U.S. Pat. No. 1,404,112. Another technique is disclosed in U.S. Pat. No. 3,421,587 wherein fly ash or another equivalent very fine particulate material is blown into the void. The particulate material is very fine, normally of a size such that 90 percent will pass a **50** mesh screen and 75 percent will pass a 325 mesh screen. Another technique for emplacing a particulate material is disclosed in U.S. Pat. No. 3,440,824. In this method a slurry of solid material and water is pumped downwardly through a conduit inserted in a borehole and the slurry is physically directed towards a second borehole by means of a variable direction nozzle attached to the lower end of the conduit and extending into the cavity. Excess slurrying liquid, e.g., water, is pumped outwardly through the second borehole to create a current between the two boreholes which it is alleged aids in distributing the solid material in the void.

The above-described methods generally represent the known techniques which are employed in an attempt to prevent subsidence caused by underground cavities and voids. All of these methods, however, suffer from some disadvantage. First, the radial distance around the borehole which can be essentially completely filled is relatively limited. Secondly, it is usually different to substantially fill the void to the ceiling. Thirdly, many boreholes must be provided when the void to be filled extends over a great distance. This latter disadvantage is particularly troublesome when the void is located beneath a populated area since structures, streets and the like prevent the drilling of a necessary number of boreholes. For example, it has been reported in the Bureau of Mines Report, cited previously, that in Rock Springs, Wyoming that if a blind sluicing method was employed as many as 3000 boreholes would be required (as many as 75 in a single square block area) to treat 200 acres of land. Even with this many boreholes the voids cannot be completely filled and support is provided only under the streets, alleys and other areas of public access. Only a very limited amount of support for structures, e.g., dwellings and the like, can be provided.

In practicing the principles of the present invention one injection borehole can replace as many as **75** or more boreholes required when employing a sluicing method. Moreover, a more complete filling of the void is accomplished.

It has been discovered that a subsurface void can be substantially completely filled to the ceiling thereof with a particulate material for an extensive radial distance surrounding a single injection conduit. This radial distance can vary anywhere from 100 to more than 1000 feet from the injection conduit. Moreover, obstructions such as remaining pillars and cave-ins will not prevent or otherwise affect the filling of the void. The area of the void located behind pillars (not in line-of-sight from the injection borehole) are readily filled by practicing the principles of the present invention.

SUMMARY OF THE INVENTION

As employed herein "minimum linear velocity" is the minimum velocity at which a suspension of particles must be conducted through a generally horizontally displaced conduit so that no substantial deposition of particles from the suspension onto the lower portion of the conduit to form an essentially stable layer occurs. For any given suspension a "minimum linear velocity" can be experimentally determined. In turn suspension means a liquid medium having dispersed therethrough solid particles, said suspension being provided by physical means, e.g. turbulent mixing, as opposed to the use of thickening or gelling agents, although thickening agents may be used as an aid in forming a suspension as employed herein.

In the practice of the present invention an aqueous suspension of solid particles is injected through a closed pressurized system, i.e., through a conduit, into a subterranean void at an injection rate such that the initial velocity of the suspension in the void is below its minimum linear velocity so as to initially deposit on the floor of the void at least a portion of the solid particles to form a mound below the conduit. The rate, however, is sufficiently great that upon the restriction of the cross-sectional area of the void by the deposited solids i.e., mound, the velocity of the suspension over the deposited particles increases to a value at least as great as its minimum linear velocity to carry additional particles over the mound to an area of greater cross-sectional area whereupon additional particles are deposited to increase the size of the mound. The method can be employed to rid the surface of waste heaps, e.g., tailings, and the like to improve environmental conditions existing on the surface of the ground.

For a background of the various investigations and experiments relating to the flow of suspensions, e.g. the determination of the minimum linear velocity of particular suspensions, reference may be had to the following articles found in the literature: "Prop-Packed Fractures - A Reality On Which Productivity Increase Can Be Predicted," E. N. Alderman and C. L. Wendorff, *The Journal of Canadian Petroleum Technology*, pp. 45–51, January-March, 1970; "The Mechanics of Sand Movement In Fracturing," L. R. Kern et al., *Journal of Petroleum Technology*, pp. 35–57, July 1959; "Sand Movement In Horizontal Fractures," Harry A. Wahl et al., *Journal of Petroleum Technology*, Vol. XV, No. 11, pp. 1239–1246, November, 1963; "How To Handle Slurries," Richard LeBaron Bowen Jr., *Chemical Engineering*, Vol. 68, pp. 129–132, Aug. 7, 1961; and "Design So Solids Can't Settle Out," J. G. Lowenstein, *Chemical Engineering*, Vol. 66, pp. 133–135, Jan. 12, 1959.

BRIEF DESCRIPTION OF THE DRAWING

The DRAWING illustrates the filling of an underground void employing the principles of the present invention wherein the suspension is injected through a substantially vertical borehole into a mined out void.

PREFERRED EMBODIMENTS OF THE INVENTION

In the practice of the present invention a conduit is first provided connecting a suitable work surface with the void to be filled. The conduit can be made by drilling a substantially verticle bore from the surface of the earth to connect with the void (as shown in the FIGURE) or other suitable connections can be made (e.g., above the roof of the void or the like). The conduit is, however, connected to the void in such a manner that a closed pressurized system is provided between the void and the injection equipment, e.g., pump, when the suspension is injected therein. The work surface can be the surface of the earth, the floor of an accessible void, e.g., tunnel, located above the void to be filled or the like.

A suspension of solids is then prepared in any suitable manner. For example, a particulate material, e.g., sand, and a carrying liquid, e.g., water, brine, etc., is mixed together (e.g., in a blender such as employed in gas and oil well fracturing operations) with sufficient turbulence to provide a suspension. The suspension is then conducted through connecting pipes or the like, and through the conduit connecting the work surface with the void at a velocity through the connecting conduit which is at least equal to the minimum linear velocity of the suspension.

The particulate material can be any solid having a density greater than the carrying liquid. The particles can range in size from about minus 3 to about 300 mesh U.S. Standard Sieve Series. For example, fly ash, sand, crush slag, limestone, gravel or other similar material can be used. When the method is employed to improve the environmental conditions located at the surface particulated tailings, trash and other wastes can be properly particulated and employed as the fill material. The exact composition of the solids is not critical to the practice of the invention. However, it is usually preferred to employ a non-cementitious material of such a particle size that the mine void remains permeable to the flow of subsurface fluids. If a non-permeable fill is used damaging pressure may be built up causing adjacent mine flooding or the like. Usually a particulate material which is most readily available to work site is used.

The carrying liquid is preferably an aqueous liquid, e.g., locally available water or brines being preferred.

The concentration of the particulate solid in the suspension is not critical to the practice of the present invention. Generally a concentration of about 0.5 pounds of particulate solids per gallon of aqueous solution to about 10.0 pounds/gallon can be employed. The amount of solids influences the rate at which the void can be filled employing a certain injection rate. The maximum amount is dependent on the equipment employed to pump the suspension. For example, a ratio of particulate material to the carrying liquid (by weight) should not exceed about 1 to 1 for practical handling. Preferably a ratio in the range of 1:8 to about 5:8 (solid to liquid) is employed.

The suspension having the characteristics hereinbefore defined is conducted through the conduit connecting the work surface with the void at a sufficient rate such that upon being ejected from the conduit and into the void at least a portion thereof is propelled through the void at a velocity at least equal to the minimum linear velocity of the suspension.

The minimum rate at which the suspension must be injected can be readily determined by employing, for example, the following formula which is adaptable to a filling operation wherein a substantially vertically displaced cased injection conduit is employed. The formula is $V = Xd \pi Dv$ wherein V is the injection rate of the suspension (for illustrative purposes in cu. ft/min.); X is a number of 3 or greater (this factor relates to known relations between particle diameter and the tendency to bridge in a confined space; d is the diameter (in feet) of the largest particles in the suspension; D is the diameter of the base of a cone formed by a mound of the particles employed in the suspension having a height equal to H (wherein H is equal to the height of the fill desired in the void) with a natural angle of repose α; and v is equal to the minimum linear velocity of the suspension. As applied to the filling of a void through a substantially vertical conduit, as shown in the Figure, D is the diameter of the base of the inverted cone formed by the crater shaped mound **17**, wherein H is taken to be equal to the height of the void **10.** It is evident that the diameter of the base of the inverted cone (shown in the drawing) is essentially equal to the diameter of the base of the cone shaped mound formed by particles in the non-moving carrying liquid employed to suspend the particles, i.e., dependent on the natural angle of repose of the solids in the liquid.

The suspension is introduced into the void until a certain desired area of the void has been filled with particulate material to a desired height (preferably to the ceiling thereof).

It is theorized that the void is filled with the particulate material in the following manner. The suspension is continuously being introduced into the void. When the suspension is first emitted from the injection conduit and strikes the floor of the void, the initial velocity of the suspension is below its minimum linear velocity (because of the difference in cross-sectional area of the injection conduit and void) and a certain amount of the particulate solids will settle out to form a stable mound on the floor of the void. The mound will continue to increase in height and the cross-sectional area of the passageway between the top of the mound and ceiling of the void will decrease until the velocity of the suspension moving over the rim of the mound increases to at least its minimum linear velocity. When the suspension reaches such a velocity particles are carried over the rim of the mound and are deposited on the outer edge thereof where the velocity of the suspension again is below the minimum linear velocity. This is a continuous condition which is controlled by the rate at which the suspension is being introduced into the void. The mound will continually grow in a radially random direction away from the outlet of the injection conduit until the distance therefrom is such that the velocity of the suspension cannot be maintained above its minimum linear velocity.

Thus, the distance that the void can be filled is dependent on the rate at which the suspension is injected into the void.

The "minimum linear velocity" for any particular suspension can readily be experimentally determined or it can be determined by employing formulae known in the art which have been developed by investigations such as those taught in the references hereinbefore cited. The minimum linear velocity for any particular suspension can be readily determined by simple laboratory procedures, for example, as described hereinafter.

One embodiment employing the principles of the present invention is shown in the FIGURE. It is desired to fill the mined-out void **10** substantially to the ceiling thereof with a particulate material (e.g., sand). The height of the void is designated by the letter H. An injection conduit **11** (e.g. ranging in size from about 16 to 20 inches in diameter) is provided, e.g. by drilling, to connect the void **10** with the working surface **12**, in this instance the surface of the ground. The borehole is also normally cased with inner pipe **11***a* (e.g., ranging in size from about 12 to 14 inches in diameter). The size of the injection conduit **11** is only limited by the equipment which is available to mix and inject the suspension. The system is connected in such a manner that when the suspension is injected through a closed pressurized system an aqueous suspension of a particulate material is injected (e.g., by pumping) through the conduit **11** and into the void **10.** The mixing, supply sources (e.g., sand and water), and injection equipment are schematically shown in the FIGURE as **13, 14, 15** and **16**, respectively. As the suspension is injected down the conduit **11** at the predetermined critical injection rate a donut shape mound **17** of particulate material is formed on the floor of the void. As the mould increases in height the distance (h) (and cross-sectional area) between the rim of the mound **17** and the ceiling **18** of the cavity decreases causing the linear velocity of the suspension to increase in a value above its minimum linear velocity and particulate material will be carried over the rim of the mound. To assure that the minimum linear rate will be reached in the void the suspension can be injected through the conduit **11** at a rate at least as great as the minimum linear velocity of the suspension. Thereafter the linear velocity of the suspension will again drop below its minimum linear velocity causing a further settling of material with a subsequent growth in the radial size and height of the mound. The mound progresses out in a random fashion radially from the injection conduit **11.**

The suspension is injected for any desired length of time, or until a certain desired area of the void is filled with the particulate material, or until the distance from the borehole is such that there is insufficient available hydraulic horsepower to extend the mound further.

As previously indicated the rate at which the suspension is injected through the injection conduit **11** is critical to the practice of the present invention and, for example, can be calculated for any fill material employing the following formula: $V = Xd\,\pi\,Dv$. Also, the suspension can be injected through the injection conduit at a rate at least equal to the minimum linear velocity of the suspension through a conduit having a diameter equal to the diameter of the injection conduit.

As can be seen the critical value V is not dependent upon the size (i.e., cross-sectional area) of the injection conduit **11.** However, from a practical standpoint the conduit cannot be so large that there is inadequate horsepower to inject the suspension at the required rate or so small that sufficient pressure is built up to fracture the formation around the hole or in the void.

For illustrative purposes, the application of the above-defined formula employing a suspension of sand and water to fill a void having a height (H) of 6 feet is defined hereafter. Injection rates V for various size ranges of sand are calculated and set forth in the following Table I. The angle of repose and minimum linear velocity v of the suspension were experimentally determined. The value for V is calculated for an X value of 3 and 10. The minimum linear velocity of the suspension (v) was determined experimentally by pumping a suspension of sand and water (in a concentration of 2.5 pounds and sand/1 gallon of water) through a 4 inch inside diameter pipe held in a substantially horizontal position. The velocity of the suspension was adjusted until a layer of sand started to deposit on the bottom of the pipe. The velocity of the suspension was then increased until no further sand was deposited and the velocity at this point was taken to be equal to the minimum linear velocity of the suspension. Since the minimum linear velocity can vary depending on the size and density of the particles, the density of the liquid and other similar parameters, the minimum linear velocity of any particular suspension should be determined prior to practicing the present invention.

The equipment employed to practice the present invention should be capable of blending and injecting a suspension of sand and water at a rate of at least up to **300** barrels per minute. As indicated blending and injection equipment of the type commonly employed in hydraulic fracturing operations (e.g., in oil and gas wells) can be used. Centrifugal type pumps are preferred since they are the most efficient presently known means for obtaining the necesasry volumes and pressures. However, positive displacement pumps, e.g., piston pumps, can be employed.

What is claimed is:

1. A method of disposing of solid waste materials and filling underground voids which comprises:

a. particulating said waste material to form solid particles ranging in size from about minus 3 to about plus 300 mesh;

b. forming a suspension of said solids in an aqueous liquid;

c. injecting said suspension through a closed pressurized system into said void in a substantially vertical direction at an injection rate at least equal to that calculated by the formula $V = Xd\,\pi\,Dv$, wherein v is the minimum rate of injection in cubic feet per minute, X is a number of 3 or greater, d is the diameter in feet of the largest solid particles in said suspension, D is the diameter of the base of a cone form by said particles when settled in said carrier liquid when motionless, said cone having a height about equal to the height of the void to be filled, and v is the minimum linear velocity of said suspension,

d. permitting the suspension to flow through said void in a manner such that the suspension seeks its own direction, and

e. continuing such injection and subsequent flow through the void until an area of the void is filled with solid particles in a pattern determined by the flow of the suspension through the void in the self-seeking direction.

TABLE I

Mesh Size	Diameter of Largest Particle Feet	D Ft	v Ft/Min	α °	Tangent α	V Cu Ft/Min $X=3$	V Cu Ft/Min $X=10$	V Bbls/Min $X=3$	V Bbls/Min $X=10$	V Gallons/Min $X=3$	V Gallons/Min $X=10$
100–200	$.49 \times 10^{-3}$	7.2	168	59	1.66	56	186	426	1380	10.2	34
20–40	2.76×10^{-3}	16	350	37	0.75	145	483	1080	3600	25.8	86
4–6	1.56×10^{-2}	18.5	840	34	0.65	2280	7600	17000	56667	40.5	1350

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,852,967 Dated December 10, 1974

Inventor(s) J.D. Stewart and M.E. Hesler

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 1, line 57, delete "in" and insert --is--.

Column 6, line 13, delete "mould" and insert --mound--.

Column 7, line 27, delete "necesasry" and insert --necessary--.

Column 8, line 4, delete "v" and insert --V--.

Column 8, heading of columns 7 & 8 of Table I, delete "Gallons/Min".

Column 8, heading of columns 9 & 10 of Table I, delete "Bbls/Min" and insert --Gallons/Min--.

Column 8, heading of columns 11 & 12 of Table I, insert --Bbls/Min-- under "V".

Signed and sealed this 1st day of April 1975.

(SEAL)
Attest:

RUTH C. MASON
Attesting Officer

C. MARSHALL DANN
Commissioner of Patents
and Trademarks