Jan. 31, 1967 A. L. ARMENTROUT 3,300,984

SUBTERRANEAN DAM AND METHOD OF MAKING THE SAME

Filed July 5, 1966

Fig. 1.

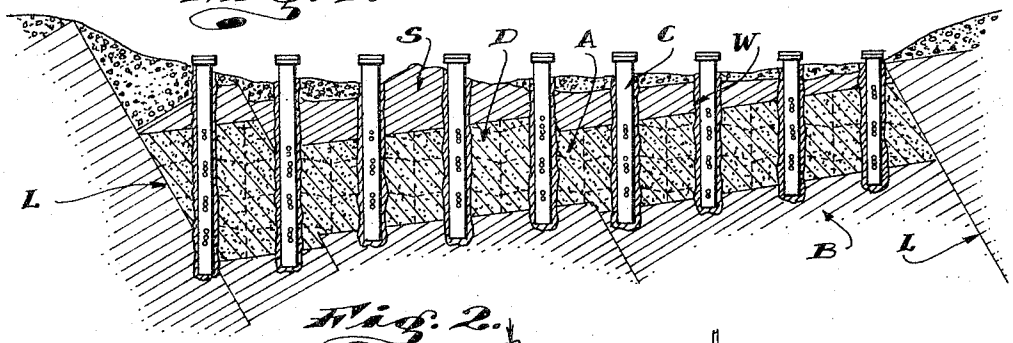


Fig. 2.

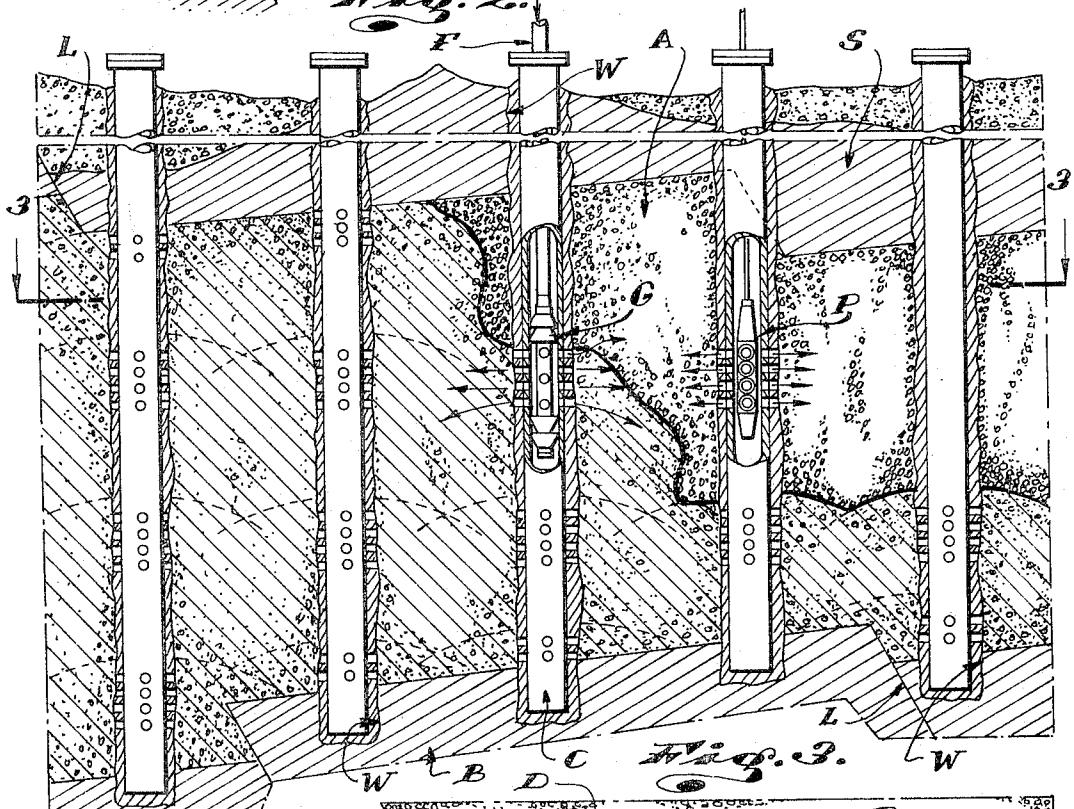
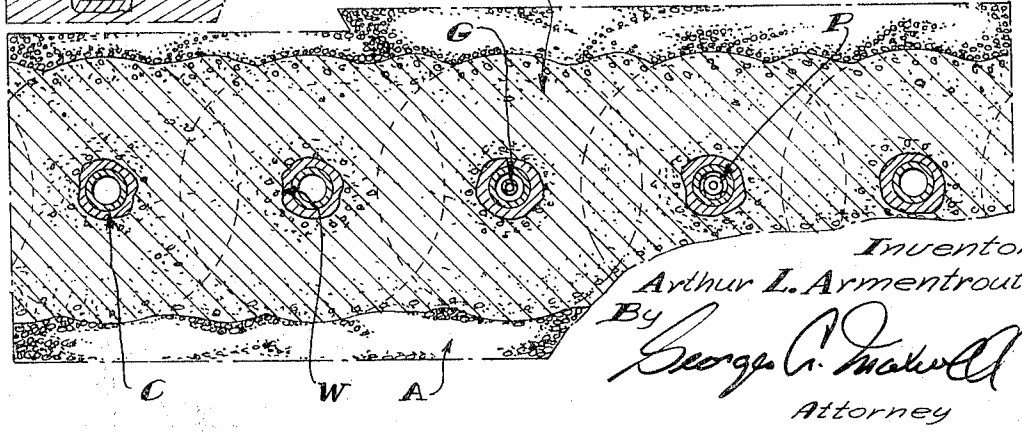


Fig. 3.



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SUBTERRANEAN DAM AND METHOD OF MAKING THE SAME

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5 Claims. (Cl. 61—1)

This invention has to do with subterranean dams and is more particularly concerned with a novel method of establishing the same.

In many places throughout the world where fresh water is in short supply, there are underground or subterranean streams and rivers which flow through aquifers in the earth's formation. Such aquifers are ordinarily established of pervious beds of boulders, gravel and sand, contained at their tops, bottoms and sides by impervious beds or layers of clay.

Frequently, these aquifers are several hundred feet under the earth's surface and conduct the water flowing therethrough into the sea or ocean below the sea level. Such aquifers may be from a few feet in vertical thickness to several hundreds of feet, and from a few hundred feet to several miles in lateral width.

In the event of over-production of fresh water from aquifers, as by means of wells, the flow of water is reversed and salt water from the ocean moves back or upstream into the aquifer.

For example, the above-noted condition exists in the Oxnard Aquifer, in the County of Ventura, State of California. Here the seawater is advancing or intruding into the aquifer at a rate of about four feet per day and over 8,000 acres of very valuable farmland are underlain by poisoned or salted out sections of aquifer.

The above example is but one of many such situations existing throughout the world, and which present a major threat to a larger portion of the world's fresh water supply.

It has long been known that great quantities of fresh water, now flowing through aquifers beneath the earth's surface, but not readily recoverable for one reason or another, could be made available for use if one could effectively establish a dam in the aquifer so as to capture the waters, upstream of the dams and effectively raise the water level to an extent where pumping could be effective by means of wells.

In several places, attempts have been made and are being made to dam fresh water aquifers for the purpose set forth above, by digging trenches in the earth, from its surface, to intersect the aquifers to be dammed and filling the treaches with suitable dry clays, such as bentonite clays, to establish cut-offs or dams therein. This method has proved to be reasonably effective in certain and limited situations where the aquifers are extremely shallow and very close to the surface of the earth. Such trenching procedures are not practical or feasible in situations where the aquifers are of any substantial depth, or where the aquifers are beneath the surface of the earth any great distance. It will be apparent that the above-noted method of damming an aquifer is materially limited and restricted by the limits to which trenching machines and the like can be effectively employed.

An object of my invention is to provide a strong and effective cut-off or dam in an aquifer below the earth's surface.

Another object of the present invention is to provide a structure of the character referred to which is such that it can be rapidly established, requires but a reasonable and practical amount of damming or cut-off material and is such that it is economically feasible and practical to establish.

An object of the invention is to establish a dam of

the character referred to by drilling a plurality of wells across an aquifer to be dammed in close proximity to each other and which extend into the rock or clay bed at the base of and underlying the aquifer.

A further object is to case the wells and to cement the casings solid on the outside in the formations through which the wells extend by the methods of cementing, which are well known and practiced in the art of establishing oil, gas, and water wells, and so as to prevent displacement of the casings.

Still another object of my invention is to perforate the casings of the wells and the cement in which they are set by means of perforating methods and apparatus, which are well known in the well drilling art.

It is yet another object of my invention to provide a method wherein the set casing of each of the several wells is first perforated adjacent the bottom of the aquifer and first or primary lower masses of damming material are injected into the aquifer through the wells to extend continuously across the bottom thereof and to subsequently perforate the casings of the several wells above each previously deposited mass or masses of material whereby a vertical, impervious dam structure built up of layer upon layer of damming material is established from the bottom of the aquifer to the top thereof or to a predetermined height therein.

It is an object of my invention to employ a damming material having chemical properties whereby the material can be initially mixed with water to establish a pumpable slurry for the purpose of injecting it into the aquifer to be dammed and is such that it will, in a predetermined period of time, after it is injected into the aquifer, set up and harden into a firm pliable plastic mass to establish a dam structure, the shear strength of which is sufficiently great to withstand the highest hydrostatic pressures to which the dam might be subjected and a structure which is not subject to being blown out and washed away, through the aquifer, by the body and head of water it is intended to dam and hold.

Another object of the present invention is to employ a material of the character referred to which, when set up, is sufficiently strong so that the width of the dam to be established can be maintained at a minimum whereby the volume of material required to establish the dam is reduced to a low, reasonable and feasible amount.

It is a further object of the invention to establish a thin, strong and durable dam structure in an aquifer by injecting pumpable slurries of chemically active clays which will set up and harden into firm, but somewhat flexible plastic masses after they are injected into a formation, in vertical and longitudinally spaced, intimately joined together deposits along a vertical plane extending transverse the aquifer.

Yet another object of my invention is to provide a method of the character referred to wherein, under most desirable circumstances, the wells are spaced a distance equal to approximately the width of the dam to be established whereby the radial flow of damming material into the formation of the aquifer from each well, towards each adjacent well, joins and builds up with the flow and deposit of material from each of said adjacent wells to build up and establish a damming structure in the formation of the aquifer of substantially uniform desired width intermediate the wells.

The foregoing and other objects and features of my invention will be fully understood from the following detailed description of a typical preferred form and application of my invention, throughout which description reference is made to the accompanying drawings, in which:

FIG. 1 is a diagrammatic sectional view of an earth formation with a dam structure as provided by the present invention established in a fresh water aquifer therein;

FIG. 2 is an enlarged view of a portion of the structure shown in FIG. 1, with parts thereof shown in section to better illustrate the details of the invention; and,

FIG. 3 is a sectional view taken as indicated by line 3—3 on FIG. 2.

In the drawings, I have illustrated a typical fresh water aquifer A of sand, gravel or other porous earth formation through which water can freely flow and arranged between a surface layer S and a bed layer B of earth, established of rock or clays and through which water cannot flow.

The top surface of the bed layer B and the bottom surface of the surface layer S are not smooth, even or uniform and have high and low spots and/or portions.

In the case illustrated, and as is frequently the case, the sides of the aquifer are defined by faul lines L in the earth's formation.

In carrying out the present invention, and to establish a cut-off structure D in the aquifer A, a plurality of wells W are drilled and established in the earth along a line extending transverse or from one side to the other of the aquifer. The wells enter the top of the overburden or surface layer S, extend through the aquifer A and enter the bed layer B.

In accordance with conventional well drilling methods and construction, the wells are provided with steel casings C and are cemented in the formations through which they extend to anchor and hold them in fixed position. The wells W are drilled, cased and cemented in accordance with well known well drilling equipment and well known drilling practices or procedures, which need not be amplified for the purpose of this disclosure.

In practice, the lateral space of the several wells is determined by several factors. The most significant or important of these factors are the length, width and depth or vertical extent of the aquifer, the permeability and porosity of the formation of the aquifer and its ability to accept the damming material to be injected into it, the viscosity and shear of the material at the time of injection, the ultimate height of the damming structure and the resulting pressures to which the dam structure will be subjected, the stability of the aquifer and the shear strength of the damming material after it is set in the aquifer.

The porosity of most of the aquifers with which applicant is familiar is about thirty percent. In practice, and in carrying out this invention, the permeability and porosity of the aquifer to be dammed can be determined by coring and sampling the aquifer. Such coring and sampling, where circumstances required, can be performed at each well site.

The above and other related factors must be considered, properly weighed, and balanced in any given case, with the view of establishing the desired dam structure with a minimum amount of material and a minimum number of wells.

It is to be noted that the wells W to be drilled are generally relatively shallow wells, a few hundred feet deep, which can be drilled and established rapidly and inexpensively and are not to be likened to or compared with deep oil wells and the like, the costs of which are great.

The greatest cost or expense in carrying out the present invention is the cost of the daming materials and the cost of pumping that material into and through the formation of the aquifer A to establish a damming structure of desired and sufficient width, height and length therein.

Accordingly, the principal factor to be considered in determining the longitudinal placement and the ultimate number of wells W which must be established along the line of the dam site is the required length of the dam structure to be established.

Assuming that the dam D to be established in the aquifer A must be a minimum of twenty-five feet wide in order to be of sufficient strength to function properly, due consideration having been given to the strength of the damming material and the nature and stability of the aquifer, the damming material must be forced and injected into the formation to flow radially outwardly fifteen feet from each well. In such a case if the wells were on thirty foot centers, the deposit of material in the aquifers, from each well would only touch, tangentially, with the deposit from adjacent wells and a damming structure thirty feet wide would not be established. However, if the wells W are on twenty-five foot centers, a fifteen foot radii flow of material from adjacent wells would meet, overlap five feet and build up to force the material between the wells laterally of the longitudinal line of the dam and would result in a dam which is substantially twenty-eight feet wide throughout its entire longitudinal extent.

In accordance with the above, it may be stated as a general rule that the wells W, in the absence of special and unique circumstances, spaced apart longitudinally of the dam structure, are preferably spaced apart a distance equal to approximately the width of the dam.

In establishing a dam substantially twenty-eight feet wide in an aquifer having a porosity of 30%, through wells on twenty-five foot centers, 212 cubic feet of damming material should be injected into the formation at each well for each vertical foot of dam structure. Accordingly, it would require 848 feet (cubic) of material for each lineal foot of a dam structure one hundred feet in depth, twenty-eight feet wide and 84,800 cubic feet of material for each one hundred lineal foot of such a structure. It will be apparent that such volumes are not excessive or impractical.

In practice, when the formation of the aquifer and/or the damming material employed presents special and unique problems, the wells can be placed closer together or farther apart as circumstances require or demand.

The first or primary perforating operation is restricted or limited to the lower end portion of each well immediately above the bed B, and is but the first of several subsequent perforating operations which will be performed in that well and each of the other wells as the method of establishing the dam is carried out.

In practice, perforating the casing is carried out by a perforating gun or tool P of any desired form and construction. Since the tool P forms no part of the instant invention, detailed description thereof will be dispensed with.

When the first well or wells to be perforated have been perforated, a slurry of damming material is pumped through the well or wells, through the perforations and into the formation of the aquifer. A predetermined volume of such material is injected into the formation to assure solid radial penetration of the material a distance laterally of the longitudinal line of the dam site, a distance equal to the ultimate width of the dam to be established. The slurry of damming material is pumped down through and into the lower perforated portion of each well casing through a string of fluid conducting pipe F entered into the well from the upper end thereof. The lower end of the fluid conducting pipe is provided with suitable packing tool G at its lower end to prevent the fluid, pumped downwardly therethrough, from flowing back up through the annulus established by the casing and the pipe.

After the lowermost portion of the dam structure is thus established, by a first layer of damming material, the casing of that well or the casings of those wells through which the first and lowermost layer of damming material was flowed, immediately above the first deposit or layer of damming material and the casings of each of the other wells having portions in the formation of the aquifer on a common horizontal plane therewith are perforated in a similar manner and slurries of damming material are injected through those wells and into the formation of the aquifer to build up and establish a next or second layer of damming material on top of and overlying the first layer and the adjacent higher surfaces of the bed B.

The above procedure is continued until all of the several wells have been perforated and the entire longitudinal

extent of the dam structure is established on the bed B. The foregoing procedure is then continued to establish layer upon layer of deposited damming material throughout the longitudinal extent of the dam until the dam is established from the bottom to the top of the aquifer and from one side to the other thereof and to any desired width and height, as circumstances require or as desired.

The damming material employed in carrying out my invention is one of those materials which is such that it can be advantageously mixed with water to make up a pumpable slurry which can be easily and conveniently injected into and through the formation of the aquifer to be dammed and is such that it will, after the passage of a predetermined time, set up and stiffen or harden so as to increase its strength and stability materially.

Portland cement would be satisfactory except for the following factors: it does not set up rapidly enough, the presence of salt water adversely affects its ability to set up, it sets up hard and rather inflexible and is, therefore, subject to cracking, and, finally, it is rather expensive.

Oxychloride cements would be very satisfactory in the presence of either salt or fresh water and will set up fairly fast, but, again, such cements are rather expensive.

In the art of oil well production and more particularly in the art of lost circulation materials for use in oil wells, there are several relatively inexpensive materials, employing clays and certain chemical additives, which can be mixed with water to establish a pumpable slurry and which are such that they will set up rapidly and firmly to establish flexible plastic impervious masses which are exceedingly stable and durable.

Several of the above-noted chemically active setting clays, which are particularly suitable for use in carrying out the instant invention are disclosed in my Patent No. 3,028,913, issued Apr. 10, 1962, and entitled Recovering ing Lost Circulation in Wells.

For the purpose of carrying out this invention, the lost circulation material set forth in Example 16, in column 8 in my above-identified patent, and which employs Sepiolite-type clays would be most satisfactory as this material works well in the presence of either salt or fresh water and its setting time can be controlled so that it will set up in seconds, a few minutes or hours. Further, this material, when set, will withstand shearing forces of at 40,000 pounds per 100 square feet, is available in great supply, and is extremely inexpensive, costing less than one-third the cost of any other material known to me, and which has characteristics which render it serviceable for carrying out the instant invention.

It is to be noted that rig time, that is, the required time to carry out the method here provided, is a major cost factor, and, as a result, it is extremely important, from an economical standpoint, that the damming material be such that it can be made to set up in seconds or minutes, rather than in hours, as would be the case with the use or employment of Portland cement.

In practice, and where circumstances require that the damming material set up at an extremely fast rate, as where there is a rather rapid flow of water through the aquifer, an accelerator, such as sodium chloride, sodium hydroxide, or another suitable material depending upon the nature of the damming material, can be injected into the formation ahead of the slurry of damming material, to saturate the formation with the accelerator and so that when the slurry of damming material enters the formation, it sets up within a matter of seconds.

After the dam is established or during the building of the dam, core samples can be taken to determine the effectiveness of the penetration of the damming material in the formation of the aquifer.

Further, subsequent to establishment of the dam, test wells downstream of the dam can be established to check on leakage, or similar wells can be established upstream from which periodic samplings of the water can be obtained to determine the impermeability of the dam, where salt water intrusion is sought to be checked, by the salt content of the water.

Having described only a typical preferred form and carrying out of my invention, I do not wish to be limited or restricted to the specific details herein set forth, but wish to reserve to myself any modifications and/or variations that may appear to those skilled in the art and which fall within the scope of the following claims:

Having described my invention, I claim:

1. A subterranean aquifer dam structure including, a plurality of wells in spaced relationship across the lateral extent of the aquifer and having casings with perforations communicating with the aquifer, said wells entering the earth's formation above said aquifer, extending downwardly through the aquifer and entering the formation below the aquifer and a plurality of vertically spaced, horizontal deposits of damming material extending radially into the aquifer from the perforations in each well casing, the deposits of each well being intimately joined together and with the deposits of each adjacent well and establishing an impervious dam in the aquifer.

2. A structure as set forth in claim 1 wherein, the wells are spaced apart a distance approximately the width of the dam and the deposits of each adjacent pair of wells meet and are displaced laterally of the line of the wells whereby the dam is of substantially uniform width.

3. A structure as set forth in claim 1 wherein, said damming material is firm, flexible, plastic clay.

4. A structure as set forth in claim 1 wherein, the wells are spaced apart a distance approximately the width of the dam and the deposits of each adjacent pair of wells meet and are displaced laterally of the line of the wells whereby the dam is of substantially uniform width, said damming material being firm, flexible plastic clay.

5. A method of establishing a dam across the line of flow in a subterranean aquifer which comprises, first, drilling and casing a plurality of wells in longitudinally spaced relationship of the dam site to enter the earth formation above the aquifer, extending downwardly through the aquifer and entering the base formation below the aquifer; next, entering a perforator into each well and perforating the casing to establish communication between the interiors of the casing and the aquifer; next, entering a fluid conducting line with a packing tool at its lower end into each well and pumping and injecting a first slurry of setting clay into the aquifer to join and seal with the base formation and to join with a first slurry of like material injected into the aquifer through each adjacent well; next, permitting said slurries to set to establish an uninterrupted first layer of firm damming material; next, elevating the fluid conducting line and packing tool and pumping and injecting a next slurry of like damming material above the preceding layer of damming material to join and seal therewith and with similar slurries injected into the aquifer through adjacent wells, permitting said next slurries to set to build up and increase the height of the uninterrupted deposit of hard, flexible damming material; next, repeating the foregoing steps of raising the fluid conducting lines and packing tools, injecting slurries and permitting said slurries to join the preceding set material and each other and permitting those slurries to set until said uninterrupted deposit of set material is built up to a desired height and width and length to establish the dam.

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