

UNITED STATES PATENT OFFICE

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EARTH EXPLORATION

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6 Claims. (Cl. 73—51)

This invention relates to methods of determining the probable productivity of oil sands from analyses of characteristics of core samples.

In drilling oil wells in fields containing gas under pressure the well is kept flooded during the drilling with water or a water-mud suspension of sufficient density to create a hydrostatic pressure sufficient to prevent the gas from escaping and the well from "blowing." After the drilling is completed, a casing is put down the well and the sides of the well are sealed off except for the layer or layers of sand at the "horizon" from which oil or gas, or both, are to be taken. But if the engineers in charge of the drilling have made a mistake as to the expected production from the horizon left exposed and the well instead of producing oil, produces water, or nothing at all, then by various relatively expensive operations the other horizons are opened up or drilling is recommenced and the well is sunk to a greater depth in the hope of finding more productive sands.

Hence in drilling a well there is need for an accurate survey of the sand formations through which the well is drilled as regards the probable productivity of the sands. By "productivity" is meant whether sand will produce nothing, gas, gas and water, gas and oil, or gas, oil and water, and the relative amounts of each such fluid. Also, the quality of the oil produced, if any, is important because production of relatively small quantities of a better grade oil might prove more profitable than production of larger quantities of less valuable oil.

To this end during the drilling operation it is customary to cut cores from sands through which the well is drilled and which are thought likely to be oil producing. But because of the difficulties in analyzing such cores and the time required for such analysis, and because of the fact that the cores are flushed by the drilling water prior to cutting and because cores cut from sands containing gas under pressure lose this pressure and so their original condition when being brought to the surface uncased, these cores have been given only a cursory examination. They are generally analyzed only by smelling them to see if they have oil, by blowing through them to see if they are permeable, and by sucking them to see if they have gas and salt water. And the results from such an analysis are followed only when they are definitely positive. And as often as not guesses made from such analysis prove wrong.

Thus, although cores give the best and most

knowledge about the condition of substrata sands, because no satisfactory methods of analysis or discovery of critical characteristics have been made, other methods of surveying the sands through which an oil well is drilled have been developed.

One of the methods recently developed is that of introducing an electrical conducting solution into the water circulated through the well and making electrical measurements supposed to reflect indications of permeability and oil saturation. But at best this type of survey is general in nature, and does not tell the relative proportions of oil, gas and water that will be produced. Such a test is made generally as a supplement to coring to aid in telling whether or not sands possible of production have been passed through without coring or proper core analyses.

Another test used is the drill stem test which is used when the driller feels his well may have reached oil-producing sand. In this test an actual sample of the fluid that sand at the well bottom produces is obtained. But this test is expensive and time consuming. Also it may be misleading because it is inclusive rather than exclusive of what may be several different layers of a formation being tested. Thus, for example, a six inch layer of "water sand" has been known to "drown out" five feet of oil-bearing sand and so temporarily condemning the horizon being tested.

Thus, although these tests now in commercial use are helpful where a well has been drilled without coring, or without adequate analyses of cores taken from the well, the tests do not take the place of coring and do not satisfactorily tell with the desired accuracy the best sands to produce from along the well length.

In the present invention characteristics of cores, critical as indicative of the oil-producing nature of the cores, are rapidly determined as the cores are taken from a well, and accurate oil production characteristics of the sands through which the well is drilled are obtained as the well is cored. From the analyses, an exploration chart of the sands through which the well is drilled may be made, as shown, for example, in Figure 1, and showing permeability versus depth and oil-producing possibilities versus depth. Thus, during the whole time in which the well is being drilled the men in charge may have before them an accurate record of the oil-producing possibilities of the sands through which the well has passed. The invention is particularly applicable to determining oil-producing characteristics of sands which contain gas and oil under pressure.

Thus one of the objects of the invention is to provide a new method of determining oil production from core analyses.

In the drawing,

Fig. 1 is a graph of a survey of an oil well made in accordance with the invention;

Fig. 2 shows partly in perspective and partly in cross-sectional elevation apparatus for measuring the bulk volume of a sample and the space of the sample occupied by a compressible fluid; and,

Fig. 3 shows in vertical cross section apparatus for determining oil and water saturations of a core sample.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawing.

I have discovered in dealing with cores cut from sands containing gas, free or dissolved and under pressure (often as high as 300 atmospheres) and raised to the well surface in an uncased condition that a relationship exists between the percent free gas content in the core, the permeability of such cores, the pore contents, and the probable producing characteristics of the sand from which the core was cut, and that this relationship can be used as an index of the substrata sands to prophesy whether they will produce nothing, gas, gas and water, gas and oil, or a mixture of gas, oil and water, and proportions of production. Further, I have discovered a rapid method for analyzing the free gas content and permeability so that this index may be plotted at the well as rapidly as the cores are taken out. Further, I have discovered rapid methods for making such further analyses as, for example, percent oil saturation and percent water saturation, as may be desired when additional information is needed. These latter inventions are described in my co-pending divisional application Serial Numbers 351,891 and 351,892, both filed on August 8, 1940.

The graph or exploration chart shown in Figure 1 is illustrative of the kind of chart that may be obtained. When the readings on the chart are interpreted in the light of the following interpretation Table A, the exploration chart indicates the type of fluid production to be expected from the sands that have been cored. The ranges given in Table A may vary within different fields but may be readily ascertained in a new field by noting production data of a few typical wells surveyed in accordance with the invention.

TABLE A

	Pore contents of core	Free gas in core	Kind of production
		Percent	
I	1. Water+gas.....	0-8	Water.
	2. Water+gas.....	8+	Gas.
II	1. Water+oil+gas.....	0-4	Water.
	2. Water+oil+gas.....	4-6	Doubtful.
	3. Water+oil+gas.....	6+	Oil+gas.

The above Table A may be used as a standard for comparison, for example, for the Gulf Coast and oil fields having similar producing characteristics and applies in instances where the core sample is raised to the surface uncased and in a flushed condition, although if the amount of flushing is small the values may be increased.

In interpreting data obtained from the core analysis in terms of Table A, when doubtful cases are encountered the depth, oil gravity and the irregularity of gas content throughout the section being cored, are made conditioning variables and

if favorable may make the doubtful determinations positive. Thus, for example, lower gas contents are observed as being normal for shallower wells. Also sands producing an oil of a lower A. P. I. gravity generally contain lower gas contents.

It is noted, in referring to Figure 1, that the permeability is given in terms of millidarcys determined by known procedure by the flow of air through the sample. It is well established that a permeability of above a hundred millidarcys is often necessary for a commercial rate of production. Thus, even though the gas content of the sand indicates oil-producing sand, if the permeability of the sand is not sufficiently high the rate of oil production might be so slow as to prevent its being a commercially productive sand.

The usual procedure for obtaining the permeability is slow and applicable only to solid sands in contradistinction to soft sands. I have developed a method of determining whether or not a sand is sufficiently permeable to produce commercially by noting the length of time required for a non-compressible fluid to enter and compress gas in pores in a core sample. Further, this determination is made simultaneously with the gas content determination. If, for example, under a pressure of about 30-50 atmospheres the non-compressible liquid fills up the pores almost instantly the sample has a permeability sufficiently high for commercial production. Likewise, if 95% of the liquid under 50 atmospheres enters the pore space in less than one second, the permeability is sufficiently high for commercial production. If, however, the time required for filling the pores with the liquid under 50 atmospheres pressure is in excess of 5 seconds, this is definite indication of permeability unfavorable to commercial production, particularly in the Mid-Continent and Gulf Coast fields. Hence, although the graph shown is plotted in terms of millidarcys, the permeability could be plotted in terms of "permeability satisfactory or unsatisfactory to commercial production" and from data obtained as above described.

Referring again to Fig. 1, the chart contains not only the permeability and free gas curves, but also the percent oil saturation curve obtained from analytical methods to be described. The results plotted are similar to those obtained from actual practice in accordance with the present invention.

In the graph of Figure 1, the letters at the side indicate the following: "O. P."—oil-producing sands; "G. P."—gas-producing sands because of lack of sufficient oil; "W. P."—water-producing sands; "D. P."—sand of doubtful productivity (further analyses needed); and "N. P."—sands having no fluid production because of lack of permeability.

The presence of connate water in most all oil-bearing sands has been well established, but I have discovered that when the amount of water (connate water plus any drilling-mud water that may have seeped into the pores) in the pores gets above 70% (i. e. occupies 70% of the pore space), there is likelihood of water being produced rather than oil, even though oil be present. Thus the water content of the core may often become an important consideration.

I have discovered further that a relationship exists between the ratio of free gas to oil in the core and the probable gas-oil ratio under which the well will produce. The higher the free gas-

oil ratio in the cores the higher will be the gas-oil ratio of the flowing well. Inasmuch as a minimum amount of gas should be produced with each barrel of oil to secure the best yield, this in an important index and is a better index than the commonly used percent oil per bulk of core.

In connection with the method of determining sand productivity characteristics above described, I have discovered a rapid method of determining the free gas content of cores, which method is satisfactory whether the sands are solid or soft. One embodiment of this method comprises measuring the volume of a sample of the core by liquid-displacement and in such a way that the free gas content of the sample is not interfered with, and subsequently measuring the volume of space occupied by the gas. In the present embodiment this is accomplished by compressing the gas with a non-compressible liquid in which the sample is immersed, by forcing the liquid into the pores to supplant the gas, and measuring the volume of the liquid required to supplant the gas. The reading thus obtained is then translated into percent gas per unit volume of sand which itself I have discovered serves as a good indication of the probable oil-producing characteristic of the sand. The results may then be checked further with a standard for comparison such as given in the above Table A.

By measuring the rapidity with which the non-compressible liquid under constant pressure enters the pores, an index is obtained of the permeability of the sample which indications may be used as above discussed.

In using this method of analyzing the free gas content and the permeability of a porous body, it is desirable to use a liquid which does not chemically react with the materials comprising a sample and which has a surface tension such that the liquid does not penetrate the pores without being forced into them. One liquid that I have found which fulfills these requirements is mercury.

Other liquids, however, may be used which have a surface tension such as to wet the sample being analyzed, and when using such liquids the sample may first be coated with collodion which may serve to prevent the sample from being wet by the liquid but which does not prevent subsequent penetration of the liquid through the coating.

In carrying out the method a sample chamber having a suitable air vent at its top and an inlet in its bottom is shaped so that as a non-compressible liquid is flooded into the chamber through the bottom, all gas is driven out of the chamber ahead of the liquid, as the liquid reaches the vent. The amount of liquid thus required to fill the chamber is suitably measured and the liquid is then at least partially withdrawn from the chamber.

A core sample is now suitably shaped and trimmed to eliminate pits and cavities on its surface that might retain air bubbles and reduced to a size receivable by the sample container. The sample is then weighed and placed in the container. The liquid is again flooded into the chamber and the amount of liquid required to fill the chamber with the sample is noted, the difference between this reading and the former reading being a measurement of the volume of the sample. The vent is now closed and the liquid is subjected to a pressure of, for example, 50 atmospheres, which causes the liquid to penetrate the pores compressing and supplanting the gas

present so that it occupies one-fiftieth of the volume that it normally would occupy at atmospheric pressure. The volume of the liquid thus entering the pores of the sample is measured and may be corrected upwards by two percent to compensate for the residual volume of the gas at 50 atmospheres.

From this reading and the former reading of the volume of the sample is obtained the fraction of the core volume occupied by free gas. In addition, the rate at which the liquid enters the core pores under 50 atmospheres of pressure is noted to determine the permeability of the sample.

Referring to Fig. 2, the apparatus is shown for carrying out the method described above. A sampling chamber generally indicated at 10 is connected through an inlet 12 with a plunger chamber indicated at 14, of a mercury pump. The chamber 10 is closed at its top by a suitable cover plate 16 which may be bolted in place by bolts 18 after the sample is placed in the chamber. The joint between cover and chamber is made fluid-tight by a suitable gasket 20. The inside of the cover is conically shaped, as shown, and provided with a small vent 22 at the apex of the cone. The small outlet may be closed off by a needle valve 24 which is suitably threaded down through a support 26 to set in the opening 22.

With this construction the sample may be placed in the chamber while the chamber is empty by simply removing the cover 16 and then bolting the cover back on. It is possible to tell when the chamber is full of mercury with no occluded air by filling the chamber with mercury until the mercury appears in the small vent 22.

The inlet 12 of the chamber 10 communicates with the plunger chamber in which a plunger 28 is reciprocally mounted, and passes out of the chamber through suitable bearing and stuffing box generally indicated at 32. The outer end of the plunger carries a slider 33 sliding along suitable guide rods 34. Further, the plunger is hollow and threaded to receive a plunger-operating screw 35, one end of which is suitably rotatably mounted in thrust bearings, generally indicated at 36, mounted in a journal 37 secured with respect to the plunger chamber 14 by means of a heavy base 39 and the guide rods. Keyed to the operating screw 35 is a hand-wheel 38 used for operating the screw.

The top guide rod 34 is suitably marked off in units of measurement such, for example, as cubic centimeters, and the hub of the hand-wheel is also suitably marked in cubic centimeters, but in thousandths of cubic centimeters, and in accordance with the pitch of the threads on the operated screw, so that the position of the plunger may be read in terms of cubic centimeters and hundredths of cubic centimeters from the scale on the guide rod and in thousandths of cubic centimeters from the scale on the hub 38.

The end of the plunger chamber opposite the end through which the plunger enters is connected to a suitable pressure gauge, as shown.

The instrument is thus calibrated so that the amount of mercury measured in cubic centimeters, put into or taken out of the chamber, may be read from the indexes associated with the plunger 28 and its operating mechanism.

In making a determination of a sample, with the cover bolted on and the needle valve 24 open, the plunger is moved inwardly by the hand-wheel until mercury appears at the outlet 22, and the

position of the plunger is noted from the scale. The plunger is then retracted and the lid taken off and the sample, suitably prepared, is put into the chamber and the lid bolted back on. With the needle valve still open the plunger is again moved inwardly by the hand-wheel until the mercury again appears at the outlet 22 at which time the position of the plunger is again noted. From the difference of the two readings the volume of the sample is obtained. The needle valve is now closed and the hand-wheel is operated to move the plunger inwardly to maintain a pressure on the gauge equivalent to 50 atmospheres, the hand-wheel being moved as fast and for such length of time as is required to maintain this pressure. After it is no longer necessary to move the hand-wheel to keep the pressure at 50 atmospheres, the readings on the two scales are again noted and the difference between this reading and the last-succeeding reading gives correctly the volume of mercury necessary to compress the gas in the sample and to fill the pore space occupied by the gas. This latter reading, as above pointed out, is increased by two percent in order to take care of the volume of space occupied by the gas now under 50 atmospheres of pressure. By dividing the gas space volume thus obtained by the volume of the sample and multiplying by one hundred, the percent gas space per unit volume is obtained.

Also by noting the length of the time required for the mercury to enter the pores, a measure of the permeability is obtained. This procedure may be carried out rapidly and a large number of samples may be thus analyzed in a short period of time. So, for example, from a core thirty feet long, samples of the core may be taken every two inches and rapidly analyzed in the above manner, and the results plotted as shown in Fig. 1. These results are then readily translatable in terms of productivity of the sands cored by referring to a table such as Table A given above, the table, of course, varying with the particular field being drilled.

With regard to the permeability, I have found that working with a sample of from one to four cubic inches, if more than 95% of the mercury enters the pores at 50 atmospheres in less than one second, the sand is sufficiently permeable for oil production. Additional tests to be described are made in "marginal cases" to amplify the index obtained with this apparatus just described. These additional tests are also made to show the percent oil saturation and percent water saturation, such information being valuable in certain instances as above pointed out and for later possible repressuring or water-flooding production. For an immediate index, however, the information obtained from the one measurement is usually satisfactory for guiding the further drilling and for completing the well, providing, of course, the sand clearly contains oil. Further, this analysis may be made on samples taken from "soft" sands which heretofore could not be so analyzed and it does not require the extraction of the liquid from the pores before analysis.

In referring to "marginal cases" I mean instances where the results of the analysis of the gas content is so close to indicating either oil-producing or water-producing sands that further tests should be run before final decision is made as to the probable production characteristics of the sand.

Measurement of gas and water saturation

For a number of reasons it is useful to know the percent oil and water saturation of a sand. Even in the so-called oil saturated sand, that is, one that will produce oil, the water content of that sand may be as high as seventy percent. If it does run this high, although the sand may produce oil when gas dissolved in the oil is allowed to expand and escape, it may not produce oil under repressuring or water-flooding operations, so an accurate indication of these saturations is valuable. Further, in marginal cases where the permeability and percent gas content is on the border line of indicating unfavorable production characteristics, if the sand has little water as compared with oil, the doubtful percent gas results should be interpreted favorably. The present method and apparatus for analyzing core samples for oil and gas saturation enables the determination to be made relatively rapidly. Preferably one such oil-water saturation analysis is made for every few gas-content analyses, the samples being taken from portions of the core adjacent every fourth sample (for example) taken for gas-analysis purposes; the samples of the core left between being preserved for analysis if the gas analysis gives a doubtful result.

Referring to Fig. 3, a still is shown, generally indicated at 100, in which the oil and water are distilled from a sample and collected in a graduated tube, generally indicated at 102, supported below the still proper by a connecting tube, generally indicated at 104. The still comprises an insulated heater having an inner chamber 106 adapted to receive a sampling container 108. The heater comprises a porcelain core 110 spirally corrugated on its outside, as shown, open at its bottom, and closed at its top with a porcelain top 112. Inside the porcelain core is located a steel shell 114 having sides and a top and supported at its open bottom by a ring 116. Wound around the outside of the corrugated porcelain core is a resistance heating wire 118, and packed around this wire and held in by a suitable polished metal cover 120 is suitable packing 122, such as magnesium silicate. The bottom and top walls holding the magnesium silicate packing comprises an asbestos disc 124 and an annular ring 126, respectively, held together by three tie rods 128. The ends of the resistance wire come out through the top 124 and are secured to suitable insulated terminals 130 from which extends a cord for plugging into a supply of electricity.

The circular supporting plate 116 is supplied with downwardly-extending bolts 132 for clamping a base plate 134 to the supporting ring. The inside of the base plate is conically shaped at its center, as shown, and at the apex of the conical formation is provided an outlet 136 into which is brazed a short bronze tube 138. The outlet tube is connected by suitable rubber connections to a relatively long copper tube 140 serving as a condenser and terminating in a rubber stopper 142 in the top of a graduated glass tube 102. A suitable vent 144 also extends upwardly from the stopper.

While the bottom cover 134 is removed from the heater, the sampling container 108, which is open at its top, is filled with a sample of pieces of core that have previously been weighed. A spacing rod 146 pushes the container 108 to the top of the heating chamber as the base cover plate 134 is bolted in place. The container has a perforated bottom, as shown, and is preferably made of some corrosion-resisting material,

such as Monel metal, or a steel tube suitably plated with a corrosion-resistant plating.

After the container and sample have been placed in the heating chamber 106 and the base plate 134 bolted in place, the heat is turned on and the sample is slowly heated to a dull red heat which insures all oil, gas and water being driven off. The oil that is driven off in the form of vapors is always caused to move to cooler regions, and as it passes down through the tube 140 is sufficiently cooled so that it condenses and drips into the graduated tube 102. During the heating the amount of oil and water collecting in the tube is plotted against time, because the first water that comes off is the "free" water, i. e. the connate water and drill-mud water which may be present in the sample. As the heating continues, the water coming over stops for a short time and then commences to come over again. This last water to come over is probably water of crystallization and does not enter into the problem of oil production. The purpose of plotting the water distilled against time is to be able to determine how much total free water came over.

From the graduations on the tube 102 is obtained the amount of oil that came over and the amount of total water. The weight measurement of the sample put into the chamber 108 is converted to volume by means of a density measurement made in connection with the gas-content analysis of a sample taken from the same core portion by dividing the weight of the sample analyzed for gas, by the volume of the sample. Thus, from the foregoing readings it is possible to get percent oil saturation and percent total water saturation per unit volume of core.

By bringing together the results obtained from the gas-content analysis and the oil- and water-saturation analyses, the total pore space per unit volume of the sample is obtained. This method of thus determining the total pore space is simpler and more rapid than methods previously used.

This method and apparatus for determining gas and water saturation (i. e. content) is relatively rapid, requiring only about thirty-five to forty minutes per sample, and so may be made at the well. If a bank of the stills is used the results may be obtained along with the gas-content results. Further, it can be used when dealing with soft sands as well as with hard sands.

Generally it is advisable to make a slight correction upwards for the oil readings, the amount of correction being determined for each still by tests run on blanks.

Further, from this oil saturation (i. e. content) analysis a quick gravity test of the oil may be made by pouring the oil from the graduated tube into an alcohol-water solution, and adding alcohol until the oil floats suspended in the body of the alcohol-water solution below the surface. The gravity of the alcohol-water solution may then be determined by a hydrometer.

In instances where, in dealing with a sample of hard sand, it is desirable to obtain permeability readings more accurately than those obtained from the apparatus shown in Fig. 2, known methods may be used.

The subject matter disclosed in this application but not claimed is claimed in divisional applications Serial Numbers 351,891; 351,892; and 424,588.

I claim:

1. In the art of oil-well drilling, the method

of determining probable production characteristics of substrata sand that is sufficiently permeable for production purposes and that contains gas under pressure, comprising analyzing core samples taken from the sand for the space occupied by gas, and utilizing the results of such analyses as indices for indicating whether the sand will produce gas, water, or oil, or a mixture thereof.

2. In the art of oil-well drilling, the method of determining probable production characteristics of substrata sand that is sufficiently permeable for production purposes and that contains gas under pressure, comprising analyzing core samples taken from the sand for the space occupied by gas, and interpreting the results of the analyses in the light of an interpretation table made up from similar analyses of cores taken from wells in the same or similar fields and showing the kinds of production for different percents of space occupied by gas.

3. In the art of oil-well drilling, the method of determining probable gas-oil ratio production characteristics of substrata sand that is sufficiently permeable for production purposes and that contains gas under pressure comprising analyzing core samples taken from the sand for the ratio of the pore space occupied by gas to the space occupied by oil, and utilizing such ratios as indices for the gas-oil ratio production characteristics of the sand.

4. Method of determining the oil-gas-water producing characteristics of substrata sands containing naturally imprisoned gas comprising the steps of cutting successive core samples from the sands, lifting such core samples uncased from the well, testing the permeability of the successive core samples to determine whether or not the sands are sufficiently permeable for practical production purposes, testing the oil saturation of the successive core samples in terms of the amount of oil per unit volume of core sample to determine whether the sands are sufficiently oil-bearing for practical production purposes, measuring the free gas content of the successive core samples in terms of the amount of free gas per unit volume of the core sample, and utilizing said last-mentioned measurements for fluid production indices by correlating said measurements with the known fluid production indices of wells the producing performance of which in relation to their indices has been previously demonstrated.

5. Method of determining the oil-gas-water producing characteristics of substrata sands containing naturally imprisoned gas comprising the steps of cutting successive core samples from the sands, lifting such core samples uncased from the well, testing the permeability of the successive core samples to determine whether or not the sands are sufficiently permeable for practical production purposes, testing the oil saturation of the successive core samples in terms of the amount of oil per unit volume of core sample to determine whether the sands are sufficiently oil-bearing for practical production purposes, measuring the free water content of the successive core samples in terms of the amount of water per unit volume of pore space, measuring the free gas content of successive core samples in terms of the amount of free gas per unit volume of the core sample, utilizing said last-mentioned measurements for fluid production indices by correlating said measurements with the known fluid production indices of wells, the producing performance of which in relation to

their indices has been previously demonstrated, and by correlating the measurements with said free water measurements.

6. The method of determining the gas-oil ratio producing characteristics of substrata sands containing naturally imprisoned gas comprising the steps of cutting successive core samples from the sands, lifting such core samples uncased from the well, testing the permeability of the successive core samples to determine whether or not the sands are sufficiently permeable for practical production purposes, testing the oil saturation of the successive core samples in terms with the amount of oil per unit volume of core sample

5 and recording the results, measuring the free gas content of the successive core samples in terms of the amount of free gas per unit volume of the core sample and recording the results, dividing the results of the gas measurements by the results of the oil measurements and converting the quotients of the divisions into fluid production indices for the gas-oil production characteristics of the oil sand by correlating sand quotients with 10 the known gas-oil production indices of wells the producing performance of which in relation to their indices has been previously demonstrated.

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CERTIFICATE OF CORRECTION.

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It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Page 5, second column, line 28, strike out the word "pore"; and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 27th day of April, A. D. 1943.

(Seal)

Henry Van Arsdale,
Acting Commissioner of Patents.