Water Displacement in Oil and Gas Sands

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All strata not yielding oil or gas in commercial quantities or a corresponding amount of water may be called dry in a wide sense. In petroleum geology, however, we may exclude all sands of too low or fine porosity to yield gaseous or fluid contents to the hole drilled in the sand before any original pressure that its contents may be under is disturbed. Most rocks are of this class and they are not reservoirs in our definition; their "dryness" is wholly a matter of course. What are the contents of the pores or what is the exact porosity of such rocks is of almost no concern to us, for economically they are "dry."

What does interest us is the content of a rock having sufficient porosity and the pores of sufficient size to yield oil or gas in commercial quantities, if they were present under original pressure. Dryness of these reservoirs is a matter of supreme practical importance. Three views current as to such dryness seem, to me, to apply in a few cases only. It is the purpose of this paper to give reasons for this position and for believing that, in ordinary sedimentary rocks, there is only rarely a reservoir of competent porosity and undisturbed pressure that is dry in the sense of not yielding water, oil, or gas when first penetrated.

1. Gardner[1] writes of some Kentucky sands, "There has never been present any salt water or other water in the sand." Absence of water cannot demonstrate this position. It is necessary to show that the rocks were not laid down in water, but in air, and that they became so enclosed, while still above the water-table of the ground water, that water has not been able to enter since. Most of these sands, and certainly the productive limestones, were deposited in water; and such sands as have been commercially productive show no reason for believing that the overlying shale or limestone was not laid down progressively from one direction and in water that would have flooded it. No adequate explanation has been offered for this hypothesis, which is so inherently improbable.

2. Reeves[2] urges that "sands originally water filled may have been drained of their water and not filled when later covered." It is difficult

[1] James H. Gardner: Kentucky as an Oil State. *Science*, N. S. (1917) **46**, 279–280.

[2] F. Reeves: Origin of the Natural Brines of Oil Fields. Johns Hopkins Univ. *Circ.*, N. S. (1917) N. 3;

Absence of Water in Certain Sandstones of the Appalachian Field. *Econ. Geol.* (1917) **12**, 354–378.

to see how the presence of the air could prevent the entrance of water where the water overlaps the sand from one side and so has ample opportunity to expel the air. However, we have an excellent test of whether the sand is dry because air filled, as supposed by Gardner, by merely analyzing this supposed entrapped air. Instead of the air called for by Reeves' hypothesis we nearly always find methane. There are very rare occasions where it is mainly nitrogen, probably entrapped air denuded of its oxygen by the oxidizing of materials in contact. For these occasions, as at Dexter, Reeves' hypothesis is helpful; but its unimportance is measured by the extreme rarity of such cases.

3. Shaw holds that a sand may be adequately porous and hold water and yet not yield it to a drill hole because of lack of expansive force behind it. In view of the almost universal rule of an increase of pressure with depth in our ordinary sedimentary strata, such as we find in oil fields, such a failure must be excessively rare.

An absence of methane would not be expected in the sedimentary series in which our oil and gas fields are found, because these rocks are so generally charged with some gas, either free or dissolved in oil, in some part of the reservoir. Even with no methane, we know that propane and butane are soluble in water to an extent of nearly 3 per cent. so that they could give it expansibility for at least a short time.

Displacement and Resulting Movement in Oil and Gas Sands

Concluding, then, that the reservoirs now containing oil and gas originally were water filled and that the gas and oil later entered the reservoir, thereby displacing water, it becomes a matter of interest to postulate the resulting movement of the oil, gas, and water, respectively. We may assume that the oil and gas enter on all sides of the reservoir. If at the bottom they would rise to the top, although in all probability generally deflected en route along some bedding plane. Having reached the roof of the reservoir, since this is ordinarily elongated and pitching, they would move along the inclined plane until they formed an oil and gas accumulation at the upper end.

The matter of especial interest to us is the action as it finds minor dome-like irregularities. These will necessarily be filled if there is enough oil and gas to fill them. If more than enough oil and gas reach these local catchments, the oil and gas will resume their movement up dip. However, as this movement continues, the proportion of the gas in these catchments will increase. Indeed, the oil may nearly all be forced down into the general stream and so move on up to the highest oil and gas mass. In this motion upward along the crest of the reservoir, the path would not be a broad one. Any "bulge" in the roof to one side of such a "path" would not be fed with oil and gas, except such as was caught by direct upward movement to it by side paths flowing on the way to the ridge. If the crest of the reservoir was very flat and broad, we might possibly have a series of braided paths, such as one finds in some rivers of broad bed. In the top mass of oil and gas to which the paths lead, the percentage of oil to gas should be higher than any bulge below because of the excessive proportion of gas held below. This selective action explains some of the differences in relative percentage of gas and oil in different pools. Suppose now the reservoir as a whole is arched, each flank is then working as before suggested but the oil-gas mass is held at the crest instead of by the termination of the reservoir.

So far as the upward motion of the oil and gas has been discussed, we have assumed that there are no obstacles to the free motion of any molecule of oil and gas, as directed by gravitation. However, one serious obstacle, surface tension, leads to the oil or gas rounding off into a bubble, which thereby offers great resistance to motion in sandstone as fine as we generally find it. A bubble forms in each "chink" between grains, but its oil cannot move until the bubble grows so large as to extend as a bud through one of the larger passageways into the adjoining chink between grains. Only a continuous invasion can make progress. It is a mistake to think of a passage of a series of bubbles as such. The resistance in that case would be so great that gravitation at least would be impotent except with very coarse deposits.

The water must have a motion away from the upper part of the reservoir as the movement of the oil and gas upward along the roof drives the water, in part, back into the shale and, in part, down the reservoir to the lower end. Again, we must consider the effect of depressions in the floor (whether depositional or deformational) on the water as it recedes to the lower end of the reservoirs. The water would fill each depression and spill over its oil in the general movement down the reservoir. It retains a disproportionate share of water after all the oil and water have passed this depression going down dip. Some of the water may be forced out through the floor of the reservoir, but it would usually leave the water in excess until the gas accumulation was quite large. Therefore we conclude that these depressions are less favorable points for oil and that most of the oil will accumulate at the lowest part of the reservoir, assuming that the displacement continues that long. The lowest part of the reservoir being so frequently a matter of lateral variation or "tailing" of the bed, this place is more difficult to locate. Hence the search for oil in sands without water is more difficult than in those carrying much water. It is not a case of mere reversal, seeking anticlines in one case and synclines in the other. Structure is, then, of still less help in the waterless sands than would otherwise be supposed.

DISCUSSION

David White,* Washington, D. C.—This is a most interesting point concerning the genesis and distribution of oil, gas, and water in rocks. According to common acceptance, a dry sand is one from which oil, water or gas will not exude when it is penetrated by the drill or the mine shaft. However, strictly speaking, there is no arenaceous sediment or clastic, not excepting eolian sands, which has not been laid down in water or has not later been submerged beneath and filled with water before any sealing cap-rock has been laid down. All sands have at some time been full of water. The expulsion of the water under varying conditions is a topic not yet adequately discussed. It does not seem to have been generally recognized that the essential reason why oil does not flow from the sand when resistance is removed by perforation by the drill or the mine shaft probably lies in the fact that former pressures have been reduced to the point where capillary resistance prevents the outflow into the void. There is one more question: Does the deformation occur while the oil, gas, and water are in process of migration, or do these migrate after the deformation occurs? Deformation takes a long time. The migration also ought to require a long period. Is not the migration in progress when the deformation is developed?

G. H. Ashley, Harrisburg, Pa.—Within the past few months there has been, in the McKeesport gas pool in western Pennsylvania, a development that, if it has been properly interpreted, has some bearing on this problem. The principal gas reservoir is the so-called Speechley sand, found at a depth of about 2900 ft. (884 m.). Between 400 and 500 ft. above that is the Elizabeth sand. The first big well contained too much gas to be carried off by the 6-in. main that had been laid, so a valve was placed in the main to allow the escape of gas above a pressure of 430 lb. Mr. Tonkins, of the Peoples Gas Co., suggests that as a result of the back pressure thus generated in that big well the gas from the lower sand entered the upper, or Elizabeth, sand and enriched it, as indicated by the fact that other wells put down to the upper sand have increased their flow and later wells have obtained an enlarged flow from that upper sand. If that is true, it indicates that the Elizabeth sand was dry, not because nothing would flow out of it or into it, nor because of closeness of grain, for otherwise the sand would not have taken up gas.

Sidney Paige,† Washington, D. C.—You say the back pressure; could the back pressure have been any greater than the original pressure before the oil was tapped? How would this new movement have occurred? It is not clear to me.

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G. H. Ashley.—Before the tapping of the lower sand, there was no connection between the upper and lower sands.

Sidney Paige.—It came up along the pipe?

G. H. Ashley.—It came up along the pipe; there was no tubing or piping between the sands. The 100-ft. sand was the last one that was cut off.

R. H. Johnson.—I should say that hydrocarbons are still coming in while deformation is going on. The main reason for that is that the deformation is particularly active in making hydrocarbons, as David White's work has well shown. Most of the hydrocarbons must come into the reservoirs quite a little later than was formerly thought.

May I add a point in connection with this well at McKeesport? At the Elk City gas field, the other prominent gas field we have had recently, the pressure started to decline at a rather rapid rate, but when the pressure reached a certain point, the decline, although we were taking out still more gas, was not so rapid. In explanation, it was said that the well was tubed to a place above the productive sands, so that there was an open hole of several feet. This sand, when first struck, I would suggest therefore was feeding in there just as the Elizabeth was being fed at McKeesport, so the pressure dropped fairly rapidly during this period of underground wastage; but after this sand had been fed to its capacity, apparently the pressure declined more slowly. I suspect that something very similar happened at McKeesport.

If we could have had pressures on that well right along, we could have learned something about the feeding situation. The Elizabeth sand was fed until it would take no more. From then on, of course, it was not as serious a source of underground wastage except as the gas might go through other wells than those of the owner.

These Elizabeth sands are not as large as they really ought to be, considering the magnificent chance of being charged by this gigantic well, which seems to be the result of a lower porosity. The sands yielded a small amount of gas before this feeding process and the amount since is only moderate compared with the great wells; I should say that was because it did not have the capacity to receive much of that gas.

E. W. Shaw,* Washington, D. C.—In the Caddo, Elm Grove, and Monroe fields, Louisiana, we have such extensive underground migration of gas that after some of the big wells have been completed but not successfully cased the country all around sizzles. The gas creeps from one sand to another and sometimes blows out the surface as much as ¼ mile from the well where it left its natural reservoir.

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I do not see the bearing of this on the question of dry sands, concerning which there seems to be a good deal of difference of opinion, for the reason that when the gas rises from a lower sand, where the pressure is high, to a higher sand, where the pressure is low, it is not essential, and it is not to be inferred that the pores in the higher sand are empty or even free from liquid contents. All that is required is that the gas or liquid move off somewhere else or accommodate itself in smaller quarters.

I was much interested in Mr. White's remark that we are all agreed that pores are filled with something. If we can agree on this we have made a real step in advance. The following step to be taken is longer and more difficult, but it is a step that we must take sooner or later. This step is to recognize that most dry sands are myths.

R. H. Johnson.—The question of the helium in the Kansas and some of the Texas gases, I think, has a bearing on Reeves' hypothesis of entrapped air. Those gases have more helium in proportion to nitrogen than the air.

In this paper, I have accepted the notion that we might have entrapped air to explain these nitrogen reservoirs. Since writing that, I have become more skeptical. We can easily explain away the lack of oxygen; that can be taken up to make carbonate, but why this super-atmospheric amount of helium? These helium gases may have a deep-seated origin over faults that do not come to the surface. May they not be gases of a cosmic nature—gases that have been extruded from original earth stuff from still greater depths, that have worked along some faults and have not been able to get closer to the surface?

Do not think that that means I am inclining toward any inorganic origin of hydrocarbons, but if we do not accept that hypothesis, we have difficulty in getting that much helium because the air must have been entrapped, and it is utterly unreasonable to suppose there was more helium in the air then than there is now. I dare say that higher up in the air, there is a greater amount of helium, but that will not help us because these gases were laid down close to the earth's surface, and the gravitational contrast was as great then as it is now.

H. W. Hixon, New York, N. Y.—That question of helium in the gases goes back, I believe, to the origin of the hydrocarbons; and while Mr. Johnson evidently does not believe in the inorganic origin of oil and natural gas, I most decidedly do. If you assume that the earth had an origin, it must have been either according to the planetesimal hypothesis or a gaseo-molten condition. Taking the latter view, a planet above its critical temperature is all gaseous. Under that condition, by applying the law of the diffusion of gases, you have each gas occupying the whole space of the body of the planet as if the other gases were not there.

Gravitational compression will produce a condition of density greater than that of the solids at sufficient depth, so that when such a planet cools, the solid material, being lighter than the highly compressed gases, will act just as if it were a solid throughout. You still have, in the body of the planet, some of each of the gases that were present in the original planet when it was all gaseous.

As regards the origin of petroleum and natural gas, there is just the same reason for the hydrocarbons being in that gaseous interior as any of the other gases. That is the reason why, from volcanoes, all the known gases of the atmosphere and others are extruded. So the origin of helium goes back to the original gaseous planet, like the origin of the hydrocarbons. I take that stand, knowing that nearly all petroleum engineers and geologists believe that petroleum and natural gas are of organic origin.

I first became interested in this matter when I heard Mr. Eugene Coste speak on the subject. He did not, however, go back as far as that and simply denies that fossils or organic matter produce oil. I can see how from the application of the law of diffusion of gases to a gaseous planet, where all of these things would come about in that way, the oil and gas would be entirely of inorganic origin. In the question whether the dome is the cause of the accumulation of gas or the gas the cause of the dome, I think you have the cart before the horse. I think the domes are caused by the accumulation of gas, the gas causing the dome or the anticline or both.

David White.—The origin of the helium in such large amounts in the natural gas of parts of Ohio, Kansas, northern Oklahoma, and Texas is a geological problem of great interest and importance that is yet to be solved, and it is greatly to be hoped that the oil- and gas-field geologists will find the key to the situation. There is some circumstantial evidence pointing toward the occurrence of the helium-rich gas of Kansas and Oklahoma over areas of deep-seated faults or disturbance. The same may be true of the north Texas region. But the singular fact that the helium now occurs, in general, in the shallow sands, and is present only in relatively small amounts or not at all in the deep sands in most areas is baffling. Apparently the Ohio area, Hocking and Vinton Counties, in which the helium is found in the Clinton as well as in the Berea, offers no exception. One does not look for badly disturbed rocks in the center of the basin in southeastern Ohio, although the unexpected frequently happens, and it may have happened in this case.