The Oil Drum
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Tech Talk: Producing oil shale by burning it in place

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This is part of the continuing series that I have been writing about oil shale. And, while I just digressed in talking about using nuclear devices to break the rock and heat it, the key problems that those posts highlighted remain. The first was that the oil is not really oil and won't flow to the well, and the second is that there are no easy paths for the oil to flow though, even if it could. And this creates a problem when it comes to getting the kerogen (or oil for simplicity) separated from the rock around it. As I said in the first post on this topic, the oil can be separated in a retort, after being mined. The retorting can be self-energized and, by heating the oil it can be transformed into a form of bitumen that can then be further refined into a commercial grade. And if you think it is easy, there is this quote I found at Econbrowser, that might give you some perspective. He quotes Bubba, of Belly of the Beast:

> If you heat this shale to 700 degrees F you will turn this organic carbon (kerogen) into the nastiest, stinkiest, gooiest, pile of oil-like crap that you can imagine. Then if you send it through the gnarliest oil refinery on the planet you can make this s*** into transportation fuel. In the mean time you have created all kinds of nasty byproducts, have polluted the air and groundwater of wherever you have extracted it.

Mining shale and then processing out the oil is, therefore, fairly expensive, both in terms of energy, and hard dollars. At the same time, once the oil is extracted, the spent shale has to be disposed of. That costs more money. Considering all these potential expenses and potential problems, it is therefore not surprising, from the beginning, that the idea of trying to create the initial retort in the rock, and making that transition to oil in-place looked as though it might be a winner.

There has been considerable technical success in recent times in getting natural gas from the tight shale around the country, but natural gas is, comparatively, easy to extract if some additional cracks are artificially driven through the rock to create the needed permeability.

Unfortunately that only potentially treats one of the problems with the oil shale. The other is that the oil will not move, even if the cracks are there, unless it is heated to the point that it will either vaporize, or transform into a flowable hydrocarbon. And this takes a lot of heat. Thus the attraction of having a nuclear device to create a cavity, radically fracture the rock around the cavity, and generate enough heat to start an underground fire, that could be sustained, and controlled, by adding additional air, and from which the oil could be released.

OK, so accepting that we can't use nukes, can we do this another way? Because of space and time I'm going to talk of the more conventional retorting today, based on the idea of doing most of the processing of the oil in place. Why do we need to do that? Well, it gets very expensive to mine and move that rock from the deeper deposits, and though it has been and is being done for metal ores, their costs are still much higher than that of oil.

If we can process the rock in place, so that the oil is heated sufficiently, then we save the transportation costs. So what will we need? For the more conventional approach we still need some sort of cavity in which to start the fire, and to allow it to spread. Then there has to be air fed to the fire to keep it going (and this will require that boreholes be drilled down into the area to sustain the air flow). And then there has to be some way of getting the mobilized oil out of the ground, so that it all doesn't end up being burned down there.

It is an idea that has been suggested for a number of different energy sources. And it is why I included a post on in-situ combustion processes at the beginning of this series. The first dealt with burning coal in place, and then I wrote about the THAI process that is being investigated in Canada for producing the heavy oil in the sands above Fort McMurray.

It might be helpful to insert a slight digression here. In a normal oil refinery, the heavy oils, or residuum, that come out of the bottom of the initial fractionating column have almost no light hydrocarbons left in them, and so are sent to a Coker, where at a temperature of around 1200 degrees, the final hydrocarbons are driven off, and cracked into lighter fractions, leaving the carbon residue known as coke (or petroleum coke to distinguish it from that made from coal). From my youth I can tell you that coke is a much harder fuel to start burning than conventional coal, since it no longer has any volatiles left in it. Thus, for example, even after the intensity of the fires in the Kuwaiti oil field, coke was deposited around the burning wells and required barrels of C-4 to break it up, so that the fire fighters could reach the top of the well, put out the fire, and replace the fixtures. The reason that I mention this is that Petrobank are burning this coke to provide the heat for the reactions. And from the modifications from the first test to the second have found that the process needs a lot of air to be supplied to the burning zone to sustain the fire - over the full face of the burn. I'll come back to that in a bit.

The situation with the oil shale is a little more complex than for oil sand, since the structure of the rock is tighter than the sands in Alberta, and the oil has to be heated to a significantly higher temperature before it will transition and move. The first underground experiments were carried out by Sinclair, in 1953 and 1954. (So we are back to paper references -see Ref 1 at the end). In those days, drilling technology wasn't as advanced and so, for the first experiments, they drilled a hole near the outcrop of the shale, and then created a crack from the well to the outcrop by pressurizing air in the well until the rock fractures (a simple variant on hydrofracing a well). By adding sand, the crack can be propped open so that air can get into it. It took a couple of tries to get it working, but they were able to start fires in the oil shale at the well, and then by continuously pumping down air, carry the fire along the crack. The heat of the fire changed the kerogen to oil, in the same way as with the retort, and oil was seen coming out of the crack at the outcrop. The rock around the well was, however, fairly fractured from being near the outcrop, so that air passage to encourage the flame to progress, was possible. It is worth quoting some of the conclusions to that work:

> Under field conditions - particularly if the operation requires high pressures - volumetric conformance and thermal efficiency can differ significantly from model predictions. The burning zone probably will expand to more closely follow the retorting isotherm and shorten heat transfer distances. In addition, convection may become significant. To illustrate, shale retorted under simulated overburden pressures in the laboratory does not spall or crack as it does at low pressure. Instead, a consolidated rock having high porosity and low permeability remains after pyrolysis of the kerogen. Bulk

> volume is greater than in the un-retorted state. It is possible that some of the injected air will move through this permeable matrix of spent shale to more fully utilize the fuel content of the spent shale and accelerate heat transfer to raw shale over the rates computed from the mathematical model.

Coring of the oil shale as a precursor to the aborted nuclear shot at Rio Blanco (Ref. 2) showed that at depth the shale appeared to have considerable jointing, which would be a real help in any in-situ retorting method, as Socony anticipated (Ref. 3). When looked at under a microscope, the retorted shale also had a number of voids, left by the volatized kerogen, that provided some permeability to the shale (Ref. 4).

It is the presence or absence of cracks, voids and other passages that the controls the success of conventional in-situ retorting of oil shale. Cyclic hydro-fracing or air fracing of the shale can induce a series of fractures around a well bore at depth, but these are going to be relatively narrow. There is not the mobility within the structure that one gets from the oil sands. Further the environment has to be heated to a much higher temperature to induce transition first to the bitumen and then to the crude. In the tight rock that exists under pressure at depth, the only path that air has to the fire is from boreholes drilled to that depth. (In contrast with close-to-surface conditions where ground fracturing will open cracks to the surface.) With the cracks being relatively narrow the air that must be supplied to the fire must be at a relatively high pressure, and in considerable volumes.

Without an underground cavity, into which some of the rock can displace, or a means for removing some of the rock to allow multiple fractures of the shale, and fracture opening to allow air access, starting and sustaining a large underground fire will be a significant undertaking.

Unfortunately also "Lean shale tends to be brittle, fracturing under stress, while rich shale tends to be tough and resilient, resisting fracture by bending, and tending to yield plastically under stress." (Ref. 5) This is going to make it harder to grow the cracks where we need them to be.

The other problem with in-situ retorting is controlling the flame front to go where you want it. It is hard to control where the fractures go underground, and the path that the air takes, to make sure that all the shale is retorted, so much more air has to be pumped underground than might be needed otherwise. And this is where it gets frustrating because, though it may only take 260 Btu to raise a lb of shale to 900 degF, (Ref. 6) and that can come from the carbon content of the shale (the coke above), getting enough air there and having somewhere for the released oil and gas to go can take a lot more energy.

For example if two wells are drilled, say 500 ft apart, and a crack run between them, then the air to the burning front, and the flow from it, is gong to be limited by the width of the crack. These processes are relatively slow. A model of the process (Ref. 7) has shown that it can take 10 years for the front to move from one well to the next. During that time air has to be continuous injected, and the volume of air required, for a barrel of oil recovered can be calculated.

Depending on the temperature at which the air was injected (since it shouldn't cool the fire) it can take between 24,000 scf (standard cubic feet) and 86,000 scf/bbl. To get that air into the fire effectively it would have to be pumped into the well at 2,500 psi. (A conventional air compressor runs at around 120 psi). To generate a flow of 50,000 barrels a day was found to require an air compressor system run at 272,000 horsepower. To cut a longer story short, this turns out not be economic, at 1968 costs.

Hmm! Well, I am not quite finished, but perhaps this explains in part why Shell are using heaters, rather than fire. I will have a short discussion of that, next time.

References

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