In Situ retorting of oil shale

Posted by Heading Out on July 4, 2006 - 8:39pm
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Tags: economics, gasification, in-situ retorting, oil shale, retorts, thai [list all tags]

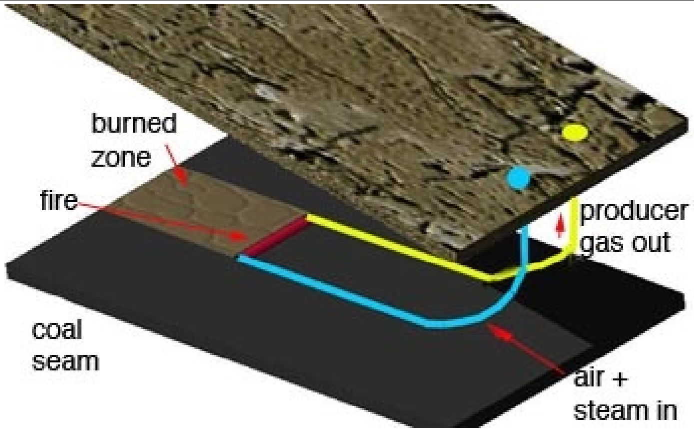
In posting about oil shale, one of the points that needs stressing is that the oil is not really oil. And this creates a problem when it comes to getting the kerogen (or oil for simplicity) separated from the rock around it. As I said in the first post on this, the oil can be separated in a retort, after being mined. The retorting can be self-energized and, by heating the oil it can be transformed into a form of butumen that can then be further refined into a commercial grade of shale oil that can be similar to a more conventional crude.

Mining shale, however, is 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.

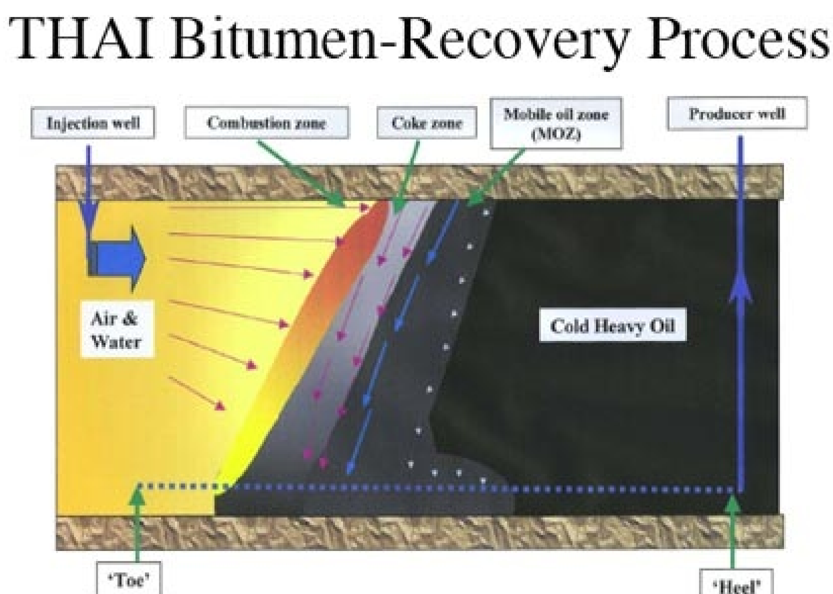
Before going on, I should also like to clarify something I wrote about last time. As was noted by mbnewtrain and bubba the nuclear shots that I described were only in rock that contained natural gas, rather than a kerogen. The oil shale test never took place. And the difference between the two is important to understand. While there are a number of ways of getting gas to flow from a tight (i.e. low permeability) reservoir - mainly by creating cracks in the rock that the gas can then migrate to, that is not enough with the oil shale, where 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 nuke's can we do this on a smaller scale ? What will we need. Firstly 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. For example, back in the 1970's tests were carried out at Hannah, WY to see if coal could be gasified in place. It had been thought that the natural joints (bedding planes and cleat) would be enough to allow air to reach the fire from an adjacent borehole, but in the field it was found that horizontal boreholes were required to control the flame front. A recent experiment along these lines is being carried out in China.



As also has been mentioned in comments up in Canada the toe-to-heel air injection process known as THAI is being tested by Petroleum Equities(pdf file). And I have taken an illustration from one of their talks to illustrate the process.



Source: 2005 International Thermal Operations Symposium

A more advanced technology to recover bitumen in situ, Toe to Heal Air Injection (THAI), is advancing toward commercialization.

See also Commodity Mine. As you can see, this is a variant on the coal idea, except that with the oil sand being thicker, it is possible to use a vertical well to feed air into the flame front. The process gets its name from the fact that the oil is recovered through a horizontal well drilled (the blue dotted line) under the zone being processed. The heat, and presence of steam, lowers the viscosity of the bitumen, so that it flows down to the well, and the fire, and recovery process migrate from the toe of the horizontal well (initially under the vertical one) back to the heel (where the horizontal well swings from the vertical). The process has been described more fully at green car congress, and is being tried at Whitesands, where, the first test is underway.

> The Pre Ignition Heating Cycle (PIHC) at the WHITESANDS pilot project has commenced its initial start up with steam injection into the vertical injection well. The PIHC phase is programmed to continue for approximately 90 days with steam injection in the first vertical and horizontal well pair. Air injection in this first well pair will commence when the bitumen around the vertical injection well has been sufficiently mobilized. Once combustion is initiated in the first well pair, we will begin the PIHC

> phase for the second well pair. All three well pairs are expected to be on production by the end of 2006. We are also evaluating the potential to initiate a test of our CAPRI^{TM} technology later in 2006.

(From Petrobank pdf file).

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 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 this 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 intend to burn this coke as the source of heat for the reactions (so that they don't have to use oil or gas product - which can be recovered). This is going to require that a lot of air 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, since the structure of the rock is tighter than that 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.

I had been asked if there was evidence of shale expanding during this process, and bearing in mind that there is some additional fracturing during burning, the conclusions to the first tests are worth quoting.

> 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 of the structure that one can anticipate 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 try and conclude, with a short discussion of that, next time.

The series also includes:

[Where it is]

[Mining the shale]

the nuclear option

nuclear field tests

Ref. 1 Grant B.F. "Retorting Oil Shale Underground - Problems and Possibilities", 1st Oil Shale Symposium, CSM, 1964.
Ref. 2 Stanfield K.E. "Progress Report on Bureau of Mines - Atomic Energy Commission Corehole, Rio Blanco Country, Colorado", 3rd Oil Shale Symposium, CSM, 1966.
Ref. 3 Sandberg C.R., "Method for recovery of hydrocarbons by in situ heating of oil shale", US Patent 3,205,942, 1965.
Ref. 4 Hill G.R. and Dougan P. "The characteristics of a low temperature in-situ shale oil", 4th Oil Shale Symposium, CSM, 1967.
Ref. 5 Budd C.H. McLamore T.T., and Gray K.E. "Microscopic examination of mechanically deformed oil shale," 42nd Petr. Engrs Fall Mtg, SPE 1826, 1967.
Ref. 6 Carpenter H.C. and Sohns H.W. "Application of above ground retorting cariable to in situ oil shale processing", 5th Oil Shale Symposium , CSM 1968.
Ref. 7 Barnes A.L. and Ellington R.T. "A Look at in situ oil shale retorting methods based on limited heat transfer contact surfaces", 5th Oil Shale Symposium, CSM, 1968.