PROGRESS IN OCCIDENTAL'S SHALE OIL ACTIVITIES*

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Without a doubt, in situ processing, as first presented in 1974 and subsequently dubbed "modified in situ processing," has moved into the forefront of both development and commercialization activities. My objective is to trace this development from its inception in the late 1960's and then describe Occidental's plans for commercial operations on Tract C-b.

Rather than provide a chronological history of process development, I would like to describe the developments as they occurred against a background of other shale oil activities. Shale oil development work has been underway since the late 1920s (BuMines); reactivated, 1944. Eleven years ago, Occidental began looking into this exciting resource. The year was 1967; west Texas sweet crude oil was posted at $3.30/Bbl; Persian Gulf crude was $0.90/Bbl FOB Ras Tanura; and the U.S. was importing 1.1 million B/D of foreign crude oil.

In oil shale, most activity was centered on room-and-pillar mining and surface retorting. TOSCO was most active, Union Oil and the Bureau of Mines had long since shut down their surface retorts, and a consortium of six oil companies and the Colorado School of Mines was preparing to shut down the Anvil Points facility they had operated for several years under lease from the U.S. Bureau of Mines. Paraho was seven years away from starting its oil shale program at Anvil Points.

Some interesting efforts in in situ processing had also been attempted. Sinclair had long since abandoned its Operation Haystack, a "true" in situ concept, involving fracturing between wells and underground combustion. Equity was testing the use of hot natural gas and was later to test the use of superheated steam in oil shale zones having some pre-existing porosity. The Bureau of Mines was experimenting with fracturing and retorting near-surface oil shale deposits outside of Rock Springs, Wyoming. Shell Oil Co., was three years away from inaugurating its solution mining/in situ test work near Piceance Creek. One nuclear project had been abandoned, and Western Oil Shale was two years away from announcing Project Utah, its proposed nuclear rubblization for in situ retorting. These in situ efforts had one thing in common: unsatisfactory yields -- at least not sufficiently attractive to continue warranting private financing. Each privately funded effort was ultimately shut down.

It was at this time and in this environment that Occidental personnel first conceived of and subsequently undertook development of its in situ process. We had evaluated the then present processes and rejected each one for the following reasons:

(1) While in situ processing conceptually held significant advantages in both operating and capital costs, spent shale disposal, water requirements, and the like, no process had been successfully developed. More fundamental, there appeared to be no reasonable solution to the problem of creating the required permeability and porosity.

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*Ed note: Matter suited to oral presentation modified or omitted.

(2) While surface processing was being well-engineered and was at a relatively advanced state of development, each approach was, mechanically, highly complex, required tremendous materials handling operations, had possible environmental problems in spent shale disposal, and, as a result, was highly capital intensive. We simply did not believe these processes would prove economically viable, in particular to Oxy, which could not afford massive capital investments for individual high risk projects.

(3) The nuclear approach had serious technical drawbacks, and was probably neither environmentally nor politically acceptable.

The Occidental process has been described many times; there is no need to repeat the basic description. Highlights of process changes, as they have evolved, will be presented in a review of our test program. Suffice to say that we could see in our process - at that time - a major breakthrough in process economics; important advantages in environmental areas; shale oil resource recovery and use; and minimization of water requirements.

Like all processing ideas, the transition from concept to demonstration is a critical step. And, in this case, the transition was particularly challenging as both mining and chemical processing operations would be attempted that were vastly different from the state of the art.

From a mining viewpoint, we would be attempting to control fragmentation or particle size in a situation where the swell factor or mined void was severely limited, relative to normal mining practice. Further, the void volume had to be distributed evenly, a task never considered in mining operations.

From a chemical processing viewpoint, the sheer size of the retort or reactor, the range in particle sizes, the low void volume, and extremely low linear velocities, all presented challenges beyond those inherent in normal processing operations. It is one thing to measure and control what is going on inside a typical refinery fixed-bed, processing unit that might be 12 to 14 ft (3.6-4.2 m) in diameter and 120 to 140 ft (36-42m) tall; it is quite a different operation when the reactor has 1/2 acre or more of cross-sectional area and is 200 to 300 ft (59.9-90 m) tall. One can readily measure what is occurring in the refinery reactor; this is not so in in situ retorts. A combination of limited measurements, sophisticated chemical engineering analysis and interpretation would be required.

Thus, while the process concept was, and is, basically simple, transition to the demonstration phase was a formidable task. Yet, there was a much more mundane task that had to be undertaken first. This was the matter of land acquisition. We determined early that the most critical aspect of this process development would be a field demonstration of both the rubblization and in situ retorting steps. We had immediately recognized that no amount of laboratory work or computer analysis would answer basic process questions; they would have to be tested in the field.

Land acquisition efforts began in 1968 and continued until June 1972, when agreement was reached on the Logan Wash test site. The list of companies with whom we negotiated is confidential, but includes major land holders in Colorado. The most promising of these negotiations reached an impasse in mid-1969. From that point, Occidental investigated other land opportunities in Colorado, Utah, and Wyoming -- including core drilling in the Washakie Basin in Wyoming in 1969. We asked the Department of Interior to move speedily on the prototype lease sale and participated in that program by core drilling a short distance from the present C-a Tract and by bidding on two of the lease sites.

This should serve to emphasize the bottlenecks that exist for a new developer. Had any land been available in 1968, instead of 1972, we would be four years closer to commercial operations. In fact, had sufficient acreage of high grade oil shale been available, we might well have a commercial shale oil industry today. The delay has been plainly and simply bureaucratic, for the federal government holds 80 percent of the oil shale resource. As it was, we signed a lease/option agreement on approximately 2000 net oil shale acres (800 ha) with a 76-meter (250-ft) thick oil shale section, averaging 17 gallons per ton, in June 1972.

Site access work began in July after receipt of a BLM Special Land Use Permit, the first of over 100 permits obtained to date for this development project! Mining commenced in early September.

Between 1968 and 1972 there was little real accomplishment in oil shale development. Of particular interest to us, however, was a test program carried out at Laramie, Wyoming, by the U.S. Bureau of Mines. As part of a program to evaluate the nuclear rubblization in situ retorting concept, the Bureau constructed and operated a 136-metric ton (150 short ton) capacity, batch oil shale retort. Mined oil shale, having a conventionally blasted particle size distribution, was loaded into this vessel and retorted, using gas combustion technology. The tests, which started late in 1969 and continued for several years under this specific test objective, demonstrated for the first time that a randomly-sized rubble zone could be retorted satisfactorily. Large oil shale boulders were included in individual runs and, upon analysis after retorting, these boulders were found to have been completely retorted. Since they represented well below 10 percent of the total oil shale feed, no real information was obtained in these early runs relating to shale oil recovery. Nevertheless, these results provided Oxy with further encouragement: if the oil shale could be well rubblized, according to our concept, we would be able to obtain acceptable retorting yields.

Occidental's field test program started with mining and retorting three in situ retorts, each approximately 93 sq meters (1000 sq ft) in cross-sectional area, and varying in height from 22 meters to 35 meters (72 to 114 ft). These were small in comparison to the envisioned commercial retorts, yet they were large enough to test basic concepts and to permit scale-up to full size at a later date. They were also large by any normal process development standard. For example, the smallest retort contained approximately 3600 metric tons (4000 tons) of oil shale. These three in situ tests utilized two basic rubblizing concepts; one concept was to provide the mined void volume in a vertical column; the other, to provide it as horizontal rooms, or slices, out of the ultimate retort cross-section.

The first mine opened, known as the experimental mine, consisted of a single adit 2-1/2 x 2-1/2 meters (8 ft x 8 ft) and approximately 425 meters (1400 ft) long, with individual, horizontal cross-cuts to each of the three retorts. Retort 1E was prepared in the winter of 1972. The void volume was mined in the form of a small room at the base of the room and a vertical center raise having a circular cross-section. Blast holes were vertical and paralleled this center raise. Once blasted, the retort was bulkheaded and piping connections were completed. Start-up tests included extensive tracer studies. Start-up was attempted in May 1973. Various problems associated with ignition, temperature, and pressure measurements and control, sealing of the retorts, and other mechanical problems delayed actual retorting until July. Once these start-up difficulties were overcome, Retort 1E operated satisfactorily and produced over 1200 barrels of oil, representing a high recovery in relation to theoretical volume for this first experiment.

Retort 2E, prepared in 1973 and retorted in 1974, used the same basic rubbling design as 1E but with several significant changes. These changes were: a reduced void volume, a change in the blast pattern, and an increase in retort height by 6 meters (20 ft). Various other noncritical improvements were made on the basis of Retort 1E experience. Retort 2E provided additional experience in fragmentation and retorting. The 6 meters (20 ft) of additional retort height consisted of oil shale considerably lower in grade than that normally processed in surface retorts. Retort 2E operated with a greater pressure drop and lower flow rate and produced 1400 barrels of shale oil.

While Retort 2E was being prepared, road construction started for a new mining operation, approximately 2/3 of a mile (756 m) away. This mine was designed with two purposes: (1) to test at least one full-size, in situ retort, and (2) to provide a large scale development mine that could be converted to commercial operation without opening new adits and installing new permanent facilities. In essence, this mine represented the first commercial mine design for an in situ operation. Our present C-b design incorporates many features of this original design.

Retort 3E, the final retort in the experimental mine, used the second type of rubbling technique with two sub-levels above the retort floor. These sub-levels or "horizontal slices" were mined from a short vertical raise outside the retort. Blast holes were perpendicular to the free faces.

Retort 3E was about 12 meters (40 ft) greater in height than Retort 1E and, again, the added height was in low grade oil shale. Because of the different fragmentation system, this retort had significantly different operating characteristics than the prior retorts. Its operation was improved over the previous retorts, due to its design and, obviously, because many of the problems uncovered during development and processing of the earlier retorts had been solved. Retort 3E produced 1600 barrels of shale oil, bringing total production to over 4000 barrels.

Retort 4, the first large scale retort in the "commercial" mine, was originally designed as a scale-up of 50 times, using the Retort 1E design. This design was subsequently improved by substituting two vertical slots for the center raise concept of the first retorts. Essentially, these slots extended from the floor of the retort to a mined-out room at the top of the retort. Blast holes were drilled from this upper level.

The scale-up to Retort 4 was needed to evaluate factors that might not be critical with smaller retorts, as well as to demonstrate the process on a near commercial scale. Specific areas requiring scale-up were: geologic and rock mechanic factors, enlargement of the blasting pattern, and retort flow control over a 1300 sq meter (14,000 sq ft) cross-sectional area. While the blasting pattern effects could be treated theoretically as they related to tons of rock broken, theory could not project, with any accuracy, particle size distributions or the effect of the limited void volume. Likewise, the effect of geologic variables could only be determined by these large scale tests. Theory could suggest qualitative effects but not quantitative. And, based on these scale-up tests, we can now say that these effects are highly important and must be understood for proper retort design.

The size of Retort 4, described previously, was 82 meters (270 ft) in overall height (about the same as a 25-story building), and 36 m by 36 m (120 ft by 120 ft) in cross-section. Geologically, it included oil shale from above the Mahogany zone, averaging about 15 gallons per ton; the Mahogany zone itself; the barren "B" groove, and some 10- to 15-gallon per ton oil shale below the "B" groove.

In this area, the Mahogany zone contains a 26-meter (85-ft) section of 25 gallon per ton oil shale. Within that is a 15-meter (50-ft) section, averaging 30 gallon per ton and, within that, a 10-meter (32-ft) section of 35 gallon per ton. From this, it can readily be seen that retorting covered the full range of oil shale grades that might be encountered on any site. Pressure drop measurements were carefully made as the retorting moved down through the various oil shale grades.

Oil production from Retort 4 was approximately 30,000 barrels, somewhat less than expected from the ore in place. Reasons were varied, but mostly related to geologic conditions aggravated by mining techniques that prevented adequate rubblization of a specific section of the ore body. On balance, Retort 4 was considered very successful and gave valuable fragmentation and retorting experience. In addition, a new approach to retorting was used for part of the run. All previous retorts had used an air/recycle system. Retort 4 also used this system at the start; for the balance, a steam/air system was successfully tested. We now believe that this system has sufficient advantages in shale oil yield and effluent gas quality to warrant its use over the air/recycle system. We expect to use the steam/air system in our commercial operation on Tract C-b.

In September 1977, Occidental entered into an agreement with ERDA (now DOE) for joint funding of engineering development and a technical feasibility demonstration of Oxy's vertical, modified in situ process. This contract extends through 1978, with Phase I retroactive to November 1, 1976. It includes testing of two advance retort designs, Retorts 5 and 6. Phase II will cover ancillary facility development on Tract C-b.

Retort 5 stretched the vertical slot system to its extreme by reducing overall void volume to 17.4 percent. At the same time, the geologic conditions that complicated the Retort 4 blast were overcome by several design changes. This design incorporated a single slot in place of the dual slot of Retort 4, and also a 12-meter (40-ft) barrier, or sill pillar, directly above the section to be rubblized. In practice, the vertical slot was pulled only to within 12 meters (40 ft) of the air inlet level. Blast holes drilled through this sill pillar were not loaded at the top 12 meters (40 ft), leaving the pillar unfragmented during rubblization. The blast holes then served as a distributor plate for the retorting gas. Retort 5 also incorporated a significantly enlarged blasting pattern, and an altered blasting system. During retorting, it became evident from tracer studies that a good distribution of the void volume did not obtain overall; this was further confirmed when channeling occurred. Corrective measures were only partially successful; oil yield was low. Sufficient shale oil, however, was obtained for a limited refinery test in Chevron's Salt Lake City refinery. Encouraging results were presented by Chevron at the Toronto API meeting.

Preparations for Retort 6 are well under way, with retorting planned to start this summer. Retort 6 is a scale-up of the Retort 3E design using two intermediate mining levels between the top and floor levels. It uses the sill pillar concept of Retort 5, has a 23 percent design void volume, and will have a greater dispersion of the explosive throughout the oil shale mass before rubblization.

In any review paper, it is difficult to discuss technical accomplishments in any detail. It is possible, however, to list major developments and/or areas which have been and are under investigation. We have broken these areas of work into six categories, shown in a series of figures. Each one could well be the subject of an individual technical paper (figs. 1-6).

One indication of the technology, developed on this project, is the extent of the patented data. As a result of the past five and one-half years of actual field testing, 25 U.S. patents have been issued, five more will issue shortly; 60 applications are on file and more than a third of these have received favorable action. Over 50 new applications are in process of being prepared. Also, as a direct result of Occidental's test program, Ashland Oil and Occidental entered into a partnership agreement which will lead to commercial operation of the C-b Tract. Ashland has transferred a 75 percent interest in this rich oil shale reserve to Occidental in return for the right to use the Oxy process to develop this tract. We are moving ahead rapidly toward this reality. Shaft sinking operations are under way. These are large shafts, and it will be nearly three years before much underground development work may commence. According to the plan, when the shafts are completed, work will begin on an ancillary test facility to demonstrate the process on a full scale, and, at the same time, begin development mining that will lead to commercial operations in late 1983 or early 1984.

Figure 1. Fragmentation variables.

(1) Explosive parameters, comparison of explosives and detonation systems.
(2) Effects of geology on fragmentation.
(3) Explosive patterns: Spacing, hole size, timing, etc. (Both small- and large-scale.)
(4) Mined void volume geometry.
(5) Retort orientation with respect to geologic conditions.
(6) Effect of retort size.

Figure 2. Fragmentation evaluation.

(1) Visual inspections.
(2) Drilling within the rubble.
(3) Flow tests and pressure tests.
(4) Tracer tests.
(5) Correlation to theoretical predictions.
(6) Mining after retorting.
(7) Retorting measurements.
(8) Remote measurements.

Figure 3. Fragmentation event factors.

(1) Evaluation and measurement of close-in seismic effects.
(2) Measurement of seismic effects at distances up to 20 miles away.
(3) Measurement and control of air blasts.
(4) Protection of sensitive equipment and nearby facilities.
(5) Protection of bulkheads on existing adjacent operating retorts.
(6) Noise measurements.
(7) Reentry.
(8) Bulking full.
(9) Scale-up from small operations.
(10) Use of ammonium nitrate fuel-oil (ANFO) explosive in wet holes.
(11) Up-hole loading systems.
(12) Protection of surrounding pillars and exposed backs (roof).
(13) Hydrologic effects.

Figure 4. Gas containment factors.

(1) Prevention of pillar cracking, opening of joints, etc., during rubbling.
(2) Bulkhead designs.
(3) Sealing of bulkheads to the oil shale formation.
(4) Sealing formation leaks.
(5) Pressure balances.
(6) Effect of local geologic features.
(7) Maintenance of all pillars and walls used for seals during the retorting.
(8) Evaluation of thermal cracking potential and prevention of leaks resulting from thermal cracking.
(9) Maintenance of boundary pillar integrity during mining and prior to rubbling.

Figure 5. Retorting measurements and control.

(1) Conventional temperature, pressure, and flow-measuring devices and variations of the same.
(2) Use of indirect measuring systems to locate flame front and other pertinent retorting conditions.
(3) Drilling within rubbled retorts and making in-rubble process measurements.
(4) Development of a mathematical model to project in-rubble conditions to diagnose external measurements and analysis and to correlate with actual in-rubble measurements.
(5) Material balances around retorts for accurate oil, water, and gas yield data.
(6) Variations in retort gas compositions.
(7) Effect of oil shale grade variations.
(8) Correction of nonideal flow occurrences and other undesired retort operations.
(9) Retorting of surrounding pillars.

Figure 6. Downstream evaluations.

(1) Oil and water separation.
(2) Oil clean up, aerosol measurement and elimination.
(3) Power generation from offgas.
(4) Other gas disposal systems.
(5) Corrosion.
(6) Oil handling.