Oil Shale Mining and Material Handling: Considerations for Future Research and Development

by

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Abstract

In order to replace present United States oil imports by the production of shale oil, 15 million tons/day of oil shale (at 20 gal/ton) would have to be mined and processed. Mining oil shale to replace even 10% of imported oil will require a few very large mines (100,000 - 500,000 tons/day) or many smaller ones (50 - 100,000 tons/day). The requirement of such monumental production rates in order to make significant contributions to U.S. oil supply must influence the directions of future mining research. Design of mining systems, capable of very large production rates and high resource recovery, should be the foremost concern. At present, open pit, block caving, and various stoping systems appear promising.

Existing mechanical mining machines which use disc and roller cutters, such as tunnel boring machines, shaft drills, and raise borers, are capable of high drivage rates in oil shale; underground mines should be designed to take advantage of their development speed. The strength of some oil shales is such that present day mining machines using dragbits (e.g., roadheaders) are severely taxed, and therefore, may see only limited use in mine development.

Research has been done in revolutionary rock fragmentation techniques (e.g., electric, electromagnetic, particle beam, and plasma fragmentation), but their application to practical, large volume mining systems is presently constrained by high cost and operational complexity. Less glamorous research aimed at other aspects of the mining systems (roof support, transport, blasting efficiency, ventilation, backfill, and reclamation) is more likely to produce significant near term benefits.

Introduction

The information presented in this paper was assembled during an evaluation of mining and material handling (M&MH) technology applicable to the production of shale oil[1]. The evaluation was prepared for the Department of Energy, Idaho Operations Office, under Contract Number DE-AC07-76ID01570 and was conducted during the period of October 1986 to April 1988. The evaluation had two objectives, to review the state of the art in M&MH and to suggest fruitful areas for research and development (R&D). We approached the task from two directions: (1) an information search to assess the applicable technology and to develop a list of research needs and opportunities; and (2) a rating of research needs and opportunities by a panel of industry experts.

The technology assessment consisted of electronic and conventional literature searches and consultation with individuals from: (1) the mining industry, (2) equipment manufacturing companies, (3) academia, (4) appropriate government agencies (U.S. Bureau of Mines, U.S. Geological Survey, U.S. Department of Energy), and (5) various state and local agencies. From the information obtained, a table of research needs and opportunities was developed.

A panel of experts from the oil shale industry was formed for the purpose of suggesting more research needs of significance and for rating the relative importance of the tabulated research needs. The panel met twice, once for a preliminary discussion and once for a formal prioritization and development of recommendations for DOE-sponsored research.

The ideas presented here come mostly from the information search part of the evaluation and therefore contain the authors' prejudices. The panel members contributed valuable advice and guidance during development of the assessment but they cannot be held responsible for any shortcomings of this paper.

Desirability of High Production Rates

Mining and processing of oil shale is one possible way to increase domestic petroleum production so that oil imports can be reduced. The goal of any oil shale development program in the U.S. should be to supply enough of the domestic demand for petroleum products to make a significant reduction in oil imports. In order to put this goal into perspective the following arithmetic is submitted:

- Present U.S. oil imports are about 7 million bbl/day (300 million gallons/day).
- To replace imports with oil from 20 gal/ton oil shale requires mining and processing 15 million tons/day (assuming 100% recovery).
- To replace even 10% of imports with shale oil requires mining and processing 1.5 million tons/day.
- It should be kept in mind that these calculations refer only to the oil shale itself. In an open pit operation with a 1:1 stripping ratio approximately two times this much material must be mined and handled in order to strip the overburden. In any kind of mining operation the spent shale will also have to be moved into fill areas.

These numbers are sobering, particularly when compared to the production figures of some of the largest mines in operation today (Table 1). The Bingham Canyon porphyry copper mine in Utah produced about 100,000 tons/day at its peak of activity. The large open pit copper mines in South America produce tonnages comparable to Bingham.

The largest operation in the Athabaskan tar sands produces about 250,000 tons/day. Although this is not a hardrock operation, the tar sand is drilled and blasted before it is moved with bucket wheel excavators[2]. In terms of production rates, this operation is closer than any other existing mine to the type of mega-production (greater than 100,000 tons/day) that we envision for oil shale.

Table 1. Current mining production figures.

Table 1.
CURRENT MINING PRODUCTION FIGURES*

Mine	Type	Ore Production	Total Material Moved
CHUQUICAMATA (CHILE)	OP[1]	96,500 T/DAY	386,000 T/DAY (3:1 STRIPPING RATIO)
EL TENIENTE (CHILE)	UG[2] (BLOCK CAVE)	94,500 T/DAY	94,500 T/DAY
BINGHAM CANYON (UTAH)	OP	96,000 T/DAY	384,000 T/DAY (3:1 STRIPPING RATIO)
ATHABASCAN TAR SANDS	OP	250,000 T/DAY	?
OIL SHALE PRODUCTION NEEDED FOR REPLACEMENT OF 10% OF IMPORTS			
	OP	1,500,000 T/DAY	3,000,000 T/DAY (1:1 STRIPPING RATIO)
	UG	1,500,000 T/DAY	1,500,000 T/DAY (MUST BE BACKFILLED)

* U.S. BUREAU OF MINES DATA
1 OPEN PIT
2 UNDERGROUND

The USSR is the world's largest producer of oil shale today. Production there is about 80,000 tons/day (it has been as high as 110,000 tons/day in the past) from 14 mines, the largest of which is an open pit with a mining rate of about 15,000 tons/day. Throughout its production history (since WWI), the USSR has mined a total of about 1.3 billion tons of oil shale[3].

In view of these considerations, it is obvious that if oil shale is to play a significant role in establishing United States energy independence it will have to be mined and processed in enormous quantities. We suggest that design of mining systems capable of mega-production should be the overriding concern for future M&MH research and development. This requires not only technical and scientific studies but also cooperation among industry, government, and local entities. Depending upon future oil prices, it may be possible for companies to mine profitably using the 40,000 tons/day room and pillar operations envisioned for production a few years ago. However, this type of piecemeal operation is not in the best interest of maximum energy production from the resource. It results in very low resource recovery from numerous small mines operating on negotiated tracts that usually are not ideally situated for optimum recovery. What is needed is a unified approach to make the best oil shale deposits available for large tonnage mining operations.

Mining Systems

Several presently available mining systems may be capable of delivering high tonnage production. Open pit mining with high volume production is well developed and used worldwide. Large open pits around the margins of the the western Tertiary basins or over near surface eastern deposits should be considered. The possibility of using open pit mining in the central part of the Piceance Basin should also be evaluated; the overburden thickness is 1000 feet, but the deposit is thickest there and the stripping ratio is still about 1:1 or less.

High volume, low cost production from underground mines is less well developed and will require considerable R&D to meet the economic requirements for large scale oil shale mining. Underground mining may not be applicable in the thin, low grade eastern deposits. However, for thick western deposits some underground mining systems have potential for high production rates. Block caving or panel caving of thick deposits can deliver high tonnages at low cost if the mined material will cave spontaneously after blast initiation. However, western oil shales have high cohesion and lower fracture density than ore deposits that are commonly block caved so that methods to force them to cave may have to be developed. Large areas of surface subsidence are a consequence of caving mining systems. Since this is environmentally unacceptable, ways to prevent surface subsidence would have to be developed; it is not clear that this is possible.

A relatively new stoping mining system called vertical crater retreat (VCR)[4,5,6] has potential application to large scale oil shale mining. Although this system has historically been applied to relatively low tonnage, high grade precious metal deposits, it should be evaluated for use in oil shale. The VCR system has several advantages over other underground mining systems:

1. The blastholes are loaded and detonated from the top rather than from underneath, resulting in a safer operation.
2. Spherical charges can be used in the blasting operation, producing more uniform fragmentation than conventional blasting. This may open the door for use of continuous transport systems to move run-of-mine oil shale to processing facilities.
3. Based upon local rock mechanical properties, the stope size and shape can be optimized for maximum production rates and ability to stand open until they are backfilled.
4. Stopes could be backfilled from above, perhaps using the blastholes to convey the backfill material. If competent cemented backfill were used, subsidence could be minimized.
5. Stope size can be closely controlled so that blocks of shale between previously backfilled stopes could be mined, resulting in very high resource recovery.
6. Proper sequencing and spacing of large numbers of stopes could result in large volume mining necessary for mega-production.
7. Relatively simple patterns of haulage drifts would be amenable to development by tunnel boring machines.
8. The cohesive nature of western oil shale would allow use of large stope sizes, contributing to the ability to mine large volumes of material.
9. The system is highly flexible and can be used for almost any orebody spatial configuration. The thick tabular shape of western oil shale deposits is ideal for deployment of a large array of VCR stopes. Also, selective solution mining or borehole mining of the saline/nahcolite/dawsonite layers utilizing the VCR blastholes could be a cost effective way to generate swell openings for VCR blasting.
10. Development of methods to inexpensively and accurately control the positions of long (about 2000 feet) drill holes may make it possible to drill the necessary blastholes from the surface. This could reduce mining costs and shorten development time by making it unnecessary to develop drilling levels above the stopes.
11. VCR stoping might be the most viable technique for developing vertical modified in-situ retorts.

The Role of Mechanical Mining Machines

Mechanical mining machines are machines which can fragment, load, and transport ore. They commonly consist of a fragmentation head, a loading mechanism, and a conveyor transport system. The fragmentation head usually contains a number of cutting devices which are rolled or dragged across the rock face to break off pieces. Roller cutters include disc cutters and button cutters. They break the rock by applying enormous pressure to small areas of the rock so that chips are spalled away. Drag bits are toothlike devices that are dragged across the rock, breaking and prying fragments from the face.

Mechanical mining has several advantages over conventional drill and blast mining:

1. It produces a uniform small fragment size that is easy to load and transport with continuous transport systems.

2. It does less damage to the rock that must remain so that ground integrity is maintained and support requirements are considerably reduced.
3. It makes smoother walls in underground openings, allowing the ventilation system to be more efficient.
4. It removes a dangerous element from the mining system - explosives.
5. It combines several elements of drill and blast mining - fragmentation, loading, transport - into a single continuous process.
6. Since it is a continuous process it does not expend time with crew changes (i.e., drilling, explosives loading, blasting, and mucking).
7. It is amenable to automation.
8. It provides the capability for selective mining.

The compressive strength of oil shale varies considerably (Figure 1), but much of it is sufficiently strong that it can be cut only with difficulty by presently available dragbit machines. It has been demonstrated that use of high pressure waterjets can increase the capabilities of dragbit machines in some types of rock[7]. A current DOE research effort is aimed at evaluating the productivity increase that waterjet assist affords to the mining of oil shale[8].

Oil shale can be effectively mined by machines using disc or roller cutters. In fact, tunnel boring machines (TBMs), shaft drills, and raise borers are capable of efficient operation in rocks much harder and more abrasive than oil shale[9,10]. Oil shale has several characteristics that make it especially amenable to mining with disc cutters:

1. Its compressive strength is well within the capability of disc cutters. This makes possible very high drivage rates in oil shale.
2. Since it is composed mostly of carbonate minerals and clay minerals, it is much less abrasive than many of the quartz rich rocks that are routinely cut by disc cutters. Therefore, cutter wear should be minimal.
3. Its cohesion (especially in western shales) may enable it to stand open with very little support after the passage of a disc cutter machine.

The use of TBMs, raise borers, and shaft drills could significantly increase the speed of development in underground oil shale operations. For this reason, underground operations should be designed to make full use of these types of machines. The design should take into account the minimum turning radius of high-speed TBMs so that they could be used to drive the haulage and access drifts. The sequence of haulage level and shaft development should be such that most shafts can be mined by raise borers. Use of these types of machines can reduce the time between initiation of the project and production of revenues so that the entire mining operation is more economically feasible.

It should be pointed out here that no presently available mining machine is capable of high tonnage production in oil shale. Some underground development machines such as TBMs and raise borers are capable of cutting oil shale, but the amount of broken material they produce is small in comparison to the production of a large mine. Some open pit production machines, such as bucket wheel excavators (BWEs), can move large tonnages of loose material (including some blast fragmented material), but are not capable of breaking oil shale.

Revolutionary Fragmentation Techniques

Considerable research has been directed at development of ways, other than blasting or striking with a harder object, to break rock[11]. Many schemes have been tested or suggested; they include mechanical, chemical, electrical, electromagentic, plasma, and particle beam procedures. Most of the schemes have one basic flaw--they try to use technologically complex and expensive energy sources to break rocks. Since explosives can be produced very inexpensively and drilling of blast holes has become very efficient, it is difficult to find cheaper ways to break rocks. For these reasons many of the revolutionary fragmentation schemes have met with technical success but dismal economic failure. For example, high powered lasers can be made to drill holes and cut slots in rock. However, they have material handling problems, such as removal of molten rock from the hole so that the beam can effectively melt more rock or reduction of effective energy transfer to the rock because of clouds of rock vapors. In general, the research has not been directed to development of an operational mining system; rather it has concentrated on only one part of the system, i.e., rock fragmentation.

An additional aspect of many revolutionary fragmentation techniques that makes them particularly undesirable for oil shale mining is that they involve high temperature processes. Especially in underground mines high temperature processes could create unacceptable risk of explosions and fires in the oil shale and in gases evolved from the oil shale.

Suggested Research and Development Directions

Based upon the precepts discussed in previous sections, the following directions for future R&D are suggested:

1. Select optimum mining sites and perform engineering design studies for large production rate mining systems with economically and environmentally acceptable characteristics. Two examples are suggested:
   a.) Design a VCR system with appropriate stope size, spacing, and sequencing to sustain long term mega-production and at the same time to prevent surface subsidence by backfilling of the stopes with cement generated from processed oil shale.
   b.) Design a mega-production open pit that would sustain long term operation and allow for reconstruction of aquifers and ground surface with processed oil shale and relocated overburden material.

Both of these examples are complex issues that require input of data that does not yet exist. Can competent cemented backfill be generated from processed oil shale? What are the mechanical and chemical (leaching) properties of oil shale cement? Does cemented backfill from oil shale production have properties that will enable it to assume the functions of the pre-mining hydrologic system? If not, how can the hydrological properties be favorably modified? Can drillhole guidance systems be developed so that long VCR blastholes can be drilled from the surface? If so, how do the costs compare with development of underground drilling levels? Is it possible to fragment oil shale in VCR stopes or open pit benches to sufficiently uniform, small fragment size that it can be transported on conveyors? What limitations

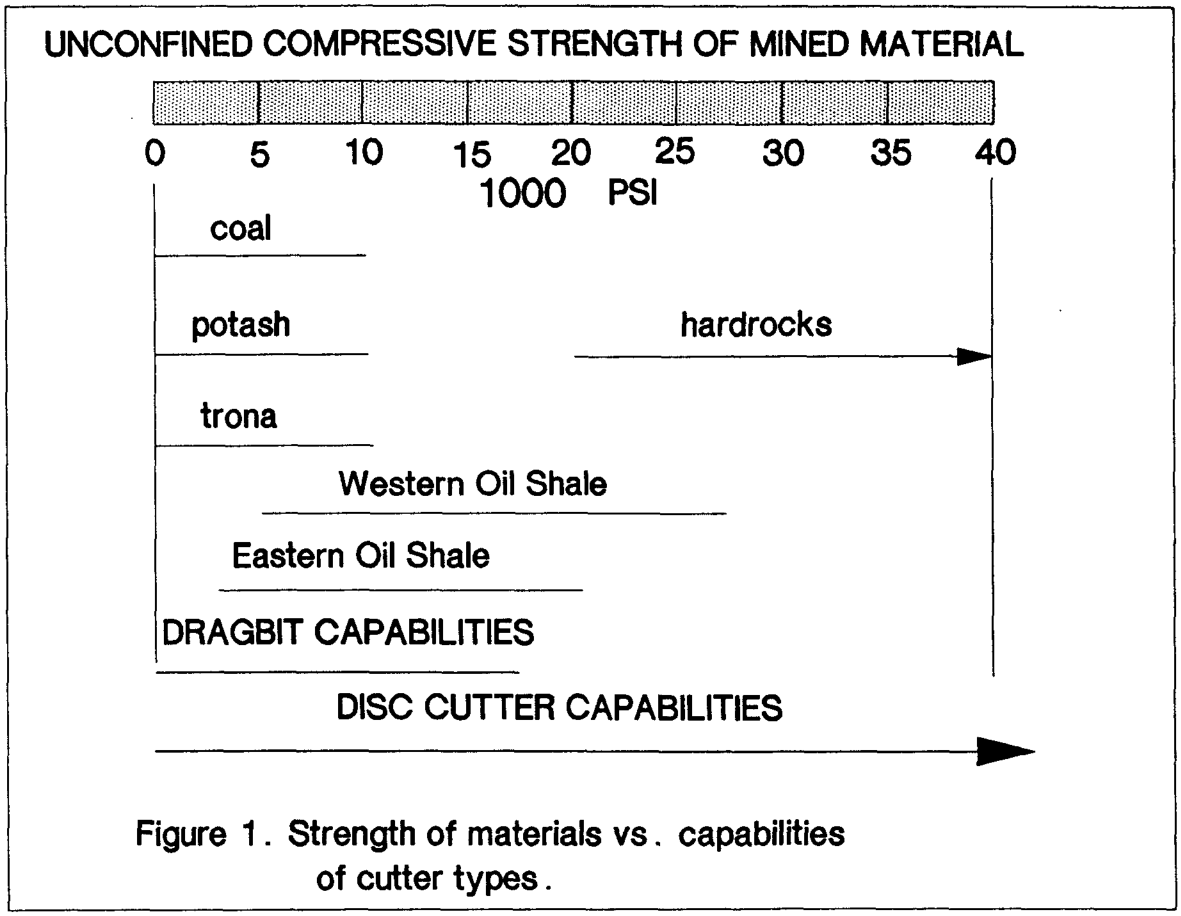

Figure 1. Strength of materials vs. capabilities of cutter types.

do the mechanical properties of various types of oil shale impose on VCR stope size or large open pit slopes?

2. Development of high volume continuous mining and transport systems. This also involves several interrelated aspects. One way to attack the problem is to design mechanical mining machines capable of large tonnage production in oil shale. For dragbit machines it is not clear whether this will require only improved design of cutter bits using available materials (such a polycrystalline diamond compounds) or if a breakthrough in development of high strength, abrasion and heat resistant materials is needed. Another approach is to modify the conditions so that presently available high volume machines can be used. For example, blasting efficiency could be improved so that oil shale can be uniformly fragmented to sufficiently small particles that BWEs can be used to load and transport the material. Alternately, perhaps BWEs and run-of-mine conveyors could be upsized so that large blocks left by present blasting techniques could be loaded and transported.

3. Initiation of some type of forum in which industry, government, and landowners can work together to assemble viable large scale projects. This would require streamlining the regulatory process and development of operational syndicates for long term mega-production.

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