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Recovery of Oil From Oil Shale -- An Overall Technological Perspective

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Abstract

The hydrocarbon content of oil shale can be converted into liquid oil which is a possible energy resource for the future. Different aspects of shale oil recovery is briefly discussed. The technology of modified in situ oil shale retorting, which is receiving increasing attention for commercialization, is discussed in a little more detail.

1. INTRODUCTION

Oil shale does not contain any liquid oil, rather it is a varied mixture of solid inorganic and organic matter (1). The hydrocarbon content of oil shale which can be converted into liquid oil is known as kerogen. Kerogen is insoluble in common organic solvents. Fortunately, however, it is thermally unstable and upon heating to above 700 degrees F produces oil. Also produced during decomposition are some light hydrocarbons and coke which may be utilized as an energy source for further extraction and for power generation for the recovery plant facilities. The term "retorting" is used to mean the recovery of oil from oil shale by thermal decomposition. Retorting can be carried out either above ground or underground, the latter being more commonly known as "in situ" retorting.

2. BACKGROUND AND HISTORY

Extensive deposits of oil shale exist in the U.S. in Colorado, Utah and Wyoming and in some mid-eastern states (1). It is also available in many other parts of the world. Estimates of total recoverable oil run in to trillions of barrels and far surpass the total estimated recoverable crude petroleum reserves in the world.

Investigators have been involved in research for the last half-century to develop the technology for oil shale retorting (2,3,4). The basic process under study has always been thermal extraction. Depending on the mode of heat transfer retorting can be classified into the following categories (5):

(a) indirect heating by radiation and conduction

(b) direct heating by circulation of externally heated fluid

(c) direct heating by combustion of carbonaceous matter in oil shale

(d) heating by contact with hot recycled solids.

Retorts of the type (b), (c) and (d) have been considered for commercialization (3,5). Each type has special advantages and disadvantages based on the ease of material handling, need for external energy, chemical yield, etc.

Retorting can also be classified as (4):

(1) aboveground

(2) in situ (underground).

Aboveground retorting is associated with large mining operations, large scale solids handling, large capital investments for mining equipment and retorting plant facilities, and disposal of large quantities of spent shale. In situ retorting minimizes most of the problems mentioned above and is favored over aboveground retorting for commercialization at this time (6). In situ retorting can again be classified as true in situ or modified in situ (7,8), the latter being at the most advanced stage for commercial exploitation.

For mining, both surface mining (open pit or strip) and underground mining (room and pillar, longwall) have been considered (5,9,10,11). Choice of mining condition depends on the location of the deposit and its accessibility, economics, bed depths and the effects on the environment. In any case, the mining operations necessary for aboveground retorting will be massive in nature and the capital investment requirement will be enormous.

In order to achieve the desired permeability in the bed and for size reduction of the oil shale particles, fracturing is necessary (5,11). Hydraulic, electrical and nuclear fracturing techniques, and the use of chemical explosives have been investigated. Nuclear fracturing would be most economical but is not preferred for obvious environmental reasons.

There is a scarcity of water in the region containing the most rich oil shale reserves in this country (12). This region is partially agricultural and depends on irrigation. The water requirement for retorting plant facilities may raise many legal problems at various levels of the government.

Oil from oil shale is a heavy, viscous liquid with a high pour point and contains some undesirable elements. Some treatment and upgrading of this oil would be necessary prior to shipment to a refinery. Treated crude shale oil once refined, however, can provide many extracts and may be used either as a liquid fuel or as a raw material for petrochemical industries. Results of some recent investigations on the health effects of oil shale retorting indicate that shale oil production is no more hazardous than natural oil production (13).

For the design, optimization and control of the retort and retorting, a mathematical model which gives an adequate description of the process is desirable. Various government agencies and private industries have been involved in recent years in the development of mathematical models for oil shale retorting (8,14,15,16,17,18). The models are tested with laboratory and field test data and show reasonable agreement for the percentage oil recovery, retorting advance rate and temperature profile in the retort. These models will be useful in devising alternate processes, suitable control schemes and in determining optimum operating conditions for oil shale retorting.

Various aspects of oil shale retorting have been briefly discussed in this section. References cited here will provide additional and detail information to the reader on any particular topic. Modified in situ oil shale retorting, which is receiving increasing attention for commercialization, is discussed in the following section in a little more detail.

3. MODIFIED IN SITU OIL SHALE RETORTING

The technique of vertical forward combustion is used in modified in situ oil shale retorting. A schematic of the process is shown in Figure 1. The process involves mining a portion of the bed and fracturing of the remainder to create the necessary void volume in the retort for the passage of gas and liquid. External heating of the top of the retort is used initially to start retorting. Kerogen decomposes forming oil which flows down under gravity. Spent shale contains some residual carbon which undergoes combustion with external air supply and provides the energy for subsequent retorting. A mixture of air and recycled gas may be used to control the rate of movement of the flame front to optimize the rate of recovery and chemical yield. The oil collects at the bottom and is recovered by pumping.

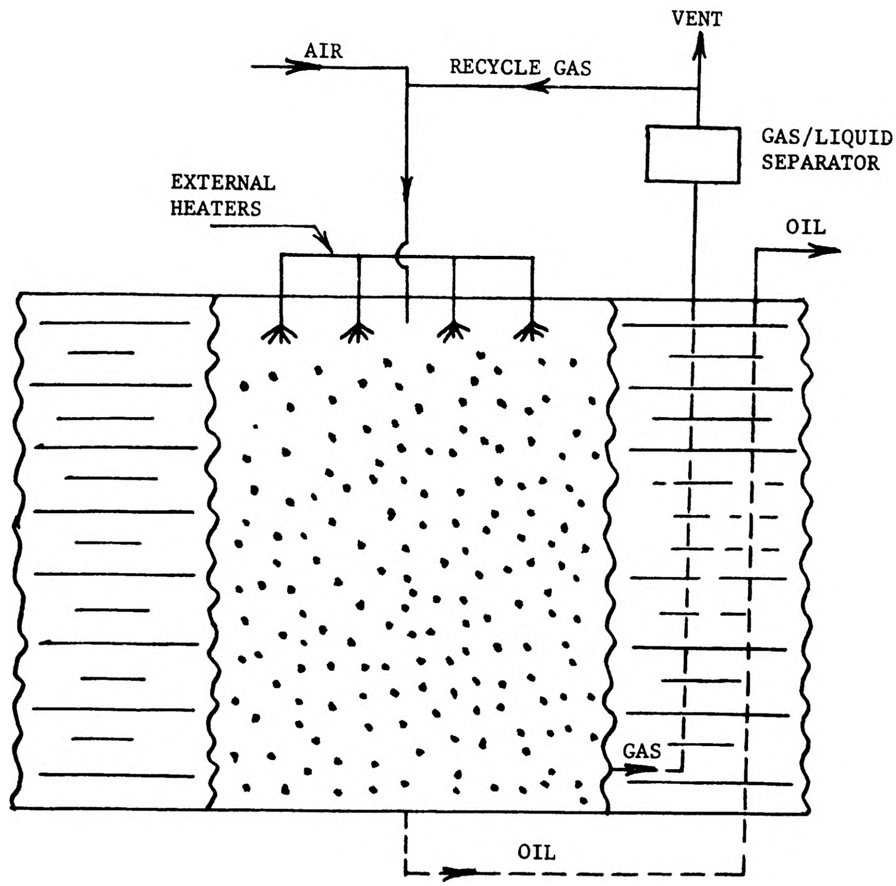

FIGURE 1. MODIFIED IN SITU OIL SHALE RETORTING

The void volume in the retort is an important process variable. During their field tests, Occidental Oil Company used a void fraction of about 0.15 to 0.20 (8). Laramie Energy Research Center (LERC) used a void fraction of about 0.40 for their pilot plant, where modified in situ retorting was simulated in an aboveground retort (19). A lower void fraction is desirable since it reduces the mining cost, however, the retorting advance rate decreases with decreasing void fraction. The ideal void fraction needs to be determined by process optimization study such that a balance between the mining expenses, percent and total oil recovery, and retorting advance rate is achieved.

Another important process variable is the oxygen concentration in the incoming gas phase. If pure air is supplied (oxygen concentration 21 percent), a substantial amount of oil produced may undergo combustion. The retorting advance rate is fast but the percent oil recovery is less. Pilot plant test results by LERC reported oil recovery of about 50 percent under this condition (19). A reduction in oil combustion and a controlled retorting advance rate can be achieved from a reduction of oxygen concentration in the gas phase by mixing air with some of the produced gas. When the oxygen concentration is about 8 to 9 percent, the retorting rate is too slow and seems to be impractical. Field test and pilot plant results indicate that an oxygen concentration of about 13 to 15 percent is desirable for optimum oil recovery and retorting advance rate (8,15). The retorting rate is also dependent on superficial gas velocity.

With increasing superficial gas velocity, the retorting rate increases.

The major chemical reactions that occur during in situ oil shale retorting are:

(1) decomposition of kerogen
(2) combustion of residual carbon
(3) decomposition of inorganic carbonates
(4) combustion of oil
(5) combustion of the combustible material in the gas phase.

Various mechanisms have been postulated to describe the kinetics of kerogen decomposition (1). The degree of complexity varies from a single first order reaction producing oil, gas and coke to a chain of series and parallel reactions, with the production of different intermediates and products. The combustion of residual carbon provides a fraction of the energy for sustaining the retorting process. The rest of the energy required is provided by combustion of the combustible material in the gas phase (carbon monoxide and light hydrocarbons) and by combustion of a fraction of the oil produced. Thus, once initiated, in situ oil shale retorting is self sustaining and does not require additional external energy input. For obvious reasons it is desirable to design the retort such that the combustion of the oil produced would be the minimum. Oil shale contains some inorganic carbonates ($CaCO_3$ and $MgCO_3$) which also undergo decomposition. These are endothermic reactions and fortunately act as heat sinks and control the temperature peak in the retort. The distribution of particle sizes, created by fracturing, plays an important part in some of these reactions. Work is continuing towards a better understanding of the kinetics and mechanisms of the various chemical reactions.

The complexities involved in oil shale retorting can hardly be overemphasized. There are some inherent uncertainties due to the unknown formation of an underground retort. Particle size distribution and non-ideal flow conditions of both gas and liquid phases increase both the complexity and the uncertainty. The phenomenon of possible partial oxidation of kerogen is not clearly understood. However, research is continuing and progress has been made in all areas and the practicality of modified in situ oil shale retorting has been successfully demonstrated by field tests. Oil recovery of about 65 percent has been achieved (8,19) which probably could be increased by process optimization.

4. CONCLUSION

To summarize, oil shale has been known as a potential energy source for a few hundred years. Commercial exploitation was not feasible due to the lack of sound technology and for various economic and environmental reasons. In recent years technological advances have been made and the practicality of oil shale retorting has been adequately demonstrated by field tests. In situ retorting minimizes environmental problems and, in today's oil economy even the high price of shale oil could be justified. The growing demand for energy, gradual depletion of natural oil and gas, political problems associated with the distribution of oil from the Middle East, and the huge potential shale oil reserves make it an inevitable energy resource for the future and the authors feel that the commercial exploitation of shale oil is only a matter of time.

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