DEVELOPMENT OF THE IIT RESEARCH INSTITUT RF HEATING PROCESS FOR
IN SITU OIL SHALE/TAR SAND FUEL EXTRACTION--AN OVERVIEW

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ABSTRACT

The history and current status of development of IITRI's RF process for in situ oil shale/tar sand fuel extraction is described. A brief description of the salient features of IITRI's RF process is given, together with a review of past laboratory development activities. Activities within IITRI's current cooperative development program, jointly funded by government and industry, are also described, including oil shale field tests, tar sand field tests, and supporting laboratory and analytical studies.

DESCRIPTION OF THE PROCESS

In order to offer promise as an economically attractive and environmentally acceptable in situ oil extraction technique, the RF process must make very efficient use of its input electrical energy for heating, without producing external electromagnetic radiation. The key to IITRI's success in meeting these criteria is an electrode array which provides nearly uniform volumetric heating of the resource material enclosed within the array, with small heat loss and negligible radiation outside this volume. These benefits are achieved through use of the triplate transmission line concept.

Research on IITRI's RF technique has been in progress since 1975, and during that time has progressed from simple conceptual analysis, to laboratory experimentation, to the present where field experiments of modest size have been performed. It is the purpose of this paper to briefly describe the heating concept and trace its development up to the present time.
Figure 1 Triplate Line Conceptual Design. (A) Solid Wall Totally Enclosed Cavity; (B) Solid-Wall Cavity With Side-Wall Removed; (C) Discrete Conductor Realization of (B).

Government interest in the process began in 1978 when IITRI received DOE funds for a study of the application of RF heating techniques to tar sands. During this program, research activities were carried out to measure tar sand electrical properties and conduct laboratory experiments to demonstrate the feasibility of uniform RF heating and the low RF leakage inherent in the transmission line approach. Additional experiments were carried out in the laboratory to investigate fluid replacement and gravity drive as two possible tar sand production alternatives. The laboratory research was complemented by preliminary analysis of the net energy ratio (NER) and economic benefit of the process.

EARLY STUDIES OF THE RF TECHNIQUE

Initial development of the process was carried out by IIT Research Institute during the mid-1970's as in-house research on the application to shale oil recovery. This effort included measurements of oil shale electrical properties, primarily dielectric constant, loss tangent, and breakdown characteristics, and simulated in situ heating in laboratory reactors. In the latter tests, RF heating feasibility, oil shale pyrolysis by RF heating, pyrolytically induced oil shale permeability, and autogenous gas production were demonstrated.

As part of the in-house laboratory effort, RF hosting reactors capable of pyrolyzing up to 10 Kg oil shale were constructed and used for numerous experiments. The experimental results indicated that pyrolysis of oil shale kerogen by this method is feasible, and showed that the dielectric properties of Ohio shale are sufficiently well behaved that experiments can be carried out by relatively straightforward implementations.

into holes drilled either from the surface or from drifts mined into the deposit in question. The tubular electrodes may also be useful in providing an exit path for the hydrocarbonaceous products liberated by heating. Some conceptual large scale implementations of the technique are shown in Figures 2 and 3.
Figure 2 Conceptual Design of Shale Oil Recovery Facility

IITRI RF In-Situ Technology

Figure 3 Conceptual Design of RF Process for a Tar Sand Deposit
duce four to ten times more energy than it consumes for typical Utah tar sands, with the actual value depending upon the richness of the deposit, the characteristics of the oil and the rock medium and the overall recovery (see Figures 4 and 5). Total production costs were assessed as well in the economic study, and were estimated to be in the order of $6/bbl (1979 dollars, exclusive of pre-refining charges) for the 70% recovery case. An independent economic assessment of the RF process placed production costs for an oil shale application at about $15/bbl.

Several new research activities aimed at development of the process were begun in 1979. These initially independent programs, funded by DOE and private industry, were subsequently combined into a broadly structured cooperative program which covers 27 months and includes: (1) field tests of the process as applied to oil shale, (2) field tests of the process as applied to tar sand, and (3) supporting laboratory and analytical studies. The SSM cooperative program is jointly funded by government and industry. Technical direction of the cooperative program is provided by the Laramie Energy Technology Center, with the entire effort under cognizance of DOE's Office of Advanced Technology Projects. Activities and accomplishments within this present program are described in the following paragraphs.

PRESENT PROGRAM ACTIVITIES

Oil Shale Field Tests

After completion of preparations which began in August 1979, two RF heating experiments using the IITRI technique were conducted in Avintaquin Canyon, Utah, in the period January-March 1980. Oil Shale volumes of approximately 1 meter (weighing ~2 tons) were heated by the RF process in each test, using electrode arrays which were horizontally emplaced in convenient shale outcrops.

At the test location, which is about 30 miles SW of Duchesne, Utah, a 6 meter thick shale bed is accessible in outcrops permitting the conduct of horizontal experiments at modest cost. A 52 meter length of the test outcrop was prepared by light blasting to remove weathered shale and form a vertical cliff face. Arrays of holes were then drilled and electrodes were inserted to a depth of 1 meter (somewhat more in the case of outer guard-plane electrodes). A steel frame was attached and sealed to the shale cliff face outside each array, and after

![Figure 4](image_url)

**Figure 4** Net Energy Ratio Values for Bitumen Recovery

![Figure 5](image_url)

**Figure 5** AC Power Costs Per Barrel for RF Heating of Utah Tar Sand
All electrical connections were completed, a steel cover was mounted to the frame forming a shroud for product collection (see Figure 6).

The purpose of these first field experiments was simply to gain initial experience and test the basic feasibility of bringing oil shale to pyrolysis temperatures in situ by RF heating, and of collecting products of the pyrolysis. Each triplate electrode array was inserted into the shale deposit directly from the cliff face and terminated in an open circuit at a depth of approximately 1 meter. No mechanism was incorporated for control of standing waves within the transmission line. Each array was connected via rigid coaxial cable to a variable impedance matching network, and thence to the RF power source, a 40 KW radio transmitter. For the tests, forward RF power levels were kept in the range of 5 KW to 20 KW and the matching network was adjusted to hold reflected RF power levels below 250 W. All test operations were at a frequency of 13.56 MHz.

In the first test, temperatures over 340°C were recorded at the excitor electrodes and 4.5 gallons of oil was collected. In the second test, temperatures above 400°C were reached and more than 20 gallons of oil was collected. Product collection was impaired for the tests by the presence of a number of cracks and fissures in the outcrop which allowed a portion of produced vapors and liquid to escape without being collected. Despite this situation, the 20 gallons of oil collected in the second test represented 22-30% of the oil content of the shale emplaced within the (1 meter) triplate array. RF leakage was seen to be very low, measured at 70 dB below the input power to the deposit, even though no attempt was made to optimize the electrode pattern for fringe field reduction.

Tar Sand Field Tests

Field tests of the application of IITRI’s process to tar sand are also included within the present program. The initial test, which was conducted in February 1981, was planned as a quick-look experiment to validate the heating concept and equipment designs, and to test the gravity drive bitumen recovery technique. A second field experiment planned for the summer of 1981, will heat over a longer period and will achieve higher temperatures, but will use the same basic equipment complement prepared for the initial test. Specific plans for the second test are presently being formulated based on the results of the first experiment.

Preparations for the initial quick-look experiment encompassed site selection, equipment preparations, and site development. After consideration of some two dozen tar sand sites and detailed study (including coring) of the three most promising locations, the Asphalt Ridge area near Vernal, Utah was selected as the optimum site for the planned test program. In August 1980, arrangements were completed with SOHIO Shale Oil Company for use of a portion of their holdings on Asphalt Ridge for the tests.

Immediately upon obtaining permission to utilize the SOHIO property, and after securing the necessary approvals, development of the site for the planned tests was begun. Activities undertaken and completed including grading and fencing of the test area, installation of electric power service, mining of the collection chamber and tunnel, and drilling of the planned series of vertical electrode holes (Figures 7 and 8). A vertical electrode emplacement pattern was chosen for this experiment primarily in order to test the gravity drainage production concept.

About 25 meters (60 tons) of tar sand was included in the test volume. Electrode holes some 6 meters long were drilled vertically into the tar sand from an exposed surface outcrop to a lower collection room mined into the deposit. In addition to providing a collection area for bitumen draining by gravity...
Figure 7 Tar Sand Field Experiment -- Site Plan

Overburden

Array

Coax Trailer

Power Transformer Pad

Figure 8 Tar Sand Field Experiment -- Site Cross Section
through the deposit, the mined chamber also provided access to the lower ends of the heating electrodes. With this access, the terminal impedance could be adjusted periodically during the heating period to provide correction for transmission line standing wave effects, and thereby achieve more nearly uniform heating longitudinally through the deposit.

In parallel with the site selection and development activities, all of the special equipment necessary to the experiment was designed, prepared, and shipped to the Utah site. This includes: a 200 KW radio transmitter to supply heating energy, a dummy load and heat exchanger for transmitter checkout, specialized electrical impedance matching and transmission line transition equipment, a modular system for collection and storage of gas and liquid products, ancillary subsystems for transmission line and matching network cooling, and appropriate data collection sensors, instrumentation, and recorders.

Plans for the first experiment called for heating at two or three RF frequencies, and for production of about 3% of the total bitumen within the test volume (= 1 bbl) over a one-week period at temperatures in excess of 120°C. Subsequent to the gravity drainage experiment, the tar sand was to be heated to temperatures above 300°C where some in situ cracking would take place and rapid production of a much lighter oil would result.

Heating tar sand deposits to 120°C with gravity drainage is of commercial interest since most Utah tars should flow readily at this temperature. Depending on the deposit, overall bitumen recoveries via gravity drainage have been projected, based on a computer reservoir analysis, to approach 80% using IITRI’s process because of the large number of product collection paths available in the electrodes. Even for a pessimistic assumption of only 40% recovery, Figures 4 and 5 show a net energy ratio on the order of 5 and an electric power cost of only a few dollars per barrel. Heating to high temperatures may prove to be of even greater interest since it should produce a light oil which does not require pre-refining.

The gravity drainage portion of the experiment was very successful, producing about 2% of the bitumen (0.7 bbl) in less than four days, and giving evidence of excellent RF heating behavior. Temperature measurements indicated that heating was quite Wore and In good conformity with computer-predicted values. In addition, RF leakage measurements indicated that radiated electromagnetic fields were 80 dB below the power level entering the triplate line. For this portion of the test, RF power levels ranged up to 75 KW. Initial heating took place at 2.2875 MHz, with the frequency changed to 13.56 MHz after 3 days.

The second portion of the experiment was not conducted, however, because after 3 days of heating, subsidence of a portion of the tar sand mass into the collection room blocked tar recovery and caused a short circuit within the electrical transition assembly. This event required premature termination of the field experiment. The subsidence problem which was encountered does not represent any fundamental limitation on the process, but rather presents the engineering problem of developing a technique for fully supporting the softened and unconsolidated tar sand volume while permitting liquid tar and gaseous products to escape for collection. A solution to this problem has since been developed and will be tested in a second tar sand experiment later in 1981.

Supporting Laboratory and Analytical Studies

To complement and advance the field test activities, a parallel program of laboratory and analytical studies has also been instituted. These activities began in late 1979 and will continue to the end of the cooperative program.

The study activities which have already been carried out include: (1) electrical studies to measure the dielectric and electrical breakdown characteristics of oil shale and tar sand samples from several sources, and to study heating uniformity in a simulated field experiment, (2) chemical and physical studies to analyze material properties, conduct oil shale pyrolysis experiments, study bitumen production by gravity drainage and autogenous drive, and develop a tar sand reservoir analysis simulation capability; and (3) analytical studies to develop, and exercise for experimental design, a simple two-dimensional computer simulation model describing heating and thermal effects resulting from application of the IITRI technique in arbitrary configurations and media.

Dielectric measurements were made for a number of oil shale samples under simulated constrained in situ conditions. The tests showed that while the parameters vary with site and grade of shale, the dielectric absorption in all cases decreased rapidly
as temperature rose above 200°C, falling to a relatively constant value up to 450°C. Dielectric breakdown occurred only at temperatures above 420°C and at RF power densities far in excess of those anticipated for a commercial facility. The measurements also demonstrated that the dielectric absorption is independent of oil and gas production.

Induced oil shale permeabilities perpendicular to the bedding planes were also measured under simulated 50 psi overburden pressure at 450°C. The measured values ranged from 300 to 900 millidarcies and were some three to five times greater than previously reported.

Even higher permeabilities are expected where gas flow is parallel to the bedding planes. Such high induced permeabilities should allow excellent shale oil product recovery. TGA and long-term pyrolysis studies were also carried out for oil shale and showed that good recoveries occur for the RF process when final retorting temperatures are between 350°C and 420°C.

A series of laboratory experiments on tar sand samples supported by computer aided reservoir analysis demonstrated that, for certain deposits, good bitumen recoveries are possible by gravity drainage. Recovery rates are enhanced by the development of autogenous vapor pressure (such as occurs by the evaporation of water), and by the presence of a large number of production paths (as is the case with a triplate array). In addition to these experiments, analytical techniques developed within the program allowed prediction of deposit temperatures which would occur in the tar sand field test. Temperature measurements made during the test corroborated the predictions.

In addition to the study work already undertaken, additional work planned for the remainder of the present contract period includes an updated and refined economic assessment for both oil shale and tar sand applications of the process, engineering studies of resource properties and improved techniques and process materials, and preliminary planning for larger field tests to be conducted in the future.

The present combination of laboratory and field work is leading to a very thorough understanding of the RF process, and its application to oil shale and tar sands. Many of the earlier reservations regarding certain features of the process have now been solved and much of the background work necessary for scaling the techniques toward the pilot-plant scale has been completed.

FUTURE PLANS

Because IITRI's in situ recovery process shows great promise toward providing an economically attractive method for shale oil and tar sand bitumen extraction in a manner which will have minimal environmental impact, it is believed that expeditious development of the technique beyond its present research stage is in best interests of the nation in the quest for energy independence. To further this development, preliminary planning has been carried out toward establishment of a long range program of development aimed at demonstrating capability for heating larger resource volumes (e.g. 300 m³) in situ and at demonstrating continuous oil production at a modest level (e.g. 10 bbl/day). These steps are deemed essential in bringing the RF technique to a high level of development and in acquiring the data necessary for an accurate and realistic assessment of the economy of the process.

REFERENCES


