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

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April 1981
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.

INTRODUCTION

Several years ago engineers at IIT Research Institute conceived an RF dielectric heating technique for extraction of oil from shale, tar sands, and other hydrocarbonaceous resources. The technique, which after initial laboratory confirmation was granted U.S. patents, makes use of a transmission line approach to dielectric heating using special patterns of electrodes inserted into boreholes in the target resource, and energizing these with an RF voltage at selected frequencies (generally in the lower short-wave band). The approach has several unique characteristics, namely (1) it can produce nearly uniform volumetric heating of the resource in situ, (2) it is adaptable to nearly all resource types, (3) it has little environmental impact and does not radiate a significant amount of RF energy, (4) it requires little mining and no on-site combustion, and (5) it yields a high quality product. Preliminary studies have also indicated a favorable net energy ratio and low cost for the process.

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 RF heating concept and trace its development up to the present time.

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.

The basic triplate line configuration is shown in Figure 1a, with more practical approximate configurations indicated in Figures 1b and 1c. Theoretical analysis of the cylindrical conductor triplate line equivalent indicates that the enclosed electric fields are essentially uniform except near and beyond the edges of the inner electrode row. This suggests that any dielectric material which is present between the electrode rows will be heated nearly uniformly. Moreover, by use of an excitation arrangement where the RF voltage source is connected to the center row of electrodes with the outer rows being maintained at ground potential, and by maintaining the proper line geometry, virtually all of the RF energy can be contained within the precise volume of the triplate line, with essentially no RF heating of adjacent material and no electromagnetic radiation to cause a health concern.

In addition to possessing these fundamental properties, the triplate line heating concept is adaptable to a wide variety of resource materials by careful selection of the electrode array configuration and by adjusting the RF frequency to the specific dielectric properties of the resource. Application of the triplate concept to any given resource deposit would, of course, depend on the specific situation, but in general the triplate electrodes will consist of rows of metal pipes inserted
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)

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.

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 tests. The experimental results indicated that pyrolysis of oil shale kerogen by this method is feasible, and showed that the dielectric properties of Oho shale are sufficiently well behaved that experiments can be carried out by relatively straightforward RF implementations.

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 to 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.

The analytical and experimental work carried out in this program demonstrated that the electrical parameters of Utah tar sand will permit highly efficient matching of power into typical deposits, and showed that nearly uniform RF heating is possible. Laboratory tests of in situ RF heating using the triplate electrode array concept on tar sand samples as large as 250 Kg indicated that, under ideal conditions, up to 85% of the bitumen could be recovered by fluid replacement (tertiary) recovery methods. Computer simulation studies showed that similar very high recovery should also be possible using gravity drive in combination with tubular electrodes which serve as production paths. Economic studies showed that the IITRI RF in situ process should pro-
Figure 2 Conceptual Design of Shale Oil Recovery Facility, Emnnynono
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$^3$ (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
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.

Despite this situation, the 20 gallons of oil collected in the second test represented 22-30% of the oil content of the shale enclosed 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 fringing 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

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 develop-
ment activities, all of the special equipment neces-
sary 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 trans-
mission line transition equipment, a modular system
for collection and storage of gas and liquid prod-
ucts, ancillary subsystems for transmission line and
matching network cooling, and appropriate data col-
lection sensors, instrumentation, and recorders.

Plans for the first experiment called for heat-
ing at two or three RF frequencies, and for produc-
tion of about 3% of the total bitumen within the test
volume (= 1 bbl) over a one-week period at tempera-
tures 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 crack-
ing 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. Depend-
ing on the deposit, overall bitumen recoveries via
gravity drainage have been projected, based on a com-
puter reservoir analysis, to approach 80% using IITRI's
process because of the large number of product col-
lection 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
w very successful, producing about 2% of the bitu-
gen (0.7 bbl) in less than four days, and giving
evidence of excellent RF heating behavior. Tempera-
tyro measurements indicated that heating was quite
*Wore and In good conformity with computer-predicted
values. In addition, RF leakage measurements indi-
cated 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 funda-
mental 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 activi-
ties, 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 mea-
sure the dielectric and electrical breakdown char-
acteristics of oil shale and tar sand samples from
several sources, and to study heating uniformity in
a simulated field experiment, (2) chemical and physi-
cal studies to analyze material properties, conduct
oil shal pyrolysis experiments, study bitumen pro-
duction 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 applica-
tion of the IITRI technique in arbitrary configura-
tions 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 RE process, and its application to oil shale and tar sands. Many of the earlier reservations regarding certain features of the process have now been resolved and much of the background work necessary for scaling the techniques toward the pilot-plant stage 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 a 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