Society of Petroleum Engineers

SPE 28619

Pilot Testing of a Radio Frequency Heating System for Enhanced Oil Recovery From Diatomaceous Earth

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This paper was prepared for presentation at the SPE 69th Annual Technical Conference and Exhibition held in New Orleans, LA, U.S.A., 25–28 September 1994.

Abstract

This paper describes a high power, full scale field demonstration of a radio frequency (RF) downhole applicator system which has the objective of ultimately expanding the scope of Texaco's thermal operations beyond conventional operations. Field testing of KAI Technologies radio frequency heating system was performed in the Texaco Denver Producing Division's Midway area, N. Midway field, CA, in a shallow diatomite reservoir during the summer of 1992. Two tests (a low power test and a high power test), gave every indication that RF technology is a viable way of heating a formation.

Summary

An in-situ borehole radio frequency (RF) antenna heating system at a depth of 620 feet was implemented at a Texaco oil recovery site in Bakersfield, California. A pilot test was conducted to demonstrate the ability of the RF system to both focus thermal energy at high efficiency into a particular subsurface deposit of diatomaceous earth and thereby raise near borehole temperatures to levels that would increase the rate of oil recovery. Prior to conducting this test a laboratory treatability study was conducted which determined both the design of the RF heating system and the temperature that is required for the diatomaceous earth to release its oil. The results of the treatability study and pilot test are discussed along with an overview of the theory and the utility of RF heating for enhanced oil recovery. Plans for further testing and RF system costs will be presented.

Background

The development of technology for producing oil from heavy oil and tar sand deposits by thermal means has been on-going in the petroleum industry for many years. Since the early 1970's one of the technologies pursued has been radio frequency heating where heating is produced by the absorption of electromagnetic energy by the polar molecules in the formation. In addition to conventional steam flooding other thermal enhanced oil recovery (EOR) techniques have also been evaluated i.e. conduction heating, hot gas injection using electric or gas fired calrods, and electrothermal techniques. A good summary of the current state of electromagnetic techniques for thermal EOR is given in the paper by F.S. Chute and F.E. Vermuelen[1]. Topics discussed are electric preheat-steam, eddy current, electromagnetic flooding, single-well radio frequency (RF) stimulation, electrocarbonization, and microwave retort.

Technical Approach

The purpose of the radio frequency (RF) pilot test in Bakersfield, CA was to demonstrate the controlled application of RF energy for thermal EOR in a single borehole environment. A diatomaceous earth site was selected because this type of earth does not respond well to conventional steam injection methods. RF by its nature penetrates the earth, allowing the formation to become heated beyond the immediate vicinity of the borehole without reliance on thermal conductivity.

The objectives of this test field were: to verify controlled application and focusing of RF energy at a depth of 620 feet; and to measure the depth of penetration of the RF energy and thermal pattern it produced. To accomplish these objectives a downhole applicator was designed with the assistance of electromagnetic codes which simulated the electromagnetic environment of the field site using data gathered through laboratory measurements of the diatomaceous earth, and using near surface low power measurements of the applicator radiation pattern and impedance at a nearby field site. Mobile RF equipment was provided with an RF generator capable of delivering 25 kilo-watts (kW) of continuous wave power at 13.56 MHz. The RF generator and its associated monitoring equipment were controlled by computer which collected data for analysis and control on: energy consumption, applicator efficiency, and the operating condition of the RF heating system.

Theoretical Aspects of Radio Frequency Heating

The power dissipated within the diatomaceous earth is the result of the interactions of the dielectric constant of the material with radio frequency energy. The power dissipation is briefly derived from first principles and yields a simple expression involving the electric field E established in the earth, which is linked to the field of the applicator inserted into the borehole. The power dissipated will be attenuated as the electromagnetic fields penetrate the diatomaceous earth, an effect depending on the earth dielectric properties and frequency.

Power Dissipated

Radio frequency heating involves the conversion of electromagnetic energy into heat. Energy is transported through the earth by means of electromagnetic waves. The flow through a closed surface can be calculated from the integration of the power density vector or the Poynting vector of Electromagnetic Theory[2].

$$\overline{S} = \overline{E} \times \overline{H} \quad \text{watts/meter}^2 \qquad (1)$$

where $\overline{E}$ and $\overline{H}$ are the vector electric and magnetic field intensities associated with the electromagnetic energy and

$$P = \int_S (\overline{E} \times \overline{H^*}) \cdot \overline{ds} \quad \text{watts} \qquad (2)$$

is a description of the inflow of electromagnetic energy through a closed surface. Using Maxwell's Equations gives the result that the average power flow into a defined volume is

$$P_{ave} = \frac{1}{2}\omega\epsilon_0\epsilon'' \int_V (\overline{E}^{*}\cdot\overline{E})\, dV \quad \text{watts.} \qquad (3)$$

The complex dielectric constant of the earth is $\epsilon' - j\epsilon''$ where ϵ' is the real part controlling the length of the applicator (proportional to wavelength) and ϵ'' is the imaginary part proportional to the RF energy absorbed in the soil. This fundamental parameter varies with frequency and temperature and is measured in the laboratory or in the field with special electronic instrumentation.

In the region where E is a constant, the following simplified expression describes the total average power dissipated in volume V.

$$P_{ave} = \omega\epsilon_0\epsilon'' E_{rms}^2 V \quad \text{watts} \qquad (4)$$

$$(5)$$

$$\text{or} \quad p = \omega\epsilon_0\epsilon'' E_{rms}^2 \quad \text{watts per cubic meter}$$

where the product of radian frequency ω, free space dielectric constant ϵ_0 and loss factor ϵ'' is the electrical conductivity σ in units of Siemens per meter. Hence

$$p = \sigma E^2 \qquad (6)$$

where the conductivity, $\sigma = \omega\epsilon_0\epsilon''$

E is the rms electric field intensity in volts per meter. Equation (6) shows that the product of conductivity or frequency and the imaginary part of the dielectric constant (loss factor) are crucial in determining the electric field required to establish a given power density within the soil.

Rate of Rise of Temperature

As the radio frequency energy is absorbed in the earth, its temperature increases at a rate depending on several parameters. The energy required to raise the temperature of a mass m(kg) of earth from ambient temperature T_A°C to T°C is

$$mc_p(T - T_A) \quad \text{joules} \qquad (7)$$

Therefore, during the initial heatup of soils,

we have $\sigma E^2 dt = \rho c_p dT$ where ρ is the mass density of material in kg/m^3 and c_p is the specific heat at constant pressure. The initial heatup rate is therefore

$$\frac{\sigma E^2}{\rho c} = \frac{dT}{dt}\,. \qquad (8)$$

The rate of rise of temperature depends on $\sigma/\rho c$ for a given electric field E. The quantity $\sigma E^2/\rho$ = **SAR** is defined as the specific absorbed power in watts per kg.

An example of RF heating within a soil volume with homogeneous dielectric properties is given in **Figures 1 and 2**. The ambient temperature for this example was arbitrarily set at 100°C. **Figure 1** is the temperature distribution after 4 days of heating and **Figure 2** is after 30 days of heating using 20 kW.

<u>Laboratory Dielectric Measurements</u>

Dielectric measurements versus temperature were performed. The dielectric constant and conductivity data from these measurements are presented in **Figure 3**. From 50°C to 295°C the dielectric constant and conductivity of the sample steadily approach the dielectric constant of sand, indicating the removal of water and hydrocarbons.

Dielectric measurements were also made over a wide range of frequencies at room temperature using a 2 foot diameter hemispherical chamber half filled with diatomaceous earth into which a 6 inch long electric monopole was inserted[3]. The data from this experiment is presented in **Figure 4** and exhibits a decreasing dielectric constant with increasing frequency and a conductivity which generally increases with frequency. At approximately 200 MHz the monopole is at its first resonance, marking the cutoff point for this method.

Laboratory Radio Frequency Heating Studies

To better understand the heating characteristics of the diatomaceous earth and the changes in its dielectric properties that occur with heating, a laboratory study using RF was conducted. The study employed a one kW, 50.55 MHz (HF) heating source and a 200 W, 144 MHz (VHF) heating source. The HF source was used to heat soil samples in a modified 55 gallon drum with an electric monopole. It was verified that the diatomaceous earth could be efficiently heated with RF to the temperature of 150°C. Afterwards, another sample holder was constructed, the high pressure vessel (HPV) with a monopole to simulate the soil overburden conditions present at the field site.

One of the RF heating experiments with the HF source involved heating a Bakersfield sample to 150°C at 400 watts. After 49 minutes the goal temperature of 150°C was achieved. The total heating time was 1.5 hr. **Figure 5** shows a plot of the temperature versus time. After heating the sample, a visual inspection revealed that the diatomite had been transformed into a dry sandy powder next to the monopole applicator, but further away the sample became wet, an indication of "water movement" produced by the RF. Furthermore, some oil had drained through the dry sand and accumulated at the bottom of the sample holder. In addition to recording the temperature, the impedance of the monopole applicator was measured prior to and after heating with RF to observe the changes in the dielectric properties of the diatomaceous earth during RF heating.

Following this experiment the HPV was used with the VHF source to heat a diatomaceous earth sample under conditions similar to the field test. The sample was heated to between 100°C and 150°C in a hermetically sealed environment with a confining pressure equivalent to 500 feet of overburden. The HPV is a 1 foot high, 1 foot diameter steel container with simulated overburden applied by a 60 ton press. The RF applicator, an 8 inch long vertical electric monopole, was inserted through the bottom plate. This plate also had adjustable valves which allowed liquids to be removed. One hundred and fifty watts of RF power was applied steadily for a period of 8.5 hours. Temperature measurements were made with a fiber optic temperature probe. **Figure 6** shows the heating curve closest to the monopole over the entire heating cycle. A maximum temperature of 100°C was achieved near the outer wall of the HPV at 5.3 hours. The dielectric properties of the sample were also measured periodically during heating.

Computer Modeling of the Applicator

A computer model of an insulated dipole antenna derived from the work of Professor R.W.P. King of Harvard University[4] was used to calculate the electric field intensities produced by the field test RF applicator at 13.56 MHz with 25 kW of radiated power. The calculated electric field intensities were translated into initial heating rates for later comparison to the field measurements made at the field site temperature sensor boreholes T10, T20, and T30. These boreholes were located at 10, 20, and 30 feet, respectively on a radial line away from the RF application well, 100D.

Figure 7 depicts a model of the RF heating process. A low conductivity zone of radius A_2 has been established around the applicator by RF heating. The

RF heating has resulted in the removal of water and liquid hydrocarbons. A wet unheated zone (A_3) lies beyond this separated by a transitional region referred to as the vapor zone. Three different cases were evaluated using the dipole computer model. Case 1 represents the condition of the earth prior to RF heating. Case 3 is when the vapor zone has propagated to T30, a distance of 30 feet. A combination of wet and dry zones has now been established around the applicator by RF heating. Plots of the electric field data for these cases at 25 kW radiated power and 13.56 MHZ are presented in **Figure 8a** (Case 1) and **Figure 8c** (Case 3), **Figure 8b** is at an intermediate time. The data is for cuts perpendicular to the applicator for radial distances of 0.5 (1.6 ft.), 1.0 (3.2 ft.), 2.0 (6.4 ft.), and 4.0 m (12.8 ft.) from the RF applicator. The locations of the temperature monitoring wells and the position of the center of the applicator (Well 100D) are marked. This data shows that as the soil is dried out by heating, the conductivity decreases near the applicator borehole, allowing the electric field strength to increase further away from the applicator. During the first 24 hours it was predicted that a 12°C/hr heating rate would be achieved within 3 feet from the applicator. Temperature monitoring well T10 will achieve its maximum heating rate of 3°C/hr after 2-3 days, T20 will reach 0.8°C/hr after 1-2 weeks, and T30 will reach 0.2°C/hr after 4-5 weeks for 25 kW of absorbed power.

Using NEC-3I[5], the method-of-moments numerical electromagnetics code developed by Lawrence Livermore National Laboratory the precise electromagnetic environment in which the RF applicator would operate was modeled to assist with the design of the RF applicator. This resulted in an applicator that was 25 foot long and housed within a 30 foot long fiberglass shroud with a metal fishneck assembly attached to the top end allowing the applicator to be supported mechanically. During the heating test the RF applicator was attached to approximately 700 feet of 7/8 inch diameter pressurized coaxial transmission line (flexible) and its center was positioned at a depth of 620 foot in well 100D.

Description of Bakersfield Field Test Site and RF Heating Equipment

The high power test was at the North Midway field,Midway area, CA in well 100D which had been specially prepared for the test. The well was located where the diatomite interval was relatively homogeneous and temperature monitoring wells could be located on strike. A paved area accommodated the RF equipment trailer, a house trailer which was used as an office, an electrical power diesel generator, and sufficient space for a pulling rig, service trucks, coiled drum feeding systems for the coaxial RF transmission cables, and operating personnel vehicles.

Well 100D was drilled to casing depth (538 feet) and logged. This casing shoe depth was a few feet within the diatomite interval which started at 500 feet. The completion was then made with the customary steel casing to the casing shoe. Next, the well was drilled to 780 feet and logged (dual induction - SFL, gamma ray, compensated neutron-lithodensity and long space sonic) and a 250 foot RF transparent glass/epoxy composite liner temperature resistant to 200°C was hung. This line was perforated (40 mesh, 36 row, 6" center, 2" slots) over its bottom 80 feet. The well was gravel packed from the top of the liner down, using a cross over tool. The gravel pack was installed to allow for drainage of heated diatomite oil during the test and to provide desaturation of the heated zone.

The three observation wells T10, T20, and T30 located 10, 20, and 30 feet from well 100D were drilled and T30 was logged. All three of these wells were completed with high strength, temperature resistant PVC pipe. These monitoring wells were used to measure temperature and magnetic field profiles.

Figure 9 shows the completion of well 100D. Also shown is the placement in the well of a pump housed in glass/epoxy composite production tubing. The position of the RF applicator within the well is shown next to the tubing. This completion was designed so that the RF energy could be applied at any depth and heat the fluids near the wellbore at that depth; these fluid would then drain through the gravel pack, collect in the well sump and be pumped out. The voidage so created would allow the RF energy to propagate further out into the formation continuing the process.

For this field test a mobile RF heating system was used. The mobile system was assembled around a 25 kW, 13.56 MHz generator which was contained within an instrument shelter. In addition to the RF generator, the instrument shelter contained all the necessary electronic components to monitor and control the heating process. The RF heating system was controlled by an 8286 data processor with GPIB (general purpose interface bus) controller which was provided with a complete set of RF system diagnostics and which continuously recorded and filed this data for later analysis. A generic block diagram of the instrument shelter is shown in **Figure 10**.

The purpose of the dummy load was to allow operation of the RF generator into an optimum load (50 ohm) without connection to the applicator. The matching network was used to improve the overall system efficiency by ensuring that the RF generator is looking into a near optimum load while it fed power to the transmission line. The network analyzer was used for real time measurement of the applicator's efficiency when the RF generator was off. The vector voltmeter monitored the applicator and its efficiency continuously when the RF generator was on.

Results of the Bakersfield Field RF Pilot Test

The field test was run at the Bakersfield, CA site during the summer of 1992 over a period of several weeks. It demonstrated a proof-of-concept for the controlled application of RF energy for thermal EOR from a single borehole environment. The objectives for this initial phase were: 1) to verify that the I applicator provided a focused radiation pattern a efficiently delivered RF energy to the formation; a 2) to measure the depth of penetration of the I energy and the corresponding temperatures generat by the absorption of RF energy by the diatomaceo earth at 13.56 MHz. During this test there was attempt to measure the oil/water product produced RF heating as this was not considered an objective the program.

The RF applicator's efficiency in delivering I energy to the diatomaceous earth formation w determined by measuring its "return loss". This w measured continuously during RF heating by t vector voltmeter and periodically when the RF pow was off by the network analyzer. Return loss is measure of the amount of transmitted power reflect back from the applicator as compared to the pow incident on the applicator. It is measured in decibe (dB). A -3 dB return loss means that half of t incident power is reflected back towards t generator. During the test excellent return loss valu were measured prior to and during RF heating. A values were less than -10 dB at 13.56 MHz. In o case, a return loss of -30 dB was measured whi represents an applicator efficiency of 99.9%. **FIG** shows the return loss of the applicator measured ov a 99 hour heating cycle versus frequency. T minimum return loss for the applicator occurs ne 13.56 MHz, as designed.

The test also demonstrated the ability of the I applicator to focus its radiation pattern into t desired region which was centered at 620 foot dept coincident with the center of the 25 foot applicato Measurements of the vertical magnetic radiati pattern which is proportional to the electric fie pattern were conducted in monitoring well T1 These measurements are compared to theoretical da generated by NEC-3I in **FIGURE 12.**

During the field test magnetic field streng measurements were conducted at monitoring wells

T10 and T20 with a specially designed tool. The difference between these measurements was used to determine how much the electric field was attenuated by the diatomaceous earth. These measurements revealed that the formation attenuated the RF field significantly more than the laboratory measurements and calculations suggested.

Heating of the formation was measured using a temperature probe in T10 and the results compared well to the theoretical initial heating rate (**Figure 13**).

A picture of the 25' RF applicator prior to lowering it into the borehole is shown in **Figure 14**. **Figure 15** shows a view of the 25 kW 13.56 MHz mobile RF heating system at Bakersfield, CA.

Radio Frequency System Costs

The cost for a generic system is divided into the following categories with a typical range of assembled equipment costs for each grouping of system components. The grouping descriptions are:

- **Heating applicator** for a vertical emplacement borehole with a light weight 30-ft emplacement tower and 100 ft. of flexible 1-5/8" transmission line and rigid line components to connect the applicator to the RF heating module. The applicator and transmission lines will employ Teflon® components and therefore the operation of this system is limited to a maximum temperature of 200°C.

- **RF heating module** capable of delivering 25,000 Watts of RF power from a ceramic vacuum tube through a tuner designed for a single frequency of operation (constructed by the vendor for either 27.12 or 13.56 MHz). The unit typically requires a 50 kVA, 3-phase power source. Vacuum tube designs require a much lower initial investment than solid state devices but do have higher maintenance and operating costs over the system's useful lifetime. Solid state systems can develop significant economic advantages for large, multi-year applications.

- **Control computer** with basic sensors and system interfaces for time and temperature control as well as operation logging. Simple wire line remote control capability is provided along with suitable software. The computer system is transient and surge protected by an uninterruptable power supply.

- **Equipment shelter** for a fixed site installation with a usable interior volume of 7'x7'x 15' with heating, ventilation and air conditioning for instruments. The unit must also have input and output ducting to provide 600 CFM filtered air for the RF generator. The shelter also contains a 3-phase, 480 VAC, 100 Amp. power panel and a 1-phase 110/220 VAC power panel with a 10 KVA transformer.

The above items are provided below in terms of low and high range costs for the groupings. The low range sets a boundary for either minimum capability and design margin systems or costs associated with volume discounts for key components. The high range is defined by one-of-a-kind construction costs and the use of premium components. Commercial costs are presently being targeted in the low range or lower depending on the application.

Capital Cost Summary

	Low range	**High range**
Heating Applicator	13,050	26,500
RF Heating Module	80,100	112,200
Control computer	14,450	75,500
Equipment shelter	18,000	44,500
TOTAL	**$125,600**	**$258,700**

System Operating Costs

The operating cost of the generic system described under capital costs is based on the following components that are extremely variable due to the labor components involved in complete costing:

- Electrical power costs - Typical utility costs run from $0.05 to $0.15/kwh. With a typical total system energy conversion efficiency of 45% the AC input energy would be 55 kW. The system electrical utility cost would range from $2.75/hr to $8.25/hr for each 25 kW of RF energy delivered to the target region.

- Supporting equipment and tools are required for setup, operation and maintenance of one or more systems. A typical site installation will need approximately one month of this detailed support capability. Therefore support equipment through selective short term rentals or long term leasing or purchases add a cost of $5,000 to $20,000 to each site installation budget.

- Scheduled maintenance and repair costs as well as periodically replaceable components (e.g. vacuum tubes). For a ceramic vacuum tube based system, the material costs are typically $2 to $5 per heating hour with scheduled outages for replacement after every 3,000 hours of operation. Service of this type can typically be accomplished by one technician in less than one day.

- Mobilization of the system summarized here is at the component level with on-site assembly of pre-tested system modules. RF heating system components can be mounted in trailers or on truck bodies to minimize many reoccurring setup costs if the system is to be transported frequently.

Conclusions

From the above tests it is concluded that RF heati
performs as theoretically envisioned. It wil
however, require equipment design modifications fo
sustained operations at downhole conditions. Ther
was evidence of high antenna downhole efficienc
(99.9%) during operation. The applicator (antenna
focused the energy beam where required. Sustaine
operations, adequate depth of penetration an
economics could not be determined for this tes
Reasonable cost fiber optic systems should b
developed if continuous temperature monitoring in th
presence of RF energy is required.

There is a need for additional development of th
system components used in this test. Suc
components include well completion parts, we
tubulers, and temperature monitoring capability
Radio frequency heating technology is sound and ha
potential use in special oil recovery needs. It
application, however, should be carefully evaluated i
terms of where and under what conditions it would b
most economical in operation. The addition
development and testing of these components wi
provide a basis for evaluating the oil recover
economics of the process.

Recommendations for Future Work

For the continued development of thermal EOR it
recommended that additional field work be conducte
using the prototype RF heating system discussed i
this paper to fully evaluate its effectiveness prior t
commercial operations. These future tests wi
include the deployment of a pumping system that ca
continually measure the amount of product recover
during RF heating operations and establish th
baseline product recovery rate without RF. It is als
recommended that a fiber optic temperatur
monitoring system be employed to measure th
temperature of the formation as it will not interfer
with the electrical field during high power operatio

Acknowledgements

The authors greatly appreciate the financial and technical support of Texaco's E & P Technology Department (EPTD) and for their permission to publish this work.

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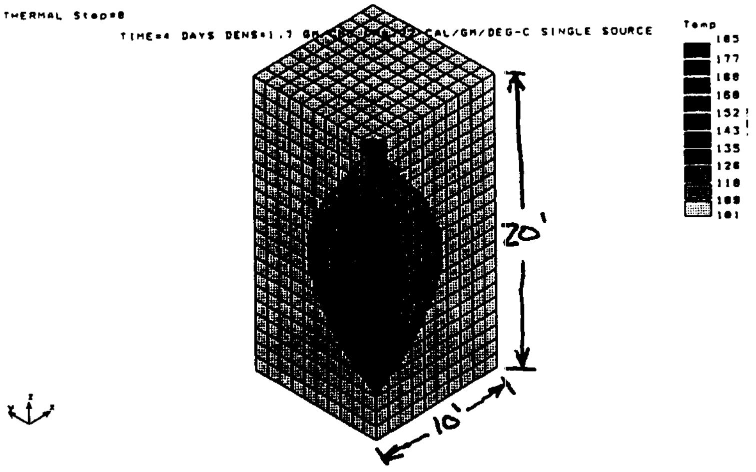

Figure 1. Single Applicator Temperature Profile (After 4 Days of Heating)

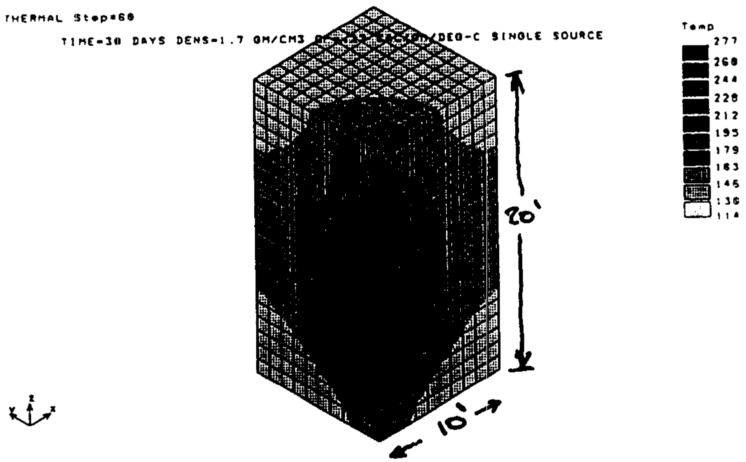

Figure 2. Single Applicator Temperature Profile (After 30 Days of Heating)

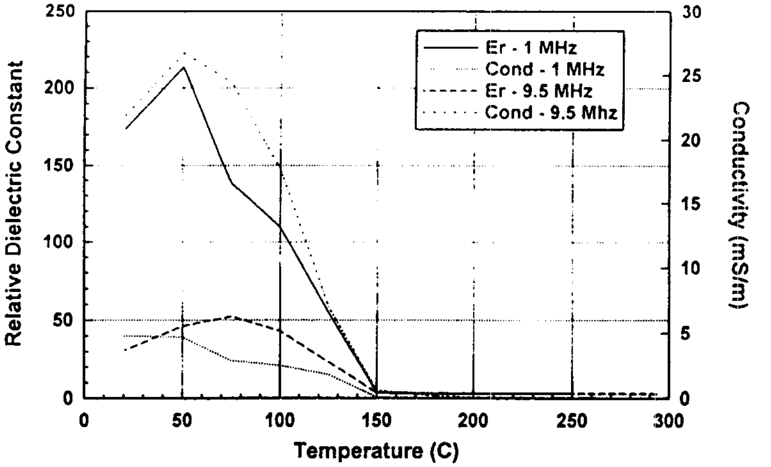

Figure 3. Dielectric Properties of Diatomaceous Earth versus Temperature

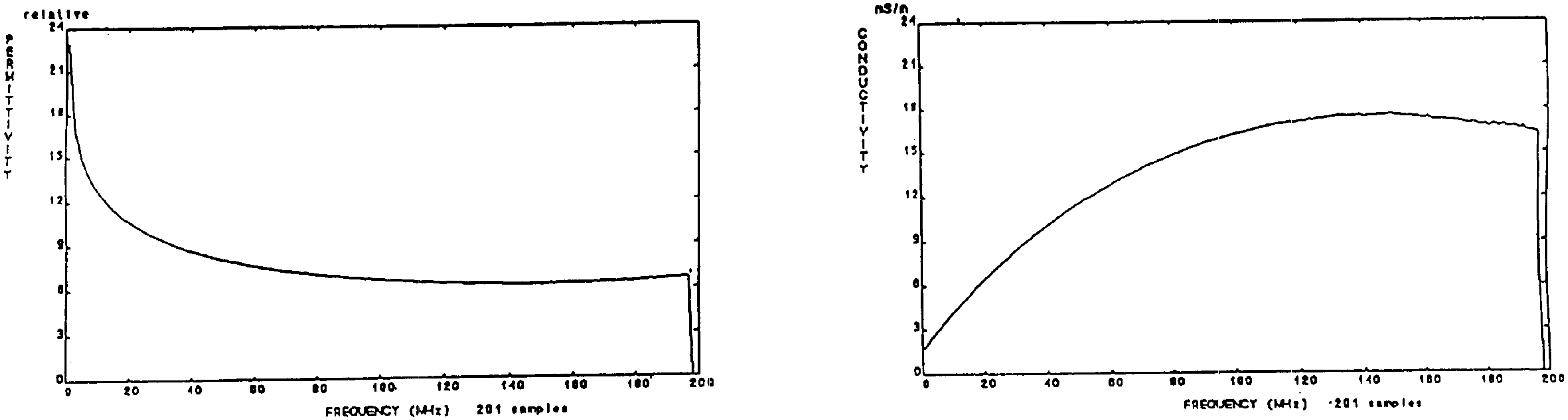

Figure 4. Dielectric Properties of Diatomaceous Earth at Ambient Temperature (20°C) versus Frequency

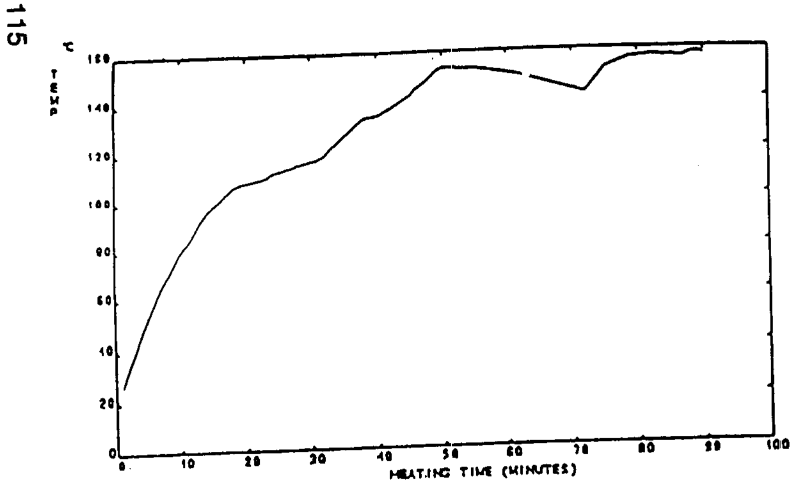

Figure 5. Temperature versus Time using Laboratory HF RF Heating System

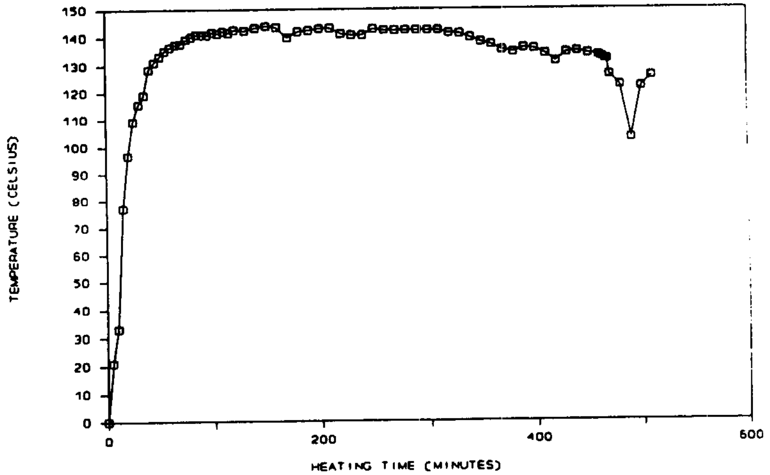

Figure 6. High Pressure Vessel Experiment Temperature versus Time

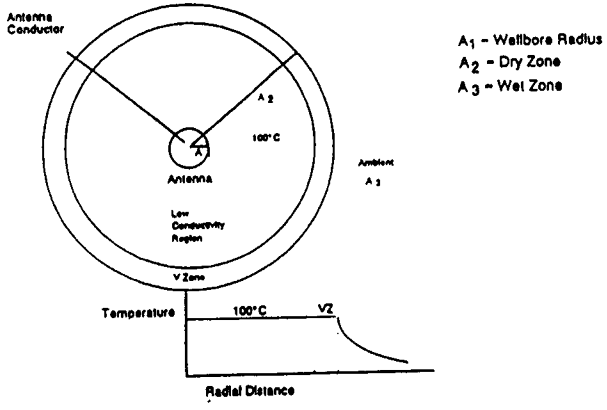

Figure 7. Dynamic Model of RF Heating

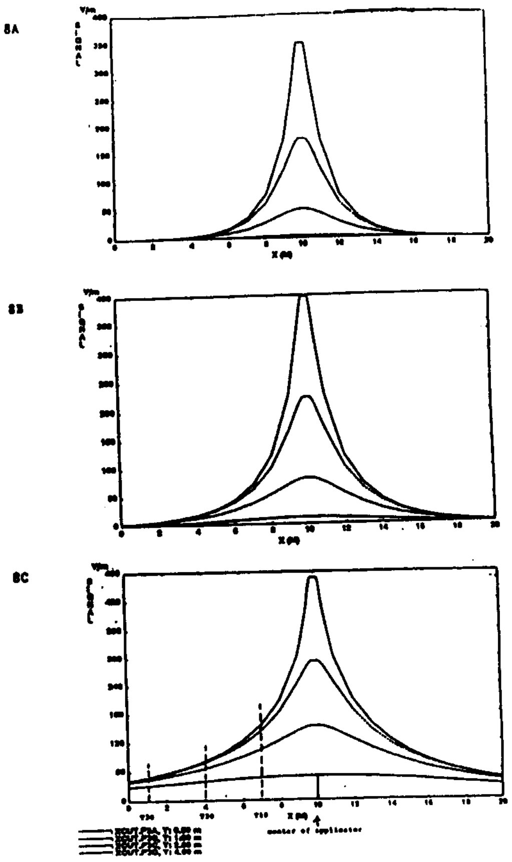

Figure 8. Predicted Electric Field of Bakersfield RF Applicator at 25 kW and 13.56 MHz

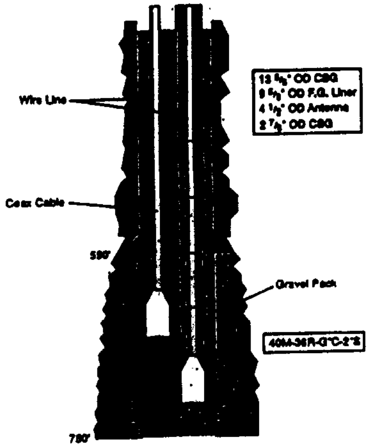

Figure 9. Well 100-D Schematic

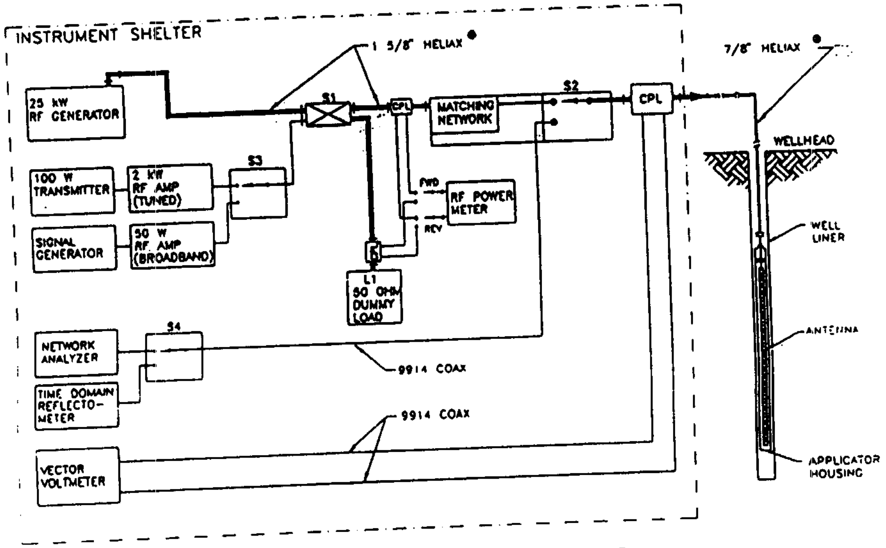

Figure 10. Block Diagram of RF Heating System

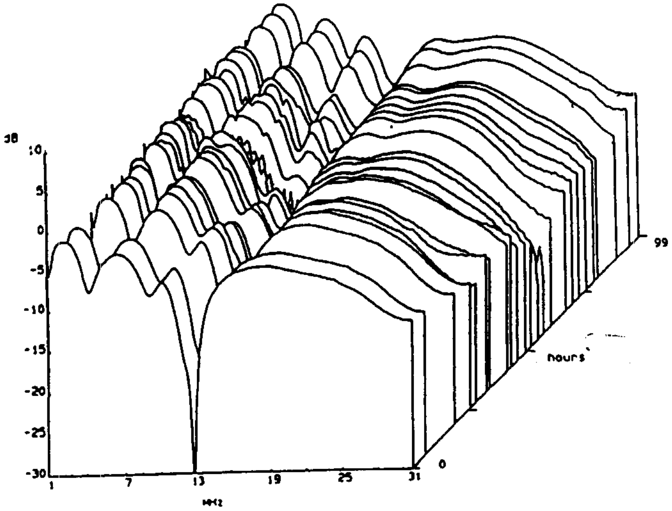

Figure 11. Return Loss of RF Applicator versus Frequency and Time

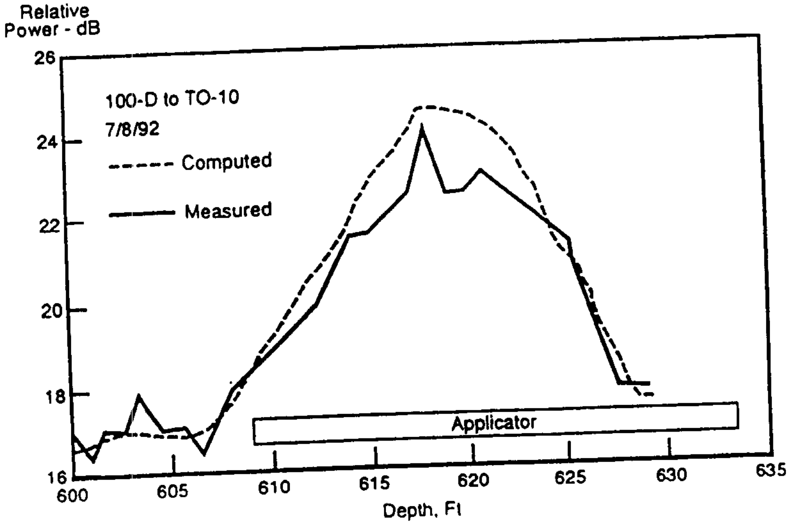

Figure 12. RF Applicator Pattern versus Theory

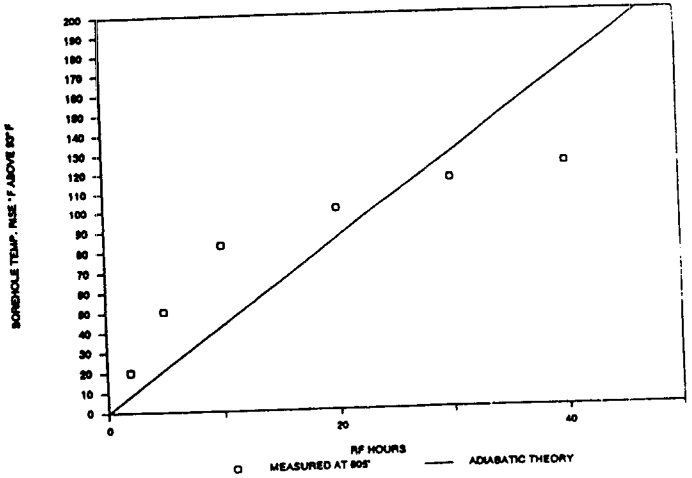

Figure 13. Theoretical Temperature vs. Time at 14.4 kW Delivered to Formation Compared to Field Test Measurements

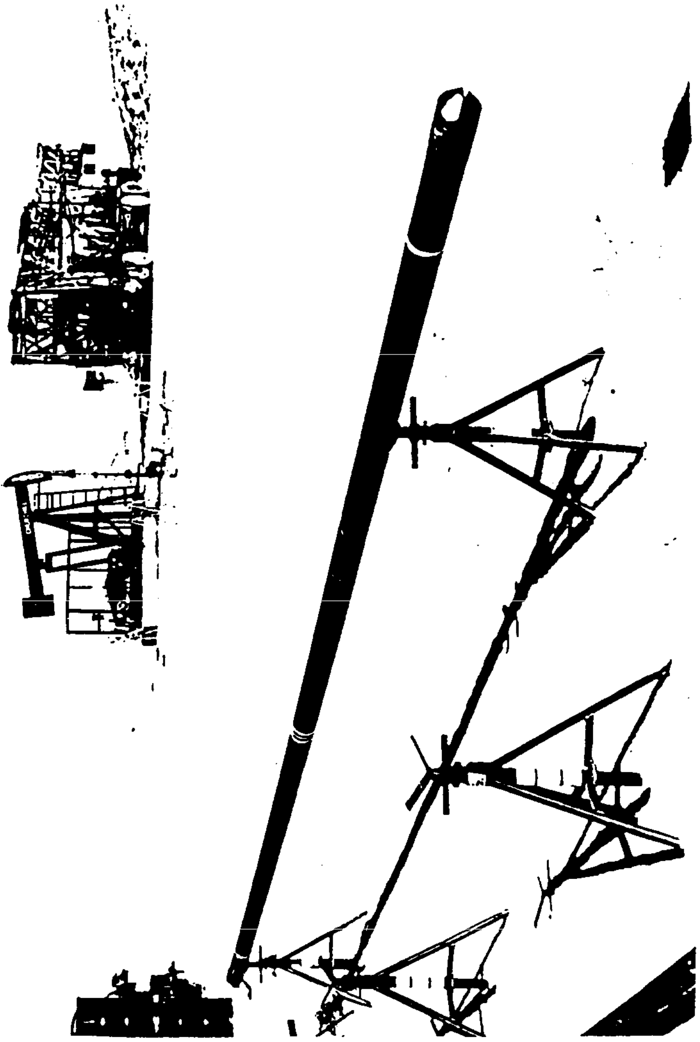

Figure 14. 25' RF Applicator at Bakersfield, CA

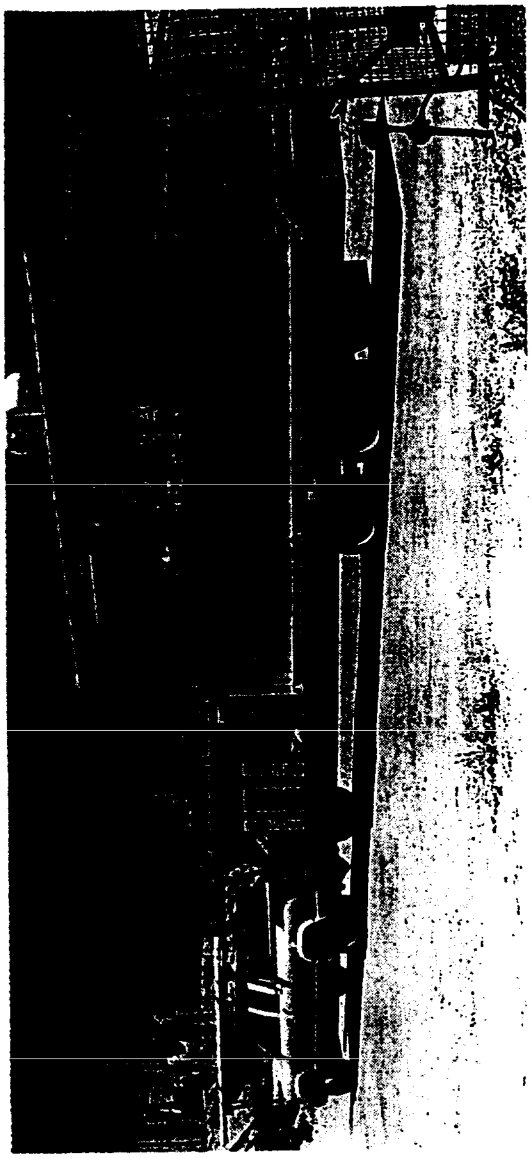

Figure 15. 25 kW 13.56 MHz Mobile RF Heating System

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This paper, as submitted, did not include the following corrections and clarifications to better address oil field applications of radio-frequency heating.

ERRATA

Page 4, col. 1, paragraph 2, line 5.
CHANGE: 50.55 MHz (HF)...
TO: 50.55 MHz (VHF)...

NOTE: Both the 144 and 50.55 MHz sources were operated within completely shielded environments. These frequencies are not suitable for use outside of the controlled laboratory environment.

Page 6, col. 1, paragraph 2, line 7.
CHANGE: "The RF heating system... for later analysis."
TO: "The RF heating system was controlled by a laptop computer with an 80286 processor and a GPIB (general purpose interface bus) controller card which was interfaced to diagnostic instrumentation and the 25 kW RF generator. The custom software package employed with this system recorded RF system diagnostic measurements that were continuously monitored during the heating cycle (e.g. temperature, RF output, reflected power, complex reflection coefficient). During non-heating periods, the system was used to make low power swept-frequency diagnostics using a network analyzer to characterize the heating zone in greater detail. All data was recorded on magnetic disks for later analysis."

Page 6, col. 2, paragraph 2, line 14.
CHANGE: "In one case, a return loss of -30 dB was... 99.9%."
TO: "In one case, a return loss of -30 dB was measured which indicated an applicator power acceptance efficiency of 99.9%. This efficiency represented an optimum match to the RF power transmission line and the RF generator. The applicator typically delivered power to the surrounding oil-bearing formation with an efficiency in excess of 95%. The entire RF energy delivery system, with a typical transmission line and tuner efficiency of 77% (for approximately 800 ft. of RF transmission line) delivered power with an efficiency of greater than 75%."

Page 7, col. 1, paragraph 5 (first bullet item).
CHANGE: "Heating applicator ..... [this section of text applies generally to environmental remediation systems and not specifically to oil field applications of the technology]."
TO:

- **Heating applicator/transmission line** systems for vertical boreholes are typically implemented with a 3/8" dia. wireline rig to suspend the applicator. The applicator is enclosed in a nitrogen-pressurized housing and weighs less than 100 lbs. A constant-tension cable-reel rig is used to independently suspend a flexible 7/8" RF transmission line that is connected to the top of the applicator housing. The coaxial transmission line is constructed with a Teflon suspended copper inner conductor with a corrugated outer copper jacket with a nominal diameter of 1". The cable weighs 0.45 lb/ft. The wire line and transmission line are typically bundled with thermocouple sensor lines (in commercial configurations these three items may be efficiently packaged as a single, stainless steel jacketed cable assembly). The typical operating temperature limits are set by the use of epoxy resins in the applicator's pressure housing that limit operation to 150 deg. C or Teflon which limits operation to 200 deg. C. However, in some applications it may not be necessary to contain the applicator in a pressure housing. Ceramics may be substituted for Teflon to raise the applicator's operating temperature to well above 300 deg. C.

Page 7, col. 2, paragraph 5
CHANGE: The "Heating applicator line" and the **TOTAL** line in the **Capital Cost Summary**. The original numbers reflected an environmental remediation application and not specifically a typical oil field application.
TO:

Capital Cost Summary	Low Range	High Range
Heating Applicator/Transmission line	$30,000	$125,000
Includes purchase of 700-ft. of 7/8" transmission line, cable reel and sensor lines. The wire-line rig and cable-reel holder are to be rented separately and are not included in the low range figure).		
RF Heating	$80,100	$112,200
Control computer	$14,450	$ 75,500
Equipment shelter	$18,000	$ 44,500
Total	**$142,550**	**$357,200**