Ignition Equipment and Procedures for Thermal Recovery Projects

By JON T. MOSS

T. O. R. Developments, Inc.

INTRODUCTION

Ignition is the first step to combustion oil recovery. This important phase utilizes sophisticated techniques to ignite the oil bearing formation by increasing the reservoir temperature near the injection wells to a level that will promote active combustion in the formation. Equipment and methods of ignition are discussed herein.

Proper ignition starts the successful combustion project. Once the reservoir is ignited, the high temperature burning front moves through the formation, and exceedingly high oil recoveries have resulted from this type recovery process. Poor or improper ignition can result in decreased combustion efficiency with a considerable amount of the injected air by-passing the burning front. Since all air injected must be compressed, unreacted air represents an economic loss; and when only limited combustion is achieved, the overall economics of a thermal project can be seriously affected.

A recent article by Strange[1] discusses various ignition schemes with numerous references to the subject. Strange[1] classified ignition methods as to the broad categories of spontaneous and artificial ignitions. Some crude oils, particularly those in many of the California heavy oil reservoirs, are of such chemical nature as to be susceptible to spontaneous ignition when contacted by injected air. Time of spontaneous ignition varies from a few days to several months. The ignition process can be accelerated by increasing the down-hole temperature at the injection well by artificial means.

Where the reservoir is not susceptible to spontaneous ignition, artificial methods must be used. The many different techniques that have been used include: surface heat injection, chemical methods (generally a substance readily susceptible to oxidation such as phosphorous), and down-hole heaters. Electrical heaters and gas or liquid fueled burners are widely used for ignition purposes. These have advantages over other ignition systems in that well bore temperatures can be maintained at desired levels, the rate of heat input to the formation can be varied, and the operational period can be of such duration as to insure ignition if at all possible. Both electrical and gas bottom hole heaters are described herein.

WELL COMPLETIONS

As a highly important preliminary step to ignition, consideration must be given to the desirable ignition points for a particular formation. The main factor to consider is which section or sections of the formation should be ignited to realize maximum oil recovery from the project. Once this is decided, the injection well completion can be designed. Often, existing wells are found suitable or can be reworked for ignition. The injection well, however, must be completed so that air enters at the selected point, and the well must be properly cemented to confine the high pressure air to the formation or zone ignited. Wells have been successfully ignited through perforations, open hole, slotted liners, gravel packs and through tubing set on conventional packers. Successful ignition jobs confine the high temperature zone to the formation interval, and in most cases conventional down-hole equipment withstands ignition temperatures.

When it is desirable to separate closely spaced formation stringers, the impermeable shale separations between the formations should be competent, and high temperature cement used in cementing the pipe through these sections.

Once the injection well is completed, back flowing of the well should be avoided. If this does occur, however, any oil that might enter the well bore should be removed from the well before ignition to prevent excessively high temperatures. Thermal expansion of the casing does not normally occur in open-hole completions, and experience with numerous perforated completions indicates that well damage due to thermal expansion seldom occurs but almost never occurs to the extent that the injection well must be reworked.

ELECTRICAL IGNITION EQUIPMENT

Although a wide variety of electrical heat generating devices are available, standard resistance type heaters are normally used in down-hole ignition. Fig. 1 shows surface equipment for electrical ignition systems. Basic equipment requirements are simple—an electrical cable of suitable length, high pressure lubricator, electrical power supply, an air injection system, and the electrical heater. For best control and maximum efficiency of the ignition operation, down-hole temperatures should also be measured.

Power supply systems generally used are 220, 440, or 880 volts. The electrical power can be supplied by temporary generator units or from normal field power sources, through suitable transformers. The use of commercially available power is usually justified because of dependability and convenience. Down-hole electrical heaters are designed as to a specific voltage and power phase. Load requirements range between 10 and 40 KW, and the power supply must not only be compatible with the heater design but also must be capable of the maximum load delivery. A temporary transformer located near the injection system is highly satisfactory for this service.

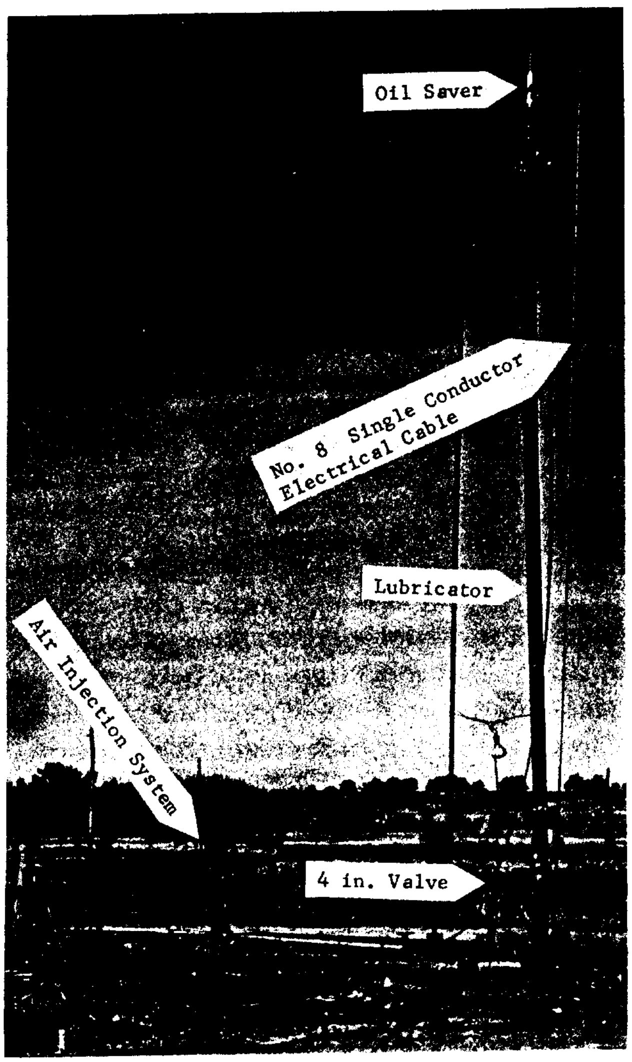

Fig. 1 Surface Installation for Electrical Ignition.

The lower end of a 20 KW, 440 volt heater is shown in Fig. 2 before it is to be inserted into the pressure lubricator. Several standard heaters are available in sizes ranging from 20 to 40 KW. The maximum diameter of the heater is 3.25 in. which is adaptable to running in oil wells completed with four in. or larger casing. The heater elements are made with an alloy metal sheath material of 0.625 in. O. D. which can operate continuously at 1500° F. Electrical resistance wire inside the elements is insulated with magnesium oxide. Another heater design which uses only three elements can be run through 2 in. pipe. This 10 KW, 440 volt heater is only 1.61 in. O.D.

The design of electrical heaters is quite flexible and a heater can be built for almost any special application. Fig. 3 shows that the power delivery of a specific heater decreases with the length of electrical cable (depth). A single phase 20 KW, 440 volt heater will deliver only 13 KW down-hole with 2000 ft of No. 8 electrical cable. Fig. 3 also shows that power loss is less if three-phase 440 volt heater design is used. Line losses can be reduced by using larger electrical cable or by increasing the voltage. No. 8 cable is normally used at shallow depths and No. 6 and No. 7 for deeper holes.

Cable insulation is normally made of oil resistant rubber or plastic. If temperatures higher than 300°F are anticipated, Teflon insulation is suggested. The insulated cable is supported by a double-wrap wire armor with a breaking strength of about 16,000 lbs. Particular care should be taken to make certain that the oil saver shown in Fig. 1 will afford a pressure seal against the electrical conductors.

Proper operation of the igniter is indicated by current and voltage measurements. Heater temperatures can be controlled by varying the power

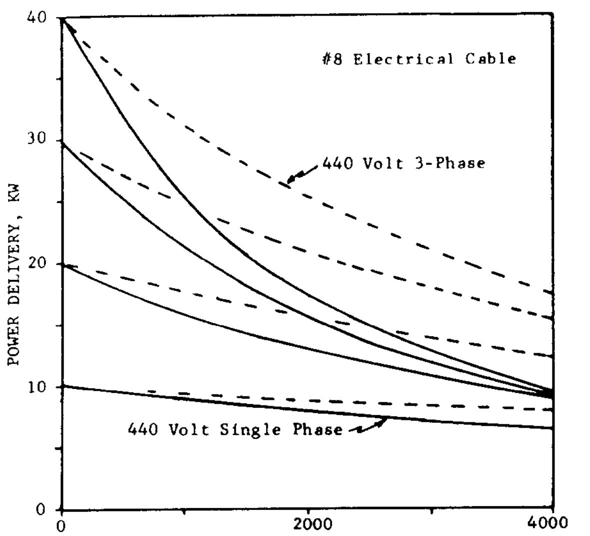

Fig. 3. Electric Heaters Decrease in Power Delivery Due to Line Losses in the System.

to the heater, either by adjusting the voltage, or by simple on-off control of the heating cycle Temperatures can also be controlled by proper adjustment of the air injection rate. It is always desirable to measure the heater temperature. Thermocouples can be used for this purpose. These can be built into the heater and the temperature signal transmitted to the operator through small lead wires in the conductor cable; but at shallow depths. It is convenient to equip the injection well with a thermowell pipe. Temperature surveys can then be measured at any point opposite the formation, as well as for heater control.

Electrical ignition has certain operating characteristics superior to other heating systems. The main advantages are: (1) position of the heater can be changed so that all parts of the well bore are exposed to ignition temperature and (2) temperature control of the heater is fast and dependable. Disadvantages may be listed as: (1) practi-

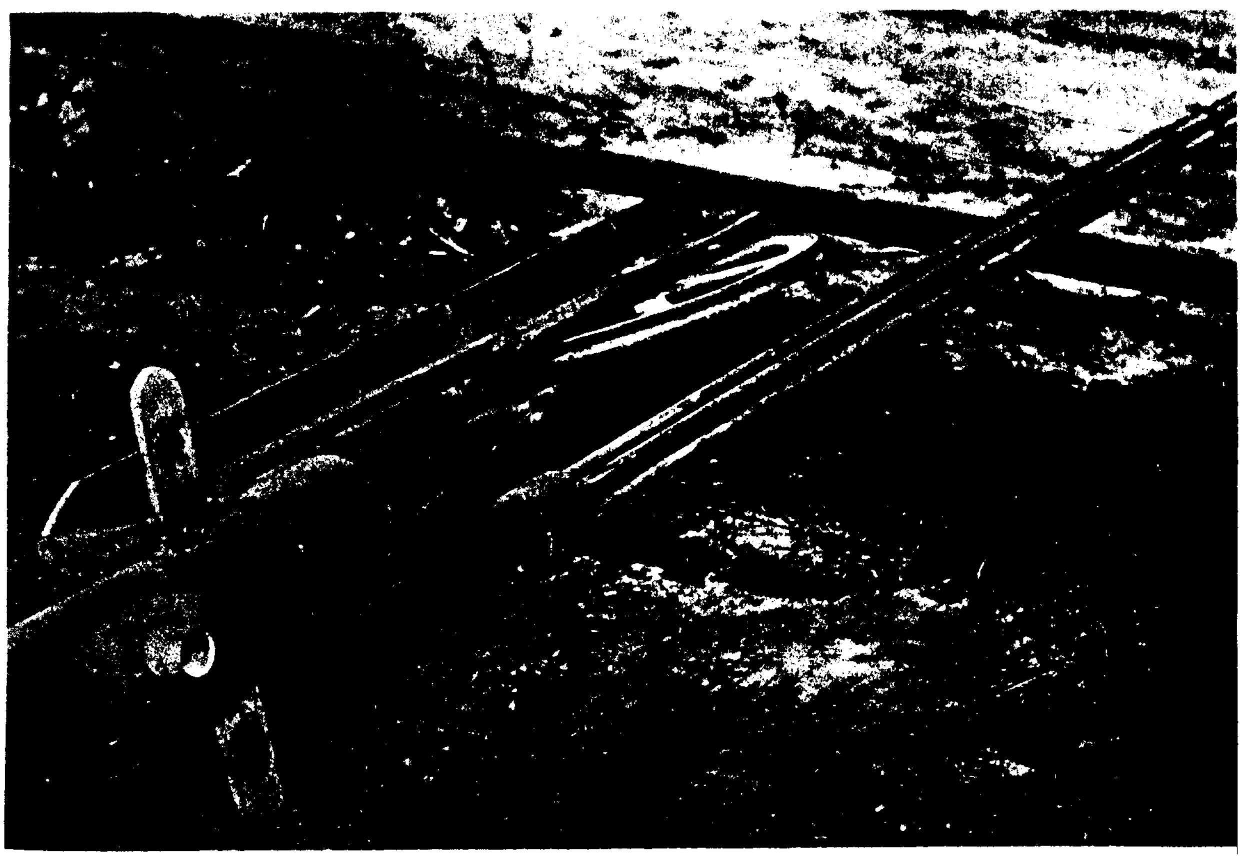

Fig Fig. 2 View of 20KW, 440 Volt Electrical Heater and Pressure Lubricator cal depth limitation of equipment, (2) short operating life of down-hole equipment, and (3) limited heat generating capacity. Electrical equipment is also somewhat cumbersome to run at shallow depths and this becomes more difficult at higher pressure and increased depths.

DOWN-HOLE GAS IGNITION EQUIPMENT

The gas ignition systems are extremely easy to run and are not limited as to depth or, within practical limits, rate of heat generation. The particular system described herein was developed by Pan American Petroleum Corporation[2] and has been used in numerous oil fields.

Basically, the ignition consists of injecting gas down the tubing and air down the annulus at a controlled ratio. The gas and part of the air stream are mixed and burned inside a down-hole heat-shield which protects the oil well casing from excessively high temperatures. The excess air that is available for cooling the heat shield varies from 78 to 93 per cent, and this air, now preheated, enters the formation to initiate and support combustion.

Fig. 4 shows two of the heat-shields. The stainless steel shells are lined with a refractory material which confines the gas flame temperatures inside the shield.

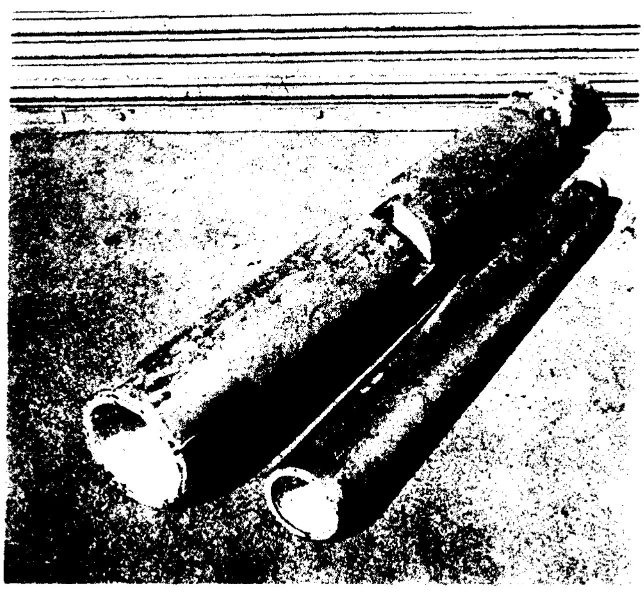

Fig. 4 Down-hole Heater-Shields for Gas Burner Ignition

The down-hole burner is measured into the hole by wire line. The burner is shown in Fig. 5 as it extends from the wire line lubricator. The small lines shown at the well head are for gas while the air enters through the two in. line. The nitrogen cylinder near the well head is used while loading the ignition chemical in the burner and as a safety measure, it is used to separate gas-air interfaces during the operation.

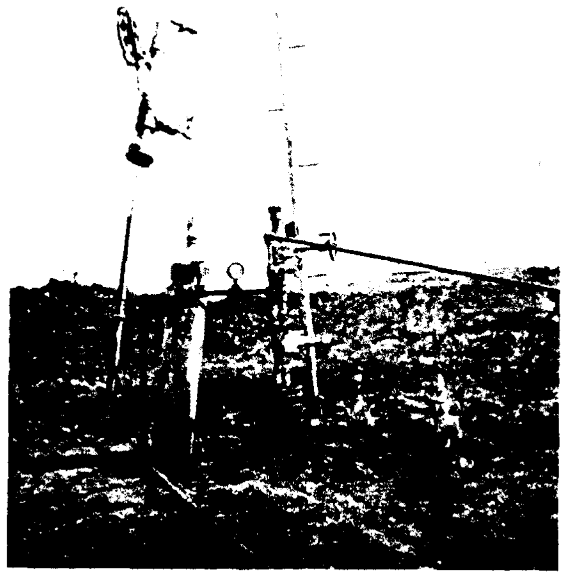

Fig. 5 Downhole Burner and Injection Well for Gas Burner Ignition

A 3500 psig pressure, portable gas compressor is shown in Fig. 6. This machine is completely water cooled and has a maximum capacity of about 20 MSCFD. Fuel gas is compressed to the necessary pressure and discharged through an orifice meter at closely regulated rates.

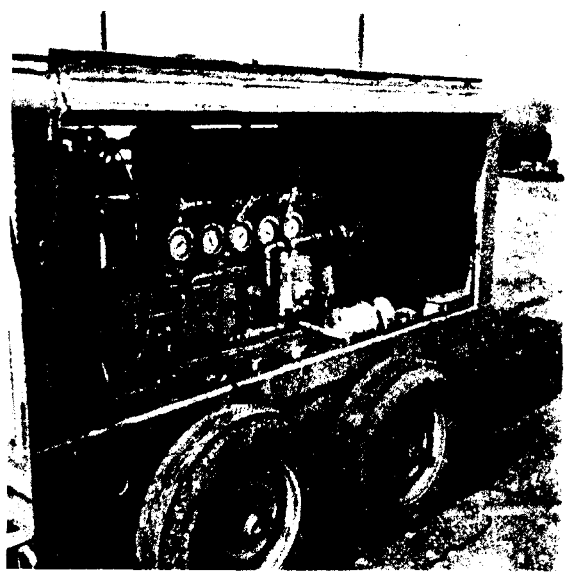

Fig. 6 Gas Compressor for High Pressure Gas Supply to Burner

Accurate gas and air metering are the most important features of this ignition system. Fig. 7 shows the integral orifice DP cell gas meter. At the right side of Fig. 7 is the air injection meter. Under adiabatic conditions the temperature of the air delivered to the formation can be controlled by adjusting the air-gas ratio. Just as in electrical ignition, the well bore should be free of oil to avoid excessive temperatures. Temperature measurements at or above the heat-shield are made routinely and by equipping the hole with a small thermowell string, sand face temperatures can be measured and controlled to a high degree of accuracy.

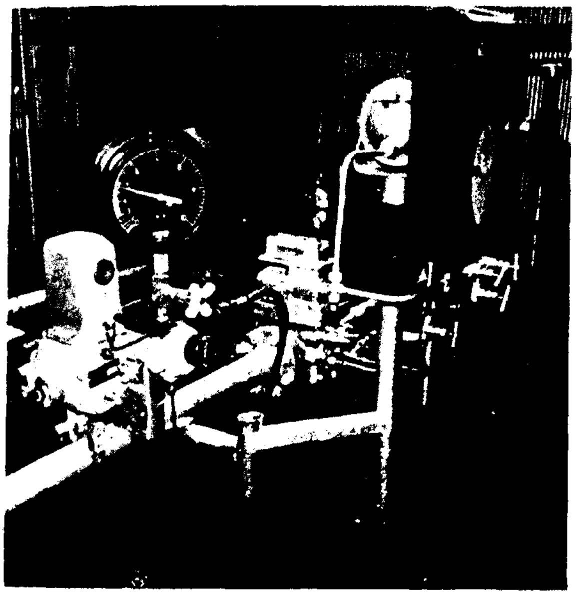

Fig. 7 Gas and Air Meters for Gas Burner Ignition

HEAT REQUIREMENTS

Temperature rise of the injected air can be estimated from Fig. 8 which is applicable to both gas and electrical ignition. Fig. 8 is indictive of stabilized heating conditions where all heat generated at the burner is transferred to the injected air stream. For example, a gas burner operated at five MSCFD gas rate will increase the air temperature 900°F if the air injection rate is 300 MS CFD. Fig. 8 also shows that a 40 KW electrical heater can heat about 200 MSCFD of air to the same 900° temperature increase. This indicates the desirability of gas ignition at higher air injection rates. The suggested maximum rate for the gas burner is about 600 MSCFD of air at a 900°F temperature rise at a gas rate of 10 MSCFD.

Although the rate of heat injection and the temperature level are important, the total quantity of heat injected also appears to be a factor in successful ignition operations. Strange[2] summarized several field cases which indicate that the total heat injected during ignition ranges from about 0.4 to 3.3 MM Btu per ft of pay thickness. Ramey[3] has presented technical considerations of ignition heat requirements. Oils susceptible to spontaneous ignition generally require very little heat input after ignition temperature is reached. About one MM Btu per ft is usually sufficient for shallow oil sands over 20 ft thick containing a 17° to 25° API oil. The heat supplied should probably be increased for thin zones and for lighter, less viscous, oil reservoirs. As a matter of practical operations, maximum heat should be generated for the deeper thermal projects because ignition (and re-ignition where necessary) is both time consuming and expensive, with both factors usually magnified at depths over 4000 ft.

The total ignition time may be approximated once the heat requirements are estimated, if the desired heat injection rate can be maintained. Fig. 8 is useful in this estimation. For example, if the formation is 30 ft thick and the estimated heat requirement is one MM Btu per ft, the total heat generated will be 30 MM Btu. Assume that an air rate of 200 MSCFD is desirable and can be maintained, and that the operating temperature is 1000° (a 900°F increase over air density temperature). Fig. 8 shows that a gas burner rate of 3.3 MSCFD (or a 40 KW heater) is necessary. The heat generation rate is 3.3 MM Btu per day based on a heating value of the gas = 1000 Btu/cu ft); thus the time required for the ignition will be about nine days.

IS IT BURNING?

Often the actual time of ignition is almost impossible to detect. There are numerous indications, however, that are helpful during the operation. The first indication comes from temperature measurements made across the formation. Fig. 9 shows temperature surveys during an electrical ignition. On curve (1), with the heater at position (1), ignition is obvious in the top eight ft of the zone. Also obvious is that little or no air is entering the formation below about 11 ft from the top of the zone. The well was checked and sand fill cleaned out. Then temperature curve (2) was obtained with the igniter at position (2). In case (2) ignition appears satisfactory but interpretation of the temperature results is not positive.

Fig. 10 shows similar temperature profiles during a gas burner ignition. Temperature survey (1) indicated burning at several points because the igniter temperature was only 480°F. Active burning is obvious at 22 ft below the top perforation, but is probably oil burning in the well-bore. Temperature curve (2), measured several hours later, shows several residual inflection points attributed to formation burning, although the well had been cooled in between the temperature surveys.

When down-hole temperatures exceed those shown on Fig. 8 for given injection conditions, additional heat is being generated by combustion. Under stabilized conditions, an increase in temperature with depth below the heater is indicative of combustion.

Air injection performance during ignition often shows that combustion has occurred. Fig. 11 shows the air injection rate and injectivity during ignition. The air injectivity decreased from a stabilized value of about one to about 0.6 SCFD $\triangle P^2$. A two or three fold decrease of injectivity during ignition is not unusual. Factors that cause this are increased air temperature and viscosity due to well bore and formation heating,

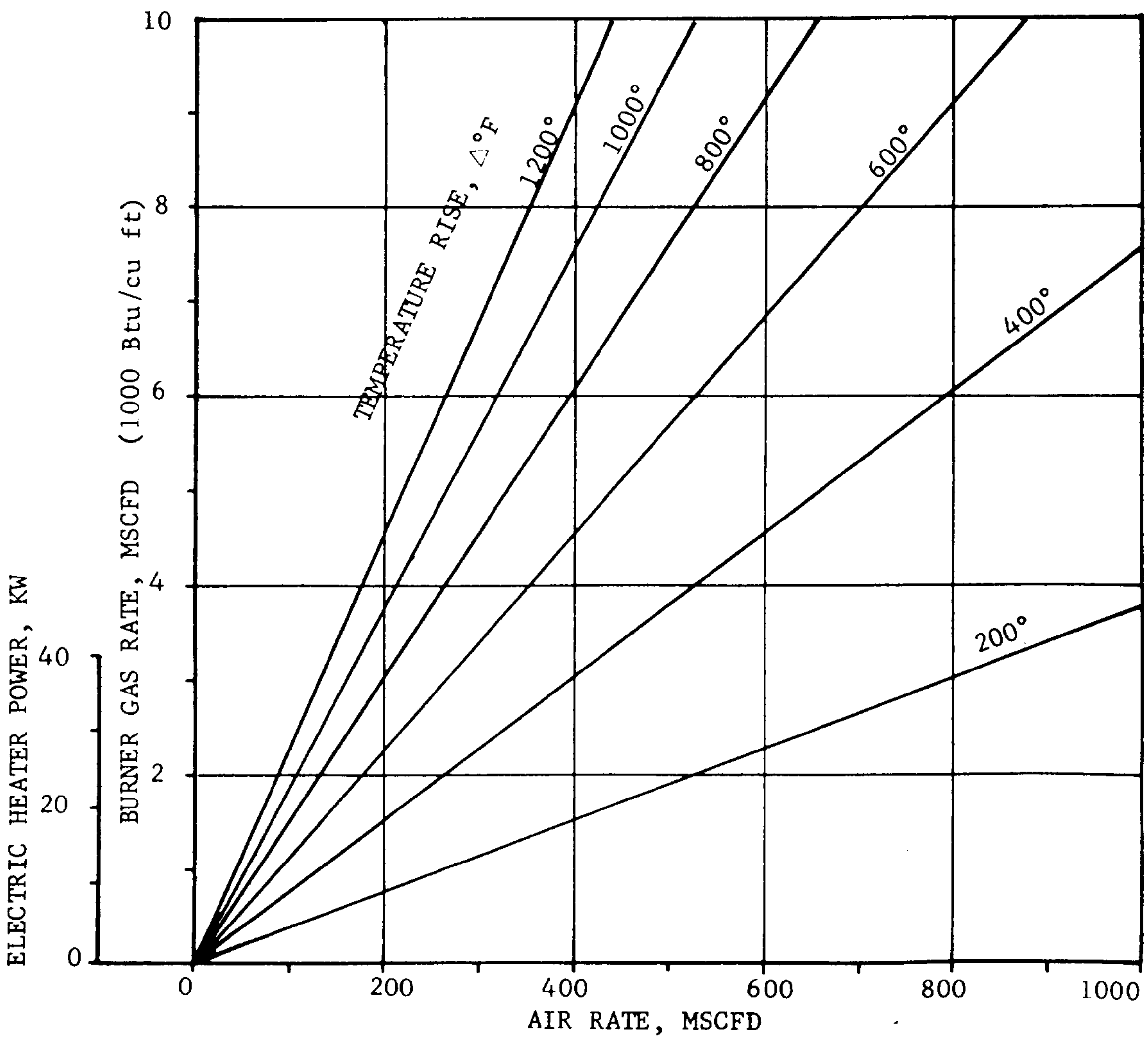

Fig. 8. Temperature Rise of the Injected Air can be Estimated.

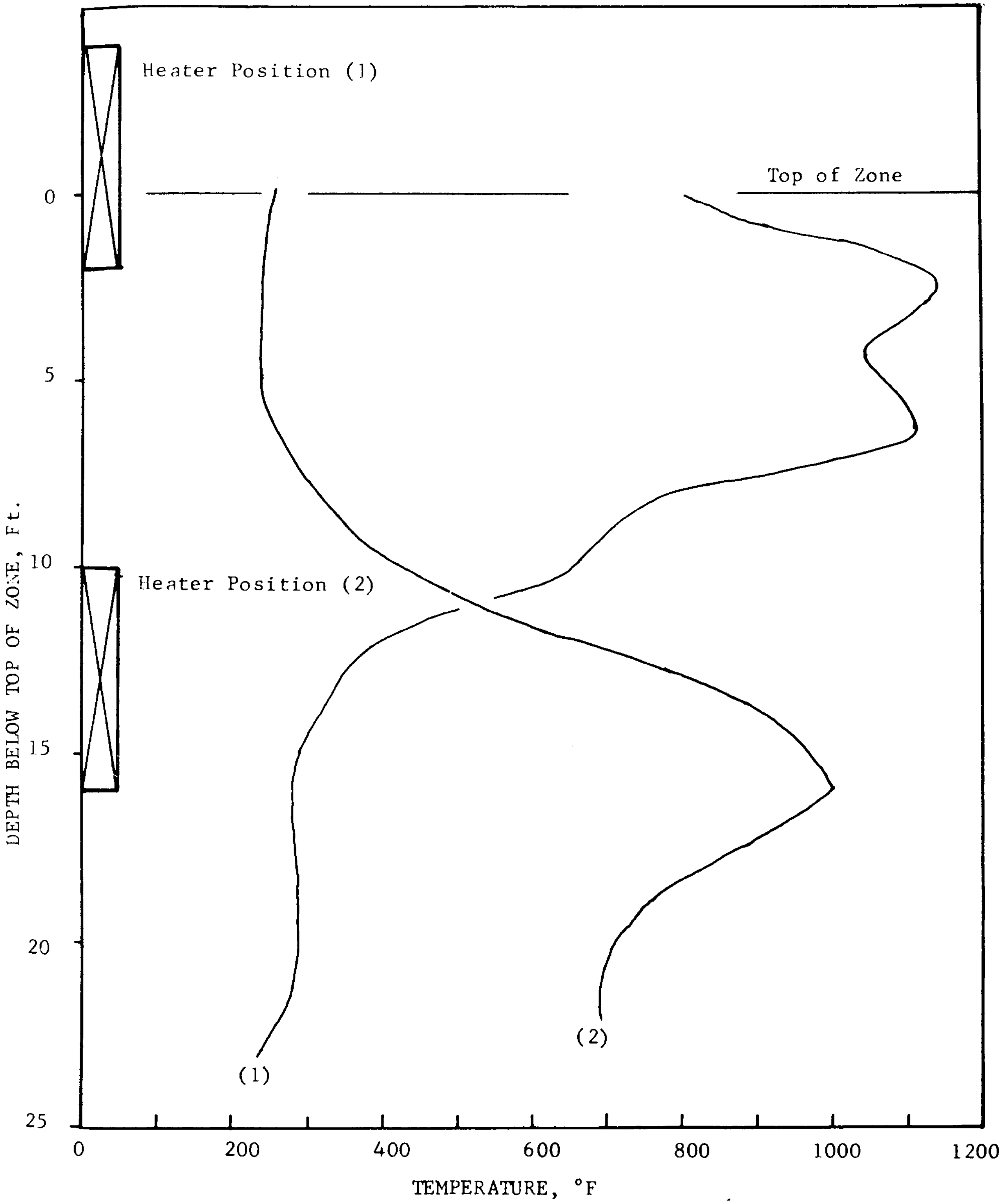

Fig. 9. Temperature Profiles During Electrical Ignition.

but primarily if the effect is sustained, the decreased injectivity is attributed to oil moved by the burning front which reduces air permeability in the zone ahead of the burning front.

Increased injectivity sometimes occurs during ignition, however, when the well bore had been plugged or damaged in some manner. Usually air injection at low temperature levels cleans the well bore, and where damage was severe, the injectivity increases.

Where combustion is highly efficient, the produced gas contains carbon dioxide and carbon monoxide but no oxygen. Therefore, analysis of produced gases offers still another positive indication of ignition. Case I of Fig. 12 shows gas produced from an oil zone which is not too susceptible to low temperature oxidation. A decrease in oxygen content on the second day of ignition indicates combustion. After six days operation the oxygen content decreases until it is

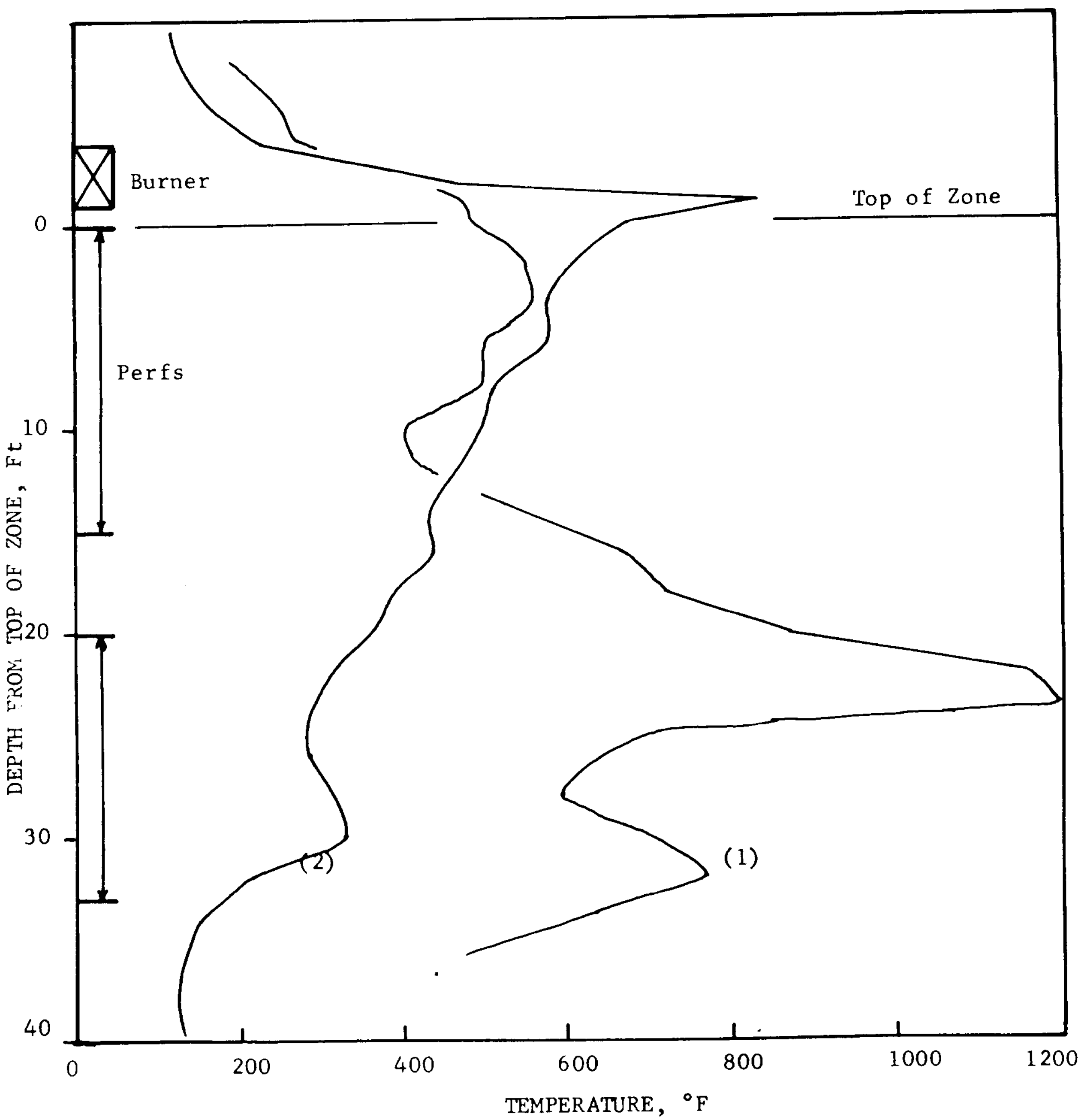

Fig. 10. Temperature Profiles During Gas Ignition.

positive that the formation is burning and even the carbon dioxide content has started increasing.

Where the oil is susceptible to oxidation, little or no oxygen appears in produced gases. Case II of Fig. 12 shows a very gradual increase in carbon dioxide. In fact, no definite indication of burning was obtained during the first igniter operation period. The second heating period lasted 12 days but the detection of combustion, as indicated by the carbon dioxide content of the produced gas, was positive only after about 15 days.

The lag in carbon dioxide appearance is due to its greater solubility in reservoir liquids. Carbon monoxide is also indicative of combustion, but it remains at about the one-two per cent level. At even modest pressure levels, however, it is usually weeks or months before the produced gases reflect stabilized burning front conditions.

REFERENCES

1. Strange, L. K. "Ignition: Key Phase in Combustion Recovery", Petroleum Engineer, p. 105, Nov. Dec. 1964.
2. Champion, F. E., Glass, E. D., Kirkpatrick, J. W., and Vaughn, J. C., "Burner Apparatus", U. S. Pat. No. 2,997,105, Aug. 22, 1961.
3. Ramey, H. J., Jr., "Transient Heat Conduction During Radial Movement of a Cylindrical Heat Source - Applications to the Thermal recovery Process", Trans. AIME 216, p. 115, 1959.

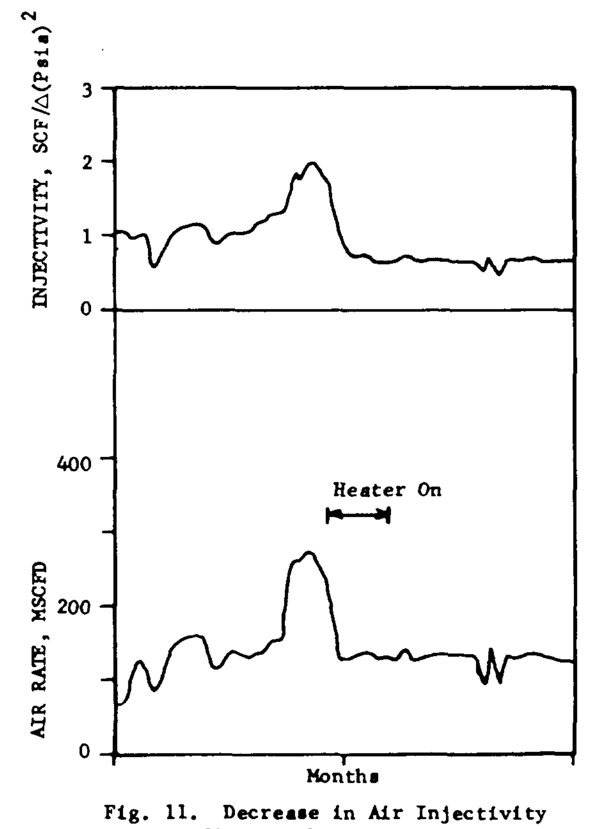

Fig. 11. Decrease in Air Injectivity often Indicates When Ignition Occurs.

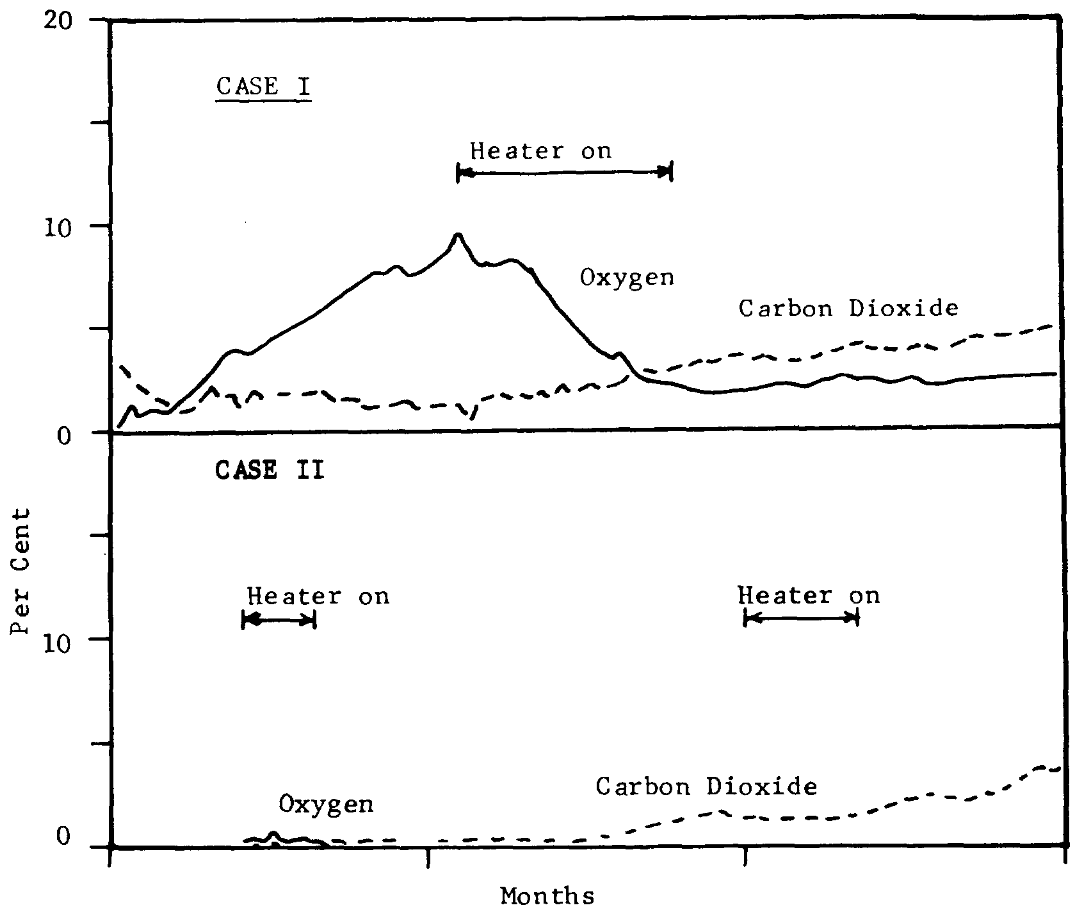

Fig. 12. Produced Gas Composition Indicates Ignition.