Cathodic Protection Of Well Casing

By T. W. McSPADDEN
Pan American Petroleum Corporation

INTRODUCTION

External corrosion of well casing has long been an expensive problem for well operators and is becoming more costly as deeper wells are drilled and the age of wells is lengthened because of proration trends and advances in secondary recovery techniques. Therefore, the economical mitigation of this type of corrosion is of utmost importance.

During the past 10 yr, cathodic protection has been applied to the casing of several thousand wells; and, based on preliminary information [1, 13] it appears that cathodic protection in sufficient amounts will greatly reduce or eliminate corrosion on the exterior of the casing. Various methods have been used to determine the amount of current to apply to well casing with values ranging from less than 1 amp to as high as 30 amp having been used. A number of papers 2, 3, 4, 5, 6, 7, 8, 11, 12, 13 have been published regarding the application of cathodic protection to casing, and the methods used to determine the amount of current to be used.

DISCUSSION

Nature of Corrosion Process

Corrosion may be defined as the destruction of a metal by chemical or electrochemical reaction with its environment. Its reactions are rarely simple and may be profoundly influenced by minor constituents in the metal or by mechanical, chemical, electrical or biological factors in the environment. The driving force of corrosion in the presence of water (this includes practically all cases), is electrochemical; but it may be accelerated by such mechanical agencies as erosion or stress. The potential difference which is developed in the corrosion cell determines the tendency of the reaction to proceed. The rate at which the corrosion reaction proceeds is usually determined by the resistance offered to the reaction by the corrosion by-products.

If the surface of a corroding metal could be examined under a powerful microscope, tiny anodic and cathodic areas could be seen. These areas are often so small as to be invisible to the naked eye, and so numerous as to be almost inseparable. There are many causes for this condition: such as inclusions in the metal, lack of homogeneity, surface imperfections, orientation of grains, localized stresses and variations in environment. If one anode and one cathode could be seen in a giant view (Figure 1), electrons would be seen being released by the formation of ferrous ions. The ferrous ions flow from the anode toward the cathode through the electrolyte where they meet the hydrogen ions in the solution which act as electron acceptors at the cathode surface, 1 election being accepted in the neutralization of one hydrogen ion. The hydrogen then appears as hydrogen gas coating the surface of the cathode. As this process continues, oxidation and electrolytic corrosion of iron occurs at the anodes, and plating out of hydrogen occurs at the cathodes. The accumulation of a layer of hydrogen on the metal slows down the corrosion reaction by a process called cathodic polarization. If the hydrogen layer is not disturbed, the reaction becomes stifled or reduced.

However, if some depolarizing agent such as oxygen is introduced into the system, it reacts with the hydrogen to form water and by this removal of the hydrogen film the corrosion is allowed to proceed. Therefore, the cathodic reaction can involve either hydrogen evolution or some reaction with oxygen. Equations involving oxygen reaction are shown in Figure 1.

The terminology used in this report and in most cathodic protection work defines "current flow" as occurring from positive to negative in the metallic conductor which is the reverse of electron flow. In the electrolyte, which is the environment in which corrosion occurs, conventional current flow is negative to positive, anode to cathode.

Causes of External Casing Corrosion

The main recognized causes of external casing corrosion are as follows:

1. Electrolysis resulting from electric current flowing down the casing from surface connected lines and leaving at local anodic areas.
2. Electrolysis resulting from the discharge from the casing of currents generated by electrical potentials developed between strata in the earth or between dissimilar surfaces on the exterior surface of the casing.
3. Action of anaerobic sulphate reducing bacteria.
4. Acidic water.
5. Oxygen bearing waters.

Methods of Determining Corrosion

The severity of external casing corrosion and the need for cathodic protection or other remedial measures can be determined most conclusively by pulling and visually inspecting the casing. The recently developed Shell casing inspection tool can be used to determine casing wall thickness, therefore, is useful in locating corroded sections of casing in a well. The tool measures only the wall thickness of the casing. If internal corrosion is suspected, it is necessary to run a caliper survey to determine if casing thinning indicated by the tool is the result of internal or external corrosion.

The casing potential profile described below can be used to detect the presence of large anodic areas. However, small anodic areas may not be observed. The potential profile tool was first described by Ewing in 1948 and essentially it provides a method for studying the currents flowing in the casing.

Mechanically, 2 sets of knife contactors are insulated from each other and spaced 25 ft apart. Leads from each contactor are brought up through the supporting cable and connected to a microvolt

ELECTROCHEMICAL CORROSION

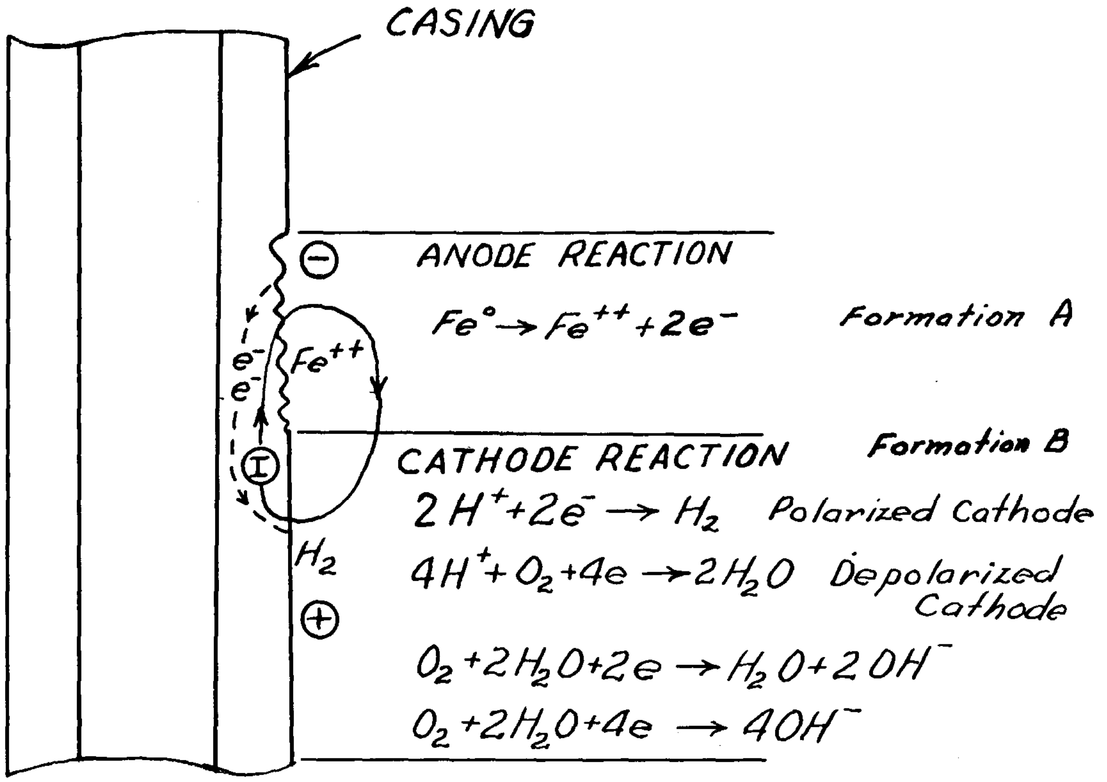


Fig. I

meter on the surface. A voltage (IR drop) reading is obtained between the 2 contactors. A plot of the voltage vs depth (Figure 2) uses the polarity of the bottom contactor as a reference yields a "potential profile" of the well. The voltage readings can be converted to current by taking into consideration the resistance of the length of casing between the knife contacts (usually 25 ft). For 5 1/2 in., 14 lb, J-55 casing the resistance is about 5×10^{4} ohms per 25 ft. In other words, a voltage drop of 500 microvolts indicates 1 amp of current flow.

Study of the profile will reveal that a slope upward to the left indicates an anodic or corroding zone. A slope upward to the right indicates a cathodic or noncorroding zone. In Figure 2 an anodic area is shown on the native state curve from a depth of 3800 ft to 4800 ft and a cathodic zone is shown on the 7 amp curve.

This tool is also useful in studying the distribution of applied current and the effect of applied currents on the gross cells. Considerable corrosion activity can and does occur within a 25 ft section which may not be detected by the profile tool.

Reduction or Elimination of Corrosion

There are several methods whereby external corrosion of well casing can be reduced or eliminated:

1. Surface lines can be electrically insulated from well casing to reduce electrolysis caused by current flow from the surface lines down the casing.
2. Protective strings of casing may be set through known corrosion zones. This program is not always applicable as corrosive zones are not always clearly defined at the time of well completion, especially in new fields.
3. Well casing may be cemented to the surface. This method has been very effective in reducing casing corrosion; but because of the added expense and mechanical difficulties of high column cementing it is not used extensively.
4. The exterior surface of the casing may be coated with a corrosion resistant material such as coal tar or asphalt. Because of the cost and the uncertainty of the effective lift of coatings on well casing the use of coated casing has been limited to date.

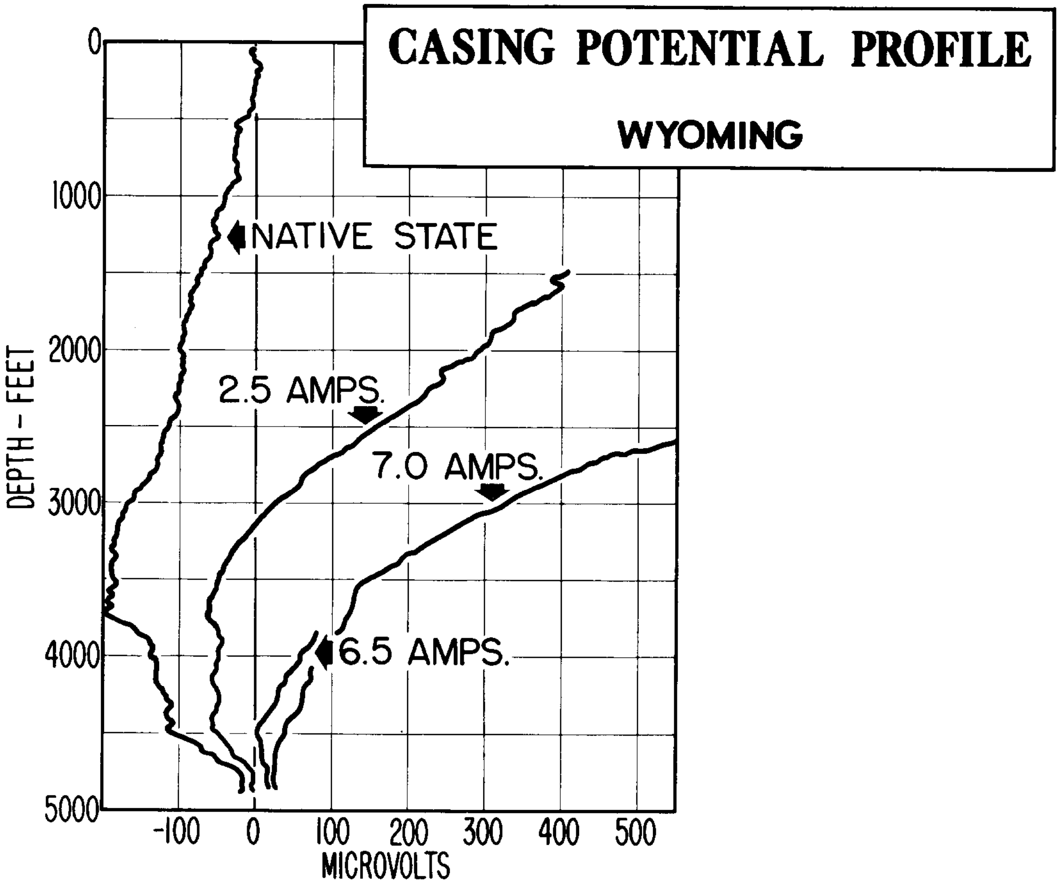


Fig. 2

5. The environment around the casing may be changed by treatment of the mud system prior to cementing the casing. Efforts to date have mainly involved treatment to increase the PH of the mud and the addition of oxygen scavenging agents. Both methods should be effective in reducing the corrosion initially, but may be rendered ineffective through contamination by formation waters.

6. Cathodic protection is the use of an impressed current to prevent or reduce the rate of corrosion of a metal in an electrolyte by making the metal the cathode for the impressed current.

In making the metal structure the cathode, the cathodic protection current entering the metal from the electrolyte maintains a continuous layer of hydrogen on the surface of the metal and, thereby, stifles the corrosion reaction between anodes and cathodes on the metal surface. Hydroxyl ions are also formed at or near the metal and cause an increase in the PH of the electrolyte. This increase in alkalinity is detrimental to the life processes of sulfate reducing bacteria.

Cathodic protection installations using sacrificial anodes can be made on wells requiring small amounts of current, less than 1 amp, for $100 to $200 per well. Rectifier installations to supply several amperes of current can usually be made for about $500 per well and the cost of operation is usually a few dollars per well per month. Therefore, it is obvious that the application of cathodic protection, especially on wells already completed, is much more attractive and less expensive than attempting to squeeze cement or circulate a protective fluid over the corrosive zone. Such remedial work may cost several thousand dollars per well and may not insure permanent protection.

The source of the impressed current may be from sacrificial anodes, generated direct current, or rectified alternating current. Both magnesium anodes and rectifiers are being used to furnish cathodic protection in West Texas.

After the decision has been made to apply cathodic protection, the big question is "How much current will be required?" to provide the desired protection. During the past 10 yr, cathodic protection has been installed on several thousand wells. Two methods, the casing potential profile and the surface potential survey (E-log I curve), have been used to determine the required amount of current.

The casing potential profile previously described can be used to measure the current distribution on the oil string casing. Originally, it was believed that current sufficient to erase any gross anodic areas was ample to eliminate all corrosion. Apparently, in some fields, this premise is valid, based on results of several years of cathodic protection on several hundred wells.[13] In other fields it has been found that merely eliminating the gross anodic areas was not sufficient and experience has indicated that cathodic protection current density as high as possible 3 ma/sq. ft.[12] is required to provide protection of casing in contact with extremely corrosive sour brine.

Since it is not practical to obtain a casing potential profile on each well, the log current-potential (E-log I) method of current determination has been extensively used. The E-log I curve involves a rather simple, inexpensive procedure which can be run above ground without disturbing subsurface equipment. The usual procedure for running the test includes the following steps: The flow line is disconnected or insulated from the well and a native state casing-to-earth potential is measured. A small value of cathodic protection current is applied usually for 2 to 3 minutes; then it is interrupted and the casing-to-earth potential is again measured as quickly as possible after interruption of the test current. The current, in an increased amount, is again applied and the above process repeated until a curve of a characteristic shape is obtained. Data obtained in this manner are plotted as in Figures 3 and 4, with the casing-to-earth potential shown as a logarithmic function on the applied current.

In measuring the casing-to-earth potential, a copper-copper sulfate reference electrode is placed in the soil 200 to 5000 ft from the well and the potential between the electrode and well casing is measured with a vacuum tube boltmeter or potentiometer. A schematic diagram of a typical hook-up to obtain E-log I curves is shown in Figure 5.

The theory of the log current-potential curve is based on the premise that a protected casing is considered an ideal hydrogen electrode which is reflected by an abrupt change in potential when hydrogen is formed over the entire casing surface. Most of the earlier curves obtained on shallow wells usually exhibited one fairly distinct change in potential (Figure 4). The point of intersection of lines drawn tangent to sections of the curve was used to indicate the value of current which was required for protection. As deeper wells were surveyed and higher test currents were used, E-log I curves which exhibited two changes in slope of the potential curve were observed and these changes have sometimes been seen as two "breaks" (Figure 3). There has been considerable discussion during the past few years as to whether the so-called two-break curves were the result of improper instrumentation or stepwise polarization of the casing. A cursory search of the literature,[2,6,7,8,9,10,11,12] reveals that possibly the 2 break type curves are the rule rather than the exception. Dennison and Romanoff[9] have suggested that if the lower portion of the curve as shown in Figure 3 represents the overvoltage for hydrogen, it would seem to follow that the middle section of the curve represents the cathodic reduction of oxygen.

Since numerous so-called 2 break curves have been observed, it is very important to determine, if possible, which break on the curve should be used to determine when protection has been achieved as the current values between the first and second breaks sometimes vary by a factor of four. Tests conducted in a Wyoming field by Pan American[7] indicated that anodic areas on the casing, as shown by casing potential profile, were not erased until a current value near that indicated by the second break or the beginning of the final straight line portion of the curve, was applied. The 2 correlation curves obtained on 1 of the Wyoming test wells are shown in Figures 2 and 3. Cathodic protection of the approximate value shown by E-log I curves obtained on 20 wells was applied to 157 wells in 1957

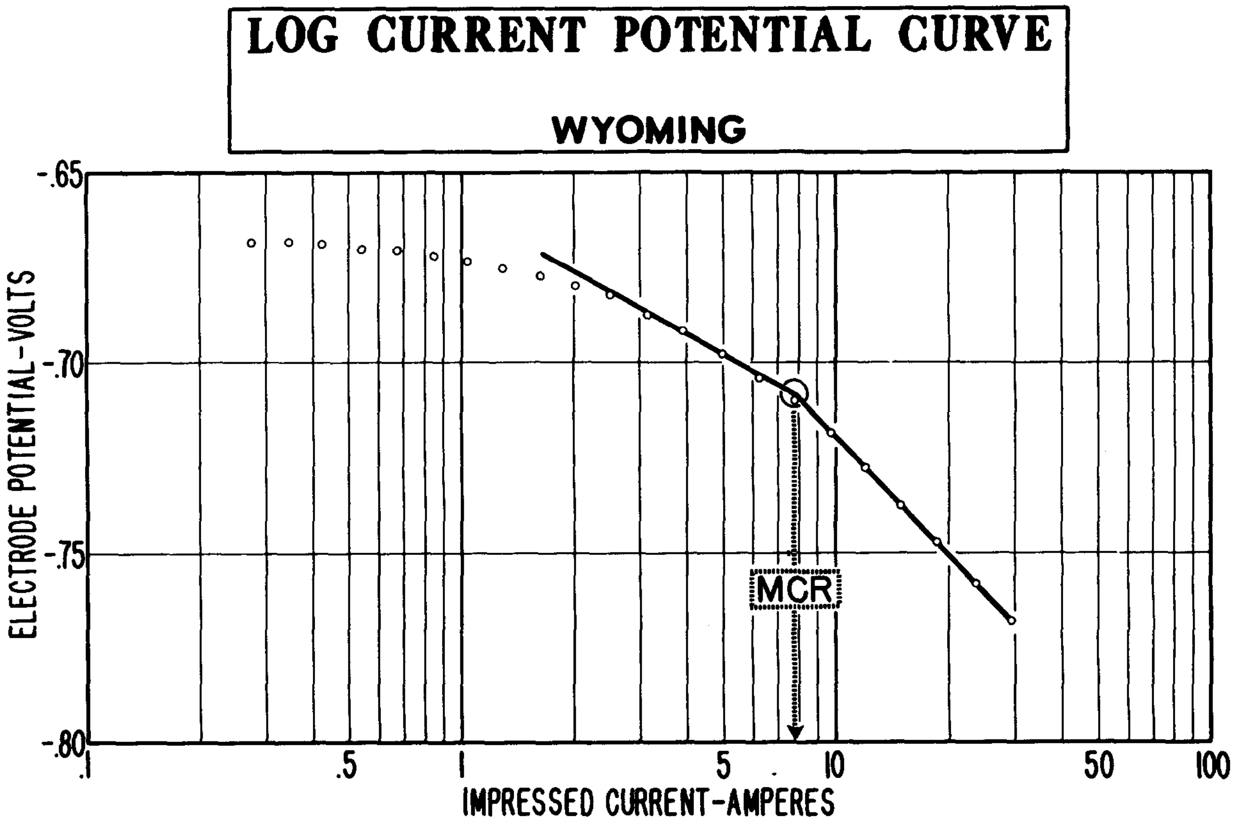
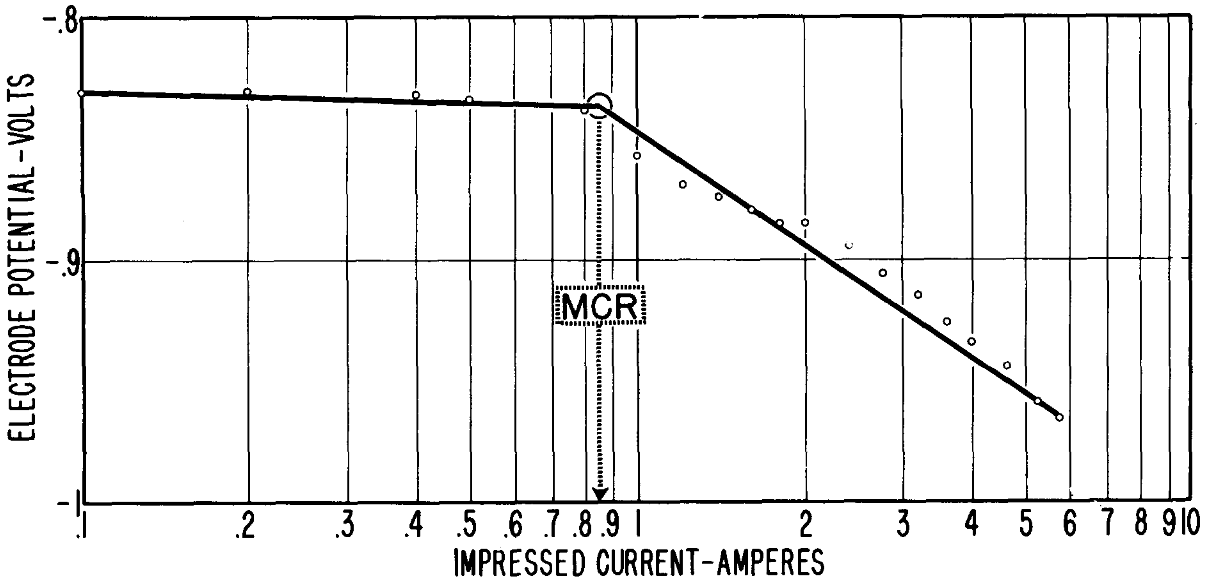


Fig 3

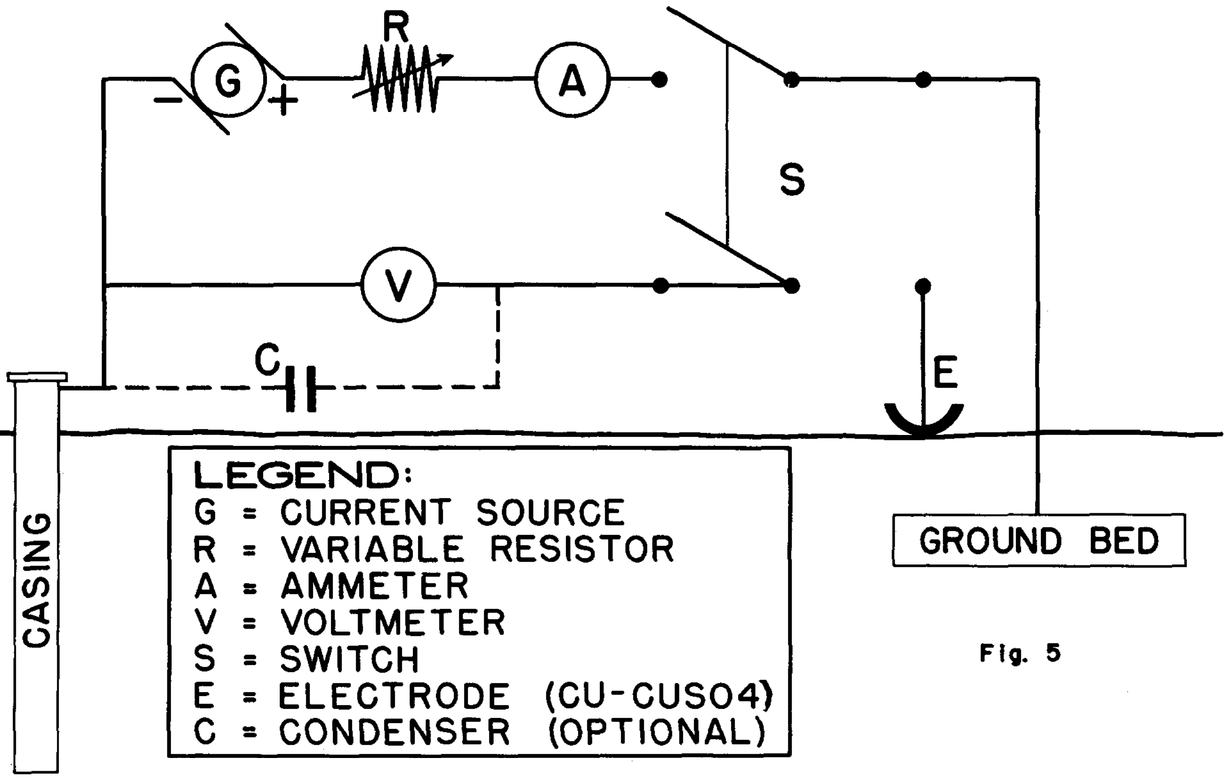
LOG CURRENT POTENTIAL CURVE
OPEN CIRCUIT
E_O



MCR = MINIMUM CURRENT REQUIREMENT

Fig 4

SURFACE POTENTIAL MEASUREMENTS DIAGRAM



LEGEND:
G = CURRENT SOURCE
R = VARIABLE RESISTOR
A = AMMETER
V = VOLTMETER
S = SWITCH
E = ELECTRODE (CU-CUSO4)
C = CONDENSER (OPTIONAL)

Fig. 5

and the casing leak frequency shown in Figure 6 indicates that good protection has been obtained to date.

Haycock[11] as a result of laboratory work, has also indicated the beginning of the final straight line portion of the curve is the value of current required for protection. Greathouse and others[12] reporting results of a 2 yr test on a Kansas well indicated the current shown by the beginning of the final straight line portion of the curve was probably very close to the minimum current required to control corrosion.

Data have been obtained in some fields which indicated only 1 deflection in the curve, and this single deflection point has been used as the minimum protection current value. In one West Texas Strawn Field Pan American applied the value of current as shown by the "first break" of the E-log I curves to 67 wells in 1957 and the leak frequency curve shown in Figure 7 indicates that good protection is being achieved.

Kogen[13] has recently reported that cathodic protection as determined by the intersection of the 2 straight lines (approximately the same as the first break) method of interpretation of the E log I curve has been effective in reducing external corrosion of casing in the Hugoton Field.

In September, 1960 Pan American applied 8 amp of cathodic protection to each of 53 wells in a West Texas Spraberry field based on E-log I curves which, by the Morris-Haycock method of interpretation (beginning of the final straight Line), had indicated protective currents in the order of 6 - 8 amperes. Casing leaks continued to occur as shown on the leak frequency curve, Figure 8. In September, 1961 casing was pulled from 1 well for inspection. The casing which had been exposed to the San Andres Zone, or the zone between the base of the intermediate pipe at 3350 ft to a depth of 5000 ft was entirely covered by a layer of iron sulfide and there was no visible evidence of any carbonate scale which is normally associated with a cathodically protected structure. Numerous deep pits were observed in addition to a hole which was located at 4700 ft. A casing potential profile was run on another of the protected wells in the same field and, as shown in Figure 9, current of 20 amp was required to provide current pick up of .5 ma/sq ft over the corroding interval. In early 1962, 18 amp of current was applied to all wells and 4 leaks occured up to September, 1962. No additional leaks have developed since that time; therefore it is hoped that protection has finally been achieved.

It can be seen from the above data that current requirement determination is not always simple and clean cut. In some cases the mere elimination of anodic areas on the casing as shown by the casing potential profile has apparently been sufficient to reduce corrosion substantially. While in other areas

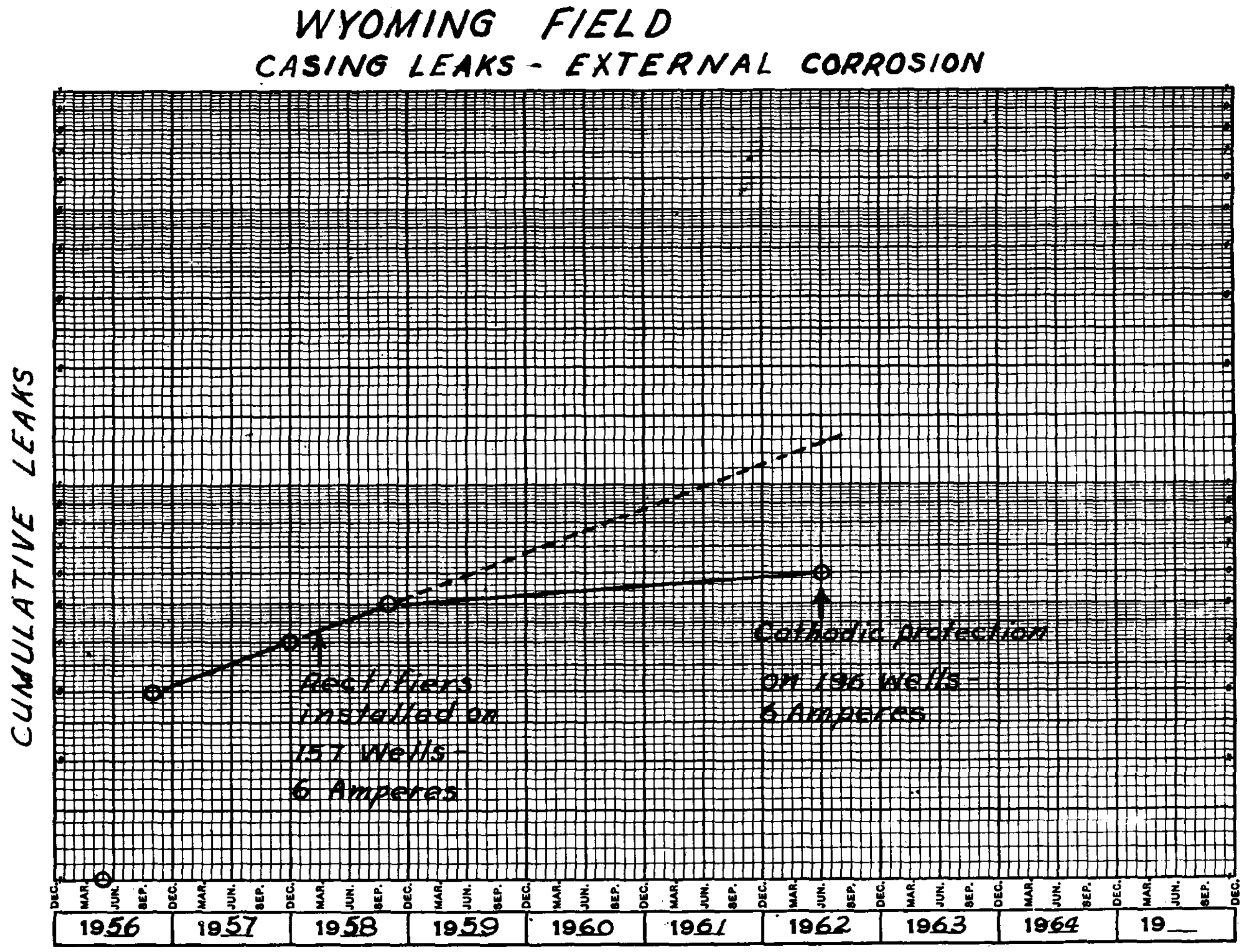


Fig. 6

where very corrosive waters are present a current density of 0.5 ma/sq ft may possibly be a minimum for protection. The above information also indicates that up to this time the interpretation of the E-log I curves is subject to critical review. It appears that E-log I data may be more reliable for shallow wells or for wells in which the corrosive zone is near the surface than for deeper wells or wells that have long corroding sections.

It is not intended that the E-log I curve be concondemned because at this time no other inexpensive method of current requirement determination is available. However, it is believed that additional work both on instrumentation and interpretation will be required before the E-log I data can be accepted as being a universal criterion. It may be necessary to establish minimum current densities for given corrosive areas by trial and error over a period of years as in the case of the above mentioned Spraberry Field.

One problem in connection with cathodic protection is that of interference between protected and unprotected structures. Interference may be defined as corrosion or metal loss on an unprotected casing which is the result of stray cathodic protection current from a nearby cathodic protection system. Cathodic protection current from a rectifier ground bed spreads over a large area of the earth in its travel to the extremities of a connected metallic structure (well casing) under protection. If another metallic structure (well casing) lies within the path of the current, a portion of the current will enter the unconnected casing, usually near the surface, and will leave the casing at some other point. Metal is lost where the current leaves the unconnected well. The degree of inteference is a function of the total current output of the cathodic protection source and the resistance between the ground bed and unprotected structure. Examples of interference on two wells are discussed in the following paragraphs.

The casing potential profile shown as Run No. 1 on Figure 9 was made with the rectifier on the test well operating at amperes and the rectifier on an offset well located 1320 ft away operating at 19 amp. On Run No. 2 the rectifier on the test well was operating at eight amperes and the offset rectifier was turned off. The increase in current pickup on the test well casing which was observed when the offset rectifier was not in operation indicates that current from the offset rectifier had been influencing the current distribution pattern on the test well. However, there is no indication of interference which could be defined as being damaging to the test well casing. The only detrimental effect of the current from the offset rectifier was a slight reduction in the current distri-

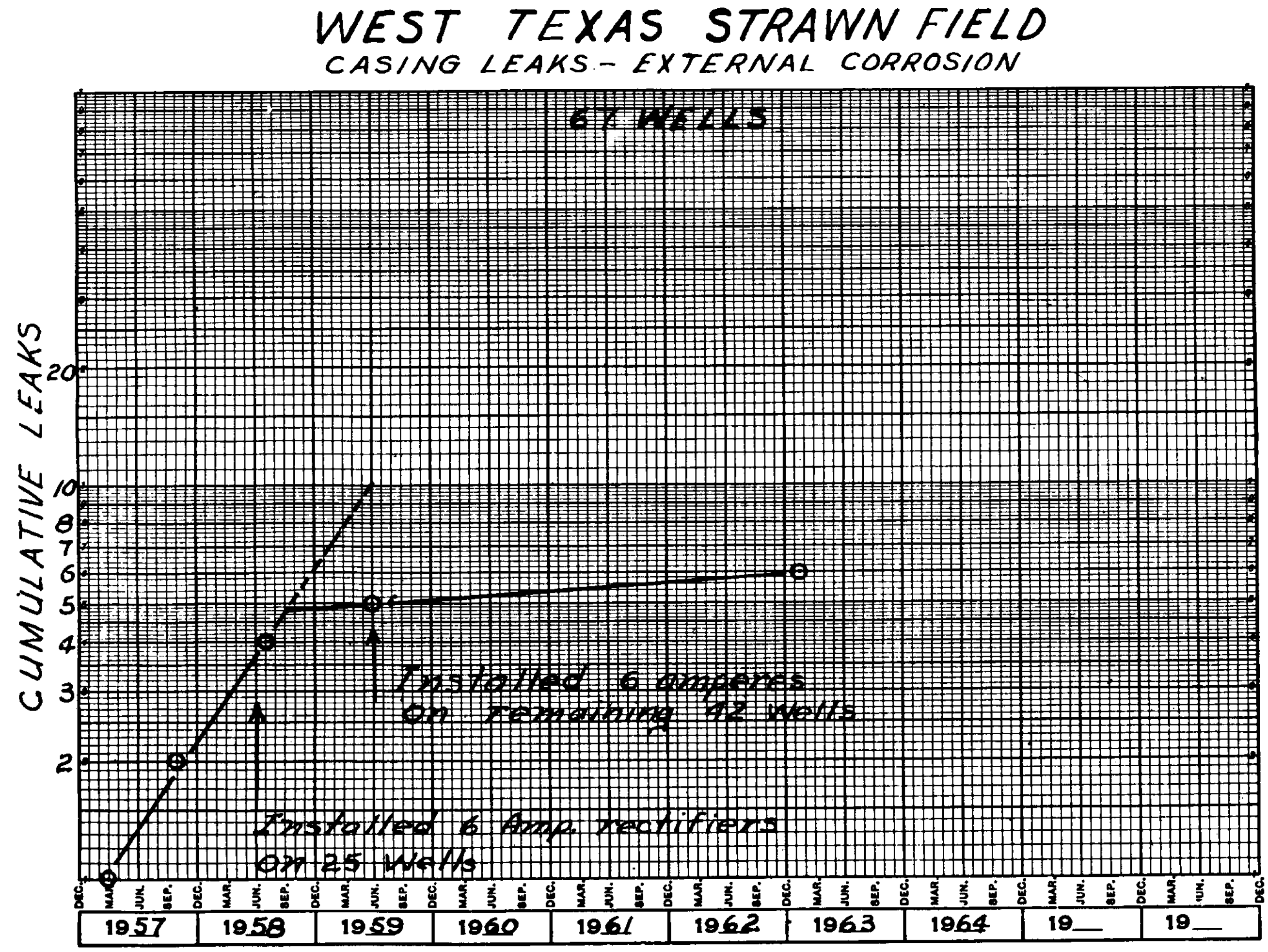


Fig. 7

bution on the test well casing. On Runs No. 3 and 4 the rectifier on the test well was operated at 14 and 20 amp respectively and no evidence of interference was shown on either profile.

An interference test on a Wyoming field well is shown on Figure 10. The test consisted of obtaining the native state casing potential profile, rerunning the profile with 5 amp applied to offset wells but not to the test well, and finally running the survey the third time with five amperes being applied to all wells. The departure between the native state and interference potential curves indicates that about 0.45 amp from the offset wells flowed through the casing of the test well. The current entered the test well between 325 ft and 1600 ft eliminating all anodic areas in that section. The current flowed out of the casing between 1800 ft and 3825 ft and generally intensified corrosion in that area. The current loss from the casing is indicated on the profile as anodic areas from 1800 ft to 2700 ft, 3125 ft to 3475 ft and intensified the anodic section that already existed at 3475 ft to 3825 ft. However, the third curve on Figure 10 indicates that application of current to the test well canceled all the anodic effect of the interference current. With the application of 5 amp of current, all the test well casing becomes cathodic except the section from 3750 ft, to 3825 ft. However, current calculations indicate that net current flow from this section was only 0.11 amp when 5 amp of current were applied as compared to 0.28 amp native state and 0.37 amp under interference conditions. Therefore, the application of current to the test well canceled the effect of the interference current as well as part of the naturally occurring anodic current.

The above tests indicate that interference can be nullified by the application of cathodic protection to wells which have been subject to interference.

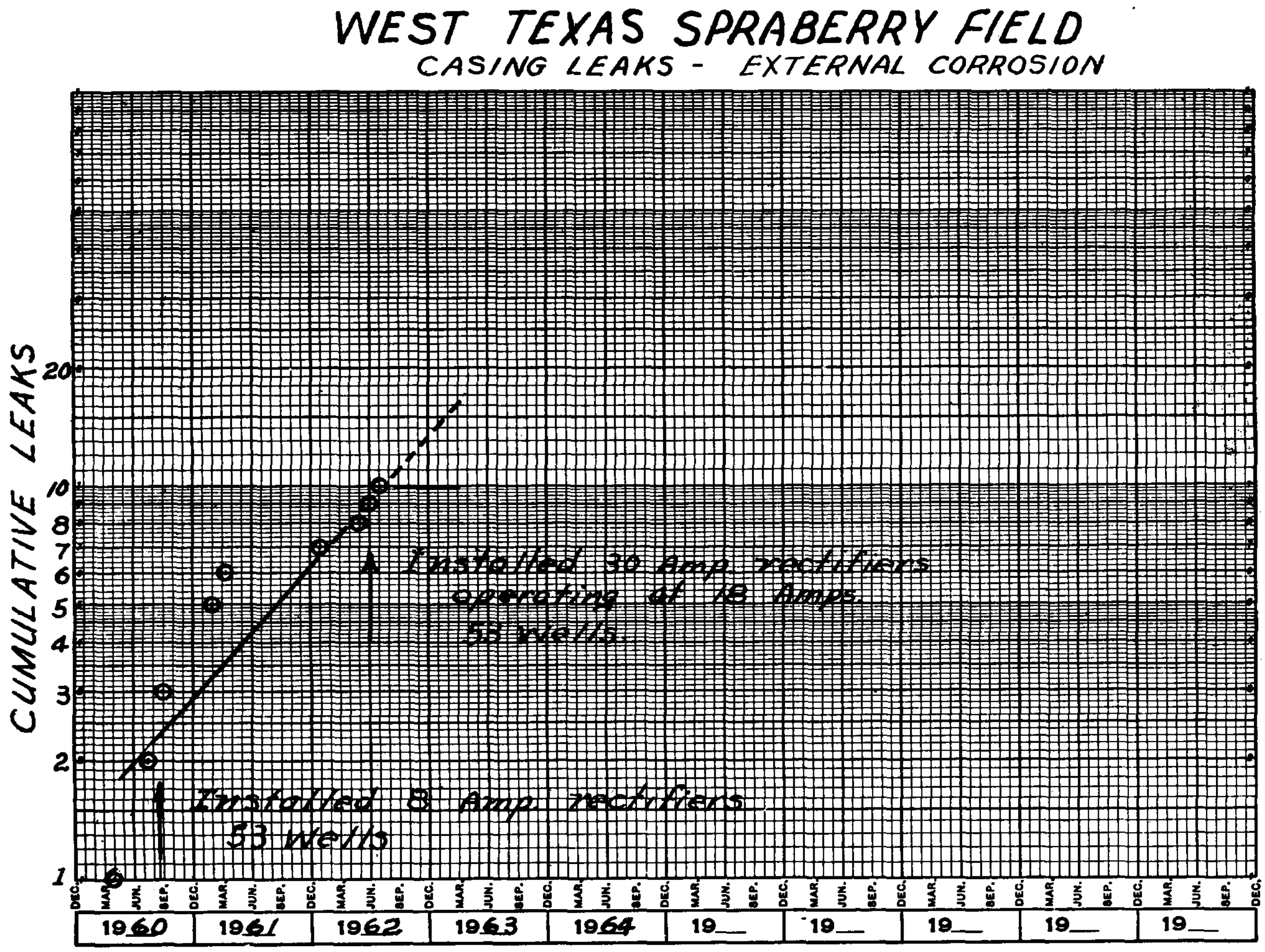


Fig. 8

CASING POTENTIAL PROFILE
WEST TEXAS FIELD WELL

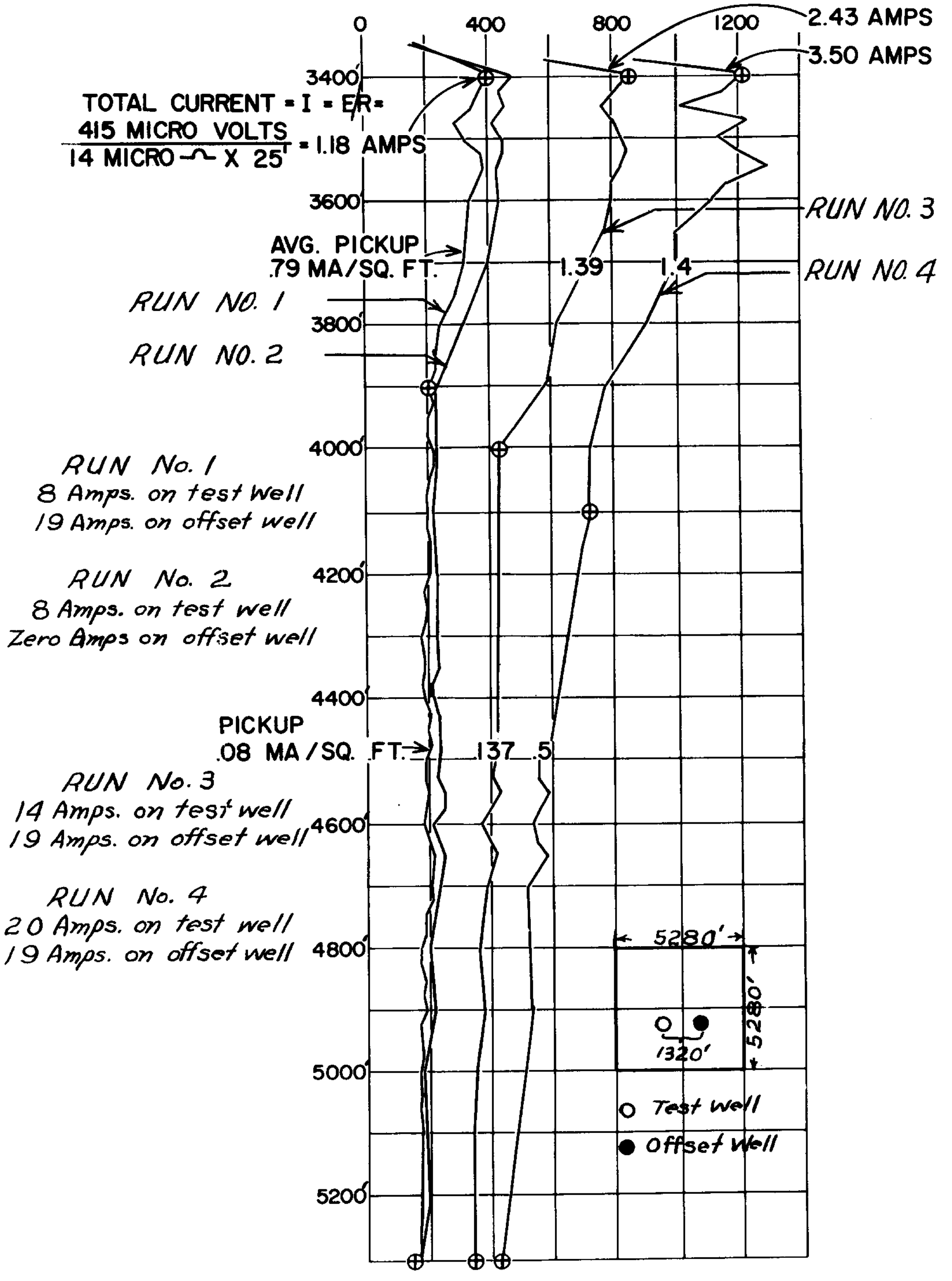


Fig. 9

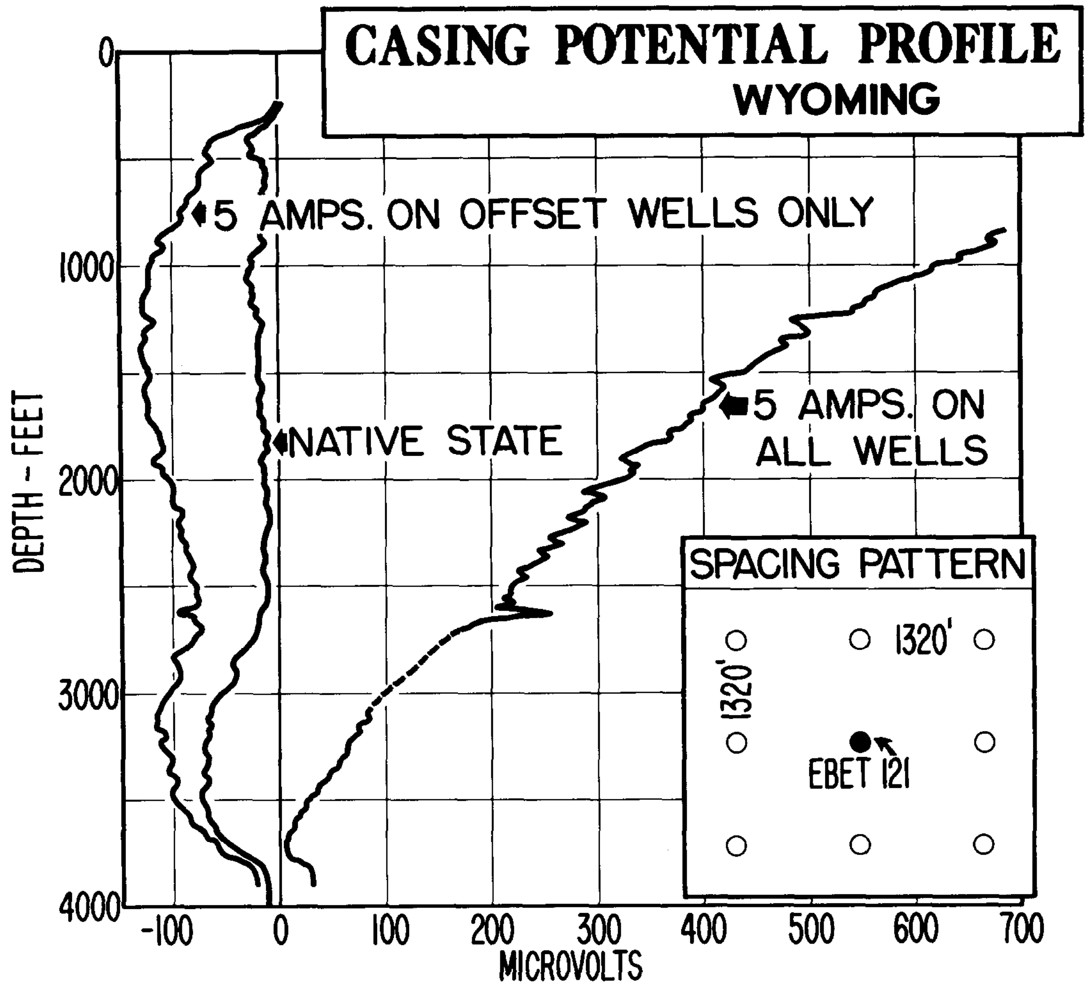


Fig. 10

CONCLUSION

1. Cathodic protection, when applied in sufficient amounts, is effective in reducing or eliminating external casing corrosion.

2. The casing potential profile provides the most positive method of determining distribution of cathodic protection current on well casing.

3. The E-log I curve offers an inexpensive method of determining cathodic protection current requirements for well casing. Available data indicate that the beginning of the final straight line portion of the curve indicates the minimum protective current value in many cases.

Additional correlation of E-log I data, current density and field case histories should be made in order to define more clearly the interpretation of the E-log I curve.

4. Present information indicates that interference can be safely controlled.

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