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MAGNETIC WATER TREATMENT DEVICES  
THE RESULTS OF A UNIVERSITY STUDY

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## INTRODUCTION

Despite adverse evaluations by some water technology experts and inconsistent performance in field tests, a variety of magnetic water treatment devices (MTDs) continue to be promoted for the prevention of scale and other deposits in water-using systems. Proponents of MTDs make the following specific claims.

1. Minimum or no power input and little or no technical control are required for continuous operation.
2. Scaling conditions are alleviated by precipitation in the bulk of the solution rather than on the walls of the heat exchanger or other plumbing surfaces. This bulk precipitation results in a sludge which can easily be removed in sump regions of low flow.
3. Already existing scale is removed from the plumbing.
4. The use of acid and other chemicals for scale control is reduced or eliminated.
5. The system can be operated at higher cycles of concentration than would otherwise be feasible, thereby reducing blowdown/bleedoff requirements.
6. Potential pollution from system discharges and the concomitant cost of waste water treatment are reduced because the conditioning method is non-chemical.

In spite of these potential benefits, the use of MTDs in the United States is extremely limited and surrounded by an atmosphere of skepticism with regard to their actual effectiveness. Although results in the American literature (1,2) have been mostly negative, certain workers, primarily outside of the United States (3), have reported success using magnetic devices for water treatment. Given the number of claims that MTDs do have a positive effect in retarding scale formation and the potential benefits to be derived from the successful application of these devices to water treatment, the Baylor Magnetics Research Group has undertaken a study, sponsored by the American Petroleum Institute, to evaluate the principles of magnetic water treatment.

## PROJECT RATIONAL

Previous studies (references 1 and 2, for example) have been almost exclusively evaluative in nature. Typical experiments involve the installation of a magnetic water-treatment device in a pilot- or laboratory-scale rig which is then operated for some specified time period to determine the amount of scale accumulation in the system. There are only two possible results of this kind of test: positive (scaling is reduced) or negative (no significant effect on scaling is observed).

While evaluative testing of this kind may provide a quick "yes" or "no" answer for determining a product's effectiveness in applications almost exactly analogous to the test conditions, it does not provide any insight into how the device might function or why or under what conditions the device might fail. This results in a dilemma when different tests appear to produce inconsistent results.

Evaluative tests of this type often deal with a large number of variables, some of which are interrelated and some of which are difficult to control. As a result, if the tests reveal that scaling is reduced when magnetic devices are used, it is often difficult to rule out the possibility that some factor other than the magnetic treatment device is responsible for the positive effect. The situation is just as controversial if no reduction in scaling is observed. Because there exists no scientifically verifiable theory of operation for MTDs, proponents of these devices can always claim that the test was conducted under inappropriate experimental conditions and the results are, therefore, invalid. This logical dilemma has been the basis for the controversy surrounding the use of magnetic treatment devices. The controversy has been prolonged because each new study has continued to follow the same evaluative type of testing procedures, and nothing new or substantial has been learned through this repetition.

In undertaking this project, it was decided that there could be little benefit derived from beginning yet another evaluative test prior to acquiring some understanding of the basic principles behind MTD operation. To obtain this understanding would require a more scientific approach to the problem--one in which hypotheses concerning MTD operation were postulated and then systematically tested and evaluated. Once a scientifically verifiable theory of operation of MTDs has been developed, a set of general criteria for optimizing MTD performance could be developed through application of these principles. Finally, these criteria could be tested using more conventional evaluative procedures.

The present study was begun by assuming that something does, in fact, happen when water is processed through an appropriately designed magnetic treatment device. Given this hypothesis, the first goal was to determine what this effect (or effects) might be. Once the effects have been established experimentally, it should be possible to study each, and determine which, if any, might be related to the amelioration of scale formation.

In view of the number of previous studies which have failed to find an easily observable effect, it was further postulated that the sought-after effects of magnetic water treatment might be quite small. For this reason, all of the initial experiments have been designed, not to simulate "real" operating conditions as would be found in the field, but instead to involve conditions which might in some way amplify the effects of magnetic water treatment.

Finally, the present study assumes that if there is a scientific explanation for the claimed effects of MTDs, then this explanation will not require postulations of mysterious and as yet unknown, pseudo-scientific phenomena related to the action of the magnetic field on water or dissolved

electrolytes. Any sound theory of MTD operation must be based on well-known laws of physics and water chemistry.

A fundamental law of physics states that the motion of a conductor through a magnetic field will cause a voltage to be produced. This principle of electromagnetic induction was first demonstrated by Faraday (4) and applies not only to conducting solids such as wires, but also to conducting fluids such as aqueous solutions containing dissolved electrolytes. Magnetic flowmeters (5) provide a well-known application of the generation of a potential using a conducting liquid.

Although passage of water containing dissolved ions through an MTD should theoretically produce a voltage, this has never been demonstrated for a commercial, off-the-shelf MTD operating under manufacturer's specifications. This paper describes the results of a series of electrical measurements made using specially modified MTDs and attempts to relate these measurements to preferential precipitation of calcium carbonate in the bulk of the solution.

#### EXPERIMENTAL

APPARATUS - Figure 1 shows a diagram of the test rig assembled for these studies. This rig consists of a reservoir for filling and a treatment loop which permits solution to be continuously recirculated through a magnetic treatment device under controlled laboratory conditions. The variable speed pump allows adjustment of the flow rate from zero to a maximum of 50 gallons per minute.

To minimize contamination, polyvinyl chloride (PVC) piping and other plastic materials have been employed wherever possible. Where metal components are required, nonferrous materials such as brass or copper have been utilized. The rig includes access to a chilled water source which allows for automatic control of the temperature of the circulating solution to within one or two degrees Centigrade. Various ports in the rig are available to

incorporate such probes as thermometers, glass pH electrodes, and reference electrodes, allowing for "on-stream" measurement of temperature, solution pH, and other experimental parameters during an actual test run.

A 2-inch diameter magnetic treatment device, manufactured by Hydrodynamics, Inc. of Gretna, Louisiana, was selected for these studies. This unit, shown schematically in Figure 2, was chosen because it produces a magnetic field which is orthogonal to the fluid flow. Through the proper sizing of motor, pump, and lines in the laboratory rig, this off-the-shelf, commercial MTD can be operated well within the manufacturer's design limits.

In addition to their standard commercial MTD (Model 1), Hydrodynamics has also supplied three specially designed MTDs for comparison testing. Model 2 is identical to the commercially available model in all respects except that model 2 is not magnetized. Model 3 contains a magnetic assembly housed in plastic pipe rather than the normal stainless steel housing. Model 4 is identical to model 3, except that model 4 is not magnetized.

The magnetic field strength present in the gaps between the pole pieces of the model-3 MTD was measured using a Bell 610 gauss meter. These measurements have shown that the upstream gap has a magnetic field strength of 1250 gauss while the downstream gap has a field strength of 1500 gauss. At this time, it is not known whether the difference in field strength between the upstream and downstream gaps is a deliberate design feature or merely a matter of quality control. Similar measurements on model 4 gave a field strength of 20 gauss.

ELECTRICAL MEASUREMENTS - The induced electric field can not be measured by simply connecting a voltmeter across two points 180° apart on the model-1 MTD because the model-1 magnet is contained in a metal housing with conducting walls. The presence of the conducting walls will short-circuit the majority of the induced current through the walls of the magnet housing, rather than

through a load in the voltmeter. Thus, a voltmeter placed across two points on the magnet housing will measure only the IR drop through the metal, which will be very small.

To make the voltage measurements, two electrodes of known composition were installed 180° apart in the plastic-walled MTD (Model 3) at positions orthogonal to the magnetic field and the fluid flow, as shown in Figure 3. The potential difference developed across these electrodes was then measured using a high-impedance Keithley 190 digital multimeter.

Flow rates in the rig were measured using a Doppler flow meter (Dynasonics, model UFT-503), and solution temperatures were monitored with a digital thermometer ("Quick," by Novo, Cole-Parmer Instrument Co., No. GP-8517-00) accurate to 0.1° C. All solutions were prepared from deionized water, and reagent-grade sodium chloride was employed to adjust the conductivity. Solution conductivity was measured using a conventional conductivity bridge (Industrial Instruments Inc., Cedar Grove, New Jersey) with a Yellow Springs Instrument Co. electrode Model RC-16B23403 (cell constant of 1.0).

Current was measured by placing a 10 ohm resistor between the electrodes and measuring the voltage drop,  $e$ , across the resistor,  $R$ , using a high impedance Keithley 190 digital multimeter. The current,  $i$ , was calculated from Ohm's law ( $e = iR$ ).

## RESULTS

A large number of voltage measurements have been made for different solution conductivities, at different flow rates, and using electrodes of different composition. Figure 4 shows some typical results obtained when voltages were measured between two brass, two stainless steel, and two Ag/AgCl (In Vivo Metric Systems, Healdsburg, California) electrodes as a function of solution flow rate. Each pair of electrodes was placed in the upstream (1250

gauss) portion of the model-3 MTD. Solution conductivities were similar, measuring approximately 2100  $\mu\text{S}$  in all examples shown. No difference in results was observed when solution conductivity was varied over a range from 25 to 16,000  $\mu\text{S}$ .

The results of these voltage measurements indicate that the measured voltage is a linear function of solution flow rate. A plot of voltage versus flow provides two parameters, a slope and an intercept. The intercept depends on the electrode material with brass and stainless steel showing a significant zero offset. Provided the magnetic field is held constant, the slopes are approximately independent of electrode material and solution conductivity.

Experiments analogous to those described above, but using the unmagnetized unit (model 4, measured field strength 20 gauss), did not produce a significant voltage. All of these results are consistent with the fundamental laws of physics involving magnetohydrodynamic generation of electric fields and will be discussed below.

When a conducting fluid flows through a magnetic field, the total electric field vector,  $E_T$ , may be calculated from the equation,

$$E_T = E_S + E_{\text{ind}} = E_S + (V \times B) \quad (1)$$

where  $E_{\text{ind}}$  is the electric field vector induced by the fluid flow,  $V$  is the fluid flow vector, and  $B$  is the magnetic field vector (4). The term  $E_S$  refers to any static electric field present in the absence of fluid flow. Since the vector  $E_{\text{ind}}$  is determined from a vector cross product, the magnitude of  $E_{\text{ind}}$  will be greatest whenever the flow vector  $V$  and magnetic field vector  $B$  are orthogonal to each other. The direction of the vector  $E_{\text{ind}}$  is orthogonal to the plane established by the vectors  $V$  and  $B$  (4). Equation 1 assumes that the Hall effect (another voltage generated by charge separation in the magnetic field and orthogonal to that given by the equation above) can be neglected because of the nature of the conducting fluid (5).

The measured voltage,  $e_T$ , is related to the induced electric field,  $E_{ind}$ , by Equation 2,

$$e_T = e_S + (E_{ind} \cdot L) = e_S + [(B \times V) \cdot L] \quad (2)$$

where  $e_S$  is the static voltage and  $L$  is the distance between the two electrodes placed in the magnetic field. According to Equation 2, a plot of  $e_T$  versus  $V$  should be a straight line where the intercept is given by  $e_S$  and the slope is given by the scalar product  $(B \cdot L)$ . Variations in slopes for runs 1, 2, and 3 are the result of slight differences in  $L$  and electrode polarization effects. In the case of the Ag/AgCl electrodes, which are reversible, the plot gives an essentially zero intercept.

The slope of the plot using the depolarized Ag/AgCl electrodes should provide an independent measurement of the magnetic field strength  $B$ . Attempts to calculate  $B$  from plot 2 in Figure 4 are complicated by difficulties in obtaining accurate flow rates,  $V$ , at a location between the pole pieces of the magnets due to turbulence in this area. Values obtained for  $B$  range from 388 G to 2000 G depending on the location of the flow sensor and assumptions made about the relationship between measured flow and actual flow through the pole piece gaps.

In order to establish the magnitude of the induced voltages relative to a known potential, a saturated calomel electrode (SCE, Corning No. 476109, ceramic junction) was installed in a port adjacent to the MTD. When the SCE was connected through the Keithley multimeter to one of the previously installed Ag/AgCl electrodes, this permitted the induced voltages to be referenced relative to the known SCE potential.

As shown in Figure 5, voltage measurements using one Ag/AgCl electrode versus an SCE reference electrode give the same linear plot against solution flow rate as observed previously. These two curves represent results taken

for each of two Ag/AgCl electrodes, located  $180^\circ$  apart on the upstream (1250 gauss) side of the MTD.

The difference between the two curves at any given flow rate can be seen to correspond to the voltage measured previously at that same flow rate using two Ag/AgCl electrodes (Figure 4) without the SCE. The zero flow offset is a measure of the difference between the Ag/AgCl and SCE potentials in the absence of fluid flow, and is a function of the chloride ion concentration.

The results of the voltage measurements (Figure 4) suggested that the MTD could produce a current flow between the pair of electrodes. Figure 6 shows two typical plots of current as a function of solution flow rate for the stainless steel electrodes using a solution conductivity of  $2100 \mu\text{S}$ . Since flow rate is linearly related to voltage, Figure 6 is actually a plot of current versus applied voltage. The shapes of these curves are typical (6) of a current-voltage plot in which electrolysis occurs. In the initial portion of the curve (low voltage), the electrodes are not in equilibrium with the solution and only a very small current is observed. The current remains small until the applied voltage reaches the "decomposition voltage," at which point a cell reaction begins to occur. At higher voltages, the current increases according to Ohm's law.

Curve 1 in Figure 6 represents current measurements taken in the downstream portion of the MTD (1500 gauss field strength), and curve 2 represents current measurements taken in the upstream portion of the MTD (1250 gauss field strength). As predicted from Equation 1, the "decomposition voltage" occurs at lower flow rates in the higher field strength portion of the magnet assembly. (Higher magnetic field strength produces higher voltage for the same flow rate.) Also, the slopes of both curves in the Ohm's law portion of the plot should be proportional to the solution conductivity, which

is the same for both measurements. Given the scatter present in curve 1, these two slopes are probably equal within experimental error.

Once the induced voltage can be referenced relative to a standard potential (the SCE), it is possible to speculate about the reactions which could occur at the electrode during MTD operation. As shown in Figure 6, the "decomposition potential" for the upstream (1250 gauss) portion of the MTD occurs at a solution flow rate of about 4.25 feet/second. This corresponds to a voltage of 34 and 18 mV relative to the SCE reference potential, or approximately +282 and +266 mV relative to the normal hydrogen electrode (NHE). As shown by the Pourbaix diagram for iron (Figure 7), these potentials indicate that oxidation of iron should produce either  $\text{Fe}^{2+}$  or  $\text{Fe}_2\text{O}_3$  and not magnetite, which is  $\text{Fe}_3\text{O}_4$ . Which of the two possible iron corrosion products actually results will depend on the pH of the solution.

As suggested by the current-voltage plots, examination of the stainless steel electrodes employed in these MTD experiments revealed noticeable corrosion on the electrode surfaces, indicating that electrolysis was occurring during MTD operation. A second set of identical stainless steel electrodes was suspended in a beaker containing untreated sodium chloride solution of the same conductivity as that used in the MTD study. After time periods equal to or longer than those required for the MTD studies, only slight discoloration of the suspended electrodes was observed.

It has also been observed that an iron-containing colloid is released into the solution whenever the model-1 or model-3 MTDs are operated. This material is generally orange-brown in appearance, typical of  $\text{Fe}_2\text{O}_3$ . In the case of model 1 (commercially available), visual inspection of the device has shown that both the magnet as well as the metal housing appear to be pitted. In the case of model 3 (plastic housing), only the magnet has been affected. While models 2 and 4 (containing non-magnetized units) show some sign of

corrosion, qualitatively the degree of corrosion does not appear to be as great as in the magnetized units. The metal housing in the commercially available model 1 has been analyzed by x-ray fluorescence scanning electron microscopy, and the results correspond to 18-8 stainless steel.

#### SIGNIFICANCE OF THE MEASUREMENTS FOR SCALE REDUCTION

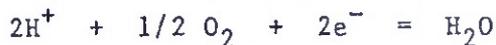
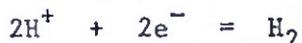
Based on the experimental data obtained to date, the most plausible mechanism for MTD operation seems to be the generation of a precipitation catalyst which results in the heterogeneous nucleation of scale-forming materials and produces preferential precipitation in the bulk of the solution rather than on the walls of the plumbing. A material which is a good precipitation catalyst need not be present in large amounts to induce heterogeneous nucleation.

It has been shown that passing a conducting solution through an MTD generates a small voltage through electromagnetic induction. If, as is typical of an ordinary commercial MTD, the unit has conducting metallic walls, a current can flow through the unit as demonstrated by the experimental results. While the current flow in the solution is carried by dissolved ions, the current flow through the metal housing of the MTD must be carried by electrons. To complete the circuit, ion flow must be converted to electron flow at the solution/housing interface. As a result, electrolysis, consisting of both an anodic (oxidation) and cathodic (reduction) reaction, will take place.

It has already been shown that in anodic regions of the device, oxidation of the metallic housing of the MTD could occur, producing either iron(II) or iron(III). One way in which the MTD might produce nucleation centers involves the adsorption of calcium on colloidal iron oxides produced as a result of magnetohydrodynamic current generation. The adsorption step would then be

followed by the heterogeneous precipitation of insoluble calcium salts on the colloidal particles. Scanning electron microscope studies on precipitates formed during field tests of MTDs have revealed the presence of iron centers in some of this material (7).

In cathodic regions of the housing, the reduction of water could occur. This can be formulated in a variety of ways (8) depending on the conditions at the cathode (pH, presence or absence of oxygen, etc.). Several examples are given by the following half-cell reactions:



No matter which one of the possible half-cell reactions actually occurs, each results in the production of a localized region of high alkalinity at the housing surface.

The cathodic reaction provides another mechanism by which MTDs can be envisioned to operate. In this mechanism seed crystals of salts such as calcium carbonate might form at cathodic regions along the surface of the MTD housing as a result of the electrolytic production of a localized excess of hydroxyl ions. (High pH would create localized regions of supersaturation.) If conditions are such that the rate of dissolution of these seed crystals is slow, they could be carried by the fluid flow into regions of bulk supersaturation where they could initiate the rapid, spontaneous precipitation of scale-forming salts in the bulk of the solution.

Preliminary measurements of pH versus time on a recirculating NaCl solution show that the pH of the circulating solution does tend to increase slowly with time. Figure 8 shows a plot of pH versus time for one set of experiments using the commercially available model-1 MTD (curve 1) and the

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unmagnetized model-2 MTD (curve 2). Both runs used identical NaCl solutions, and the rig was cleaned out with distilled water between tests.

These experiments have been repeated only a limited number of times. The initial "hump" in the plot seems to be a common feature of all runs made so far and may be due to degassing of the solution (loss of carbon dioxide). However, the pH changes after the degassing stage are not strictly reproducible, and in some cases the unmagnetized units have produced final pH values which were higher than those produced by the magnetized units. Further work involving these pH measurements is in progress.

In both of the proposed mechanisms, the MTD can act merely as a catalyst or initiator of the precipitation process. Once the bulk precipitation process has begun, a slurry will be circulated throughout the plumbing system, assuring a constant supply of nucleation centers for bulk precipitation and thereby reducing the amount of scale deposits on the plumbing walls. The overall electrolysis cell, composed of the oxidation of iron and the reduction of water, is a thermodynamically spontaneous process (8) which can occur even without the application of an outside potential. Thus, the current generated by the MTD may simply serve to increase the rate of an already spontaneous process which, in essence, is nothing more than the corrosion of iron.

#### CONCLUSIONS

It has been shown that voltages and currents are produced when conducting solutions are flowed through a magnetic water treatment device whose magnetic field is orthogonal to the fluid flow. It has been postulated that the electrolysis products which result from this process could be involved in causing the preferential precipitation of calcium carbonate in the bulk of the solution rather than on plumbing surfaces. Further work is currently in progress to test this hypothesis.

#### ACKNOWLEDGEMENT

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## LEGENDS FOR FIGURES

- Figure 1 Schematic diagram of test rig. R, reservoir; IV, intake valve; P, pump; SP, sensor port; M, magnetic treatment device; PG, pressure gauge; NP, nitrogen purge; AB, air bleed; CC, cooling coils; T, thermometer; D, drain; O, observation port.
- Figure 2 Schematic diagram of magnetic treatment device used in this study.
- Figure 3 Orientation of electrodes used in electrical measurements. E, electrodes; PP, pole pieces; VM, voltmeter. Pole pieces serve to focus magnetic field and increase the solution flow rate in the gap.
- Figure 4 Measured voltage versus solution flow rate. Curve 1, brass electrodes; Curve 2, Ag/AgCl electrodes; Curve 3, stainless steel electrodes; Curve 4, Ag/AgCl electrodes; solution conductivity 2100  $\mu$ S; curves 1, 2, 3 using model-3 MTD in 1250 gauss portion of the magnetic field; curve 4 using model-4 MTD with 20 gauss magnetic field.
- Figure 5 Measured voltage referenced to a saturated calomel electrode versus solution flow rate. Model-3 MTD, both curves represent positions in the 1250 gauss portion of the magnetic field and are 180° apart from each other, solution conductivity 15,000  $\mu$ S, Ag/AgCl electrode.
- Figure 6 Measured current versus solution flow rate. Model-3 MTD; Curve 1, 1500 gauss portion of the magnetic field; Curve 2, 1250 gauss portion of the magnetic field; solution conductivity 2100  $\mu$ S; stainless steel electrodes.
- Figure 7 Pourbaix diagram for iron. Solid lines represent boundary conditions for the various oxidation states of iron. Sloping dashed lines indicate the boundary conditions for the oxidation and reduction of water. Potentials are given in volts relative to the normal hydrogen electrode (NHE).
- Figure 8 Solution pH versus time. Solution pH plotted versus recirculation time in the test rig. Curve 1 shows the results of one test employing the commercially available model-1 MTD. Curve 2 shows the results of one test employing the model-2 MTD which is similar in construction to the model 1, but is not magnetized.

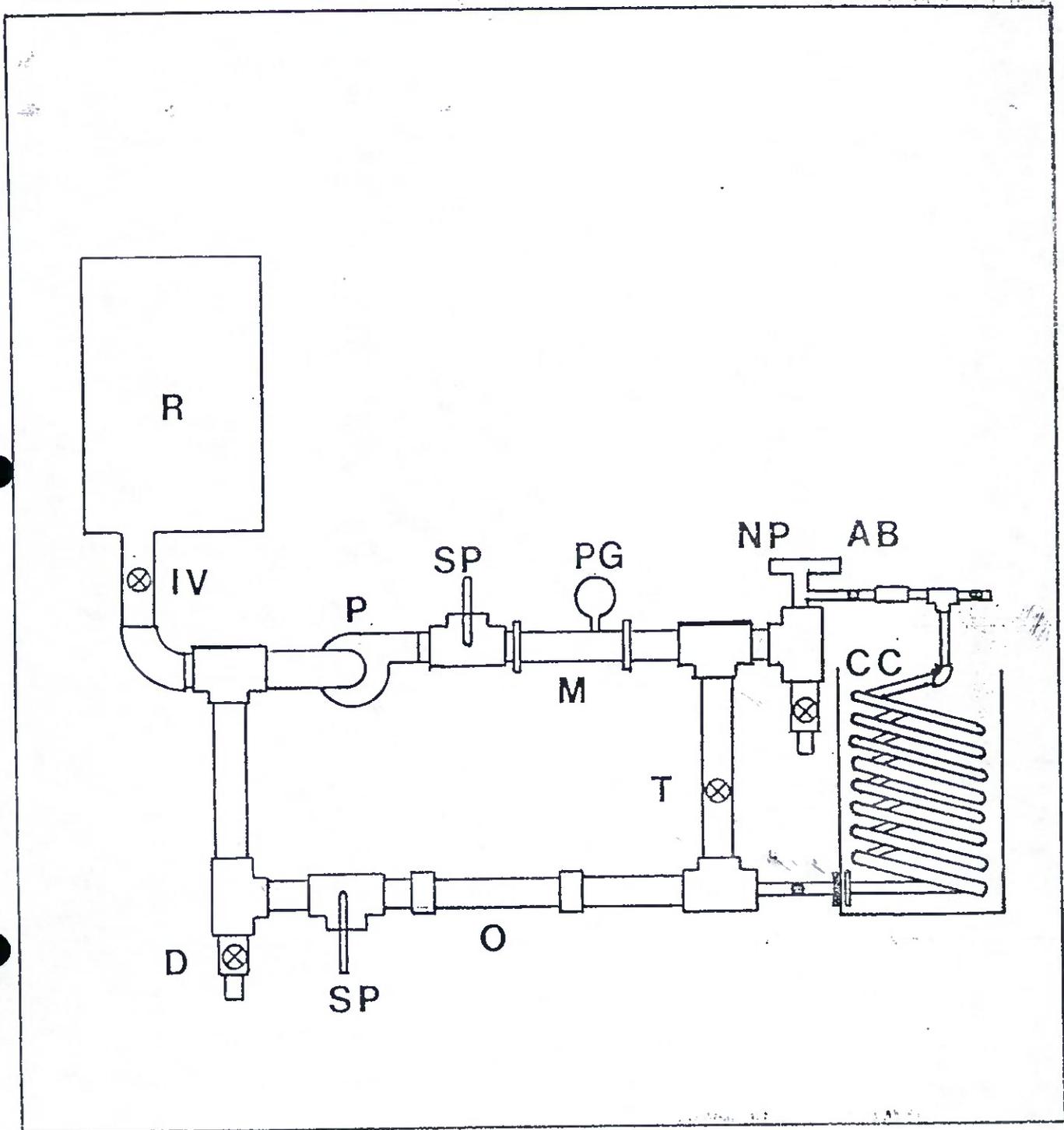
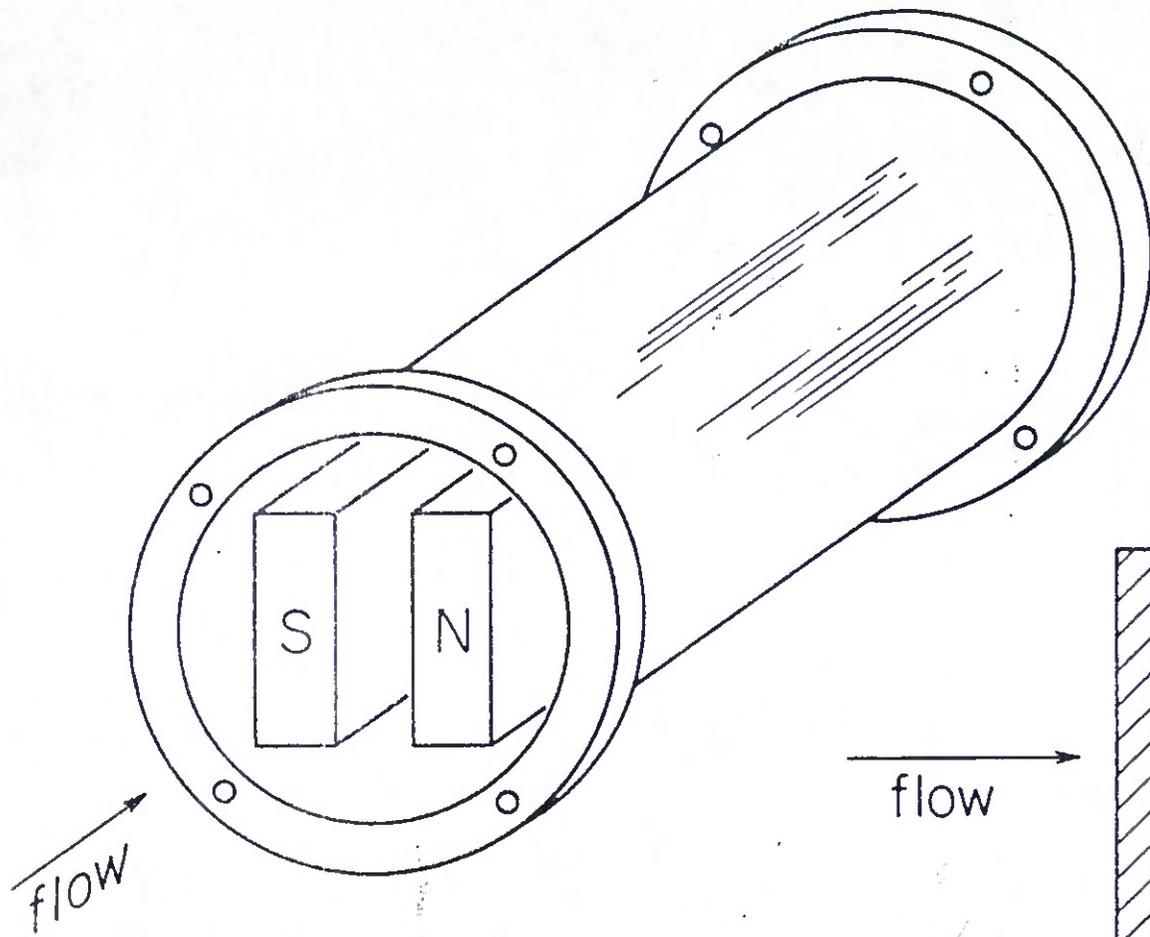
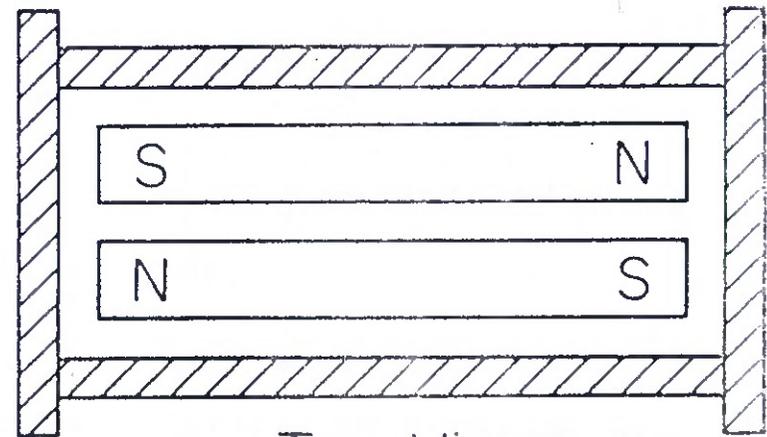


FIGURE 1



flow →



Top View

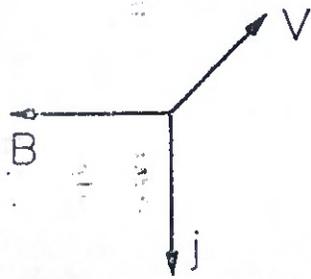


FIGURE 2

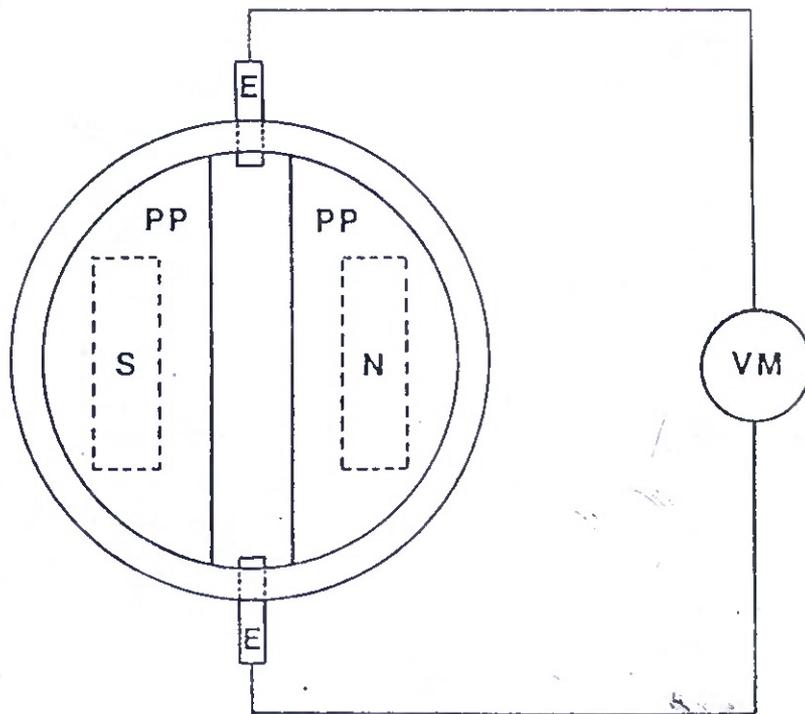


FIGURE 3

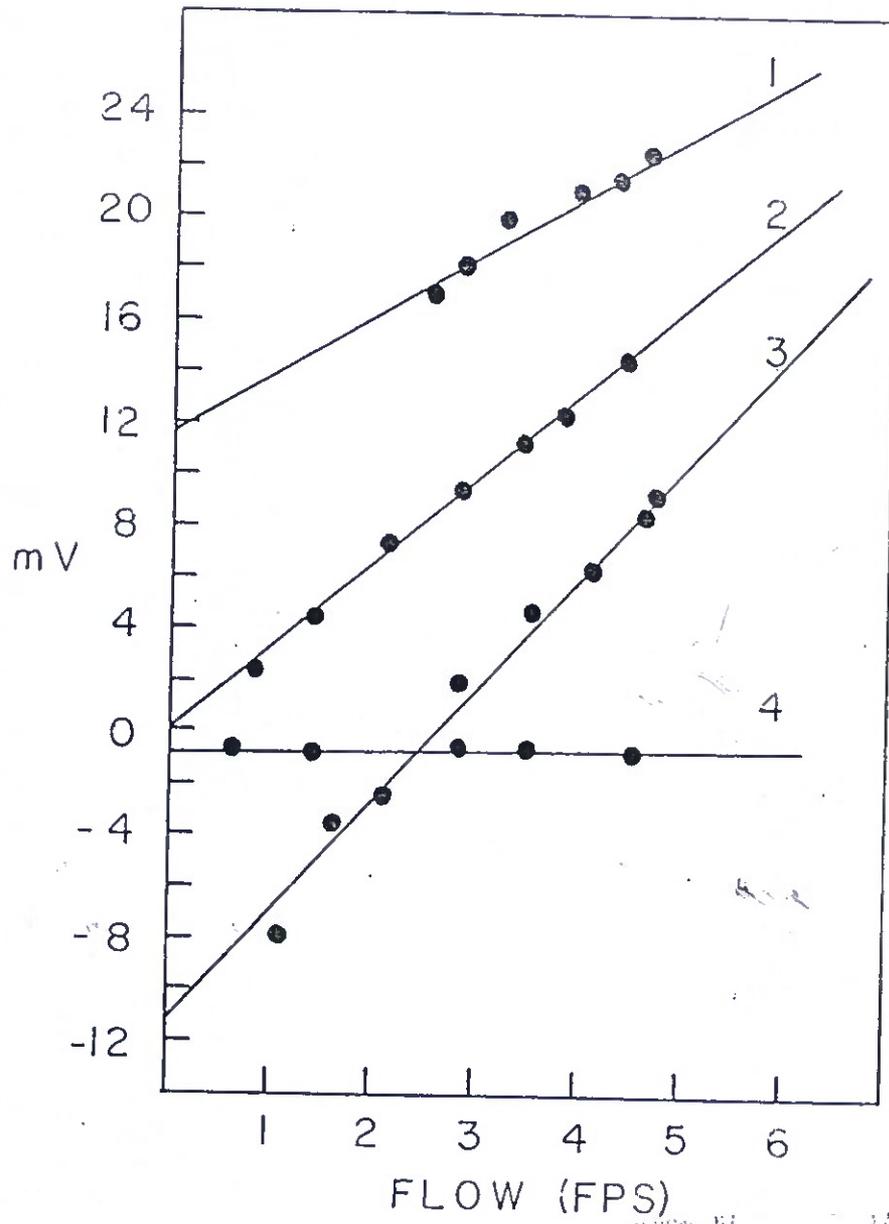


FIGURE 4

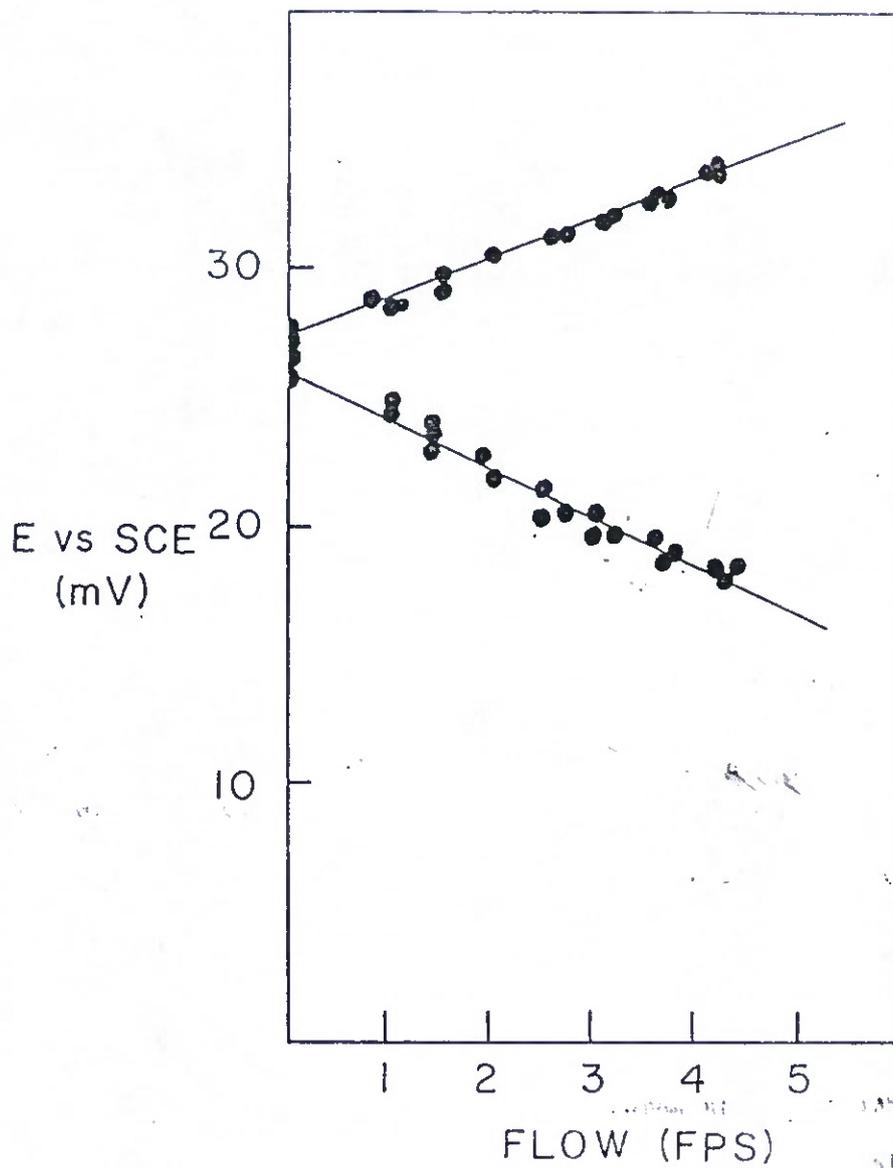


FIGURE 5

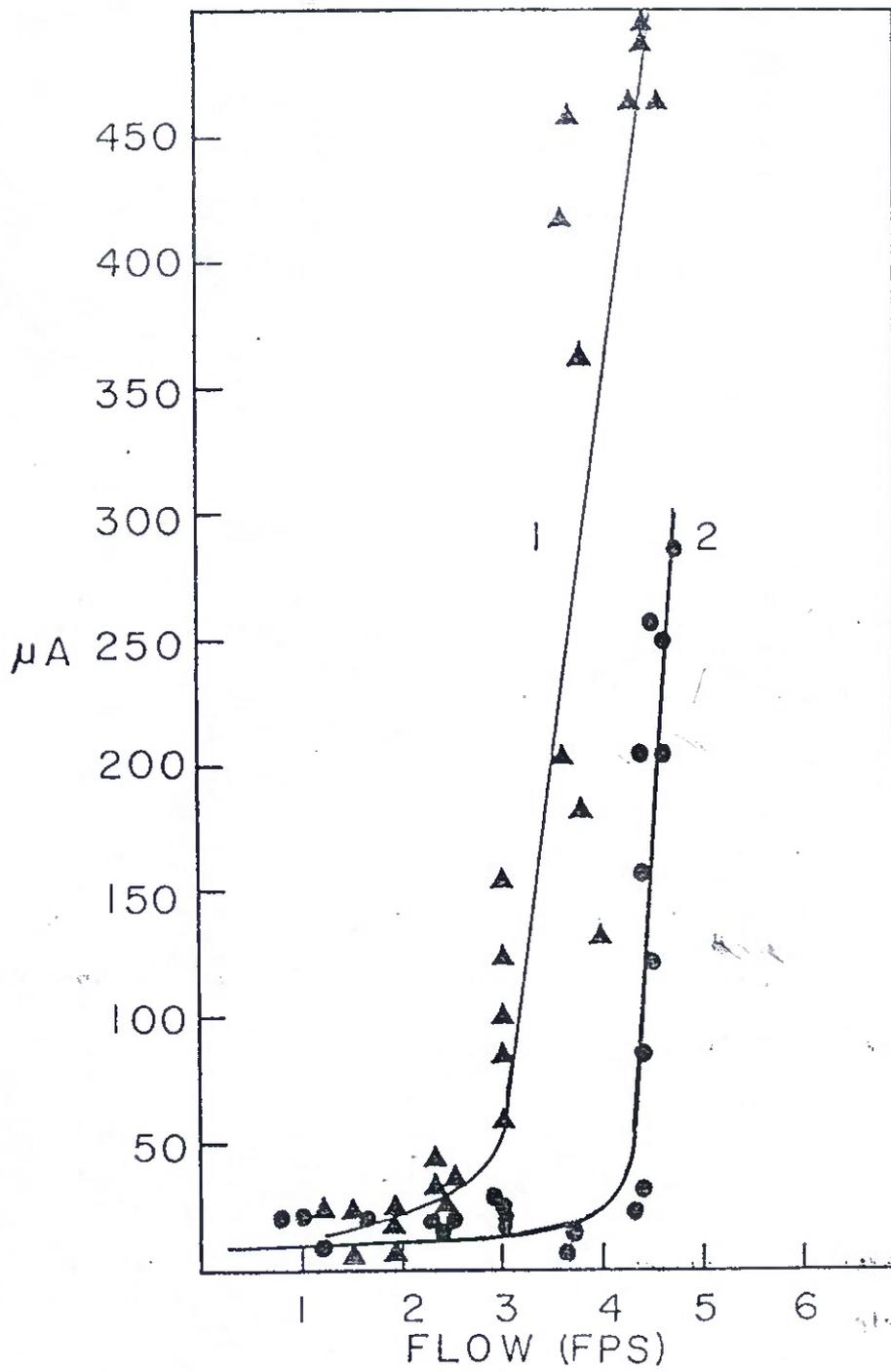


FIGURE 6

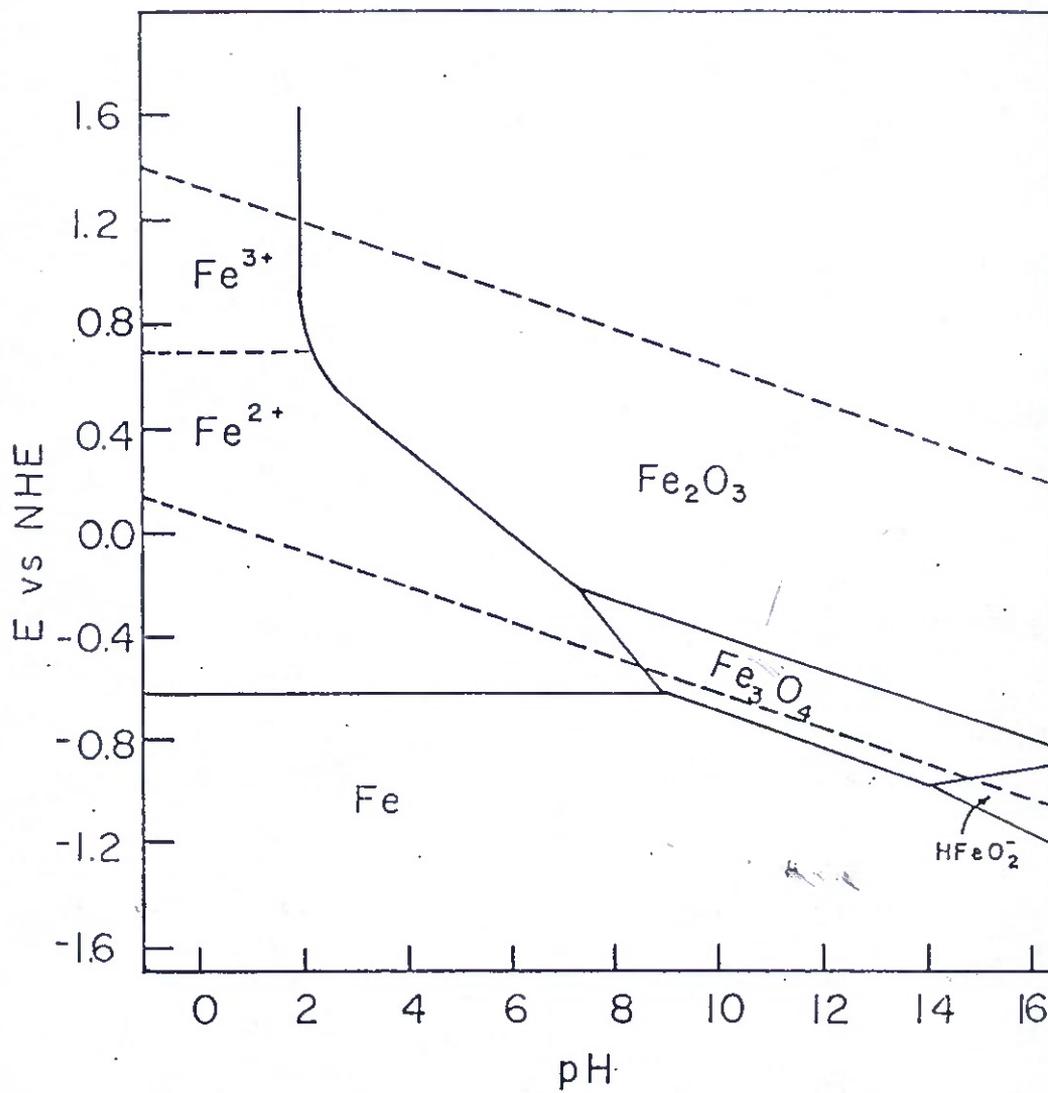


FIGURE 7

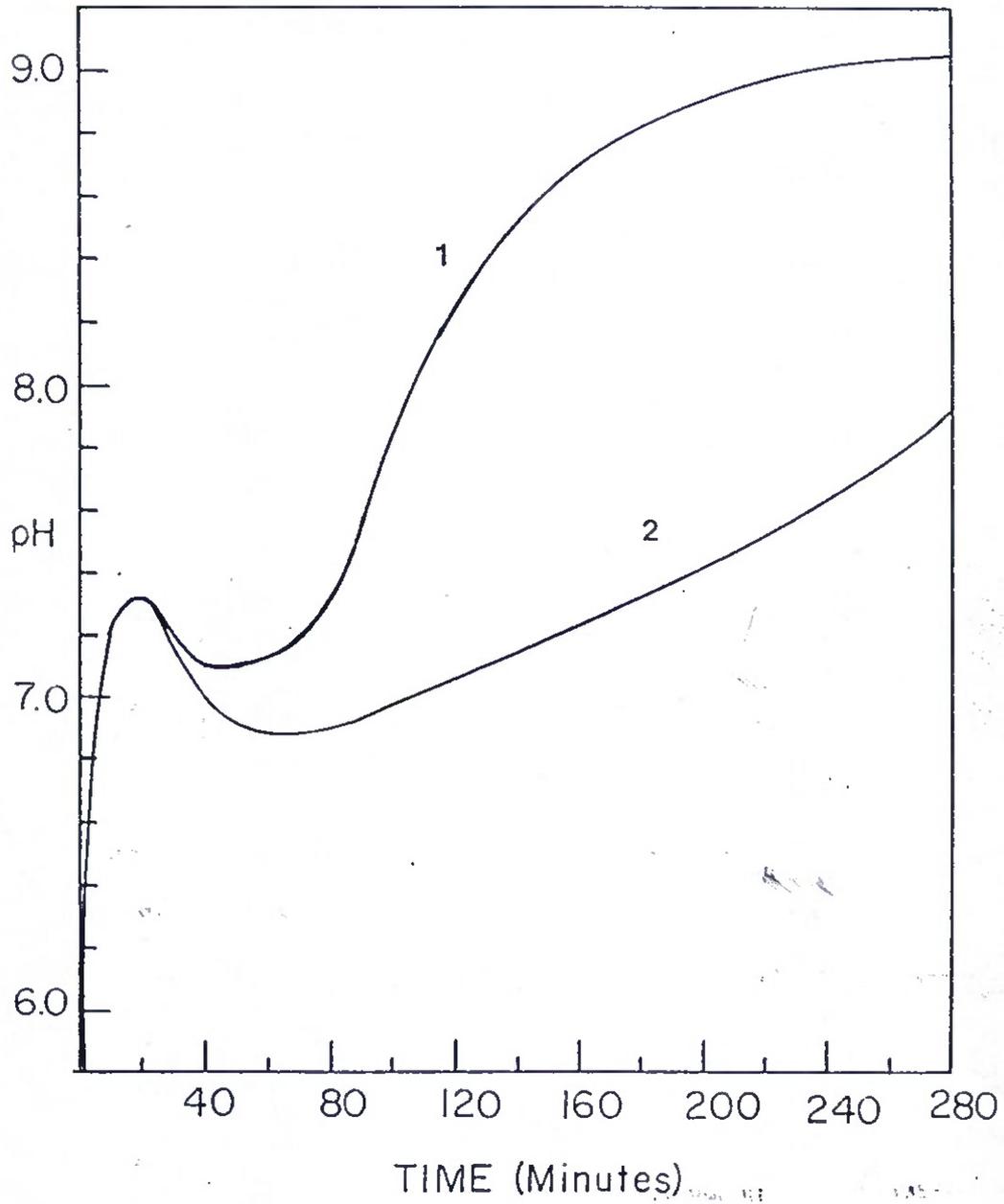


FIGURE 8