LECTROS INTERNATIONAL LIMITED

A REVIEW OF THE THEORY AND APPLICATION OF ELECTRO OSMOSIS AND ELECTRO DAMP-PROOFING

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CONTENTS

1. INTRODUCTION

History

18th Century: Germany: It was discovered that applied voltage affected capillary action.
19th Century: It was further discovered that water was moved from a positive anode to a negative cathode when an electrical potential was applied.

Theory

Moisture rises from the earth by capillary and osmotic action. Differences in electrical potential have been recorded between damp structures and earth.

Passive Osmotic Systems

Based on earthing a suitably placed electrical conductor usually copper. Holes are drilled into a wall at approximately 500mm intervals extending some two thirds into the wall. Copper electrodes formed from the copper conductor are inserted into these holes and backfilled. The electrical conductor is then connected to the ground via an earthing rod or rods.

Active Osmotic Systems

A small direct electrical voltage is applied between two electrodes. A series of corrosion resistant anodes are placed in the wall to be damp proofed. These are connected via a power unit to an earthed conductor, the cathode.

2. SUMMARY

This paper is a review of the available literature of electro osmosis, and its practical application, with particular reference to active damp-proofing systems.

The mechanism of electro osmosis is well established, as is its practical application in soil and slurry dewatering. However, there appears to be little scientific literature relative to damp-proofing.

Confirmation of the effectiveness of electro damp-proofing, as in other alternative treatments, is difficult to obtain since such installations are in main used in conjunction with other remedial measures.

Full acceptance of the technique may be difficult due in part to recent history with the passive system of electro damp-proofing.

3. BACKGROUND

Lectros International Limited are suppliers of a system of damp-proofing for buildings which relies on the principle of electro osmosis, the migration of water through a porous medium under the influence of an electric field gradient, for its successful operation.

Our particular variant of the technique involves the embedding, at regular intervals, of small wire anodes coated with a platinum group element in the wall requiring treatment. These anodes are connected in a ‘ring main’ configuration, to a low voltage power supply. The circuit is completed by a copper coated earth rod driven into the ground at a lower level than the anodes in the wall and at some distance from them. The earth rod is connected to the negative side of the DC power supply and becomes the cathode in the electrolytic part of the circuit. Since, in most instances, electro osmosis causes water to flow towards the cathode, the expectation is that the wall will dry out. In effect the electric field opposes the capillary rise resulting from fine scale porosity in the wall structure.

The use of such a system could present many practical pitfalls in its application. In particular a suitably stable, insoluble, anode material must be used, vulnerable cable connections must be avoided a far as possible, especially in the anode circuit, and good electrolytic contact must be maintained between anodes and the wall. The Lectros system is well thought out in these respects, particularly in its use of platinum group element coated anodes connected solely with titanium wire and all titanium crimp connectors. Our system is well designed for ease of installation, with very comprehensive installation notes.

Despite careful engineering of our system and the installation of tens of thousands of systems in the United Kingdom, we feel that the principle of electro osmotic damp-proofing has not found general acceptance with the building industry, possibly due to the lack of both understanding of the principles and evidence that the method will work in damp-proofing applications.

4. THEORY OF ELECTRO OSMOSIS

The theory of electro osmosis is covered in consideration detail in most text books on physical chemistry or electrochemistry, of which three have been referred to for the present review (2-4). A detailed treatment is beyond the scope of this document but the following outlines the principles and discusses the factors influencing electro osmotic flow.

4.1 ELECTROKINETIC PHENOMENA

Electro osmosis is one of a group of effects known collectively as electrokinetic phenomena. These are associated with the electrical charge frequently present on the surfaces of two phases in contact with each other. The application of a voltage (or electromotive Force) to such interfaces causes movement of the phases in relation to each other. The movement of the two phases in relation to each other produces the converse effect, i.e. the formation of a voltage. The four electrokinetic effects can be simply stated as follows.

4.1.1 Motion Caused by Applied Voltage

4.1.1.1 Electro Osmosis - Liquid caused to move through a porous, static medium.

4.1.1.2 Electrophoresis - Solid particles caused to move through a stationary liquid.

4.1.2 Voltage Produced by Movement of Phases

4.1.2.1 Streaming Potential - Voltage produced by liquid being forced through a porous, static medium.

4.1.2.2 Sedimentation Potential - Voltage produced by the freefall of particles through a liquid.

Of these 4.1.1.1 is the most important in the context of damp-proofing, with the liquid being the aqueous solution responsible for the dampness and the porous static medium being the wall. It is worth noting, however, that 4.1.1.2, electrophoresis, may contribute to damp-proofing by moving particulate matter in the pores towards the anode, producing blocking and affecting capillary rise of water. A streaming potential, 4.1.2.1, will also be produced during capillary flow of water through the wall.

4.2 PHYSICAL BASIS OF ELECTRO OSMOSIS

When a solid material is in contact with an aqueous solution, there exists a separation of charges such that the solid surface acquires an electrical charge, of positive or negative sign, with the layer of solution immediately adjacent to the surface acquiring an equal charge of opposite sign, thus preserving charge neutrality. This situation is illustrated schematically for a capillary, or pore, such as would exist in a typical wall, in Figure 1. The charge separation forms what is referred to in electrochemistry as a double layer and the difference in electrical potential produced by the charge separation is known as the electrokinetic, or zeta, potential, §. Figure 1 represents a considerable over-simplification when compared to the real situation at a surface, but is sufficient for present purposes, where the inner charged layer can be regarded as fixed at the solid surface, while the outer layer, which in practice is somewhat diffuse, can be regarded as mobile within the solution.

If an electrical potential is applied across the ends of the pore, from an external power source, the icons in the outer part of the double layer will move in a direction dependent upon their charge and in so doing will cause the bulk of the solution to move by exerting a viscous drag. Most solids acquire a negative charge in moderately pure water, giving a positive charge in the outer layer. The flow of water is thus generally in the direction of the cathode (5) as shown in Figure 1.

4.3 FACTORS AFFECTING ELECTRO OSMOTIC FLOW

Without detailing their derivation here, the rate of flow generated by electro osmosis can be expressed in one of two equivalent ways:

$$\text{Volume/unit time} = \frac{\S\ D\ V\ q}{4\ \pi\ \eta}$$

or

$$\text{Volume/unit time} = \frac{\S\ D\ I}{4\ \pi\ \eta\ \kappa}$$

Where
§ = zeta potential
D = dielectric constant of water
V = voltage gradient along pores
q = total cross-sectional area of all pores in the solid
η = coefficient of dynamic viscosity of solution
I = electric current flowing
K = specific conductance of the solution

Of the listed variables, D will effectively be a constant and the effects of the remainder on the rate of flow to be expected are discussed in the following subsections.

4.3.1. Zeta Potential

The rate of flow produced by electro osmosis is directly proportional to the value of the zeta potential and the direction of flow will be dependent on its sign. As stated above, for most aqueous solutions the sign is such that water migrated to a cathode, while for reasonably dilute solutions the value of § is in the range 0.02 – 0.05 volts. However, the value can be reduced and the sign reversed by certain dissolved ionic species. The ions most likely to have such effect are multivalent species of charge sign opposite to that carried by the fixed layer on the solid. Thus aluminium ions (trivalent Al^3+) in solution might be expected to markedly reduce the efficiency of electro osmosis in promoting flow. For any given solid and solution composition, the magnitude and sign of the zeta potential are not predictable on theoretical grounds, and the efficiency of electro osmosis, therefore, needs to be determined empirically for each situation.

4.3.2. Voltage Gradient

As might be expected, the volume flow of water due to electro osmosis will be directly proportional to the applied voltage gradient in the porous medium.

4.3.3. Pore Cross-section

Again, unsurprisingly, the flow rate is proportional to the total cross-sectional area of the pores. Perhaps less obviously the rate is independent of the individual pore dimensions. Thus, electro osmosis will be most effective in vey porous media, but it does not follow that the very fine capillaries which give the highest capillary rise (maximum height of rising damp) will be most amenable to high rates of electro osmotic flow.

4.3.4. Coefficient of Viscosity

Electro osmotic flow rate will decrease with increasing solution viscosity, but the viscosity of aqueous solutions does not change greatly with increases in dissolved salts and, therefore, any effects will be small. For example, the presence of 111g/1 calcium chloride will lower the flow rate to 76% of the value for pure water, all other parameters being equal.

4.3.5. Current

The electro osmotic flow rate will be directly proportional to the current flowing from the voltage source.

4.3.6. Specific Conductance

This parameter relates current to voltage gradient, and is the link between the two expressions for flow rate. At constant current an increase in specific conductance will lower the voltage gradient and hence the flow rate.

4.4. SUMMARY

The theory of the physical principles underlying electro osmosis if well developed and understood. The effectiveness of the phenomenon in promoting water flow is dependent on three primary variables which, in turn, influence the secondary parameters discussed above, namely:

Primary Variable	Secondary Parameter	Effect on Water Flow
Nature of solid	Zeta potential	Varies
	Porosity	Increase in porosity Increases flow
Composition of Solution	Zeta potential	Varies. Increasing dissolved species usually reduces § and decreases flow.
	Coefficient of Viscosity	Minor effect. Dissolved species usually decrease flow.
	Specific conductance	Increasing concentration of dissolved species increases K and decreases flow.
Applied Voltage Gradient	Current	Increasing voltage increases both current and water flow.

5. PRACTICAL APPLICATION OF ELECTRO OSMOSIS

A computer search of appropriate UK databases for examples of the application of electro osmosis has revealed only limited literature on the topic. Those papers discovered were obtained initially in abstract form and selected papers were then obtained in full for further study. In some cases these latter papers produced further references not revealed by the database search. A review of the references obtained is given overleaf.

5.1 DEWATERING OF SLUDGES AND SLURRIES

The largest volume of literature revealed by the database search concerned the use of electro osmosis for dewatering of various slurries (5-14). Of these references three were obtained as full papers for further study (9-11). Dewatering of sludges by the use of electro osmosis is clearly a practical proposition under a range of circumstances. Test results are often consistent with the theoretical equations of electro osmosis (13) and in particular the relationship between water transport and voltage (6). The method, being insensitive to pore size, is attractive for dewatering sediments of fine particle size (7,9). It is stated as effective fro mine tailings (14) and for sludge difficult to dewater by mechanical means (13).

For dewatering of clays, the rate of dewatering increases with increasing applied voltage; dewatering to 50 wt% solids occurring in 1 day at 1 volt applied and 15 minutes at 50V applied (9). This compares with 4-6 days dewater to the same extent under natural drainage. Dewatering slows down rapidly at above 50 wt% solids due to the much reduced conductivity (9). Due to an increase in conductivity the presence of dissolved salts allows dewatering to proceed at lower voltage or better dewatering at the same voltage at least at concentrations up to 10^{-2}M (10). However, electrolyte concentrations above 0.1M severely limit the effectiveness of dewatering of clays presumably due to increasing influence on the zeta potential (10). In the experiments described, water migration was always towards the cathode, but with varying degrees of efficiency (9-11).

5.2 SOIL CONSILIDATION AND DRAINAGE

Of the papers referenced on this topic (15-21), two were obtained for a more detailed review (15, 21). The technique uses an electric field to drive water to wells, situated at the locations of the cathodes, from which it is then pumped. As with sludge dewatering, electro osmosis is only used for difficult situations where conventional dewatering occurs either too slowly or inefficiently. A typical example is the dewatering of a cofferdam embankment, where large earth movements occurred during conventional dewatering, and electro osmosis was used, successfully, to stabilise the situation (20). However, the prediction of the effects of electro osmotic dewatering in any given situation, either experimentally or mathematically, is extremely difficult, mathematical analysis involving the use of time-dependent finite element analysis (21).

5.3 ENHANCED OIL RECOVERY

The use of electro osmotic transport of reservoir water to promote enhanced recovery of hydrocarbons has been investigated in both Austria (22) and France. The Austrian work used as its starting point the good results obtained in dewatering difficult to drain soils, and developed a test procedure to determine the applicability of the technique to petroleum-bearing strata. Effectiveness was limited as salinities above 1000ppm in sandstone, and was more efficient in sands containing clay.

5.4 CATHODIC PROTECTION

Although not an application of the process, the effect of electro osmosis is sometimes observed in the application of cathodic protection to buried structures where the passage of current causes the ground around the anodes to dry out, reducing their efficiency (23, 24).

5.5 DAMP-PROOFING

The literature on electro osmotic damp-proofing is disappointingly sparse. There are a number of patents describing the technique (25-29) but, as with all patents, the evidence of effectiveness of the described method must be regarded as suspect in the absence of external supporting evidence. There is some literature in trade journals but these are generally aimed at selling and are devoid of any technical backup (30-32). As part of a discussion on damp-proofing systems in general, Sharpe (33) briefly mentions both active electro osmotic systems, the subject of the present report, and the, largely discredited, passive systems. The latter are briefly discussed in Section 6, but are largely outwith the scope of this study.

6. DISSCUSSION

The occurrence and principle of electro osmosis has been established for a considerable length of time, being first observed in 1809 (36), with the mathematical basis essentially complete some 70 years later (37). The practical application was to soil dewatering in 1936 (21) and it has now become well established (15-21) for use in difficult soils. It is equally well established for dewatering of slurries (5-14). Despite the possible effect of various dissolved species in reversing the zeta potential, in all cases discussed in the literature, water migrates to the cathode over a wide range of conditions and solution compositions, although it is clear that increase in concentration of dissolved species can impede electro osmosis. Although theoretical analysis of any given case is complex, and sometimes impossible, the practical evidence from the established applications of electro osmosis might appear to indicate that it would be a viable method of removing damp from porous building materials. That it is acknowledged as such by those responsible for the regulations governing building techniques is due to a variety of reasons, discussed below.

The early application of the principles of electro osmosis to damp-proofing used to so-called passive technique. This used two electrodes or groups of electrodes, one in the wall to be dried and the other in the adjacent ground. These electrodes were then electrically connected, to short out the potential difference between ground and wall. It was believed that this potential was due to the flow of water up the wall (the streaming potential) and that the removal of the potential difference would impede the flow. It is indeed a fact that a potential difference can be measured between wall and ground, but this could be due to the different electrochemical environment between the two locations rather then any streaming potential.

Theory indicated that the formation of a streaming potential acts to retard capillary rise, so that any success in removing the streaming potential would, in fact, promote rising damp! For these reasons it is impossible to give passive electro damp-proofing any sound physical basis and, despite reports of many successful installations, this method is now little used.

It is clear from earlier sections of this report that active electro osmosis systems have a much more sound theoretical basis. However, scientific investigation of their effectiveness in building materials is limited. Despite this, there are reported to be many thousands of successful installations, with few reported failures if the system is properly engineered.

However, it could be argued that the apparent success of the damp proofing industry as a whole is probably due to the scarcity of true rising damp. It is generally accepted that structural moisture contents at the base of walls of under 5% do not indicate undue levels of rising damp, although associated hygroscopicity may lead to the spoiling of decorations and plaster.

When tested with an electrical moisture meter such areas will inevitably be diagnosed as suffering from rising damp, and the installation of a damp course will be recommended. However, it is not unreasonable to suggest that in a large number of cases the installation of the damp course alone will provide little benefit.

It is known that only readings taken using a carbide moisture meter can be relied upon to give accurate moisture valued in the presence of dissolved salts, such as will usually be present in older structures. A more accurate analysis taking into account these salts can be made using laboratory, oven drying and weighing techniques.

7. CONCLUSIONS

1. The scientific principle of electro osmosis is well established, and the theory well understood.

2. The application of the technique to soil and sludge dewatering has found use and acceptance.

3. In all cases in the literature, water transport is from the anode to the cathode.

4. In principle the technique should be applicable to the materials used in building construction.

5. There is very little literature on the scientific investigation of electro osmosis in building materials.

6. The practical effects of electro damp-proofing are, as competitive systems, impossible to isolate from the effect of other remedial works such as re-plastering, carried out at the same time.

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Fig. 1 PRINCIPLE OF ELECTRO OSMOSIS