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Electrophoretic dewatering of mine tailings using geosynthetics

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ABSTRACT: Mining companies invest large capital annually for building and maintaining tailings dams with no prospect of return on this investment. Tailings dams are simply a necessary direct cost to mining companies. The application of electrophoretic principles for dewatering tailings dams may have far reaching implications in the mining industry because of its potential for enabling cost effective and safer design, maintenance and control of these structures which constitute a hazard to society. By dewatering the tailings, destabilizing pore pressures acting within the dams are reduced, resulting in more stable and economical tailings structures. The risk of ground water pollution can also be significantly reduced. Electrokinetic geogrids minimise or eliminate one of the greatest problems associated with electrophoresis, namely the severe corrosion that occurs at the anode, thus providing a long term solution. Another problem which can be eliminated is the ion replacement caused by some electrodes which reduces the zeta potential of the clay fraction within the tailings consequently reducing electrophoretic efficiency. By implementing electrophoresis the use of flocculants in thickeners can potentially be replaced with a possibly cheaper alternative. This paper presents the results of tests using electrokinetic geogrids to establish the potential for rapid sedimentation of tailings suspensions of various origins. Tailings types studied include diamond and zinc tailings and those deriving from the processing of mineral sands. The laboratory tests carried out provide a useful indication of the enhancement of rates of settlement achieved and the power consumption required for achieving these results. Complete settlement of suspended solids has already been achieved with two tailings at rates far greater than those that would have occurred without electrophoresis. Practical aspects related to quality control on site to reduce corrosion due to cracking of the protective plastic are also discussed.

1 INTRODUCTION

One of the greatest influences in the South African economy over the past 150 years has been the mining industry. It has helped shape South Africa and provided the resources with which our economy has grown.

It is now our responsibility to generate a solution for the more economical design and maintenance these structures, both existing and those planned in the future. One such solution is the use of electrophoretic dewatering technique. This technique entails the use of conductive geogrids, placed within the slurry. When a current passes through these geogrids a potential is set up between the anode (positively charged electrode) and the cathode (negatively charged electrode). One can encourage deposition and flow due to the current polarizing the material as well as inducing a flow of electrons and negative particles towards the anode. The research carried out describes the potential for using this technique in South Africa, and quantifies the benefits that can be achieved by testing of a geogrid for its dewatering potential with existing tailings material.

Electrophoretic dewatering has far reaching applications in the mining industry for de-watering of tailings dams. By dewatering, one can dramatically reduce the moisture contents of slurries as well as allow for faster excess pore pressure dissipation and increase in shear strength to create more stable tailings. This reduction of pore water within the dam will greatly reduce pollution as well as lessen the possibility of failure.

By developing this technology and others like it, we will hopefully enable the continuation of our invaluable mining activities with a significant reduction of cost and damage to the environment.

2 THEORY

The explanation behind the electrophoretic process lies in the electrochemical nature of the soil particle surfaces and pore water. According to colloidal theory, a soil particle (particularly a clay particle) has a negatively charged surface. Surrounding this particle is a double layer of positive ions such as K+, Na+, or Ca+.

Fig.1 is a diagram showing a negatively charged clay particle. As one moves further away from the clay particle one can see that the attractive negative force diminishes. The particles closest to the clay are very strongly attached to it but as one moves further away from it we find a second layer of positive ions which are attracted to the clay, but this attraction is not strong enough to hold them in place.

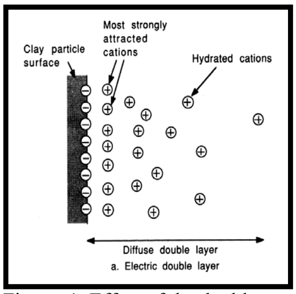

Figure. 1: Effect of the double layer of a negatively charged clay particle.

This forms a diffuse double layer within which the ions are relatively free to move. Now because of the polar nature of water molecules they orient themselves around the positive ions as shown in the Figure.2. This causes the radius of an ion to increase to several times its non-hydrated dimension. Application of a current to a saturated soil causes the positive ions to move towards the cathode dragging the pore water with it.

3 FACTORS AFFECTING ELECTROPHORESIS

An important aspect affecting electrophoresis was found by Laursen et al (1997), was that the conductivity of the clay phase is greater than that of other components of the soil. Thus it is the volume fraction of the clay phase which determines the sample conductivity. Also the exchange capacity of the clay (i.e. active or inactive clays) plays an important role in the electrophoretic efficiency. Due to this negative charge on the clay particle it will be drawn to the anode (positive electrode) creating a deposition of material on the geogrid. At the same time other free ions within the slurry will be drawn to the respective electrodes depending on their charge. Another phenomenon that occurs within the mine slurry is that of polarisation of the smaller particles within the slurry as shown in Figure.4a & 4b. This polarization causes an agglomeration of particles which, once heavy enough, begin settling.

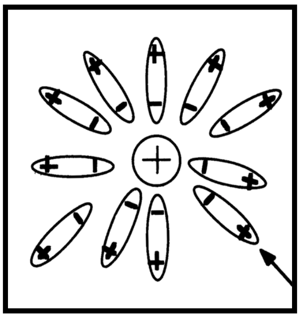

Figure. 2: Orientation of water molecules around positive ions in slurry.

Lockhart et al (1983) found for sodium, hydrogen and copper clays (samples prepared in the laboratory by treating kaolin clays with a solution of sodium chloride, calcium chloride, aluminium sulphate, hydrochloric acid, and copper sulphate) dewatering began at 1V DC. For calcium clays dewatering started between 5.5 – 10V DC and for aluminium clays at 25V DC, but did not dewater appreciably until 150V DC. This showed a relative binding strength for cations of increasing valency at the surface of the clay particles.

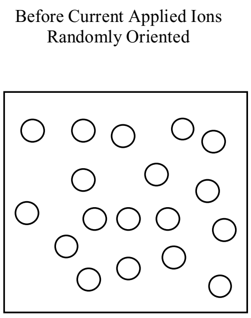

Fig. 4a : Section through bucket showing randomly oriented ions within slurry

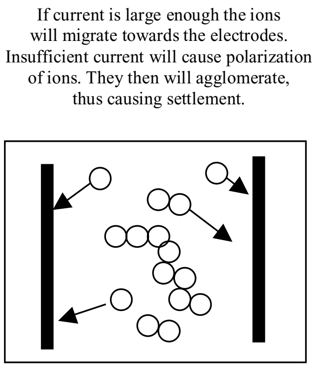

Fig. 4b : Section through bucket showing theoretical ion orientation after application of current.

It was proposed that hydrogen and copper clays easily discharged the hydrogen and copper ions present within their internal solution to the external solution (as described in the Donnan et al (1924) concept) and then onto the cathode, thus adding free ions for electroosmosis. This is in contrast with aluminium, sodium, and calcium clays, which are strongly electropositive, where electrophoresis would be maintained by polarization and electrolysis alone, making the outflow alkaline due to the hydroxyl ions formed.

As the association between clay surfaces and high valency cations increases, the zeta potential decreases. With the aluminium clays the zeta potential should be lowered due to the higher valence of the aluminium not allowing cation exchange as described by Donnan, thus giving a lower electroosmotic potential than if hydrogen of copper was present.

This phenomenon has a direct effect on the type of electrode chosen for the research. For iron, copper and magnesium electrodes the reactions at the anode are as follows :

$$Mg \rightarrow Mg^{2+} + 2e^-$$
$$Fe \rightarrow Fe^{3+} + 3e^-$$
$$Cu \rightarrow Cu^{2+} + 2e^-$$

For an inert anode such as carbon coated stainless steel or a geogrid electrode it is the electrolysis of the water the reaction of which is $6H_2O + O_2 \rightarrow 4H_3O^+ + 4e^-$.

4 ADVANTAGES OF GEOGRID ELECTRODES

There are a number of advantages to using geogrid electrodes: With metallic electrodes, in this aluminium, it was then found that the aluminium eventually displaced the sodium in the clay, but this displacement eventually began to resist further dewatering because the aluminium ion bond to the clay is far greater than that of sodium or hydrogen, thus very little ion movement is allowed and the zeta potential of the material drops. It has been shown that when using carbon coated electrodes the Na^+ in the clay was replaced by H^+ ions due to hydrolysis creating a hydrogen clay. This replacement does not resist further dewatering due to the weak bond strength of the hydrogen ion to the clay particle. With the inert geogrid electrode, the cation replacement described by Donnan et al (1924)will continually occur due to the weak inter particle bonding of the H_3O^+ and its ability to displace other cations within the clay particles internal solution, allowing for constant ion replacement and thus increasing and maintaining the electrophoretic potential. Even if the cations present in the clay are strongly attached to the clay particle the H_3O^+ will displace the stronger bonded cation and thus increase the electroosmotic potential. Another advantage of using the geogrid electrodes is the overcoming of the electrode corrosion problem. At the time of developing this test it was thought that using copper tubing would be a suitable electrode for a quick and relatively easy test to determine the electrophoretic potential of a material. After some experiments it was quickly established that these electrodes would not be suitable because of the high rate at which they were corroded.

5 DISADVANTAGES OF GEOGRID ELECTRODES

The factors described above impact greatly on the use of the geogrids. From Lockhart et al (1983) research these geogrid electrodes can be considered to be inert and thus the $6H_2O + O_2 \rightarrow 4H_3O^+ + 4e^-$ anodic reaction takes place which requires more energy than if metallic electrodes were used. This forces the use of much larger voltages and consequently currents to achieve the same results. On the other hand, low voltage performance of aluminium electrodes has been found compared to inert electrodes because the following $Al \rightarrow Al^{3+} + 3e^-$ reaction requires far less energy than the reaction shown above for the inert electrode. Despite the successful use of the geogrids, the test also brought to light some shortcomings. When taking into consideration the use of these electrodes on a larger scale and where long term use is expected, there will have to be high levels of on site quality control to avoid damage to the plastic covering the metal stringer. This came to light when a number of the tests failed, and upon closer inspection of the electrode, it was found that it had corroded significantly. There appeared to be ingress of the tailings into the plastic. This ingress was due to tiny cracks that developed during handling and transportation of the electrodes from Newcastle.

6 TESTING

The testing consisted of simply placing the geogrid electrodes, obtained from Newcastle University Upon Tyne into a bucket, with a separate control bucket to calculate evaporation losses, and 10VDC and 1.15Amp applied. Figure.5 shows the electrodes used. An alternative to using two electrodes as the positive and negative terminals was to use one electrode as both cathode and anode, but this gave poor electrophoretic efficiency and was disregarded. These tests can be used to rapidly determine the viability of particular tailings to the process of electrophoresis from which the extent to which the electrophoretic process affects dewatering can be quantitatively measured

The materials tested were mineral sands, zinc tailings, Cullinan diamond tailings and Orapa diamond tailings, from which the volume of water evaporated as well as electrolyticaly removed from the buckets was determined. The settlement and accumulation of free water were also be calculated.

The reason for doing the bucket tests was to determine the effectiveness of the geogrid electrodes when used for electrophoretic sedimentation as well as to assist in initial feasibility for the application of electrophoresis for particular tailings. Electrophoresis is particularly important for material which is freshly deposited at high moisture contents, and has been shown to be applicable for diamond mine operations where the material is deposited in valley dams. The larger particles settle under gravity, to some extent, but the supernatant water is very cloudy. By using these electrodes one can induce an electrophoretic effect and fully remove these suspensions, thus allowing for extraction of this supernatant water and increasing the capacity of these dams.

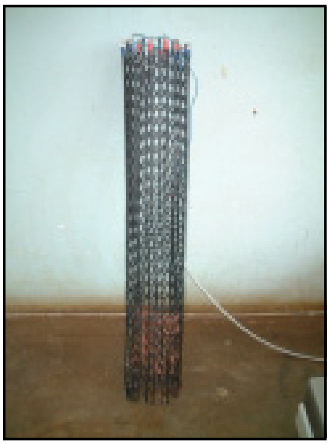

Figure. 5 Circular Geogrid electrode used for research

7 RESULTS.

From results obtained from experiments carried out on high moisture content samples, excellent dewatering efficiencies where obtained this test has been found to be valuable. Table 1 shows the breakdown of the results.

Of all the tailings investigated the diamond tailings showed the best results and thus will be discussed in further detail. For the Cullinan tailings, the control bucket lost 232ml due to evaporation. In addition to this loss, the application of the 10VDC potential resulted in an extraction of 373ml due to hydrolysis. This experiment was conducted at 7560% moisture content which is as obtained from the overflow of the thickener, which never settles out on site. This was seen where after three weeks the control bucket had not changed at all, whereas the electrophoretic bucket had completely settled out after two days at the applied 10VDC. This gave an efficiency of removal of 77% when comparing final height of initial material to total initial depth of slurry in the bucket. This experiment showed the excellent effect electrophoresis may have on a material with very low solids content. The extent of the electrophoretic sedimentation can be seen in Figure 6a and 6b.

Figure 6a. Before Testing

Figure 6b. After Testing

The data obtained from the Orapa tailings showed that there is very little difference in settlement but the electrophoretic test removed twice the amount of water that the control bucket. This small difference in settlement is attributed to the position of measurement of the settlement as well as the considerably lower moisture content than that used with the Cullinan tailings. The majority of the settlement occurred in the centre of the bucket whereas the readings were taken from the edge of the material. Due to the mounding and cracking of the surface it was difficult to find a position from which consistent measurements could be taken. Even though the settlement results showed little electrophoretic effect, 690ml of water was drawn off the control bucket after completion of the test as opposed to 890ml drawn of the electrophoretic bucket with an additional 122ml lost due to hydrolysis. As before the electrophoretic effect removed one and a half times more water than the control bucket, and in this test the moisture content was reduced an additional 118% from the control bucket.

From additional larger scale testing done on the diamond tailings the above observations have been confirmed. The electrode corrosion also seems to be greatly affected by the quality control during transportation and thus corrosion can be minimise. Another finding from these experiments was that it seems that a constant current of approximately 1A is required for the electrophoretic effect to operate effectively. At lower currents, the material in suspension does not settle out. This can not be attributed to the current being strong enough to create sufficient polarisation within the slurry for the agglomeration of particles. What has been found in larger scale experiments is that sedimentation occurs even with the lower current of 0.3A, but the process takes far longer to reach completion. This low current leads to the slow movement of these particles towards their respective electrodes, with the clay being deposited at the anode. The movement of clay particles towards the anode may not necessarily be a hindrance if the geogrids are placed at the top and bottom of the sample. With this configuration and a low current, sedimentation can be accelerated. The disadvantage of this process would be the greater length of time required for sedimentation to occur. Also on site checking of electrodes, especially the anode at the bottom of the layer, which will corrode far more than the cathode, would be very difficult if not impossible. With these factors in mind, economic factors due to due to power consumption and the extent to which quality control is available on site, will be the deciding factors between a larger or smaller current application . Thus there is a limit where sedimentation will occur between 0.3A and 1.15A. Tests are currently being carried out to determine this transition point.

Table 1 : Results testing results

					Water lost during process (ml)					
		Conductivity Ms/cm	pH	Settlement (mm)	Evaporation	Hydrolysis	Dewatering (cm^3)	Initial Moisture Content (%)	Final Moisture Content (%)	Water removed from soil matrix (ml)
Zinc Tailings	Control	19.23	1.5	19.5	181.75	-	954	95	77	1135
	EO	19.17	1.4	22.6		240.55	1548	95	63	1970
Cullinan Diamond Tailings	Control	-	-	59	232	-	-	7563	7563	232.00
	EO	-	-	66.7		374	-	7563	1593	606
Orapa Diamond Tailings	Control	3.7	8.5	32	93	-	690	400	260	789.73
	EO	2.8	10	34		122	890	400	142	1105
Mineral Sands	Control	0.4	8.2	12	208	-	-	150	-	208
	EO	0.4	7.9	16		222	-	150	-	430

8 APPLICATIONS

To date the geogrids have only been used for electroosmotic applications in dewatering of reinforced earth walls and sensitive clays in the UK. The use of these geogrids as electrodes lends itself to numerous other applications. The main application investigated in this paper has been its use in diamond mines. Due to the very fine nature of the particles in question, being pumped in slurry form to the tailings dams, there is a large problem with supernatant water on the dams surface in large quantities.

These suspended particles in the water reduce the final capacity of the dam by reducing the overall volume of material that can be stored, and forcing the mines to look into construction additional tailings impoundments.

9 CONCLUSIONS

By developing this technology in conjunction with the geogrids which can be used to remove these particles from the water, the mines will be able to recover a large percentage of the original capacity of the dam, which will in urn increase the life of the impoundments and reduce costs for the mine. By using geogrids as opposed to conventional metal electrodes the problem of corrosion can be overcome thus making this technology feasible. The geogrids can be installed within the impoundments, but another application is currently being investigated at the University of the Witwatersrand to use these geogrids within existing thickening tanks or towers and thus increase sedimentation rates and reduce solids contents before pumping out to the dams. This will greatly reduce the amount of water used on the mine as it is now not allowed to evaporate off the dams surface, and rather can be treated and reused or safely disposed into municipal streams. From this research it has thus been found that the geogrid electrodes proved to be extremely successful when used for electrophoretic dewatering of mine slurries reducing moisture contents up to 4.5 times what they originally where and increase the volume of pore water removed from the slurries by 3 times what is being achieved currently.

10 REFERENCES

Acar, Y.B. Gale, R.J. & Putman, G. (1990) "Electrochemical processing of soils: Theory of pH gradient development by diffusion and linear convection". Journal of Environmental Science and Health, Part A, 25, No. 6, 687-714.

Broś, B., Dzidowska, K., and Koszela, J., "Influence of Flocculants on the Process and Efficiency of Electroosmosis in Fine-Grained Soils.", Proceedings of the 8th ECSMFE, Helsinki, 1983.

Casagrande, L , "Electroosmosis in Soils", Geotechnique, Vol. 1, 1949. pp1959-1977.

Colloid Science " Zeta Potential in colloid science" by Hunter

Crow, D.R., 1974 "Principles and Applications of Electrochemistry"

Esrig, M.I. (1968), "Pore pressures, consolidation and Electrokinetics", Journal of Soil Mechanics Foundation Engineering, Division of American Society of Civil Engineers. 94, SM4, 889-921.

Gray, D.H. & Mitchell, J.K. (1967), "Fundamental Aspects of Electroosmosis in soils." Journal of Soil Mechanics Foundation Engineering, Division of American Society of Civil Engineers. 93, SM6, 209-236.

Hamir, R.B., Jones, C.J.F.P, and Clarke, B.G, "Electrically Conductive Geosynthetics for Consolidation and Reinforcing Soils", Newcastle University.

Jones, C.J.F.P, Shim, G.S.C, " Consolidation Trial using Electrokinetic Geosynthetic Electrodes", University of Newcastle Upon Tyne Research Report No. 010/01

Paul Jason Laidler, "The Dewatering of Bentonite Slurry using Electroosmosis and Electrophoresis", June 1999.

Lamont-Black, J. " EKG: The next generation of geosynthetics", Ground Engineering October 2001

Lockhart, N.C. (1983) "Electroosmotic dewatering of clays III : Influence of Clay Type, Exchangeable Cations, and Electrode Materials.", III Colloids and Surfaces. Vol.6, 238-269

Mitchell, J.K. (1991), "Conduction phenomena: From theory to geotechnical practice." Geotechnique 41, No.3, 299-340.

Shang, J.Q., "Electrokinetic Sedimentation: A Theoretical and Experimental Study", Canadian Geotechnical Journal (1997) pp. 305-314.

Shang, J.Q., "Electrokinetic Dewatering of Clay Slurries as Engineered Soil Covers", Canadian Geotechnical Journal (1997) pp. 78-86.

van Olphen H., 1963 "An Introduction to Clay Colloid Chemistry"

West, L.J. and Stewart, D.I. "Effect of Zeta Potential on Soil Electrokinetics", Geonvironment 2000, Proceedings of a Specialty conference sponsored by the Geotechnical Engineering Division and the Environmental Engineering Division of the American Society of Civil Engineers.

Winterkorn, H.F. and Fang, H.S., "Foundation Engineering Handbook"