ELECTRICAL CONDUCTIVITIES OF SOME EGYPTIAN BEACH SAND MINERALS AND THEIR EFFECTS IN ELECTRICAL SEPARATION

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الخلاصـــة :

يُعتبر المونازيت والزركون والروتيل، والاليمانيت من أهم المعادن المتواجدة في رمال شواطئ مصر. لذا طُرحت اقتراحات عديدة لضمان حسن وكفاءة فصلها عن بعضها وغيرها. وقد ظهر أن الفصل الكهربائي يلعب دورا أساسيا في تنقية تلك المعادن وهو يعتمد على الاختلاف الطبيعي في قيم توصيليتها الكهربائية.

واهتمت الدراسة بوضع وصف للخلية التي تمَّ استخدامها لقياس التوصيلية الكهربائية لهذه المعادن. وكذلك وضُعت علاقة كمية تربط بين هذه المعادن لضمان حسن وكفاءة عمليات الفصل فيما بينها. كما وُضع برنامج للحاسب الآلى لحساب مَيْل منحنيات الخواص الكهربائية، حيث تمَّ حساب المقاومة النوعية، والتوصيلية، وزمن الاسترخاء لتلك المعادن، بالإضافة الى معامل ترابط البيانات وهو مقياس لكفاءة النظام المستخدم ودقته. وكانت بنسبة أفضلية تفوق ٩٩٪.

وعلى وجه العموم يمكن القول بأن التوصيلية الكهربائية تتأثر بشدة بدرجة حرارة وحجم حبيبات المعدن وأن وجود شوائب الحديد على سطح حبيبات المونازيت وفي داخل حبيبات الزركون تتحكم بشدة في قيمة التوصيلية الداخلية لتلك المعادن.

ABSTRACT

The most important and strategic minerals in the Egyptian beach sands are monazite, zircon, rutile, and ilmenite. Due to their importance, several flowsheets were designed for their economic separation. Electrostatic separation plays an important role in most of these flowsheets depending on the main differences between their electrical conductivity. This paper describes the design of a cell for the measurement of the electrical conductivities of the minerals. It also establishes a quantitative relationship between the electrical conductivity and the behavior of these minerals during their electrical separation. A computer program was written to facilitate the calculation of the slope of the discharge curve from which the

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electrical conductivity or the reciprocal resistivity, relaxation time, and the data correlation coefficient for the tested minerals are obtained. For all the tests performed, the correlation coefficient value was found to be better than 99%. In general the electrical conductivity was shown to be a function of both temperature and grain size. It was found also that the presence of iron staining on the surface of monazite grains and inclusions in the zircon grains alters noticeably the bulk conductivity of the tested minerals.

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INTRODUCTION

The large deposits of Egyptian black sands contain strategic and economic minerals which are suitable for industrial exploitation as they furnish many raw materials for atomic energy and other aspects of our growing and expanding metallurgical and engineering industries. These minerals are monazite, rutile and ilmenite. The main practice used for recovering these minerals from the beach sands depends on the use of gravitational, magnetic and electrostatic separation. The latter plays the most important role for the final cleaning of these minerals to realize the very high purity required for their use in industry. Temperature of the minerals and their grain size are among the important factors that control their behavior during the electrostatic separation. This study therefore tried through the measurement of the electrical conductivity of the treated minerals to find a relationship between the conductivity and such two parameters, thus helping to avoid as far as possible the maze of uncertainty still governing the field of the electrical separation technique.

CONDUCTIVITY CELL DESCRIPTION AND COMPUTATIONAL METHOD

The measurements of conductivity in this work were performed using a special cell, made of nickel plated and fitted with a central rod of the same material, recommended by Lawver [1] as shown in Figure 1. This cell is a modification of that proposed by ASTM [2] which has proved unsatisfactory in practice.

Minerals grains were packed to the fill line while the cell was being vibrated. The resistance of the cell was measured by the condenser discharge circuit shown in Figure 2. With this circuit, it is possible to measure a wide range of resistance (R), simply by varying the value of a polystyrene capacitor (C) and using suitable recording instruments. Most measurements were made with a Farnell *x-y-t* plotter connected to the output of Keithley Model 616 electrometer.

By using the built system, one can easily show that the voltage V at time t is given by the relation:

$$V = V_0 e^{-(t/RC)}$$

where V_0 = the voltage at time $t = 0$

In theory, if R is independent of V and thus independent of t, a plot of $\ln(V_0/V)$ *versus* t should be linear with a slope of $1/RC$.

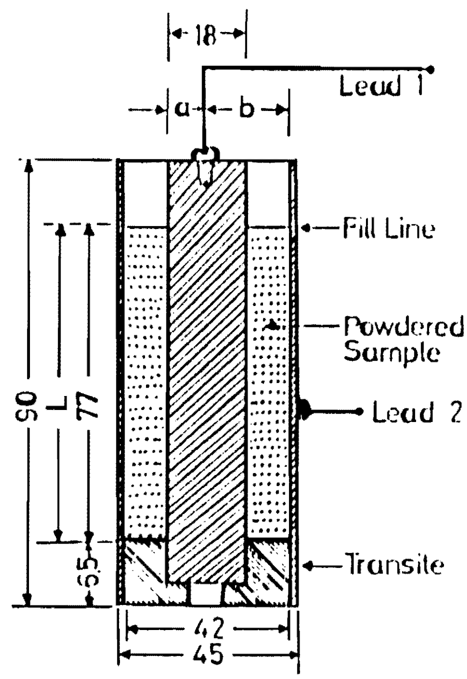

Figure 1. Detail of the Conductivity Cell. Dimensions are in Millimeters.

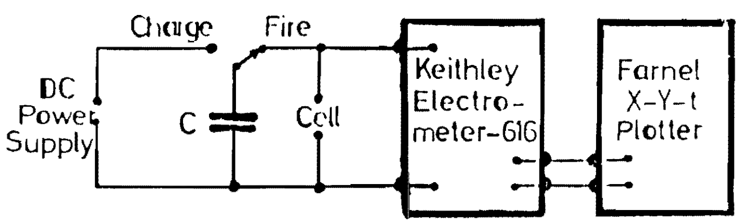

Figure 2. Schematic Diagram of the Discharge Circuit.

In order to facilitate the measurements, a computer program was written to obtain least-square fit of a straight line (and hence a value of the slope) and to calculate the multiple correlation coefficient.

As we measure the resistance, the effective conductivity (σ) can be easily calculated as follows [3]:

By Gauss's law, the field (E) at a distance (r) between the electrodes is:

$$E = \frac{1}{2\pi\varepsilon_0} \cdot \frac{\lambda}{r} = \frac{dV}{dr}$$

Thus

$$-\int_{V_a}^{V_b} dv = \int_a^b \frac{\lambda}{2\pi\varepsilon_0} \cdot \frac{dr}{r}$$

and

$$\lambda = \frac{V_{ab} \times 2\pi\varepsilon_0}{\ln \frac{b}{a}}.$$

Thus

$$E = \frac{V_{ab}}{r \ln \frac{b}{a}}$$

By definition:

$$\text{current density } j = \sigma E = \frac{i}{\text{area}}$$

$$i = 2\pi L\sigma \frac{V_{ab}}{\ln \frac{b}{a}} = \frac{V_{ab}}{R}.$$

Thus

$$\sigma = \frac{\ln \frac{b}{a}}{2\pi LR} \text{ mho m}^{-1}$$

where:

L = length of the inner electrode that is filled with mineral grains.
V_{ab} = potential difference between the inner and outer electrode.
a = radius of the inner electrode.
b = radius of the outer electrode.
λ = charge per unit length of inner electrode.
R = the total (combined surface and volume) resistance.

EXPERIMENTAL RESULTS AND DISCUSSION

The investigations made during the course of these tests have been carried out on pure minerals prepared from Rosetta beach black sands. Using the cell shown in Figure 1, and the discharge circuit shown in Figure 2, the conductivities or the reciprocal resistivities, relaxation time and correlation coefficient for monazite, zircon, rutile, and ilmenite were investigated. These results are tabulated in Table 1 and typical discharge curves for these minerals are represented in Figures 3 and 4.

The results obtained are in good agreement with the behavior of these minerals during the high tension electrostatic separation. The observed differences in the electrical conductivities of such minerals explain the results of their separation from one another using the electrical separation indicated by Hammoud and Khazbak [7]. They stated that they

Table 1. Resistivity Measurements and Relaxation Time for Monazite, Zircon, Ilmenite, and Rutile.

Mineral	Resisitivity ohm-cm	Conductivity mho-cm	Relaxation time (s)	Correlation coefficient
Rutile	6.7×10^{8} –1.0×10^{9}	1.0×10^{-9} –2.5×10^{-9}	9-9.1	99.0
Ilmenite	5.6×10^{9}–9.1×10^{9}	1.1×10^{-10}–1.8×10^{-10}	700-751	99.3
Zircon	5.6×10^{10}–9.1×10^{10}	1.1×10^{-11}–1.8×10^{-11}	2500-2585	99.3
Monazite	3.2×10^{11}–1.0×10^{12}	6.0×10^{-13}–4.0×10^{12}	15 885-160 050	99.0

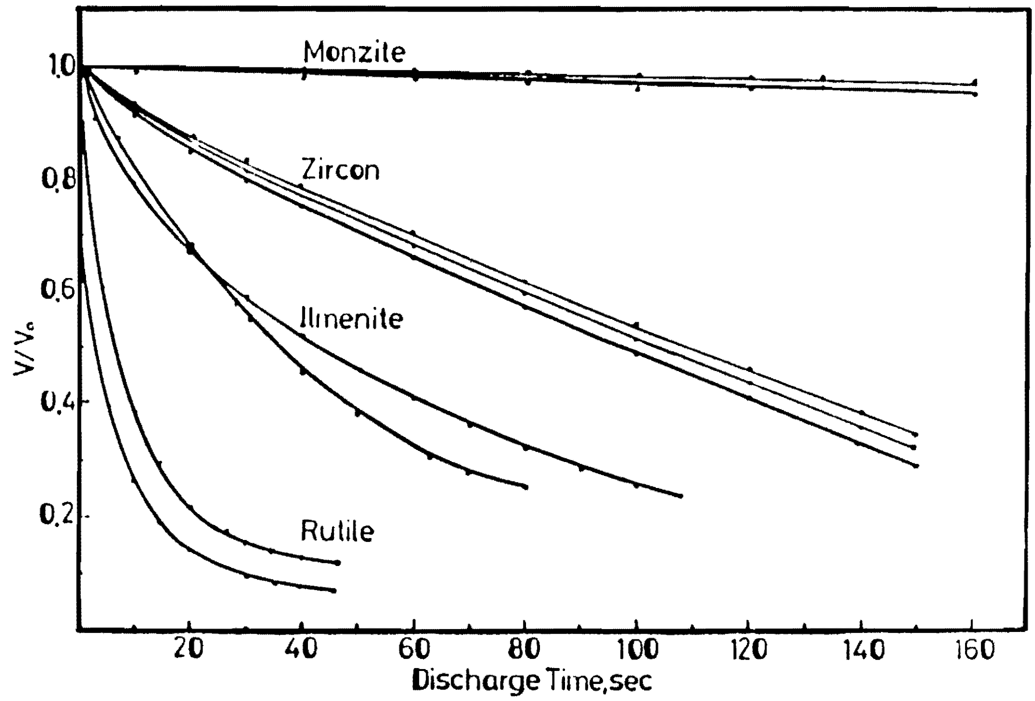

Figure 3. Discharge Curves for Monazite, Zircon, Ilmenite and Rutile. Samples are Collected from Different Locations.

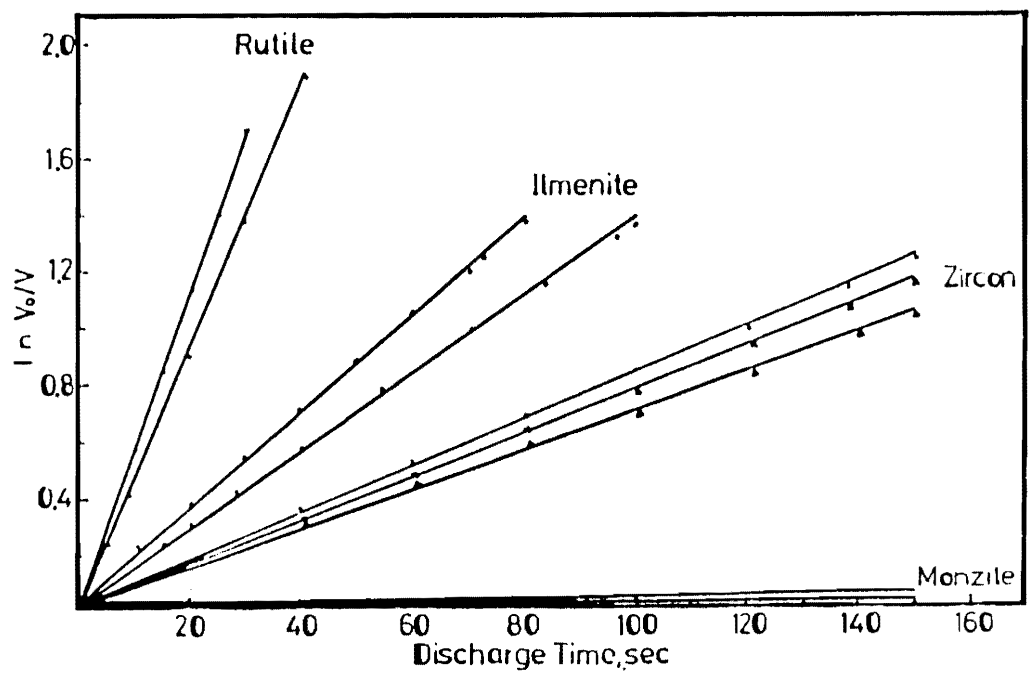

Figure 4. Ln(V_0/V) Versus Discharge Time for the Investigated Minerals.

have applied the electrical separation to separate in a mixed field setting the conducting minerals as ilmenite and rutile from the non-conducting monazite and zircon, as shown in Figures 5 and 6. Using this method, it was possible to produce a refined high grade monazite with more than 97.0% monazite content. At the same time a highly resistive rutile variety was electrically separated from zircon concentrate with 99.4% zircon content and less than 0.4% rutile and other opaque conducting minerals. It was found that some of the tested zircon samples were found to have relatively high surface conductivity due to the presence of conducting admixture contaminating the surface of the grains as ocheous iron and adhered salts.

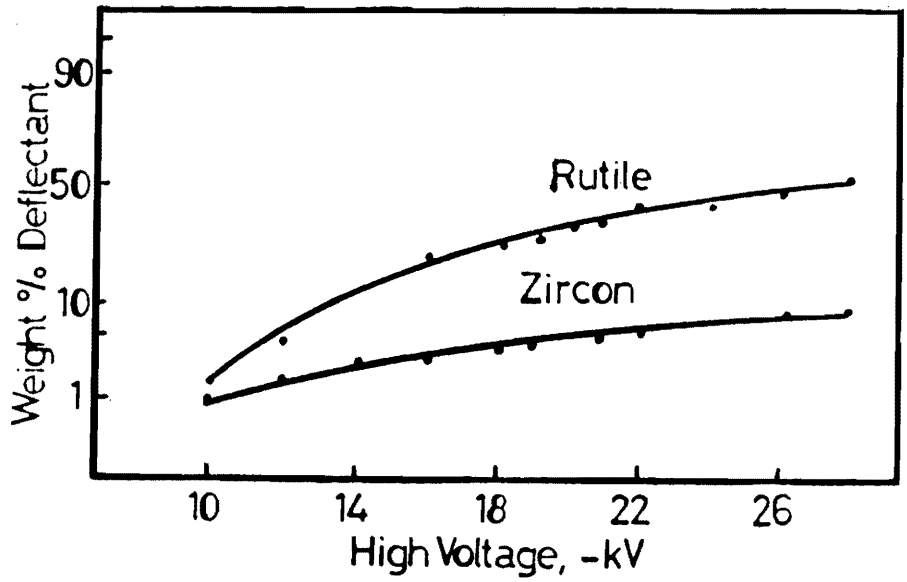

Figure 5. Effect of Voltage on the Electrostatic Deflection of Zircon and Rutile.

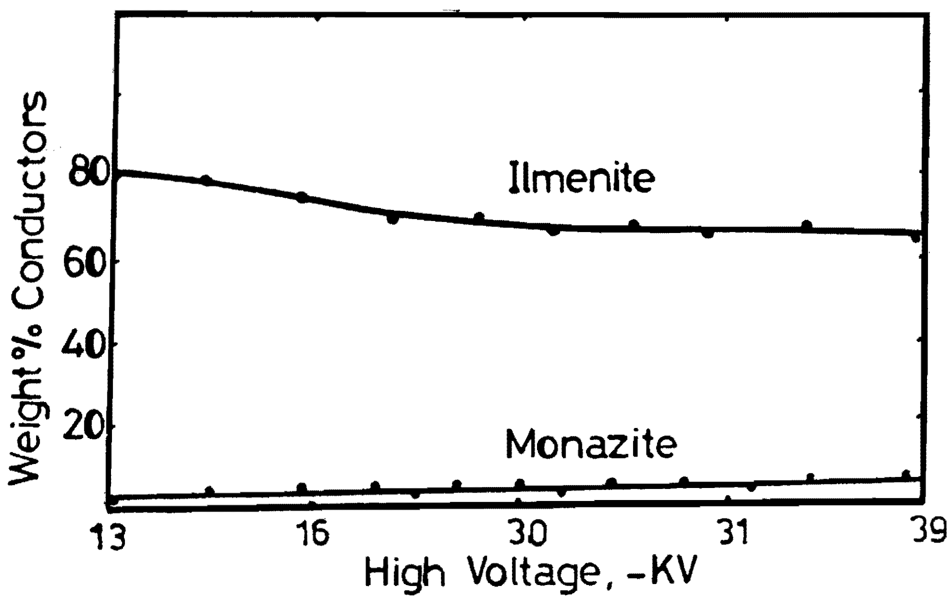

Figure 6. Effect of Voltage on the Electrostatic Deflection of Ilmenite and Monazite.

The surface conductivity of such particles was noticed to be affected by air humidity. Microscopic examination revealed that these particles are composed mainly of metamict and brown zircon and grain with shades of a reddish brown coloration.

It was noticed also that the tested rutile sample has a noticeably high conductivity which is in good agreement of our previous studies on the electrical separation of rutile which revealed that the Egyptian rutile grains were found to be electrically heterogeneous. It was noticed that some of the rutile grains behave as a non-conducting mineral and adhere to the carrier rotor even in the most weak ionization, whereas with the most powerful attainable ionizing field, an appreciable fraction behaves as a good conductor. This strongly conductive fraction was found minerographically to be rich in rutile–ilmenite complexes.

The effect of both the temperature and grain size of these minerals on their conductivity has been investigated as follows:

1. Influence of Temperature

The effect of temperature has been tested by a series of investigations at temperatures ranging between 20°C (room temperature) and 205°C. A thermocouple was immersed in the middle of the mineral samples in the cell and connected externally to a digital thermometer. The cells were then put in a muffle furnace which was adjusted to the required temperature of testing. At the same time the cell was connected to the conductivity measuring system as indicated in Figure 2. The results obtained as represented in Figure 7 indicated that a marked increase in conductivity was observed as the temperature increased for all the tested minerals which is in good agreement with their behavior during the high tension electrostatic separation [4–7]. These results confirm that both of the surface and bulk conductivities and electrical permitivities of the particles change as a result of heating, moreover that non reversible changes in conductivity of both dielectrics and semiconductors occur as a result of heating [8, 9].

It can be noticed that both of monatize and zircon are the most resistive minerals at room temperature. The resistivity of zircon was found to be little altered by heating whereas that of monazite is strongly lowered at the same conditions. Accordingly a sharp separation of the two minerals can take place at high temperatures. For ilmenite and rutile, it is obvious that their resistivity is moderately altered by heating.

Frass [8] indicated that minerals that have a very high resistivity can not be separated from each other on the basis of the difference in electrical conductivity, even though the difference in conductivity is large. A high-resistivity particle will not acquire a charge by conduction at a rapid enough rate. To com-

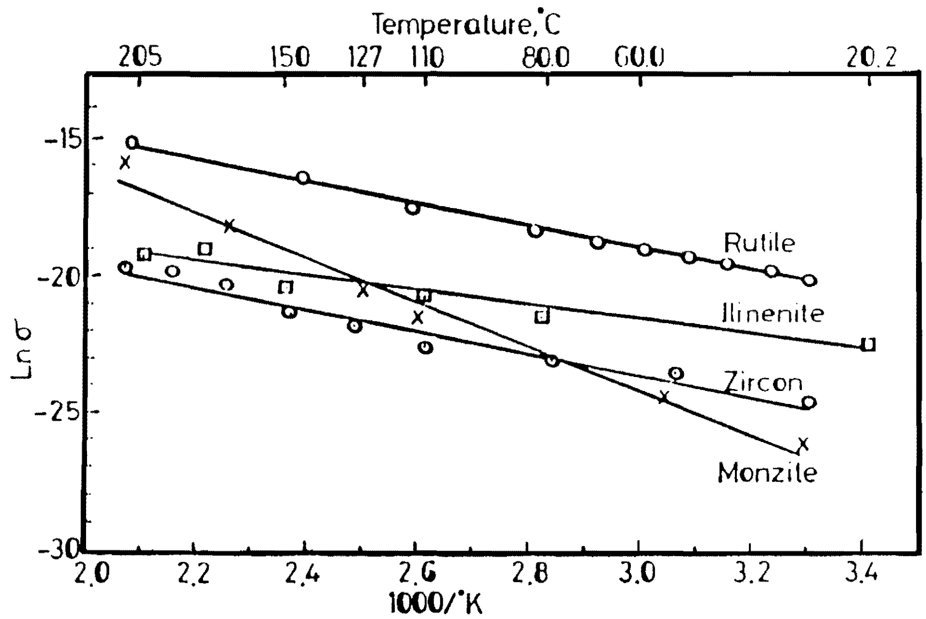

Figure 7. Temperature Dependence of Conductivity.

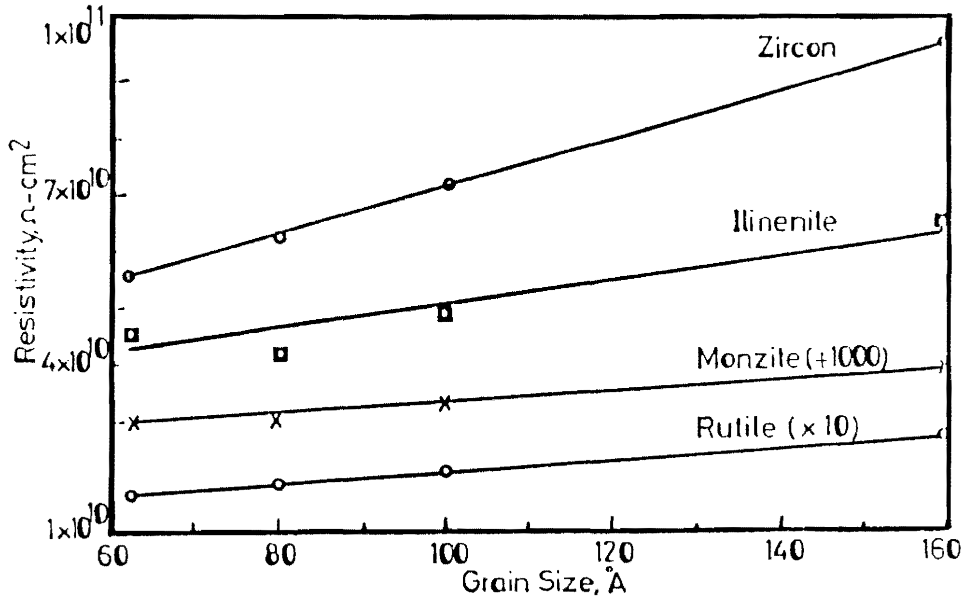

Figure 8. Grain Size Dependence of Conductivity.

pensate for the low rate, the electric-field intensity of the electrostatic separator can be raised. However, too high an intensity results in a corona emission from the particle, and the particle acquires charges by this effect. Because the charges are not caused by differences in conductivity, there is no selectivity in the separation. The only alternative is to raise the temperature until the resistivity spectrum of the minerals is lowered to a range that has a high selectivity for separation. Also particles that have too low a resistivity—lower than the high selectivity range—cannot be separated because the charging rate is too high. An analogous solution in this case would be to lower the temperature.

2. Influence of Grain Size

For testing the influence of the grain size of the minerals on their conductivity, tests were carried out using sieved fractions of the minerals. The sizes used were between 60 U mm and 160 U mm. Measurements of the conductivity, resistivity, and relaxation time have been conducted using the previously indicated technique with the same circuit shown in Figure 2. The results as represented in Figure 8 show that the resistivity of the tested minerals increases progressively as the grain size increases. The results are in good agreement with the observed behavior of the tested minerals during the electrical separation [4–7].

CONCLUSIONS

This study gives useful information for the first time about the measurement of the electrical conductivity (or the reciprocal resistivity) of monazite, zircon, ilmenite and rutile which in turn can give a quantified explanation for the behavior of these minerals during their electrostatic separation. Comparing the resistivity data obtained from this study, one can notice that monazite is the most resistant mineral followed by zircon, ilmenite, and rutile. The presence of rutile at the end of the group as the most conducting mineral confirms the finding that in the Egyptian rutile there is a strongly conductive fraction rich in ilmenite–rutile complex.

Effect of both the temperature and grain size on the resistivity of these minerals is quite pronounced and suggests that the best electrostatic separation for monazite from zircon is at high temperature, whereas for the separation of ilmenite and rutile from the other minerals it is better to be at temperature below 60°C.

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