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# Electroosmotic Drying of Slime Consistence Wastes

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August 1979

# ELECTROOSMOTIC DRYING OF SLIME CONSISTENCE WASTES

by

Kazimierz Ukleja
Central Research and Design Institute for Open-pit Mining
Poltegor
51-616 Wroclaw, Poland

Project Number 05-534-2

Project Officers

Russell Fitch
John Hardaway
Cooper Wayman
Regional Office, Region VIII
U. S. Environmental Protection Agency
Denver, Colorado 80203

INDUSTRIAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

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# FOREWORD

When energy and material resources are extracted, processed, converted and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The U. S. Environmental Protection Agency through its Regional Offices and Office of Research and Development is striving to develop and demonstrate new and improved methodologies that will meet these needs both efficiently and economically.

The effort reported here was conducted as part of the Environmental Protection Agency's Scientific Activities Overseas Program and was a cooperative venture between Region VIII and the Industrial Environmental Research Laboratory-Cincinnati. The research was conducted by Poltegor, the Central Research and Design Center for Open-pit Mining, Wroclaw, Poland.

In this report methods to dewater the tailing slimes produced during sulfur processing are described. The semifluid character of the material presents significant handling and disposal problems. In a dewatered form the slime would not only present less environmental problems, but also has the potential to be used as an agricultural soil amendment.

Results of this work will be of interest to persons concerned with the disposal of slime-like tailings material, e.g., phosphate and sand and gravel. The methodology developed here probably has potential application in these areas.

For further information contact Region VIII or the Resource Extraction and Handling Division, IERL-Cincinnati.

Alan Merson
Regional Administrator
Denver, Colorado

David G. Stepnan
Director
Industrial Environmental Research Laboratory
Cincinnati

## SCIENTIFIC ACTIVITIES OVERSEAS

### (Special Foreign Currency Program)

Scientific Activities Overseas, developed and implemented under the Special Foreign Currency Program, are funded from excess currencies accruing to the United States under various U.S. programs. All of the overseas activities are designed to assist in the implementation of the broad spectrum of EPA programs and to relate to the world-wide concern for environmental problems. These problems are not limited by national boundaries, nor is their impact altered by ideological and regional differences. The results of overseas activities contribute directly to the fund of environmental knowledge of the U.S., of the host countries and of the world community. Scientific activities carried out under the Program therefore offer unique opportunities for cooperation between the U.S. and the excess foreign currency countries. Further, the Program enables EPA to develop productive relationships between U.S. environmental scientist and their counterparts abroad, merging scientific capabilities and resources of various nations in concerted efforts toward U.S. objectives as well as their own.

Scientific Activities Overseas not only supplement and complement the domestic mission of EPA, but also serve to carry out the mandate of Section 102(2(E) of the National Environmental Policy Act to "recognize the world-wide and long-range character of environmental problems, and where consistent with the foreign policy of the United States, lend appropriate support to initiatives, resolutions, and programs designed to maximize international cooperation in anticipating and preventing a decline in the quality of mankind´s world environment".

This study has been funded from Public Law 480. Excess foreign currency money is available to the United States in local currency in a number of countries, including Poland, as a result of a trade for U.S. commodities. Poland has been known for its extensive mining interests, environmental concern, and its trained and experienced engineers and scientists in this important energy area.

# ABSTRACT

The objective of this research is the examination of field techniques that remove water from sludge -tailings produced as a waste during floatation of sulphur ore. The research was conducted with the idea of utilizing these wastes in agriculture as a soil amendment useful to neutralize acid soils. The main hindrance to economic utilization of this type of wastes is their semifluid character. This fluid character persists for many years, making it impossible to economically excavate and transport the material for agricultural use. The technique investigated for draining the sludge is comprised of a three stage system of drying as follows:

(1) gravitational draining of water impounded in the bowl of the sedimentation basin; x/

(2) draining a substantial part of the water in the sludge using electroosmosis which allows removal and some transport of the sludge; and

(3) further drying to a relatively dry, plastic state by spreading under conditions that facilitate atmospheric drying, or adding dry material to the electroosmotically dewatered sludge.

The technical aspects of working with various types of excavating equipment of transportation with lorries and trailers, the storage, the mixing of sediments with fly ashes collected by electrofilters in power plants fired with bituminous coal or lignite, and distribution on cultivated lands was also examined. The stages of drying are discussed in more detail below.

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x/ The term sedimentation basin is used to denote a tailings disposal area.

1. Gravitational drainage of water accumulated on the basin formed on top of the sediment was accomplished in stages by:

   - syphoning water from the basin and discharging the water beyond the pile;
   - digging sumps in bottom of water - accumulating bowl and pumping water as it drained to these sumps;
   - sloping the surface toward the low areas and digging of ditches from the low areas toward the edge of the basin;
   - installation of a pipe from the ditch over the edge of the pile to permit continued gravitational discharge from the pile.

   The objective of these operations was to keep infiltration of precipitation to a minimum.

   Considerable technical difficulties were encountered during the construction of this gravitational drainage system. The semi-fluid character of the sediment made the use of mechanized equipment impossible and open ditches continually filled with sediment. These problems were complicated by frequent rains. The ditches had to be systematically deepened since it was impossible to achieve the full depth until the material had dried.

2. Drainage of excess water incorporated in the sludge (fluid sediments) required the following procedures:

   - laboratory and field investigations to determine the physico - chemical characteristics of sediments that affected dewatering;
   - laboratory model and field tests to determine the important variables for efficient design and execution of electro-osmotic draining, including identification of the best arrangement of the electrical field to induce the electro-osmotic phenomenon;
   - small scale field investigations of electroosmotic draining on a relatively small sedimentation basin in Ogorzelec (fig. 2) in order to correlate laboratory and field tests;

- installation and operation of an electroosmotic system on the large sedimentation basin in Ogorzelec (fig. 2);
- refinement of the electroosmotic system using 8 tests (fig. 73-80) of different field arrangements amounts of current and periods of current application;
- systematic meteorological tests, comprised of measurements of atmospheric precipitation, evaporation, air and soil temperatures, wind velocity and insolation;
- periodic measurements of subsidence of the surface of the large sedimentation basin in order to calculate total losses of water from sediment during draining.

One of the main tasks of these investigations was the determination of an optimal arrangement of the electroosmotic field. On the small experimental sedimentation basin in Ogorzelec the battery of filtercathodes was placed in the central part, where the material contained the most water and the material contained the highest fractions of clay-sized particles. The perforations cut in the wall casings of the filtercathodes were very small (diam 4 mm) to prevent inflow of tailings, but they quickly became plugged. When large holes were used (4 x 50 mm), it was also necessary to pack the holes with nylon gauze. This packing hindered the installation of pipes, and reduced the electric resistance of the filtercathodes. Moreover, the filtercathodes were often surrounded by water during the periods of rain. The coarser grain material surrounding the anodes dried out and thus caused an increase in electrical resistance. To circumvent these problems in the large settling basin, the filtercathodes were placed in the intermediate zone between the clay-rich materials in the inner part of the sedimentation basin and the sandy material forming its external embankment. The battery of anodes was placed in the central part of the sedimentation basin.

This change in arrangement also allowed easy access to filtercathodes independent of weather conditions, and pumping of water from the zone of highest content to a zone containing less water and thus provided more favourable conditions for water to flow to the filtercathodes.

The tests involving the application of current at varying times and rates were designed to determine an optimal rate for dewatering. These tests show that the optimal application (test § 8) requires 1.34 kWh electric power to produce 1 l of water. The electroosmotic system was designed to reduce the water in the central zone of the sedimentation basin by about 10 percent. At the resulting water concentration it appeared possible to begin to work the material with mechanical equipment such as shovels.

3. The shovels were used to place the material in simulated windrows (about 2 m high) where they were open to the atmosphere. It was found that the material dried best when it was placed on dry, permeable soil (as opposed to soils with a shallow water table or on polyurethane sheets).

The drying of the windrows was enhanced if they were placed in a manner that exposed them to the sun and the prevailing winds. The material removed from the basin was also mechanically mixed with dry fly ash from power plants fired with either bituminous or brown coal (lignite). Such mixing resulted in the:

(1) Immediate drying of sediment to optional consistency (dependent on proportion of components), and

(2) A more suitable mixture with respect to use in agriculture (and use of the waste fly ash).

The experiments of fly ash mixing included transportation to and spreading on agricultural land.

Mechanical handling of the wastes was most efficiently achieved using draglines. Power shovels were not efficient since the material stuck to the walls of the buckets. Special equipment was designed to alleviate the problem with power shovels. An electrical current was applied to the shovel for a short period to release the clayey sediment.

The results of this research work present one of many possible technologies for drying semi-fluid sediments. Due however to variety of physical-chemical properties of fluid industrial wastes, to the different systems of deposition and to various climatic conditions, the questions posed by drying other wastes will require performance of additional research in this respect.

This report was submitted in fulfillment of project number 05-534-2 between the United States Environmental Protection Agency and the Central Research and Design Institute for Openpit Mining, POLTEGOR, 51-616 Wrocław, Rosenbergów 25, Poland.

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- the Institute of Geotechnique of the Wrocław Technical University, which contributed microscope investigations in electroosmotic drainage and structural changes in tailings also surveys and observations of vertical displacement of the talings pond surface in Ogorzelec;
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- Mr. Russell Fitch
- Dr. Copper Wayman.

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# SECTION 1

# INTRODUCTION

Many industries require large amounts of raw materials which have to be concentrated with water. The large amounts of tailings produced must then be disposed of.

The fluid character of these spoils often requires disposal in large sedimentation basins. Such basins use large amounts of arable and forest lands.

Seldom are there opportunities to store these tailings in abandoned open pits or on areas not otherwise in demand. The areas used for disposal of tailings often create a threat of slides to the surrounding areas.

Independently of the storage site the surface of such tailings is always very weak. This makes impossible to reclaim their surface and make it unaccessible for any activity.

These tailings have a potential for good use in agriculture as a means of improving the structure and fertility of soils. Some tailings may have a potential to be used as raw materials for building materials. In some cases these wastes could be used to fill otherwise uneven terrains. The main obstacle to economic utilization is their semi-fluid character which prevents handling with mechanical devices and transportation with conventional means. Drying of the tailings is therefore an important issue and thus constitutes the main subject of this research.

## SECTION 2

## CONCLUSIONS

1. The test results characterized the clayey material produced during the process of sulphur ore floatation at Ogorzelec as follows:

   - high percentage of clay-sized materials
   - high water content - about 54 - 37 percent
   - bulk density of from 1.64 to 1.9 $G/cm^3$
   - high CaO content over 40 percent. $SiO_2$ content of 12 percent.

   The experimental results must also be related to the climatic conditions characterizing Ogorzelec. These conditions are:

   A cool, humid climate with considerable frequency and quantity of precipitation (over 1000 mm annually) and with average annual temperature + 5.6°C.

2. The region of the sedimentation basin is situated in mountains of elevation on the order of 870 m, and the sedimentation basin itself is located at an elevaticn of 640 m above sea level.
   The experiments were conducted during periods of extremely wet weather and thus the results were achieved under adverse conditions.
   The investigations have shown that provision for continued gravity drainage of sufrace water is a prerequisite for successful electro-osmotic drainage of sediment. Otherwise the precipitation will enter into the sediment and defeat the purpose of dewatering. If water does accumulate on the surface, the current should be withdrawn from the electroosmotic system to prevent additional infiltration.

3. Various electroosmotic field arrangements produce different drainage effects. Localization of filtercathodes in the central part of a sedimentation basin causes an inflow of fine - grained sediment into wells through the casing holes and renders dewatering ineffective. Further, the area surrounding the anodes dries out quickly, which increases the resistance to current flow. Placement of filtercathodes in an intermediate zone (intermediate particle size) facilitates efficient and uniform drying.

4. Laboratory tests indicate that electroosmosis also causes a number of structural changes in the tailings. These changes include:
   - reorientation of sediment skeleton elements
   - migration of grains towards the electrodes
   - formation of unstable aggregates of the very small grains
   - suphosis
   - formation of cell structures
   - chemical corrosion of grains
   - stabilization of sediment structure.

   The least advantageous effect of electroosmosis on the structure is the preferred arrangement of particles caused by the variable direction of current flow. This caused a reduction in permeability. Periodic interruption of the current flow tended to counteract this preferential arrangement. During the cessation of current a partial disintegration of the preferential structures occurs along with further liberation of water. Upon renewal of current, electroosmotic drainage continues until the preferred orientation again impedes water drainage. Each successive break in current supply allows drainage to be resumed.

5. The time length of switching-on and switching-off of current producing the electroosmosis effect has real significance in the economy of electric energy consumption and in distribution of this consumption in time.

   For this purpose 8 tests were performed on the large sedimentation basin, differing in intensity and in voltage of feeding current, in cyclicity of its connection and disconnection, and in time of the breaks length in field electric supply. As a measure of efficiency of considered tests was adopted consumption of electric energy per liter of pumped out water (KWh/l). Comparison of tests shows that the most advantageous current supply arrangement in respect of energy consumption is a supply of 400 A current and 86.5 V voltage to the field. A one-day-on, one-day-off cycle gave an efficiency of 1.34 KWh/l. A significant reduction in water discharge after cessation of current application followed by a fast rise after reconnecting the current indicates further advantages of a 12-hour cycle. This cycle has a further advantage in that the current can be switched off during day and connected at night to utilize current during the hours of lower demand.

6. The total quantity of water pumped from the filtercathodes during all the amounts to 104 cubic meters. The elevation surveys of the surface of the sedimentation basin bowl drawdown indicates a total with drawal of 1346 $m^3$. Differences in these values can be explained by:
   - evaporation effects
   - electrolysis effects occurring during application of current
   - water losses by escape of water down the well.

   Further quantitative determination of these factors has encountered some difficulties.

7. The tests show that the quantity of water drained was affected by the wet weather, and thus optimal dewatering was not achieved. However, the ability to gain access to and to work with the tailings is drastically improved. These positive effects include:
   - precipitation does not percolate into the sediment and with the exception of the top layer of about 30 cm thick;
   - pits dug in the sediment to a depth of 2-2.5 m maintain their vertical walls for longer time, both when they are filled with water and when empty.

   Reconstruction of the soil structure is effected by the electro - chemical processes occurring during periods of application of electric current. Such phenomena were identified during microscope observations.

8. It is advisable to reduce the moisture content (using electroosmotic systems) to 30-35 percent. This facilitates handling with light mechanical shovels. Further drying of sediment, as is required for use for constructing embankments, or in agriculture, can be achieved through atmospheric drying.
   Atmospheric drying can be achieved by windrowing the material in mounds 2-2.5 m high, on a permeable subsoil. Rain water must be quickly drained from the piles.

9. The drained sediments were most effectively handled using draglines. Use of mechanical shovels would require the use of electrical current of short duration (about 40 secs.), to empty the bucket of the sticky sediment.

10. In circumstances where fly ash are available, mixing of the ash with this sediment results in a mixture with good physical characteristics for treating certain soils (often sandy). However, the chemical effect of the fly ash on vegetation was not addressed. Such mixing does not depend on first windrowing and drying the material and thus has potential advantages.

## SECTION 3

## RECOMMENDATIONS

Investigations and observations performed in the course of draining sedimentation basins in Ogorzelec have shown that the problem of drying fluid industrial wastes must be considered in connection with the method of disposal into sedimentation basins, with their economic usability, with techniques of mechanical handling and transportation and with the implications of mixing with other components.

In light of the experimental results, a number of general recommendations can be formulated.

1. Prior to disposing of fluid industrial wastes into a tailings sedimentation pond, one should consider the following:
   - the eventual economic usability of the wastes;
   - whether the wastes will be removed from the sedimentation basin, or whether they are to remain.

   If the wastes are to remain in the sedimentation basin, the final phase of the deposition should be designed to drain the surface with a gravitational or assisted discharge of precipitation beyond the sedimentation basin. This would facilitate reclamation of the sedimentation basin surface.

   In cases where removal of sediment is anticipated, the depositional process should be designed with drainage systems buried in the pile.

2. In cases of disposal of fluid wastes in an uncontrolled manner, one should ensure drainage of surface water, preferably through gravita-

tional flow to a location away from the sedimentation basin. This is a necessary condition to permit reclamation work of further draining the wastes.

3. There may be cases where there will be no way to provide gravity drainage (as for example at Ogorzelec). In such cases the water should be drained using a syphon or pumps, after which ditches should be dug to permit gravity drainage.

4. The vertical arrangement of electrodes creates a number of difficulties of technical and exploitational nature, in view of which in future research one should examine the feasibility of horizontal arrangement of electrodes application with gravitational drainage to the central water intake, or to natural flow.

5. The most advantageous arrangement of electrodes was one in which the anodes were installed in the central, clayey portion of the sedimentation basin and the cathodes in an intermediate zone, which contained less water and was comprised of coarser particles.

6. In wastes with high percentages of small grains, voltages (potential difference of the 0.15 - 0.2 V/cm rank) should be used for relatively long periods of time. This allows:
   - smaller consumption of electric power;
   - more uniform drainage of the sediment; and
   - better effect of soil structure reconstruction in the effect of electrochemical processes.

   The current should be routinely interrupted in order to:
   - decrease the power consumption at a cost of only a small decrease in water draining,
   - improve the drainage by preventing preferred orientation of clay particles and reductions in permeability caused thereby, and
   - decrease the cost of energy by using it only during times of non-peak (usage).

7. Frequent pumping of the filtercathodes increases the effect of electro-osmotic draining. There appears to be merit in constructing

a permeable layer at a depth such that water drawn to the cathodes would constantly drain, by gravity, from the cathodes. Thus inconvenient pumping would not be required.

8. For economic reasons it is advised that electroosmotic draining of sediments be used only to achieve a state that allows handling with mechanical equipment (in the case of Ogorzelec this moisture content ranged from 35 to 38 percent). Further draining of sediments as may be necessary for use (to water contents of 20-26 percent) should be achieved through atmospheric (natural) drying or through mixing with water absorbing components, e.g., with fly ash generated in power plants.

9. Handling of the partially-dried sediments was best achieved with light draglines since these had no problem in emptying the bucket. Clamshell excavators have little difficulty in emptying sediment containing 35 percent moisture. One should however avoid the use of power shovels unless its bucket is fitted to provide an electrical current at the time of dumping. The current breaks the bond between the sediment and the steel bucket.

10. Initially favorable results were indicated when fly ash was mixed with the partially - dried sludge. Such mixing also has the following benefits:

- a decrease in number and quantity of sludge and ash in sedimentation basins if the resulting mixture is utilized;
- economic utilization of mixture of both components, with the object in their use for embankments' formation, or for soil improvement; and
- stabilization of fly ash if it is quickly mixed with sludge and not allowed to remain in settling ponds as a source of fugitive dust.

## SECTION 4

## THE DESCRIPTION OF PROJECT OUTLINES

The wastes derived in the processing of various type of minerals when deposited in tailing ponds may constitute a real harm to the environment. This particularly concerns tailings in a fluid or semifluid form, causing the risk of breaks of embankments and flooding of their neighbourhood with fluid or semifluid wastes. These may easily occur in the effect of big sudden showers, tectonic quakes, or other reasons and could take place mainly in the case of sedimentation basins, elevated above the terrain level. Moreover they can contaminate the environment chiefly through an infiltration of solutions of disadvantageous pollutants to the ground and to superficial waters.

To this type of tailing ponds belongs the pond of post-flotation slimes located in Ogorzelec, where project research was carried out. This pond was constructed on a slope of a valley in a hilly area. Its surface is elevated 25 m above the terrain surface and it was filled with semifluid wastes coming from sulphur ore flotation.

Relatively large amounts of atmospheric precipitation in this region, and low natural evaporation from the terrain surface hindered natural drop in moisture content of tailings, during eight years after their deposition there. The above factors and the shape of this tailings pond bowl were causing also the continuous retention of water to a depth of 1.5 m.

This state required a 3-stage system of slimes dessication which was investigated during 3 years and is discussed in this report.

## THE OBJECTIVE AND PROGRAM OF RESEARCH

The object of this research was to investigate and develop methods of drying tailings produced in a flotation process for sulphur ore. The following three phase system of drying was adopted:

- development of system for drainage of shallow "ground water" and runoff from the surface of the pile;
- withdrawal of ground water contained in the tailings using electro-osmosis;
- subjecting the partially-dried material to the atmosphere with maximum exposure to the air or mixing the material with power plant fly ash to further facilitate drying.

Studies to determine procedures to economically use the tailings and to transport, store and distribute the dried material on agricultural lands were also conducted.

### Program of research work

The research program was planned to be executed in three stages.

Stage I : (1974/75) Investigations of physical and chemical properties of tailings laboratory tests of drying utilizing electroosmosis, the establishment of a reference elevation line for later subsidence measurements and a study of pertinent elements of the climate in Ogorzelec.

Stage II: (1975/76)

- drainage of surface water from the tailings sedimentation basin,
- installation of an electrokinetic system designed to dewater the clayey tailings,
- systematic surveys of progressive subsidence of the sediments undergoing dewatering and continued measurement of pertinent climate characteristics in the region of the sedimentation basin.

Stage III: (1976/77)

- continued surface and subsurface drainage of the sedimentation basin,
- continued subsidence surveys,
- continuation of observations of climate,
- investigation of mechanical handling of partially - dried tailings and spreading for natural (atmospheric) drying,
- investigation of mixing tailings with dry fly ash to reduce moisture content,
- testing and distribution of dried tailings for agricultural soil amendments.

## THE SCOPE AND METHOD OF RESEARCH WORK ASSIGNMENTS

The water content of existing tailings sedimentation basins may be reduced using different techniques depending on the amount of dewatering desired. Where the sedimentation basin is to be revegetated, surface water may be drained using pumps and a system of open ditches, or a subsurface horizontal drainage system.

When a removal of the tailings is required in addition to draining the surface water, subsurface drainage is required to achieve a sufficiently low water content to allow handling with mechanical excavation and transportation equipment.

The tailings produced by floatation of e.g. sulphur ore have a high content of clay-sized particles which are difficult to drain. Thus it is necessary to assist dewatering, in this case through osmosis. When these tailings must be excavated and transported for such uses as for agriculture (for a deacidification or other improvement in the soil structure), then the water content must be even lower than can be achieved through electro-osmotic draining for a lengthy period. Therefore in this case atmospheric drying or mixing with fly ash was used to further dry the tailings.

In order to develop an economic and technically viable dewatering system, the character of the tailings must be determined and the pertinent climatic variables must be measured. To refine the methods of electro-osmotic drainage, and to identify methods of excavating the sediments with power shovels and distributing with agricultural equipment, the changes in water content of the tailings must be periodically measured.

Laboratory tests

Laboratory tests were performed to determine the physical - mechanical and chemical properties of the tailings sediments.

Investigations of the physical characteristics included determination of the weight and bulk density, natural humidity, grain size distribution, consistency and of the consolidation index.

The measurements of the mechanical properties also included determination of the bulk modulus.
The chemical tests included determinations of:

a) for tailings sediment - pH and concentrations of calcium oxide (CaO), silica ($SiO_2$), magnesium oxide (MgO), iron oxide ($Fe_2O_3$), aluminium oxide ($Al_2O_3$), zinc (Zn), sulphur (Sulphide and sulphate) (S), chlorine (Cl), lead (Pb), chromium (Cr), cobalt (Co), copper (Cu), and manganese (Mn)

b) for water - pH and concentrations of the following ions: $Fe^{+2}$, $Fe^{+3}$, $Cl^{-1}$, $Ca^{+2}$, $Mg^{+2}$, $SO_4^{-2}$, $N_{(NO_3)}$, Mn and $Al^{+3}$.

Laboratory model tests

Laboratory tests included small scale model tests of various methods of electro-osmotic draining of sediments. The objective was to select an optimal variant for specified conditions of a particular tailings sedimentation basin.

These model tests were conducted to test the efficiency of drainage with direct current in the following spatial arrangements:

- a rectangular reservoir with dimensions 300 x 150 x 100 cm, and varying the configuration of electrodes, current and voltage,
- a round reservoir with dimensions of diam. 40 and h = 30 cm where the anode is the perimeter of the reservoir and cathodes are the pipe filters of differing configurations,
- a round reservoir of dimensions diam 40 and h = 30 cm where the anodes are strips of metal sheet, and cathodes are pipe filters of differing configurations,
- a round reservoir of dimensions diam. 40 and h = 30 cm where the anodes are strips of metal sheet, and cathodes are pipe filters of differing configurations.

The laboratory investigations also included testing variants of mechanical mixing of the tailings with dry fly dusts.

## Climatological investigations

A meteorological station was established in Ogorzelec, to identify meteorological conditions in the vicinity of the tailings pond. Of special concern were the precipitation temperatures, and wind patterns characteristic of the area, all of which materially affect the process of field evaporation.

The process of water evaporation depends as a rule on three factors: on the amount of thermal energy, on the absorbing capacity of air for water vapour, and on the degree of air turbulence. Quantitative determination of solar energy gain in the form of total radiation requires special tests with costly equipment. Therefore this had to be limited to measurements of sums of real insolation. Knowing the length of a day, one can, in an indirect way, determine the solar radiation.

The capacity of the atmosphere to absorb water vapour depends on the actual temperature of air and on the quantity of water vapour previously contained in the air. The absorption capacity can be expressed in terms of the remaining water that can be added to attain saturated conditions. The water content expressed in millibars (partial pressure) may easily be converted to grams of water vapour which a unit volume of air can absorb. Turbulence can generally be described by the wind velocity.

Measurements of other parameters (temperature of air and soil, vapour pressure) were made to satisfy empirical formulae that evaluate evaporation (formula of Penman (refs. 26, 27), of Turc (ref. 44), of Thornthwaite (refs. 42, 43).

The phenomenon of evaporation can be very accurately determined through direct measurements. For this purpose a Wild 's evaporimeter with an umbrella shutter was installed.

An essential component element of the water balance of an area is precipitation. It was measured by means of pluviometers. Precipitation causes changes in soil humidity, which affects drying. Determination of the potential for drying tailings under actual field conditions through empirical formulae which take into consideration the meteorological conditions, should be checked through direct measurements of field evaporation. Such measurements were performed at Ogorzelec with the aid of specially constructed evaporimeters. The construction and operation of these evaporimeters are discussed later in this report.

## SECTION 5

## DISCUSSION OF LITERATURE

Literature reviews included publications on soil mechanics, hydrogeology, technology of storing the flotation tailings, sedimentology, etc.

Of even greater importance was information concerning the possibilities and methods of drying, digging, and using the tailings economically. The selection of literature presented below is connected chiefly with these issues.

The drainage of tailings has been achieved through various methods.

A mechanical method, based on filtering the sediment (vacuum filters), or on centrifuging water by means of a basket or a casing centrifuge have been used. Both methods require a large amount of energy and achieve an average water content of 40 to 50 percent (refs. 28,29). This water content is still sufficiently high so as to prevent economic utilization of the tailings in a number of situations.

Drying at a raised temperature seems also to be uneconomic due to significant energy requirements and the appreciable cost of the equipment needed for water evaporation (refs. 28, 40).

Among the many other methods of draining tailings, two deserve further attention. These are drainage through application of electrical current and mixing with substances which bond the water.

Electroosmotic drainage of soil is discussed in many papers (refs. 3,4,5,7,15,16,17,18,19,22,24,31,33,34,35,36,37,38,45,46,47,50). Under the influence of direct current passing through a wet soil, the phenomenon of electroosmosis takes place as well as a number of other occurrences such as: polarization of electrodes, electrolysis of water, soil heating, and electrocataphoresis.

Part of the current flows through the soil skeleton, and part through the water contained in pores. Under the influence of direct current water particles tend to move along the lines of the electric field from positive pole (anode) to the negative pole (cathode). Negatively charged silt particles migrate in the opposite direction. Cases may occur where acid soil components with positive charges migrate to the cathode, and alkaline particles migrate toward the anode.

While many factors determine the effectiveness of electroosmotic drainage, the most important ones are the type of soil, the density of current conducted through the soil medium, the potential (voltage) charge across the field, the soil humidity, and the temperature. These variables may be represented by a socalled "coefficient of electro-osmotic flow" ($K_E$). This coefficient is determined for the specific conditions in which the process of electroosmotic drainage is carried out and is expressed in $cm^2$/Volt·sec.

The tests have shown that $K_E$ is independent of the content of silt despite the fact that these particles normally determine the hydraulic permeability. The amount of electric energy depends on the type of soil, on the exchange capacity, on the amount of water in the soil, and on the volume of soil to be drained.

Soils with a fluid consistency have the least overall resistance to electrical current. Below the limit of plasticity the resistance changes relatively little, while above it rises rapidly. The relative amounts of water in a free state and in bonded state are important in determining resistance. Free ground water (gravitational) conducts the current best, bonded water conducts water poorly, and hygroscopic water does not conduct current at all. A decrease in the soil moisture results in an increase in electric resistance of the soil.

In order to achieve optimal drainage under specific field situations, it is advisable to first employ laboratory model tests. Analysis of electroosmosis show that there are numerous physical elements which affect the efficiency of electroosmosis and that at least 18 of these may be modelled (ref. 31).

In order to transfer the results of laboratory tests to field conditions one must preserve a high degree of geometric similarity and constant values of variables modelled. If this scaling principle is followed, the field results may be accurately predicted.

Electroosmosis is a phenomenon that varies with time. Irreversible chemical changes always accompany it.

Contrary to electrokinetic consolidation electroosmotic drying does not produce a hard material and the soil is not dried uniformly.

The principal de-watered zone is located by the anode; the intermediate part has a somewhat better consistency than it had before the process, whilst the zone by the cathode remains essentially as it was prior to draining. Electroosmosis is adversely affected by the irregular depositional patterns of a typical tailings sedimentation basin and thus the desired effect may not always be achieved.

Another method which promises good drying capabilities is mixing of the tailings sludge, once it may be handled, with dry, water sorbing materials (ref. 28). Such substances can be so selected as to increase the utility of the sediment. Substances could include burnt lime and a number of waste products such as fly ash from power plants fired with bituminous or brown coal, waste material from the lime industry.

Burnt lime reacts easily with water: 1 g of $CaO$ bonds (stoichiometrically) 0.32 g of water. This reaction generates also a large quantity of heat, (16 K cal/mol), which contributes to the evaporation of water from sediment (ref. 28). The equation for the reaction is:

$$CaO + H_2O = Ca(OH)_2 + 16 \text{ Kcal.}$$

The hydrated lime becomes harder with time as carbon dioxide is absorbed.

Lime is utilized in Japan, for the dewatering and hardening of river silts.

If the tailings sludges are dried to such extent that convential transportation is possible, then material may be utilized for more uses and over a wider geographical area. For example sediments having a high shear strength, adequate compressibility and granulometric composition can be used as foundation material (ref. 21). Sediments which have an appropriate chemical composition, an especially high calcium oxide content and a small proportion of toxic components can be used in the production of cement (ref. 8).

If the tailings are to be economically used, the options for use will be enhanced if the locations of use are located close to the mines (26). Perhaps the widest use of flotation tailings, considering the scale of utilization, and economic effects, should be in agriculture. Tailings from flotation of the sulphur ore, which can be used as deacidifying and improving soil structure fertilizer (refs. 6,11,12,39), may have a high potential for such use.

The factor determining the fertilizer value of tailings chemical composition. It would be useful as a soil amendment, should contain more than 40 percent calcium oxide and magnesium oxide and no toxic admixtures of elements in quantities harmful to plants. It is desirable if microelements such as the Na, K and Mn are present. The texture and organic content are also important.

Studies of the use of selected wastes in agriculture were carried out by the Institute of Cultivation, Fertilization and Pedology in Puławy (refs. 11,12). These studies consisted of laboratory tests and field tests ( a total of 150 tests during a 2 years´ period). The generalized results of these studies are contained in table 1. This table presents the relative crop yields resulting from various treatments of the soil with sulphur ore tailings, fly ash (lignite) and lime (per M. Kac - Kacas (ref. 11).

Table 1

Average crops of plants from two series of tests in the first and second years after treatment (100 % = crop on soils not treated)

(M. Kac - Kacas. Ref. 11)

| Fertilizer \ Cultivation and crops | Barley (1-st year | Clover (2-nd year | Oats (1-st year | Rye (2-nd year |
|---|---|---|---|---|
| | crops % | crops % | crops % | crops % |
| 1. Flotation lime (of ore) sulphur | 113.3 | 115.3 | 106.0 | 111.8 |
| 2. Fly ash from power plant (of lignite) | 110.9 | 113.1 | 114.6 | 108.9 |
| 3. Standard lime (ground limestone and agricultural limestone) | 112.0 | 114.2 | 109.8 | 108.8 |

These test results performed on acid and strongly acid soils, show that treatment with tailings produces results equal to those resulting from the use of chemical fertilizer, and the "flotation lime" treatment produces even better results. Presumably these results are due to the sulphur content. (ref. 11). Attention is also directed to the satisfactory results achieved by treating with ashes from power plants.

## SECTION 6

## DESCRIPTION OF THE FLOTATION SEDIMENT (TAILINGS) BASIN IN OGORZELEC

Field tests were designed and conducted to determine the best method of drying and removing saturated flotation tailings deposited in a sedimentation basin in Ogorzelec, near the Kamienna Góra, Voivodship Jelenia Góra, Poland.

### LOCATION OF THE SEDIMENTATION BASIN

The tailings on which field tests were performed were deposited in two sedimentation basins situated in the valley of Świdnik, a tributary of the river Bóbr. This valley lays between the mountain range Rudawy Janowickie from the Lasocki Ridge, and the Hills of Lubawska Pass and is narrow and encised. The valley is oriented SW-NE.

The region is somewhat mountainous. Representative elevations are: in the South 650 - 830 m, in the West 727-850 m, and in the North 800-850 m (above sea level).

The surface of the study area lays at an altitude of about 620 m. The slope of the valley at the study site ranges from 3 to 8$^{o}$ and has a Northern exposure (figs. 1,2,3).

### GEOLOGY

The region of the sedimentation basins, the upper part of the Świdnik valley, belongs to a large geological unit of Western Sudety, the Karkonosze. This area of the so called "eastern shield" of the

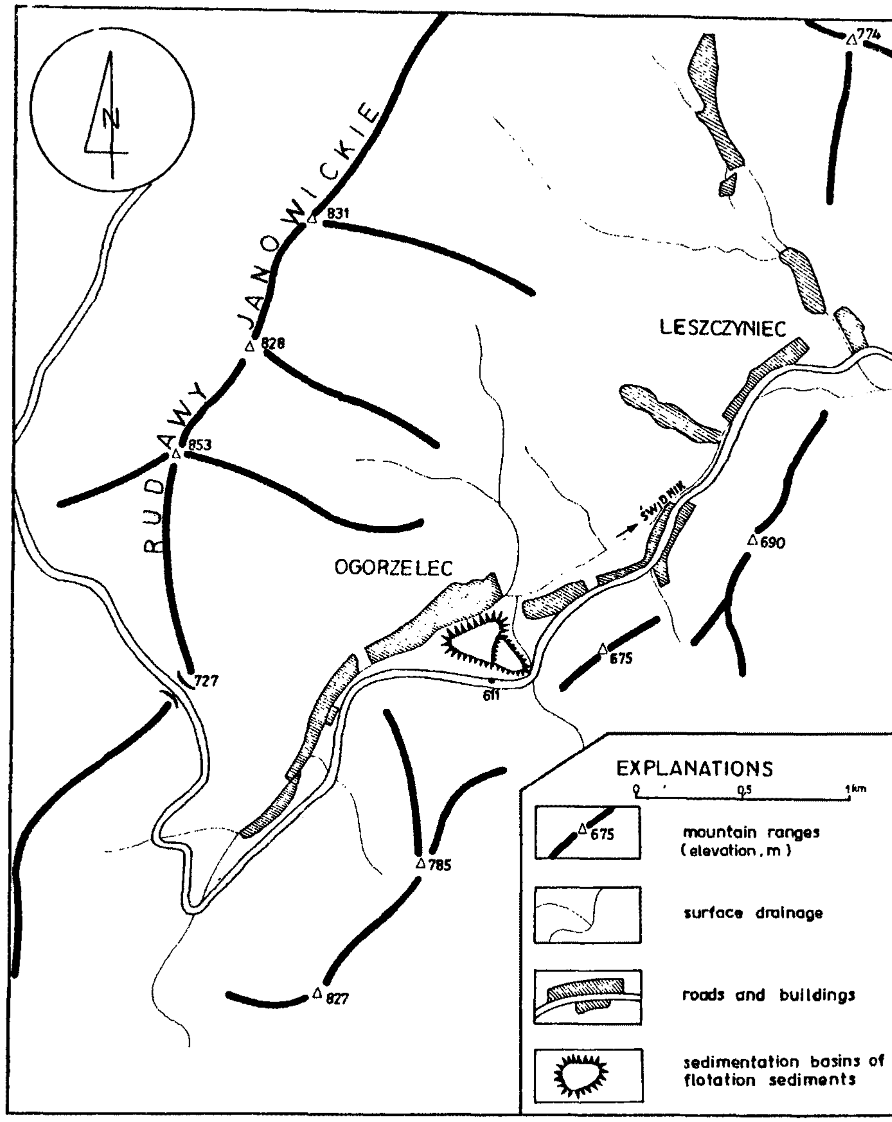
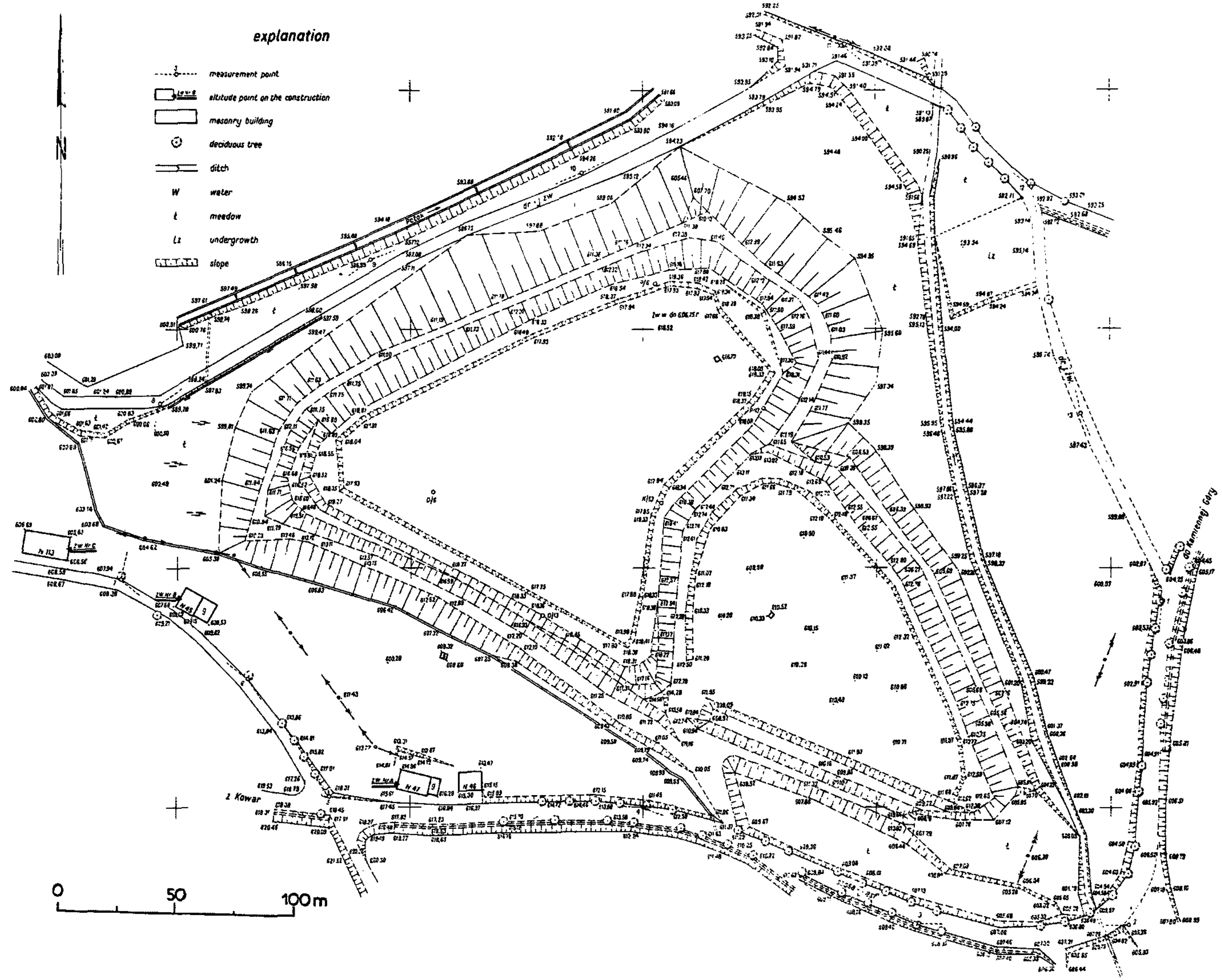



FIG. 1 LOCATION OF THE FLOTATION SEDIMENT (TAILINGS) BASINS IN THE AREA OF OGORZELEC

Fig. 2 SURFACE CONFIGURATION OF SEDIMENTATION BASIN OF FLOTATION TAILINGS



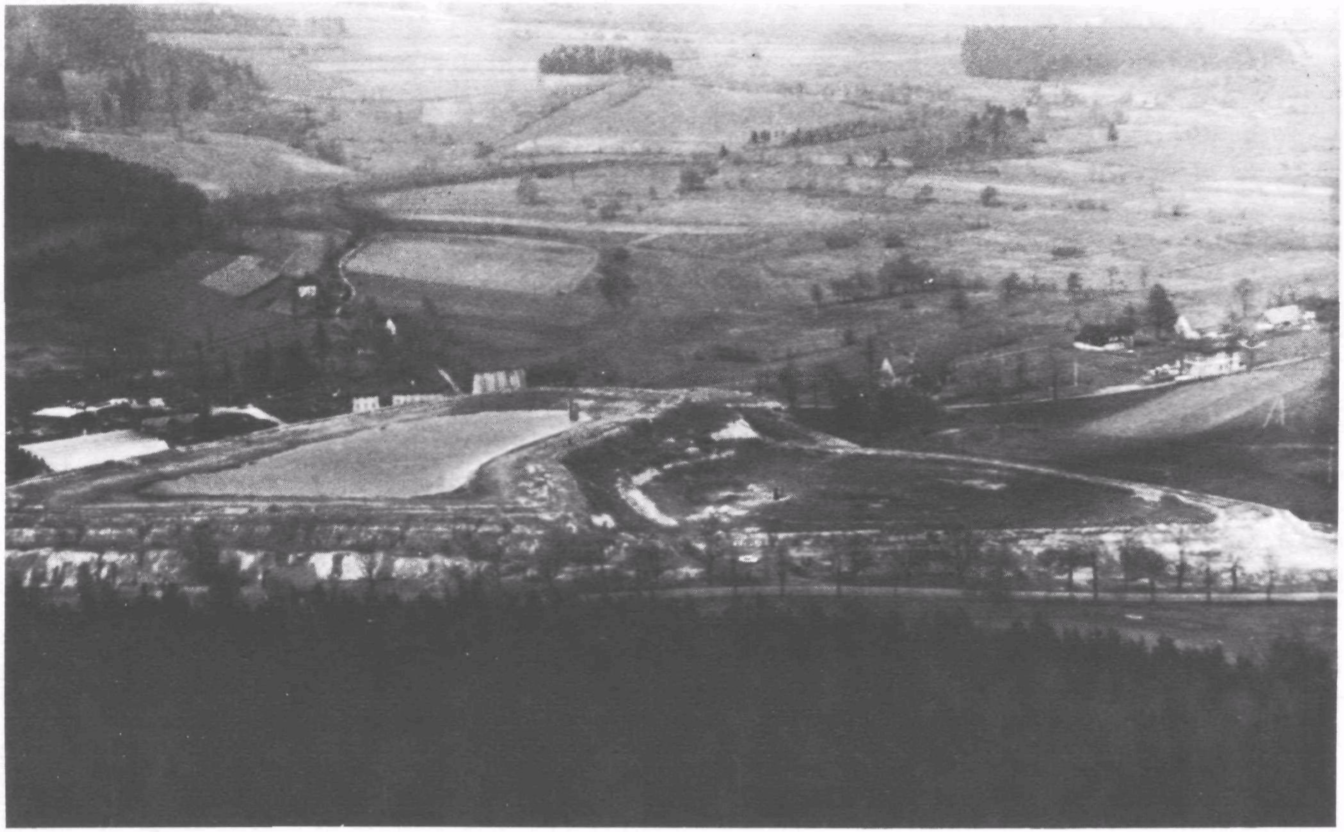


Fig. 3. General view of sedimentation basin in Ogorzelec.

Karkonosze includes a large granitic intrusive. Rocks of Algonkian age are located along the contact of intruding granite and paleozoic formations. These include various types of crystalline schist, quartzite, gneiss, and amphibolites. In the area of the sedimentation basin these are covered with a layer of fluvial sediments, including gravels with cobblestones several centimeters in diameter large, sandy clays, and clayey gravels. The depth of these sediments varies from 0.5 to 1.5 m.

## CONDITIONS OF THE TAILINGS´ DEPOSITION AND SEDIMENTATION

The tailings sediments studied are a waste product of an operation conducted in the 1960´s in an experimental facility for dressing and processing sulphur ore. The ore was obtained from deposits located in the vicinity of the city of Tarnobrzeg.

The flotation tailings were slurried to the sedimentation basin via pipelines and were discharged along the perimeter of the sedimentation basin. A number of low, earthen embankments were constructed along the basin to provide detention of the tailings slurry. Coarser fractions settled out in the vicinity of these embankments while the smaller particles were carried on by water toward the center of the basin (fig. 4). This results in a tailings deposit which may be divided into two zones, (fig. 5), an outer zone containing a sandy - silt fraction of sediments, and an inner zone containing a clayey-silt fraction. These differences in granulometric composition of the zones produce different hydraulic permeability and water yields for the zones.

The tailings at Ogorzelec were deposited in two sedimentation basins located adjacent to each other (figs. 2,3). The smaller basin is filled solely with sediments produced from sulphur flotation, and has a depth of from 4 to 10 m. The larger one, called the "main basin", has a more complex structure, since the upper 10 m contains sulphur ore tailings and the lower part contains waste products produced during the dressing of iron sands and barite ore. The external slopes of both sedimentation basins are partially reinforced by slag, debris

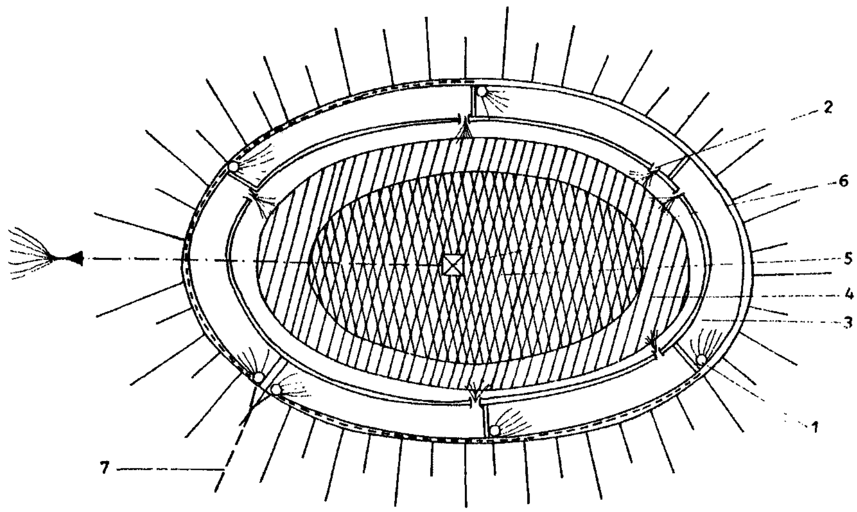



Fig.4 EXAMPLE OF DISTRIBUTION OF SIZE FRACTIONS WITHIN THE BOUNDS OF SEDIMENTATION BASIN THROUGH ADOPTION OF CHAMBER SEDIMENTATION METHOD.

1 – points of tailings discharge, 2 – flow of tailings from bays of initial sedimentation, 3 – zone of deposition of sand fraction 4 – zone of deposition of silt fraction, 5 – zone of deposition of silt – clay fraction, 6 – overflow tower, 7 – pipelines delivering tailings

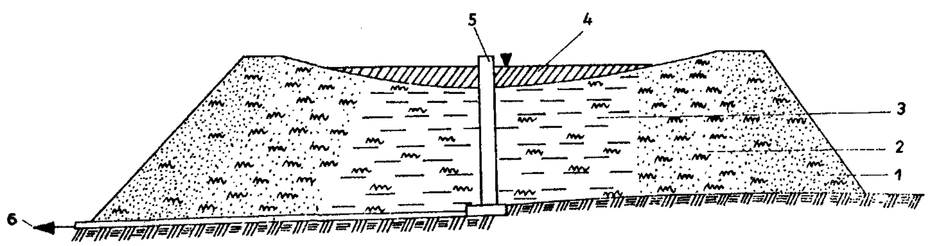



Fig.5 CROSS SECTION OF SEDIMENTATION BASIN (CONDITIONS BEFORE DRYING)

1 – sand – silt sediments
2 – silt – sand sediments
3 – silt – clay sediments
4 – surface water table
5 – overflow tower
6 – offtake of surface water

and filter cake from the sulphur smelting operation that followed the flotation process.

## PHYSICAL AND CHEMICAL PROPERTIES OF TAILINGS

### Physical properties

In order to determine the physical properties of tailings deposited in the flotation reservoir in Ogorzelec, the following laboratory determinations were performed during 1974-76:

- granulometric composition
- water content
- specific gravity
- bulk density
- bulk density of soil skeleton
- limits of consistency.

All analyses were made in accordance with procedures contained in Polish Standards PN-75/B-04481. Samples of the tailings were collected at 56 points on the main sedimentation basin. The locations were distributed along 8 profile lines in such a way that in the zone near the perimeter there were 18 points and in the interior zone there were 38 points (fig. 8).

At these locations samples were collected at selected depths to 5.5. m. A cylindrical sample collection device fitted with a piston was used to collect the soft-plastic material. The available equipment did not permit collection of samples from greater depths. However, a few samples were collected from greater depths (to 10 m) during the installation of the electrofilters.

The physical features of the undisturbed (prior to drying) tailings are presented in the following discussions.

a. Granulometric composition

The grain size distribution was determined for 67 samples collected from various depths and locations along the previously noted profile lines.

The laboratory methods of sieve and of areometric analysis were used. The sediment samples, each weighing 40 g, were covered with distilled water for 24 hours in order to produce a soft-plastic consistency and uniform saturation with water. The sample was first sieved through a 0.15 mm mesh. That remaining on the sieve was washed off with distilled water to an evaporator, and desiccated at a temperature of 105$^{\circ}$C. After drying the gravimetric content of particles greater than 0.15 mm was determined. When this large fraction constituted more than 2 percent of the total weight of a sample, the fraction was subjected to further sieve analysis of the larger fractions.

The material passing through 0.15 mm mesh was poured into a conical flask. As this sediment coagulates easily, a solution of sodium hexametaphosphate and anhydrous sodium carbonate was added as an anticoagulant. Due to the high percentage of calcium in the sediment (calcium dust), neither ammonia nor water glass could be used as an anticoagulant.

The solution of sodium hexametaphosphate (technical name calgon) and anhydrous sodium carbonate was mixed in proportions of 37.7 g of calgon and 7.94 g of anhydrous sodium carbonate per liter of distilled water. This anticoagulant was then added to the sediment sample (40 g mass) at a rate of 10 ml at the time of heating to boiling plus 10 ml after boiling.

After anticoagulation treatment and accurate measurement of the suspension measurements with an hydrometer were performed at the following time intervals: 30 secs., 1 min., 2 min., 5 min., 15 min., 30 min., 1 hour, 2 hrs, 4 hrs, 24 hrs and 48 hrs. Readings of the hydrometer's immersion depth were made using the top level of meniscus and the observed values were corrected through addition of the hydrometer correction factor and a correction for the difference of suspension temperature and the calibration temperature for the instrument.

The proportional content of particles in sediment was read from appropriate nomograms prepared for each of the used in research hydrometers.

The results of each sample analyses were presented in the form of grain size dist ribution curves. From these curves, more comprehensive diagrams for the external and the internal zones of the basin were prepared (fig. 6,7).

The content of selected particles in the two zones vary widely from sample to sample, but the following analyses shows that the sands fraction is almost always minor in the internal zone:

Range in particle sizes in external zone:

- sand zone 4 - 77 %
- silt zone 19 - 76 %
- clay zone 4 - 20 %

Range in particle sizes in internal zone:

- sand zone 0 - 10 %
- silt zone 84 - 86 %
- clay zone 4 - 26 %

The silt fraction predominates throughout the basin. A high sand content shows only in a small number of samples collected on the fringe of the sedimentation basin. This type of granulometric composition of postfloatation wastes is controlled by the processing technology for sulphur ore. The distribution of particles within the sedimentation basin is controlled by the method of disposal (figs. 4,5).

b. Water content (w)

The natural water content of the tailings (w) was determined as the ratio of the water by weight (gw) contained in sediment to the weight of the soil skeleton (gs), which may be expressed as a percent as follows:

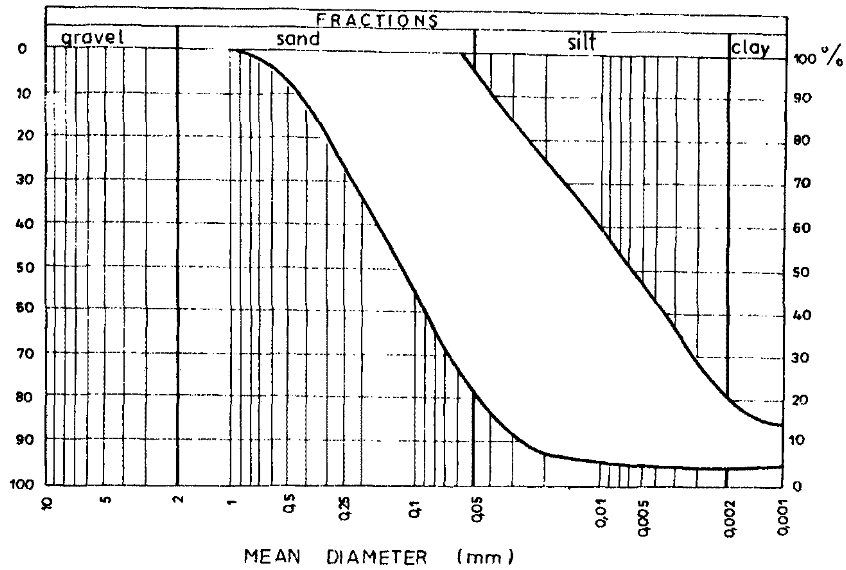



Fig.6 EXTREME LIMITS OF GRAIN SIZE DISTRIBUTION CURVES
- OUTER ZONE ( EMBANKMENT )

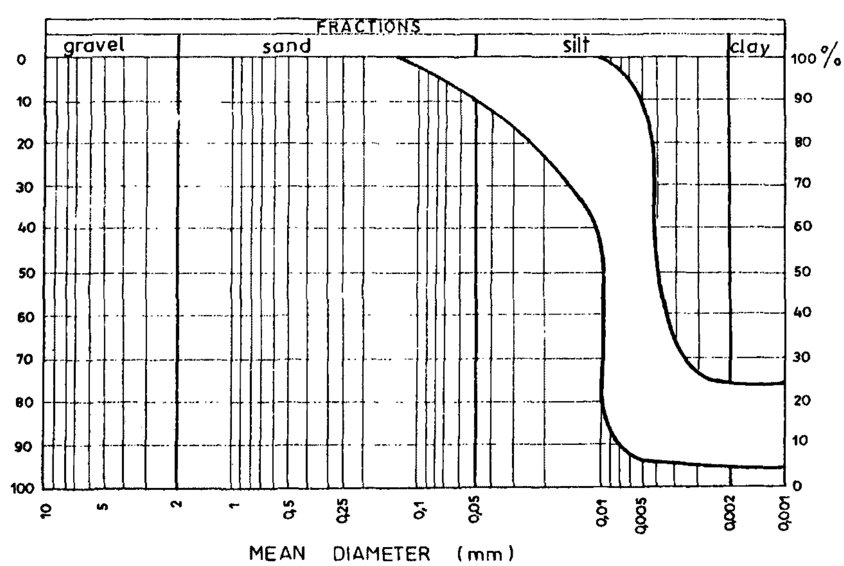



Fig. 7 EXTREME LIMITS OF GRAIN SIZE DISTRIBUTION CURVES
- INNER ZONE

$$w = \frac{Gw}{Gs} \cdot 100\ \%$$

Two 30 g portions of each sample were weighed (to the nearest 0.01 g) and dried at 105°C. Desiccation proceeded to the point where no further weight loss was observed. After the determination of the sample weight the water content was computed.

In order to determine the spatial distribution of water in the main sedimentation basin samples for analyses were collected from locations shown in figure 8.

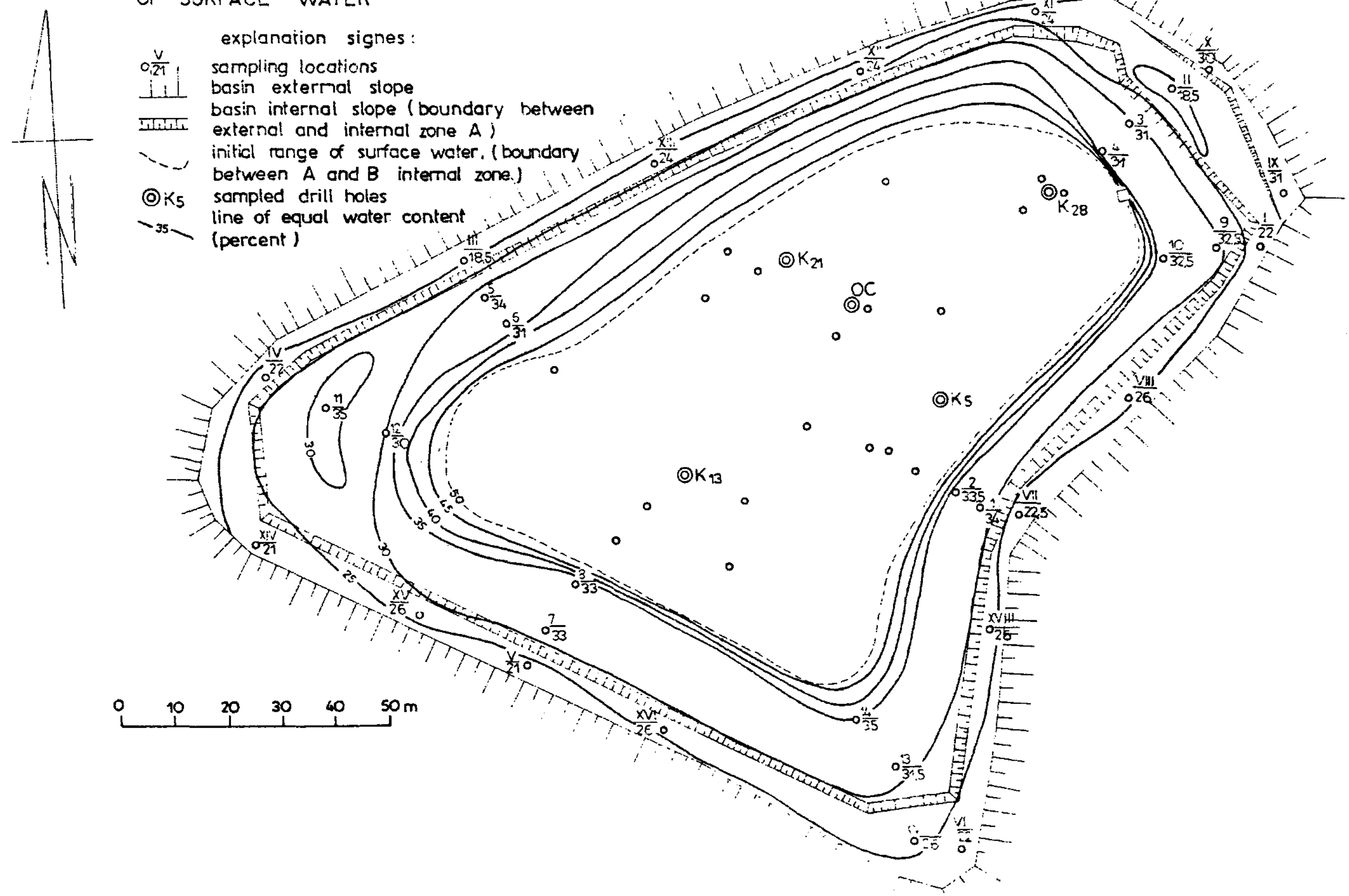
The cylindrical piston sampler did not give reliable results for these determinations since the depth at which the sample was collected could not be easily determined. This was represented by the large scatter of the data. In September of 1976 an improved collection device was made which allowed accurate sampling to a depth of 3 m. The results of water content, specific gravity and density analyses for the period prior to September 1976 were discarded as unreliable.

A plot of the water content of the near surface layer of the main sedimentation basin (fig. 8) was prepared on the basis of analyses of samples collected (with the help of a gimlet), from depths to 1 m. The figure shows the distribution of water in the near - surface tailings immediately following the drainage of surface water from the bowl of the basin. The 50 percent water content isoline conforms to the perimeter of the surface pool of water prior to drainage.

The external boundary of the water pool has been used to further divide the internal zone of the tailings into two parts, A and B, as shown on figure 8 and used in table no. 2. (Zone B is within the original water pool; zone A is that portion of the internal zone which is outside the pool).

The data in table 2 illustrate the water content in the near surface layer of sediment and also in lower layers (to 9.5 m depth) preceding the commencement of electroosmotic draining. Changes in water content occurring with depth in internal zone B, were determined on the basis

Fig. 8 DISTRIBUTION OF WATER CONTENT IN TOP LAYER OF THE MAIN SEDIMENTATION BASIN, DIRECTLY AFTER DRAINAGE OF SURFACE WATER



of analyses of samples taken from wells drilled specifically for the electrofilters (locations designated $K_5$, $K_{13}$, $K_{21}$, $K_{29}$, O.C. - fig. 8) since the piston sampler did not provide accurately locateable samples as previously discussed.

c. Specific gravity ( $\rho^s$ )

The specific gravity of the tailings material was determined through solution of the following equation:

$$\rho^s = \frac{m_g - m_t}{m_{wt} + (m_g - m_t) - m_{wg}} = \frac{\text{weight of solid}}{\text{volume of solid}}$$

where:

Mg = mass of flask and soil dried at 105 to 110°C, in grams

$m_{wt}$ = mass of flask and distilled water at a temperature 20°C, in grams

$m_{wg}$ = mass of flask with soil and water in grams

$m_t$ = mass of dry flask, in grams.

The sediment samples used for determinations of specific gravity were dried at a temperature of 105°C for 24 hours. The sediment was then ground in a mortar. To the calibrated flask was added 10 g of ground sediment, and distilled water to half of the measuring flask and was maintained for 20 minutes in a boiling state. The flask was then cooled to 20°C and filled up with distilled water, also with a temperature of 20°C, to the measuring mark.

After completing the measurements, the flask was cleaned and weighed with an accuracy to 0.01 g. Specific gravity determinations were repeated five times for each sample.

Values of designations of specific gravity are presented in table no. 2.

The tests show that the sediment in the external zone of the sedimentation basin averages 2.72 g/cm$^3$, while the internal zone contains less dense material (2.64 to 2.67 g/cm$^3$).

d. Bulk density ( $\varrho$ )

Bulk density was determined using cutting cylinder with a volume of 8.6 cm$^3$. After filling the cylinder with sediment it was weighed. Division of the mass by the volume according to the following formula gives bulk density:

$$\varrho = \frac{m_m}{V} = \frac{m_{mt} - m_t}{V_p};$$

where:

$m_m$ = mass of sediment sample in natural state (g)

v = volume of sample (cm$^3$)

$m_{mt}$ = mass of cylinder with sediment (g)

$m_t$ = mass of cylinder (g)

$V_p$ = internal volume of cylinder (cm$^3$).

Average values of bulk density are as follows: in external zone of basin - 1.75 g/cm$^3$; in internal zone - from 1.75 to 1.94 g/cm$^3$. Results of determinations are shown in table 2.

e. Bulk density of the soil skeleton ( $\rho$ d)

Bulk density of the soil skeleton was computed according to the formula:

$$\rho d = \frac{100 \cdot \rho}{100 + w}$$

where:

$\rho$ = sample bulk density ($g/cm^3$)
w = natural water content (%).

The bulk density of the soil skeleton of tailings in the external zone averaged 1.40 $g/cm^3$. In the internal zone, the average density ranged from 1.19 to 1.48 $g/cm^3$ depending on the place and depth of the sample collection (table no. 2). The bulk density of the soil skeleton varied in the same manner as bulk density of the samples.

f. Consistency limits

1. Plasticity yield point

Determinations of the plasticity yield point were conducted on four samples of sediment taken in internal zone of the sedimentation basin. These samples had a fluid consistency in their natural state. In order to reduce the moisture content, the sediment was dried at room temperature to a plastic state. The material was rolled and portions were used to determine the moisture content. The plastic yield point for each sample is an artihmetic means of moisture content determinations. The results are as follows:

Sample no. 1 - 24.8 %
Sample no. 2 - 30.6 %
Sample no. 3 - 25.5 %
Sample no. 4 - 28.0 %

Table 2

Physical characteristics of tailings from sedimentation basin in Ogorzelec (before electroosmotic draining initiated)

| Zone of sedimentation basin | Depth of sample | Number of investigation points | Number of samples | Physical changes: extreme values / average value | | | | Figure showing grain size distribution |
|---|---|---|---|---|---|---|---|---|
| | | | | Natural humidity % | Specific gravity g/cm$^3$ | Bulk density g/cm$^3$ | Bulk density of soil skeleton, g/cm$^3$ | |
| External zone (banks) | 0.5-1.0 | 18 | 15 | 14-34<br>24 | 2.70-2.74<br>2.72 | 1.50-2.09<br>1.75 | 1.11-1.56<br>1.40 | fig.6 |
| Internal zone A | 0.5 | 14 | 14 | 30-38<br>33 | 2.65 | 1.62-2.00<br>1.90 | 1.32-1.52<br>1.44 | |
| | 1.0 | 14 | 14 | 24-37<br>32 | 2.65 | 1.62-2.01<br>1.90 | 1.30-1.62<br>1.45 | |
| Internal zone B | 0.2-0.5 | 5 | 5 | 34-54<br>47 | 2.64 | 1.69-1.87<br>1.74 | 1.19-1.39<br>1.20 | |
| | 1.5 | 5 | 5 | 34-52<br>45 | 2.66 | 1.66-1.92<br>1.74 | 1.09-1.43<br>1.19 | fig.7 |
| | 3.5 | 5 | 5 | 32-41<br>37 | 2.66 | 1.83-1.90<br>1.86 | 1.29-1.44<br>1.37 | |
| | 5.5 | 5 | 5 | 34-39<br>37 | 2.67 | 1.79-1.88<br>1.85 | 1.28-1.38<br>1.35 | |
| | 7.5 | 5 | 5 | 21-37<br>31 | | 1.85-2.07<br>1.93 | 1.38-1.71<br>1.48 | |
| | 9.5 | 2 | 3 | 30-33<br>32 | | 1.90-2.00<br>1.94 | 1.42-1.55<br>1.47 | |

The average moisture content at the yield point for all samples is 27 percent.

2. <u>Liquid limit</u>

Liquid limit was determined on the Casagrande apparatus. The same samples used in tests for yield point were used to determine flow limit. The results were plotted according to the graphical method of liquid limit determination where the water content is measured as a function of "blows" the sample has received in the casagrande apparatus. The water content after the equivalent 25 blows is the liquid limit. The slope of the line is the flow index. The liquid limits calculated for the samples were:

Sample no. 1 - 41.0 %
Sample no. 2 - 44.9 %
Sample no. 3 - 48.3 %
Sample no. 4 - 44.3 %

The average of these is 44.7 percent.

The degree of plasticity flow was computed employing the following formula for the consistency index where $W_L$ is the water content for the liquid limit, $W_p$ is that for the plastic limit and W is the water content under natural conditions:

$$I_L = \frac{W - W_p}{W_L - W_p}$$

using this degree of plasticity flow, the state of the tailings were designated as follows:

Sample no. 1 - $I_L$ = 0.95 - soft - plastic state
Sample no. 2 - $I_L$ = 0.71 - soft - plastic state
Sample no. 3 - $I_L$ = 0.52 - soft - plastic state
Sample no. 4 - $I_L$ = 0.49 - plastic state.

The index of plasticity for each sample was also computed according to formula:

$$I_p = W_L - W_p, \quad (\%)$$

where $W_L$ and $W_p$ are as before. The results are:

Sample no. 1 = 16.2 %
Sample no. 2 = 14.3 %
Sample no. 3 = 22.8 %
Sample no. 4 = 16.3 %

the average index of plasticity is 17.4 percent.

Chemical characteristics

Chemical analyses of sediment were made using standard analytical methods for calcium wastes, where such are used to fertilize agricultural lands. Content of particular elements was measured in terms of selected compounds.

Calcium and magnesium were determined through the composite versenate method or conversion to the oxides CaO and MgO. Results of chemical analyses are provided in table 32 and 33 and results of analyses for basic components are contained in table 3.

Samples No. 1,2 and 3 (table 3) represent (respectively) the external zone:

(1) the intermediate zone,

(2) and the central internal zone,

(3) of the main sedimentation basin.

Sample no 4 was collected from a central part of small sedimentation basin.

These samples have average contents of calcium (40 % of CaO), silica (11.6 %) and insoluble compounds in comparison with agricultural soil amendments. The content of magnesium oxide reaches about 1 percent. The content of sulphur in a sulphide form fluctuates from 0.16 to 2.09 percent. The aluminium oxide content ($Al_2O_3$) from 1.37 to 4.27 percent and iron oxide content ($Fe_2O_3$) from 0.79 to 1.61 percent.

Table 3

Results of basic chemical analyses of tailings

| No. and place of sampling | $H_2O$ % | Content in dry mass, in % | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaO | MgO | Cl | S (sulphides) | $Fe_2O_3$ | $Al_2O_3$ | $SiO_2$ | Insolubles | Losses after sintering |
| 1. External zone, main basin | 18.77 | 44.61 | 0.60 | 0.00 | 0.16 | 0.799 | 1.37 | 10.72 | 1.85 | 31.86 |
| 2. Intermediate internal zone, main basin | 25.48 | 37.56 | 1.07 | 0.00 | 2.09 | 1.584 | 4.27 | 12.02 | 1.85 | 34.99 |
| 3. Interior internal zone, main basin | 21.52 | 38.96 | 0.87 | 0.00 | 1.93 | 1.318 | 3.80 | 11.57 | 2.11 | 36.07 |
| 4. Internal zone, small basin | 27.46 | 38.03 | 0.74 | 0.00 | 2.01 | 1.617 | 3.96 | 12.07 | 2.61 | 35.21 |

## DESCRIPTION OF LOCAL CLIMATE IN THE REGION OF OGORZELEC

### Method of measurements and discussion of results

Meteorological tests were carried out at the meteorological station established in Ogorzelec during the period: 1 Jun. 1975 through 30 Jun. 1977. Measurements of temperature and of relative atmospheric humidity were made with an Augustus psychrometer, placed in a meteorological instrument shelter at a height above the ground of 2 m. Daily values for the 0100 hour were recorded from the hygrothermographs in accordance with instructions for the Polish network of meteorological stations. Minimum and maximum thermometers were also installed in the shelter.

Measurements of the soil temperature at depths of 5,10 and 20 cm were made with soil thermometers. Measurements of minimum temperatures at the soil surface (5 cm above the soil) were obtained with the minimum thermometer.

Daily sums of precipitation were measured with the Hellman pluviometer with the intake located at a height of 1 m. The intensity of precipitation during the warm half of the year was measured with a daily pluviograph.

The wind velocity and direction were determined with a Wilde anemometer, installed 11 m above the surface.

Daily sums of solar insolation were measured with a heliograph (Campbell - Stokes).

The meteorological measurements have been prepared in a form of daily average, 10-day average, and monthly average and were specifield in working tables. The monthly values were selected from these comprehensive tables for later presentation in this report.

Evaporation from a free water surface was determined with the Wilde evaporimeter placed under an umbrella roof, 50 cm above the soil surface. Measured values were analyzed in the form of daily, 10-daily and monthly sums.

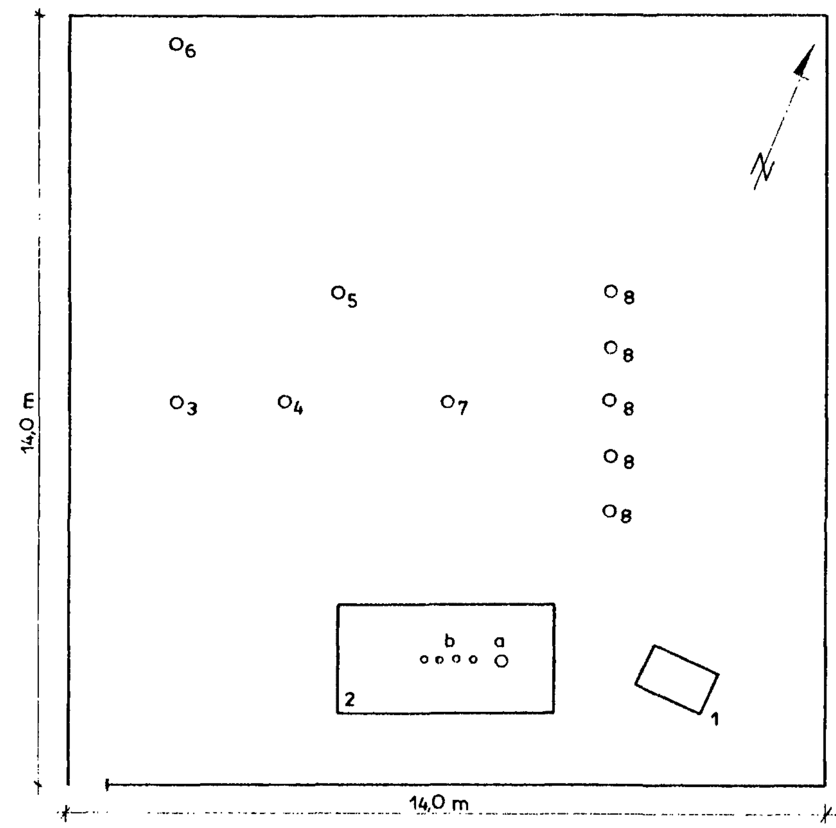



Fig 9 METEOROLOGICAL STATION IN OGORZELEC

EXPLANATIONS

1 — meteorological shelter
2 — check area with no vegetation
2a — minimal-reading soil thermometer
2b — elbow soil thermometers
3 — Hellmann's pluviometer
4 — pluviograph
5 — heliograph
6 — Wild's anemometer
7 — Wild's evaporimeter with umbrella roof
8 — soil evaporimeters

Fig. 10. Meteorological station in Ogorzelec - general view.

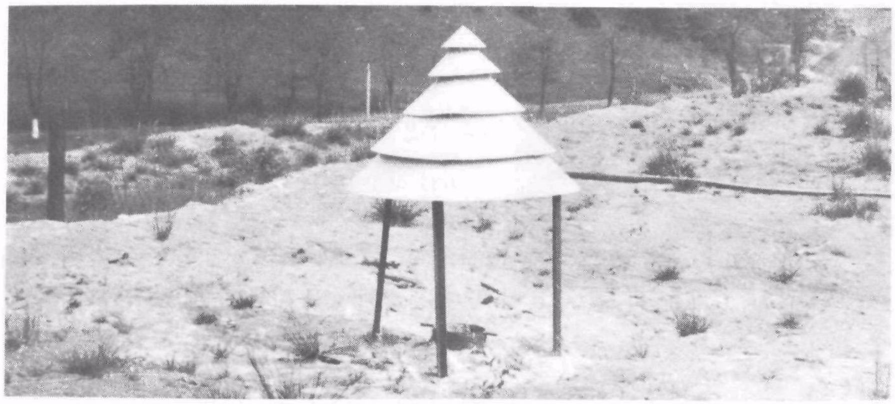


Fig. 11. Shielded evaporimeter installed on the main sedimentation basin.

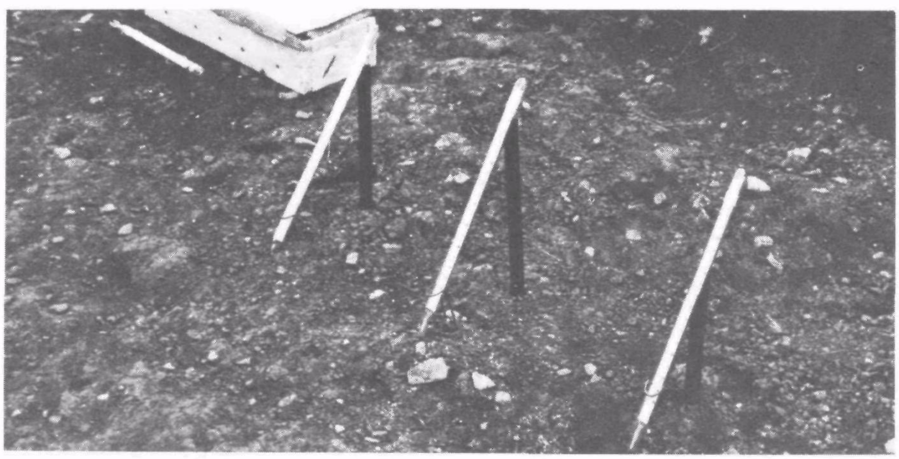


Fig. 12. Meteorological station-soil thermometers.

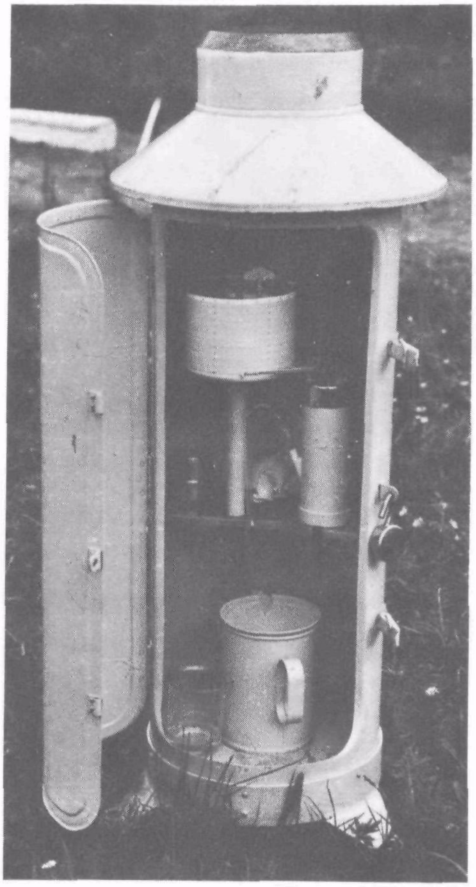


Fig. 13. Meteorological station - pluviograph

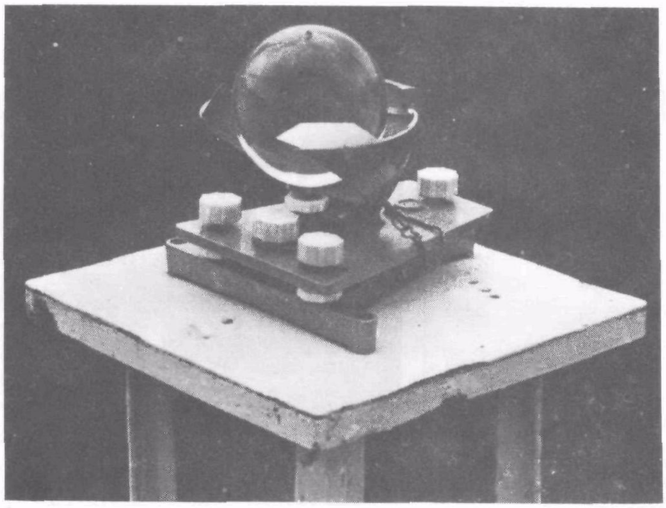


Fig. 14. Meteorological station - heliogaph.

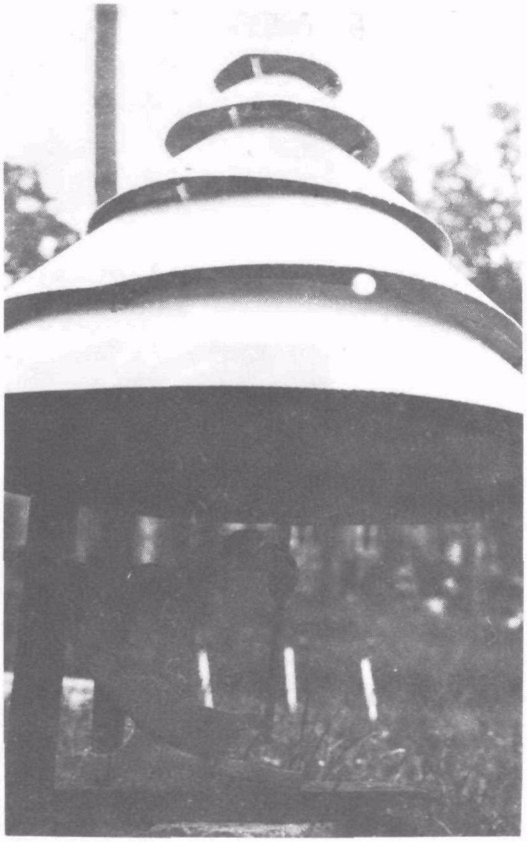


Fig. 15. Meteorological station - Wild evaporimeter under an umbrella roof.

Field evaporation from the tailings was measured directly at the tailings site using gravimetrical soil evaporimeters, with surfaces of 250 $cm^2$ and depths of 30 cm.

Using the precipitation amount, the quantity of percolation and difference in the monolith weight during the period of measurement, the field evaporation was determined.

Results of meteorological measurements in Ogorzelec during the investigation

Ogorzelec is included in the zone of moderately cold and relatively humid climate designated by Schmuck and Sudety (ref. 25). Owing however to the lack of meteorological stations in Ogorzelec prior to this research the analysis of climatic conditions was based on data obtained from 1951 to 1970 at Paprotki (located about 5 km south of Ogorzelec), and from Jelenia Góra (20 km N.W.). Long term observations of selected climatic elements at these stations are presented in table 4.

The characteristic feature of temperatures in the mountains is temperature smaller difference between summer and winter in comparison to the lowlands. Also the daily fluctuations in temperature in the mountains are more pronounced. At the elevation of Ogorzelec, the warm temperatures of summer, (i.e., the period with average monthly temperatures above 15°C) are essentially not present.

Long term precipitation patterns were also determined from data collected at the Paprotki station, which is situated much like the Ogorzelec station, on the lee of the mountains. The month with highest precipitation is July (112 mm table 4). The lowest precipitation occurs during the winter months. Despite a small distance separating Paprotki from Ogorzelec, investigations made in 1975/77 suggest that the total annual precipitation in Ogorzelec is at least 150 mm higher than the 707 mm at Paprotki.

Long term values of other meteorological variables were determined from measurements at Jelena Góra, little more distant from Ogorzelec

Table 4

Long term average data (from the period 1951-1970) of air temperature (t, in °C), and monthly atmospheric precipitation (P, in mm) at the station Paprotki, and average monthly partial saturation of air humidity, (d, in mb), sums of actual insolation (s, in hours), total solar radiation, (T, in Kcal . cm$^{-2}$), and wind velocity (V, in m/sce.) in station Jelenia Góra.

| | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. | Apr.--Sept. | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| t | -5.0 | -3.0 | 0.6 | 5.7 | 9.9 | 13.5 | 15.0 | 14.1 | 10.8 | 6.8 | 1.4 | -1.9 | 11.5 | 5.6 |
| P | 24 | 31 | 35 | 50 | 89 | 90 | 112 | 85 | 47 | 56 | 51 | 37 | 473 | 707 |
| d | 1.2 | 1.1 | 1.9 | 3.0 | 3.8 | 4.8 | 5.0 | 4.3 | 3.5 | 2.7 | 1.6 | 1.2 | 4.1 | 28 |
| s | 46 | 70 | 112 | 133 | 178 | 188 | 189 | 176 | 144 | 110 | 43 | 37 | 1008 | 1426 |
| T | 2.0 | 3.5 | 6.8 | 9.4 | 12.7 | 13.5 | 11.3 | 11.5 | 8.1 | 5.1 | 2.1 | 1.5 | 68.5 | 89.5 |
| v | 3.1 | 3.0 | 3.2 | 2.6 | 2.4 | 2.2 | 2.3 | 1.9 | 2.3 | 2.6 | 3.0 | 2.8 | 1.4 | 2.2 |

since there seemed to be relatively spatial variability (with exception of partial saturation). Partial saturation is expected to be higher at Ogorzelec.

Maximum insolation occurs in June and July but the amounts are not particularly large. The wind velocities are rather low at Jelenia Góra for locations in valleys.

Detailed characterization of climatic variables at Paprotki and Ogorzelec during 1975 and 1977 is presented in table (5) and on figures 16 and 17. These observations indicated no significant deviations from the longer term averages.

The air temperature during 1975 - 1977 at both Ogorzelec and Paprotki was similar with the exception of June 1975 (Ogorzelec was cooler by 1.1°C), and June 1976 (Ogorzelec was warmer by 0.7°C) with respect to long term averages, temperatures during August 1976 were cool and during September 1975 were warmer. The distribution of precipitation differed between stations. With the exception of December 1975 and July 1976, when the precipitation was almost the same as in long term, in the remaining months observed were significant deviations from normal. January 1976 and August 1977 were extermely wet (500 and 470 % higher precipitation). September 1975 and June of 1977 were quite dry. In terms of solar insolation June and July of 1976 and August of 1975 were quite sunny. The insolation in June of 1975 and September 1976, and July and August of 1977 was relatively low.

The partial saturation of air approximated the long term values with the exception of three consecutive months of 1976 (May, June and July) exceeding average values by as much as 3 milibars.

The wind velocities consistently followed the long term average values.

Table 5

Average monthly values of air temperature in °C in Paprotki ($t_p$); in Ogorzelec ($t_o$), sums of atmospheric precipitation in mm in Paprotki ($P_p$) and Ogorzelec ($P_o$); and sums of insolation in hours (s), average monthly humidity undersatuarion of air in millibars (d) and wind velocity in m/sec. (v) in Ogorzelec in years 1975 - 1977

| | | I | II | III | IV | V | VI | VII | VIII | IX | X | XI | XII |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1975 | $t_p$ | | | | | | 14.0 | 15.8 | 15.2 | 13.6 | 5.4 | 0.0 | -1.0 |
| | $t_o$ | | | | | | 12.9 | 16.1 | 15.6 | 13.7 | 6.2 | 0.1 | -0.9 |
| | $P_p$ | | | | | | 87 | 106 | 77 | 20 | 64 | 40 | 31 |
| | $P_o$ | | | | | | 127 | 179 | 53 | 24 | 94 | 54 | 44 |
| | s | | | | | | 91 | 168 | 203 | 158 | 90 | 41 | 26 |
| | d | | | | | | 4.0 | 5.7 | 4.9 | 4.3 | 2.1 | 1.2 | 1.2 |
| | v | | | | | | 1.9 | 2.0 | 1.5 | 1.9 | 1.6 | 2.1 | 3.2 |
| 1976 | $t_p$ | -3.5 | -3.0 | -2.8 | 4.2 | 10.2 | 13.4 | 15.8 | 12.2 | 10.1 | 7.9 | 3.2 | -3.4 |
| | $t_o$ | -2.6 | -2.1 | -2.5 | 4.3 | 10.4 | 14.1 | 16.2 | 12.8 | 10.1 | 8.4 | 3.3 | -2.9 |
| | $P_p$ | 100 | 19 | 15 | 16 | 39 | 41 | 114 | 73 | 40 | 63 | 72 | 40 |
| | $P_o$ | 151 | 26 | 35 | 35 | 73 | 45 | 112 | 87 | 67 | 77 | 141 | 61 |
| | s | 40 | 96 | 86 | 133 | 191 | 253 | 217 | 193 | 98 | 109 | 27 | 25 |
| | d | 1.2 | 1.3 | 1.7 | 2.9 | 5.8 | 7.8 | 7.7 | 4.5 | 2.8 | 2.5 | 1.4 | 1.2 |
| | v | 3.9 | 2.2 | 2.2 | 2.1 | 1.7 | 1.8 | 1.4 | 1.2 | 1.3 | 2.3 | 2.6 | 2.0 |
| 1977 | $t_p$ | -2.4 | -0.7 | 4.0 | 3.5 | 9.5 | 13.9 | 13.8 | 13.6 | | | | |
| | $t_o$ | -2.1 | -0.1 | 4.3 | 3.7 | 9.9 | 14.2 | 14.2 | 13.9 | | | | |
| | $P_p$ | 22 | 49 | 22 | 37 | 112 | 116 | 132 | 168 | | | | |
| | $P_o$ | 34 | 78 | 45 | 70 | 143 | 133 | 180 | 387 | | | | |
| | s | 29 | 56 | 95 | 122 | 145 | 150 | 148 | 116 | | | | |
| | d | 1.0 | 1.3 | 2.5 | 2.7 | 4.5 | 5.0 | 5.0 | 3.3 | | | | |
| | v | 1.8 | 1.6 | 2.9 | 3.1 | 1.8 | 1.5 | 1.9 | 1.8 | | | | |

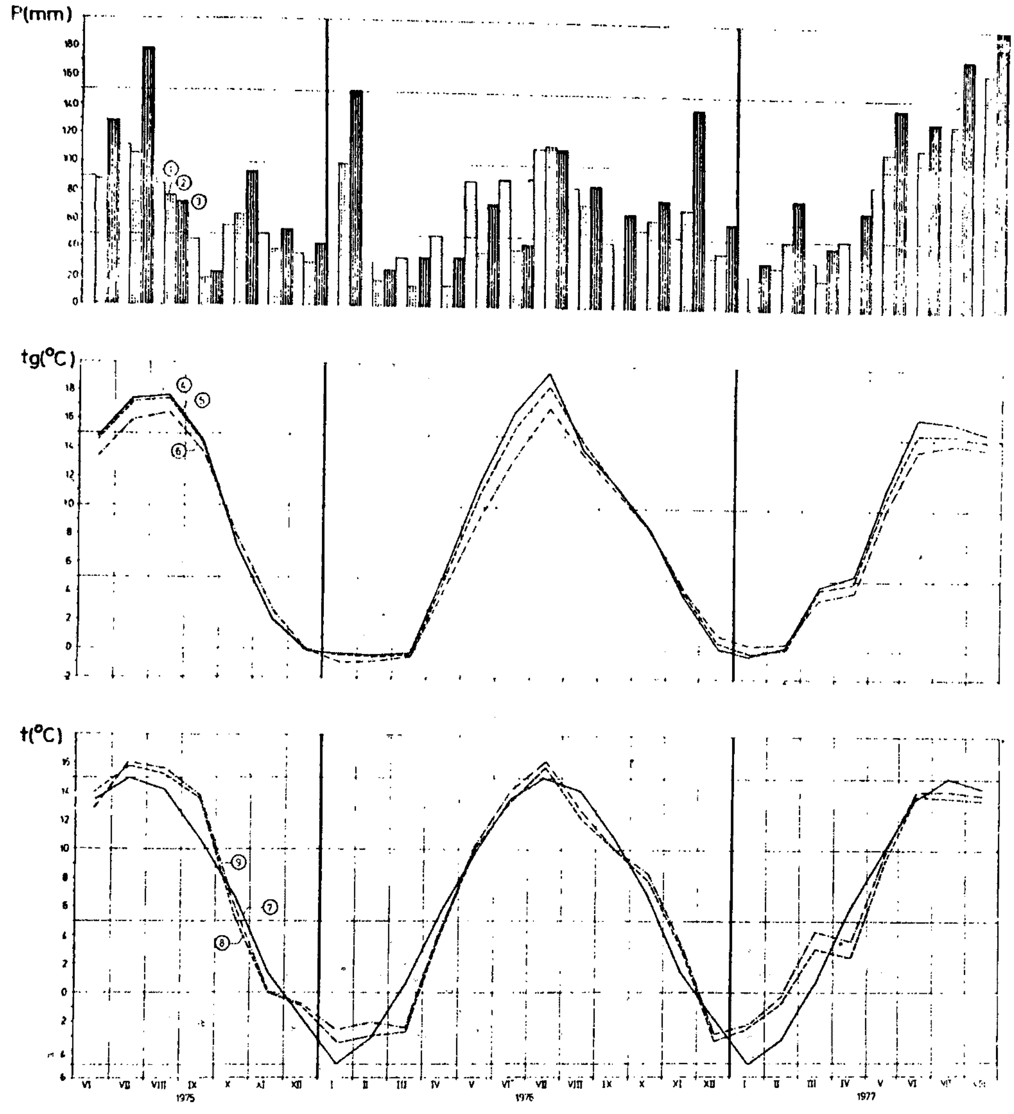



Fig. 16 MONTHLY VALUES OF ATMOSPHERIC PRECIPITATIONS (P IN mm), OF SOIL TEMPERATURE (tg) AND OF AIR TEMPERATURE (t,°C) 1975–1977 AT PAPROTKI AND OGORZELEC
1 – long term precipitation 1951–1970 in station Paprotki. 2 – precipitation in station Paprotki in years 1970–1977. 3 – precipitation in station Ogorzelec in years 1970–1977. 4 – temperature of soil in station Ogorzelec at 5 cm depth. 5 – temperature of soil in station Ogorzelec at 10 cm depth. 6 – temperature of soil in station Ogorzelec at 20 cm depth. 7 – long term air temperature 1951–1970 at Paprotki. 8 – air temperature 1970–1977 at Paprotki. 9 – air temperature 1975–1977 at Ogorzelec

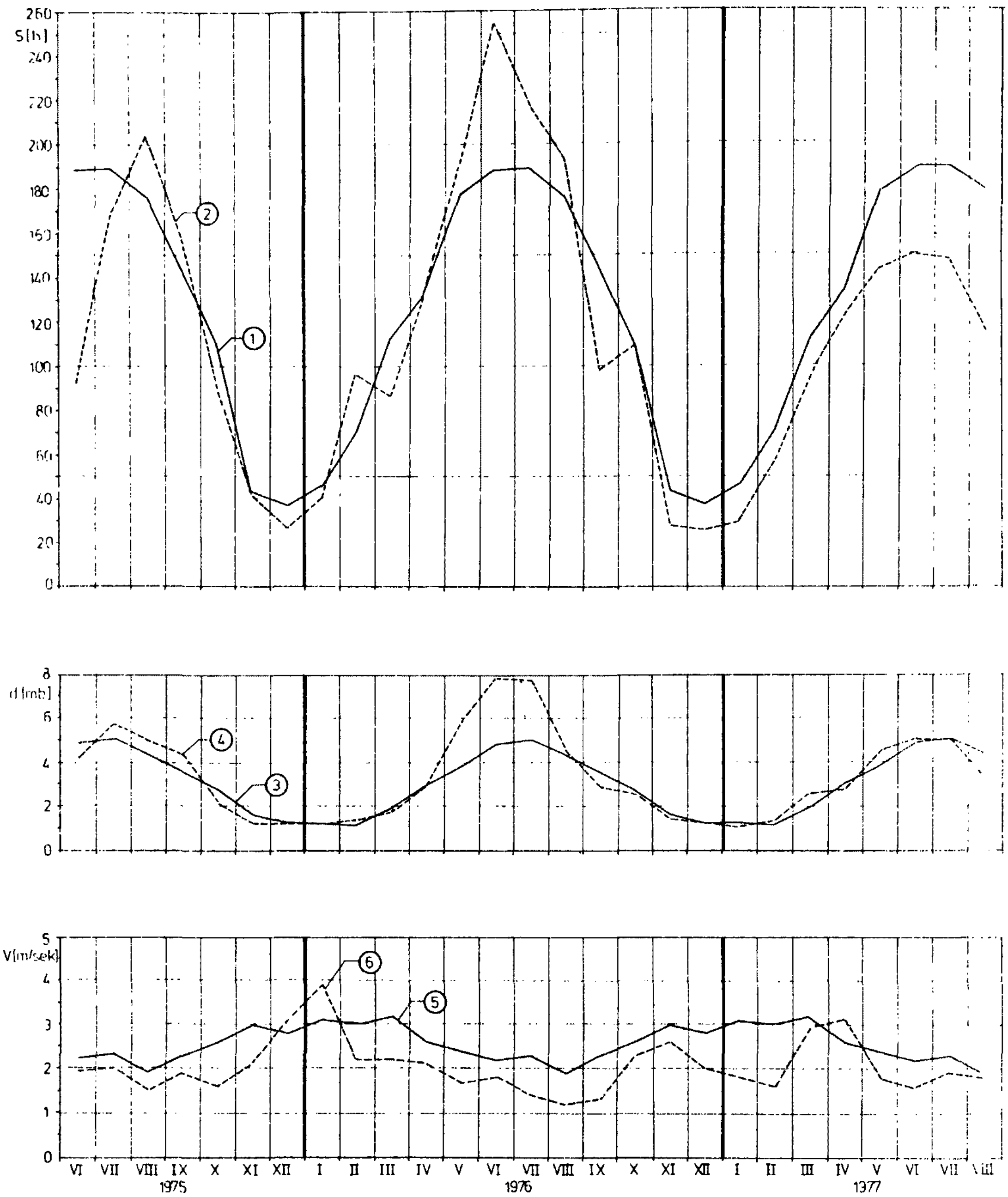



Fig17 MONTHLY VALUES OF ACTUAL INSOLATION ( S IN HOURS ) PARTIAL AIR SATURATION ( d IN mb ) AND WIND VELOCITY ( v IN m/sec ) IN STATION OGORZELEC.

1 - long term insolation for 1951 - 1970, 2 - insolation for 1975 - 1977, 3 - long term partial air saturation for 1951 - 1970, 4 - partial air saturation for 1975 - 1977, 5 - long term wind velocity for 1951 - 1970, 6 - wind velocity for 1975 - 1977

SECTION 7

# PREPARATORY STUDIES FOR THE DESIGN AND CONSTRUCTION OF A SUBSURFACE DRAINAGE SYSTEM FOR THE TAILINGS AT OGORZELEC

## MODEL TESTS OF ELECTROOSMOTIC DRYING

The tailings in the sedimentation basins are difficult to drain. It was, therefore, decided to conduct model tests prior to field tests to determine the optimal values of the current density, the type of electrodes, and the best spatial arrangement.

### Research model configuration no. 1

This stand was designed with the objective of observing electroosmosis phenomenon in the tailings and to determine the general conditions benefiting draining.

A container of reinforced plates was constructed with dimensions of 300x150x100 cm. The interior of the box was lined with fiberglass, impregnated with epoxy resin. The resin was applied to seal off the box and to electrically insulate the box from the sediment.

Electrofilters made of aluminium pipes with diameters ϕ 40 mm and ϕ 25 mm were spaced as shown in fig. 18. Pipes were connected in groups with a flat copper bar. Figure 19 shows the model after filling with tailings.

A 5 kVA autotransformer and a rectifer on siliceous diodes in Graetz system were employed. An electric diagram is shown in fig. 20.

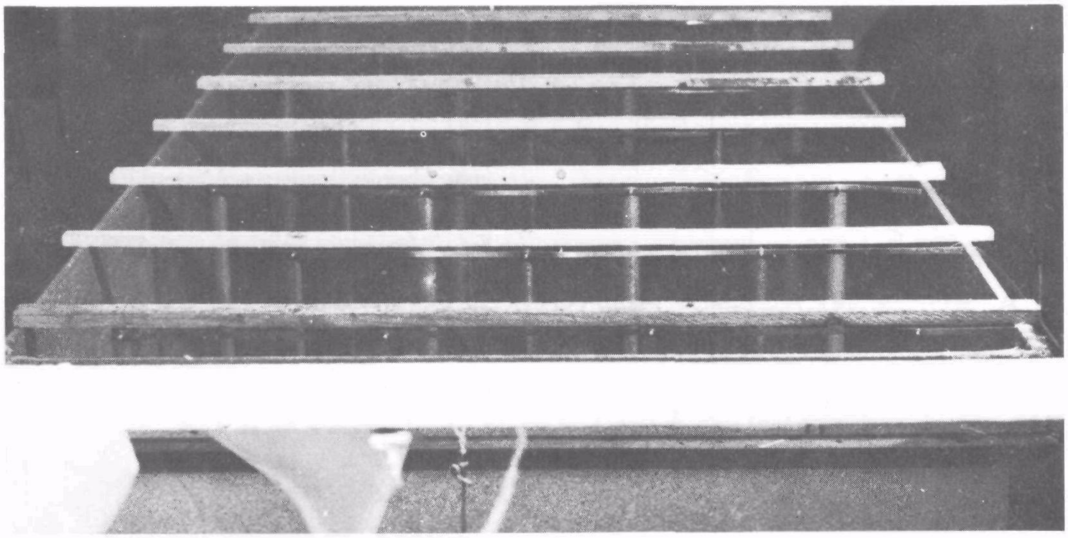


Fig. 18. Research stand no. 1 - reservoir for model tests.

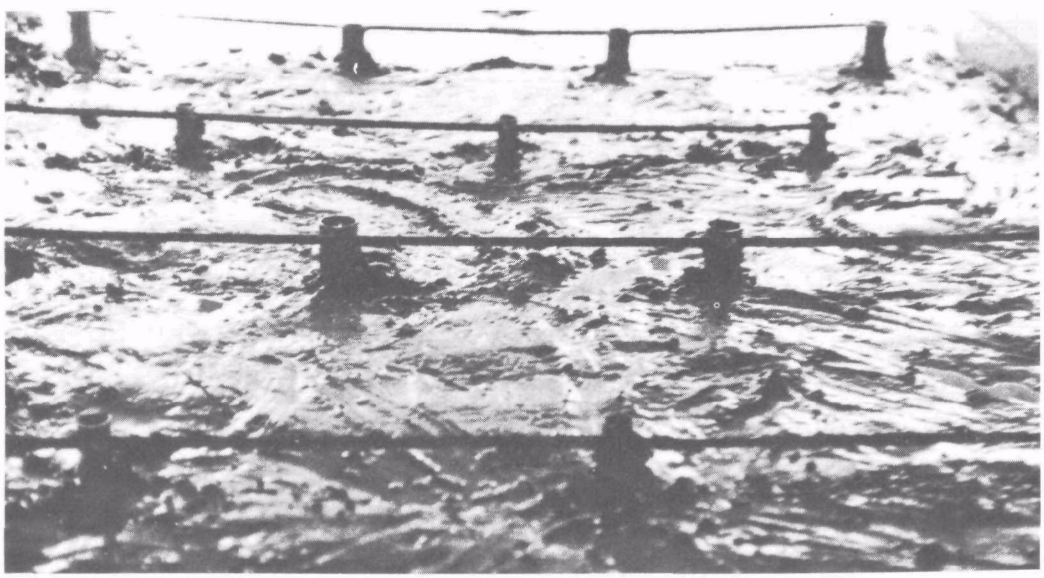


Fig. 19. Fragment of model stand no. 1 - after filling with sediment.

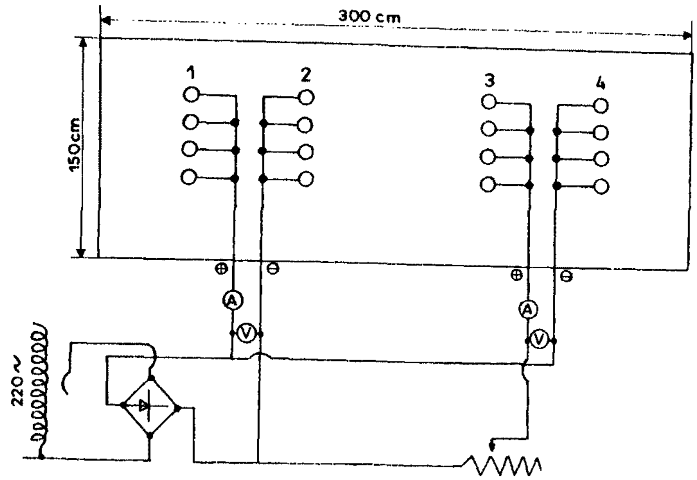



Fig.20 SCHEMATIC OF ELECTRICAL SYSTEM FOR RESEARCH MODEL No.1
(1,2,3,4 - INDICATES ROWS OF ELECTRODES)

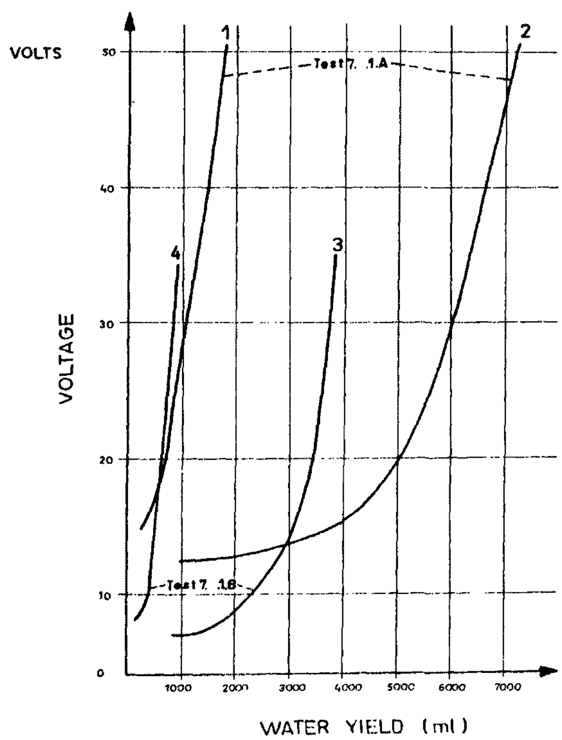



Fig.21 AVERAGE TOTALIZED WATER YIELDS WITH CONSTANT CURRENT INTENSITY - TESTS 7. 1.A AND 7. 1.B
(1,2,3,4 -INDICATES ROWS OF ELECTRODES)

This system can simultaneously produce two different current densities on two different groups of electrodes.

Four and one-half $m^3$ of tailings were compacted uniformly in the box. The electrofilters were purged to remove sludgeand the pipes connected such that row 2 served as a cathode and wells of row 2 and row 1 were the anode. A constant current of 2 A was applied giving 0.5 A per well (Test 7.1.A).

A second field was simultaneously created using row 4 as the anodes and row 3 as the cathodes. A current intensity of 1 A was applied to these resulting in 0.25 A per well (Test 7.1.B.). The intensity was corrected twice a day at the time accumulated water was discharged. The average total yields of "wells" of particular rows are shown on fig. 21. The diagram suggests the rate of current density has a strong influence on water yield. While most of the water accumulated at the cathodes, small quantities also accumulated at the anodes. Water in cathodes was a yellowish, light green, while that at the anodes was dark grey. This suggested different chemical compositions. Water chemistry tests were therefore performed. The results are summarized in table 25. The "anode water" contained a large amount of $SO_4$, which also explains the intense corrosion of the aluminum pipes observed during the tests.

The corrosion also attacked steel anodes. Additional tests were performed to identify measures that could protect against corrosion. Pipe coatings of various types were applied with an epoxy resin. The value of the resistance between two aluminium pipes without any coating was used was a reference (R=1) to compare the effect of the anti-corrosion coatings on the efficiency of producing water with given amounts of current. The following coatings were tried:

- paint containing 80 % of lead minium; R = 5.22,
- paint containing 80 % of lead minium with 5 % carbon black added; R = 5.3
- paint with 32 % zinc dust; R = 10.8
- paint with 30 % coal dust; R = 16.8

- paint with 32 % zinc dust and 5 % coal dust; R = 11
- electrode of carbon black; R = 2.6

These coats greatly increase the contact resistance, and only the electrodes made of carbon black appear to have potential for use. However such electrodes are fragile and difficult to fabricate in adequate lengths and thus do not have a practical application.

Additional tests were made on coating steel pipes with lead, using a method of thermal plating. Given the considerable resistance of lead to chemical action, one could presume that lead-treated pipes would have a greatly extended life. The model tests performed on lead plated pipes confirmed the potential for longer life. However one could not completely prevent corrosion. Corrosion caused scaling of the lead plate. It appears that metal scrap might be best for anodes, assuming that it is expendable, since economical means of controlling corrosion were not identified. It is advisable to protect the surfaces of the electro-filters with a thin lead coating.

Model research configuration no. 2

These laboratory investigations were performed on relatively undisturbed tailings sediments collected in a cylinder 40 cm in diameter and 30 cm in height (volume 37.68 liters).

These tests were performed to determine changes in resistance occurring with changes in the type of electrode.

The samples were collected such that after removal of the upper 15 cm of tailings at the field site the cylinder was pressed into the sediment. After removing the sediment around the sides, the tailings inside the container were cut from the underlying material with a metal sheet and rotated by 180$^{o}$ (fig. 22-25).

Cathodes were inserted in the tailings to estimate their electric resistance (R), calculated from voltage and current measured at 10 min. intervals.

For the standard filter - steel pipe coated with layer of lead and without an outer shield (figure no. 26 and test 7.2.C.) the results are presented in table 6.

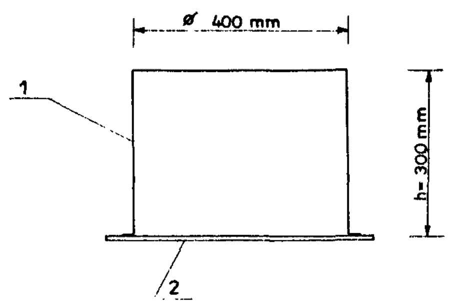



Fig. 22 DIMENSIONAL SKETCH OF CONTAINER FOR MODEL TESTS - CONFIGURATION NO. 2
1 - cylinder of steel sheet, 2 - textolite plate

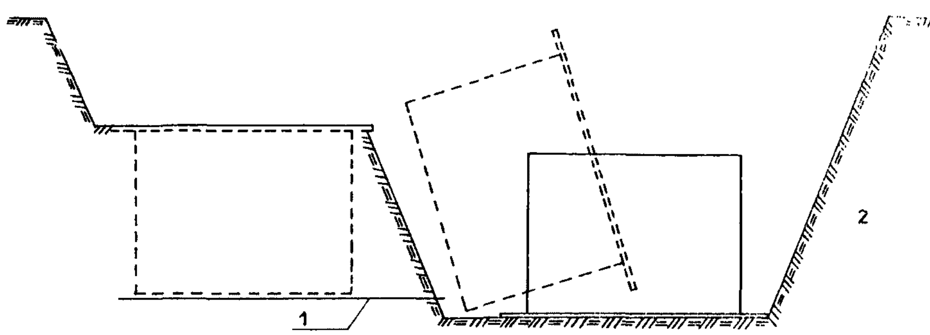



Fig. 23 METHOD OF COLLECTING TAILINGS TO MINIMIZE DISTURBANCE FOR MODEL TESTS
1 - metal sheet, 2 - tailings

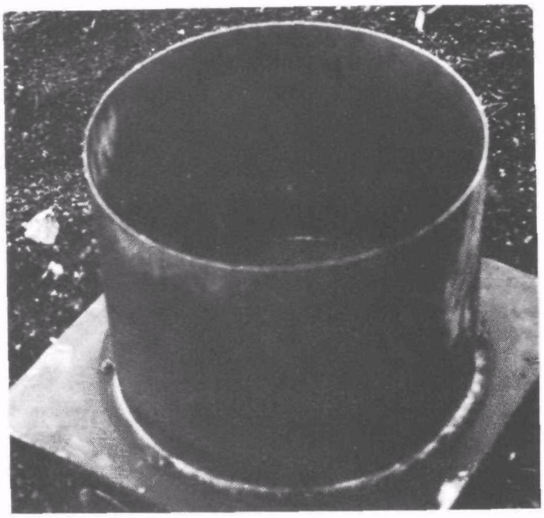


Fig. 24. View of container for model tests - configuration no. 2.

Fig. 25. Container for model tests filled with tailings.

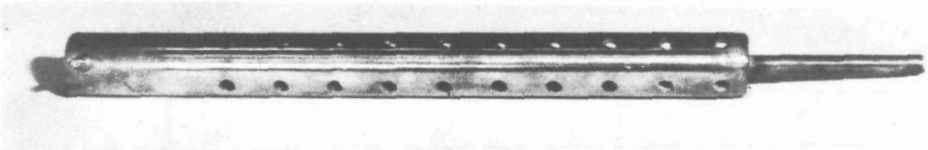


Fig. 26. Standard steel filter-cathode-lead coating.

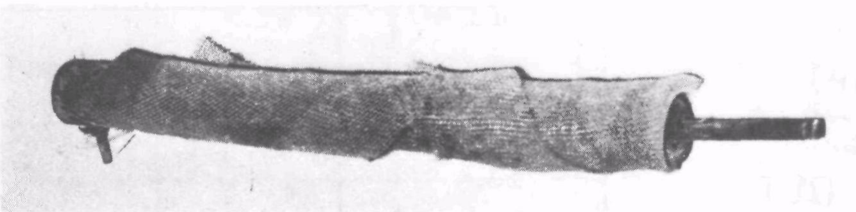


Fig. 27. Filter-cathode wrapped with nylon gauze.

Results of test 7.2.C.

Table 6

| Electrical variables | time 0 min. | 10 min. | 20 min. | 30 min. |
|---|---|---|---|---|
| Voltage U (V) | 18.2 | 20.5 | 6.6 | 7.5 |
| Current I (A) | 1.30 | 1.55 | 0.45 | 0.51 |
| Resistance R ($\Omega$) | 14.0 | 13.4 | 14.6 | 14.5 |

The cathode consisting of a steel pipe wrapped in a single nylon gauze (mesh 1 x 1 mm test 7.2.D. ) was also tested and the results are presented in table 7.

Results of test 7.2.D.

Table 7

| Electrical variables | time 0 min. | 10 min. | 20 min. | 30 min. |
|---|---|---|---|---|
| Voltage U (V) | 7.5 | 10.2 | 13.6 | 14.6 |
| Current I (A) | 0.48 | 0.72 | 0.98 | 11.0 |
| Resistance R ($\Omega$) | 15.6 | 14.3 | 14.0 | 13.2 |

The experimental results using a cathode doubly - wrapped with nylon gauze are presented in table 8 (test 7.2.E. ).

Results of test 7.2.E.

Table 8

| Electrical variables | time 0 min. | 10 min. | 20 min. | 30 min. |
|---|---|---|---|---|
| Voltage U (V) | 10.6 | 13.0 | 21.0 | 25.5 |
| Current I (A) | 0.44 | 0.57 | 1.06 | 1.35 |
| Resistance R ( Ω ) | 24.1 | 22.8 | 19.8 | 18.9 |

A fourth filter arrangement consisting of gravel packing was also tested (test 7.2.F. ). The results are indicated in table 9.

Results of test 7.2.F.

Table 9

| Electrical variables | time 0 min. | 10 min. | 20 min. | 30 min. |
|---|---|---|---|---|
| Voltage U (V) | 8.8 | 7.7 | 20.3 | 11.0 |
| Current I (A) | 0.12 | 0.106 | 0.15 | 0.17 |
| Resistance R ( Ω ) | 73.2 | 72.6 | 68.7 | 64.7 |

Analysis of these results indicates that the unwrapped filter has the lowest resistance. Thus such filters require the least amount of electrical energy for unit discharges of water. The standard filter has one fundamental drawback, that is the need to make numerous very small holes to allow water to seep in and to keep the tailings out of the casing. The addition of a nylon gauze increases the resistance a small amount but this increase appears to decrease slightly with time. If the gauze simplifies the construction of the perforations, the gauze could be useful.

It may be possible that after a certain time the resistance of the wrapped cathodes will approach the values of the unwrapped, standard cathodes. Considering these observations systematic model tests were iniated to determine the effects of a filtration shield on the resistance and on the inflow of water to the filters.

Model research configuration no. 3

This configuration was used to further investigate relationships between resistance and water discharges with gravel filtration shields. Two models were constructed in containers just as for configuration no. 2. The initial water content of the tailings was 36.48 percent.

The positive electrode, the anode, was the wall of the container. The cathodes were a standard filter without a shield (test 7.3.6.) and a filter with a gravel packing (test 7.3.H).

After installing the filters, both cathode arrangements were fed with direct and uniform current from two feeders (fig. 28, 29). Measurements included current (I), the corresponding voltage (U) and the water discharges (Q). The results of these measurements are presented in tables 10 and 11.

Graphical representation of the change in resistance with times for the two tests is shown in figure 30. Resistance initially decreased during both tests. It then rose to values essentially equal.

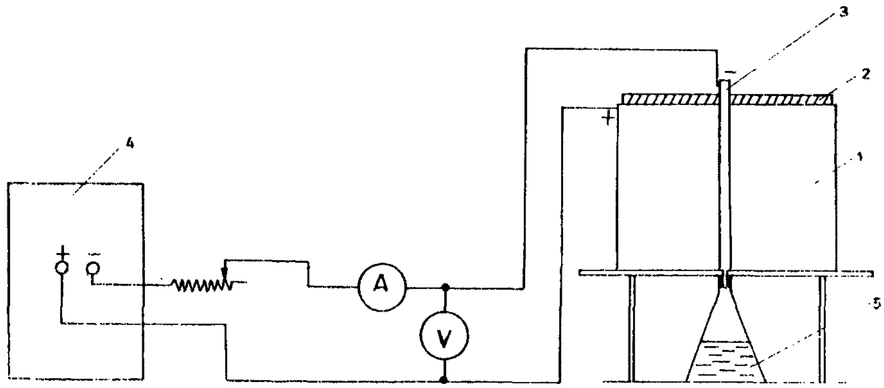



Fig.28 SCHEMATIC FOR ELECTRICAL SYSTEM USED FOR STANDARD FILTER (WITHOUT SHIELD) - TEST 7.3.G.
1 - container with pulp, 2 - pressure load, 3 - standard filter, 4 - D.C. feed, 5 - water reservoir

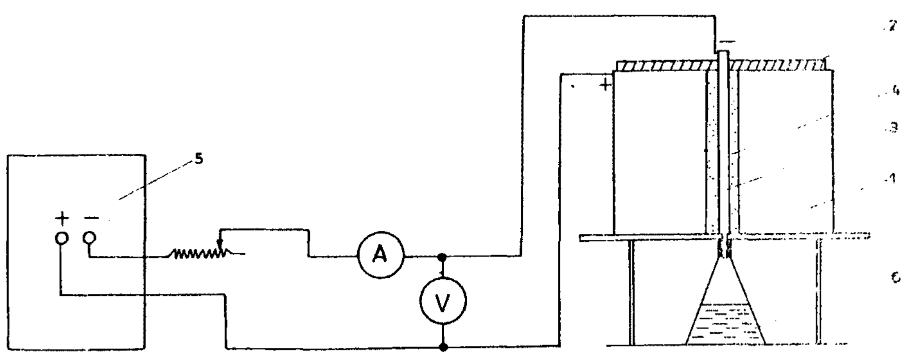



Fig 29. SCHEMATIC OF ELECTRICAL SYSTEM USED FOR FILTER WITH GRAVEL PACK SHIELD - TEST 7.3.H.
1 - container with pulp, 2 - pressure load, 3 - filter, 4 - gravel packing, 5 - D.C. feed, 6 - water reservoir.

Further changes in the resistance indicated cracking of tailings and for this reason are not taken into account.

It was found that the filter packing presents considerable resistance with electrolyte, i.e. with water discharged under the action of electro-osmosis. The water discharges of the two tests varied some what (table 12 and fig. 31) which indicates some restriction to flow caused by the gravel packing.

Valid comparisons of resistance were obtained during a period of 2 days. Continuation of the tests was not appropriate since the sediment was cracking. It was therefore decided to perform another comparison test of 3 filters with a different arrangement and power supply.

Table 10

Change of resistance with time R = f (T)

Test 7.3.G.

| Measurement | Current (A) | Voltage (V) | Resistance (Ω) | Time of sampling | |
|---|---|---|---|---|---|
| | | | | Day | Hour |
| 1 | 0.75 | 9.6 | 12.8 | 29 Jan.75 | 10.00 |
| 2 | 0.75 | 9.5 | 12.6 | - " - | 10.10 |
| 3 | 0.75 | 9.2 | 12.2 | - " - | 10.30 |
| 4 | 0.75 | 8.8 | 11.7 | - " - | 11.40 |
| 5 | 0.75 | 8.6 | 11.5 | - " - | 14.07 |
| 6 | 0.75 | 14.4 | 19.2 | 30 Jan.75 | 9.15 |
| 7 | 0.75 | 14.7 | 19.6 | - " - | 12.10 |
| 8 | 0.75 | 19.6 | 26.2 | - " - | 15.30 |
| 9 | 0.43 | 21.5 | 50.0 | 31 Jan.75 | 9.00 |
| 10 | 0.610 | 28.8 | 47.8 | - " - | 10.30 |
| 11 | 0.750 | 29.0 | 38.7 | - " - | 15.30 |
| 12 | 0.53 | 29.3 | 55.3 | 1 Feb. 75 | 7.90 |
| 13 | 0.47 | 28.7 | 61.1 | 3 Feb. 75 | 8.00 |

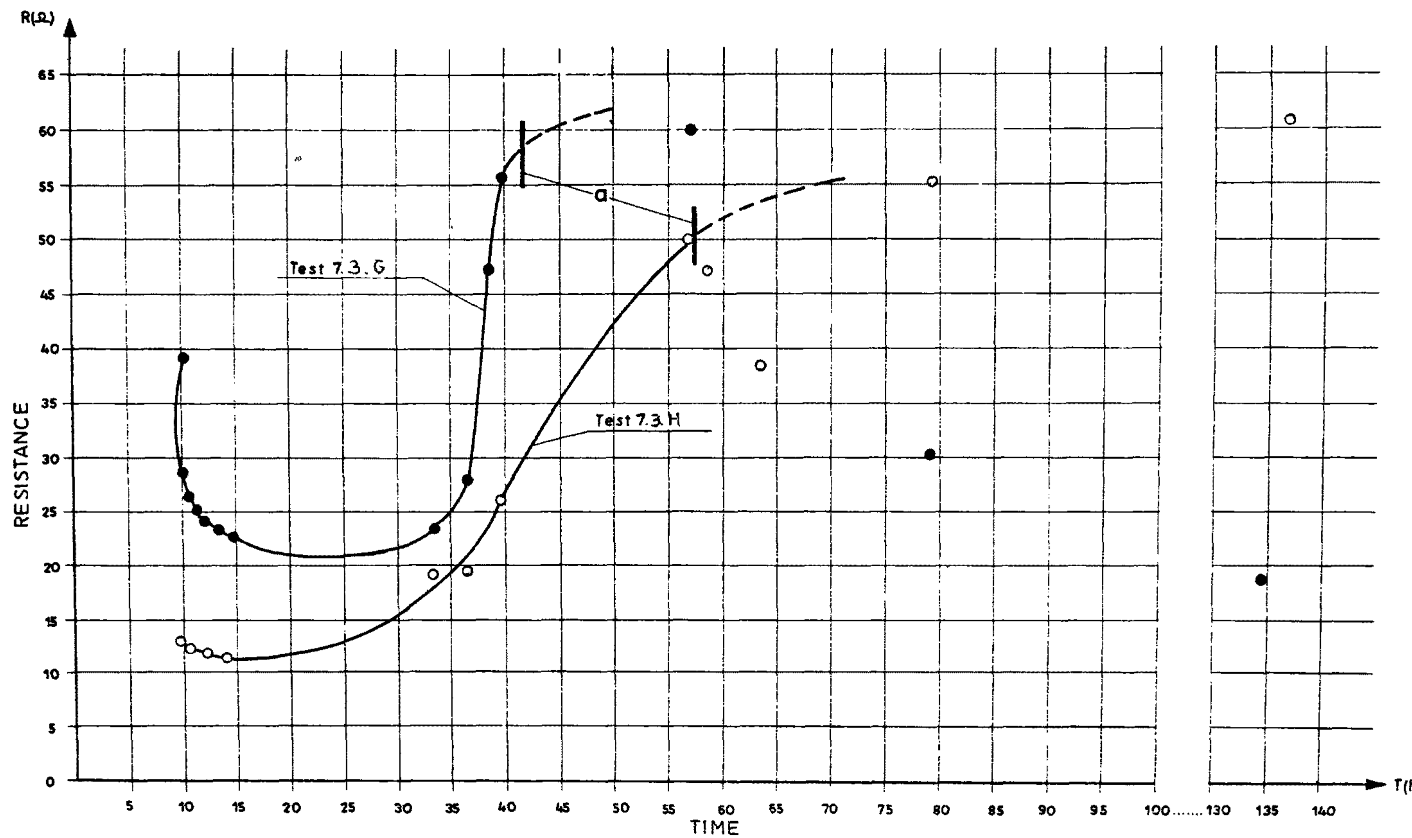



Fig.30 CHANGE OF RESISTANCE (R) WITH TIME (T). TESTS 7.3.G and 7.3.H. a—appearance of sediment fissures.

Table 11

Change of resistance with time R = f (T)

Test 7.3.H.

| Measurement | Current | Voltage | Resistance | Time of sampling | |
|---|---|---|---|---|---|
| | (A) | (V) | (Ω) | Day | Hour |
| 1. | 0.750 | 29.5 | 99.2 | Jan.29,75 | 10.00 |
| 2. | 0.750 | 21.5 | 28.6 | Jan.29,75 | 10.15 |
| 3. | 0.750 | 19.7 | 26.3 | Jan.29,75 | 10.37 |
| 4. | 0.750 | 18.7 | 25.0 | Jan.29,75 | 11.27 |
| 5. | 0.750 | 18.1 | 24.2 | Jan.29,75 | 11.53 |
| 6. | 0.750 | 17.5 | 23.2 | Jan.29,75 | 13.02 |
| 7. | 0.750 | 17.0 | 22.7 | Jan.29,75 | 14.29 |
| 8. | 0.750 | 17.3 | 23.1 | Jan.30,75 | 9.15 |
| 9. | 0.750 | 28.2 | 27.7 | Jan.30,75 | 12.10 |
| 10. | 0.620 | 29.3 | 47.3 | Jan.30,75 | 14.10 |
| 11. | 0.530 | 29.6 | 55.8 | Jan.30,75 | 15.30 |
| 12. | 0.200 | 30.0 | 60.0 | Jan.31,75 | 9.00 |
| 13. | 0.735 | 22.5 | 30.6 | Feb.1,75 | 7.00 |
| 14. | 1.10 | 20.8 | 18.9 | Feb.3,75 | 8.00 |

Table 12

Water discharges in time $Q_w = f(T)$

Tests 7.3.G and 7.3.H.

| Discharge | Time of measurement | | Water discharge in g. | |
|---|---|---|---|---|
| | Day | Hour | Test 7.3.G. | Test 7.3.H |
| 1. | Jan.29,75 | 15.00 | 233.2 | 236.8 |
| 2. | Jan.30,75 | 9.00 | 538.8 | 537.0 |
| 3. | Jan.30,75 | 15.30 | 214.5 | 277.7 |
| 4. | Jan.31,75 | 10.30 | 265.0 | 118.0 |
| 5. | Feb.1,75 | 10.00 | 164.6 | 34.2 |
| 6. | Feb.3,75 | 14.30 | 31.9 | 66.6 |
| 7. | Feb.4,75 | 10.30 | 2.5 | 10.6 |
| 8. | Feb.5,75 | 13.00 | 2.2 | 4.1 |

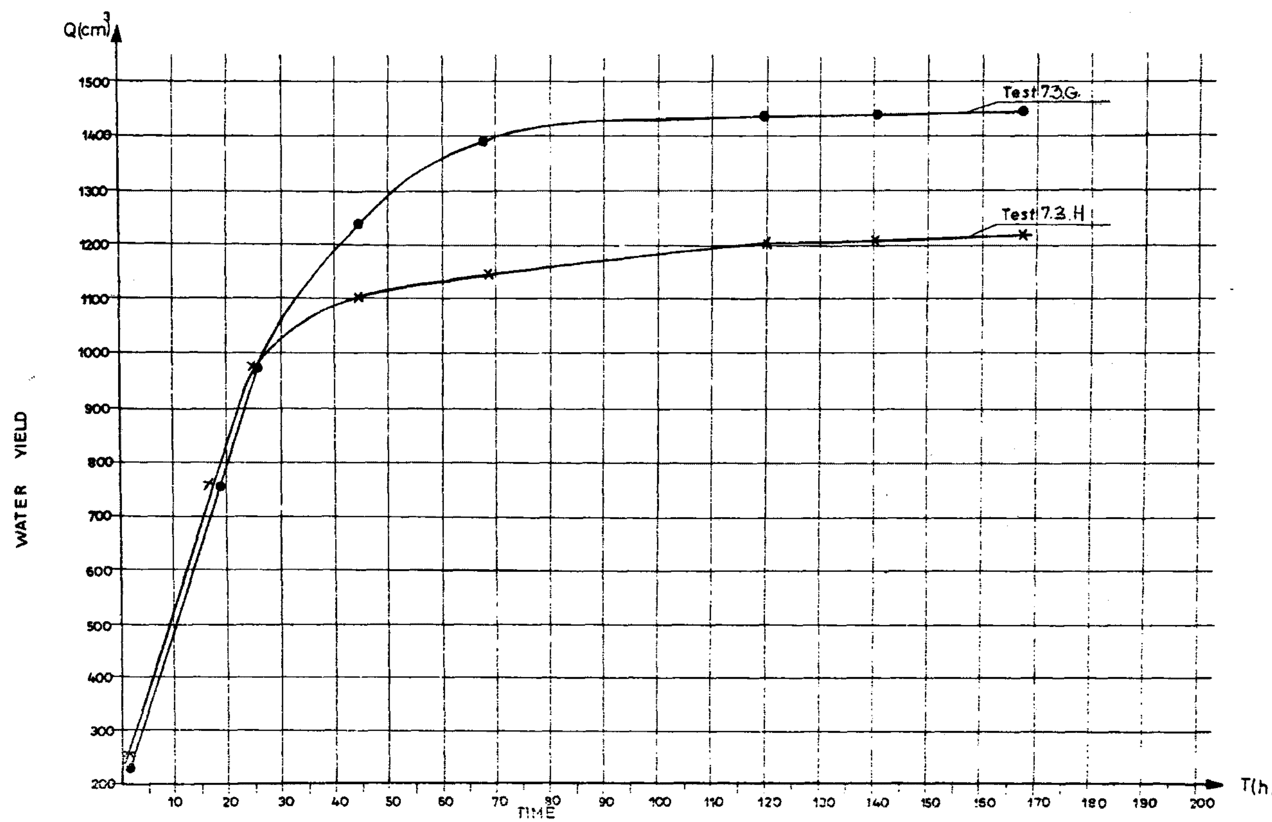



Fig.31 WATER YIELDS WITH TIME TESTS 7.3.G and 7.3.H

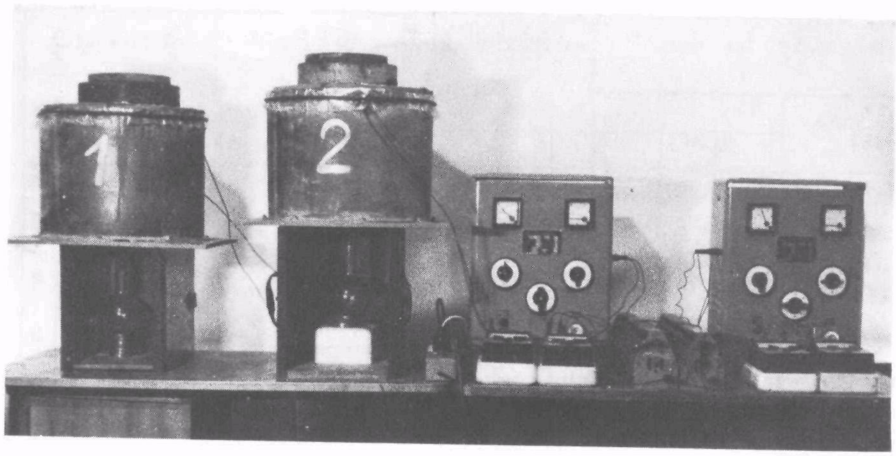


Fig. 32. General view of test configuration no. 3.

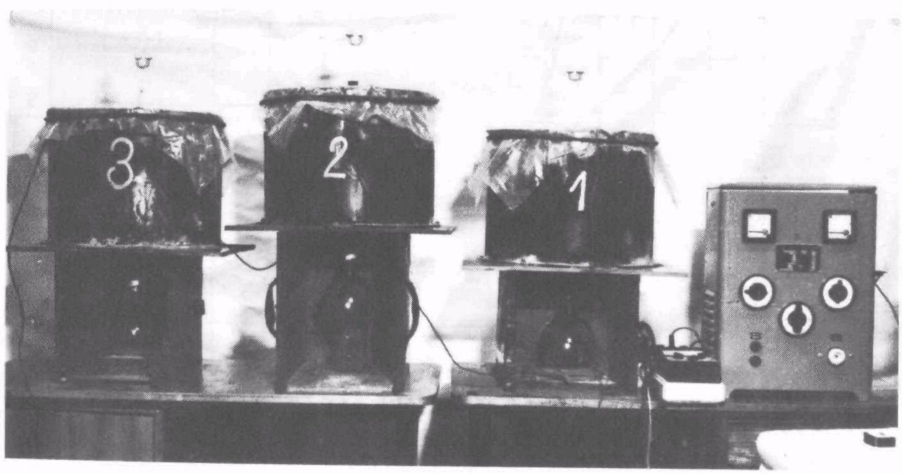


Fig. 33. General view of test configuration no. 4.

Model test configuration no. 4

This investigation was made in cylindrical containers identical to those previously described with a water content of 36.6 percent.

The configuration was composed of 3 containers connected to the same circuit. Each container had different cathodes. (Fig. 33).

To avoid the abrupt changes (increases) in resistance caused by dessication cracks in the sediment, flexible steel strips were used such that they would remain in contact with the tailings as it deformed (fig. 34).

The method of providing power to the electrodes was also modified to avoid differences in the averaged values of the electric current intensity for any of the 3 cathode configurations (fig. 35).

During the tests the current intensity was varied. Changes were monitored.

Using the relationship $R = \frac{U}{I}$, values of resistance were obtained (table 13).

The cathode filters tested were: a standard cathode (used in test 7.4.I.), a cathode wrapped in nylon gauze mesh (1 x 1 mm mesh used in test 7.4.J.) and a cathode with gravel packing (used in test 7.4.K.). The nylon gauze wrapping produced the largest amounts of water (figure 41, table 14). The resistance of the gravel - packed cathodes rose appreciably (figure 40) and produced less water (figure 41).

Considering that the wrapped filter will sink into the tailings as easily as the standard filter, the wrapped filter will likely be the more preferable configuration.

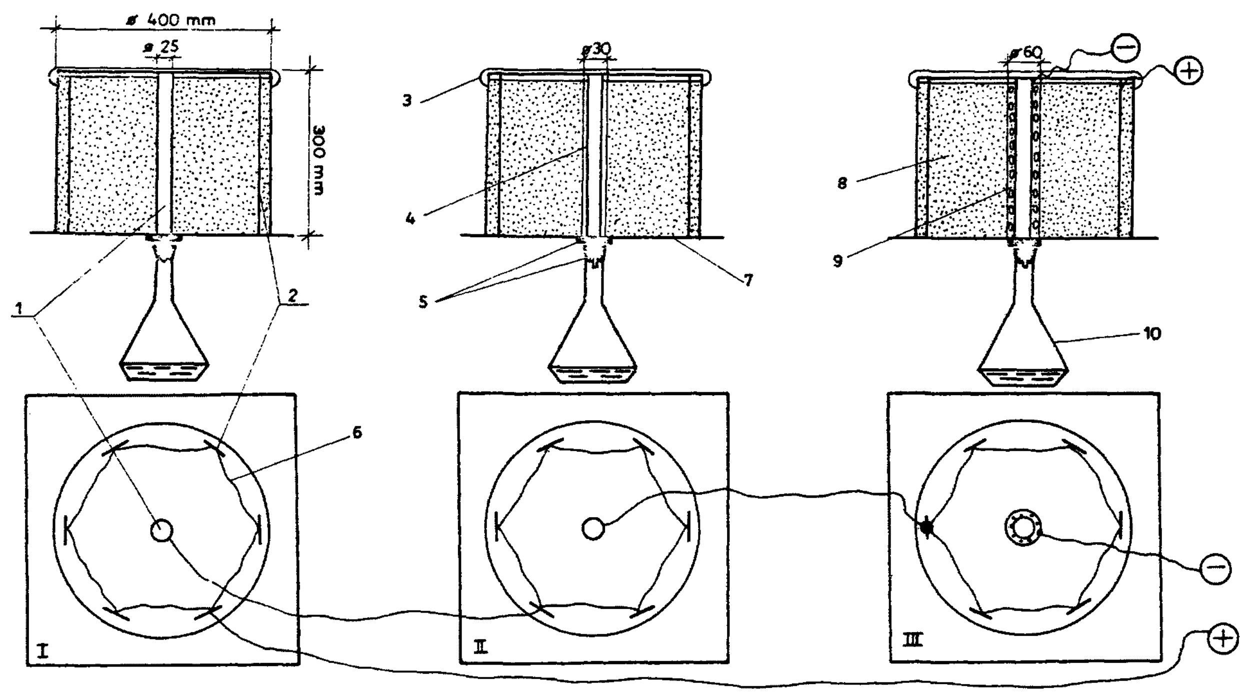



Fig.34 SCHEME OF TEST CONFIGURATION No 4
I, II, III – containers, 1 – filtercathode, 2 – anode, 3 – insulating foil, 4 – nylon gauze, 5 – washers, 6 – lead, 7 – base, 8 – tailings, 9 – gravel packing, 10 – water catchment vessel.

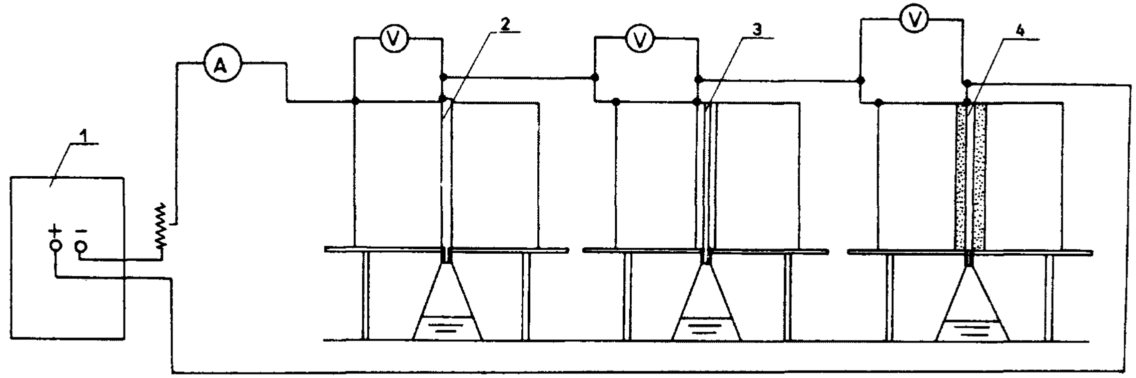



Fig.35 SCHEME OF ELECTRIC CONNECTIONS OF TEST CONFIGURATION No 4
1 - D.C feed , 2 - cathode without filter , 3 - cathode with nylon gauze ,
4 - cathode with gravel packing .

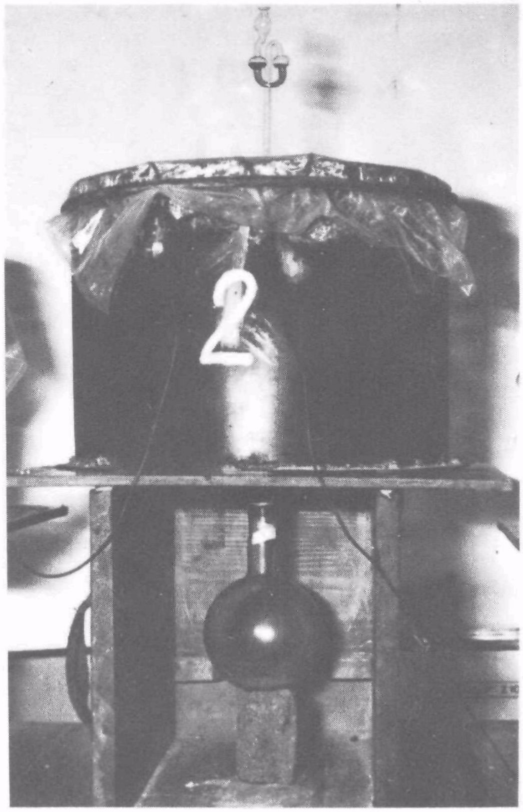


Fig. 36. Element of test configuration no. 4.

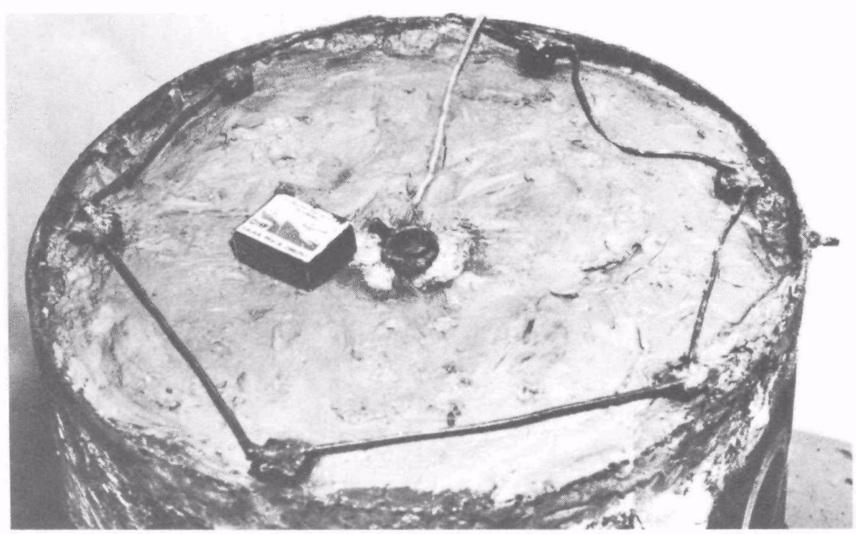


Fig. 37. View of surface of the container during tests - filtercathode without filtration shield (configuration no. 4).

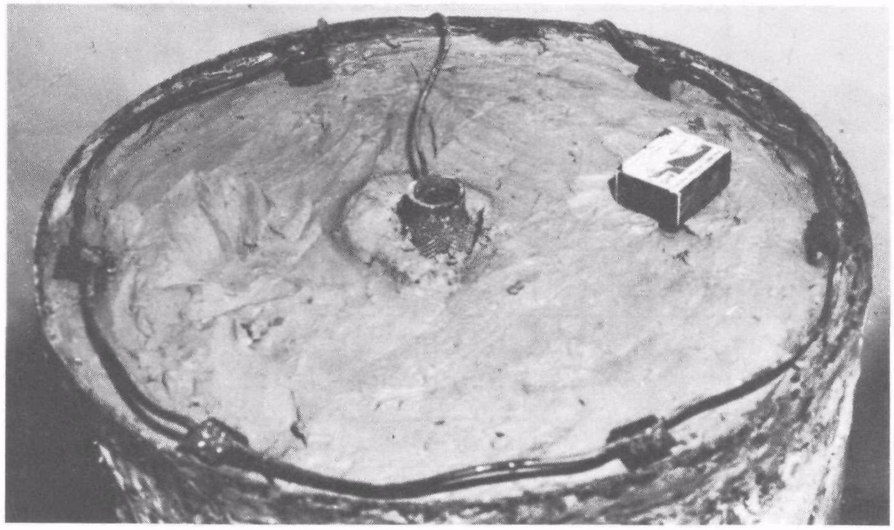


Fig. 38. View of the container surface during the tests - filtercathode shielded with nylon gauze (configuration no. 4).

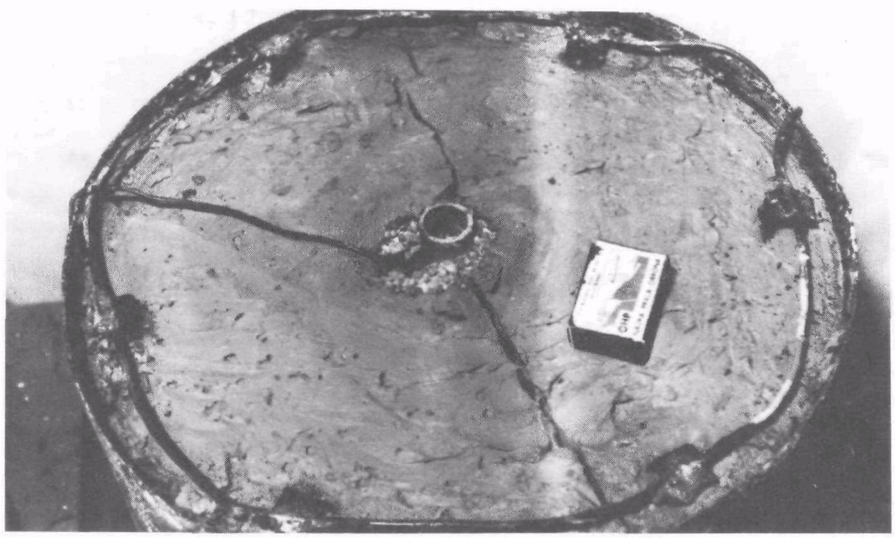


Fig. 39. View of the container surface during tests - filter - cathode surrounded by gravel packing (configuration no. 4).

Table 13

Model configuration no. 4

Resistance change in time R = t(T)

| Measurement | Current (A) | Voltages $U_1$ (V) | $U_2$ (V) | $U_3$ (V) | Resistance $R_1$ (Ω) | $R_2$ (Ω) | $R_3$ (Ω) | Time of measurement Day | Hour |
|---|---|---|---|---|---|---|---|---|---|
| 1. | 0.250 | 3.5 | 4.3 | 5.7 | 14.0 | 17.2 | 22.8 | Mar.19 | 12.00 |
| 2. | 0.295 | 3.2 | 4.5 | 5.8 | 10.7 | 15.5 | 19.6 | Mar.19 | 13.00 |
| 3. | 0.258 | 2.7 | 3.9 | 4.8 | 10.7 | 15.5 | 19.0 | Mar.19 | 14.00 |
| 4. | 0.220 | 3.0 | 4.2 | 4.6 | 13.6 | 19.1 | 20.0 | Mar.20 | 7.30 |
| 5. | 0.240 | 3.4 | 4.4 | 6.8 | 14.3 | 28.5 | 28.4 | Mar.20 | 14.30 |
| 6. | 0.245 | 3.9 | 5.9 | 7.9 | 15.9 | 24.0 | 32.2 | Mar.21 | 8.00 |
| 7. | 0.278 | 4.4 | 6.6 | 9.7 | 15.8 | 25.7 | 34.7 | Mar.21 | 15.00 |
| 8. | 0.140 | 3.0 | 6.3 | 9.9 | 21.4 | 45.0 | 70.7 | Mar.21 | 7.00 |
| 9. | 0.178 | 3.4 | 8.2 | 14.9 | 19.1 | 46.0 | 84.0 | Mar.25 | 7.30 |
| 10. | 0.218 | 3.8 | 10.5 | 21.0 | 17.4 | 48.2 | 96.5 | Mar.26 | 7.30 |
| 11. | 0.217 | 3.7 | 12.0 | 24.6 | 17.0 | 55.4 | 113.0 | Mar.27 | 7.30 |
| 12. | 0.290 | 4.8 | 17.8 | 33.6 | 16.5 | 61.5 | 114.0 | Mar.28 | 9.00 |
| 13. | 0.295 | 4.8 | 17.8 | 32.9 | 16.3 | 60.4 | 112.5 | Mar.28 | 15.00 |
| 14. | 0.274 | 4.6 | 14.2 | 36.7 | 16.8 | 52.0 | 134.0 | Mar.29 | 8.00 |
| 15. | 0.218 | 4.2 | 7.5 | 44.0 | 19.3 | 34.2 | 202.0 | Apr. 1 | 8.30 |
| 16. | 0.295 | 5.4 | 11.5 | 40.0 | 18.3 | 39.0 | 135.0 | Apr. 1 | 15.00 |
| 17. | 0.252 | 5.1 | 9.6 | 51.0 | 20.2 | 38.0 | 202.0 | Apr. 2 | 7.00 |
| 18. | 0.305 | 6.0 | 11.7 | 56.0 | 19.7 | 38.4 | 184.0 | Apr. 2 | 13.00 |
| 19. | 0.250 | 5.8 | 10.4 | 57.0 | 23.2 | 41.6 | 228.0 | Apr. 3 | 8.00 |
| 20. | 0.225 | 6.4 | 7.9 | 63.5 | 28.4 | 55.0 | 282.0 | Apr. 4 | 8.00 |
| 21. | 0.305 | 7.4 | 8.4 | 67.5 | 24.2 | 30.8 | 221.0 | Apr. 4 | 14.00 |
| 22. | 0.330 | 10.0 | 21.8 | 59.0 | 31.5 | 66.0 | 179.0 | Apr. 5 | 10.00 |

Table 14

Water discharges with time $Q_w = f(T)$

Tests 7.1.I., 7.4.J., 7.4.K.

| | Time of measurement | | Water discharge in g | | |
|---|---|---|---|---|---|
| | Day | Hour | Test 7.4.I. | Test 7.4.J. | Test 7.4.K. |
| 1. | Mar. 19 | 12.00 | 0 | 0 | 0 |
| 2. | Mar. 19 | 15.00 | 50.6 | 55.9 | 53.8 |
| 3. | Mar. 20 | 7.00 | 202.3 | 219.8 | 216.1 |
| 4. | Mar. 21 | 8.00 | 260.0 | 256.0 | 193.0 |
| 5. | Mar. 21 | 15.00 | 48.0 | 65.4 | 52.8 |
| 6. | Mar. 24 | 7.30 | 98.0 | 278.0 | 128.0 |
| 7. | Mar. 25 | 7.30 | 26.1 | 61.3 | 50.2 |
| 8. | Mar. 26 | 7.30 | 14.8 | 48.1 | 43.8 |
| 9. | Mar. 27 | 7.30 | 8.1 | 37.1 | 33.8 |
| 10. | Mar. 28 | 9.00 | 16.1 | 53.9 | 63.6 |
| 11. | Mar. 29 | 8.00 | 4.6 | 11.0 | 4.1 |
| 12. | Apr. 1 | 8.30 | 7.8 | 12.8 | 8.2 |
| 13. | Apr. 4 | 8.00 | 13.8 | 14.3 | 9.2 |
| 14. | Apr. 5 | 10.00 | 93.0 | 66.9 | 46.6 |

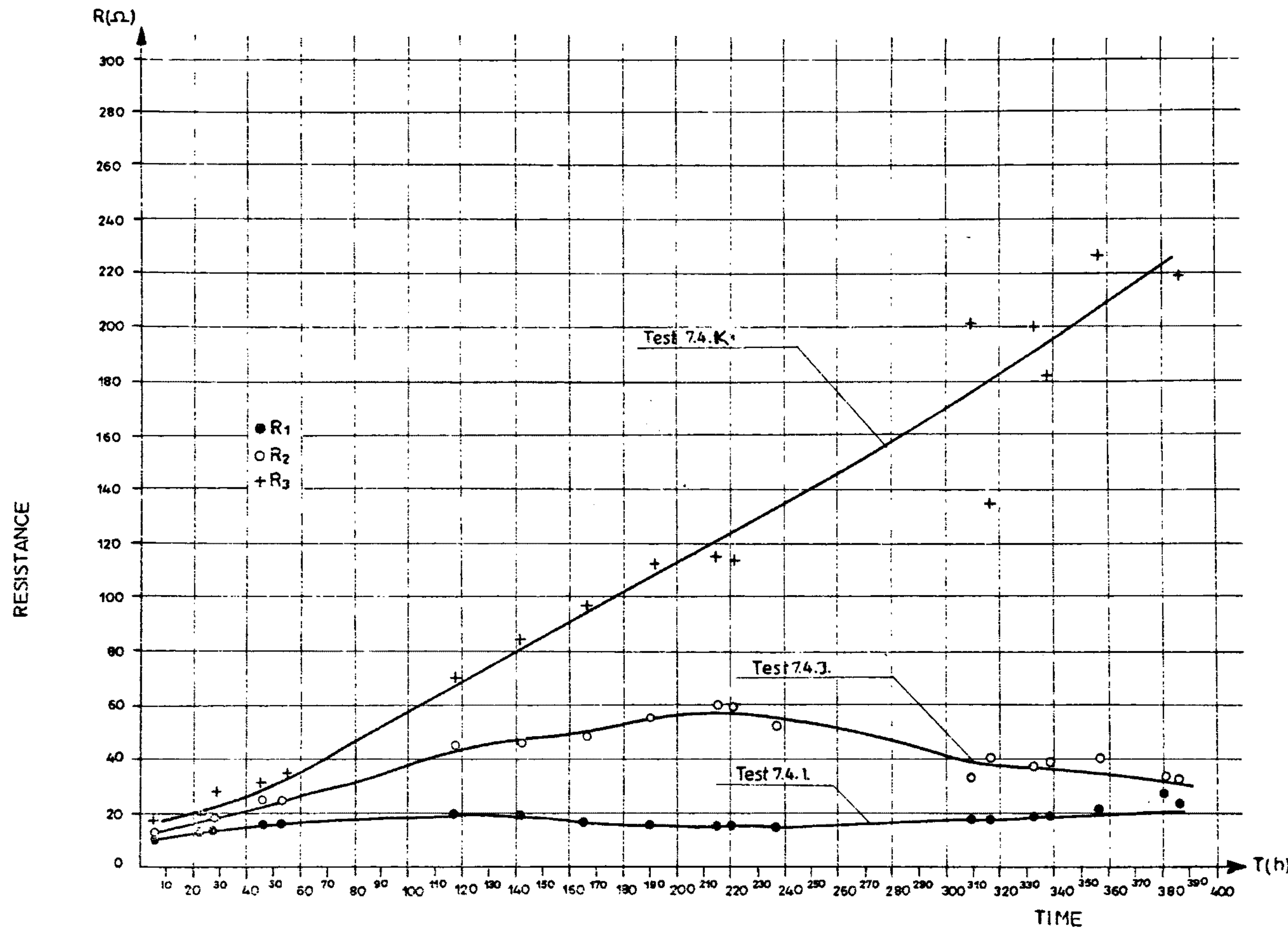



Fig.40 CHANGE IN RESISTANCE (R) WITH TIME (T). TESTS 7.4.I , 7.4.J , 7.4.K

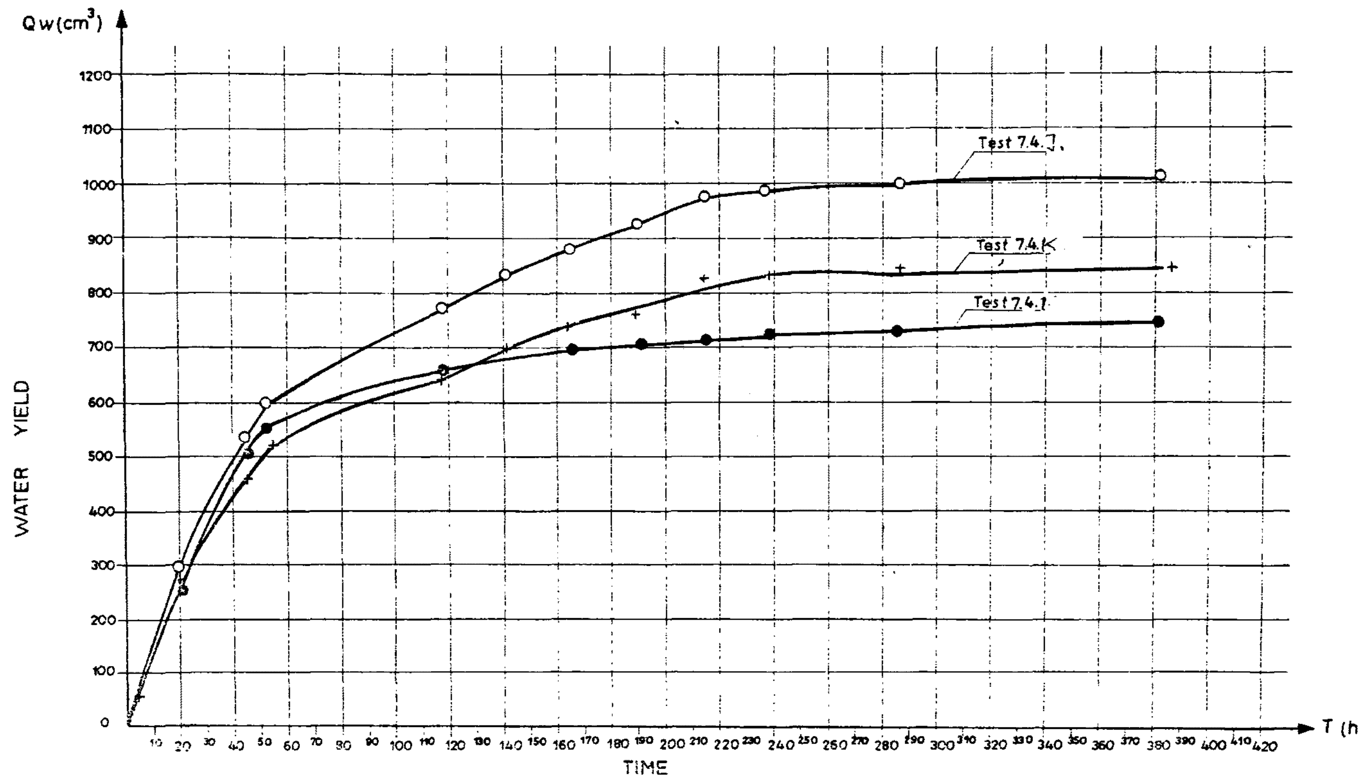



Fig 41 WATER YIELDS WITH TIME-TESTS 7.4.I , 7.4.J , 7.4.K

## INVESTIGATIONS OF CHANGES OCCURRING IN THE SEDIMENT STRUCTURE DURING ELECTROOSMOTIC DRAINAGE

### Method of investigations

The research work program comprised observation of microscopic changes in the sediment structure. Investigations of the influence of structural changes on the efficiency of electroosmotic draining performed while current was applied to the tailings.

### Microscopic investigations

A polarizing microscope of Amplival type (Carl Zeiss) with a transposing set and basic micro-slide apparatus with copper electrodes was used.

The sediment samples were magniffied from 156 to 720 times. The field force of various tests was varied at 0.23 V/cm, 0.5 V/cm, 1 V/cm and 2 V/cm. For each field force 3 test versions of current application were performed.

a) constant current
b) change in direction of current
c) intervals in current supply.

Each test was repeated 5 times on fresh tailings. Sixty tests were made, not counting the first trials. The sediment samples were moistened with 1.5 g of the water that was drawn off the field site. In effect a transparent suspension was formed and the increased surface tension profived adherence.

With magnifications of over 240 times a problem occurred since the covering glass obstructed the microscope lens. The covering glass had to be removed from its frame. This allowed increased evaporation of the suspension and observations were limited to 10 min.

In addition to these observations of tailings during electroosmosis, sediment subjected to previous electroosmosis in a laboratory reservoir

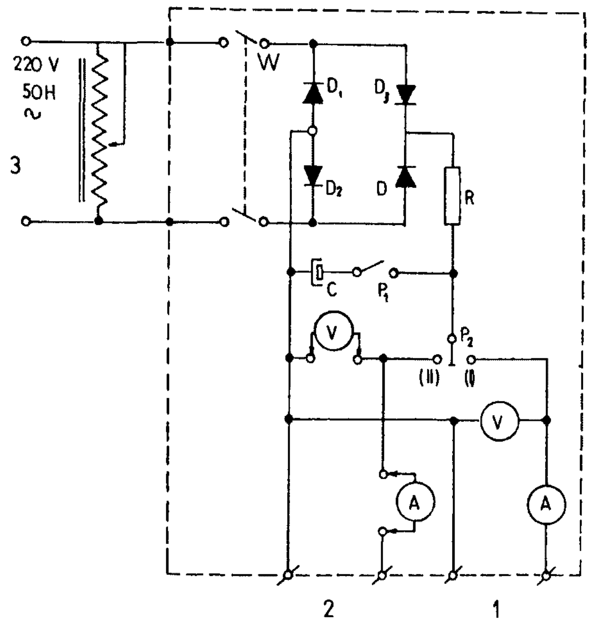



Fig42 ELECTRICAL WIRING DIAGRAM USED FOR SIMULATING ELECTROOSMOTIC DEWATERING OF TAILINGS EXAMINED UNDER THE MICROSCOPE.
1.2 - output , 3 - input

were examined. These samples were collected (at selected times) from locations near the anode the cathode, and from the middle of reservoir.

Investigations performed on miniature reservoir

The laboratory reservoir was a plastic vat. The bottom of the vat was fitted with iron pipes with slit perforations, which served as electrofilters. These filters were wrapped with a double layer of nylon gauze to keep sediment out. The electrodes were fed from the same electrical arrangement used for the microscope observations. The reservoir was placed on a stand which permitted easy access. A schematic of the reservoir is presented in fig. 43.

Microscope observations of the effects of electroosmosis

Microscopic analysis showed the undrained tailings to have a typical aggregate structure. Individual grains have small to average diameters. Large grains do not appear within the clay-silt aggregate. Rather the tailings skeleton is composed of aggregates of small particles and individual larger grains. The pore spaces range up to 0.03 mm in diameter. The mineral particles in aggregates do not show a preferred spatial orientation (geometric), nor any optical pattern (fig. 44). A temporary and local movement of material and a reorientation of grains is observed for a short period after the solution is prepared. The observations were carried out using the variations of current flow discussed in the following sections.

Electric field with intensity E = 0.23 V/cm

a) constant current

Upon application of the D.C. voltage, the following phenomena occur:

- individual grains migrate toward aggregates of smaller particles and become incorporated therein. The migration is step-wise toward the nearest anode or cathode

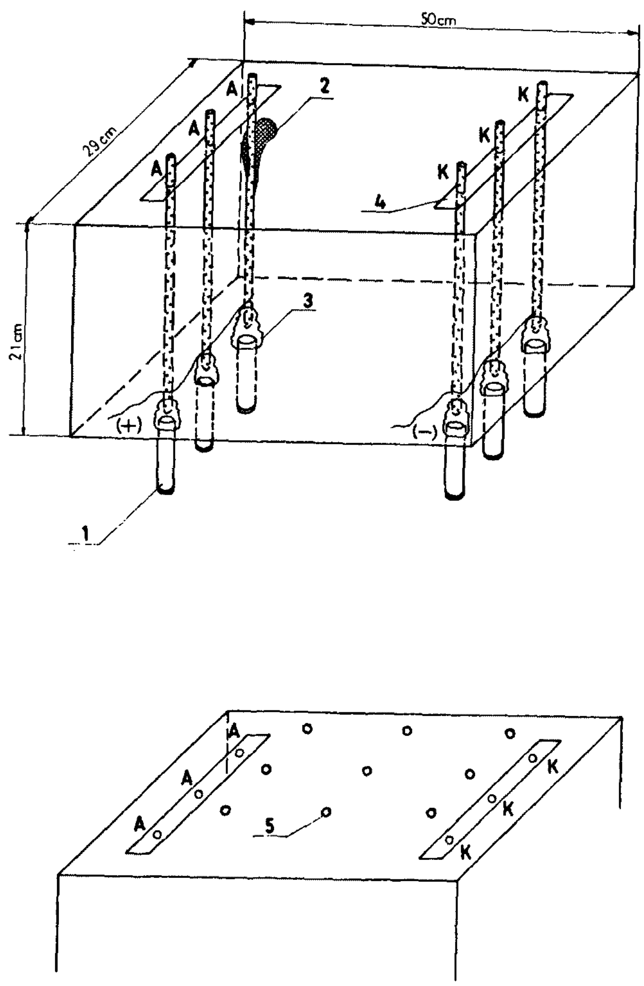



Fig. 43 SCHEME OF LABORATORY SEDIMENTATION BASIN USED TO INVESTIGATE CHANGES IN TAILINGS SEDIMENT STRUCTURE.
K – cathodes, A – anodes, 1 – measuring cylinders, 2 – gauze,
3 – rubber connections, 4 – clamps supporting electrodes
5 – location of sample collection for microscope tests.

- grains within the aggregates rotate in a sporadic step-wise manner
- a "cell-like" structure is created around the pores with diameters exceeding a number of times the diameters of grains, by chains of aggregates which may surround pores (fig. 48),
- stabilization of skeleton (after 9 to 10 min. of voltage application);

b) Changes in the direction of current (change of poles)

In the initial phases, i.e. immediately applying the voltage, the tailings behave as described for case a. At the first signs of stabilization the direction of electric current flow was reversed. This did not produce the expected changes in particle movement but instead no changes were initially observed. After a period of about 1 minute, sporadic rotations of single grains located in external parts of aggregates were observed. These movements did not persist. The current was reversed every 3 minutes. After each successive change sporadic the rotations became progressively less frequent and. after a fourth change, no movement of the grains was noted.

c) Intermittent flow of current

In this test, the current flow was interrupted every 3 minutes. A constant value of current was applied and the intensity of the field was kept the same. The test involved 3 periods of current flow and 3 periods of no current flow.

The observations may be described as follows:

- The first period of current flow was characterized by phenomena similar to those in case a;
- Pause. When the current was turned off, there were no changes in the particle distribution. On the average of 15 seconds into the cessation of current, some components of the skeleton rotated and there was a spreading of the aggregates, probably induced by loosening of the intergrain bonds in aggregates;

- Resumed flow of current. Rotation of single isolated grains. Compaction of the structure of aggregates. Migration of a few grains and aggregates toward the electrodes. Stabilization of the structures.

Electric field with intensity E = 0.5 V/cm

a) Constant flow of current

Application of a higher field intensity (E) produced structural changes in the tailings analagous to those observed at lower intensities. The only differences observed were the intensity and duration of movement. The following phenomena were observed:

- the migration of individual grains toward the aggregates of small grains and a decrease in inter-grain spaces within aggregates
- the rotation of grains within aggregates
- the migration of individual grains toward the electrodes
- the formation of cell-like structure
- the stabilization of the structural skeleton.

These movements were observed to occur with greater intensity in the case of a lower field intensity, i.e. more grains moved within the suspension. But the movements stopped earlier, and the structural skeleton appeared stable after 6 to 7 minutes.

b) Varied direction of the current flow

Regular reversal of the polarity of the current field caused particle movement similar to that observed under the lower intensity field. Sporadic rotational movements of individual grains within the aggregates, and occasional rotational movements of whole aggregates were observed.

c) Intermittent flow of current

Interruption of current caused a partial disruption of structural rearrangement of the particles. During the periods of no currents, the following movements were observed:

- the rotation of certain components, and
- a loosening of aggregates.

Upon resumption of current flow, agglomeration of the aggregates reoccurred.

Electric field with intensity E = 1 V/cm and E-2V/cm

These tests were carried out following the previously described scheme. Despite higher gradients of voltage, the observed changes were of a similar nature as those previously described. The noticeable difference was the shorter time required to achieve structural stabilization.

The qualitative character of these structural changes is shown by fig. no. 49.

Electric field with increasing intensity, (E) from 0.23 V/cm to 2 V/cm

Microscope observations of structural changes were also made as the electric field was varied in a step-wise manner. Each field intensity was applied for 3 minutes. Three sets of step-wise increases were used as follows: 0.23 - 0.5 - 1 V cm; 0.5 - 1.0 - 2.0 V/cm and 1.0 - 2.0 V/cm.

It appears from observations of these tests that the tailings structure can be more easily activated (mobilized) using higher field intensity (E). However mobilization of the particles by step-wise application of a higher E does not cause an intensive movement characteristic of the previously-described applications of consistently high intensities.

The first field intensity trial (i.e. from 0.23 to 0.5 and 1.0 V/cm did not give visible results.

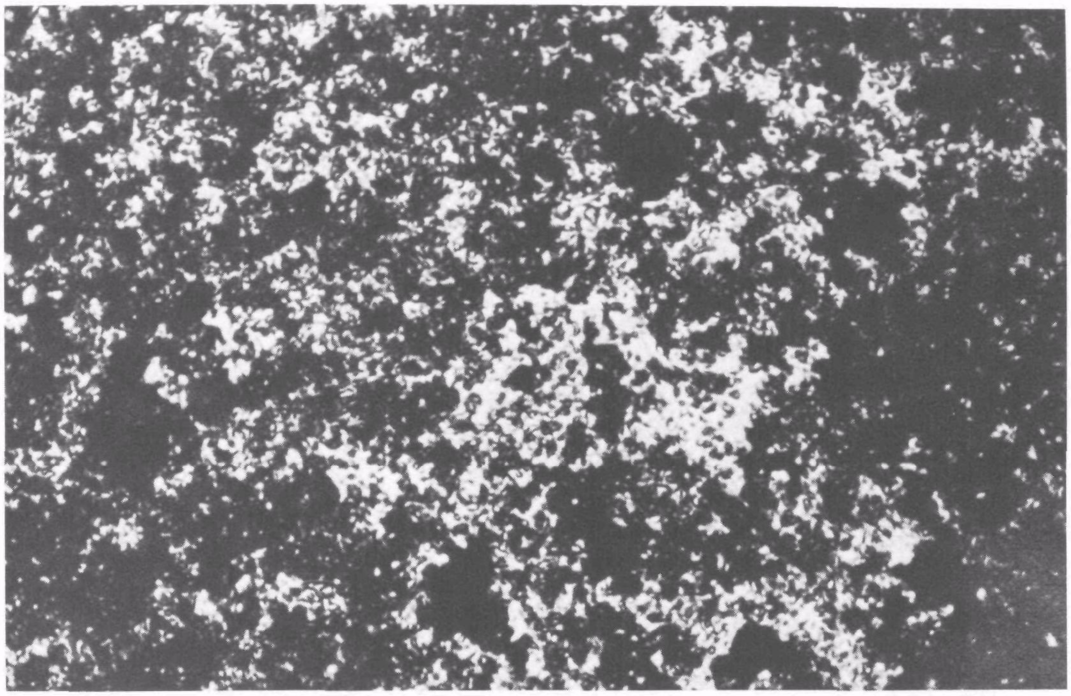


Fig. 44. Structure of tailings before electroosmosis. Light color-water, dark - sludge. Nicols II Magnified 270 times.

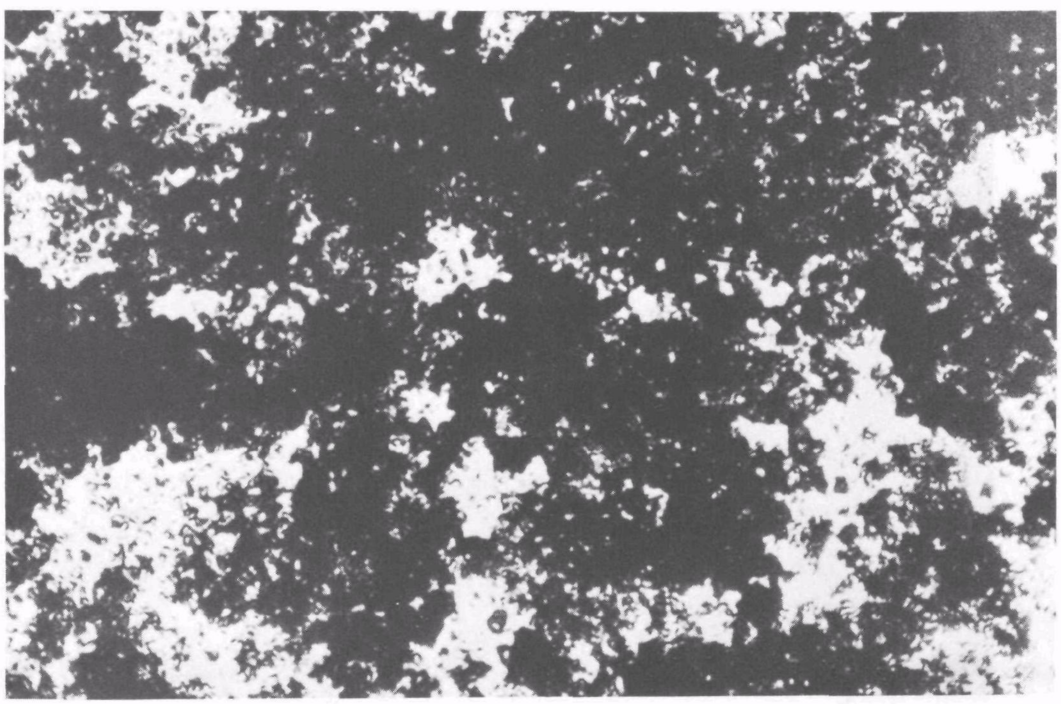


Fig. 45. Aggregate structure at start of the electroosmosis process, light color-water, dark - sludge. E = 1 V/cm. Nicols II, Magnified 270 times.

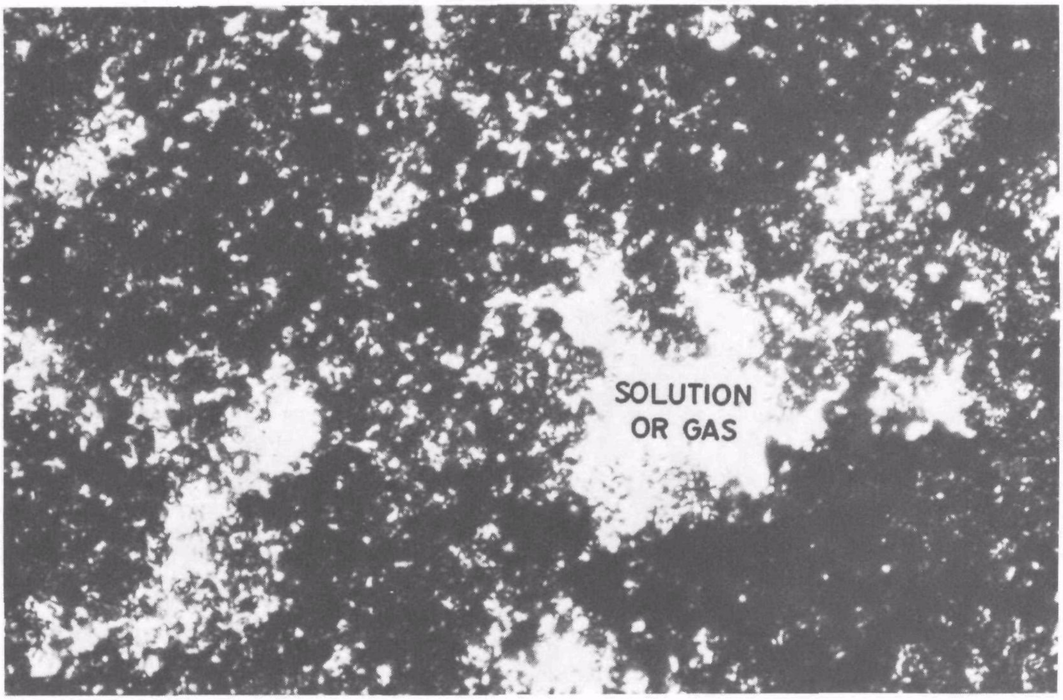



Fig. 46. Increased size of aggregated particles and trans formation to cell-like structure, E=1 v/cm. Nicols II Magnified 270 times.

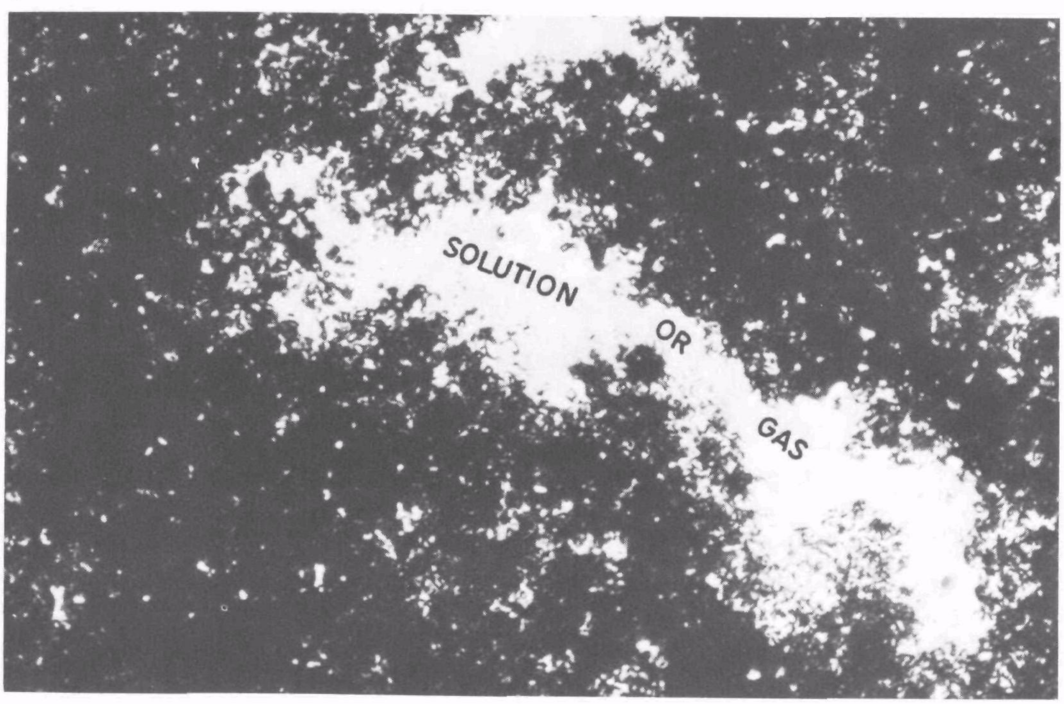



Fig. 47. Unstabilized cell structure. E = 1 V/cm. Nicols II, Magnified 270 times.

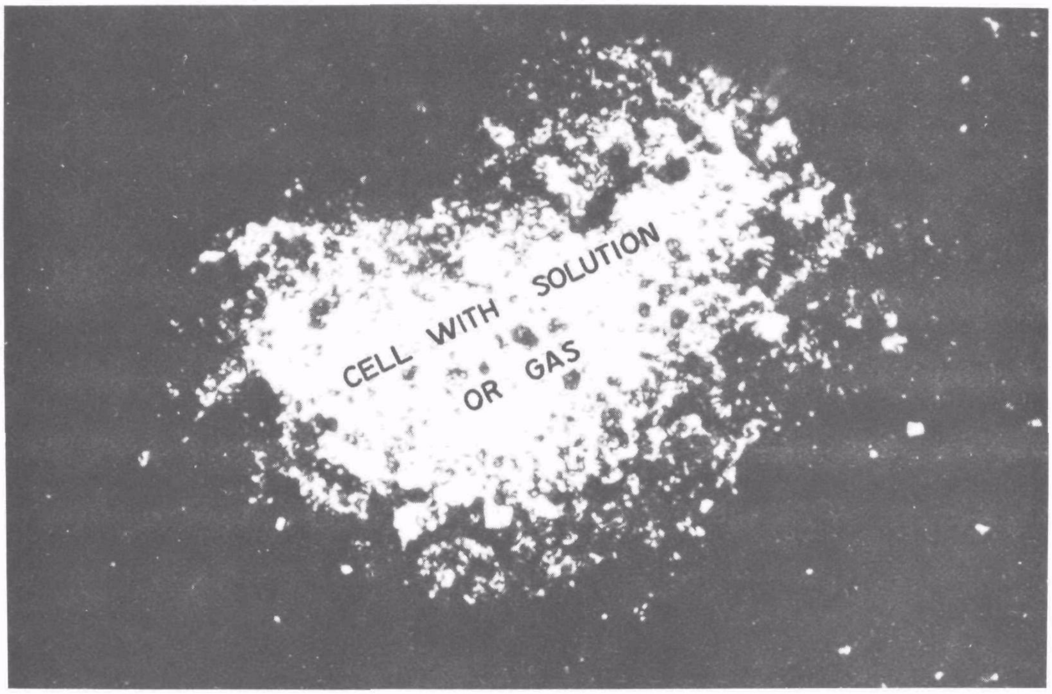



Fig. 48. Stabilized cell structure with captive solution or gas, E = 1 V/cm. Nicols II, Magnified 270 times.

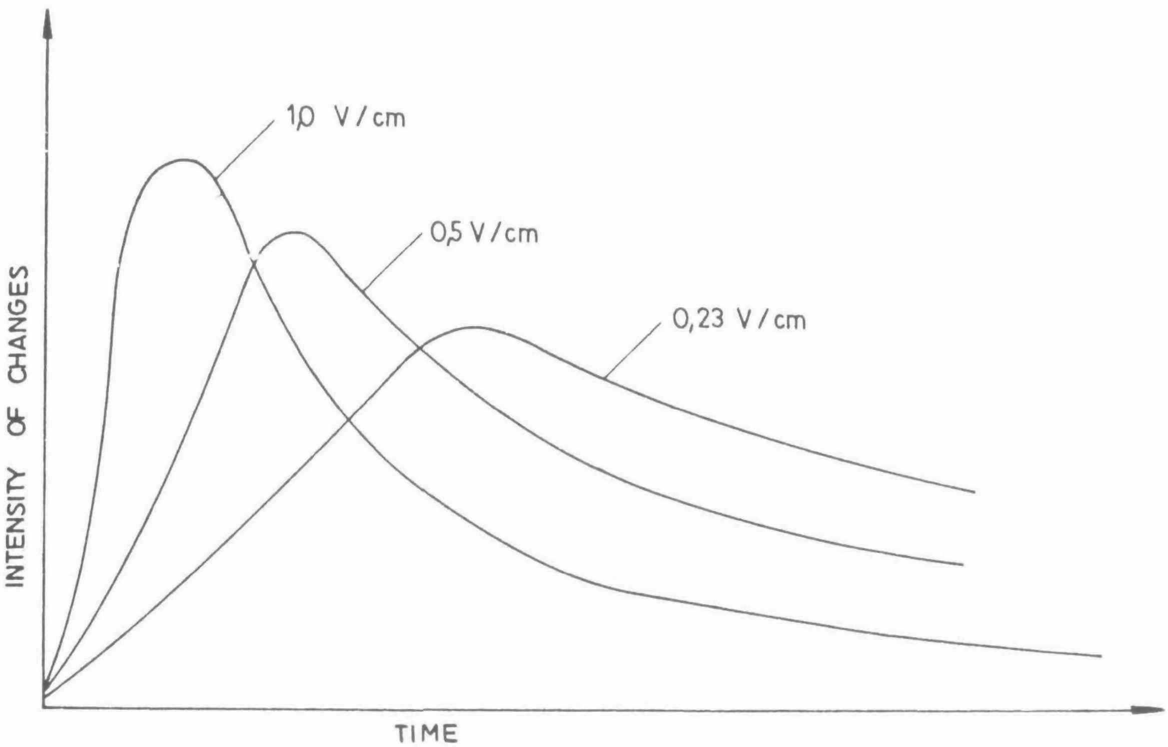



Fig. 49. Qualitative diagram of structual changes intensity in time.

Laboratory investigations carried out in simulated reservoir

Investigations of the dewatering phenomina were performed in the small laboratory reservoir using electrical fields of intensities the same as those used for the microscope observations (E = 0.23 V/cm and 0.5 V/cm). In addition a single test was performed under conditions of an increasing electrical field intensity.

Measurements of the rate of solution discharge (Q/t) from the laboratory reservoir were carried out to compare the rate of electro-osmotic draining with the observed changes in the structure of the tailings material. Independent of the measurements of discharge, measurements of changes in the water content of the tailings were also conducted.

These tests were performed on tailings collected from the sedimentation basin of Ogorzelec. The samples were collected from the area between the anodes and cathodes from depths of 0.5 to 0.8 m.

Each test in the laboratory reservoir was conducted on a fresh sample of tailings. The tailings were allowed to drain for two full days prior to testing. The results of these tests are described in the following sections.

Electric field with intensity E = 0.23 V/cm

a) Constant current flow

All the tests lasted for 221 hours, not including the preceding two days provided for gravitational drainage. The maximum drainage flow occurred 6 hours after application of current to the laboratory reservoir (9.5 ml from three filtercathodes per 1 hour).

After that value was reached, the yield of fluid began to slowly decrease. Between the 29$^{th}$ and 31$^{st}$ hour of the test an increase in yield of short duration (maximally 8.5 ml/h) was measured. After 216 hours of current flow no discharge was evident.

The change in drainage with time is shown on fig. 50. The surface of the tailings formed cracks as the draining progressed.

Within the first phase of this test the drainage was almost colourless, and contained a small amount of suspended material which quickly settled out. Starting at the 9$^{th}$ hour of the tests, the solution became canary yellow and then progressed to a willow-green colour, and, after 40 hours, it was dirty-green. Still later the drainage became pale brown, but by the end of the test it was again colourless and clear.

After a week the various colours of the drainage, which was stored in open containers, disappeared. A whitish "sediment" was deposited in the bottom of the sample containers and was observed at the surface of the water sample.

Samples of the tailings taken 50 hours after electroosmosis and examined under the microscope showed that little, transparent solution rings were formed around the grain aggregates. These are gel-like and turbid. These grains are spherical, as a result of chemical corrosion and not of any rolling action. Despite high sphericity degree the grains closely adhered to one another (fig. 47).

The gel-like rings disappeared with time (tests after 170 hours of experimentation). Most likely they may have undergone a transformation during coagulation or crystallization processes. The character and the advancement of chemical processes were difficult to estimate.

b) Variable direction of current flow

Another tailings sample was subjected to reversals of polarity every 24 hours. The intensity of the electric field was kept constant at E = 0.23 V/cm. During the first full day the color of the drainage and the rates of drainage were similar to those of the previously - described experiment (a) (see figure 51).

At the moment of the current reversal (i.e. when a cathode became an anode, and anode became cathode) the rate of water outflow decre-

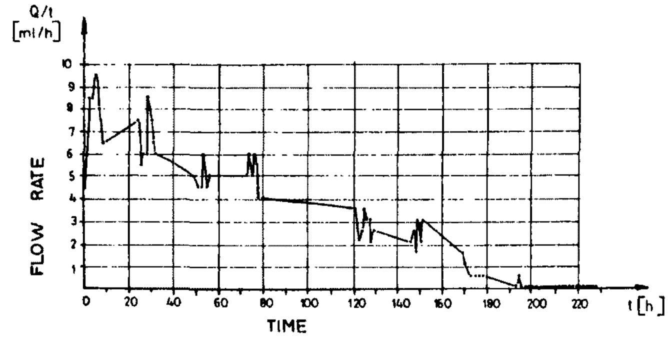



Fig. 50 CHART OF WATER DISCHARGE RATE FROM CATHODES. CONTINUOUS FLOW OF CURRENT E = 0,23 V/cm

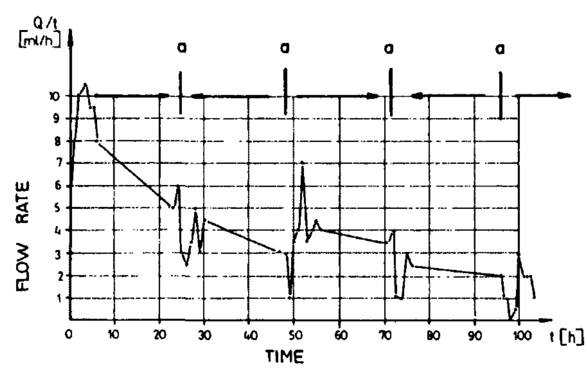



Fig. 51 CHART OF WATER DISCHARGE RATE FROM CATHODES. VARIABLE DIRECTION OF CURRENT PASSAGE E = 0,23 V/cm
a – time of change in direction of current passage

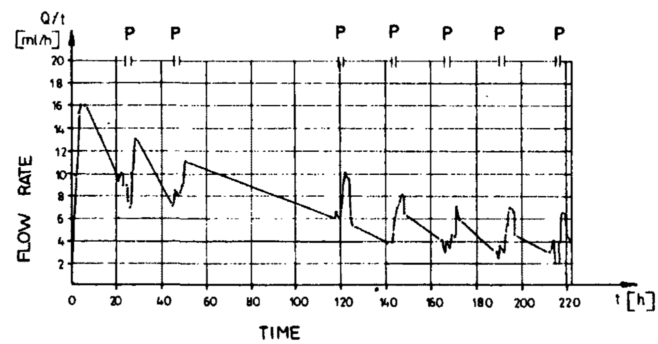



Fig. 52 CHART OF WATER DISCHARGE RATE FROM CATHODES. INTERMITTENT FLOW OF CURRENT E = 0,23 V/cm
P – time of interruption in current flow.

ased almost by half (fig. 51). By the fourth hour after the reversal the drainage had increased almost to the value measured before the reversal. Then drainage began to slowly decrease.

The second polarity reversal (after 48 hours) also caused a sudden reduction in the discharge, which after 50 hours of test began to recover. A maximum was achieved in the 52 nd hour, and afterwards the water outflow decreased. The discharge at the end of this reversal period (72 hours) was, however, higher than during the 48 th hour of the test.

After the third reversal of current, the discharge decreased again, but subsequent changes in the current flow direction did not produce measurable changes in the solution outflow rate. The test lasted for 103 hours.

c) Intermittent current flow

This test examined the effects of regular interruptions of current on the drainage. The current interruptions normally lasted for 2 hours after 22 hours of current application. A constant electric field intensity, (E = 0.23 V/cm) and a constant direction of current flow was employed.

During the initial application of current, the outflow was the same as observed for the previously described experiments. After cessation of current the outflow decreased slightly from 9 ml/h to 7-9 ml/h, and during the two-hour period it stayed at this range.

At the moment of current reapplications the discharge began to increase to 12.5 ml/h during the second hour after reapplication. Then the drainage decreased again. Further investigation shows that interruptions in the current supply cause a slight decrease in flow which is followed by an increase when the current is reapplied. The increase may amount to two times the flow rate existing immediately before the cessation of current. The character of the changes in discharge is illustrated in fig. 52.

Electric field with intensity, E = 0.5 V/cm

Tests employing an electric field intensity (E) of 0.5 V/cm were carried out in the same manner as those using E = 0.23 V/cm, i.e.:

a) with constant current flow

b) with varied direction of current flow

c) with intermittant current flow.

Generalizing the results, it can be said that no significant differences in reaction were observed with the exception that the quantity of water discharged was greater in the case of the higher field intensity. The values of discharges resulting from the higher field intensity are presented in figures 53-55.

Step-wise increases in the electric field intensity (E) from 0.23 V/cm to 1 V/cm

These tests were initiated with the lowest field intensity E = = 0.23 V/cm. After 91 hours of electroosmosis the intensity of electric field was raised to E = 0.5 V/cm. This value of E was maintained to the 139 th hour. Then the electric voltage was increased to E-1 V/cm. This value was maintained through the 216 th hour and then the test was concluded.

The changes in water outflow with increasing electric field intensity (E) are shown on fig. 56. It appears that due to the progressive increases in the field intensity there was prolonged drainage such that a greater quantity of water was discharged than during the other tests.

Correlation of microscope observations and drainage measurements using the laboratory reservoir

Electroosmosis produces different reactions in differing unconsolidated materials. It is therefore necessary to investigate these differences prior to installation of a drainage system in the field so as to obtain optimal drainage. The model tests conducted in the laboratory

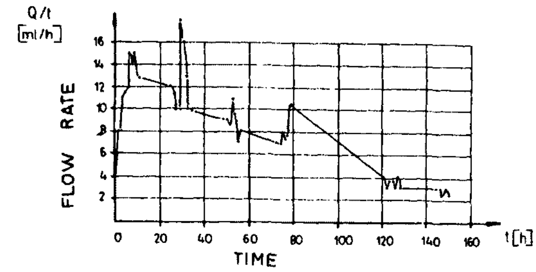



Fig.53 CHART OF WATER DISCHARGE RATE FROM CATHODES. CONTINUOUS CURRENT PASSAGE E = 0,5V /cm

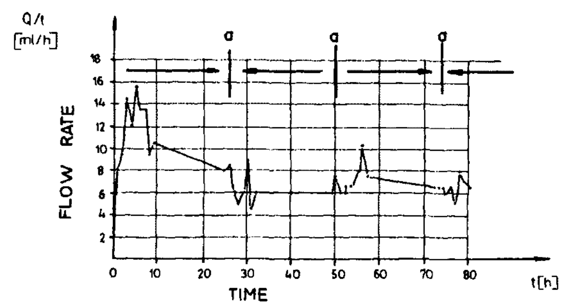



Fig.54 CHART OF WATER DISCHARGE RATE FROM CATHODES. VARIABLE DIRECTION OF CURRENT FLOW E=0,5 V/cm
a - time of change in current flow direction

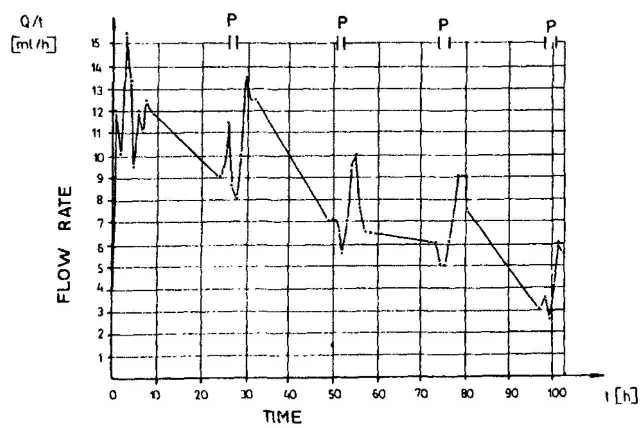



Fig. 55. CHART OF WATER DISCHARGE RATE FROM CATHODES. INTERMITTENT FLOW OF CURRENT E = 0,5 V/ cm
P - time of interruption in current flow.

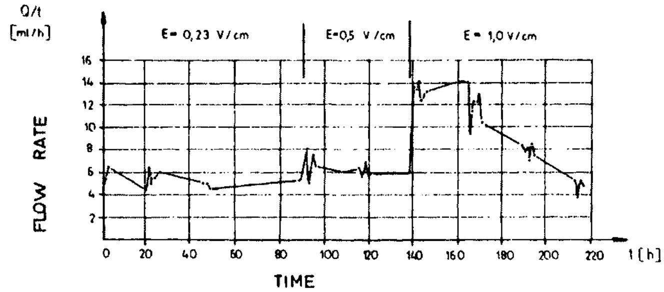



Fig. 56 DIAGRAM OF WATER DISCHARGE RATE FROM CATHODES WITH GROWING ELECTRIC FIELD INTENSITY ( E )

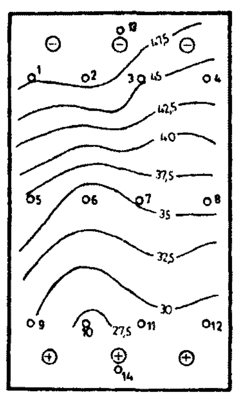


Fig. 57 WATER CONTENT TO DEPTH OF 5 CM OF TAILINGS IN LABORATORY SEDIMENTATION BASIN AFTER 283,5 HOURS OF CURRENT PASSAGE WITH INCREASING FIELD INTENSITY FROM 0,23 TO 1,0 V/cm

° 1, 2 14 – points of sample collection

—35— – line of equal humidity values ( 35% )

reservoir and the microscope observations of structural changes during electroosmosis provided much information in this regard. Through comparison of the changes in structure with the drainage rates showed that for the tailings material, the drainage rates are related, to a large degree, with the structural modifications of the sediment during passage of the current. Presented below are tables giving a summary of corresponding discharge characteristics and structural changes during electroosmosis:

a) Continuous flow of current applied to tailings

| Drainage - water outflow<br>Test made in laboratory reservoir | | Structural changes<br>Observed under microscope |
|---|---|---|
| Elapsed time of tests | Discharge rate | Manifestations of structural rearrangement |
| 1 | 2 | 3 |
| Start of electrodrainage | Systematic increase in rate of water outflow | Migration of some individual grains to existing aggregates of particles. Reorientation of individual "loose" grains and of grains in aggregates |
| 4-8 hours | Maximum discharge rate | As above. Compaction of structure into aggregates of particles. Formation of large pore spaces within these aggregates |
| 8-26 hours | Discharge decreased | Reorientation of single grains. Partial colmatation. Rings of gel-like substances formed around the aggregates |
| 26-50 hours | Initial increase in discharge followed by a systematic drop in discharge rate | Reorientation of single grains. Compaction of aggregate structures. Formation of additional voids. Smaller quantity of gel-like rings. Formation of cell-like structure |
| About 50 hours | Short duration increase in discharge rate | Further reorientation of individual grains. Sporadic occurrance of gel rings (probable partial leaching and partial coagulation of gels). Local voids within cells filled with solution |

| Drainage | | Structure |
|---|---|---|
| 1 | 2 | 3 |
| Final phase. To 221 hours | Systematic decrease in discharge rate until discharge cleared | Far advanced colmatation of inter-aggregate spaces. Cell-like structure. Stabilization of structure |

b) Varied direction of current flow applied to tailings

| Drainage | | Structure |
|---|---|---|
| 1 | 2 | 3 |
| 0-6 hours - Start od electro-drainage | Systematic increase in water outflow | Migration of some individual grains to the existing aggregates of particles. Reorientation of individual grains. Sulphosis. Formation of large pore spaces |
| 6-24 hours | Slow decrease in discharge with time | Reorientation of single grains. Partial colmatation |
| 25-48 hours- Reverse direction of current flow | Distinct decrease in discharge rate | Reorientation of some individual grains and whole aggregates. Local "loosening" expansion of structure. Stabilization of structure with increasing time |
| 49-72 hours- Reverse direction of current flow | During first 2 hours a significant decrease in discharge. Later on an increase in discharge to the equivalent of the previous day. | Reorientation of components. Sporadic movement of aggregates. Progressive stabilization of structure |
| 73-96 hours- reverse direction of current flow | Decrease in discharge rate | Reorientation of individual grains, formation of cell-like structure. Structure stabilization. |
| 97-103 hours- Successive changes in current flow direction | Low discharge rate maintained | Cell-like structures formed. Structural stabilization |

c) Intermittent flow of current applied to tailings

| Drainage | | Structure |
|---|---|---|
| 1 | 2 | 3 |
| 0-24 hours - Continuous current | A steady increase followed by a decrease in the discharge rate | Aggregation and reorientation of grains. Suphosis. Formation of large pore spaces. Partial colmatation |
| 25-26 hours First break in current supply. | Decrease in solution discharge rate | Reorientation of some grains. Loosening of intergrain bonds with aggregates. Partial decolmatation. |
| 27-48 hours- Resumed current flow | Initial increase in discharge, followed by a decrease | Aggregation and reorientation of grains. Suphosis. Formation of large pore spaces. Colmatation |
| 49-50 hours- Second break | Decrease in discharge rate | Reorientation of grains. Loosening of aggregates. Partial decolmatation |
| 51-119 hours- Resumed current flow | Increase in rate during first three hours then a gradual decrease | Occasional reorientation of grains. Extensive compaction of structure in aggregates. Colmatation. Formation of cell-like structures. |
| 120-121 hours Third break. | Discharge rate decrease. | Reorientation of individual grains, partial decolmatation and splitting of some cell structures |
| 122-143 hours Resumed current flow | At first rapid increase in discharge, then a slow decrease | Reorientation of individual grains. Compaction of aggregates. Formation of cell-like structures. Stabilization of structure. |
| Successive interruption in current flow up to the 223-rd hour | Similar as in third break and subsequent period of current flow as previously described | Continuation of structural modifications described for preceding period |

b) Increasing electric field intensity applied to tailings

| Drainage | | Structure |
|---|---|---|
| 1 | 2 | 3 |
| Through 92 nd hour-0.23 V/cm | Same as described for continuous flow of current | Same as described for continuous flow of current |

| Drainage | | Structure |
|---|---|---|
| 1 | 2 | 3 |
| 93-139 hours-0.5 V/cm | Initial increase in solution discharge rate followed by a decrease with time | Reorientation of individual grains. Reconstruction of some aggregates. Development of voids among aggregates. Formation of cell-like structures. Stabilization of structure |
| 140-216 hours - 1.0 V/cm | As above | As above |

Summary of the test results

a) The effect of electroosmosis in tailings material differs according to the character of the electric field (constant, varied, periodically interrupted).

b) The internal structural changes occurring during electroosmosis have great influence on the effects of water discharges. These structural changes are:
- reorientation of the particles
- migration of grains toward the electrodes
- aggregation of grains
- suphosis
- formation of cell-like structures
- chemical corrosion of grains
- stabilization of the structure in its rearranged form.

c) The least favourable version of electroosmotic draining is that where the direction of current flow is periodically reversed. Changes in direction of current flow caused insignificant rearrangement of the structure. But the solution which had migrated during current passage in one direction was forced to retrace its flow path when the current was changed. Therefore drainage from the interior of the tailings was quite limited. With each change in the direction of electric current, drainage was reduced.

d) The highest drainage rates occurred during the tests of periodically interrupted current supply. During interruptions in current supply, a partial "splitting" of the aggregated particles occurs and allows the solution to move. When the current supply is resumed, the water is initially free to move to drainage points. Drainage continues until the aggregate structures are again formed. Each successive break in current causes freeing of a portion of the captive water. This water has a very limited potential to be recaptured by the sediment.

e) Some structural changes of the sediment result from chemical reactions. The chemical processes infrequently observed to take place in sediment included: corrosion of grains, formation and disappearance of gel-like rings around aggregates, and changing colours of discharged solutions.

f) Once stable cell-like structures and compact aggregates are formed the drainage of water (solution) stops, despite high water content of the sediment. The water is confined in these structures. To further reduce the water content, these structures must be broken. This is partially accomplished by the periodic interruptions of current.

## ADDITIONAL MEASUREMENTS AT FIELD SITE

In order to answer a number of questions that arose during the laboratory tests, additional tests were performed directly at the tailings disposal site. These tests started with measurements of specific resistance of the sediment.

Its value was determined to be $4.6 \cdot 10^2 \Omega$ /cm. The surface of electrofilters, the spacing between them and the type of material to be used was also investigated in the field. Electrodes constructed of aluminium with diameters 50.125 and 150 mm, were driven into the tailings to a depth of about 2 m with spacings of 5 and 10 m. Steel electrodes, with diameters of 200 mm were also tested (Tests I to VII ). Detailed results of these tests are presented in table 15.

Table 15

Electrical resistance of tailings as a function of various electrode construction, spacing, depth, voltage and current intensity (Tests I to VII

| Test no. | Electrode diameter (mm) | Length of electrodes-depth of sinking (m) | Spacing of electrodes (m) | Applied voltage (V) | Current intensity (A) | Electrical resistance (Ω) | Material of electrodes |
|---|---|---|---|---|---|---|---|
| I | 50 | 2.40 | 5 | 35 | 5 | 7.0 | aluminium |
| II | 125 | 1.90 | 5 | 53 | 10 | 5.3 | aluminium |
| III | 200 | 1.90 | 5 | 46 | 10 | 4.6 | steel |
| IV | 50 | 2.30 | 10 | 74 | 10 | 7.4 | aluminium |
| V | 125 | 1.90 | 10 | 57.5 | 10 | 5.75 | aluminium |
| VI | 150 | 2.0 | 10 | 48 | 10 | 4.8 | aluminium |
| VII | 200 | 1.90 | 10 | 23.5 | 5 | 4.7 | steel |

Additional initial tests were made with steel electrodes sunk to a depth of 7 m, spaced 10 m apart, in two configurations: one anode and one cathode (electrical resistance amounted to 1.9 Ω ), and one anode with two cathodes (electrical resistance was 1.36 Ω ).

These same arrangements were tested for a fortnight and electric resistances increased to 2.1 Ω and 1.41 Ω respectively. These increases in resistance (by about 10 %) were caused by the corrosion of the steel pipes, some thing one has to deal with in draining a sediment.

These investigations showed that the electrical resistance, notably the most essential value to permit efficient design of an electroosmosis system, must be calculated from field tests.

The results of the field tests were used to design an electroosmosis dewatering system for installation in the smaller of the two tailings piles at Ogorzelec.

## ELECTROOSMOTIC EXPERIMENTAL STATION CONSTRUCTED ON THE SMALL SEDIMENTATION BASIN IN OGORZELEC

In the process of initial tests made on the laboratory reservoir, and the investigations on the main sedimentation basin, large divergences between the laboratory and the field values of electrical resistance were measured. Differences were also found between the laboratory, and field water discharges. In order to acquire the data necessary to design an adequate drainage system for the main sedimentation basin in Ogorzelec an electroosmotic system was installed on the small sedimentation basin containing the same and identically stored sediment and located adjacent to the main basin.

The installation was constructed in accordance with the diagram of fig. 58. It consisted of 4 steel filtercathodes, 6 m long, with 34 cm diameters. Filter - cathodes were perforated with 4 mm diameter holes in a 100 x 100 mm pattern.

The anodes consisted of pipes with 100 mm diameters, were 6 m long and were not perforated.

The filter - cathodes were sunk along the axis of the sedimentation basin, at 10 m intervals, and were surrounded by 20 anodes, located 11 m from the axis of the filtercathodes.

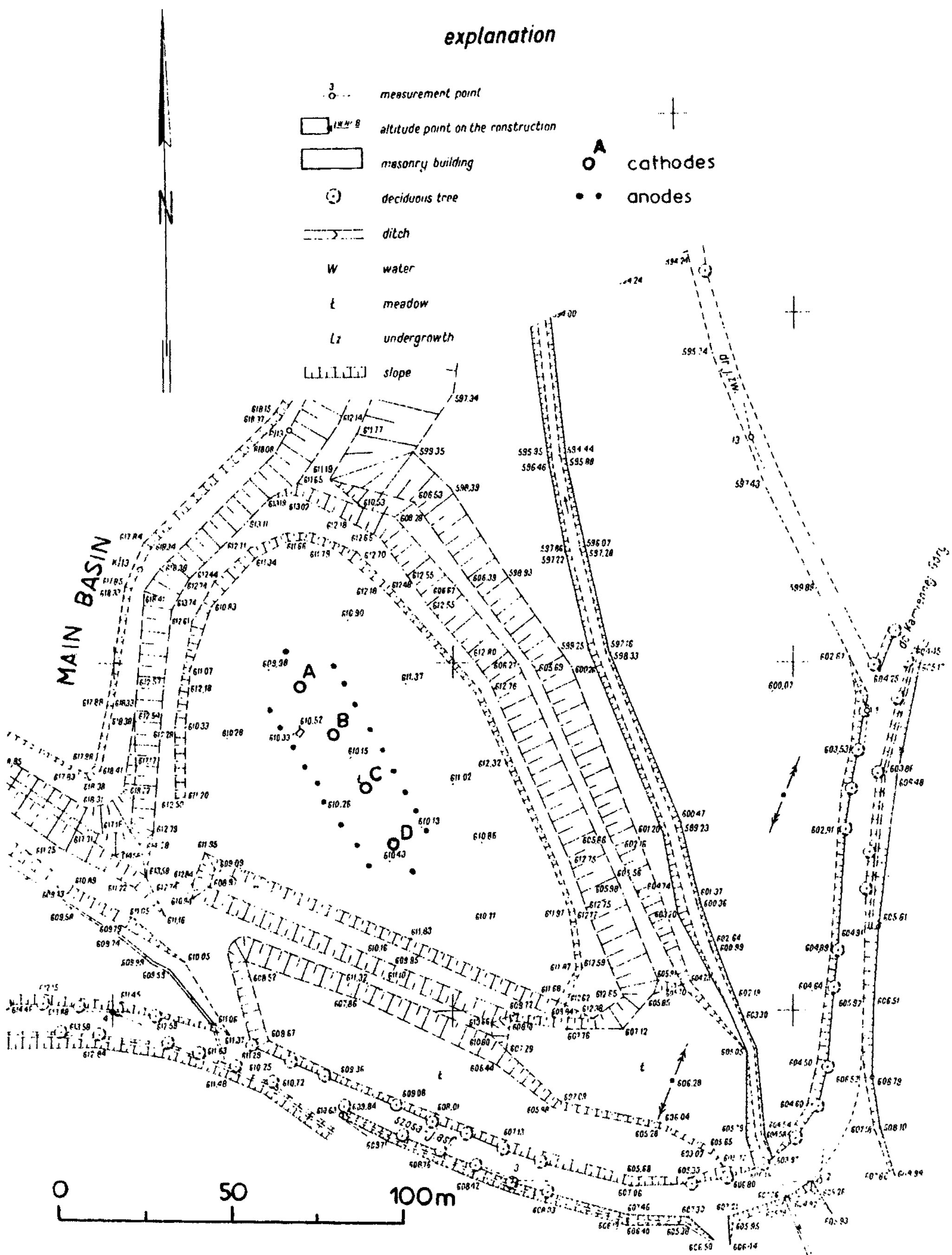
The number of anodes was chosen so that the sum of their surfaces would be approximately equal to the sum of surfaces of the filter-cathodes.

Groups of anodes and cathodes were connected with a copper lead of a 25 $mm^2$ section. These leads were supplied from an 80 ampere supply.

Initially no voltage was applied to the electrodes, in order to observe eventual discharges of water expected to take place without electroosmosis.

For a period of one and a half month there was no discharge of water observed. Thus it was demonstrated that it was not possible to

Fig.58 PLAN OF THE SMALL SEDIMENTATION BASIN SHOWING LOCATIONS OF ANODES AND CATHODES



collect any water at the electrodes through natural drainage.

A voltage of 40 V was then applied to the electrodes. This caused a flow of current (82 A) between the electrodes. Assuming a uniform current propagation, this is equivalent to 20.5 A per filter-cathode.

After current application for 18 hours' measurements made of the water columns in the filter cathodes gave the following results: A - well - 24 cm, B - 52 cm, C - 53 cm, D - 63 cm. Calculating volumes gives 6.6 liter; 14.3 l; 14.5 l; and 17.3 l respectively.

The accumulated water in wells was pumped out and to find out whether the application of current would result in gravity drainage, the voltage was removed. The water levels indicated that the discharge rates decreased to nil over the four hour period that current was not applied. The voltage was reapplied and systematic measurements of the water level increments continued for 18 days, at dates provided in table 16.

Table 16

Increments of water level in 12 hrs measurement periods (in cm)

| Date of measurement | wells | | | |
|---|---|---|---|---|
| | A | B | C | D |
| Apr. 30 | 22 | 78 | 69 | 83 |
| May 2 | 26 | 41 | 43 | 84 |
| May 4 | 25 | 62 | 60 | 90 |
| May 6 | 20 | 53 | 60 | 80 |
| May 9 | 21 | 50 | 65 | 83 |
| May 13 | 26 | 56 | 63 | 86 |
| May 16 | 27 | 58 | 67 | 89 |
| May 18 | 28 | 58 | 65 | 90 |

Measurements of the water inflow rate in consecutive days of the research period were performed according to following plan:

- pumping out of accumulated water in well,
- measurement of water table level in emptied wells

- repeated measurements of water table level after 12 hours time

In order to determine the electroosmotic actual water discharges from a well measurements were made (table 16) only for periods in which no precipitation occured. After 18 days of operation, on May 19 the voltage was again removed from the electrofilters and water was removed from wells. The water levels were observed during following 14 days and found to systematically decrease (table 17).

Table 17

Increments of water level in 12 hrs measurement periods after switching off current ( in cm)

| Date of measurement | Wells | | | |
|---|---|---|---|---|
| | A | B | C | D |
| May 20 | 20 | 40 | 50 | 60 |
| May 21 | 20 | 38 | 43 | 60 |
| May 22 | 18 | 36 | 40 | 60 |
| May 23 | 16 | 30 | 40 | 60 |
| May 27 | 10 | 25 | 35 | 50 |
| May 29 | 9 | 20 | 30 | 45 |
| Jun. 1 | 5 | 15 | 20 | 40 |
| Jun. 3 | 0 | 5 | 10 | 20 |
| Jun. 5 | 0 | 0 | 0 | 5 |

This experiment showed that after a long period of electroosmosis, gravity drainage may continue for a while, but will decrease with time. The reduced drainage can be attributed to the plugging of the particle skeleton of the tailings. When after emptying of wells on June 8 the voltage was reapplied, water began to discharge again. However, the discharge rates were essentially equal (table 18).

Table 18

Increments of water level in 12 hrs measurement periods after resumed voltage application on the electro-filters (in cm)

| Date of measurent | Wells | | | |
|---|---|---|---|---|
| | A | B | C | D |
| Jun. 10 | 10 | 10 | 11 | 12 |
| Jun. 11 | 9 | 10 | 10 | 12 |
| Jun. 13 | 10 | 10 | 10 | 12 |
| Jun. 16 | 10 | 11 | 11 | 11 |
| Jun. 19 | 11 | 12 | 11 | 12 |
| Jun. 20 | 11 | 12 | 11 | 13 |
| Jun. 23 | 12 | 13 | 12 | 13 |

After repeated reapplied voltage on June 8, was observed that water collects not only in the cathode wells, but also in depressions formed around the filter - cathodes. The quantity of this water was difficult to measure. Its presence suggests that the holes in the filter-cathodes were plugging. Further, of this phenomenon indicated the cathodes were corroding during the period when no voltage was applied.

Corrosion caused visible plugging of the small (ϕ 4 mm) perforated holes in the electrofilter. Therefore the water attracted to the electro-filter is forced to the surface through voids formed by escaping gases produced in the process of electrolysis. In the light of these observations we believe that current should be applied to the filters immediately after their emplacement in the sediment, and that current should be maintained throughout the entire time of operation. In this manner the corrosion is controlled and the gases pass through the perforated holes thereby keeping them unplugged.

In the course of collecting samples for water content determinations toward the termination of the tests, it was noted that the force necessary to drive the sampler into the tailings increased. If this increased structural resistance was to be explained only by a decrease in water content, the areas of tailings located adjacent to the cathodes, where water accumulates, should be easier to penetrate. However, these areas were not easier to penetrate.

In order to investigate this phenomenon, the chemical compositions of samples were measured. Samples from areas near the cathodes were compared with samples from between the electrodes. The results are presented in table 19. These comparisons did not reveal any significant differences. It was concluded that the increase in strength of the tailings could be explained only by increased stabilization of the structure ("petrifaction") throughout the area affected by electroosmosis.

Table 19

Chemical composition of selected tailings samples located within. the electroosmotic zone of the small tailings pile at Ogorzelec

| | Sample B taken by cathode | Sample D - zone between the electrodes |
|---|---|---|
| sinter. losses | 27.70 % | 25.80 % |
| $SiO_2$ | 9.80 % | 9.35 % |
| $Fe_2O_3$ | 0.74 % | 0.44 % |
| $Al_2O_3$ | 4.10 % | 3.55 % |
| CaO | 40.00 % | 41.80 % |
| MgO | 1.30 % | 1.80 % |
| $SO_3$ | 16.33 % | 17.22 % |
| | 99.97 % | 99.96 % |

During the course of current application and drainage a systematic subsidence surface of tailings pile in the experiment area was noticed. The measurements showed that in relation to the initial elevation the sediment surface was lowered an average of 15 cm. This is attributed to compaction attendant on the loss of water. One may then estimate

Fig. 59. Electroosmotic test area on the small sedimentation basin - after completion of drainage tests.

Fig. 60. Emplacement of syphon in bowl of main sedimentation basin.

the total quantity of water removed from the tailings from the amount of subsidence at about 150 $m^3$ if all subsidence is the result of water drainage.

Approximately 800 kVh of electrical energy were used during the experiment. This is the total energy, including energy used for electro-osmosis and to operate the pumps. Therefore using the 150 $m^3$ as the amount of water removed, the unit energy requirement was 5.3 kVh/$m^3$.

The following conclusions were drawn from the tests conducted on the small tailings pile and influenced the design of the drainage system for the large (main) sedimentation basin.

- Wells placed in the tailings will not accumulate water unless electro-osmosis is used.
- After application of an electrical field, gravity drainage to the cathodes will continue but at an ever-decreasing rate so that drainage stops in a short time period.
- When the current is interrupted, the small holes in the cathode are quickly blocked with corrosion products. Thus the holes must be larger and current must be applied almost continuously.
- The filtercathodes should not be placed in the center of the reservoir but in the intermediate zone. One will thus obtain a movement of water from the zone of fine clay and silt material to the zone of sandy material and will limit plugging of the holes in the cathode (and will allow construction of larger holes).

## DRAINAGE OF WATER IMPOUNDED IN THE BOWL OF THE MAIN SEDIMENTATION BASIN

It was deemed infeasible to work on the main sedimentation basin until the water impounded in the surface bowl had been removed. The overflow tower originally used had been filled with silt and could not be used. Therefore a siphon arrangement was employed using rubber pipe of 120 and 180 mm diameter (fig. 61). The water remaining in a few depressions after siphoning was pumped over the embankment.

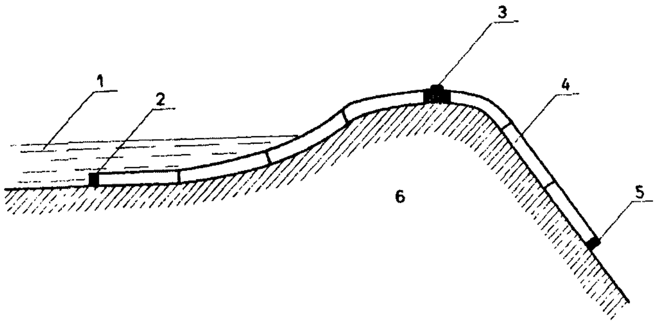



Fig. 61 TEMPORARY SYPHON ARRANGEMENT FOR GRAVITY DRAINAGE OF SURFACE WATER
1 water, 2 valve, 3 – connector with valve, 4 – reinforced rubber hose, 5 – valve, 6– embankment of tailings pile.

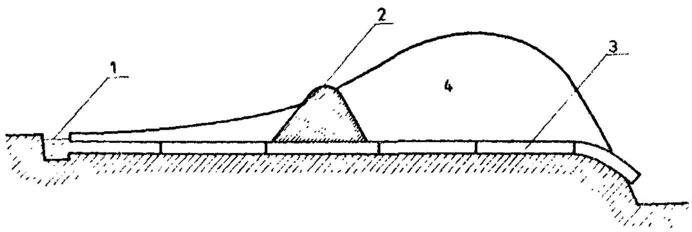
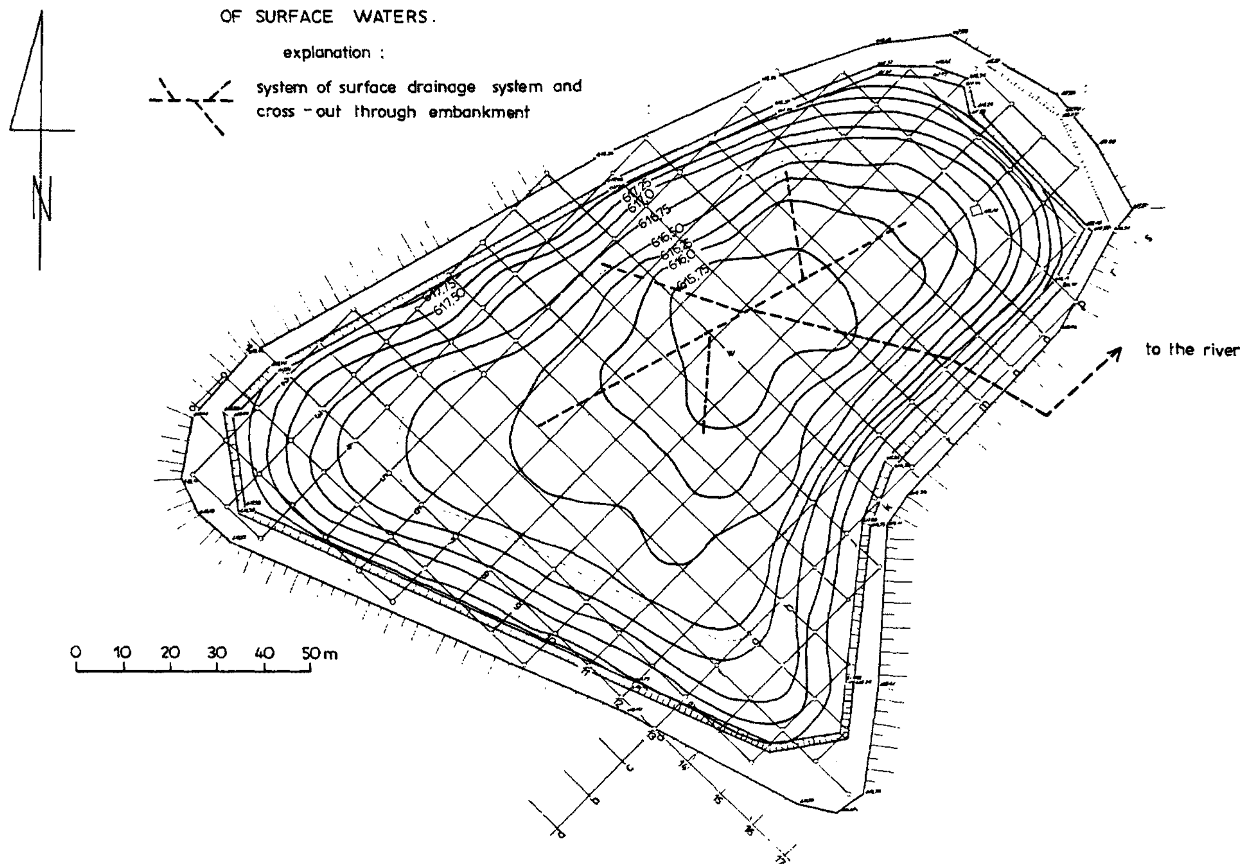



Fig. 62 PERMANENT GRAVITY DRAINAGE FROM THE SEDIMENT BASIN BOWL WITH HOSE PLACED IN A DITCH
1 – drainage from well , 2 – earth fill, 3 – reinforced rubber hose, 4 – embankment of tailings pile

A ditch was cut through the embankment to prevent accumulation of precipitation and percolation into the tailings. The ditch varied in depth from several centimeters in the center of the pile where it was linked to several ditches, to a depth of 3.5 m through the embankment.

The rubber pipe used as a siphon was then buried in the ditch to serve as a conduit (fig. 62-63). It was felt that the open ditch could be subjected to excessive erosion if it were left standing. This afforded control of the run-off, which was all the more important once waters pumped from the filter - cathodes were also discharged through this pipe.

Fig. 63 CONTOUR MAP OF THE MAIN SEDIMENTATION BASIN BOWL. THE POSITION AFTER DRAINAGE OF SURFACE WATERS.



# SECTION 8

# INSTALLATION OF ELECTROOSMOTIC DRAINAGE SYSTEM ON THE MAIN SEDIMENTATION BASIN IN OGORZELEC

## DESCRIPTION OF THE DRAINAGE SYSTEM

On the basis of analyses of research results from both the model tests and the field tests, and from investigations of physical characteristics of sediment, care was taken to install the optimal electro-osmotic drainage system.

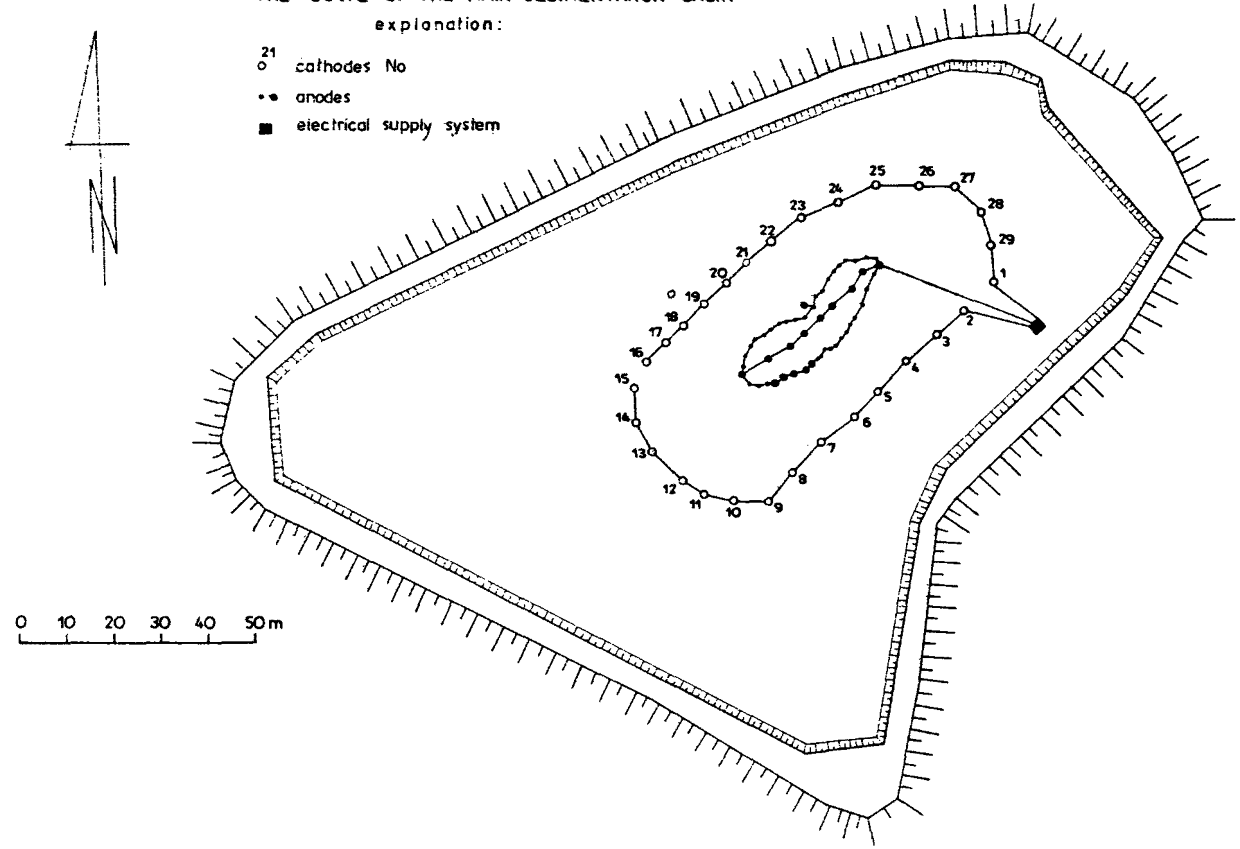
The principal design considerations were the shape of the electric field, the spacing of the electrodes, and the choice of suitable electrical supply and wiring.

### The shape of electric field and the spacing of electrodes

The most advantageous configuration for the electrodes, considering favorable conditions for current propagation is an arrangement where the distances between the sets of anodes and cathodes are equal in all directions. It is therefore a configuration consisting of regular, concentric geometric shapes.

In the case of the main sedimentation basin, the shape of the pile and the resulting horizontal distribution of water within the sediment suggested that two concentric ellipses of electrodes could be used. Anodes and cathodes were located at regular distances along these ellipses. The anodes were located along the interior ellipse while the filter cathodes were located outside in the sandier, intermediate zone.

Fig. 64 ARRANGEMENT OF ANODES AND CATHODES WITHIN THE BOWL OF THE MAIN SEDIMENTATION BASIN



An additional line of anodes was placed along the axis of the inner ellipse (fig. 58, 64).

The elipse of cathodes, designed to permit pumping of accumulated water, were located almost at the demarcation line of silty-clay and silty-sand tailings. Thus the water would accumulate in areas where its movement was facilitated.

Electrical supply and connection to anodes and cathodes

The twenty-nine filter-cathodes were connected in two groups of 14 and of 15 wells to permit independent operation of either group. The anodes (a total of 50) were connected in one group (fig. 64).

Each electrode within a group was connected with single strand copper leads (180 $mm^2$ sections). The leads were brass welding to obtain maximum conduction. Each group of electrodes was connected to the electrical supply system in a similar manner.

The electrical supply system consisted of transformer and a rectifier (fig. 67) connected as shown on fig. 65. The system also provided power for a pump used to remove water from the filter cathodes.

The transformer (100 kVA, 380/173/86.5 V) provided after a rectification, a current of 450 A, i.e. or about 15 A per filtercathode during operation of the entire field of electrodes (29 filtercathodes).

The rectifier used (PK-09/0.25 type) provides rectification of currents to 1000 A with voltage of 250 V. The method of a wiring diagram for the supply system is shown on an assembly drawing (fig. 66). Electric power was supplied to the system through an electric substation located on the premises of neighbouring workshop "Inco".

## CONSTRUCTION AND INSTALLATION OF ELECTRODES

The anodes consisted of 50 steel electrodes in a shape of pipes with diameters of either 115 mm or 298 mm. The anodes were reinforced with scrap metal. The anodes were emplaced to depths of 10 m

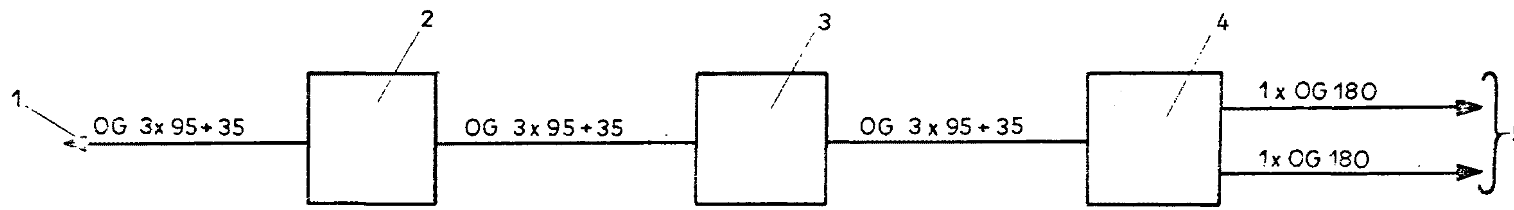



Fig.65 BLOCK DIAGRAM OF THE ELECTRICAL SUPPLY SYSTEM

1 – to main distribution board

2 – connecting box

3 – transformer 300/175/100

4 – rectifier PK–09/0,25

5 – to electrofilters ( anodes and cathodes )

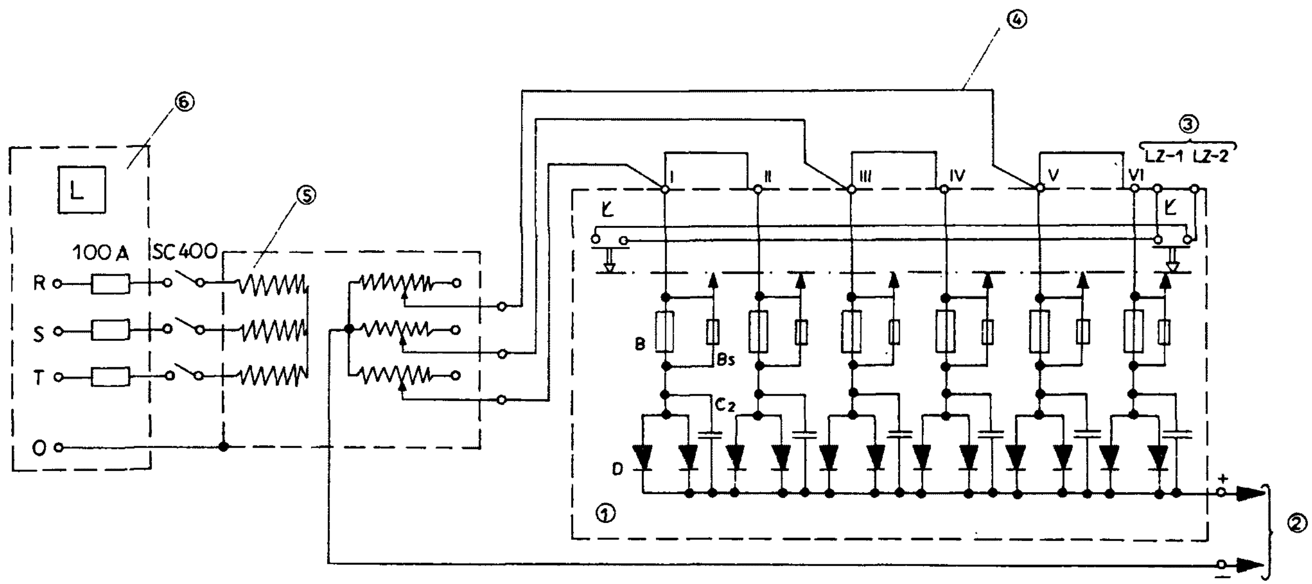



Fig. 66 TYPICAL ELECTRICAL ASSEMBLY DRAWING OF FEEDING SYSTEM CONNECTIONS OF POWER SUPPLY SYSTEM.
1 – rectifier, 2 – to electrofilter, 3 – signalling diode fuse burnout, 4 – Cu-rod 100 $mm^2$, 5 – transformer 380/175/100 V
6 – switchboard 380/220 V

measured from the terrain surface. The anodes had no perforations.

The cathodes consisted of 29 steel pipes with inner diameters of 298 mm. These were also emplaced to depths of about 10 m.

Every cathode also served a filtering well which collected water freed from the sediment by electroosmosis draining. Therefore the cathodes were perforated along the entire length. The holes were of rectangular slits with dimensions of 5 x 50 mm (fig. 68) and were spaced in such a way that within one meter of pipe there were 10 holes. The total surface area of the filter cathodes was about 340 $m^2$. The surface area on the anodes was about the same. Drilling operations for emplacement of the electrodes were conducted from February to May of 1976. Drilling was started during the winter season since the surface was frozen and access was facilitated.

A light weight steel tripod system was used to drive the electrodes into the soft, plastic tailings. (fig. 69). In the course of driving the electrodes, the phenomenon thixotropic fluidization of the sediment was observed.

Tailing was removed from the electrodes using a core drill. Sediment removal began after all electrodes had been installed so as to avoid having to redrill the slotted cathodes. A few wells were emptied with a combined method using a core drill and a bailer after adding water to the tailings in the well.

From four of the filter-cathodes and from one of anodes (the central well) the samples of sediment were taken to a depth of 9 m.

The filtercathodes were driven to a maximum depth of 10 m and the average depth of emplacement was 9 m. With time the tailings entered the cathodes through the slits and tailings flowed into the open end of the pipe such that the effective depth of the cathode was reduced.
The table no. 20 represents effective depths of filtercathodes on 16 Sept., 1976, (two months after commenced electroosmotic drainage) and on 15 Feb., 1977, after partial cleaning of filtercathodes of intruding tailings.


Fig. 67. Complex of feeding the draining installation.

Fig. 68. Filtration holes in filter - cathodes.

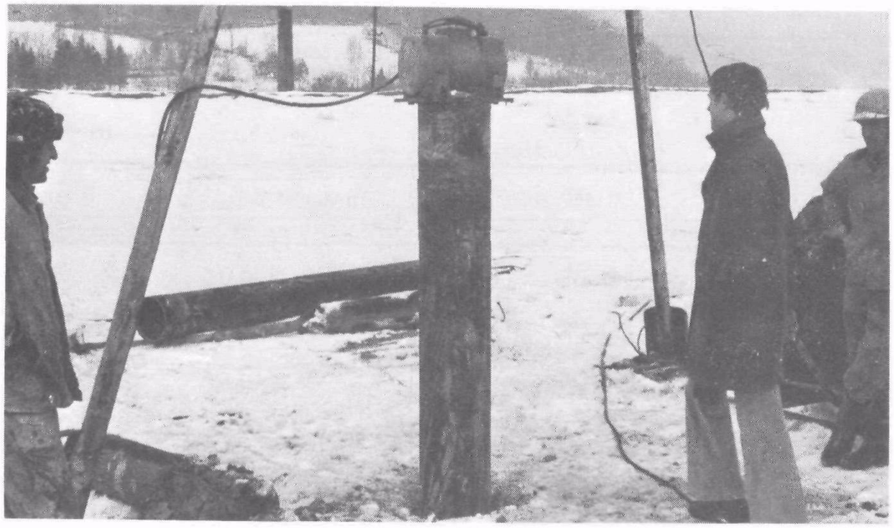


Fig. 69. Sinking filter-cathodes into sediment with the aid of vibrohammer.

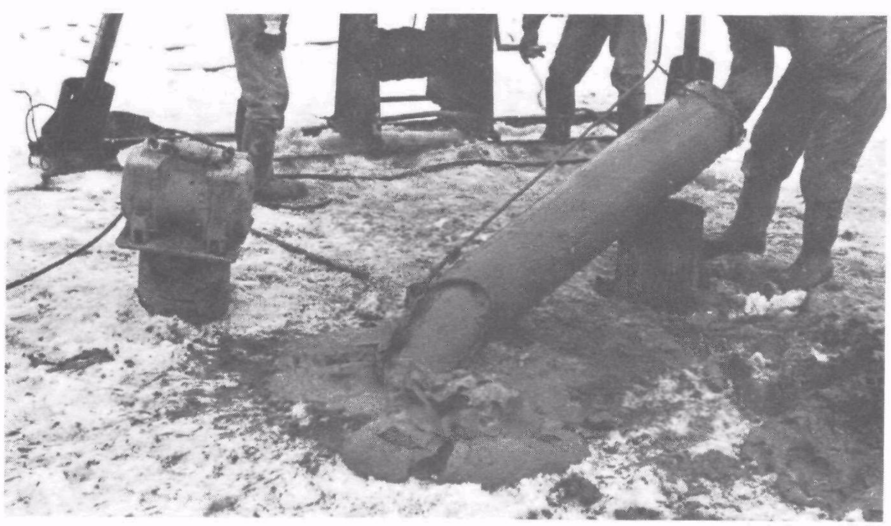


Fig. 70. Removal of sediment from filtercathodes.

Table 20

Changes in effective depths inside filtercathodes during electroosmotic draining

| No. of filter cathode | Distance of top edge from surface (protruding) m | Distance from the bottom to the surface m | |
|---|---|---|---|
| | | Sept. 16,1976 | Feb. 15, 1977 |
| 1 | 2 | 3 | 4 |
| 1 | 1.05 | 3.49 | 4.85 |
| 2 | 0.82 | 2.42 | 4.18 |
| 3 | 0.66 | 2.27 | 3.64 |
| 4 | 0.66 | 2.54 | 4.74 |
| 5 | 1.15 | 2.77 | 3.95 |
| 6 | 0.68 | 3.56 | 4.82 |
| 7a | 0.64 | 4.46 | 5.91 |
| 8a | 0.56 | 4.48 | 6.19 |
| 9a | 0.53 | 4.77 | 6.27 |
| 10a | 0.90 | 3.56 | 4.45 |
| 11a | 0.68 | 4.19 | 5.52 |
| 12a | 0.61 | 5.03 | 5.79 |
| 13 | 0.49 | 3.87 | 5.17 |
| 14 | 0.63 | 3.66 | 4.12 |
| 15 | 0.57 | 3.12 | 5.03 |
| 16 | 0.55 | 3.73 | 5.35 |
| 17 | 0.63 | 3.71 | 5.17 |
| 18 | 0.54 | 3.21 | 4.76 |
| 19 | 0.55 | 3.37 | 4.75 |
| 20 | 0.57 | 2.90 | 4.03 |
| 21 | 0.60 | 3.18 | 4.10 |
| 22 | 0.42 | 2.13 | 2.38 |
| 23 | 0.57 | 2.63 | 3.63 |
| 24 | 0.57 | 2.54 | 3.43 |
| 25 | 0.68 | 2.78 | 3.42 |

Continuation table 20

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| 26 | 0.85 | 2.91 | 3.75 |
| 27 | 1.24 | 3.11 | 4.16 |
| 28a | 0.56 | 4.62 | 6.24 |
| 29 | 0.68 | 3.27 | 6.52 |
| | T o t a l : | 98.28 | 136.32 |

## SECTION 9

## DRAINAGE PRODUCED BY ELECTROOSMOTIC SYSTEM ON THE MAIN SEDIMENTATION BASIN IN OGORZELEC

### GENERAL REMARKS

The principal investigations of electroosmotic drainage of postflo-atation tailings were performed under field conditions on the main sedimentation basin in Ogorzelec, from 21 July 1976 to 31 August 1977. This work was carried out using the installation described in the previous chapter, and consisted of a number of tests conducted under differing rates of electric supply, periods of current flow and breaks in supply, and also weather conditions obtaining during the tests.

The specific test conditions used to investigate the effects of varying the electric field were:

- A continuous power supply to all electrodes
- A continuous supply to all electrodes with periodic interruptions in current for short times
- A supply to all electrodes with long interruptions in current
- A supply of short duration to all electrodes with long interruptions in current
- A continuous power supply to one half of the cathodes
- An alternating supply to each half of the field
- An intermittent supply to all electrodes with day-long periods of supply and interruptions in supply.

The normal intensity of the current supplied to the electrodes was usually 400 A to all electrodes and 200 A to half the cathodes. The

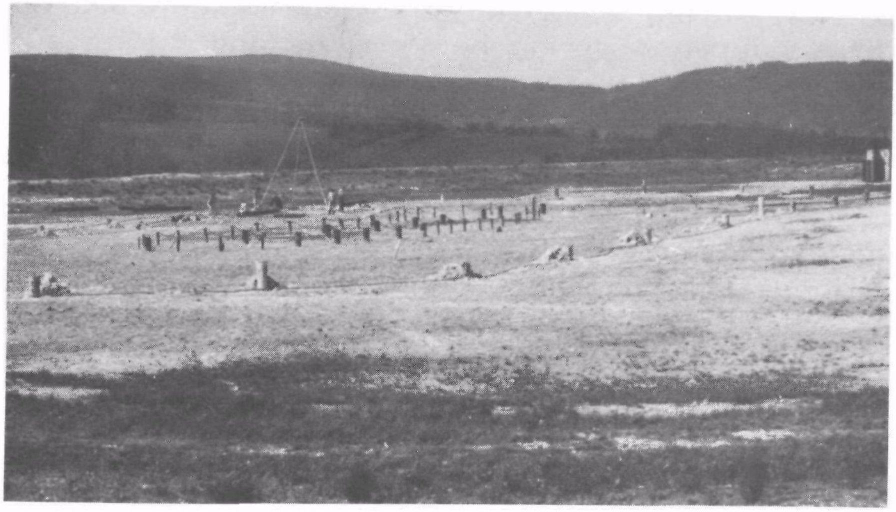


Fig. 71. Spacing of electrodes on main sedimentation basin, showing the condition of the surface during the initial phase of experiment.

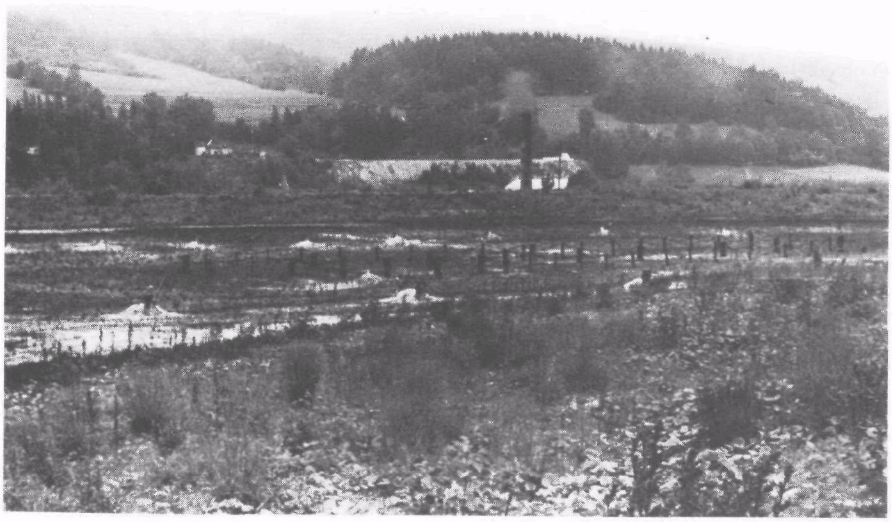


Fig. 72. The sedimentation basin surface after a year of drainage.

weather, mainly precipitations, had considerable influence on the effectiveness of electroosmosis despite the existence of the surface drainage network. Rain water did accumulate within the bowl of the sedimentation basin. This happened during heavy rains and during sudden spring thaws. During such periods the current was switched-off to forestall a forced flow of rain water into the sediments toward the cathodes. Maintenance of the surface drainage network was difficult owing to continuing subsidence of the sedimentation basin bowl, and also to infiltration of tailings into the ditches and into the rubber hose which conveyed water beyond the embankment. This impediment to surface drainage caused direct inflow of water into the filtercathodes, and distorted the measurements of discharges resulting from electroosmosis. However, such blockages occurred only sporadically. During the whole research period the accumulating water in filtercathodes was being removed with the help of plunger pumps, type NDMU 1$^1$/2 inch, with an output to 100 l/min. and maximum water rise head 9 m. The pumping operations were performed at irregular time intervals (from few to several days) usually after a complete filling of wells with water.

Additionally, the wells were always emptied regardless of water amounts before the start of new test.

The rate of water inflow into wells was determined by way of measurements of the water table level in reference to the top edge of filtercathodes. These measurements were performed in all wells at regular time intervals (every two days) with an accuracy to 1 cm. Used for this purpose was measuring tape ending in so called hydrological whistle. The position of water table level was also measured before and after each pumping operation.

On the basis of these measurements were determined the total water discharges and average discharges for typical well during the time period of each test duration, also total volumes of pumped out water were measured.

The changes in the drainage from the main sedimentation basin with time during the electroosmotic drainage process are shown in figures 73-80. These diagrams show water inflow rates (in the form of well yields) to the filtercathodes of both the entire arrangement (curve "A") and the deepest wells (curve "B"). The diagrams also show variations in the power supplied to the drainage system and indicate the dates of water pumping from the filtercathodes.

Yield of wells are making the resultant increases in water quantity obtained in wells in the effect of water inflow induced by electroosmotic phenomenon, and water losses caused by infiltration into permeable layers of sediment. A supplementary role are fulfilling the plotted at the same axis of time the diagrams of daily sums of atmospheric precipitation and of the efficiency of group of deepest wells.

Through efficiency of deepest wells one understands the percentage ratio of filtercathodes yields in this group to the yields of all other filtercathodes.

As a norm of efficiency of filtercathodes is taken the percentage ratio of total yields of 7 deepest wells to the total of effective depths of the whole battéry of filtercathodes.

## DISCUSSION OF THE TESTS

The tests started with observations of gravitational inflow of water to filtercathodes before applying current. After one week quantities (about 10-15 liters) of strongly polluted water also containing sediment were found. The inflow of pulp through the filtration holes in the cathodes and the entrance of tailings through the bottom opening of the cathodes was also observed. As noted earlier, this inflow resulted in a reduction in the efficiency of the cathodes.

Similar inflow of tailings occurred into the anodes where the level of tailings rose (within the pipe) above the surface elevation on the tailings pond.

On Aug. 21, 1976 the water accumulated in filtercathodes was pumped out and electric power applied thereby starting the cycle of tests of electroosmotic draining of the sedimentation basin.

In the following discussion of tests is considered the time of tests duration, periods and conditions of current supply, average well yields and total water yields in all wells. Average well output is the mean rate of water inflow during test time in a single well. Total water yield is the quantity of water which flows into all wells during the whole period of the test duration.

Test no. 1 is summarized in the following table.

Summary of test no. 1
Continuous supply to all cathodes with 2-3 day interruptions incurrent supply

| Period of test duration | Time of test durations, days | Supply periods, days total | Breaks in supply days total | Current intersity, A | Average well yield during test l/h | Total water dischar-ges l |
|---|---|---|---|---|---|---|
| Jul. 21 - Sep. 20 1976 (fig. 73) | 1 446,7 | 1064,0 | 382,7 | 400 | 12,4 | 17 939 |

Changes in discharge from the filtercathodes with time are presen-ted in fig. 73. The diagram shows that each time current is reapplied the yield of the wells increases. In succeeding days of electroosmosis the yields decrease in an irregular manner. During the periods of power interruption the well yields decreased quite rapidly.

Pumping of the wells enhanced the drainage of water into the cathodes considerably since the water accumulated around the cathodes would then drain under the higher potentiometric head conditions.

The third factor in addition to the electric supply and well pumping procedures that determine the output of a well is precipitation. The extent to which this factor affects the water inflow into the filtercathodes depends on the efficiency of the surface drainage system. Small amo-unts of precipitation occurring in short periods of time does not alter the well discharges. However, precipitation with great intensity and long duration does. One can observe on fig. 73 sudden increases in filter-cathode outputs caused by in filtration to the wells after heavy rains. The peak discharges are displaced in time due to the retention capability of the tailings.

The efficiency of the group of deepest wells, during this test was highest during the periods of rains and during interruptions in supply. This leads to the conclusion that the effective depth of the filtercathodes has a bearing on the capability of receiving rain water. This increased efficiency may be related to the increased potentiometric head created by pumping from deeper in the tailings pile.

The results of test 1a are summarized in the following table:

Summary of test 1a

Continuous supply of all electrodes with 2-3 days´breaks in electric supply

| The period of test duration | Time of test duration days | Periods of supply days total | Breaks supply days total | Current intensity A | Average well out put l/h | Total water yields l |
|---|---|---|---|---|---|---|
| Dec. 27,76 - Jan. 6, 1977 (fig. 75) | 264,7 | 168,0 | 96,7 | 400 | 9,0 | 2 382 |

Changes in the yields of the filtercathodes with time for test 1a are presented in fig. 75.

The results of test 1b are presented in the following table.

Summary of test no. 1b

A supply to all electrodes with 2-3 day interruptions current supply

| The period of tests duration | Time of test dura-tion days | Periods of supply days total | Breaks in supply days total | Current intensity A | Average well out put l/h | Total water yields l |
|---|---|---|---|---|---|---|
| Jan. 28 - Feb. 10, 1977 (fig. 76) | 311,6 | 205,0 | 106,6 | 700 | 18,5 | 5 764 |

The changes in yields from the filtercathodes during test 1b are shown in fig. 76.

As opposed to previous tests a much higher intensity of electric current (700 A) was applied during test 1b. This higher current greatly increased the water yields. Thirteen hours after current was applied the well yield was measured at 60.1 l/h. Figure 76 shows that precipitation was measured at the time. This yield was followed for the next 4 days by a reduction in the yield to 10 l/h. Further testing resulted in an average yield of about 13 l/h. During the entire period of the test, the rate of water inflow into the cathodes averaged 18.5 l/h. The efficiency of the group of deepest wells was generally small, however it increased considerably after disconnection of current and with the occurrence of rain. The period of test 1b was characterized with the occurrence of only a small rain, which permits a more accurate assessment of the effect of electroosmosis on drainage. After a lapse of one full day from the time the wells were pumped dry, the electric supply was again applied to all electrodes. This produced a rapid increase in water yields induced by both the reapplication of current and the increase in flow caused by pumping the filtercathodes. During a period of 2 days the yield of electrodes rose from 3.2 l/h to 17 l/h. Then, however, the yields fell by almost 50 percent. Similarly to that observed in the previously described test, the break in supply clearly produced a decrease in water yields. The relative efficiency of the group of deepest wells increased.

The results of test 1c are summarized in the following table.

Summary of test no. 1c

A supply to all electrodes, with periodic interruptions in supply of current

| The period of test duration | Time of test duration days | Periods of supply days total | Breaks in supply days total | Current intensity A | Average well out put l/h | Total water yields l |
|---|---|---|---|---|---|---|
| May 1 - May 19,1977 (fig. 79) | 456,4 | 333,0 | 123,4 | 400 | 9,4 | 4 290 |

Changes in water yields with time for test 1c are diagramed on fig. 79. In this test the periods of current supply are characterized by an increase in water discharges, and the periods of no supply by a slight decrease. The long term average yield (9.4 l/h) was positively affected by appreciable rain that occurred during the tests. The efficiency of the group of deepest wells was markedly below that observed for other tests.

The results of test 1d are summarized in the following table.

Summary of test no. 1d

A supply to all electrodes with short interruptions in current supply

| The period of test duration | Time of test duration days | Periods of supply days total | Breaks in supply days total | Current intensity A | Average well out put l/h | Total water yields l |
|---|---|---|---|---|---|---|
| May 30 - Jul. 29,1977 (fig.80) | 1462.2 | 1248.0 | 214.2 | 400 | 12.5 | 18 277 |

The diagram of changes in filtercathode yields for test 1d is fig. 80. The period of test id was characterized by frequent and appreciable rain. The effect of these rains is reflected clearly in subsequent increases in water yields of filtercathodes and in a relatively high average output of wells of 12.5 l/h.

During the entire test the efficiency of the deepest wells was below normal. The reasons for this are likely related to the times of rain being different than the times of pumping. Test 1d was interrupted during days 30 July - 5 Aug. 1977, when torrential rains fell in the area. The rains caused flooding of the sedimentation basin bowl. After the water was removed and the wells pumped out, more rain occurred on 5 July 1977 and the test was discontinued.

The general results of test no. 2 are summarized in the following table.

Summary of test no. 2

Current supply to all electrodes with short interruptions in supply (3-5 hours)

| The period of test duration | Time of test duration days | Periods of supply days total | Breaks in supply days total | Current intensity A | Average well out put l/h | Total water yields l |
|---|---|---|---|---|---|---|
| Sept. 20 - Oct. 18.76 (fig. 73) | 673.2 | 631.5 | 41.7 | 400 | 10.7 | 7 203 |

Changes in well yield with time for test no. 2 are diagramed in fig. 73. The initial phases of test no. 2 indicated a temporary increase in water yields. The water yields during periods of electrical supply were similar to those of test no. 1. The short duration (few hours) interruptions in current supply produced increases in filtercathode water yields upon resumption of current. During the period 13-14 Oct. 1976 a negative yield of the wells, was noted i.e., the water was moving into the sediment despite the fact that the electrical supply was connected to the whole field. This phenomenon appeared most clearly in the group of deepest wells. In fact, these deep wells had a low efficiency during the entire test. Intensive rains started on 18 October and lasted to 25 October, 1976. The test (no. 2) was therefore terminated.

The results of test no. 2a are summarized below.

Summary of test no. 2a

Current supply to all electrodes with short interruptions in supply

| Period of test duration | Time of test duration days | Supply periods days total | Breaks in supply days total | Current intensity A | Average well yield l/h | Total water yields l |
|---|---|---|---|---|---|---|
| Jan. 6 - Jan. 26.1977 (fig. 75) | 455.3 | 422.0 | 33.3 | 400 | 9.1 | 4 143 |

Changes in water yields with time during test no. 2a are presented in fig. 75.

The trends of water yields during test no. 2a were similar to that occurring during test no. 1. A few days after connecting the current supply an increase in the water discharge was observed. In subsequent days a small decrease occurred. Pumping out of the wells increased the well yields. The 3 to 4 hour interruptions in supply did not materially influence water yields. The test was characterized by no precipitation and thus the well yields were not affected by inflow of surface water. The group of deepest wells produced water at half the rate of the entire system.

The results of test no. 3 are summarized below.

Summary of test no. 3

Continuous current supply to all electrodes
with long interruptions in supply (4 to 6 days)

| The test duration period | Test duration time days | Supply periods days total | Breaks in days total | Current intensity A | Average well out put l/h | Total water yields l |
|---|---|---|---|---|---|---|
| Oct. 25 - Nov. 12.76 (fig. 74) | 458.0 | 275.0 | 183.0 | 400 | 9.2 | 4 214 |

Filtercathode water yield changes with time for test no. 3 are presented in fig. 74.

During the 11.4 days of current supply during test no. 3, changes in well output were similar to those observed for other test. Toward the end of the supply period, rain occurred and an appreciable increase in water inflow was measured. After disconnecting the supply and after a similar precipitation, even a much smaller and temporary increase in well output was measured.

The average output of filtercathodes was positively influenced by the rain.

The results of test no. 3a are summarized below.

Summary of test no. 3a

Continuous current supply to all electrodes
with longer periods of interruptions in supply

| Test duration period | Test duration time days | Supply periods days total | Breaks in supply days total | Current intensity A | Average well output l/h | Total water yields l |
|---|---|---|---|---|---|---|
| Feb. 10 - Feb. 20. 1977 (fig.no.76) | 263.9 | 135.0 | 128.9 | 400 | 16.6 | 4.380 |

The changes in water yields from the filtercathodes during test no. 3a are shown in fig. 76.

The initial application of current was followed by a five-day interruption in supply, during which an appreciable, although short, increase in the rate of water inflow to filtercathodes took place. During a period of the test (12 to 14 Feb. 1977) the filtercathodes were cleaned of tailings which had entered through the perforations and bottom of the wells. This had the effect of deepening the wells and changed the percentage ratio of the effective volume of the deep wells (nos. 7,8,9,10, 11,12 and 28) to the volume of all wells (B/A). The ratio was 29.6 percent and considered to represent the normal efficiency of the group of deepest wells. The deepening of all wells caused the efficiency of the group of deepest wells in subsequent test periods, to undergo a downrating, despite still existing appreciable differences in depths. The period of supply in this test proceeded typically.

The results of test no. 4 are summarized below.

Summary of test no.4

Electric supply with short periods of supply and long interruptions in this supply to well electrodes

| Period of test duration | Test duration time days | Supply periods days total | Breaks in supply days total | Current intensity A | Average well yield l/h | Total water yields l |
|---|---|---|---|---|---|---|
| Nov. 12 - Dec. 27.76 (fig. 74) | 1 079.4 | 130.0 | 949.4 | 400 | 9.0 | 9 715 |

The changes in water yields for test no. 4 are illustrated in fig. 74. Very long interruptions in the electric supply were necessitated by intensive and continuing rains. During the entire test period there were only ten days without precipitation. Hence an appreciable amount of the filtercathode yields can be attributed to infiltration of rain water.

Figure 74 shows clearly an increase in water inflow after pumping. Obiously this was caused by the increased potentiometric head difference between the water in the well and that in the tailings. Experience shows that the relatively high efficiency of the deep wells during two time periods is related to the infiltration of rainwater.

The results of test no. 5 are presented below.

Summary of test no. 5

Continuous electric supply to one half of the cathode field

| The period of test duration | Test duration time days | Supply periods days total | Breaks in days total | Current intensity A | Average well l/h | Total water l |
|---|---|---|---|---|---|---|
| Feb. 20 - Feb. 28 1977 (Fig. 76) | 216.8 | 130.0 | 86.8 | 200 | 14.0 | 3 035 |

The diagram of water discharge versus time, is provided in fig. 76. Electric current was applied to half of the cathodes (nos. 2-15) and all anodes. At the time the current was switched from the entire field of cathodes to one half of them, (with a simultaneous reduction in current intensity from 400 to 200 A) the water yields began to slowly decrease. The occurrence of appreciable rainfalls by the end of the test period caused a sudden increase in water discharge, even when the electric supply was interrupted. The efficiency of the deepest wells, despite the fact that six of them remained activated, was very low. This efficiency did increase considerably during the period of rain.

The average yield of wells during the entire test period was relatively high (14.0 l/h).

The results of test no. 5a are summarized below.

Summary of test no. 5a

Continuous supply to one half of the cathode field

| Test duration period | Test duration time days | Supply periods days total | Breaks in supply total | Current intensity A | Average well out put l/h | Total water yields l |
|---|---|---|---|---|---|---|
| Mar. 12 - Mar. 26, 1977 (Fig. 77) | 360.1 | 245.5 | 114.6 | 200 | 8.2 | 2.953 |

The water yields of cathodes during test no. 5a are shown in fig. 77. The period of this test was marked by very little precipitation. The same group of cathodes used in test no. 5 was connected.

After initial application of current and emptying the filtercathodes, a sudden increase in the water discharges occurred. The water yields remained constant for 2 days. During the next 2 days a rapid decline in the discharge rate was observed. The yields continued to decline at a slow rate through to the end of the test. A full day break in the current supply produced a faster decline in yield. Resumption of the electric supply for a period of one day reduced the rate of decrease slightly.

The efficiency of the deepest filtercathodes stayed below what was considered to be the normal level.

The results of test no. 6, consisting of observations made during a prolonged period of no current application, are summarized below.

Summary of test no. 6

Prolonged time period without electric supply to any electrodes

| Test duration period | Test duration time days | Periods of supply days total | Breaks in supply days total | Current intensity A | Average well out put l/h | Total water yields l |
|---|---|---|---|---|---|---|
| Feb. 28 - Mar. 12. 1977 (fig. 77) | 315.0 | - | 315.0 | - | 2.2 | 693 |

After a long period of experimenting with various electroosmosis procedures, a 13 day period of no current application was used to indicate whether there were any residual impacts on water inflow to the filtercathodes. The results of water yield measurements made during this test (no. 6) are shown in fig. 77.

The maximum well output (19 l/h), was observed after one day and after rain. During intervening periods of no rain, negative discharge rates (inflow to sediment) were observed twice during the test. This observation prompted a hypothesis that after a long period of electro-osmosis and drainage, the structure of the sediment changes to permit gravity drainage to some degree. The efficiency of deepest wells was not determined due to their "negative" yields (i.e., infiltration into the tailings). It was established that infiltration of water into tailings from this group of deep wells was smaller than from the other shallow wells.

Two additional tests to determine how the tailings drained during periods of no current supply were conducted. The results of tests nos. 6a and 6b are summarized below.

Summary of test no. 6a

Prolonged time period without electric supply

| Test duration period | Test duration time days | Supply Periods days total | Breaks in supply days total | Current intensity A | Average well output l/h | Total water yields l |
|---|---|---|---|---|---|---|
| Apr. 8 - Apr. 18. 1977 (Fig.no.78) | 263.5 | - | 263.5 | - | 21.1 | 5 560 |

During the period of test 6a considerable rainfall occurred causing an appreciable infiltration of rainwater to the wells. Accumulation of rain-water in the basin occured to such a large degree that the level rea-ched the top of some of the cathodes. This water flowed directly into the wells.

The results of test no. 6a are summarized below.

Summary of test no. 6b

Time period without electric supply

| The duration period | Test duration time days | Supply periods total days | Breaks in supply days total | Current intensity A | Average well out put l/h | Total water yields l |
|---|---|---|---|---|---|---|
| May 19 - May 30.77 (Fig.no.79) | 215.6 | - | 215.6 | - | 14.7 | 3 169 |

The high water yield resulted from the high amount of precipitation that occurred at the beginning of the test. During one day, 72 mm of rain flooded the sedimentaion basin bowl and caused a direct inflow of rain water to filtercathodes just as it had during test 6a.

In subsequent days the well yields decreased and became negative i.e., the water flowed into the tailings.

The results of test no. 7 are summarized in the following table.

Summary of test no. 7

Alternated supply of current to each half of the cathode

| Test duration period | Test duration time days | Supply periods days | Breaks in supply days | Current intensity A | Average well out put l/h | Total water yields l |
|---|---|---|---|---|---|---|
| Mar. 26 - Apr. 8. 77 (Fig.no.78) | 312.0 | 312.0 | - | 200 | 10.7 | 3 338 |

The changes in water yields with time during test no. 7 are illustrated in fig. 78. The two sets of cathodes were alternatively supplied with current for this test. The first group was composed of cathodes nos. 2-15, and the second group of cathodes nos. 1,16 - 29. The current supply was switched every 2 to 4 days.

The average well output of the whole field for test no. 7 was about equal to that measured for other tests. Increases in yields were produced each time the current was applied to the second group of cathodes, but a decrease in yield occurred in the first group. This was likely caused by the use of the first group of cathodes (only) in tests nos. 5 and 5a.

When there was a continuous electric supply it caused inflow of rainwater and appreciable drainage and increased the resistance of sediment in the zone between anodes and cathodes nos. 2-15 (the first group).

The results of test no. 8 are summarized in the following table.

Summary of test no. 8

Intermittent electric supply to all electrodes. Full day periods of supply and interruptions.

| Test duration period | Test duration time days | Supply periods days total | Breaks in supply days total | Current intensity A | Average well output l/h | Total water yields l |
|---|---|---|---|---|---|---|
| Apr. 19 - May 1, 77 (Fig.no.78) | 335.9 | 178.0 | 157.9 | 400 | 13.6 | 4 568 |

The variations in water yields with time are shown in fig. 78. The test was characterized by a high average well output (13.6 l/h). The yields were affected by inflow of rain water, but the greatest influence on water yields in filtercathodes appears to have been the method of applying the electrical supply. When the current was applied, the yields increased.

The efficiency of the deepest cathodes was below the expected level throughout most of the test.

## INTERPRETATION OF TEST RESULTS

Comparisons of the efficiency of the electroosmosis tests are complicated by the influence of precipitation. Despite the surface draining system precipitation caused varying amounts of water inflow into the tailings. Attempts were made to repeat tests in different weather conditions to make allowance for the precipitation factor in consideration of test results.

As another measure of efficiency the consumption of electric power per unit of drained water was used. Values of electric power consumed during the various tests, expressed in kilowatthours, are given in

## EXPLANATION FOR FIGS.73-80

### I. DIAGRAM OF CHANGES IN WATER INFLOW RATE TO FILTERCATHODES WITH TIME

$\frac{Q}{T}$ average velocity of water inflow to filtercathodes („efficiency" of filtercathodes l/h)

t time (days)

A changes in „efficiency" of the whole complex of filtercathodes and average efficiency of filtercathodes during test

B changes in „efficiency" of the group of deepest filtercathodes (nos.7-12,28)

400 continuous electric supply to all electrodes, current intensity 400A and interruption in electric supply

200 electric supply to all anodes and to first group of filtercathodes(nos. 2-15) intensity 200A

200 electric supply to all anodes and to second group of filtercathodes (nos.1,16-29) intensity 200A

### II. DIAGRAM OF TOTAL DAILY OF PRECIPITATION.

P daily total of precipitation (mm)

### III. DIAGRAM OF EFFICIENCY OF GROUP OF DEEPEST FILTERCATHODES (NOS.7-12, 28)

$\frac{B}{A}$ efficiency of the group deepest filtercathodes - calculated as the water yield of the deepest cathodes (B) divided by the wateryield of all cathodes (A)

24,1% I standard of efficiency - percentage ratio of total depth of filtercathodes as driven for group of deepest wells compared to the entire complex of filtercathodes

31,6% and 29,6% II. standard of efficiency - calculated as the percentage ratio of effective filtration (effective depth of depth of cleaning wells of sediment) of the group of deepest wells and of the whole filtercathode complex

x change of the II standard of efficiency on the date when the filtercathodes were cleaned of tailings that had entered the cathodes

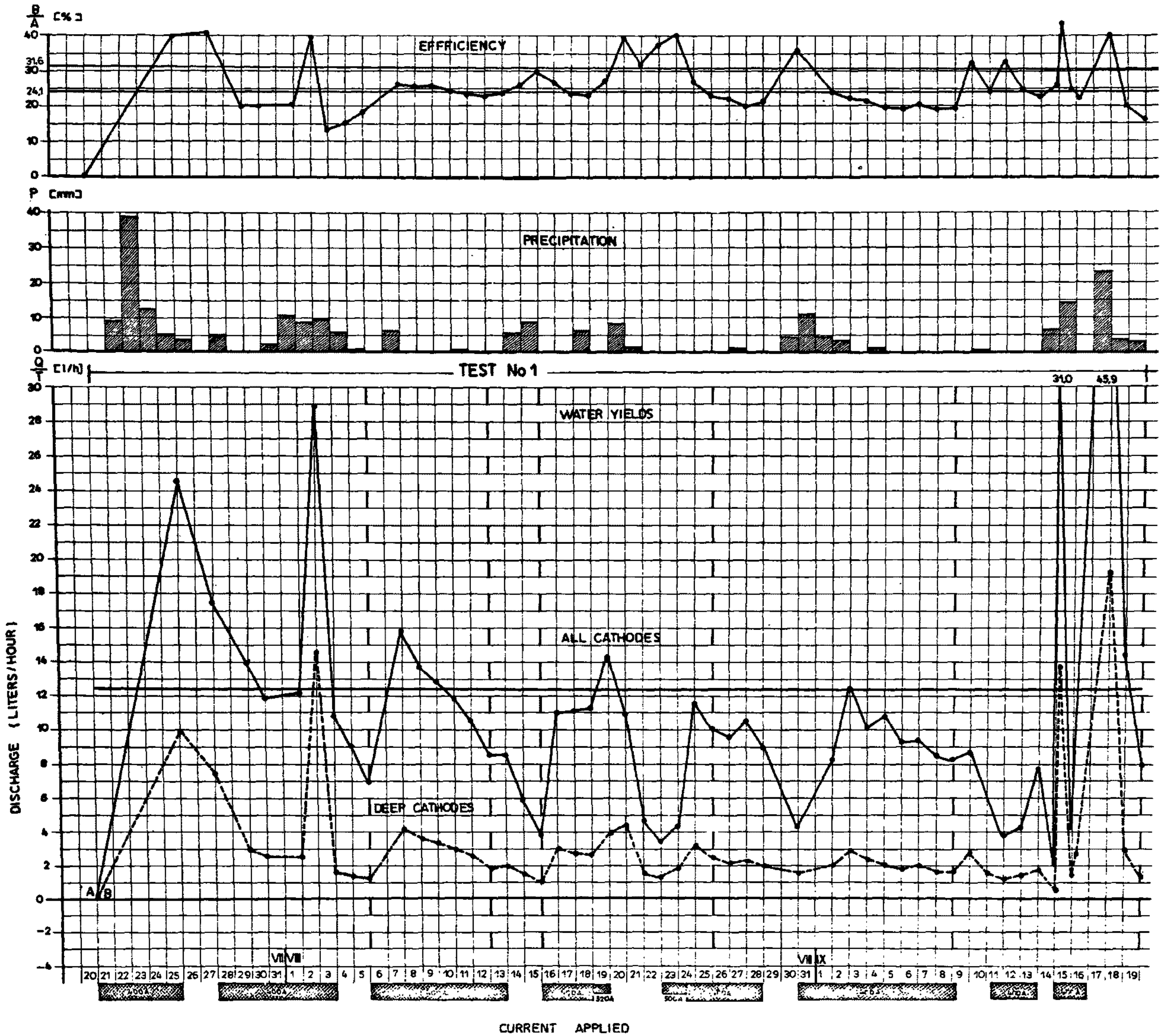



Fig. 73 CHANGES IN WATER YIELDS AND EFFICIENCIES DURING TESTS 1 AND 2. MAIN SEDIMENTATION BASIN IN OGORZELEC. 21 JUL - 25 OCT 76

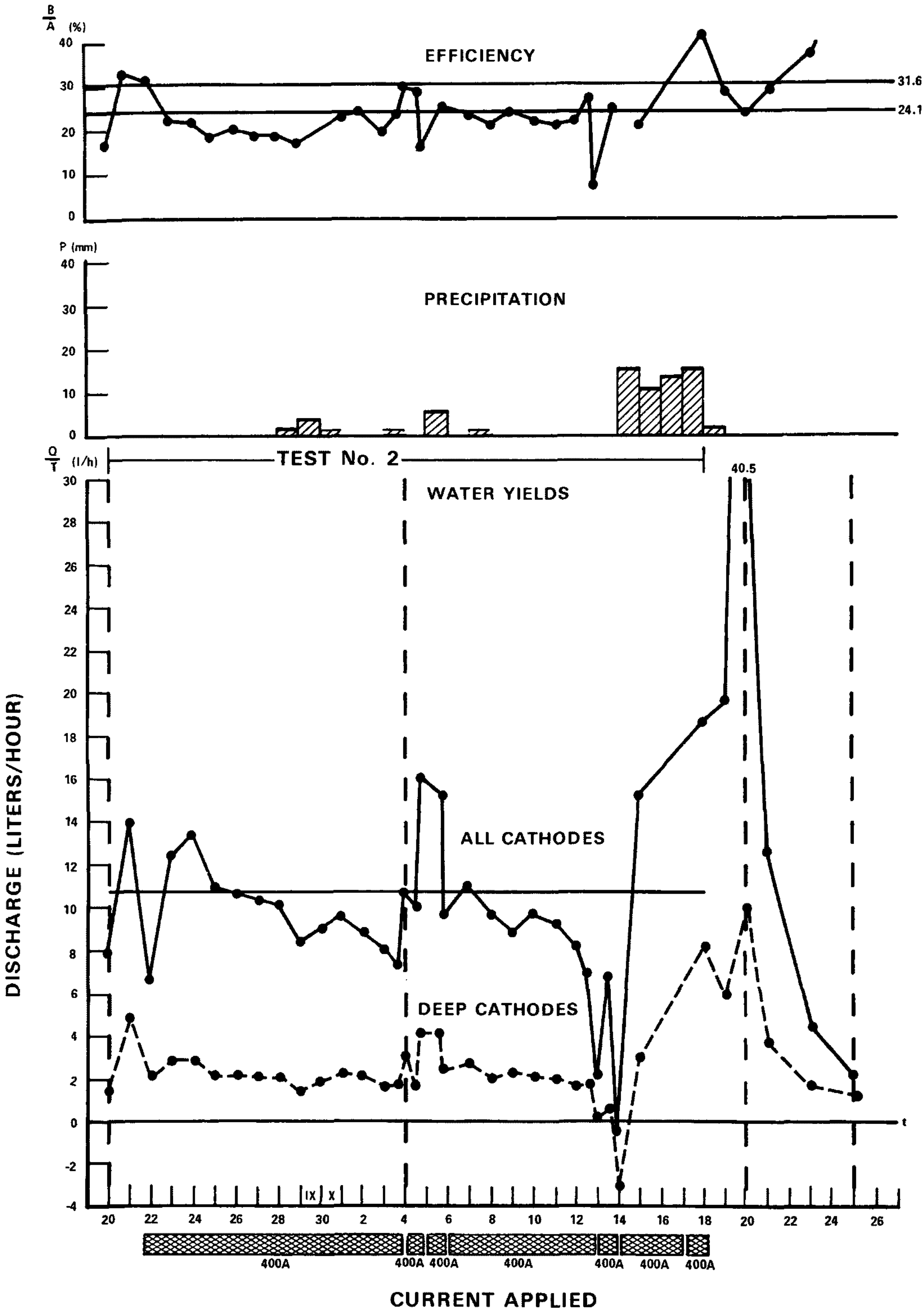



**Figure 73 - Continuation**

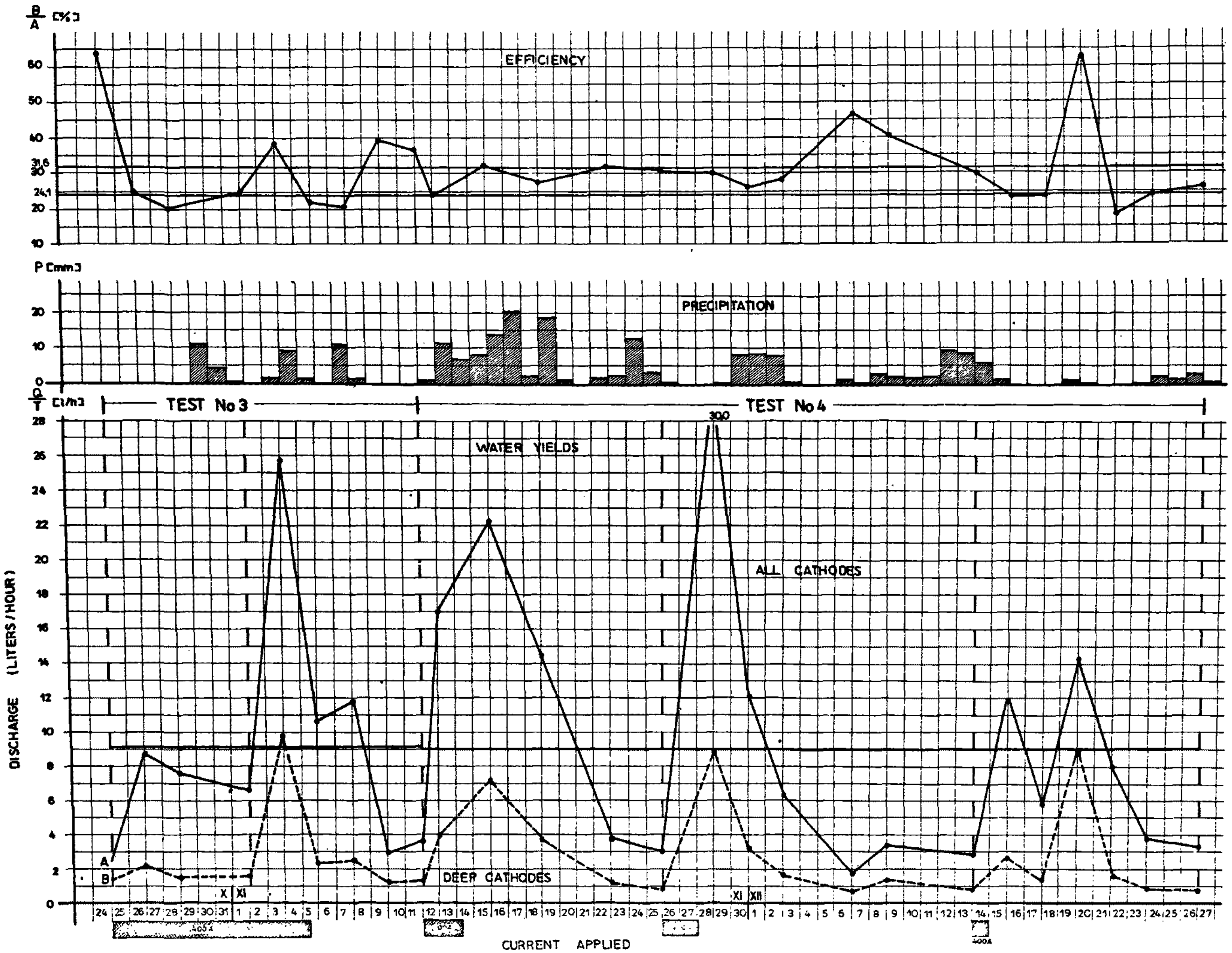



Fig. 74. CHANGES IN WATER YIELDS AND EFFICIENCIES DURING TESTS 3 AND 4. MAIN SEDIMENTATION BASIN 25 OCT - 26 DEC 76.

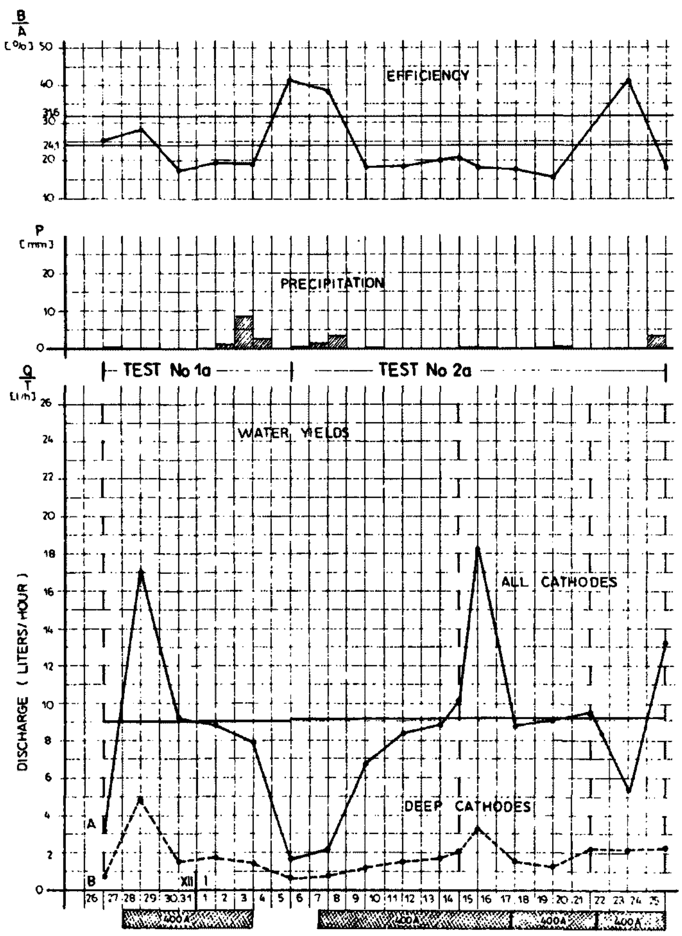



Fig.75 CHANGES IN WATER YIELDS AND EFFICIENCIES DURING TESTS 1a AND 2a. MAIN SEDIMENTATION BASIN 27 DEC - 25 JAN 77

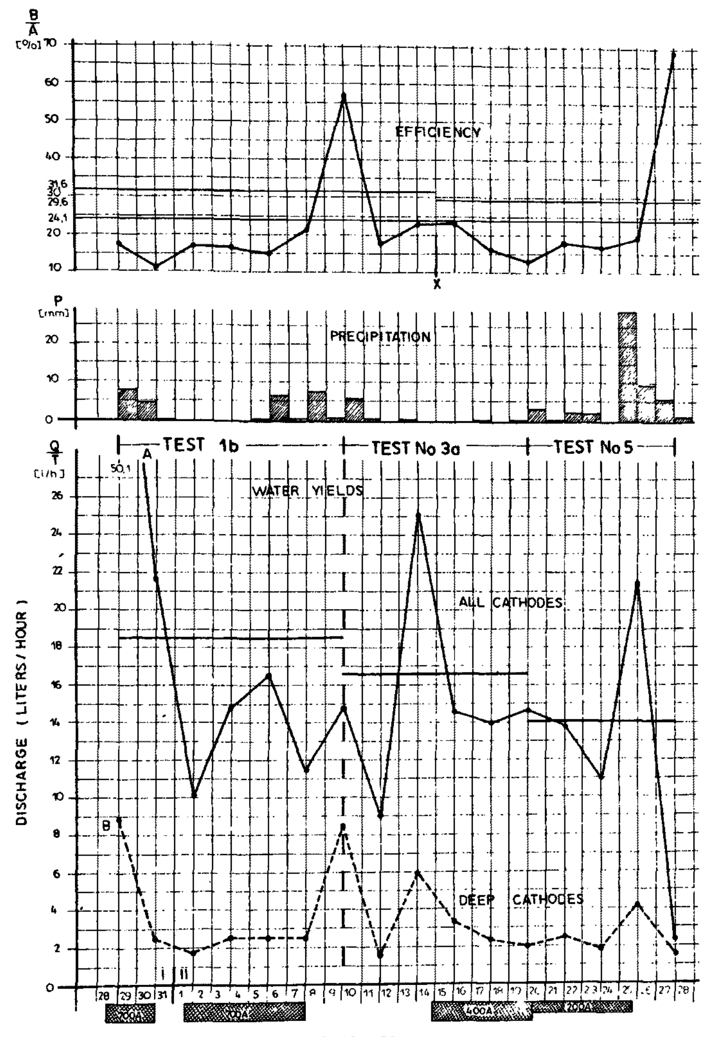



Fig.76 CHANGES IN WATER YIELDS AND EFFICIENCIES DURING TESTS 1b, 3a, AND 5. MAIN SEDIMENTATION BASIN 28 JAN - 28 FEB 77.

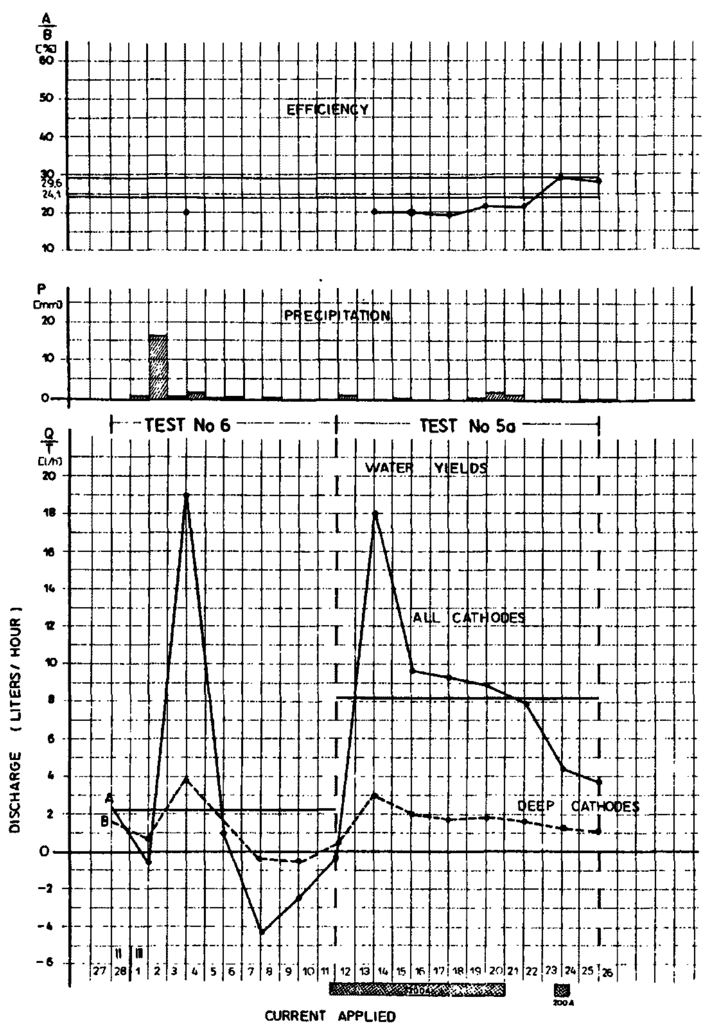



Fig.77 CHANGES IN WATER YIELDS AND EFFICIENCIES DURING TESTS 6 AND 5a. MAIN SEDIMENTATION BASIN 2FEB - 26MAR 77.

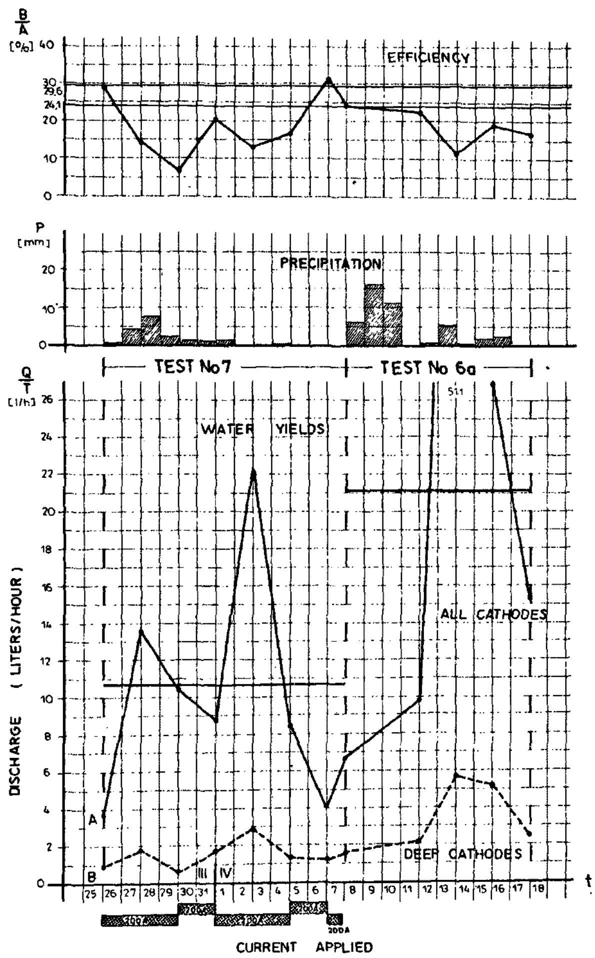



Fig 78 CHANGES IN WATER YIELDS AND EFFICIENCIES DURING TESTS 7 AND 6a. MAIN SEDIMENTATION BASIN 26 MAR - 18 APR 77.

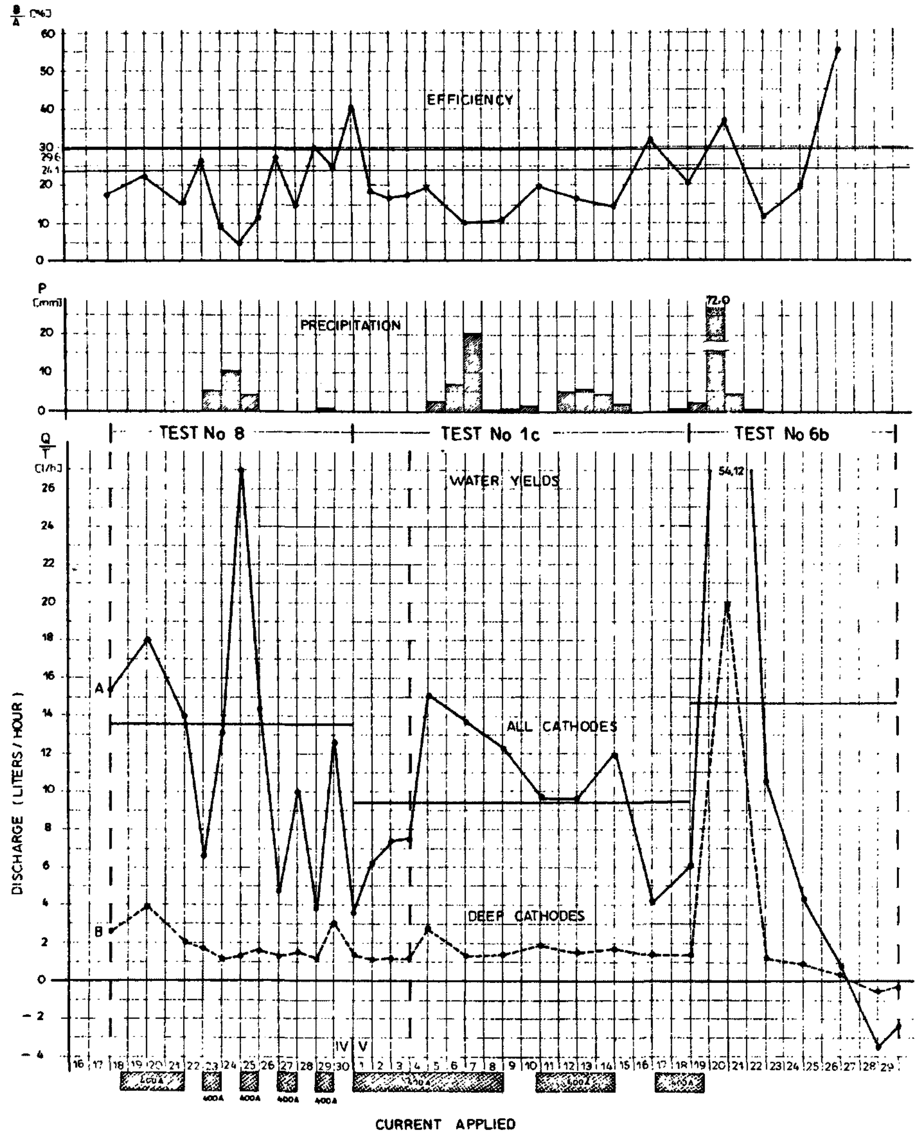



Fig. 79 CHANGES IN WATER YIELDS AND EFFICIENCIES DURING TESTS 8,1c AND 6 b. MAIN SEDIMENTATION BASIN 18 APR - 30 MAJ 77.

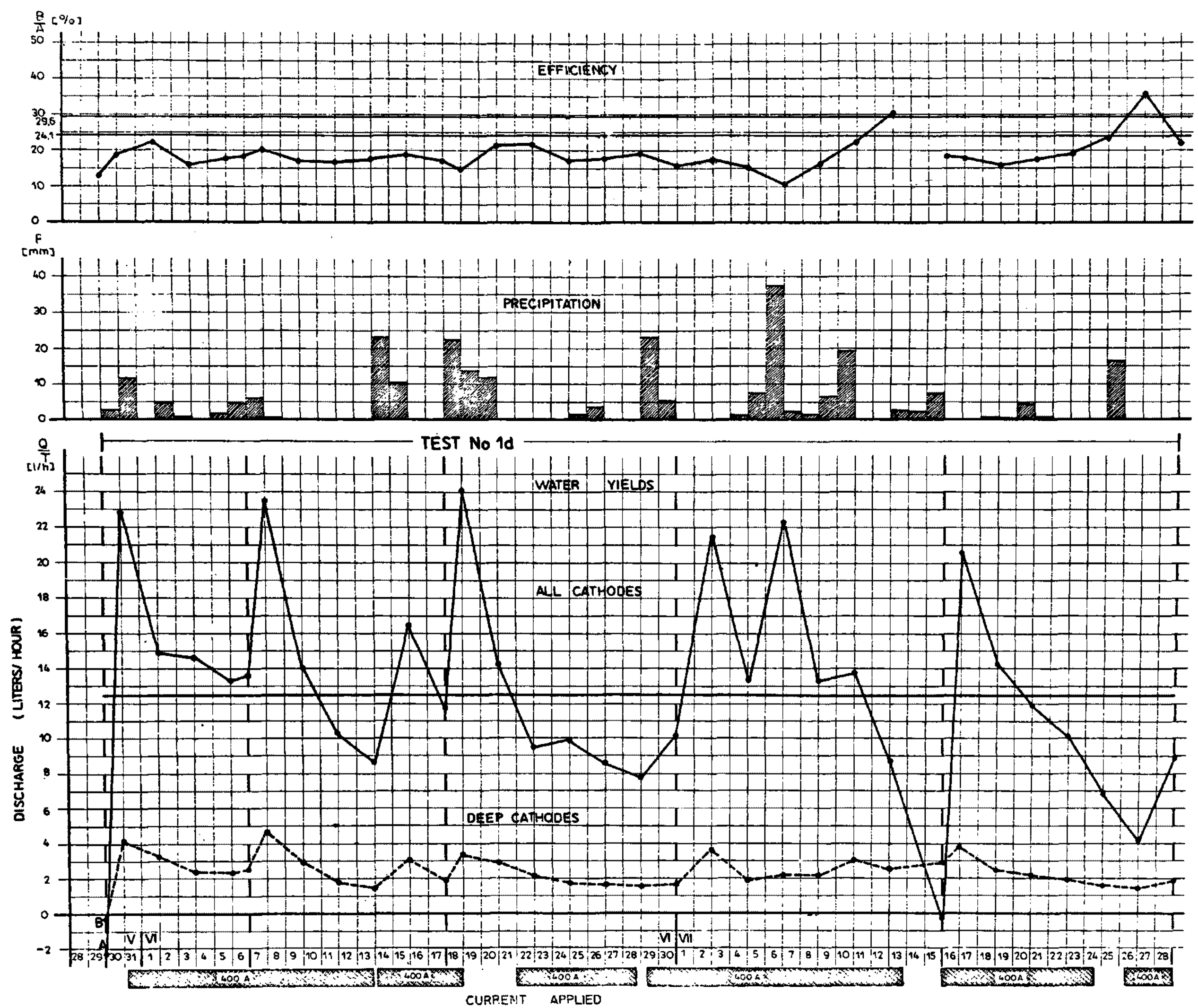



Fig. 80 CHANGES IN WATER YIELDS AND EFFICIENCIES DURING TEST 1d. MAIN SEDIMENTATION BASIN 30 MAY - 4 AUG 77.

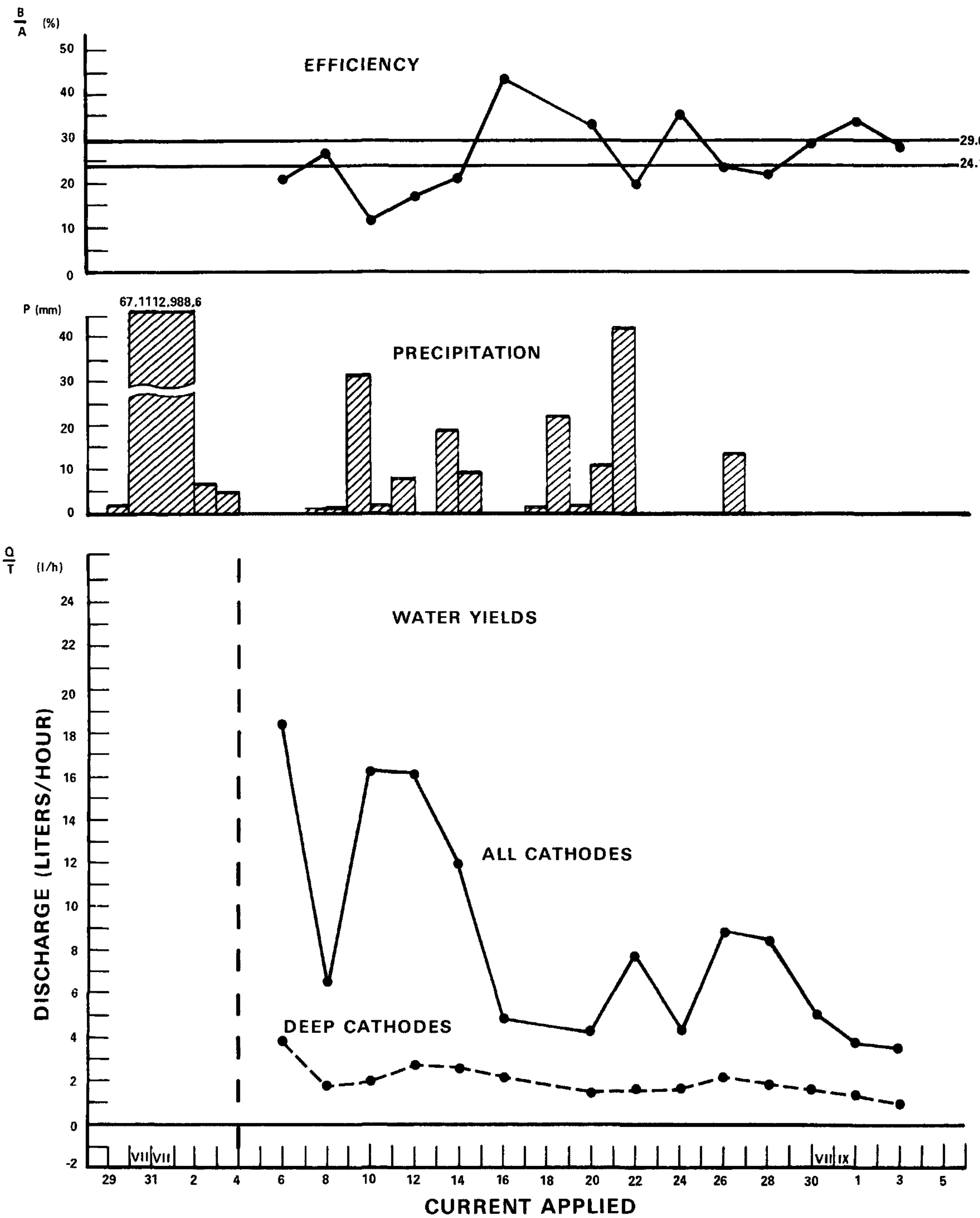



**Figure 80 - Continuation**

table 21. This table also contains a listing of the total water discharges, along with the conditions time, and amount of electric energy applied during the individual tests.

Table no. 21

Summary of results of electroosmotic drainage tests performed on the main sedimentation basin in Ogorzelec

| Test designation | Total water output | Average current | Average voltage | Total time of electric supply | Amount electrical energy consumed | Electrical energy used per liter of water removed |
|---|---|---|---|---|---|---|
| | l | A | V | h | kWh | kWh/l |
| 1 | 17.939 | 406 | 86.5 | 1064 | 37.367 | 2.08 |
| 1A | 2.382 | 400 | 86.5 | 168 | 5.813 | 2.44 |
| 1B | 5.764 | 700 | 173 | 205 | 24.826 | 4.30 |
| 1C | 4.290 | 400 | 86.5 | 333 | 11.522 | 2.68 |
| 1D | 18.277 | 400 | 86.5 | 1248 | 43.181 | 2.36 |
| 2 | 7.203 | 400 | 86.5 | 631.5 | 21.850 | 3.03 |
| 2A | 4.143 | 400 | 86.5 | 422 | 14.601 | 3.52 |
| 3 | 4.214 | 400 | 86.5 | 275 | 9.515 | 2.25 |
| 3A | 4.380 | 400 | 86.5 | 135 | 4.671 | 1.06[x] |
| 4 | 9.715 | 400 | 86.5 | 130 | 4.473 | 0.46[x] |
| 5 | 3.035 | 200 | 86.5 | 130 | 2.237 | 0.73[x] |
| 5A | 2.953 | 200 | 86.5 | 245.5 | 4.247 | 1.43 |
| 7 | 3.338 | 200 | 86.5 | 312 | 5.368 | 1.61 |
| 8 | 4.568 | 400 | 86.5 | 178 | 6.159 | 1.34 |

x - denotes ratios noticeably affected by inflow of precipitation

When comparing the electrical energy used for the various tests, the results of tests no. 3A, 4 and 5 should be omitted due to the effect of inflow of precipitation which lowered the apparent energy requirements.

Of the remaining tests, the most efficient use of electricity appeared to have been during tests 8 (1.34 kWh/l), 5A (1.43 kWh/l), and 7 (1.61 kWh/l). These tests were conducted using the following electrical supply methods:

- test 8 intermittent supply to all electrodes (400 A, 86.5 V) alternating full day periods of current application and interruption
- test 5a continuous supply to one half of the cathodes (200 A, 86.5 V)
- test 7 alternating supply to each half of the field (200 A, 86.5 V).

The electric energy consumption during the other tests usually significantly exceeds 2 kWh/l.

The highest value of this indicator (4.30 kWh/l) and thus the lowest efficiency occurred for test no. 1 B, when all cathodes were employed with 2 to 3 day interruptions in supply of a high current intensity of 700 A and a voltage of 173 V.

## SECTION 10

## EFFECTS OF ELECTROOSMOTIC DRAINING OF MAIN SEDIMENTATION BASIN

### CHANGES IN ELEVATION OF THE SEDIMENTATION BASIN SURFACE

#### The objective and scope of measurements of vertical displacements of the sedimentation basin bowl.

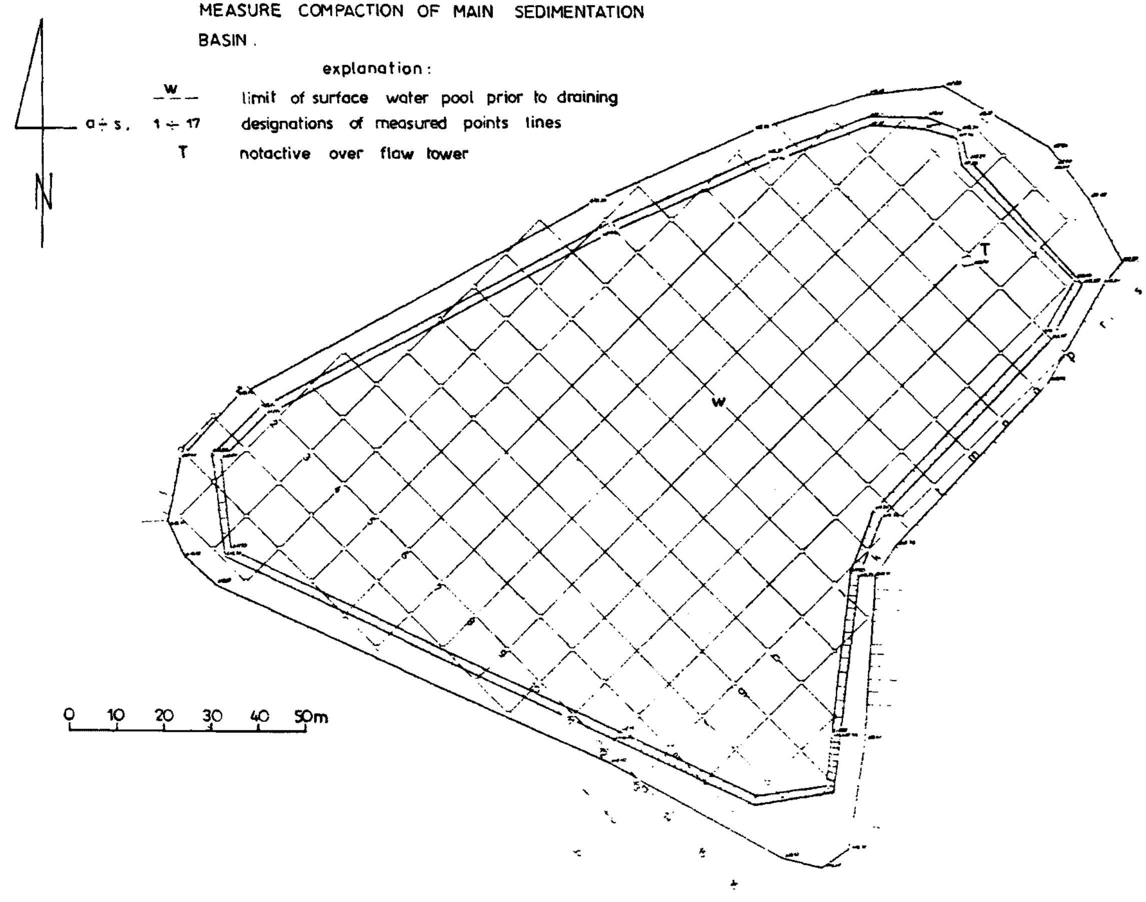
It was assumed that an effect of drying would be the compaction and vertical displacement of the surface of the tailings. Thus the elevations of the bowl area were measured before and after removing water.

The measurements performed with tachymetric method were based on a polygon network in the form of an independent, closed traverse. This network was tied to the existing national levelling net. The measurements were used to prepare contour maps for working purposes.

#### Reference line

For the purposes of periodic observations of any vertical displacements of the main sedimentation basin bowl a network of measurement points was established at the locations shown in fig. 81. A grid system of 10 m x 10 m was used and wooden piles 1 m long and 6 to 10 cm in diameter were driven at the grid intersections. The grid locations were identified using the alphanumeric (designations shown in figure 81.

Fig 81 SURFACE ELEVATION GRID SYSTEM USED TO MEASURE COMPACTION OF MAIN SEDIMENTATION BASIN .



During the initial measurements on 6 Jun. 1975 only 133 of the total 189 grid intersection points were out of the surface water pool. This initial limit of surface water is denoted on the drawing with a dashed line. Only after the surface water was drained could the remaining 56 points be measured.

In order to determine the absolute changes in elevation, three bench marks A, B and C were established on walls of buildings located outside the zone of the tailings pile. The position of these buildings is shown on fig. 2.

## Method of measurement

The elevations of the network of survey points (fig. 81) were measured using survey instruments (Koni 007 - Carl Zeiss). Measurements were made during the period from June of 1975 to September 1977. The first measurement was made on 6 Jun. 1975, and six measurements were made subsequently. The measurements were usually conducted from five instrument locations. The network was always closed to ± 5 mm or less. Observations were started and completed at location pt 13 d, the height of which was determined each time by reference to the off-site bench marks.

During the first measurements prior to drainage, the points under the water surface were levelled with the use of a levelling staff located equipped with a special stand to prevent excessive sinking of the staff. The accuracy of these readings made with respect to the water table could not be better than ± 2 cm. For this reason the data of the remaining points of the network were computed in centimeters. for the first measurement. In subsequent measurements when all points were clear of standing water the readings on the staff were made in mm. During the second set of measurements, made on 28 Sep. 75, the difference in elevations between the post tops measured in the previously submerged area and the tailings surface was accurately determined for the first time.

The following relationship was used to determine whether the area was stable:

$$(h - h') \qquad d_{max} = 2\, m_o \sqrt{n + n'}$$

where:

h and h' - elevation among inspection bench marks taken from initial measurement (h) and a later measurement (h');

$m_o$ - average error of a typical elevation survey (for one stand of levelling instrument), for which a value of $m_o = \pm 0.1$ mm was adopted

n - n' - number of stands of levelling instrument in initial (n) and in later (n') measurements.

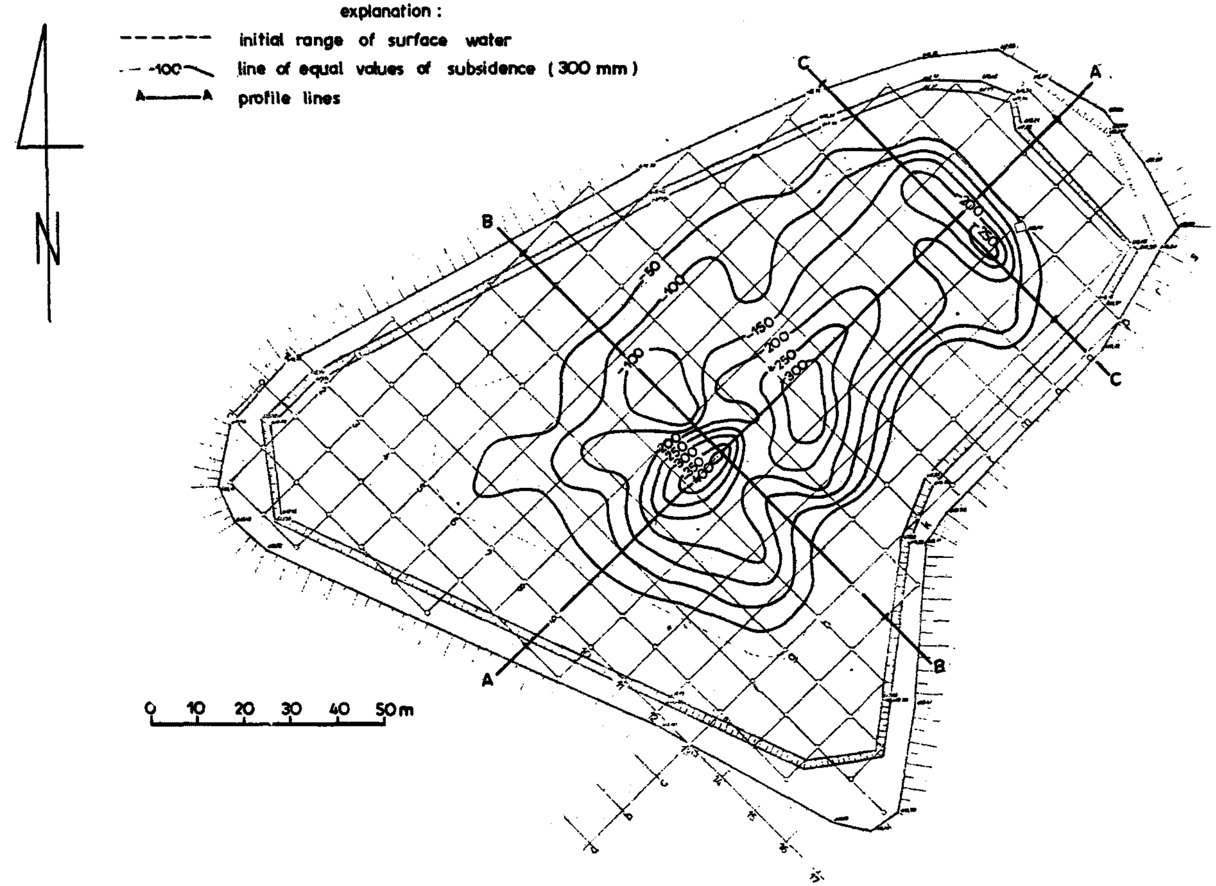
Description of the survey results

During the experiment (June of 1975 to September of 1977), 49 of the elevation piles were destroyed, of which 34 were restored, some two times.

Vertical displacements for these points were calculated as a sum of differences between subsequent measurements of the elevation and the initial measurements, and do not represent continued subsidence. Differences between actual and initial observation are presented as a numerical value and the direction of the displacement of the point is expressed in $\pm$ mm. The total reductions in elevation through the experiment are contoured in fig. 82. Three profiles of subsidence developed from each of the six measurements are presented in fig. 83. Profiles along line 9-9 (profile A) characterize progressive subsidence with time across the middle of the tailings pile. The other profiles (B and C) are located perpendicular to line 9-9 at points "i" and "o" (see fig. 82 for locations).

The profiles clearly show that the embankments of the tailings pile remained stable as the bowl subsided.

Fig 82 CONTOUR MAP OF VERTICAL DISPLACEMENTS OF THE MAIN SEDIMENTATION BASIN BOWL 6 JUN 75 - 8 SEP 77



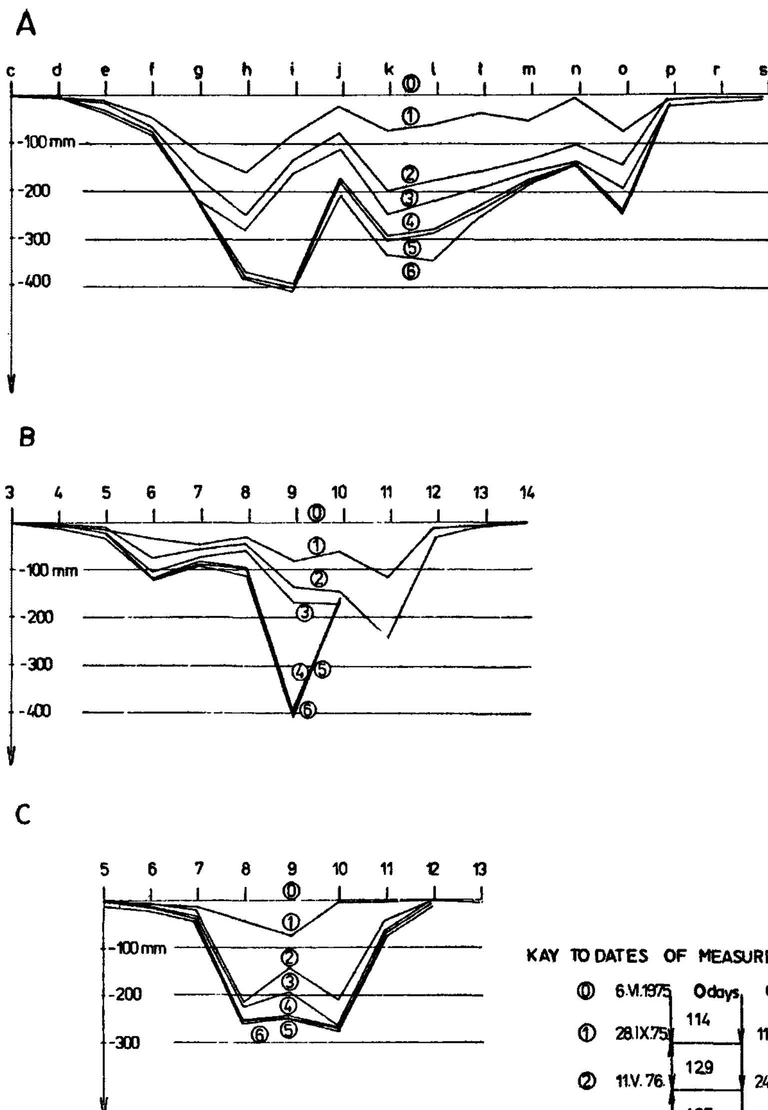



Fig. 83 CHARACTERISTIC PROFILES OF VERTICAL DISPLACEMENTS OF SEDIMENTATION BASIN BOWL, TAKEN FROM SUCCESSIVE ELEVATION MEASUREMENTS (SEE FIG. 82 FOR LOCATIONS).
A – profiles of line 9-9
B – profiles l – l
C – profiles o – o

KAY TO DATES OF MEASUREMENTS

| | | | |
|---|---|---|---|
| ⓪ | 6.VI.1975 | 0 days | 0 days |
| ① | 28.IX.75 | 114 | 114 |
| ② | 11.V.76 | 129 | 243 |
| ③ | 25.IX.76 | 137 | 380 |
| ④ | 25.III.77 | 181 | 561 |
| ⑤ | 20.V.77 | 83 | 644 |
| ⑥ | 8.IX.77 | 111 | 755 |

The irregular character of the profile lines reflects differential settling throughout the basin. The parallel nature of successive profiles suggest that the differential settling was caused by differences in the permeability of the tailings material. The rate of subsidence varied by season. Greater displacements were observed in the spring, smaller in autumn.

Figure 82 uses the difference between the initial elevation and those measured on 8 Sep. 77 as the basis for the subsidence contours. The contour interval is 50 mm.

Vertical displacements greater than 50 mm occur only on the boundary of the original surface water catchment area (on the drawing this boundary is marked with dashed line) and attain maximal values in three areas located in the middle of the tailings basin bowl.

The values of displacements presented are absolute displacements, since all measurements were tied to stable bench marks, located outside the tailings pile area. (Fig. no. 2). Stability of the inspection bench marks is demonstrated in table 22. Periodic measurements between bench marks C and B, B and A, and A and 13d (where the bench mark 13d is located within the network of points, indicate that differences ($d_i$, column 10, table 22) between the initial measurements h', and later measurements are within limits of accepted criterion of stability, $d_i$ max, (column 11), i.e. $d_i < d_i$ max.

These analyses showed that the bench marks A, B and C were stable for the duration of the surveys. However, in the case of elevations for A-13d $d_i < d_i$ max. for all measurements. Hence this point was not stable and the elevation of point 13d was computed for each measurement. For calculation of the $d_i$ max value, $m_o = \pm 0.1$ mm was used. Calculated $m_o$ values for the measurements (col. 9) were obtained within limits of $\pm$ 0.04 to $\pm$ 0.08 mm.

Table 22

Test of the stability of external bench marks

| Observation day | Bench mark | Elevation | Number of stands n | Weight $p=\frac{1}{n}$ | $h_{avr}$ | d | pdd | $m_o=\pm\frac{1}{2}\sqrt{\frac{pdd}{r}}$ average error | $d_i=h_i'-h_i$ | $d_{i\,max}=\pm 2m_o\sqrt{n+n'}$ $m_o=0.1$ used |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 0 | C | C-B | 1 | 1 | 1542.40 | 0.1 | 0.0100 | | | |
| | B | B-A | 3 | 0.33 | 7688.65 | 0.10 | 0.0033 | ± 0.05 | these | |
| Jun. 6, 1975 | A | A-13d | 4 | 0.25 | 2754.30 | 0.30 | 0.0225 | | are H | |
| | 13d | | | | | Σ | 0.0358 | | | |
| 1 | C | C-B | 1 | 1 | 1542.36 | 0.15 | 0.0225 | | -0.04 | ± 0.28 |
| Sep. 28, | B | B-A | 3 | 0.33 | 7688.20 | 0.05 | 0.0008 | ± 0.04 | -0.45 | ± 0.49 |
| 1975 | A | A-13d | 5 | 0.20 | 2752.32 | 0.05 | 0.0005 | | -1.98 | ± 0.60 |
| | 13d | | | | | Σ | 0.0238 | | | |
| 2 | C | C-B | 1 | 1 | 1542.70 | 0.15 | 0.0225 | | +0.30 | ± 0.28 |
| May 11, | B | B-A | 3 | 0.33 | 7689.15 | 0.00 | 0.0000 | ± 0.05 | +0.50 | ± 0.49 |
| 1976 | A | A-13d | 6 | 0.17 | 2752.55 | 0.30 | 0.0153 | | -1.75 | ± 0.63 |
| | | | | | | Σ | 0.0378 | | | |
| 3 | C | C-B | 1 | 1 | 1542.60 | 0.10 | 0.0100 | | +0.20 | ± 0.28 |
| Sep.25, | B | B-A | 3 | 0.33 | 7689.02 | 0.35 | 0.0404 | ± 0.07 | +0.37 | ± 0.49 |
| 1976 | A | A-13d | 5 | 0.25 | 2751.62 | 0.15 | 0.0056 | | -2.68 | ± 0.60 |
| | 13d | | | | | Σ | 0.0560 | | | |
| 4 | C | C-B | 1 | 1 | 1542.35 | 0.05 | 0.0025 | | -0.05 | ± 0.28 |
| Mar.25, | B | B-A | 5 | 0.25 | 7689.15 | 0.30 | 0.0225 | ± 0.08 | +0.50 | ± 0.57 |
| 1977 | A | A-13d | 8 | 0.12 | 2751.78 | 0.15 | 0.0027 | | -2.52 | ± 0.69 |
| | 13d | | | | | Σ | 0.0777 | | | |
| 5 | C | C-B | 1 | 1 | 1542.40 | 0.10 | 0.0100 | | 0.00 | ± 0.25 |
| May 20, | A | B-A | 3 | 0.33 | 7689.00 | 0.20 | 0.0132 | ± 0.04 | +0.35 | ± 0.49 |
| 1977 | B | A-13d | 5 | 0.20 | 2751.70 | 0.10 | 0.0020 | | -2.60 | ± 0.60 |
| | 13d | | | | | Σ | 0.0252 | | | |
| 6 | C | C-B | 1 | 1 | 1542.30 | 0.20 | 0.0400 | | -0.10 | ± 0.28 |
| Sep.8, | A | B-A | 3 | 0.33 | 7689.40 | 0.40 | 0.0528 | ± 0.11 | +0.75 | ± 0.49 |
| 1977 | B | A-13d | 4 | 0.25 | 2747.00 | 0.50 | 0.0625 | | -7.30 | ± 0.56 |
| | 13d | | | | | Σ | 0.1553 | | | |

## CHANGES IN TAILINGS MOISTURE CONTENT

In the effect of electroosmotic draining of the main sedimentation basin, there was observed general fall in the water content in tailings. In order to determine spatial changes in the humidity of sedimentation basin, samples for analyses were being collected from a determined grid of investigated points (fig. 8, 84, 85) essentially to a depth of 3 m. In the course electrodes' installation, vertical profiles of initial humidity to a depth of 10 m were made, and after completion of electroosmotic drainage - profiles of final humidity to 4.5 m depth were made.

In initial distribution of humidity in the near-to-surface layer of tailings (to 3 m) one can observe a clear horizontal zoning (fig. 8). In external zone (embankment), the humidity assuming values from 18.5 to 31 percent, on average amounted to 23.5 percent.

In internal A zone (between internal slope and the line of initial reach of water table, extreme values of humidity were shaped from 30 to 35 percent, on average - 32.7 percent. In the enclosed with line of initial reach of water table (isoline 50 %) internal B zone the humidity of tailings was more than 50 %.

In further observations of tailings' humidity changes, the following zonal partition was adopted based on the distribution of electrodes within the bowl of the sedimentation basin:

- external zone (embankment)
- internal zone outside the cathodes (between the line of cathodes and internal slope of sedimentation basin)
- interelectrode zone (between lines of cathodes and anodes)
- near-anode zone - the center (inside the lines of anodes).

Initial humidity between the lines of cathodes and internal slope amounted on average to 40.6 percent (table 23).

Investigations made after 9 months time from the start of electroosmotic draining (in May 1975) showed changes in humidity within the reach of particular zones.

Fig84. WATER CONTENT OF SURFACE LAYER OF TAILINGS AFTER 9 MONTHS OF ELECTROOSMOTIC DRAINING

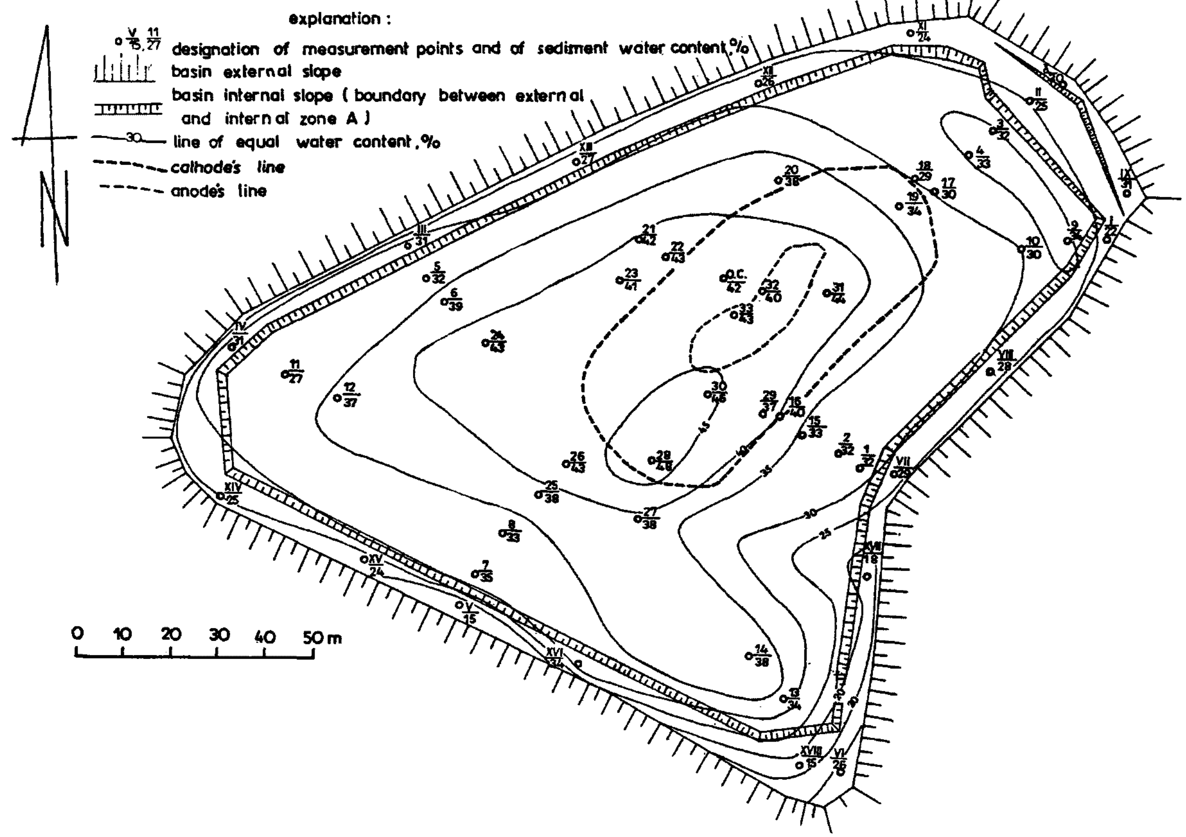
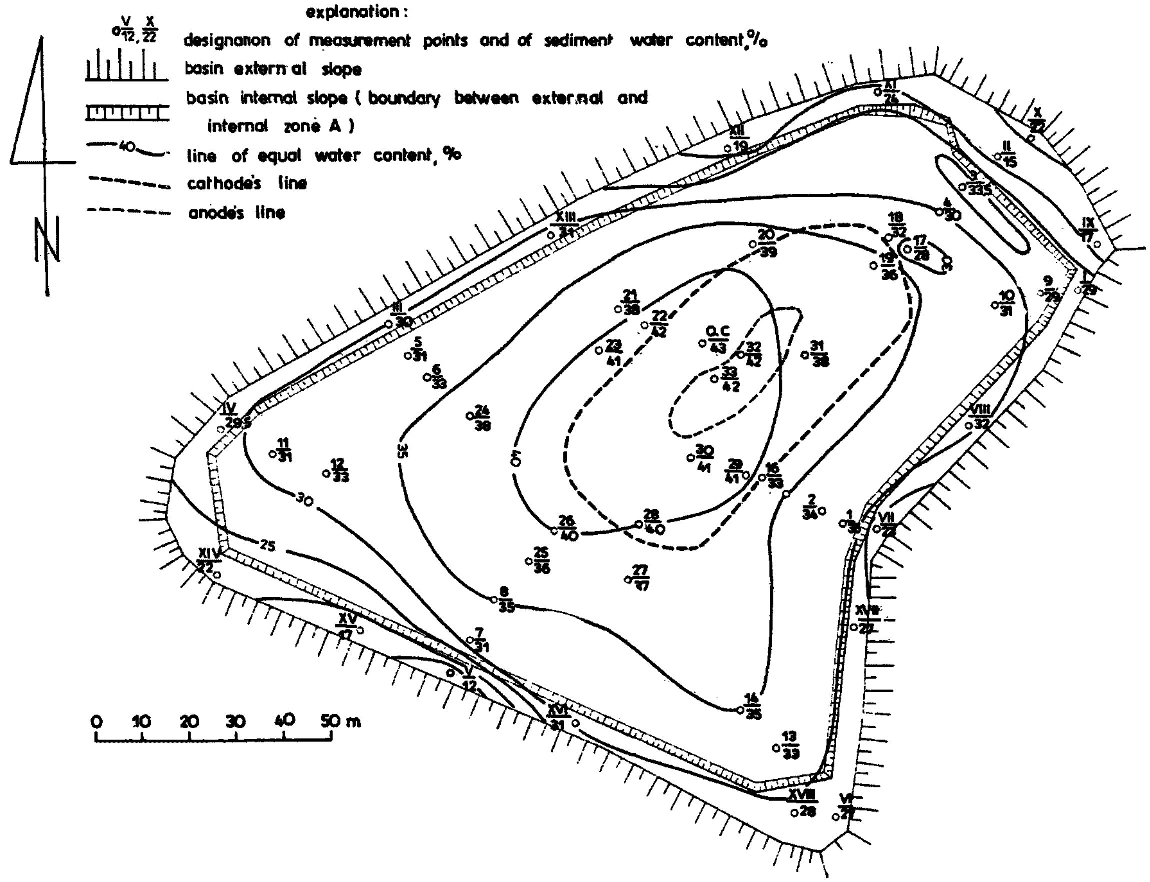


Fig.85 WATER CONTENT OF SURFACE LAYER OF TAILINGS AFTER 13 MONTHS OF ELECTROOSMOTIC DRAINING



In external zone was observed (embankment) a small rise in humidity to average value of 25.3 percent, and its significant differentiation in particular points (from 15 to 34 percent). In internal zone outside the cathodes line the average humidity dropped from 40.6 percent to 36.0 percent, by a significant differentiation in extreme values (fig. 84). In interelectrode and near-anode zones average humidity was determined respectively as 38.8 percent and 41.6 percent (table 23). Initial humidity in both zones was more than 50 percent.

After a lapse of further four months, therefore after 13 months of electroosmotic draining of the sedimentation basin, final analyses of humidity of samples collected from fixed test points were made. Distribution of average humidities within the sedimentation basin bowl reach was as follows:

- external zone - 24.4 percent (fall by 0.9 %)
- internal zone outside the cathodes - 34.4 percent (drop by 1.6 percent)
- interelectrode zone - 39.6 percent (increase by 0.89 %
- near anode zone - 42.3 percent (increase by 0.7 %).

Increase in final humidity content in relation to intermediate (after 9 months) humidity ensues largely from the occurrence in preceding the measurement considerable rains (see diagram of precipitation fig.80).

Average humidity of near-to-surface layer within the limits of the whole bowl of sedimentation basin (average for all investigated points) was falling during the tests' period, assuming values: above the 36.2 percent at the moment of commenced electroosmotic draining, 33.1 percent after 9 months of draining and 31.8 percent after further four months at time of finished tests (table 23).

Observed in all zones, with the exception of embankment, was a fall in moisture content, despite the feeding the tailings with rain water. Main factors enabling the lowering of humidity in the area outside the line of cathodes was surface drainage and gravitational flow of water to filtercathodes (wells), while in electric field, apart from the just mentioned factors - the electroosmotic flow of water to

Table 23

Changes in average humidity contents in near-to-surface layer of sedimentation basin (to 3 m) in the course of electroosmotic drainage

| Period of electro-osmotic drainage | zone | | | | Whole area of bowl |
|---|---|---|---|---|---|
| | external (embankment) | internal outside cathode line | inter - electrode | near anode (center) | |
| 0 months | 23.59 % | 40.6 % | > 50 % | > 50 ° | > 36.2 % |
| 9 months | 25.3 % | 36.0 % | 38.87 % | 41.6 % | 33.1 % |
| 13 months | 24.4 % | 34.4 % | 39.6 % | 42.3 % | 31.8 % |

filtercathodes and the presumably - gravitational discharge to subsoil unplugged soil pores. The evaporation from surface in conditions of local climate in Ogorzelec did not have greater significance in the water balance of tailings.

In accordance with the principle of moisture content distribution in soil subjected to electroosmotic drainage one could expect best results of drying in near-to-anode zone and in adjoining it part of interelectrode zone. However, despite the obtention of a relatively significant fall in humidity, it remained highest in that part of electric field. This can be explained mainly by the morphology of the surface of sedimentation basin (fig. 63), causing drifts of rain waters towards the center of the bowl, and their percolation into the tailings through the network of fissures formed in the course of drying. Thus, under the partly dry surface of tailings was formed a layer reaching deep to 2.5 - 3.5 m with a higher humidity. This situation is evident in the fig. 86, showing vertical profiles of tailings humidity contents before and after the electroosmotic drainage.

In the course of "b" curves clearly marks itself the layer with a raised humidity at depths 0.3 - 3.5 m in the near - anode zone, and 0.7 - 2.5 m in interelectrode zone.

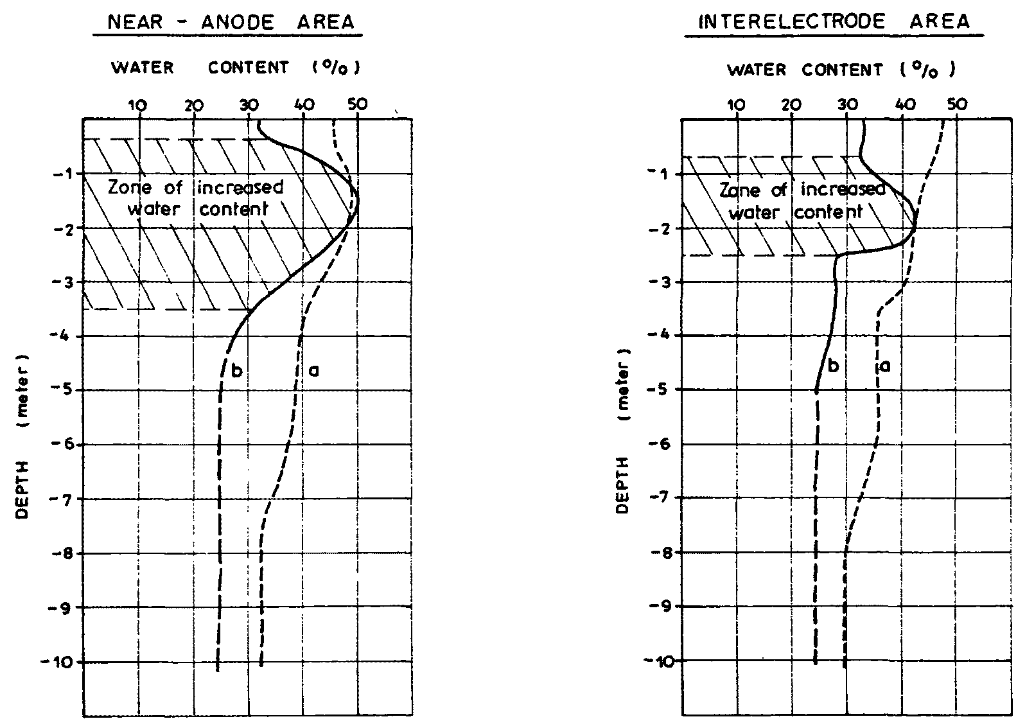



Fig. 86 DISTRIBUTION IN DEPTH OF WATER CONTENT IN TAILINGS ON NEAR-ANODE AREA AND THE INTERELECTRODE AREA PRIOR TO COMMENCED ELECTRO--OSMOTIC DRAINAGE (a) AND AFTER ITS COMPLETION (b)

The comparison of initial and final profiles of humidity affords a statement, that electroosmotic drainage brought greatest effects in deeper layers of tailings, below the reach of atmospheric precipitation influence. Fall in humidity observed in the thin superficial layer is the effect of evaporation and of drainage of tailings by the grid of draining ditches.

## CHANGES IN CHEMICAL CHARACTERISTICS OF TAILINGS AND IN WATER CONTAINED IN THEM

During the application of electric current to promote drainage, permanent changes in the chemical compounds forming the tailings took place. The measured percentage content of particular components contained in sediment not subjected to electro-osmotic drainage, and of components in sediment subjected to electroosmosis are shown on table no. 24.

Table no. 24

Results of chemical analyses of tailings from Ogorzelec before (1) and after (2) electroosmotic drainage under laboratory conditions. Major components are shown.

| | Content, in dry mass, % | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | CaO | MgO | Cl | S sulphide | $Fe_2O_3$ | $Al_2O_3$ | $SiO_2$ | Insoluble | Losses after sintering |
| (1) Prior to electroosmosis | 39.79 | 0.82 | 0.00 | 1.55 | 1.33 | 3.35 | 11.59 | 2.10 | 34.53 |
| (2) After electroosmosis | 42.00 | - | 0.00 | 2.96 | 1.24 | 3.32 | 11.44 | 3.96 | 37.03 |

Comparisons of the data in table 24 suggest that electroösmotic draining of sediments has caused a small increase in content of calcium components, an increase in the content of sulphur in the sulphide form, and an increase of insoluble components. These increases are sufficiently small as to be included within standard analytical errors and cannot be used to project impacts with great certainty.

More pronounced chemical changes were measured in the composition of water contained in sediment prior to and after electroosmosis.

Results of chemical analyses of water produced in the process of electroosmosis under laboratory conditions are provided in table no. 25.

Denotation no. 1 of table 25 characterizes water obtained in cathodes at the beginning of tests, denotation no. 2 describes water from cathodes after 3 days of drainage duration, and denotation no. 3 characterizes water in anodes after 10 days of tests.

Table 25

Results of chemical analyses of water collected at various stages of electroosmotic draining under laboratory conditions (aluminium electrodes)

| Denotation No. | Dry residue | Total suspension | pH | $Fe^{+2}$ $Fe^{+3}$ | $Cl^-$ | $Ca^{+2}$ | $Mg^{+2}$ | $SO_4^{-2}$ | Mn total | $Al^{+3}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| | g/l | g/l | | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| Cathode (start) | 4.22 | 1.52 | 10.6 | none detected | - | traces | 1.6 | 509.6 | none detected | none detected |
| Cathode (+3 days) | 5.33 | 0.79 | 12.4 | none detected | - | 0.4 | 2.3 | 105.6 | none detected | none detected |
| anode (+ 10 days) | 49.15 | 15.05 | 3.7 | - " - | 976.9 | 141.0 | 0.8 | 4368.0 | - | 2749.8 |

The chemical composition of water obtained during field tests of electroosmotic drainage of the sedimentation basin in Ogorzelec is presented in table no. 26.

Analyses were performed on water accumulating in depressions on the surface of the sedimentation basin before electroosmotic draining (1), and water taken from filtercathodes nos. 3,4,5 after 9 months of drainage (2). For comparison sake included as "denotation 3" are values of permitted concentrations of pollutants for surface waters included in the third class of purity (the lowest) according to Polish Standards.

Table no. 26

Results of chemical analyses of ground water collected during various stages of electroosmosis of sedimentation basin in Ogorzelec

| | Dry residue | Total suspension | pH | Total hardness | $Fe^{+2}$ $Fe^{+3}$ | $Cl^{-}$ | $Ca^{+2}$ | $Mg^{+2}$ | $SO^{-2}$ | $S^{-2}$ | Mn total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | g/l | g/l | | G.deg. | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l | mg/l |
| 1. Prior to electroosmosis | 1.19 | 0.03 | 7.6 | 47 | 0 | 6.02 | 342.0 | 0 | 705.6 | - | 0.15 |
| 2. During electroosmosis | 6.61 | 1.46 | 12.1 | 84 | - | - | 591.2 | 0 | 0.19 | 563.7 | - |
| 3. Class III standards | 1.20 | 0.05 | 6.9 | 28.8 | 20 | 400 | specified in terms of hardness | | 250 | 0.1 | 0.8 |

Comparisons of the "before and after" data of tables 25 and 26 indicate that the chemistry of the ground water changed significantly during electroosmosis. Differences in chemical composition are characterized in a general manner by the hydrogen ion concentration (pH). The water in the tailings in the field prior to drainage was slightly alkaline. During electroosmosis the water in the cathodes became alkaline while the water in the anodes was acid.

The water in the cathodes during electroosmosis had a higher calcium content and thus a higher hardness than prior to electroosmosis.

The most important changes in chemical composition measured during electroosmosis process were:

- a major increase in chlorine ($Cl^-$) for water in the anodes;
- the increase in calcium cation content ($Ca^{+2}$), in water in the cathodes noted earlier;
- a major increase in $SO_4^{-2}$ anion content in water from the anodes, but an equally significant decrease in this anion in waters from the cathodes;
- a large increase in the sulphur ($S^{-2}$) content in waters from the cathodes.

These changes adversely affect the quality of water to be discharged during the electroosmotic process, a fact that is clearly illustrated when the standards in table no. 26, and these are only class III standards, are used for comparison. This poor quality may cause problems in discharging the waters to the surface water system.

## SECTION 11

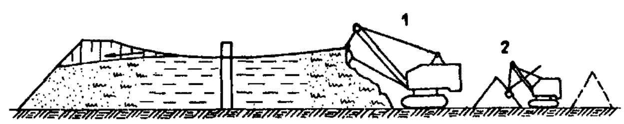
## POST-ELECTROOSMOSIS DRYING OF TAILINGS UNDER ATMOSPHERIC CONDITIONS

The utility of drying tailings under natural, atmospheric conditions depends on the precipitation and natural evaporation rate. The determination of precipitation in a relatively flat area is not difficult; sufficient accuracy is provided by standard precipitation measurements. Prediction of the water lost by evaporation is more difficult. The best results are obtained through direct measurement methods. Lysimeters or soil evaporimeters are generally used for this purpose.

Soil evaporimeters are particularly useful as the elimination of under-flowing ground water in evaporimeter largely corresponds to natural conditions of the sedimentation basin. For this project special evaporimeters were constructed with exposed surfaces of 250 $cm^2$ (similar to those used for Wild's evaporimeters), and with depths of 30 cm (fig. 91-93).

Undisturbed samples of tailings weighing 11 to 13 kg were collected from the tailings pile. The samples were weighed at about 10-day intervals, on the 1, 11 and 21 of each month. Precipitation was measured using a Hellman pluviometer installed at a height of 1 m. The weights of the samples were determined to $\pm$ 0.01 kg, which with the given surface of the instrument corresponds to $\pm$ 0.4 mm of water gain or loss.

The amount of water that passed through and out of the sample was measured to $\pm$ 2.5 ml (which corresponds to $\pm$ 0.1 mm).



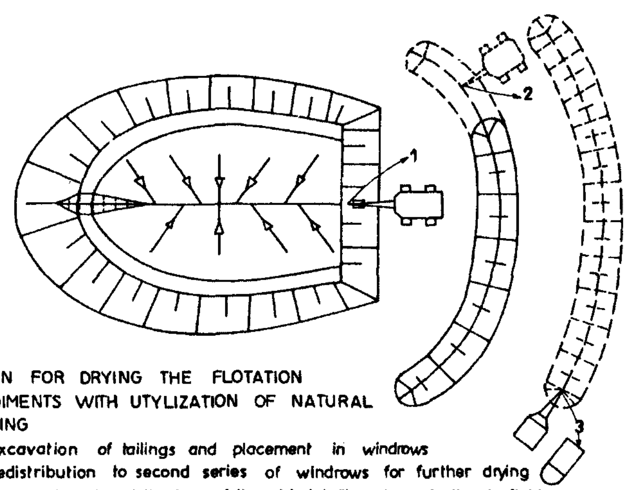




Fig.87 PLAN FOR DRYING THE FLOTATION SEDIMENTS WITH UTYLIZATION OF NATURAL DRYING

1-excavation of tailings and placement in windrows

2-redistribution to second series of windrows for further drying

3-transport and distribution of the dried tailings to agricultural fields

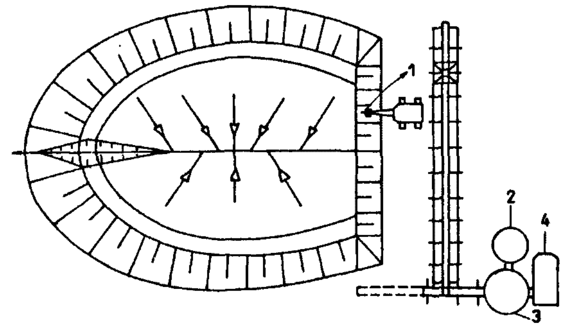



Fig.88 PLAN FOR DECREASING FLOTATION SEDIMENTS HUMIDITY THROUGH MIXING WITH DRY COMPONENTS

1-excavation of tailings and delivery to mixing facility

2-supply of dry components such as power plant ash

3-mixing facility

4-transportation and distribution of the mixture to the fields

In order to obtain information about the feasibility of drying the drained tailings under shielding from atmospheric precipitation, a portion of the evaporimeters was placed under shutter roofs, identical to those used for Wild's evaporimeters (fig. 11, 15).

## NATURAL DRYING UP THE EXPOSED SURFACE OF THE SEDIMENTATION BASIN

Evaporimeter measurements were initiated in July of 1975 using one evaporimeter without a precipitation shield and four evaporimeters with shutter roofs. The instruments were installed at the meteorological station set up near the sedimentation basin.

In April of 1976 three additional evaporimeters were installed (one with a shutter roof) directly on the main sedimentation basin. The measurements at the basin were in complete agreement with the results of evaporimeters set up at the meteorological station. It is therefore presumed that the 1975 data are representative of conditions at the basin.

Results of the observations at the meteorological station for 1975 - 1977 are presented on fig. 89 and in table 27. Precipitation, theoretical evaporation, pan evaporation and measured evaporation are presented. Pan evaporation, or evaporation from a free water surface is a valuable indicator of the composite influence of meteorological elements, and it informs us of the water vapour absorption capacity of the air under field conditions.

Losses of water from tailings are clearly larger from unshielded evaporimeters than from shielded ones. The relative values of evaporation cannot however, be directly compared. Much higher evaporation occurs from uncovered evaporimeters as a result of considerable and frequent additions caused by precipitation. The source of much of the evaporated water was therefore not the water contained in the sediment, but rather precipitation. For this reason, the efficiency of drying was much higher in the case of the shielded evaporimeters.

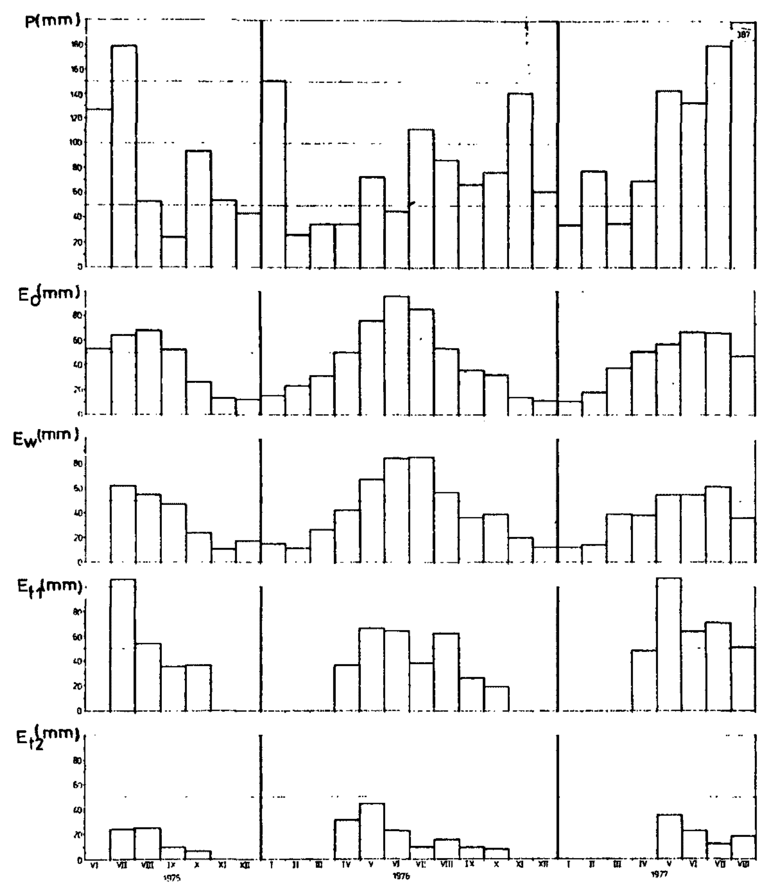



Fig89 THE COURSE OF MONTHLY COMPONENT VALUES OF WATER BALANCE IN mm IN OGORZELEC IN YEARS 1975-1977

P - atmospheric precipitations, $E_o$ - evaporation according to Bac formula, $E_w$ - evaporation of free water table according to Wild evaporimeter under umbrella shield, $E_{t1}$ - field evaporation measured with unshielded soil evaporimeters, $E_{t2}$ - field evaporation measured with shielded soil evaporimeters.

Table no. 27

Average monthly values of precipitation and evaporation (in mm) using evaporimeters with a surface area of 250 cm2 on flat terrain.

1975 - 1977

| Year Month | Precipitation | Evaporation according to Wild | Evaporimeters | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Without precipitation cover | | | Under precipitation cover | | |
| | | | Retention | Filtrate | Evaporat. | Retention | Filtrate | Evaporat. |
| **1975** | | | | | | | | |
| July | 186.3 | 62.4 | +11.6 | 68.8 | 105.9 | -27.7 | 3.8 | 23.9 |
| August | 53.1 | 54.8 | - 6.8 | 6.4 | 53.5 | -25.4 | 0.4 | 25.0 |
| Septemb. | 24.1 | 47.3 | -12.4 | 1.9 | 34.9 | - 9.1 | 0.2 | 8.9 |
| October | 93.7 | 22.6 | +19.6 | 38.2 | 35.9 | - 6.7 | 0.3 | 6.4 |
| **1976** | | | | | | | | |
| April | 34.5 | 41.5 | -22.9 | 20.3 | 37.1 | -37.0 | 6.1 | 30.9 |
| May | 73.0 | 67.3 | - 5.1 | 12.5 | 65.6 | -45.3 | 1.6 | 43.7 |
| June | 45.4 | 83.7 | -31.3 | 12.8 | 63.9 | -22.4 | 0.7 | 21.7 |
| July | 112.2 | 84.8 | +38.7 | 35.9 | 37.6 | -12.6 | 3.3 | 9.3 |
| August | 87.1 | 56.7 | - 4.1 | 28.8 | 62.4 | -15.4 | 0.7 | 14.7 |
| Septemb. | 67.1 | 36.1 | +11.7 | 29.2 | 26.2 | -10.4 | 1.0 | 9.4 |
| October | 77.5 | 38.7 | + 8.0 | 50.1 | 19.4 | - 7.8 | 0.8 | 7.0 |
| **1977** | | | | | | | | |
| April | 69.6 | 38.1 | -19.6 | 41.7 | 47.5 | - | - | - |
| May | 142.6 | 55.6 | -11.8 | 45.2 | 109.2 | -43.6 | 8.5 | 35.1 |
| June | 133.1 | 55.0 | -11.8 | 81.8 | 63.1 | -42.9 | 3.4 | 21.5 |
| July | 179.8 | 61.8 | + 1.9 | 106.5 | 71.4 | -13.1 | 0.8 | 12.3 |
| August | 387.2 | 37.4 | +214.6 | 121.5 | 51.1 | -19.8 | 1.9 | 17.9 |

The total water loss from 12 kg of tailings contained in an unshielded evaporimeter was 1.7 kg in a 4 month period in 1975. The same period of 1976, the loss of water was 1.2 kg. However, a new sample lost almost 3.2 kg or 30 % of its total weight in a four month period in 1976. Obviously the efficiency of drying was related to the amount of water present.

In the unshielded evaporimeter between the first measurement made in July 1975, and the last in October in 1975, the weight increased an average of 0.3 kg.

The total evaporation of shielded samples during the period July - October of 1975 amounted to 64.2 mm (table 27). This corresponds to a loss of water from an area of 1 ha of 642 000 liters.

During the 7 months period in 1976 from April to October, the loss of water from sediment was 136.7 mm, or 1367 $m^3$ of water for every hectare of flat area of the sedimentation basin.

During first two months if the sample is protected from precipitation, the tailings loses about 50 percent of the entrained water, through the warm half of the year. Similarly to the rate of evaporation, the vertical filtration (percolation) is greatest immediately after placement of a newly-collected sample into the evaporimeter. In April of 1976 (table 27) drainage was 6.1 mm, i.e. the equivalent of 61 $m^3$ of water draining from an area of 1 ha. During periods of precipitation (July in 1975 and October in 1976) the water filtration through 30 cm top layer of sediment is much greater (68.8 and 50.1. mm respectively).

During the period of investigations only in June of 1976 did atmospheric drying exceed precipitation in an unshielded evaporimeter (fig.90).

During the remaining months of the investigations, much precipitation occurred and the net decrease in water content of the tailings was minimal.

During August of 1975 and April of 1976 the apparent increase in the water content is within the limits of measurement error and thus is not considered noteworthy.

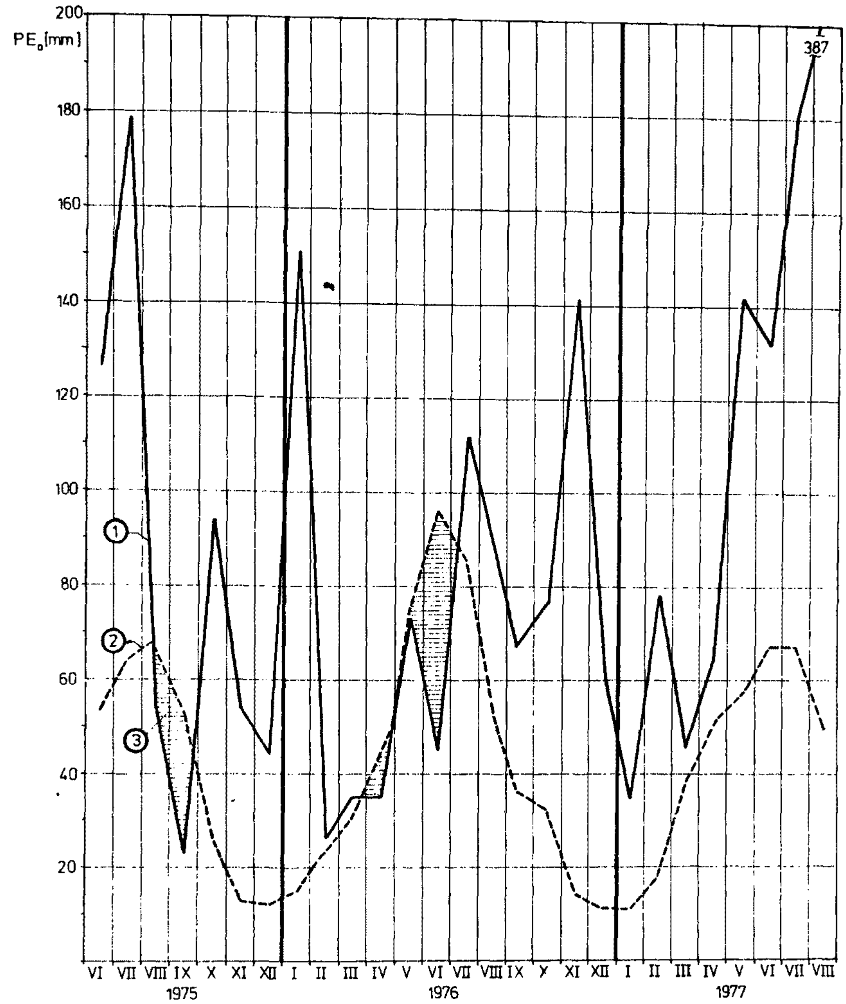



Fig.90 MONTHLY VALUES OF PRECIPITATION AND EVAPORATION (in mm) IN OGORZELEC FOR YEARS 1975 - 1977

1 - precipitation, 2 - evaporation measured according to *Baca formula* , 3 - *the area where evaporation exceeds* precipitation prevalence

Fig.91. External shield and water container of evaporimeter.

Fig. 92. Installation of evaporimeter´s container into external shield.

Fig.93. Surface of tailings after initial drying period in evaporimeter.

## ATMOSPHERIC DRYING OF TAILINGS PLACED IN WINDROWS

In comparison to the horizontal surface presented by the tailings pile, greater surface area "atmospheric drying" for a given amount of sediment is provided if the material is placed in a windrow with sloping sides. Placement of material in cone-shaped piles may induce faster drying by virtue of the following:

a) increased exposure to sun if the angles of the piles are constructed perpendicular to the sun's rays and a resultant transferred to the pile, causing evaporation

b) greater exposure to the drying action of wind

c) increased surface area for evaporation

d) increased runoff of precipitation from the slopes.

In effect the placement in windrows provides a much more favourable "water balance". The rate of drying can be further enhanced through insulation of the pile from porous and wet soils. Isolation of the tailings from a wet soil eliminates the rise of water through capillary action and, if the impermeable bottom layer is constructed properly, facilitates drainage of free water away from the tailings.

In order to determine the efficiency of drying tailings under natural conditions, several windrows were formed near the sedimentation basin in Ogorzelec.

Two formed in May of 1974 were used. The first pile contained tailings taken from the internal zone of the sedimentation basin ("A" pile). The second pile was also taken from the internal zone but was mixed with dry fly ashes from lignite. The lignite ash comprised about 15 percent of the total mass of the pile ("B" pile). The average initial water content of the "A" pile was 38.8 percent and of the "B" pile, 34.6 percent. Both piles were placed near the lowest, central part of the smaller sedimentation basin and therefore, for the duration of the investigations, had contact with surface water collecting in the sedimentation basin. The windrow was shaped as shown in fig. 94 (two

Fig. 94. Experimental windrows "A" and "B", contacting free water table of the subsoil.

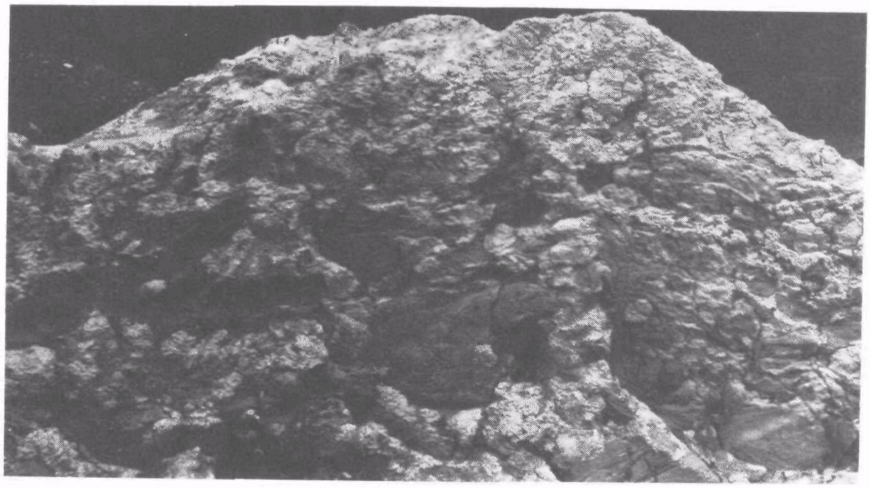


Fig. 95. Windrow "C" located on a permeable, sandy subsoil.

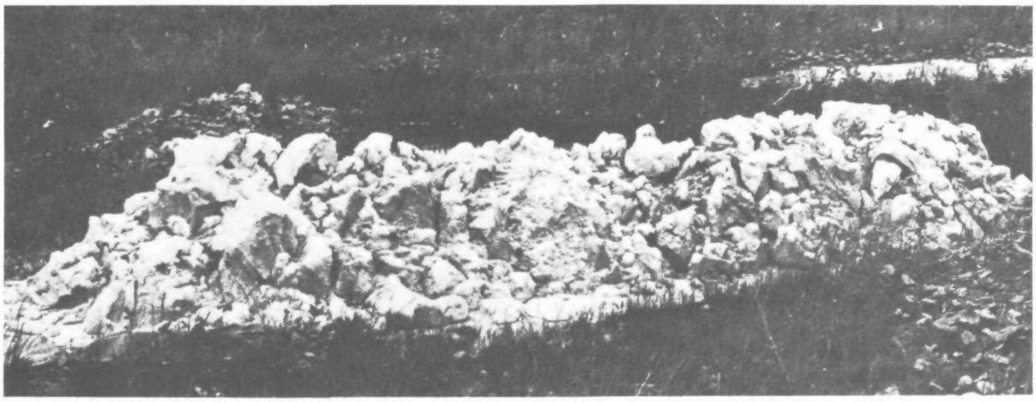


Fig. 96. Windrow "D" isolated from subsoil with impermeable foil.

cones joined at their bases. The cones were 1.7 m high. In July of 1976 another windrow ("C" pile) was constructed with sediment having an initial water content of 34.7 percent. It had a shape of an irregular cone, and was situated on the crown of the main sediment basin embankment (fig. 95). The soil underneath the "C" pile was sandy. In May of 1977, windrow ("D") with the shape of a low (1.2 m tall) mound trending W-E was constructed on the small sedimentation basin. It was isolated from the ground with an impermeable foil (fig. 96).

The surface of all piles was very uneven initially (fig. 96). This was the effect of stacking with an excavator. With time, as a result of the plasticity of the sediment and the morphological action of atmospheric agents (precipitation, wind, and thawing) the surface of the piles became smoother. This had the effect of increasing runoff and decreasing infiltration of precipitation, though it also reduced the surface area.

The measure of the effectiveness of the drying process is the reduction in the moisture content of the tailings. The changes in the water content with time for each of the windrows are presented in table no. 28.

Table 28

Changes in water content of windrowed tailings with time (%)

| Designation of windrow | Type of tailings windrow | Initial water content | Intermediate water content | Intermediate water content | Final water content | Total decrease in water content |
|---|---|---|---|---|---|---|
| | | date of observ. | date of observ. | date of observ. | date of observ. | period in months |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| A | Windrow made of tailings in contact with free water from subsoil | 38.8 | 32.2 | - | 32.3 | 6.5 |
| | | May,74 | Jan.,75 | - | Sept.,77 | 29 |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| B | Windrow of tailings layered with ash in contact with free water from subsoil | 34.6 | 31.2 | - | 31.4 | 3.2 |
| | | May, 74 | Jan.,75 | - | Sep.,77 | 29 |
| C | Windrow made of tailings placed on sandy subsoil | 34.7 | 28.7 | 26.5 | 24.6 | 10.1 |
| | | March,76 | Oct.76 | May, 77 | Sept.,77 | 19 |
| D | Windrow of tailings isolated from sub-soil | 37.6 | - | - | 29.4 | 8.2 |
| | | May, 77 | - | - | Sept.,77 | 5 |

In accordance with expectations, the best effect of drying was observed on the windrow formed on permeable sandy subsoil. During the time period of 19 months of observations, humidity of this windrow fell from 34.7 % to 24.6 %, i.e. by 10 %, indicating further trend to fall.

Good effects gave also isolation of windrow from subsoil with impermeable material (foil). During the five months time humidity here fell by 8.2. %. Decidedly poorest effects of drying were recorded on windrows, that had contact with free water table of the subsoil. After the time of 10 months the process of drying of windrows was checked, and in further period of observations (20 months), humidity content stayed withing limits of 31-33%.

## EFFECTIVENESS OF DRYING SEDIMENTS FORMED INTO WINDROWS

In forming partially dried sediments into windrows to facilitate atmospheric drying one can expect different results caused by differing inclinations of slopes and exposures to wind and sun. To determine the effect of these variables, in 1976 soil evaporimeters were installed on south - and north - facing slopes of a small pile of tailings (fig. 92) and also on flat terrain close to this pile. The results obtained are presented in table 29.

Table 29

Measurements of field evaporation for evaporimeters placed on varying and aspects (surface area ± 250 cm²).

| Year | Month | 10 - day period | precipitation in mm | Field evaporation (mm) Location: northern slope | flat terrain | southern slope |
|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1976 | April | 1 | 11.5 | 10.1 | 23.2 | 16.2 |
| | | 2 | 1.5 | 9.3 | 25.7 | 15.5 |
| | | 3 | 21.7 | 8.6 | 9.3 | 15.4 |
| | | | 34.5 | 28.0 | 58.2 | 47.1 |
| | May | 1 | 2.6 | 27.8 | 33.6 | 32.7 |
| | | 2 | 15.7 | 2.7 | 7.7 | 2.7 |
| | | 3 | 54.7 | 35.1 | 32.1 | 36.6 |
| | | | 73.0 | 65.6 | 73.4 | 72.0 |
| | June | 1 | 5.7 | 26.8 | 18.9 | 34.6 |
| | | 2 | 39.7 | 23.4 | 22.8 | 37.1 |
| | | 3 | 0.0 | 20.4 | 23.5 | 33.5 |
| | | | 45.4 | 70.6 | 65.2 | 105.2 |
| | July | 1 | 12.3 | 15.5 | 14.6 | 22.3 |
| | | 2 | 22.1 | 13.3 | 14.9 | 21.3 |
| | | 3 | 77.8 | 15.5 | 13.5 | 8.4 |
| | | | 112.2 | 44.3 | 43.0 | 52.0 |
| | August | 1 | 40.4 | 34.8 | 29.9 | 36.3 |
| | | 2 | 28.6 | 17.3 | 17.2 | 24.8 |
| | | 3 | 18.1 | 24.6 | 20.9 | 23.7 |
| | | | 87.1 | 76.7 | 68.0 | 84.8 |
| | September | 1 | 5.6 | 8.2 | 8.0 | 12.1 |
| | | 2 | 55.4 | 0.8 | 6.8 | 16.3 |
| | | 3 | 16.5 | 11.3 | 6.7 | 12.2 |
| | | | 77.5 | 20.3 | 21.5 | 40.6 |
| 1976 | Apr.-Oct. | Total | 496.8 | 341.4 | 354.3 | 439.5 |
| 1977 | May | 1 | 32.2 | 39.0 | 43.1 | 48.5 |
| | | 2 | 91.5 | 44.4 | 58.7 | 56.5 |
| | | 3 | 18.9 | 30.8 | 26.2 | 32.2 |
| | | | 142.6 | 114.2 | 128.0 | 137.2 |
| | June | 1 | 17.6 | 30.1 | 27.9 | 30.9 |
| | | 2 | 81.9 | 24.9 | 17.1 | 35.1 |
| | | 3 | 33.6 | 24.6 | 20.0 | 32.3 |
| | | | 133.1 | 79.6 | 65.0 | 98.3 |

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| 1977 | July | 1 | 75.1 | 9.8 | 6.3 | 25.4 |
| | | 2 | 18.7 | 28.0 | 24.8 | 32.2 |
| | | 3 | 86.0 | 41.7 | 42.6 | 42.0 |
| | | | 179.8 | 79.5 | 73.7 | 99.6 |
| | | 1 | 260.9 | 25.2 | 23.5 | 31.0 |
| | August | 2 | 59.6 | 15.4 | 21.2 | 19.7 |
| | | 3 | 66.7 | 23.1 | 18.6 | 25.2 |
| | | | 387.2 | 63.7 | 63.3 | 75.9 |
| 1977 | May - August | Total | 842.7 | 337.0 | 330.0 | 411.0 |

The evaporation data in table 29 must be considered only indicative of any differences since no repetitions were used and the area of the pile was relatively small and asymmetric.

Despite data defficiencies, evaporation was clearly higher on the southern slope.

The relatively smaller values of evaporation observed during April and May of 1976 in comparison to flat terrain are probably a consequence of the lower initial water content of the tailings used. In subsequent months the differences were more pronounced, and in October of 1976 the loss of water from sediment on southern slope was two times greater than on the flat area. In the period of greatest water losses (directly after depositing the tailings), very unfavourable evaporation conditions occurred on the northern slope with the exception of June 1977. In April 1976 the quantity of water evaporated from the northern slope was almost two times smaller than that evaporated from the southern slope. The total evaporation from the southern slope during 1976 was 100 mm higher than that occurring on the northern slope, and 85 mm higher than that occurring on flat land. The size of the difference is also affected by the latitude of the site.

It is concluded that placement of the partially-dried tailings in windrows allows a higher evaporation rate than placement on flat land. In view of the fact that the sun is at its highest angle in Ogorzelec during May through July, this period is ideal for efficient drying. Windrows with slopes of 20° appear to provide optimal conditions for drying.

At this northern latitude of 50°, the southern slopes of 20° receive, in May and in July, an average 8 percent more solar energy than does flat land. In June the gain of energy is 2 percent greater than on flat land. This may appear to be a small increase, but in terms of the absolute increase in solar radiation, the effect of increasing this sum by 2 percent is significant. The northern slopes of such windrows receive in May and July 20 percent less, and in June 13 percent less solar energy compared to flat area. Thus there is a gain in energy on the southern slope, but a much greater decrease in the amount of radiation falling on surface of the northern slope. From the solar radiation viewpoint an asymmetric pile with a long south-facing slope would present favorable drying conditions.

To acquire a full water balance for the tailings one should include measurements of the surface water run-off. Measurement of this parameter is difficult, especially in the case of irregularly-shaped windrows.

One should also, for the empirical confirmation of the theoretical relationships described above carry out observations of evaporation on slopes of various exposures and different slopes.

## ASSESSMENT OF CONDITIONS FOR DRYING ON THE BASIS OF METEOROLOGICAL DATA

The period of direct measurements of field evaporation in Ogorzelec is too short to draw univocally broad generalizations.

The weather conditions in the years of 1975 - 1977 did not correspond to long term average values, a fact which undoubtedly affects extrapolation of the data.

Therefore, an assessment of conditions for drying should be considered on the basis of site-specific measurements of the pertinent meteorological elements.

One should emphasize at the start that climatic conditions of Ogorzelec are, with respect to drying tailings, not very favourable. This station is situated in the mountain climates, typified by high amounts of precipitation and cooler temperatures.

To calculate the amount of evaporation based on meteorological data, a number of formulae are available. The selection of one of them is dictated by the geographic location and the climatic conditions of the region. The climatic data required are the amount of water lost to the atmosphere for a particular type of evaporation (from a free water table, from the surface of land, or a potential evapotranspiration). The selection of formula also dictates the ability to extrapolate the results to other climatic situations. The potential evapotranspiration was computed using the formula of Turc. Publications and atlases giving this value for Western Europe are available - ref. 44). Potential evaporation was calculated using the Penman (simplified form - ref. 26) and Thornthwaite formulae - ref. 43. Also calculated was the theoretical value of evaporation using the Bac formula (ref. 2) and considering three basic parameters affecting evaporation (solar radiation partial saturation of the air and wind velocity). The Bac formula enables an accurate assessment of the air capacity to absorb water vapour. This formula was developed to fit the climatic region of Wrocław, but it also suits mountain regions. It has the form:

$$E_o = 3d \cdot \sqrt{v} + 4T$$

where: $E_o$ - monthly total of evaporation (in mm)

$d$ - average monthly partial saturation of air (in mb)

$v$ - average monthly speed of wind (in m/sec.)

$T$ - monthly sum of total radiation (in Kcal . $cm^{-2}$).

The formula of Turc was developed for climatic conditions of France and Northern Africa, and considers temperature of air and solar radiation, but usually omits variations in the humidity features

of air (by using a constant for this variable).
It has the form:

$$E = \frac{0.4 \cdot t}{t + 15} J_o \left[ \left(0.18 + 0.62 \frac{S}{S_o}\right) + 50 \right]$$

where:

- $E$ - potential evapotranspiration for one month (in mm)
- $t$ - average monthly air temperature (in $^oC$)
- $J_o$ - solar radiation at the atmosphere upper limit (in cal . $cm^{-2}$ . 24 hrs day)
- $S/S_o$ - relative insolation.

The Penman formula was developed on the basis of free water table evaporation data collected in England.The simplified formula considers only the relative humidity conditions of air and wind velocity, and omits the temperature of air and solar radiation the equation is:

$$E = i \cdot 0.36 \ (e_o - e) \cdot (1 + 0.35 \ v)$$

where:

- $E$ - sum of evaporation through some time period (in m)
- $i$ - length of time period, in days
- $e_o$ - pressure of saturated water vapour (in mb)
- $e$ - actual pressure of water vapour (in mb)
- $v$ - wind velocity at 11 m height above the ground (in m/sec.).

The Thornthwaite formula for field evaporation was developed for climatic conditions of United States. It is based, as a rule, on data concerning the air temperature, and does not consider the humidity conditions the equation is:

$$E_p = 1.06 \left(\frac{10\ tm}{T_E}\right)^a$$

where:

$E_p$ - monthly field evaporation, equal to the so called "monthly consumptive use of water" (in cm)

$t_m$ - average monthly temperature (in $^{\circ}C$)

$T_E$ - temperature index equal to sum of 12 monthly values of a thermal index $i = \left(\frac{tm}{5}\right)^{1.514}$

a - $6.75 \cdot 10^{-7} \cdot T_E^{\ 3} - 7.71 \cdot 10^{-5}\ T_E^{\ 2} + 1.79 \cdot 10^{-2} \cdot T_E + 0.492.$

The monthly sums of evaporation computed with first three formulae during the period of field tests are presented in fig. 97. The field measurements of evaporation are also presented. With the exception of July of 1975, August of 1976 and May of 1977, months when the measured field evaporation was relatively high due to very large amounts of precipitation, the empirically computed values were considerably higher than the field-measured sums of evaporation. The values computed with the Bac formula were closest to the actual value. In 1976 those values calculated using the Turc formula were also close to those measured in the field.

Sums of evaporation calculated using the Penman and Thornthwaite formulae were greatly overrated as was expected for the climatic conditions of Ogorzelec and in view of the atypical weather occurring during the experiments.

An estimate of the accuracy of the predicted potential for drying under atmospheric conditions may be gained by an analysis of the

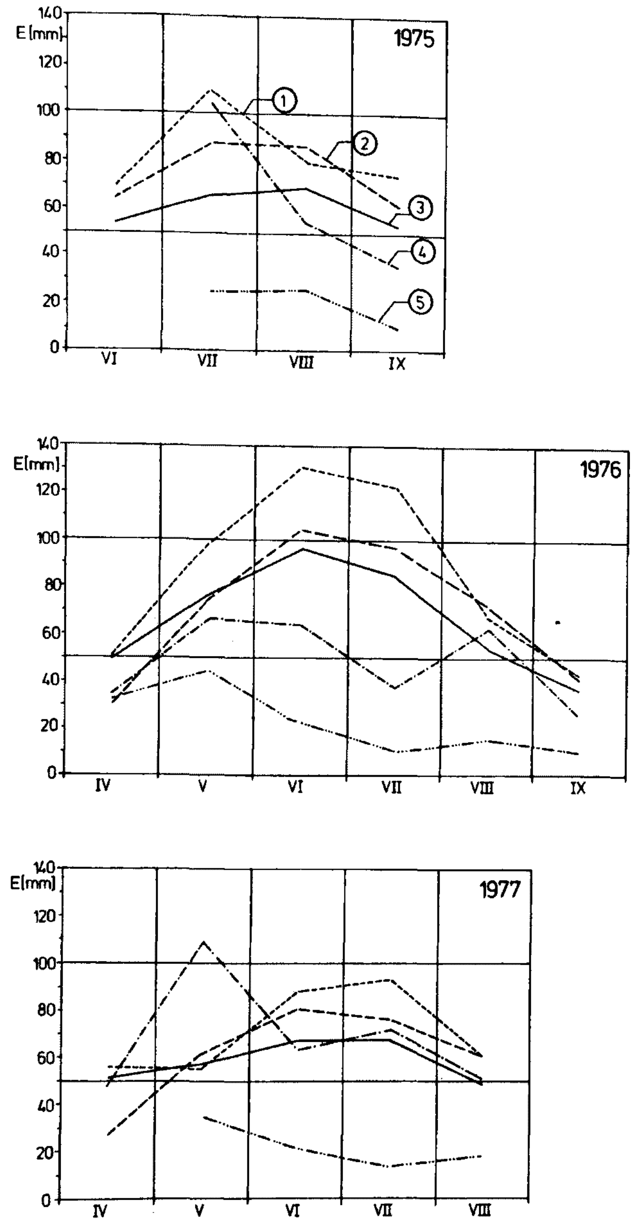



Fig.97 MONTHLY VALUES OF EVAPORATION COMPUTED USING EMPIRICAL FORMULAE AND MEASURED WITH SOIL EVAPORIMETERS IN OGORZELEC FOR YEARS 1975 - 1977

1 - evaporation according to Penman, 2 - evaporation according to Turc, 3 - evaporation according to Bac, 4 - evaporation according to unshielded soil evaporimeters, 5 - evaporation according to soil evaporimeters under shield.

monthly calculations shown in table 30 for the period 1951-1970.

Table 30

Average long term (1951-1970) monthly precipitation and theoretical evaporation (in mm) at station Jelenia Góra

| Element of banalce | Apr. | May | Jun. | Jul. | Aug. | Sep. | Sum |
|---|---|---|---|---|---|---|---|
| Precipitation | 50 | 89 | 90 | 112 | 85 | 47 | 473 |
| Evaporation acc. to Bac | 51 | 68 | 74 | 73 | 62 | 50 | 378 |
| Evaporation acc. to Turc | 37 | 68 | 87 | 88 | 75 | 50 | 405 |
| Evaporation acc. to Penman | 58 | 73 | 86 | 94 | 75 | 64 | 450 |
| Evaporation acc. to Thornthwaite | 41 | 82 | 106 | 119 | 105 | 70 | 523 |

From the data shown in table 30 it appears that independently of the formula used to calculate the evaporation, the water balance is favourable for evaporation only in April and in September (precipitation lower than evaporation). The amount of evaporation predicted for April using the Turc formula is low due to specific features of the mountainous climate in Ogorzelec (the formula considers only temperature and radiation). Values calculated using the Thornthwaite formula are too high up, since the formula does not consider humidity conditions and movement of air. The character of these variables in mountain climate limits the amount of evaporation.

In months during which the possibility to evaporate water to atmosphere is greatest (May - July), the effect of drying the sediment is counteracted by the previously mentioned adverse distribution of precipitation in a mountainous climate (fig. 90). However, on the average of every 4 years the precipitation in months May - July is lower than sums of evaporation and drying may be accomplished. On the whole one can assume that losses of water to the atmosphere by evaporation amount in the region of Ogorzelec are about 400 mm in the summer half-year (April - September) (i.e. 400 $m^3$ from 1 ha of a flat area of land).

In the event detailed, site-specific climatological data are available, other formulae are available to calculate evaporation. But if regional data are used, one must be cautious about site-specific projections. The accuracy of the calculations is strongly affected by the local topography.

## SECTION 12

## DECREASING THE WATER CONTENT OF POST-FLOATATION TAILINGS BY MIXING WITH DRY MATERIALS

Mixing dry materials with partially dried tailings can produce more easily handled tailings independent of atmospheric/climate conditions. Use of this method also creates possibilities of economic utilization of other industrial waste materials if these are normally of easily dried, and if they are located nearby. Wastes that could be used as dry additions and which easily absorb and fix water, include waste lime, smoke-box dust, and fine grained dolomite wastes.

The usability of the tailings increases when they are mixed with materials that reduce their original consistency from a plastic to a granular state. With appropriate selection of components, one can improve the fertilizer value of mixture if the content of elements and compounds essential for vegetative growth is also increased. However, prior to mixing with these dry substances, the tailings must be paritally dried in-place (i.e., in the tailings pond) so as to permit handling with machinery. The technology of drying tailings by mixing with dry components is shown in a schematic form on fig. 88.

### LABORATORY TESTS

Laboratory tests of mixing postfloatation tailings with three dry wastes were conducted. The wastes were:

- fly ash from a power plant burning bituminous coal (Czechnica power plant);

- dolomite waste material as a powder;
- fly ash from a power plant burning lignite (Pątnów power plant).

Mixing of the wastes and tailings was facilitated using a worm mill, which pressed the materials through a large mesh steel sieve.

The laboratory tests differed according to the type and amount of components, but had as their objective the determination of optimal proportions of components that would assure an acceptable consistency, humidity and structure of the resulting mixture.

It appears from the tests that the best mixture was obtained with lignite fly ash. The addition of 15 percent by weight fly ash produces firm, granular consistency and a satisfactory water content. With the same humidity of post-floatation sediment, to attain similar effects with the other wastes required 30 percent by weight of bituminous fly ash or 40 percent of dolomite dust was required.

These proportions of dry wastes ( $< 1$ % moisture) produced a reduction in the water content of the treated tailings from about 27 percent to less than 19 percent.

Figures 98, 99, and 100 show the visual characteristics of a mix of 85 percent (by weight) tailings mixed with 15 percent of any of the three dry materials. The differences in consistency, structure and humidity among particular mixtures are quite evident.

These differences result from differing chemical characteristics of the dry components, which determine the chemical and physical bonds of water. The chemical composition of dry components and of mixtures with tailings is discussed in chapter: Chemical composition of tailings mixtures and their assessment in agricultural utilization (table 33).

## FIELD EXPERIMENTS

Field experiments of methods of producing the mixtures were combined with analyses of their distribution of the resulting mixtures on arable lands as a fertilizer.

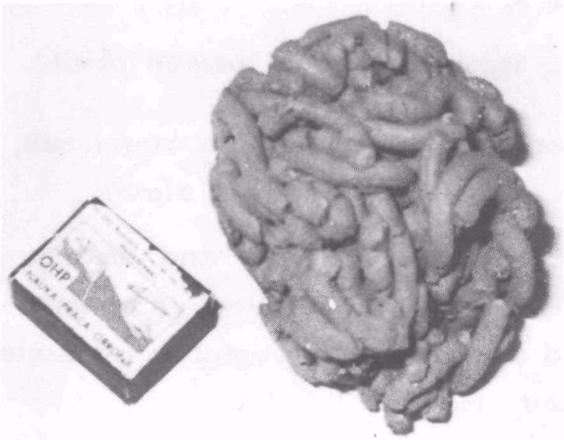



Fig.98. Mixture of tailings with dolomite dust (15 % gravimetrically).

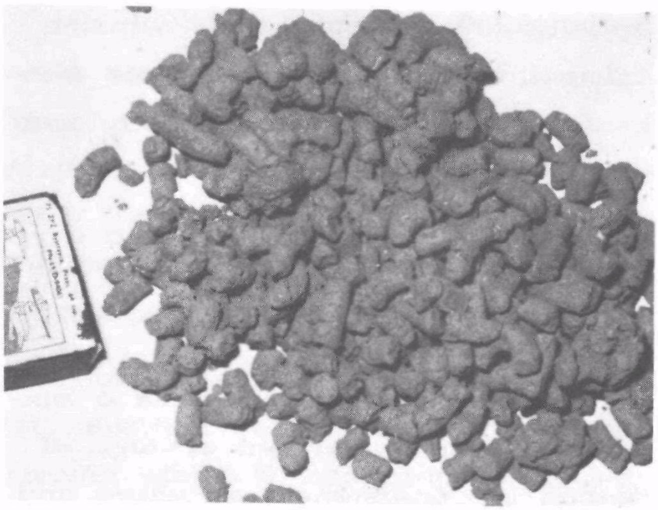


Fig.99. Mixture of tailings with ash from bituminous coal (15 % gravimetrically).

Fig.100. Mixture of tailings with ash from lignite (15 % gravimetrically).

Based on the results of laboratory tests, the field tests were conducted with fly ash from the lignite-fired power plant, Pątnów.

Components were mixed with the aid of an agricultural mixer-feeder normally used for fodder, an HO-64 type with a container capacity of 250 l (fig. 101). It was equipped with two mixing, counterrunning worms driven by an electric motor and with a distribution worm which discharged the mixture.

For the field experiments carried out directly in the sedimentation basin the tailings used had an average water content of 38.8 percent and the ash had 0.2 percent moisture. Owing to the high water content of the tailings, the amount of fly ash added had to be increased.

Satisfactory mixtures were achieved with 75 percent tailings and 25 percent fly ash by weight (fig. 102). Initial water contents of each component and of the mixture are given in table 31.

Decrease in water content of post-flotation tailings after mixing with dry fly ashes Table 31

| Proportion tailings/ash (in % by weight) | Water content (in % gravimetrically) | | | Decrease in water content (in %) |
|---|---|---|---|---|
| | tailings | fly ash | mixture | |
| 80/20 | 38.8 | 0.2 | 27.4 | 11.4 |
| 75/25 | 38.8 | 0.2 | 24.3 | 14.5 |

Despite the fact that water content of the mixture of 75 percent tailings and 25 percent fly ash is still high it is, however, suitable to be distributed on fields with standard agricultural machinery. This is possible as a result of the granular structure created by the fly ash coating the tailings with thin yet somwehat hard layers. This prevented the agglomeration of the tailings after mixing. The mixed material does not absorb humidity from air or subsoil for a reasonable time when stored.

After eight days storage of the mixture, tests were made to distribute it on soils using a typical fertilizer spreader.

Fig. 101. Agricultural mixer used in field experiments to produce mixtures of sediment and ash.

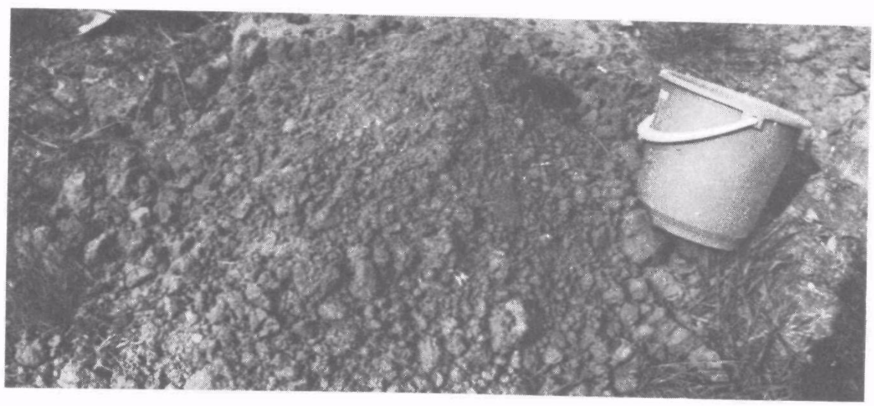


Fig. 102. Mixture of 75 percent tailings and 25 percent ash, obtained in field tests.

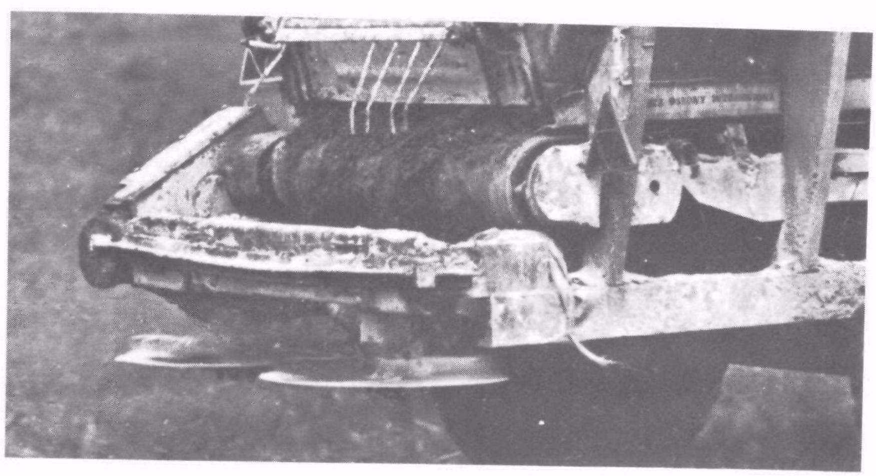


Fig. 103. Spreading of tailings ash mixture of cultivated meadow using a typical fertilizer spreader.

This spreader consists of steel box the bottom of which is a conveyor belt, which transports the fertilizer through a regulating opening onto two screw-like shafts turning in opposite directions and which distribute the material onto the field (fig. 103).

The experimental spreading was successful since the mixture was distributed uniformly over the whole area of a meadow and large lumps were broken up by the distribution system. This prevented excessice accumulations of fertilizer which could have covered vegetation.

## CHEMICAL COMPOSITION OF TAILINGS MIXTURES AND THEIR ASSESSMENT IN AGRICULTURAL UTILIZATION

The results of chemical analyses of tailings and dry waste mixes are presented in tables 33 and 34. These analyses include those for individual wastes as well as mixtures.

The chemical analyses were those normally used in Poland for tests of calcium wastes used in fertilization of soils. Manganese (Mn), copper (Cu), zinc (Zn), cobalt (Co), chromium (Cr), and lead (Pb) were measured using atomic absorption. Calcium was determined as CaO, and magnesium as MgO using a complexometric versenate method. Arsenic was determined using the distillation method.

The chemical analyses presented in tables 32 and 33 indicate significantly different chemical compositions for the various samples. The ten samples were:

Sample no. 1 - bituminous coal fly ash (power plant Czechnica)

This fly ash contains a very small quantity of calcium (as CaO), and magnesium, small quantities of manganese, copper, zinc and cobalt and quantities of lead, chromium and sulphide sulphur useful for fertilization. It contains large quantities of silica ($SiO_2$), and of insolubles (NR), which comprise more than 80 percent of the material.

Sample no. 2 - lignite fly ash (power plant Pątnów)

This fly ash contains a high quantity of calcium (as CaO) and a moderate amount of magnesium. It contains over 44 percent CaO + MgO. Microelements (Mn, Cu, Zn, Co) occur in small quantities. Lead, chromium, arsenic and sulphide sulphur are present in quantities not harming plants. Content of silica and of insoluble materials is relatively high.

Sample no. 3 - dolomite dust

This material is characterized by a high manganese content (as MgO), an average calcium content (as CaO), a small quantity of silica and insoluble materials. It contains 49 percent CaO + MgO. Microelements and sulphide sulphur occur in small quantities.

Samples nos. 4,5,6,7 - post - floatation tailings taken from different zones of sedimentation basin in Ogorzelec

Tailings represented by these samples is characterized by an average content of calcium (as CaO), of silica, and of insoluble parts. The magnesium oxide concentrations are low. Microelements (Mn, Cu, Zn, Co) occur in small quantities. The content of sulphide sulphur, of aluminium oxide are generally low to moderately low.

Sample no. 8 - tailings mixed with 30 percent bituminous coal fly ash

This mixture contains an average quantity of calcium (as CaO), a relatively large quantity of silica and insoluble materials, and an average quantity of sulphide sulphur. Magnesium was not detected. The content of manganese, copper, zinc and cobalt is small. Lead, chromium and arsenic occur in quantities tolerated by plants. From the agricultural point of view, this mixture has a small fertilization value.

Sample no. 9 - tailings mixed with 15 percent lignite fly ash

The content of calcium (as CaO), silica and insoluble materials in this mixture is average. The amount of magnesium is low and microelements also occur in small quantities. Sum of calcium and magnesium oxides exceeds 41 percent. Quantities of lead, chromium, arsenic and sulphide sulphur are tolerated by plants.

Sample no. 10 - tailings mixed with 40 percent dolomite

This mixture contains an average quantity of calcium (as CaO), is low in magnesium, silica and insoluble materials, has small amounts of microelements, and an average quantity of sulphide sulphur. Lead, chromium and arsenic occur in quantities permissible in fertilizer compounds. Small quantities of silica and insoluble materials are present. The chemical composition of this mixture indicates that the fertilizer value of this material is almost as good as dolomite (sample no. 3). On the basis of the chemical measurements of these waste materials one can conclude the following:

1. The high calcium content of all samples but number 1 make these materials similar to the agricultural lime group or to calcium - magnesium fertilizers.

2. Waste material represented by sample no. 1 (fly ash from Czechnica) containing a very low content of lime and magnesium, and a very high content of silica ($SiO_2$) and insoluble materials is, from the agricultural point of view, not suitable as fertilizer. This fact does not prejudge its eventual use for other economic purposes.

3. Dolomite powder represented by sample no. 3, due to high content of magnesium, is included into the group of magnesium fertilizers. It can also be used as a component of calcium - magnesium mixtures.

4. Analysed wastes, from fertilizer value angle, contain the necessary (for plants) micro-elements (Mn, Cu, Zn, Co). When used as fertilizer these can be a partial source of supply.

5. The quantities of lead and arsenic present are in "trace" amounts.

6. To determine real fertilizer values of investigated wastes appropriate field tests regarding their influence on crops and on characteristics of soils must be performed.

Table 32

Results of chemical analyses for the basic components in fly ash, dolomite, tailings and mixes thereof

| No of sample | $H_2O$ % | Content, dry mass (in percent) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | CaO | MgO | Cl | S sulphide | $Fe_2O_3$ | $Al_2O_3$ | $SiO_2$ | Insoluble | Sintering losses |
| 1 | 0.18 | 3.90 | 1.68 | 0.00 | 0.19 | 4.60 | 11.18 | 58.50 | 22.44 | 2.45 |
| 2 | 0.36 | 37.75 | 6.72 | 0.00 | 0.16 | 7.63 | 4.23 | 22.33 | 5.55 | 2.11 |
| 3 | 1.02 | 29.15 | 20.22 | 0.00 | 0.08 | 0.91 | 1.13 | 3.96 | 1.11 | 43.40 |
| 4 | 18.77 | 44.61 | 0.60 | 0.00 | 0.16 | 0.799 | 1.37 | 10.72 | 1.85 | 31.86 |
| 5 | 25.48 | 37.56 | 1.07 | 0.00 | 2.09 | 1.584 | 4.27 | 12.02 | 1.85 | 34.99 |
| 6 | 21.52 | 38.96 | 0.87 | 0.00 | 1.93 | 1.318 | 3.80 | 21.57 | 2.11 | 36.07 |
| 7 | 27.46 | 38.03 | 0.74 | 0.00 | 2.01 | 1.617 | 3.96 | 12.07 | 2.61 | 35.21 |
| 8 | 19.02 | 29.71 | - | 0.00 | 2.27 | 2.87 | 8.28 | 26.36 | 9.19 | 29.15 |
| 9 | 18.96 | 34.57 | 6.78 | 0.00 | 2.27 | 2.23 | 3.67 | 15.55 | 2.93 | 32.56 |
| 10 | 18.34 | 36.35 | 6.61 | 0.00 | 2.52 | 4.33 | 3.07 | 9.53 | 3.78 | 37.76 |

Table 33

Results of chemical analyses for microelement in fly ash, dolomite, tailings, and mixes thereof

| No of sample | Content of component, dry mass (in percent) | | | | | | |
|---|---|---|---|---|---|---|---|
| | Mn | Cu | Zn | Co | Pb | Cr | As |
| 1 | 0.048 | 0.009 | 0.015 | 0.009 | 0.010 | 0.023 | 0.0012 |
| 2 | 0.300 | 0.004 | 0.006 | 0.016 | 0.012 | 0.013 | 0.0005 |
| 3 | 0.086 | 0.006 | 0.016 | 0.012 | 0.018 | 0.008 | 0.0013 |
| 4 | 0.051 | 0.0091 | 0.004 | 0.0047 | 0.009 | 0.010 | 0.0002 |
| 5 | 0.072 | 0.0119 | 0.008 | 0.0037 | 0.010 | 0.010 | 0.0001 |
| 6 | 0.062 | 0.0091 | 0.007 | 0.0080 | 0.010 | 0.010 | 0.0002 |
| 7 | 0.065 | 0.0110 | 0.007 | 0.0105 | 0.009 | 0.010 | 0.0001 |
| 8 | 0.060 | 0.006 | 0.006 | 0.012 | 0.012 | 0.010 | 0.0005 |
| 9 | 0.090 | 0.003 | 0.002 | 0.012 | 0.012 | 0.006 | 0.0004 |
| 10 | 0.066 | 0.025 | 0.007 | 0.014 | 0.012 | 0.00 | 0.0003 |

## SECTION 13

## PROGNOSIS FOR DRYING TAILINGS IN DIFFERENT CLIMATIC REGIONS

Results obtained during the investigations performed in the region of Ogorzelec show the feasibility of drying tailings in that not too favourable local climate. These results and observations may be extrapolated to project results in regions with dissimilar climatic conditions. The most important components of the water balance for such extrapolations are the precipitation and evaporation.

It is essential that the appropriate formula for calculation of evaporation be selected, for the differences between particular formulae are often significant as is shown by the results of calculations in table 30. The formula of Thornthwaite and the Bac formula were chosen to best suit the available survey data. Computations were made for the Birmingham region in England representing a type of moderate oceanic climate, Nantes in France representing a warm oceanic climate, and for the same reason, the climate at Tampa in Florida, USA.

According to the Thornthwaite classification, Florida has a moist subtropical climate, while Poland belongs to the zone of moist continental climate with cooler summers. In figure 104 are included climatographs showing the annual variations of the most important meteorological elements for the locations selected. Wrocław, Poland is located several scores of kilometers from Ogorzelec, but since it is in a low lying region shows much better conditions (climatic water balance) for "atmospheric drying". Rates of evaporation according to the Bac formula for Nantes and for Birmingham are comparable in relation to other formuale and are considered accurate. The sums of evaporation accor-

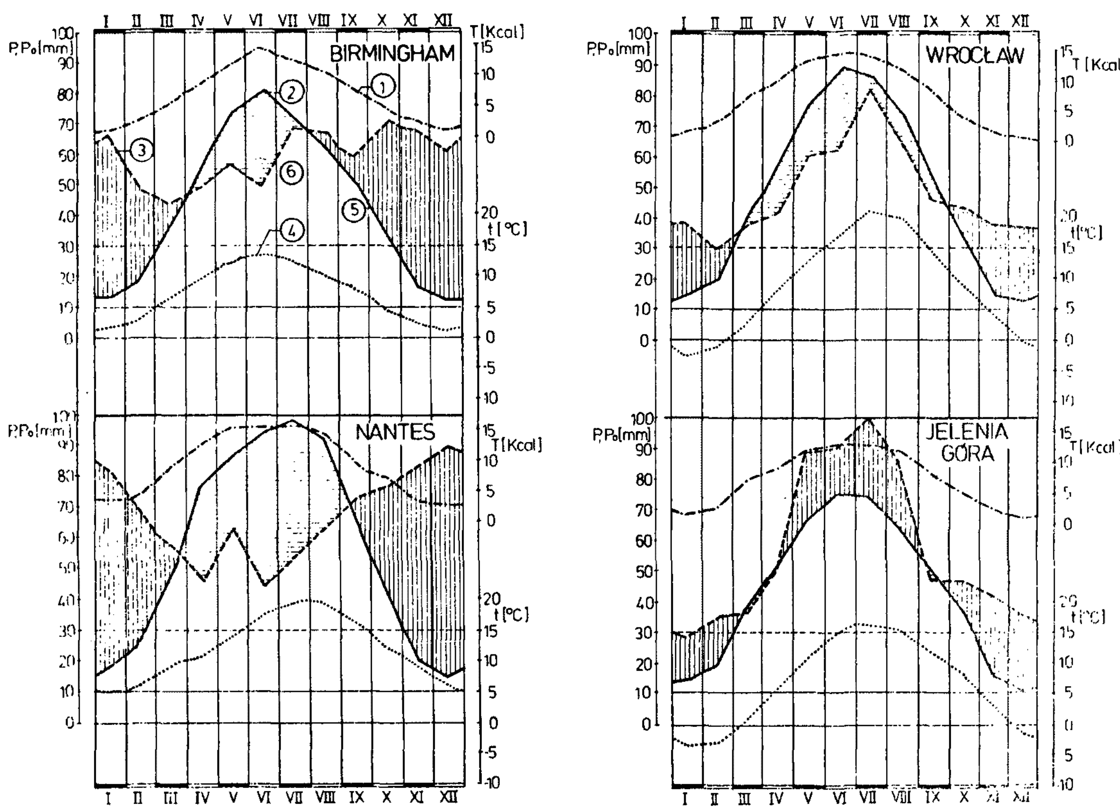



Fig 104 CLIMATOGRAMS FOR SELECTED STATIONS IN EUROPE AND IN POLAND (on the basis of average data for 1951-1970 years)

1 - total radiation in Kcal $cm^{-2}$, 2 - estimated evaporation on the basis of Bač formula in mm, 3 - atmospheric precipitations in mm, 4 - air temperature in o centigrade, 5 - the area where precipitation exceeds evaporation prevalence, 6 - the area where evaporation exceeds precipitation prevalence

ding to Bac and Penman differ during the period April - September in Nantes only 2 mm. The course of line plotted in figure 104 points to great similarity of the total solar radiation and the temperature distribution during the year.

In Jelenia Góra the precipitation exceeds the evaporation for many months the evaporation occurs during the summer months. More favourable conditions for drying occur in Wrocław, where evaporation is possible during the period of March - September. Lower evaporation appears possible at Birmingham conditions of oceanic climate of Western Europe. This is the result of the high air humidity. More advantageous evaporation conditions occur near the oceanic climate of Western Europe characterized by the Nantes station. The small amounts of precipitation occurring during the summer time high radiation values and temperature indicate that the potential for "atmospheric drying" will be good.

Table 34 provides average long term evaporation estimates according to Thornthwaite, the precipitation and climatic water balance for the already considered localities, and for Tampa, Florida. The lack of evaporation data in the table for Jelenia Góra and for Wrocław during the December - February months results from the nature of the formula used which does not allow for calculation of values during months with the air temperature below $0^{o}C$.

The calculated evaporation amounts for the European stations do not differ greatly among themselves either during the summer half - year period or during the year. The higher winter time evaporation for Birmingham indicates the oceanic location of the station. However the values for Tampa do not reflect this phenomenon. Correspondence between precipitation patterns is evident for the mountain climate of Poland (Jelenia Góra), Ogorzelec, and in the oceanic climate of Western Europe (Birmingham); the difference is only 3 mm.

Despite reservations about the amount and intensity of precipitation, it seems that the region of Florida near Tampa has very favourable climatic conditions for atmospheric drying of tailings. The number of

Table 34

Average long term monthly sums of atmospheric precipitation, of potential evaporation according to Thornthwaite, and of climatic water balance (in mm) for selected stations in different climatic zones

| Station | Months | | | | | | | | | | | | | | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan. | Feb. | Mar. | Apr. | May | Jun. | Jul. | Aug. | Sept. | Oct. | Nov. | Dec. | Apr.-Sept. | Oct.-Mar. | |
| Evaporation according to Thornthwaite | | | | | | | | | | | | | | | |
| Jel. Góra (Poland) | - | - | 9 | 41 | 82 | 106 | 119 | 105 | 70 | 43 | 16 | - | 523 | 68 | 591 |
| Wrocław (Poland) | - | - | 9 | 45 | 86 | 114 | 127 | 112 | 73 | 39 | 14 | - | 557 | 62 | 619 |
| Birmingham (England) | 17 | 20 | 30 | 60 | 83 | 103 | 110 | 90 | 64 | 38 | 20 | 16 | 510 | 141 | 651 |
| Tampa (Florida) | 51 | 47 | 80 | 99 | 140 | 156 | 165 | 158 | 138 | 112 | 67 | 50 | 856 | 407 | 1263 |
| Atmospheric precipitation | | | | | | | | | | | | | | | |
| Jel. Góra (Poland) | 29 | 34 | 37 | 55 | 89 | 82 | 103 | 95 | 47 | 49 | 42 | 35 | 471 | 226 | 697 |
| Wrocław (Poland) | 23 | 26 | 28 | 40 | 62 | 63 | 86 | 75 | 40 | 35 | 38 | 31 | 366 | 181 | 547 |
| Birminham (England) | 65 | 48 | 44 | 49 | 56 | 48 | 68 | 67 | 58 | 70 | 67 | 60 | 346 | 354 | 700 |
| Tampa (Florida) | 67 | 70 | 61 | 52 | 75 | 167 | 198 | 204 | 165 | 77 | 45 | 52 | 881 | 372 | 1253 |
| Climatic water balance | | | | | | | | | | | | | | | |
| Jel. Góra (Poland) | - | - | +28 | +14 | +7 | -24 | -16 | -10 | -23 | +6 | +26 | - | -52 | 158 | +106 |
| Wrocław (Poland) | - | - | +19 | - 5 | -24 | -51 | -41 | -37 | -33 | -4 | +24 | - | -191 | 119 | - 72 |
| Birminham (England) | +48 | +28 | +14 | -11 | -27 | -55 | -42 | -23 | - 6 | +32 | +47 | +44 | -164 | -213 | + 49 |
| Tampa (Florida) | +16 | +23 | -19 | -47 | -65 | +31 | +33 | +46 | +27 | -35 | -22 | + 2 | + 25 | - 35 | - 10 |

days with precipitation are relatively small, very fewdays are overcast (minimum of overcast in April), and the number of hours with insolation (according to Kendrew - ref. 14) greatly surpasses the data for European stations (maximum in May   3000 hours).

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# GLOSSARY

aggregate: Agglomeration of fine grains formed through their merging in space between larger components of soil skeleton.

aggregation: Proces based on merging soil grains into aggregates and movement of grains towards the center of aggregate.

anaphoresis: Migration of negatively charged particles towards anode.

deaggregation: Reconstruction or destruction of soil agg e gates.

decolmation: Process of unplugging of closed for water flow soil pores.

electrophoresis: Movement of uniformly charged particles of dispersed phase of colloidal system contained in an electric field.

electroosmosis: Phenomenon based on movement of fluid dispersion medium of colloidal system contained in electric field, versus occurring in stable phase dispersed phase.

evaporimeter: Instrument for measuring intensity of water evaporation from free water table, or from surface of soil.

colmatation: Plugging of soil pores of water passages, mainly in effect of grains migration.

microelements: Chemical elements occurring in very small trace amounts in soil, necessary for growth and development of organisms.

suphosis: Removal of some soil grains away from the region contained by electroosmosis.

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16. ABSTRACT

The objective of this research is the examination of field techniques that remove water from sludge tailings produced as a waste during floatation of sulphur ore. The research was conducted with the idea of utilizing these wastes in agriculture as a soil amendment useful to neutralize acid soils. The main hindrance to economic utilization of this type of wastes is their semifluid character. This fluid character persists for many years, making it impossible to economically excavate and transport the material for agricultural use. The technique investigated for draining the sludge is comprised of a three stage system of drying as follows:

(1) gravitational draining of water impounded in the bowl of the tailings basin;
(2) draining a substantial part of the water in the sludge using electroosmosis which allows removal and some transport of the sludge; and
(3) further drying to a relatively dry, plastic state by spreading under conditions that facilitate atmospheric drying, or adding dry material to the electro-osmotically dewatered sludge.

17. KEY WORDS AND DOCUMENT ANALYSIS

| a. DESCRIPTORS | b. IDENTIFIERS/OPEN ENDED TERMS | c. COSATI Field/Group |
|---|---|---|
| Dewatering<br><br><br>Sludge<br>Agronomy | Poland Mine Wastes<br>Slime Tailings<br>Electroosmotic drying<br>Sulfur<br>Fly ash<br>Air drying<br>Soil amendment | 43B<br>48A<br>50B<br>68C,D<br>91A<br>98D |

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