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INVESTIGATIONS ON COMBINED ELECTROCOAGULATION AND ELECTROFLOTATION APPLICATION TO REMOVAL OF PHOSPHATES FROM WASTEWATER

The work comprises laboratory test data, the purpose of which was to design an electrode set to assure correct coagulation and flotation proceeding simultaneously and to check whether it can be applied to removal of phosphates from aqueous solutions, mechanically treated municipal wastes and biologically treated municipal wastewater. As a result of preliminary evaluation of a number of electrode sets, the set selected to be further examined consisted of a perforated cathode made of acid-resistant steel and an anode of aluminium grid construction positioned above the cathode. This solution proved to be especially useful in removal of phosphates from municipal wastes both after mechanical and biological treatments. After the process was terminated, phosphorus content in the wastes did not exceed 0.3 mg P/dm^3 , and for the initial concentrations of this element up to 11 mg P/dm^3 . At the same time, it has been found that the energy consumption for treatment of 1 m^3 of wastes is not higher than 0.83 kWh , indicating that the method investigated is competitive with other electrochemical methods for phosphate removal.

1. INTRODUCTION

So far the use of mechanical and biological methods for sewage treatment is insufficient since nitrogen and phosphorus compounds are not satisfactorily removed, and their excess intensifies eutrophication of surface waters. Increasing concentrations of nutrients in an aquatic environment favour a rapid increment in the mass of organic matter which, after its degradation, increases the pollution of a receiving body of water to a degree not permitting its self-purification.

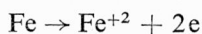
In accordance with a Liebig law, plant growth is limited by the component which first is removed from the environment. Thus, it appears that a sufficient condition to protect a receiving body against excessive eutrophication is optional elimination of nitrogen or phosphorus compounds from sewage. Many authors suppose that phosphorus removal is a more effective method preventing eutrophication [3, 7]. Nitrogen, contrary

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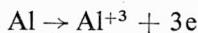
to phosphorus, can be introduced to surface receiving bodies not only with sewage but also through some species of blue-green algae which are capable of gaseous nitrogen assimilation [6].

The most often proposed method to remove phosphates from sewage is a coagulation using ferric or aluminium salts [1, 5]. This method can be employed as an individual process in biologically or mechanically treated sewage or as a process concurrent to a biological treatment, since the coagulating agent is directly proportioned to aeration tanks.

Attempts are also made to remove phosphates with an electrocoagulation method [2]. Such a system is composed of a pair of electrodes connected to a dc current source. Then, depending on the material used, either iron



or aluminium



be dissolved on the anode; a considerable amount of gas, mostly hydrogen, being released at the cathode. At a suitable pH, the iron or aluminium ions passing into the solution form a precipitate of hydroxides, which can be separated by sedimentation. In the case of electrocoagulation process, post-coagulation sludge can be efficiently separated by means of flotation with "waste" hydrogen bubbles released at the cathode. The application of the latter method is supported by the results of experiments on the removal of floccy suspended solids from sewage by an electroflotation method [4, 8].

The purpose of the work presented was to design a suitable set of electrodes which would permit a correct coagulation and flotation of post-coagulation sludge and to check its usability for removal of phosphates from water solutions, mechanically treated municipal wastes, and biologically treated wastewaters.

2. EXPERIMENTAL

Technological investigations were preceded by experiments, during which a wide range of electrode sets differing in shape, number of electrodes and materials used to their construction were tested. As a basic evaluation criterion we assumed the readiness of the released ions to pass from the soluble anode into solution bulk and a possibility to obtain small and uniform bubbles of gas across the whole space subject to flotation.

The first system being tested was composed of a perforated iron anode and a cathode made of stainless steel. During operation of the system it was found that a great portion of iron introduced did not precipitate, since a local decline of dissolved oxygen in the medium inhibited the reaction of ferrous ion oxidation. In further attempt to utilize iron as the coagulant, a three-electrode assembly was used which included a perforated iron anode and a perforated cathode and another anode made of stainless steel. Under these

conditions a complete iron oxidation was obtained, but the effectiveness of flotation of sludge decreased considerably. This was due to the numerous big gaseous bubbles which were formed by flocculation as a result of minute bubbles passing through the perforated electrodes to be electrocoagulated. It was also found that the anode made of acid-resistant steel was subject to a rapid point corrosion.

At the next stage of experiments a two-electrode system was evaluated, in which soluble aluminium anodes were used.

In this system a cathode was made, as previously, of stainless sheet metal perforated with 60 000 holes/m² of 2.5 mm in diameter. An anode of sheet aluminium 1.5 mm thick and similarly perforated was initially placed above the cathode. When running the system, it was noticed that a number of hydrogen bubbles released at the cathode were gathering under the surface of anode to form larger bubbles lifting upwards to cause disruption of a scum of separated sludge and settling those floccules that floated before now. An electrode transposition, so that the cathode was above the anode, was aimless, since it could make difficult to remove the aluminium hydroxide floccules from the anode surface. Therefore, a decision was taken to redesign the anode by making it as a grid of 3 mm aluminium wire and mesh size of 10×10 mm.

On the basis of experiments carried out, the system has been found to be optimum both for electrocoagulation and electroflotation. The process examined on a laboratory scale comprised two steps:

- a) electrocoagulation and electroflotation proceeding simultaneously for such a period of time that under the given conditions a determined coagulant dose was dissolved,
- b) flotation that takes place after the current is switched off, the hydrogen bubbles remaining in the solution raise the coagulant floccules to the surface until a clear solution is obtained.

A preliminary evaluation of the electrode systems, as well as actual technological investigations, were carried out in a simulating device in the form of cylindrical tank made of organic glass (fig. 1). The tank measured 0.1 m in diameter and was 1.2 m high.

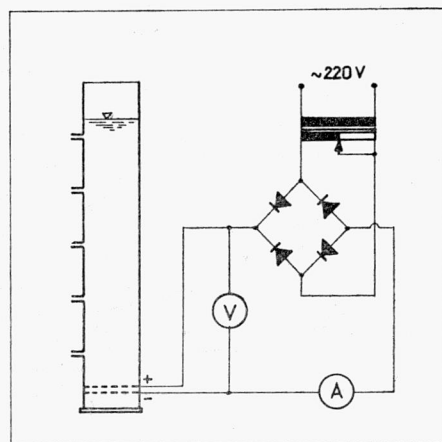


Fig. 1. Diagram of laboratory set-up used in the investigations

Rys. 1. Schemat układu laboratoryjnego stosowanego w badaniach

Particular electrode sets mounted in the proximity of the device bottom were made as exchangeable components, the gap between the individual electrodes being 15 mm. The electrodes were supplied with direct current through an autotransformer from a selenium rectifier which assured a smooth control of current intensity. An ammeter and a voltmeter were connected to the system, as illustrated in fig. 1.

The performed technological research was to determine conditions influencing the process operation, i.e. the duration of electroflotation, current density, and initial phosphate concentration depending on the degree of these compounds removal. Aqueous solutions of phosphates, typical municipal wastes after mechanical treatment, as well as biologically treated municipal wastes were used in the tests.

3. DISCUSSION OF RESULTS

As the result of the preliminary experiments, an electrode set was selected to be further examined. The set consisted of a perforated stainless steel cathode and an anode of aluminium grid construction positioned above the cathode. This set allowed a correct electrocoagulation and effective flotation of the suspended solids being formed.

During investigation of the removal of phosphates their solutions in tap water were used. The initial phosphorus content ranging from 2.3 to 14 mg/dm³ corresponded to that in the typical municipal wastes treated mechanically [7]. The pH of the solutions prepared ranged from 7.2 to 7.5. In a first measuring run, using current density of 35 A/m² of electrode, no satisfactory removals of phosphates were obtained (fig. 2). This run may be exemplified by a solution with the lowest initial phosphorus content (2.7 mg/dm³) in which 1 mg of phosphorus/dm³ still remained after 80 min. of electrocoagulation. Some improvement of results was observed after the current density increased up to

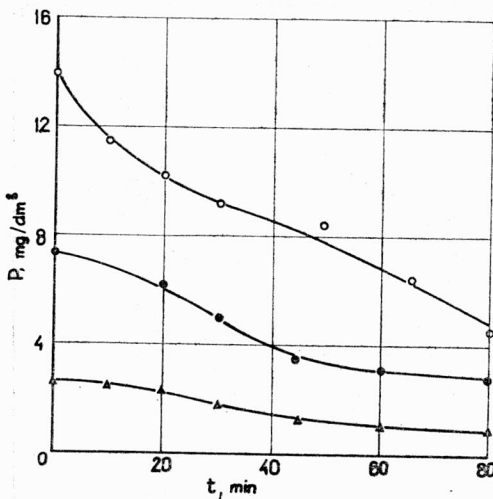


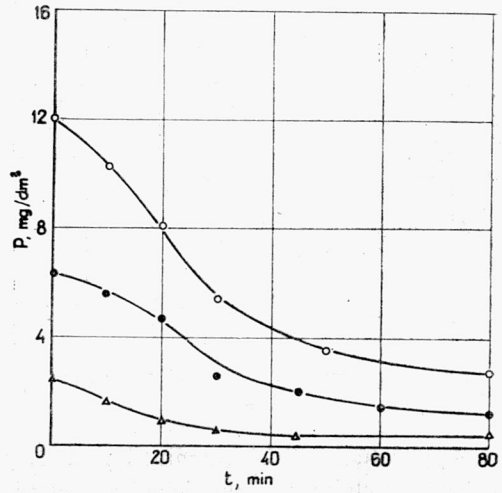
Fig. 2. Phosphate removal from aqueous solutions for different initial concentrations (current density of 35 A/m²)

Rys. 2. Przebieg procesu usuwania fosforanów z roztworów wodnych o różnym stężeniu początkowym (gęstość prądu 35 A/m²)

70 A/m² (fig. 3). And yet, under these conditions, satisfactory results were obtained only with the lowest initial concentration where phosphorus content decreased to 0.5 mg/dm³ after 45-minute process. Difficulties were encountered with flotation of the suspended solids in form of small and unstable flocks, the portion of which remained in the solution after termination of the process, thus increasing the number of analyses of phosphates carried out in unfiltered samples.

Fig. 3. Phosphate removal from aqueous solutions for different initial concentrations (current density of 70 A/m²)

Rys. 3. Przebieg procesu usuwania fosforanów z roztworów wodnych o różnym stężeniu początkowym (gęstość prądu 70 A/m²)



In the next stage, mechanically treated municipal wastes were examined, the average COD of which was 330 mg O₂/dm³ and pH ranged from 7.4 to 7.8. After a number of experiments were performed, it has been found that phosphates can be removed to a high degree and that the formed suspended solids be separated completely by means of flotation method. The rate of phosphorus removal is exemplified graphically in fig. 4 for three

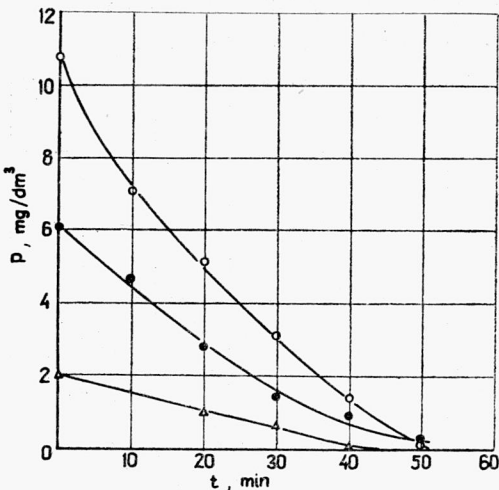


Fig. 4. Removal of phosphates from mechanically treated municipal wastes (current density of 70 A/m²)

Rys. 4. Przebieg procesu usuwania fosforanów ze ścieków miejskich oczyszczonych mechanicznie (gęstość prądu 70 A/m²)

initial phosphorus concentrations ranging from 2 to 10.8 mg P/dm³. Under these conditions and using current density of 70 A/m² the phosphorus content decreased to 0.3 mg/dm³ during a time not longer than 50 min. Average 13% decrease in the content of organic compounds was found simultaneously with the removal of phosphates.

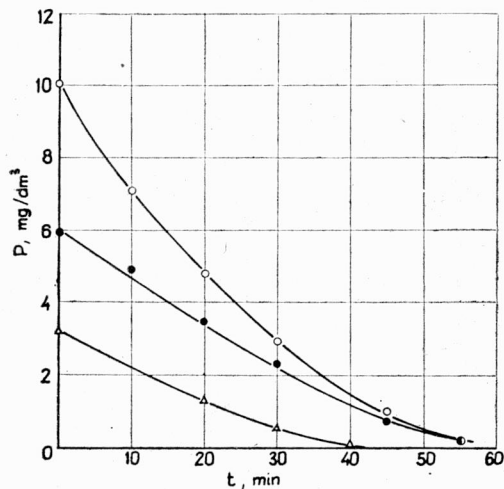


Fig. 5. Removal of phosphates from municipal wastes after biological treatment (current density of 70 A/m²)

Rys. 5. Przebieg procesu usuwania fosforanów ze ścieków miejskich oczyszczonych biologicznie (gęstość prądu 70 A/m²)

Application of the examined process proved effective also with regard to disposal of biologically treated municipal wastes (fig. 3). It follows that for initial concentrations up to 10 mg P/dm³ the phosphorus removal may be achieved to a value below 0.3 mg/dm³ within 40–55 min. As to the mechanically treated wastes, also in this case 30–60% decrease in organic compound content was achieved with initial value of COD in wastes being on the average 70 mg O₂/dm³.

From the analysis of results, it follows that better effects of phosphorus disposal in municipal wastes than in its aqueous solutions may be among other ascribed to the presence of natural colloids in the wastes, which facilitate flocculation of minute particles of post-coagulation suspended solids and increase their sorption properties.

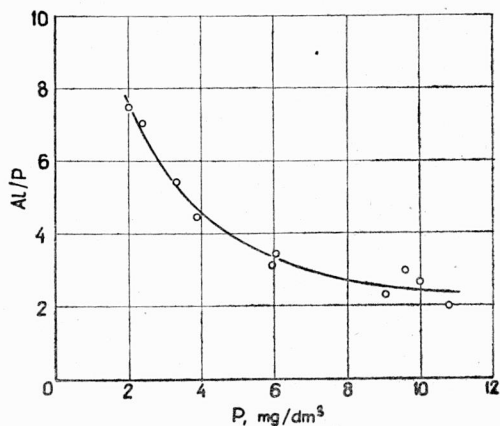


Fig. 6. Changes in Al/P weight ratio to improve the effects of phosphates removal, depending on their initial concentration in municipal wastewater

Rys. 6. Zmiany stosunku wagowego Al/P zapewniające usunięcie fosforanów w zależności od ich początkowego stężenia w ściekach miejskich

The optimal doses of aluminium introduced each time into sewage during electrocoagulation are important parameters of the process examined. Aluminium demand, determined by Al/P weight ratio, is not constant, but it decreases distinctly with the increasing concentration of phosphorus in sewage (fig. 6). Hence, the coagulant agent can be most effectively utilized while treating sewage with high phosphorus content.

Taking advantage of measured values of current parameters, power outlay have been calculated for the process. Electric energy consumption (in kWh/m³) of the treated sewage increases with the increasing initial content of phosphates and reaches the value of 0.83 kWh/m³ for the highest concentrations examined (fig. 7). In comparison with electrolytic method for removal of phosphates, where energy consumption is about 1 kWh/m³ [1], the results obtained must be accepted as advantageous.

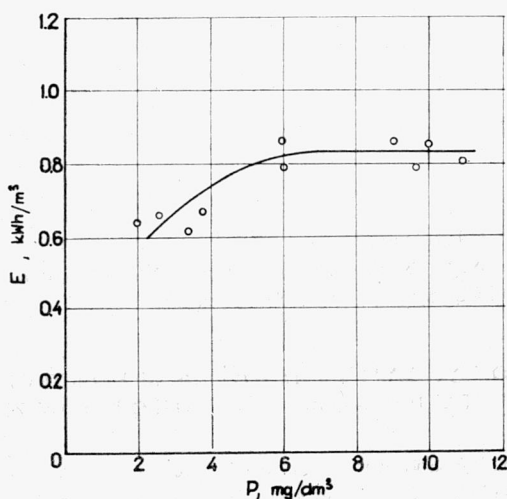


Fig. 7. The influence of initial content of phosphorus in municipal wastes on the rate of energy consumption in the process of its removal

Rys. 7. Wpływ początkowej zawartości fosforu w ściekach miejskich na zużycie energii E w procesie jego usuwania

4. CONCLUSIONS

1. Correct courses of simultaneous electrocoagulation and electroflotation processes in removal of phosphates from municipal wastes are assured by the system of electrodes consisting of a stainless steel cathode and a grid anode of aluminium.

2. By applying the process investigated to removal of phosphates from municipal wastes, the concentrations of which range from 2.0 to 10.8 mg P/dm³, it is possible to decrease the phosphorus content in effluent to a value less than 0.3 mg/dm³.

3. Aluminium consumption determined by Al/P weight ratio decreases with the increasing concentration of phosphorus in wastes to achieve the value of 2.5 mg Al/mg P at maximum concentrations.

4. When treating the wastes with initial phosphorus content ranging from 6 to 10 mg/dm³, the expenditure of energy for the combined electrocoagulation processes amounts to about 0.88 kWh/m³.

REFERENCES

- [1] CHOJNACKI A., BARTKIEWICZ B., *O zabezpieczeniu wody w odbiorniku przed zakwitaniem*, Gospodarka wodna, No. 8 (1966), pp. 304.
- [2] KULSKIJ L. A. et al., *Očistka vody elektrokoagulacej*, Budivel'nik, Kiev 1978.
- [3] PAINTER D. E., *Where does the phosphate go?* Water and Sewage Works, No. 12 (1968), pp. 566.
- [4] PALAK M., SIKORA J., ZIELIŃSKI J., *Wstępne badania laboratoryjne nad określeniem podstawowych parametrów prowadzenia procesu elektrofotacji zawieszin osadu czynnego*, Conference "Postęp techniczny w dziedzinie oczyszczania ścieków", Katowice, June 1980.
- [5] POŁOMSKI B. et al., *Badania nad usuwaniem fosforu w procesie symultanicznym bez sedimentacji wstępnej*, Conference "Postęp techniczny w dziedzinie oczyszczania ścieków", Katowice, June 1978.
- [6] SAWYER C. N., *Effects and control of aquatic growths*, J. Wat. Pol. Cont. Fed., Vol. 34 (1962), No. 2, pp. 279.
- [7] SCHMIDT L. A., MCKINNEY R. E., *Phosphate removal by a lime-biological treatment scheme*, J. Wat. Pol. Cont. Fed., Vol. 41 (1969), No. 7, pp. 1259.
- [8] STVEDEV W. P., KAKUŠEV W. F., *Ispolzovanie elektroforeza, elektrokoagulacji i elektrofotacji dla očistki radioaktywnych vod*, Radiochimija, No. 12 (1970), pp. 871.

BADANIA NAD ŁĄCZNYM ZASTOSOWANIEM ELEKTROKOAGULACJI I ELEKTROFLOTACJI DO USUWANIA FOSFORANÓW ZE ŚCIEKÓW

Praca zawiera wyniki badań laboratoryjnych, których celem było skonstruowanie zestawu elektrod zapewniającego należyty przebieg jednoczesnej koagulacji i flotacji oraz sprawdzenie jego przydatności do usuwania fosforanów z roztworów wodnych, ze ścieków miejskich mechanicznie oczyszczonych i ścieków oczyszczonych biologicznie. Po wstępnej ocenie wielu układów elektrodowych, do badań technologicznych wytypowano zestaw składający się z perforowanej katody wykonanej ze stali kwasoodpornej i położonej wyżej anody o konstrukcji kratowej wykonanej z aluminium. Rozwiązanie to okazało się szczególnie przydatne do usuwania fosforanów ze ścieków miejskich zarówno po mechanicznym, jak i biologicznym oczyszczeniu. Zawartość fosforu w ściekach po zakończeniu procesu nie przekraczała 0,3 mg/dm³ w zakresie stężeń początkowych do 11 mg P/dm³. Ustalono równocześnie, że zużycie energii elektrycznej na oczyszczenie 1 m³ ścieków nie przekracza 0,83 kWh, co wskazuje na konkurencyjność badanej metody w porównaniu z innymi metodami elektrochemicznego usuwania fosforanów.

VERSUCHE ZUR GEMEINSAMEN ANWENDUNG DER ELEKTROKOAGULATION UND FLOTATION ZUR PHOSPHATELIMINIERUNG AUS DEM ABWASSER

Zur Diskussion kommen Ergebnisse von Laboruntersuchungen bei denen versucht wurde, ein Elektrodenpaar zusammenzustellen, welches eine gleichzeitige Koagulation und Flotation hervorruft. Die Versuchsanordnung sollte zur Eliminierung von Phosphaten aus wässrigen Lösungen bzw. aus mechanisch oder biologisch gereinigtem Abwasser dienen. Zu weiteren Versuchen — nach der Bewertung verschie-

dener Anordnungen — wurde ein Elektrodenpaar gewählt, welches sich aus einer perforierten Kathode aus säurebeständigem Stahl und einer höher angelegten Gitteranode aus Aluminium zusammensetzte. Diese Anordnung bewährte sich besonders gut bei der Eliminierung von Phosphaten aus dem städtischen Abwasser. Die Phosphorkonzentrationen nach dem Verfahren waren kleiner als $0,3 \text{ g/m}^3$, bei Ausgangskonzentrationen bis 11 g P/m^3 . Der spezifische Energiebedarf war kleiner als $0,83 \text{ kWh/m}^3$ Abwasser. Die beschriebene Methode ist also gegenüber anderer Phosphateliminierungsmethoden konkurrenzfähig.

ИССЛЕДОВАНИЕ ПО СОВМЕСТНОМУ ПРИМЕНЕНИЮ ЭЛЕКТРОКОАГУЛЯЦИИ И ЭЛЕКТРОФЛОТАЦИИ ДЛЯ УДАЛЕНИЯ ФОСФАТОВ ИЗ СТОЧНЫХ ВОД

Работа содержит результаты лабораторных исследований, целью которых было конструирование арматуры электродов, обеспечивающей правильный ход одновременной коагуляции и флотации, а также проверка её пригодности для удаления фосфатов из водных растворов из механически очищенных городских сточных вод, а также биологически очищенных сточных вод. После предварительной оценки многих электродных систем для технологических исследований была выделена арматура, состоящая из перфорированного катода, выполненного из кислотной стали и расположенного выше анода с решётчатой конструкцией из алюминия. Это решение оказалось особенно пригодным для удаления фосфатов из городских сточных вод как после механической, так и биологической очистки. Содержание фосфора в сточных водах после окончания процесса не превышало $0,3 \text{ мг/дм}^3$ в области начальных концентраций до 11 мг/дм^3 . Одновременно было установлено, что потребление электрической энергии на очистку 1 м^3 сточных вод не превышает $0,83 \text{ кВт} \cdot \text{ч}$, что указывает на конкурентность исследуемого метода по сравнению с другими методами электромеханического удаления фосфатов.