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APPLICATION OF THE ENHANCED BIOLOGICAL PHOSPHORUS REMOVAL IN WASTE WATER TREATMENT PLANTS

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Abstract. In sewage plants operating with high energy density aerators some features of enhanced biological phosphorus removal are observed. The reasons of the observed phenomena are discussed according to the standpoints of the EBPR mechanism.

Key words: waste water treatment, biological phosphorus removal, activated sludge.

INTRODUCTION

Eutrophication has been a serious problem in the last few decades. The biological growth is controlled by limiting factors. Frequently some nutrient element is such a limiting factor and phosphorus (P) is a prime candidate for a limiting macronutrient [1]. Hence, the reduction of P input into water bodies can prevent eutrophication. Lately, the P input into rivers and lakes from agricultural diffuse sources has decreased in Estonia, but the need for higher P removal from sewage waters remains. In conventional biological sewage treatment plants P removal is only 20–30% [2, 3] and this is not sufficient to achieve the low P concentrations of effluents required to prevent eutrophication.

The removal of P in waste water treatment processes can only be carried out by its incorporation into a solid phase, which can be separated from water. During the biological treatment stage, the only way to remove P is its uptake or precipitation by the produced biomass. Thus, P removal will depend on the quantity of waste sludge produced and the P content [3]. In the conventional biological treatment process the P content of waste sludges is about 2% [1, 3].

In sewage plants with enhanced biological phosphorus removal (EBPR) the activated sludge or mixed liquor must pass alternately through anaerobic and aerobic stages [4]. In such plants polyphosphate containing bacteria are enriched in the sludge [5]. The activated sludges from EBPR plants have a high P content. In experimental conditions the P content is up to 11% [6] and can even be as high as 18% [7, 8].

In the aeration basins with high energy density (HED) aerators the O_2 concentrations can be very different in particular parts of basins and there can be zones where O_2 concentration is zero. Such a situation is analogical to the common characteristics of all EBPR processes: an anaerobic/aerobic sequence of both waste water and sludge. HED aerators are used at two sewage plants in Estonia. In the Viiratsi sewage plant, operating with HED aerators, some features of the EBPR process were revealed [9]. Unfortunately, one basin with HED aerators and three basins with conventional (bottom) aeration in the Viiratsi plant have common activated sludge recirculation. After reconstruction the Põlva plant has only a basin with HED aerators now. We investigated P removal in the Põlva sewage plant. The results are discussed below.

EXPERIMENTAL

The activated sludges were obtained from the Põlva sewage plant and for some experiments from the Elva sewage plant.

The reconstructed Põlva sewage treatment plant has one aeration basin with four HED aerators. The aerators are turned on/off automatically to hold O_2 concentration in the measuring point (2 m from the aerator) within the range 1.0–2.4 mg/l. The plant receives Põlva municipal waste waters and dairy factory waste waters, in an average 4000 m^3/day. The influent BOD was 150–400 mg/l, average retention time 6 h. Before the reconstruction there were seven basins with conventional (bottom) aeration and one basin with two HED aerators. The Elva sewage plant has basins with conventional (bottom) aeration and receives municipal waste waters.

For all determinations the activated sludges were centrifuged and washed with distilled water. For dry weight determination the sludge was dried at 100–105 °C for 24 h. Total phosphorus was quantified by the vanadomolybdophosphoric acid colorimetric method after persulphate digestion, according to APHA [10]. In laboratory the activated sludge was fed with the Põlva sewage water or with a medium containing (in g/l) 0.32 NH_4Cl, 0.6 $MgSO_4 \cdot 7H_2O$, 0.07 $CaCl_2 \cdot 2H_2O$, 0.1 EDTA, and 2 ml of trace metal solution containing 1.5 $FeCl_3 \cdot 6H_2O$, 0.15 H_3BO_4, 0.03 $CuSO_4 \cdot 5H_2O$, 0.03 KI, 0.12 $MnCl_2 \cdot 4H_2O$, 0.06 $Na_2MoO_4 \cdot 2H_2O$, 0.12 $ZnSO_4 \cdot 7H_2O$, 0.15 $CoCl_2 \cdot 6H_2O$ [6], and 0.022 KH_2PO_4.

Elva activated sludge was cyclically aerated 4 h and kept without aeration 2 h. Põlva activated sludge was kept aerobically only.

RESULTS AND DISCUSSION

During the first week after reconstruction the P content of Põlva activated sludge increased from 1.6 to 2.3% of dry weight. The efficiency of P removal increased too.

Subsequently the activated sludge P content decreased, the efficiency of P removal was low, and the content of suspended solids in the effluent was high due to bad sedimentation of activated sludge. A stable operating regime was reached after two months. The sludge P content was 2.0–2.4% and the P removal efficiency 30–65%. Before reconstruction the P content had been from 1.7 to 2.05% and the P removal efficiency up to 65%. Such P contents are typical of the conventional biological treatment process and there were not any features of the EBPR process, despite of the presence of a small anaerobic zone in one basin (with HED aerators) before the reconstruction. One small anaerobic zone was not sufficient to enrich sludge with polyphosphate-containing bacteria. The bulk of the sludge circulated through the basins without an anaerobic zone. Moreover, the anaerobic zone residence time was short compared to aerobic conditions residence time.

During extraordinarily high loading the concentration of dissolved oxygen outside of the aerators decreased. Concentrations in the measuring point were 0.2–0.3 mg O_2/l. The influent P content was very high too: the highest measured P concentrations were more than 18 mg/l. Approximately during a week there was a low O_2 concentration outside the aerators. At this time the sludge P content was on an average 2.1% and the P removal efficiency was below 10%. After the normalization of the oxygen concentration the sludge P content started to rise and in three weeks it reached 3.9%. The P removal efficiency was the highest (88%) after one week, the effluent P concentration was at that time 0.94 mg/l. The rise in the sludge P content was a slow process, but the P removal efficiency achieved its maximum at the beginning of the P content rise. The effluent BOD was 5–12 mg/l and the BOD removal efficiency in the aeration basin 96–98%.

The necessary condition for the achievement of an enhanced P removal is that the biomass should pass through an anaerobic zone. In the anaerobic zone the polyphosphate-containing bacteria take up easily degradable organic matter. A suitable substrate is primarily acetate. This matter is accumulated as poly-β-hydroxybuturate (PHB) [11] or poly-β-hydroxyvalerate (PHV) [12]. The energy required for the storage of PHB/PHV is produced by decomposing polyphosphate from an intercellular store. As a result, the polyphosphate accumulating bacteria will release phosphate and the solution phosphate concentration will increase. Under aerobic conditions, the polyphosphate accumulating bacteria consume PHB/PHV for growth and accumulate polyphosphate. The solution P content decreases to a level lower than that in the influent. A good P removal in the aerobic zone is obtained only if a sufficient P release occurs in the anaerobic zone [13, 14].

Most authors have reported the necessity of the virtual absence of dissolved oxygen in the anaerobic zone. Nevertheless, recently it was reported that P release began at low O_2 values, depending on sludge conditions [15]. Obviously the conditions in the sludge flocs are not idential to those in the bulk solution. When sludge organisms are brought together with sewage, O_2 is consumed very rapidly and anaerobic conditions may develop in the flocs despite the O_2 presence in the solution. At a O_2 limiting content, P uptake would probably still occur on the surface of the sludge flocs, while in the interior P is released. The measured oxygen concentration at P uptake or release depends on a gradient of O_2 within the sludge flocs.

When the O_2 concentration in the Põlva plant decreased, anaerobic conditions emerged in some zones at least in the interior of sludge flocs. The activated sludge was enriched with polyphosphate containing bacteria. The EBPR did not start to operate yet, because bacteria did not take up P near the outlet. The EBPR started to operate only when the P uptake occurred also in the very end of the basin. The precondition for P uptake is a sufficient O_2 concentration. In the front part of the basin the O_2 consumption is higher and P release will occur here for a longer time. However, the stirring is intensive in the aeration basin and the anaerobic conditions disappear here too.

The sludge P content increased some weeks after the rise in the O_2 concentration, although there should not be any P release in the aeration basin. However, during secondary clarification a P release must be expected, even when all the more easily degradable substrates from the influent have been oxidized [15]. Such an explanation is in accordance with a decrease in the P removal efficiency simultaneously with an increase in the sludge P content.

In laboratory the P content of activated sludges changed to a negligible extent. During 2 h without aeration the concentration of dissolved O_2 decreased considerably, but completely anaerobic conditions were not achieved. In sewage treatment plants the O_2 that might be present in the incoming flows is consumed very rapidly when sewage and sludge organisms are brought together [3]. To model such conditions in laboratory is our further purpose.

CONCLUSIONS

The results show that in sewage plants with HED aerators and without an anaerobic basin the EBPR process can occur. When the O_2 concentration in the basin is low, there can be anaerobic conditions in the sludge flocs. Nevertheless, such a sewage plant does not operate in a stable EBPR regime with a high P removal efficiency, as P release can occur during secondary clarification. Therefore, it is necessary to achieve that anaerobic conditions exist only in the front part of the basin (or in the anaerobic basin). In the end of the aeration basin an adequate aeration must be guaranteed to prevent P release from sludge during secondary clarification.

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FOSFORI TÕHUSTATUD BIOÄRASTAMISE RAKENDAMISEST HEITVEEPUHASTITES

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On uuritud fosfori ärastamist heitvetest Põlva biopuhastis, kus pärast rekonstrueerimist on kasutusel ainult suure energiatihedusega aeraatorid (SEA). Samuti on vaadeldud Elva biopuhasti aktiivmuda. Kuna SEA puhul on väljaspool seadet lahustunud hapniku kontsentratsioon madal, võib sellistes puhastites esineda fosfori tõhustatud bioärastamise (FTB) mehhanism. FTB-d iseloomustavad fosfori ärastamise efektiivsus ja muda kuivaine suur fosforisisaldus, mille põhjus on aktiivmuda rikastumine polüfosfaate akumuleerivate bakteritega anaeroobsete ja aeroobsete tingi-

muste vaheldumisel. Uuritud puhastusseadme tavalisel töörežiimil FTB ilminguid ei esinenud, kuid pärast erakordselt kõrget reostuskoormust, mille ajal lahustunud hapniku kontsentratsioon basseinis langes, täheldati FTB iseloomulikke tunnuseid. Aktiivmuda kuivaine fosforisisaldus tõusis üle 3%, fosfori ärastamise efektiivsus oli maksimaalselt 88%. Siiski on stabiilse FTB saavutamiseks vajalik ka SEA rakendamise puhul eelnevalt planeerida anaeroobse tsooni tekitamine aktiivmuda basseini eesosas või eraldi anaeroobse basseinina, samuti tagada küllaldane lahustunud hapniku kontsentratsioon enne väljavoolu.

ВОЗМОЖНОСТЬ ПОВЫШЕННОГО БИОЛОГИЧЕСКОГО УДАЛЕНИЯ ФОСФОРА НА СТАНЦИЯХ ОЧИСТКИ СТОЧНЫХ ВОД

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Исследованы удаление фосфора из сточных вод на Пылваской станции очистки, оснащенной после реконструкции аэраторами с высокой плотностью энергии (АВПЭ), а также активный ил на Элваской станции очистки. При использовании АВПЭ концентрация растворенного кислорода вне аэраторов невысокая. В связи с этим образуются анаэробные зоны, создающие ситуацию повышенного биологического удаления фосфора и высокое содержание его в активном иле. Причина этого – рост числа аккумулирующих полифосфаты бактерий при переменном аэробно-анаэробном режиме. При нормальном рабочем режиме станции повышенного удаления фосфора не происходит, но после чрезвычайно высокого биохимического потребления кислорода, когда его содержание в аэротенке уменьшается, эффективность удаления фосфора может достигать 88% и содержание фосфора в сухом веществе активного ила превышать 3%. Для достижения стабильного режима повышенного биологического удаления фосфора необходима стационарная анаэробная зона в начале аэротенка и зона достаточно высокой концентрации кислорода в его конце. Анаэробная зона может быть обеспечена или особым режимом аэротенка, или с помощью специально спроектированного резервуара.