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CHEMICO-BIOLOGICAL SEWAGE TREATMENT PLANTS FOR PE ≤ 9.999

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Removal of nitrogen and phosphorus compounds is not required in the case of sewage treatment plants serving the settlement units of up to 9.999 citizens and not charging treated sewage into staying waters. Therefore, it is possible to reduce the range of water treatment to merely two requirements: the BOD_5 and the concentration of suspended solids. It gives a possibility to use another technological solution in such sewage treatment plants. As a result, due to chemical pre-treatment, size of biological reactors can be substantially reduced. Such approach is justified not only by technical, but predominantly by economical issues.

Keywords: chemico-biological sewage treatment plants, nitrogen and phosphorus compounds

1. INTRODUCTION

According to the Delegation of Minister of Environment of 8 July 2004 specifying required quality of treated effluents from settlement units with PE ≤ 9.999 and in the case of receivers being lotic waters, what is only required is to decrease values of COD and BOD_5 and of the concentration of suspended solids [1]. Thus, due to limiting the requirements only to disposing organic carbon compounds it gives an opportunity to simplify considerably the technological framework of sewage treatment.

Foreign and domestic experience shows that, especially in such a situation, there is a possibility to introduce to the technological framework some facilities which will enable the process of volumetric coagulation preceding the process of biological sewage treatment. Use of the former process results in considerable reduction of BOD_5, the concentration of total suspended solids and

– incidentally – the concentration of total phosphorus. As a consequence, the reduction of biological sewage treatment reactors becomes highly feasible. Essentially, one uses then mechanico-chemico-biological treatment plants where the key role is performed by their chemical part, provided that it will not be the preliminary chemical precipitation but a full process of volumetric coagulation consisting of selected unit operations, rapid mixing, slow mixing (flocculation) and sedimentation.

This paper presents the characteristics of series of types of treatment plants receiving sewage of PE = 2.000 – 9.999 inhabitants.

2. SEWAGE TREATMENT PROCESS (FIG. 1)

Sewage incoming to settlement unit is, to begin with, submitted to the process of sieving with use of the grate or sieve. The vertical flow grit chamber is a facility to stop mineral suspended solids but it serves simultaneously as a chamber of rapid mixing to which a coagulant is provided. Sewage mixed with coagulant is sent to the flocculation chamber with spiral vortex water movement, jointed with vertical sedimentation tank in which flocculated suspension matters are stopped with use of sedimentation process. Sludge that may be labelled as preliminary or post-coagulant, settles in the lower part of the tank. Based on the calculations performed [2], i.e. for 1 minute of rapid mixing, flocculation of 20 minutes and sedimentation equal to 1 hour, it is possible to reduce BOD_5 by approximately 75%, COD by approximately 80% and the density of suspension matters by approximately 80%. Accomplishment of such treatment results is possible for the coagulant's dose of 75 g/m^3. Bearing in mind the technological and economic aspects, it is advisable to apply as a coagulant the PIX 113 of iron content equal to 11,8% [2]. It should be emphasized that the application of volumetric coagulation process will at the same time cause considerable reduction of total phosphorus concentration.

High efficacy of volume coagulation process, particularly in relation to organic carbon compounds, makes it practically impossible to remove nitrogen compounds without provision of external source of carbon; however – as it has been shown previously – it is not necessary for sewage treatment plants serving up to 10 000 inhabitants and sending their treated effluents to lotic waters.

Further biological sewage treatment, limited to additional removal of organic carbon compounds can be realized with the use of either trickling biofilters or activated sludge facilities – most often SBR-type reactors. While choosing a solution for the biological part one needs to take into account not only the costs of implementation, but also - or maybe first of all - the exploitation costs. Assuming such approach, the biological biofilters are preferred.

During the biological sewage treatment a surplus sludge results, which – altogether with the preliminary one – should be sent to sludge tank where these two types of sludge will have been mixed. This mixture of sludge can be dehydrated in the water treatment plant or it can be transferred to the closest treatment plant of bigger size. Dehydration facilities that can be employed in smaller construction are suck filling machines; while in bigger objects belt filter presses can be used. In view of characteristics of emerging sludge, one should consider necessity to use perform liquid sludge conditioning.

3. ASSUMPTIONS

While stating the dimensions of reactors that make up the series of types of mechanic-chemico-biological treatment plants, the following input data was assumed.

A. Unit wastewater flow [m^3/PE·d, m^3/PE·h]

- average for 24 hours $q_{d\_avg} = 0,12$ m^3/PE·d
- maximum for 1 hour $q_{h\_max} = 0,012$ m^3/PE·h

B. Unit contamination loading [g/PE·d]

Contamination ratios	Raw wastes	Chemically treated effluents
COD	120	24
BOD_5	60	15
Total suspended solids	70	14

C. Quality of treated effluents [g/m^3]

- COD ≤ 150 g/m3,
- BOD5 ≤ 25 g/m3,
- Total suspended solids ≤ 35 g/m3,

D. Required treatment performance parameters [%]

- COD → 85 %,
- BOD5 → 95 %,
- Total suspended solids → 94 %,

E. Unit contamination loading in treated effluents [g/PE·d]

- COD → 18 g/PE·d,
- BOD5 → 3 g/PE·d,
- Total suspended solids → 4,2 g/PE·d,

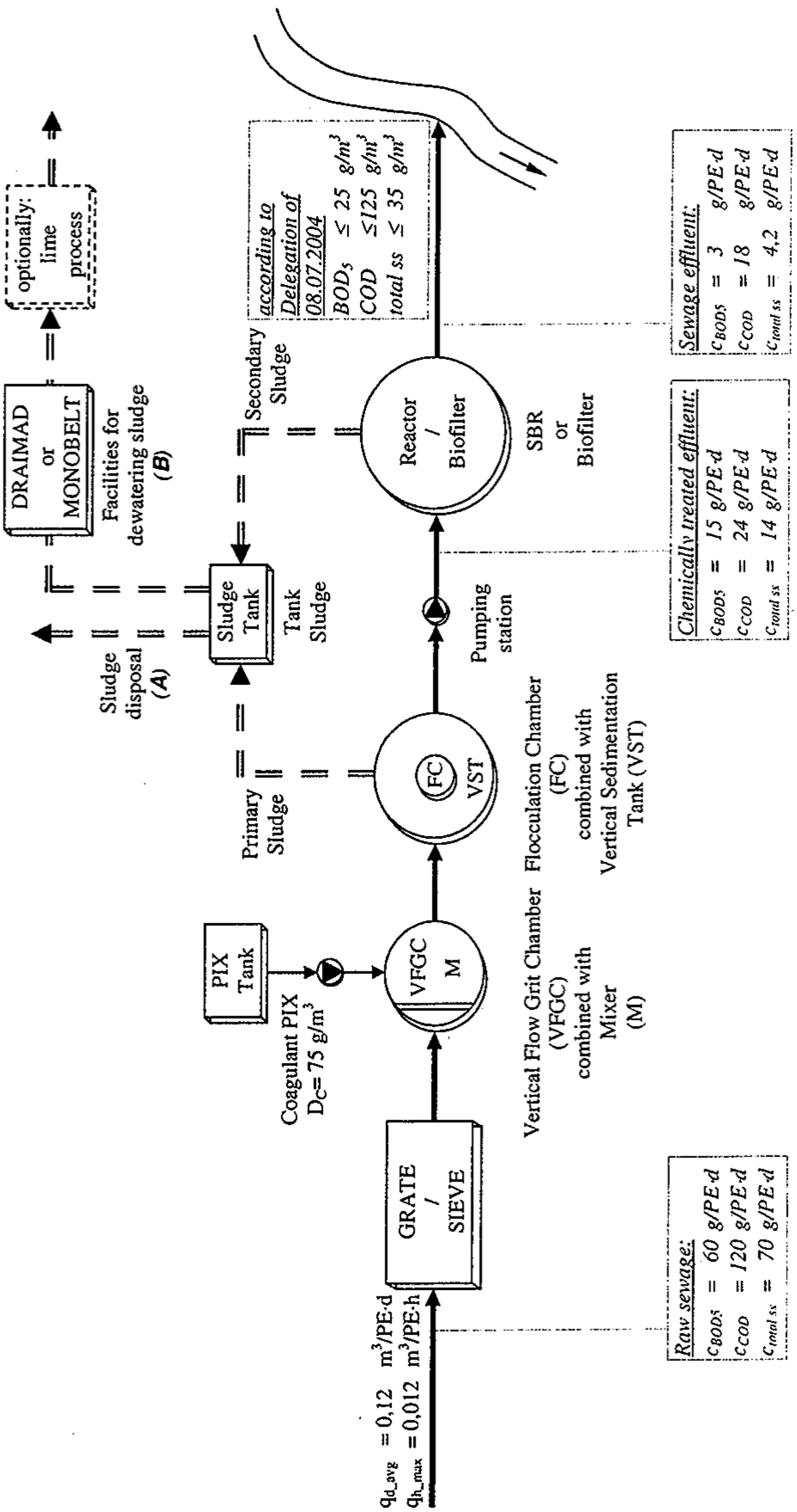

Diagram 1. A scheme of a chemico-biological waste treatment plant for PE ≤ 10 000

4. CHARACTERISTICS OF SEWAGE TREATMENT FACILITIES

As it has been already mentioned, the process of volumetric coagulation covers rapid mixing (1 minute), flocculation (20 minutes) and sedimentation (1 hour). As the mixer serves vertical flow grit chamber of a diameter between 0,6 m (for PE = 1 000) and 1,8 m (for PE = 10 000) and the height of flow part equal to 0,75 to 0,80 m, respectively. It can be assumed that the unit capacity of flow part of the sedimentation tank, related to the maximum hourly flow, will be equal to: v_{PE} = 0,0002 m^3/PE = 0,2 dm^3/PE (this volume does not cover the sedimentation part). The flocculation chamber with spiral vortex water movement has a diameter between 1,3 m and 2,9 m and a height of 4,0 m. For the sewage detention time equal to 20 minutes and the maximum flow per hour, the unit capacity of the flocculation chamber will amount to v_{FC} = 0,004 m^3/PE. With regard to the vertical sedimentation tank jointed with flocculation chamber, the unit volume for 1hour of detention time and maximum wastes flow will be equal to v_{VST} = 0,012 m^3/PE (the sedimentation part is excluded). Therefore, one can conclude that the unit net volume of the facilities used in the volumetric coagulation process will come down to:

$$v_{VC} = 0{,}0002 + 0{,}0040 + 0{,}0120 = 0{,}0162\ m^3/PE$$

at the total sewage detention time Σt = 81 minutes.

One can relate the above ratio to the average 24 hour wastes volume; then its value will be equal to v_Q = 0,135 $m^3/(m^3/d)$. The value of the v_{VC} can be also attributed to the size of the BOD_5 load that is removed in result of chemical treatment. In such a case the ratio will amount to $v_{BOD5\ disposal}$ = 0,00032 m^3/(g $BOD_{5\ disposal}$/d).

In treatment plants serving between 2 000 and 9.999 inhabitants, the consumption of coagulant PIX-113 will range between 9 kg/d and 90 kg/d. For the net price of coagulant equal to 300 PLN/ton, the daily cost of coagulant consumption will vary between 2,8 PLN/day for treatment plants of the PE =2 000 and 28 PLN/day for those with PE = 9.999. Unit costs of coagulant will be merely 0,0225 PLN/m^3. These costs constitute from 1 % to 2% of the average unit exploitation costs. The National Bank of Poland average exchange rate as of July 18, 2005 was 1 EUR = 4,1587 PLN.

During the preliminary chemical treatment of wastes some preliminary sludge will emerge of its unit dry matter being g_l = 56 g s.m./PE·d. Assuming the sludge hydration to be W_l = 97,5%, the unit volume of sludge will be equal to v_{VSTl} = 2,24 dm^3/PE·d. In effect, the daily amount of sludge for the PE = 9.999 inhabitants will be 2,24 m^3/d and for the PE = 9.999 – 22,4 m^3/d.

The biological waste treatment plant can be realized with the use of either trickling biofilters or Sequencing Batch Reactors.

The volume of the trickling biofilter plena depends on the load of plena's volume with the organic load. In line with the Rincke's equation, the biofilter's volume burden can be derived from the formula [3]:

$$A = \frac{0{,}93 - \eta_b}{0{,}17} \ [\mathrm{kg\ BOD_5/m^3 \cdot d}]$$

where: η_b – required performance efficiency of the trickling biofilters in relation to BOD_5.
Since η_b = (125-25):125 = 0,8 the burden A cannot exceed 0,765 kg BOD_5/m^3 d or 765 g $BOD_5/m^3 \cdot d$.

The unit load, expressed by BOD_5 that enters the trickling biofilter is equal to 15 g BOD_5/PE·d. Thus, without accounting for waste recirculation, the unit volume of plena will amount to:

$$v_{PV} = \frac{15}{765} \cong 0{,}02 \ \mathrm{m^3/PE}.$$

Based on the above, the required volume of plena should not be smaller than 20 m^3 for 1 000 PE and 200 m^3 – for 10 000 PE. Taking into account the wastes recirculation that results in dilution of wastes and bearing in mind the required increase of hydraulic load of biofilter's surface, trickling biofilters of BIOCLERE type were chosen for waste treatment plants of up to 4 000 PE. For treatment plants of up to 1 000 PE one can use trickling biofilter BIOCLERE B 150, for those up to 2 000 PE – BIOCLERE B 350 and for those up to 4 000 PE – two biofilters BIOCLERE B 350. In the case of larger waste treatment plants some individually projected trickling biofilters were used; however the plena's height in all of them was 3,6 m and the diameter ranged: 6,2 m (6 000 PE), 7,0 m (8 000 PE) and 8,0 m (10 000 PE). In the waste treatment plants of above 4 000 PE, the biofilter will cooperate with the secondary vertical settlement tank. Assuming the sewage detention time equal to 2 hours in relation to the average daily flow and considering a 50% recirculation, the unit settlement tank's volume is going to be equal to:

$$v_{SVST} = 0{,}015 \ \mathrm{m^3/PE}.$$

This volume does not account for the sludge part f the settlement tank.

Wastes are distributed to trickling biofilter by pumps built in the structure of BIOCLERE or by pumps located in a separated pump station working with the efficiency $1{,}5 \cdot Q_{h\_max}$.

Finally, taking into account chemico-biological setup of a waste treatment plant that uses trickling biofilters, a unit net capacity cannot be smaller than:

$$\Sigma v_{PV} = 0{,}0162 + 0{,}0200 + 0{,}0150 = 0{,}0512 \ \mathrm{m^3}.$$

With regard to SBR-type reactors, it was assumed that they will work in the setup with simultanous aerobic sludge digestion. This is related to preserving the sludge's age at the level not lower than AS = 25 days [4].

Following the guideline ATV A131P [4], a unit surplus sludge increase at the 0,93 concentration ratio of total suspended solids to BOD_5 will be equal to Δm = 0,86 (kg dry mass)/kg BOD_5. Therefore, the activated sludge load should not be higher than:

$$A' = \frac{1}{AS \cdot \Delta m} = \frac{1}{25 \cdot 0{,}86} = 0{,}047 \text{ kg BOD}_5\text{/(kg dry mass)}\cdot\text{d}$$

Since the unit contamination load in the wastes sent to the biological part is 15 g BOD_5/PE·d, therefore the unit capacity of the SBR-type reactor at the sludge concentration assumed to be Z = 3,5 (kg dry mass)/m^3 will be equal to

$$v_{SBR} \frac{0{,}015}{0{,}047 \cdot 3{,}5} = 0{,}09 \text{ m}^3\text{/PE}$$

which is the value two times higher than Σv_{PV}.

The v_{SBR} ratio can be decreased only if one resigns from simultanous aerobic sludge digestion. Under such scenario, the required age of sludge is AS = 4 days, the unit surplus sludge increase Δm = 1,05 (kg dry mass)/kg BOD_5 and, in effect, the activated sludge load is 0,24 kg BOD_5/(kg dry mass)·d. This implies the unit reactor volume value (at Z = 3,5 kg dry mass/m^3) being:

$$v_{SBR} \frac{0{,}015}{0{,}24 \cdot 3{,}5} = 0{,}0178 \text{ m}^3\text{/PE.}$$

For such solution, the summary unit volume should be not lower than:

$$\Sigma v_{SBR} = 0{,}0162 + 0{,}0178 = 0{,}034 \text{ m}^3\text{/PE}$$

It is worth mentioning that giving up of preliminary chemical treatment results in unit volumes of biological reactors being not lower than:

- in the case of the trickling biofilters framework ΣvZB = 0,075 m3/PE without preliminary sedimentation tank and ΣvZB =0,093 m3/PE with the preliminary sedimentation tank,
- in the case of frameworks with SBR biological reactors and simultanous aerobic sludge digestion ΣvZB = 0,408 m3/PE,
- in the case of frameworks with SBR biological reactors, but without simultanous aerobic sludge digestion ΣvZB = 0,082 m3/PE.

Comparing the variant that employs preliminary chemical treatment with the one without such a treatment, one can easily see sharp advantage of the former, i.e. the scenario using the preliminary volume coagulation.

During the biological waste treatment the secondary sludge will come out. Its unit dry mass and unit volume will be:

- in the case of the trickling biofilter framework g2 = 11,25 (g dry mass)/PE·d,
  vOS2 = 0,45 dm3/PE·d,
- in the case of frameworks with SBR biological reactors and simultanous aerobic sludge digestion g2 = 12,9 (g dry mass)/PE·d, and vOS2 = 1,6 dm3/PE·d,
- in the case of frameworks with SBR biological reactors, but without simultanous aerobic sludge digestion g2 = 15,75 (g dry mass)/PE·d, and vOS2 = 2 dm3/PE·d.

Both preliminary and secondary sludge will be directed to the sludge tank, equipped with an agitator so that its homogenous structure could be created. So prepared, the sludge is then sent to the dehydration in result of which its hydration will fall to approximately 80÷85%. Before using the sludge for non-industrial purposes, it should undergo a process of sludge conditioning. As one of the variants, one can also consider transporting the dehydrated sludge to the nearest treatment plant where it will undergo the process of drying or processes of drying and combustion.

5. FINAL CONCLUSIONS

1. Use of chemico-biological waste treatment plants can have competitive edge over biological plants when nitrogen removal is not necessary and also – to much less extent – in the case of phosphorus.
2. The unit net capacity of the facilities, for discussed in the paper biological waste treatment solutions, is in the range of 0,034 ÷ 0,1062 m^3/PE for the variant of preliminary chemical waste treatment and in the range of 0,082 ÷ 0,408 m^3/PE for the variant with no preliminary chemical treatment,
3. High efficiency of waste treatment in effect of preliminary chemical treatment is feasible when using volume coagulation with rapid 1 minute mixing, 20 minutes of flocculation and 1 hour of sedimentation. The high treatment result is achieved while dosing PIX-113 coagulant with the dose not exceeding 75 g/m^3.

REFERENCES

1. Delegation of Minister of Environment of 8 July 2004 on the conditions that must be met when disposing waste to waters or to ground and on substances particularly hazardous to the water environment [Rozporządzenie Ministra

Środowiska z dn. 8 lipca 2004 r., w sprawie warunków, jakie należy spełnić przy wprowadzaniu ścieków do wód lub do ziemi oraz w sprawie substancji szczególnie szkodliwych dla środowiska wodnego], Dz. U. Nr 168, Poz. 1763,
2. Heidrich Z.: *Technological and economical aspects of using various coagulants in the process of preliminary volumetric coagulation* [Aspekty technologiczno-ekonomiczne stosowania różnych koagulantów w procesie wstępnej koagulacji objętościowej], Gaz, Woda i Technika Sanitarna Nr 1/2005, pp. 24÷29,
3. Roman M.: *Sewerage system*, Vol. 2 – Sewage Treatment [Kanalizacja. Tom 2 – Oczyszczanie ścieków], Arkady, Warsaw 1986,
4. Guideline ATV – DVWK – A131P. *Statement of dimension of single-stage sewage treatment plants with activated sludge* [Wytyczna ATV – DVWK – A131P. Wymiarowanie jednostopniowych oczyszczalni ścieków z osadem czynnym] (May 2000), Wydawnictwo Seidel-Przywecki, Warsaw 2001.

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Streszczenie

W oczyszczalniach ścieków obsługujących jednostki osadnicze zasiedlone przez nie więcej niż 10 000 mieszkańców i nie odprowadzających ścieków oczyszczonych do wód stojących, nie jest wymagane usuwanie związków azotu i fosforu. Istnieje zatem możliwość ograniczenia zakresu oczyszczania ścieków do dwóch wymagań: obniżenia BZT_5 i stężenia zawiesin ogólnych. Daje to możliwość zastosowania innego rozwiązania technologicznego w takich oczyszczalniach ścieków. W takim rozwiązaniu w bardzo istotnym stopniu wykorzystuje się wstępne chemiczne oczyszczanie, które ogranicza w znacznym stopniu wielkość reaktorów biologicznych. Takie podejście ma uzasadnienie nie tylko techniczne ale przede wszystkim ekonomiczne.