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EFFICIENCY OF WASTEWATER TREATMENT FOR MICROBIOLOGICAL CONTAMINANTS IN THE INITIAL STAGE OF A PLANT-SOIL TREATMENT PLANT'S OPERATION

Krzysztof Kuczewski, Joanna Kercel-Cwalińska, Edmund Solecki, Iwona Nowak
Institute of Agricultural Building, Agricultural University, Wrocław, Poland

ABSTRACT

The article presents research results gained when purifying living – economic sewage in plant – soil water treatment of 24 hour flow capacity of 110 m^3.

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Site surveys were conducted in the period of November – December 1997. Purifying effectiveness was assessed for chemical contamination indicators: $ChZT_{Cr}$, BZT_5, general nitrogen, ammonia nitrogen, phosphoms, water slurry and a microbiological indicator – Coli test. The research proved that the treated sewage carried to the receiver was in the water cleanness class for: BZT_5 in I, ChZT in I, general nitrogen in I, ammonia nitrogen i I and II, phosphoms in I and II, water slurry in I and III. The Coli test was in the range from 0.0007 to 0.007. The achieved results prove that a high treatment effectiveness in water – treatment plants of this kind can be gained also in the low – temperature period.

Key words: sewage, plant – soil water – treatment plant, treatment effects

INTRODUCTION

Some environmental engineers share an unfounded opinion that the efficiency of plant-soil treatment plants in purifying wastewater does not comply with the current regulations, especially in the winter half-year[12].There is a decree (annex 2) that specifies the highest permissible indexes of contamination in sewage released into water and soil. It does not specify, however, permissible levels of bacteriological contaminants. Annex 1 of the decree, referring to the contamination of surface waters divided into three classes of purity, at item 57 mentions faecal coliforms and values are given with reference to the class of water purity.Table 1 presents some chosen values of contamination indexes for surface waters and the highest permissible values in sewage released into water and soil. Data included in Table 1 will be useful for interpreting research results.

Table 1. Chosen contamination indexes for surface waters and highest permissible values for sewage released into water and soil

Index	Unit	Class of water purity			Sewage
		I	II	III	
BOD_5	mg O_2/dm^3	≤ 4	≤ 8	≤ 12	30.0
COD_{Cr}	mg O_2/ dm^3	≤ 25	≤ 70	≤ 100	150.0
Ammonium nitrogen	mg N_{NH4}/ dm^3	≤ 1	≤ 3	≤ 6	6.0
Kjeldahl nitrogen	mg N/ dm^3	≤ 5	≤ 10	≤ 15	30.0
Total phosphorus	mg P/ dm^3	≤ 0.1	≤ 0.25	≤ 0.4	5.0
Total suspended solids	mg/ dm^3	≤ 20	≤ 30	≤ 50	50.0
Faecal coli titre	-	≥ 1	≥ 0.1	≥ 0.01	-

The newly-constructed plant-soil treatment plant in the village of Brzezno, designed by K. Kuczewski and J. Paluch, is the first of its kind ever built in Poland. Its main function is the treatment of sewage rather than its agricultural application. The designers went into a lot of trouble to obtain the consent for construction and for releasing treated sewage. Those difficulties resulted from the lack of recorded research results connected with the efficiency of sewage treatment in similar conditions in Poland. As there are no formal requirements regarding the bacteriological quality of treated sewage there are no systematical studies of the efficiency of eliminating bacteriological contaminants in the treatment process. According to Imhoff [8] the highest index of bacteria removal in the treatment process can be achieved by the activated sludge method or by treatnig sewage in soil plants (Table 2).

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Table 2. Efficiency ocf different ways of sewage treatment (according to Imhoff) [8]

Way of treatment	BOD_5 %	Reduction of suspended solids, %	Bacteria %
1.Fine sieves	5-10	2-20	10-20
2. Chlorination of raw sewage or of sewage from primary settling tanks	15-30	-	90-95
3. Primary settling tanks	25-40	40-70	25-75
4. Floculation tanks	40-50	50-70	-
5. Coagulation	50-85	70-90	40-80
6. Highly-loaded deposits	65-90	65-92	70-90
7. Low-loaded deposits	80-95	70-92	90-95
8. Highly loaded activated sludge	50-75	80	70-90
9. Low-loaded activated sludge	75-95	85-95	90-98
10. Soil filters	90-95	85-95	95-98
11. Chlorination of biologically treated sewage	-	-	98-99

Those two methods make it possible to obtain a very considerable decrease in BOD_5. Further lowering of bacteria levels in treated sewage can be achieved through disinfection, e.g. chlorination or exposure to UV. One should realise, however, that indexes of contamination lower than those mentioned in the Decree [12]do not mean that the sewage is safe for people.

For sanitary and hygienic control of water and soil indicator bacteria are used, e.g. *E. Coli* which, as saprophytes, live in human and animal digestive systems. Their presence in water or sewage suggests there is a possibility of contamination with faecal matter.

Considerable numbers of *E. Coli* in water (sewage) also suggest a high probability of contamination with pathogenic microorganisms.

The purpose of research was to assess the efficiency of sewage treatment in a plant-soil treatment plant in reference to bacteriological contaminants.

The most probable number of *E. Coli* and coli titre in raw and treated sewage from different parts of the plant were used as indicators. For assessing general efficiency of sewage treatment in this type of treatment plant such indexes of chemical contamination as COD_{Cr}, BOD_5, Kjeldahl nitrogen, ammonia nitrogen and total suspended solids were also considered.

The studied treatment plant was in the initial stage of operation. The research period (November, December 1997) is considered to be the time when microorganisms participating

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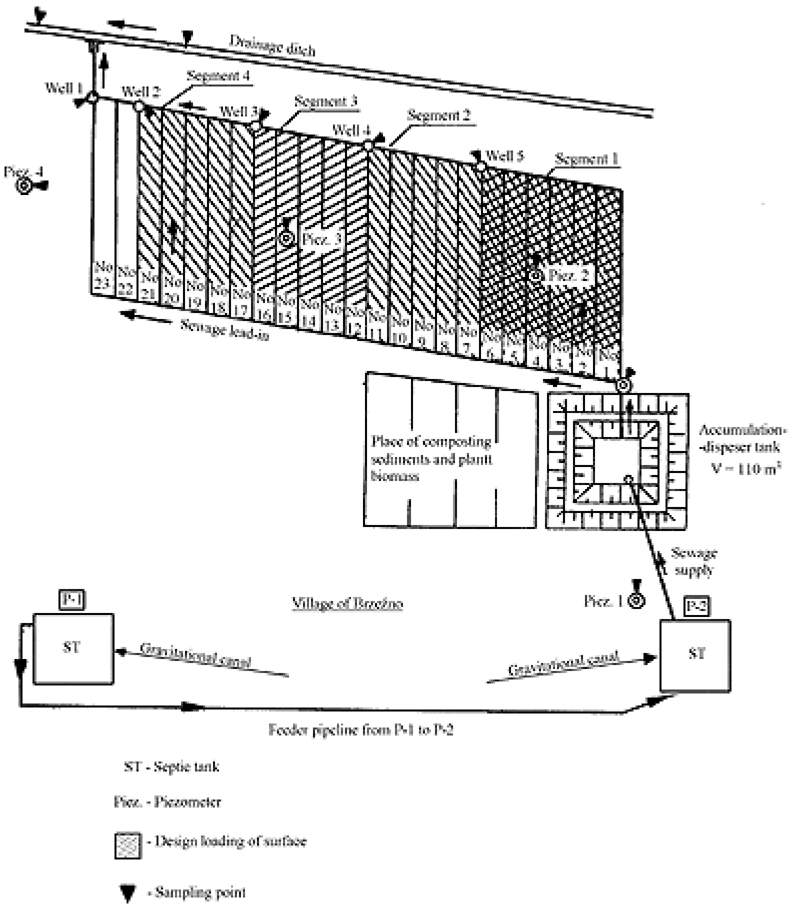
in the decomposition of sewage are less active, which results in lower efficiency of the treatment.

PLACE OF RESEARCH

When field tests were carried out the plant-soil treatment plant in Brzeźno near Prusice was in its initial stage of operation. It processes sewage from the sewered part of Brzeźno collected in two septic tanks. A flow chart of the sewage system and the treatment plant in Brzeźno are shown in Fig.1. Sewage from one part of the village is gravitationally collected in a septic tank (P-1) and pumped from the other part of the village (from tank P-1) to tank P-2. All sewage is pumped from tank P-2 to the accumulation-dispenser tank which has a capacity of 110 m^3, equal to the volume of sewage produced in a village settlement in 24 hrs. After the accumulation-dispenser tank is filled by means of a syphon system, which takes about one hour, the sewage automatically flows into a distributor and then into one of 21 units for collecting sewage. The surface of wetlands was drained, sown with a mixture of grass and planted with poplar cuttings. When sewage has permeated through the biologically active layer of the soil it is collected by a drainage system and directed to a nearby ditch. The drainage system is situated 1metre below the surface. The plant's subsurface base is built of quarternary deposits consisting of yellowish-gray medium and coarse sands constituting a continuous layer that changes in depth from 1.0 to 1.5 m. Below, there is cohesive soil, i.e. clays, fine clays and sand clays.

Fig. 1. Diagram of Brzeźno plant-soil treatment plant in Brzeźno near Prusice



The treatment plant's area is adjusted to the planned diurnal volume of sewage, i.e.110 m^3 and equals 2.30 ha. The wetlands were so designed that the diurnal volume of sewage is collected by a single unit where it stays for no longer than 24 hrs. Theoretically the rotation of inflows occurs every three weeks, so one unit is fed with sewage every 21 days. Should such needs arise, it is possible to decrease the inlowing dose by shortening the rotation time to 7 - 10 days and simultaneous feeding of two or three units. The wetlands area is divided into four segments and sewage wells have been installed (Fig.1), which makes it possible to assess treatment efficiency in each individual segment. The area of each unit equals 1150 m^2 and maximum concentration of treated sewage flowing out of the unit happens ca 2.5 hrs after the inflow.

Maximum yearly design dose of sewage equals 1730 mm, i.e.17300 m^3/ha. In Nov. 1996, due to lower than expected amount of sewage, a decision was made to use the first segment of the plant, as far as Well 5 (Fig.1). In the winter half-year that part of the plant was loaded with sewage according to the technical design. Any surplus of inflowing sewage was directed to the other part. Total sewage fed into particular segments until the date of research is shown in Table 3.

Table 3. Total volume of sewage in m^3 taken by particular segments of the treatment plant until the day of research

No	Segment	Date of research	
		09.11.1997	02.12.1997
1	1	8360	8690
2	2	5060	5280
3	3	4070	4290
4	4	3795	4125
5	∑ 1+2+3+4	**21285**	**22385**

METHOD AND RESULTS

Field tests of the efficiency of sewage treatment were carried out in a plant-soil treatment plant in its normal operation. Samples for chemical and bacteriological analyses were taken at the following points:

- Well 5 - treated sewage coming from the first segment of the plant,
- Well 4 - a mixture of treated sewage from segment 1 and 2,
- Well 3 - a mixture of sewage from segments 1, 2 and 3,
- discharge outlet to drainage ditch.

Samples of raw sewage were taken from a well situated behind the accumulation -dispenser tank.

Chemical analyses of raw and treated sewage were carried out in the Institute of Environmental Studies and complied with the current norms. Bacteriological analyses of *E. Coli* numbers and coli titre were made at the Microbiology Department of Agricultural University in Wroclaw. Samples of raw and treated sewage for chemical and bacteriological tests were taken simultaneously. This was done twice, i.e. on Nov.9, 1997 and Dec.12, 1997. On Nov.9 air temperature was 6.2 °C, the temperature of raw sewage 11.6 °C and of treated sewage leaving the plant 9.6 °C, and on Dec.12 3.0 °C, 6.8 °C and 5.6 °C respectively. Bacteriological tests showed that the numbers of saprophytic *E. Coli* in raw sewage sampled at different times varied from $4 \cdot 10^6$ to $4.5 \cdot 10^8$ and from $3.8 \cdot 10^6$ to $4 \cdot 10^8$ for faecal *E. Coli*. Numbers of coliforms checked at different points of the plant were considerably decreased (Table 4). Numbers of faecal *E. Coli* in treated sewage leaving the plant changed from 140 to 1500, which translated into coli titre varied from 0.009 to 0.0007 (Table 5). A decreased value of coli titre was obtained for higher numbers of *E. Coli* in raw sewage. The analysis of test results from different parts of the plant shows considerable fluctuations in th numbers of *E. Coli* and in coli titre. Those changes were affected by the location of units which were fed with sewage right before the tests. The highest numbers of *E. Coli* in treated sewage occur in the first phase of sewage outflow after feeding the unit.

Table 4. Microbiological analysis of raw sewage and sewage treated in plant-soil treatment plant in Brzeźno (numbers of *E. Coli*/cm^3)

Place of sampling treated sewage	Test date			
	09.11.1997		02.12.1997	
	E. Coli saprophytic	E. Coli faecal	E. Coli saprophytic	E. Coli faecal
Raw sewage	4 000 000	3 800 000	$4.5 \cdot 10^8$	$4.0 \cdot 10^8$
Well 3	900	400	95	95
Well 4	150	40	95	45
Well 5	1100	600	150	45
Discharge outlet	200	140	11000	1500

Table 5. Coli titre for raw and treated sewage in plant soil treatment plant

Place of sampling treated sewage	Test date			
	09.11.1997		02.12.1997	
	Coli titre saprophytic	Coli titre faecal	Coli titre saprophytic	Coli titre faecal
Raw sewage	$3 \cdot 10^{-7}$	$3 \cdot 10^{-7}$	$2 \cdot 10^{-9}$	$3 \cdot 10^{-9}$
Well 3	0.0011	0.0025	0.0105	0.0105
Well 4	0.0067	0.025	0.0105	0.021
Well 5	0.0009	0.0017	0.0067	0.021
Discharge outlet	0.005	0.007	0.0001	0.0007

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Simultaneous to microbiological tests were studies of treatment efficiency for some chosen indexes of chemical contaminants. They showed that indexes for BOD_5 and COD_{Cr} were very low in all segments of the plant including the discharge outlet of sewage treated in the tested plant (Table 6). Also analyses of treated sewage that included biogenic indicators, i.e. Kjeldahl nitrogen, ammonium nitrogen and phosphorus, showed that treated sewage contained insignificant amounts of those compounds that were much below the permissible values, Table 1 [12].

Table 6. Chemical analysis of raw and treated sewage in Brzeźno treatment plant

Place of sampling treated sewage	Test date			
	09.11.1997		02.12.1997	
	BOD_5	COD_{Cr}	BOD_5	COD_{Cr}
	$mg\ O_2/dm^3$		$mg\ O_2/dm^3$	
Raw sewage	168.0	350.8	208.0	338.8
Well 3	0.6	10.6	3.9	12.3
Well 4	1.4	12.8	5.2	15.2
Well 5	0.8	9.4	3.9	12.7
Discharge outlet	1.2	14.9	2.4	11.4

Results of raw and treated sewage analyses are shown in Tables 7 and 8. Table 8 additionally shows suspended solids in raw and treated sewage flowing out of different segments of the plant.

Table 7. Chemical analysis of raw and treated sewage in Brzeźno treatment plant (Kjeldahl nitrogen, ammonium nitrogen)

Place of sampling treated sewage	Test date			
	09.11.1997		02.12.1997	
	Kjeldahl nitrogen	Ammonium nitrogen	Kjeldahl nitrogen	Ammonium nitrogen
	$mg\ N/dm^3$		$mg\ N/dm^3$	
Raw sewage	96.4	80	71.2	59.5
Well 3	1.5	1.04	1.65	0.59
Well 4	1.42	1.08	1.18	0.59
Well 5	1.2	0.94	2.55	0.66
Discharge outlet	2.01	1.04	1.38	0.63

Table 8. Chemical analysis of raw and treated sewage in Brzeźno treatment plant (total phosphorus, suspended solids)

Place of sampling treated sewage	Test date			
	09.11.1997		02.12.1997	
	Total phosphorus	Suspended solids	Total phosphorus	Suspended solids
	mg P/dm^3	mg/dm^3	mg P/dm^3	mg/dm^3
Raw sewage	12.5	288	11.8	102
Well 3	0.17	68	0.16	30
Well 4	0.16	19	0.17	12
Well 5	0.23	70	0.12	24
Discharge outlet	0.14	46	0.06	8

DISCUSSION

Assessing microbiological efficiency of sewage treatment in a plant-soil treatment plant one should also analyse the efficiency of the chemical contaminants removal, without which the assessment may not be valid. Tests carried out in late autumn and early winter showed that the studied plant performed unususlly well in removing microbiological contaminants (coli titre). Treated sewage coming from different parts of the plant revealed very low numbers of *E. Coli*. Treatment efficiency resulting in lower numbers of saprophytic and faecal coliforms reached almost 100% (Table 9). The authors do not know of any sewage treatment plant that would be so efficient.

Table 9. Efficiency of microbiological treatment of wastewater (coli titre) in Brzeźno treatment plant [%]

Place of sampling treated sewage	Test date			
	09.11.1997		02.12.1997	
	Coli titre saprophytic	Coli titre faecal	Coli titre saprophytic	Coli titre faecal
Well 3	99.973	99.988	99.99999	99.99999
Well 4	99.9955	99.9988	99.99999	99.9999
Well 5	99.9666	99.9824	99.9955	99.9995
Discharge outlet	99.994	99.9957	99.921	99.9996

According to Boćko and Kutera [9] the highest reduction in *E. Coli* numbers can be obtained in constructed wetlands (Table 10).

Table 10. Decrease in bacteria in municipal wastewater after soil filtration [9]

Place and way of irrigation	Width of filtering soil stratum /cm/	Bacteria reduction %	
		in total	*E. Coli*
Irrigation fields on sandy soil permanently flooded as lagoons	120	95-97	99.9
Soil filters on loose sand permanently flooded	120	90-99	99.9
Disposal fields on loose sand fed with high doses of sewage /500 mm/	120	85-99	99.0
Irrigation fields on clay with under-sand, highly-loaded	120	94-99.6	99.9
Irrigation fields on different soils	100	90-97	99-99.9
Irrigation fields on sandy soil fed with small doses	100	99-99.9	99.99
Irrigation fields with sprinkling system on clay sand	25 40 60	93-99 96-99.6 97-99.9	99.9 99.9 99.9

Bacteriological comparison of sewage treated in different parts of the plant (Table 11) makes it clear that as far as sanitary requirements are concerned it represents class 3 of water purity or slightly exceeds the borderline values for this class. Referring sewage treated in a plant-soil treatment plant to classes of water purity and considering indexes of aerobic contaminants and biogenic compounds one can conclude that for BOD_5 treated sewage, independent of the part of the plant, represents class 1 with the purifying effect of 97.5% to 99.6% (Table 12). For COD_{Cr} sewage leaving the plant also represented class 1 and the purifying effect varied from 95.5% to 97%. The same was true for the Kjeldahl nitrogen content. Treatment efficienfy for this contamination index varied from 96.4% to 98.8% (Table 13). Ammonium nitrogen content was within permissible limits for classes 1 and 2. In comparison to raw sewage, Kjeldahl nitrogen was lowered by 98.6% to 99%.

Table 11. Sewage effluent in Brzeźno treatment plant compared to classes of water purity

Place of sampling	Test date			
	09.11.1997		02.12.1997	
	Coli titre faecal	Class of purity	Coli titre faecal	Class of purity
Well 3	0.0025	under class	0.0105	III
Well 4	0.025	III	0.021	III
Well 5	0.0017	under class	0.021	III
Discharge outlet	0.007	under class	0.0007	under class
Receiving body of water	0.0125	III	-	-

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Table 12. Efficiency of treatment for BOD_5, COD_{Cr} [%] and class of water purity as represented by treated sewage

Place of sampling treated sewage	Test date							
	09.11.1997				02.12.1997			
	BOD_5		COD_{Cr}		BOD_5		COD_{Cr}	
	class of purity	η %	class of purity	η %	class of purity	η %	class of purity	η %
Well 3	I	99.6	I	97.0	I	98.1	I	96.4
Well 4	I	99.2	I	96.4	I	97.5	I	95.5
Well 5	I	99.5	I	97.3	I	98.1	I	96.2
Discharge outlet	I	99.3	I	95.8	I	98.8	I	96.6

Table 13. Efficiency of treatment for Kjeldahl nitrogen, ammonium nitrogen [%] and class of water purity as represented by treated sewage

Place of sampling treated sewage	Test date							
	09.11.1997				02.12.1997			
	Kjeldahl nitrogen		Ammonium nitrogen		Kjeldahl nitrogen		Ammonium nitrogen	
	class of purity	η %	class of purity	η %	class of purity	η %	class of purity	η %
Well 3	I	98.4	II	98.7	I	97.7	I	99.0
Well 4	I	98.5	II	98.6	I	98.4	I	99.0
Well 5	I	98.8	I	98.8	I	96.4	I	98.9
Discharge outlet	I	97.8	II	98.7	I	98.1	I	99.0

High efficiency of treatment was also observed for total phosphorus with a decrease of 98.2% to 99.5% and water purity was comparable to classes 1 and 2 (Table 14).

Table 14. Efficiency of treatment for total phosphorus, suspended solids [%] and class of water purity as represented by treated sewage

Place of sampling treated sewage	Test date							
	09.11.1997				02.12.1997			
	Total phosphorus		Suspended solids		Total phosphorus		Suspended solids	
	class of purity	η %	class of purity	η %	class of purity	η %	class of purity	η %
Well 3	II	98.6	under class	76.4	II	98.6	II	70.6

Well 4	II	98.7	I	93.4	II	98.6	I	88.2
Well 5	II	98.2	under class	75.7	II	99.0	II	76.5
Discharge outlet	II	98.9	III	84.1	I	99.5	I	92.2

Phosphorus content in effluent varied from 0.14 to 0.06 mg P/dm^3.

Suspended solids in effluent complied with the requirements for classes 1 and 3. During the purification process the composition of suspended solids was changing. In raw sewage it was mostly of organic origin while in treated sewage mineral solids prevailed. Mineral suspended solids in treated sewage appeared mostly due to the washout of small particles from the soil.

The obtained results prove a very high efficiency of sewage treatment, which cannot be provided by treatment plants based on the active sludge or bacterial jelly methods. Treated sewage leaving the plant was comparable to water representing classes of purity from 1 to 3 with differences depending on the studied index. The numbers of *E. Coli* found in sewage treated in a plant-soil treatment plant can be obtained for sewage treated in a biological plant after exposure to UV.

Coliform numbers in treated sewage reach 10^4/cm^3. Fig.2 shows a typical decrease in coliform numbers in the process of wastewater treatment [4].

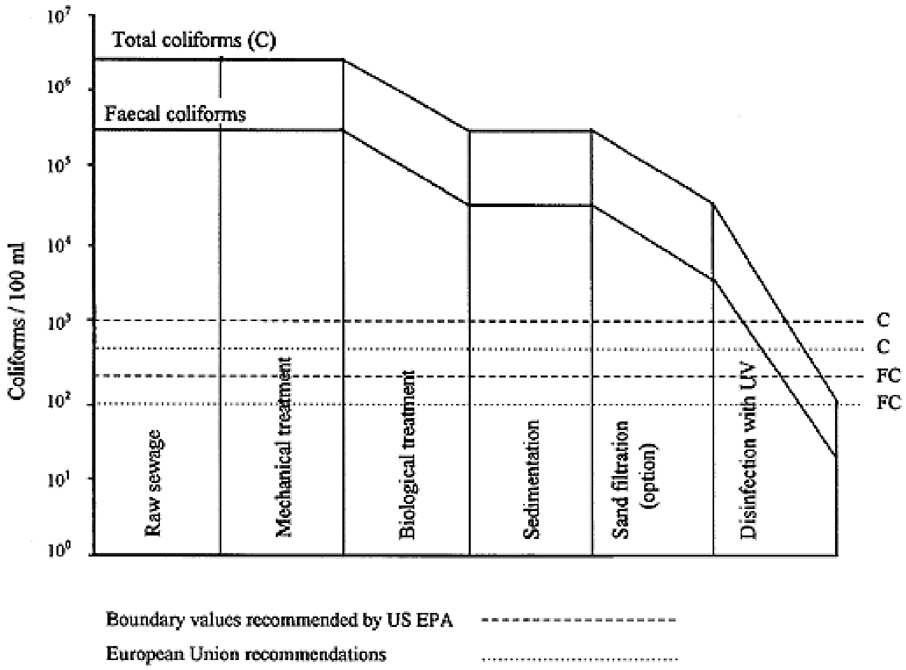

Fig. 2. Standard lowering of coliforms in wastewater during treatment processes [4]

One can ask here how it happens that wastewater is so efficiently treated in a plant-soil treatment plant. Firstly, wastewater is treated in the active stratum of the soil. A large part of decomposed chemical compounds in sewage is absorbed by root systems of grass and trees overgrowing the treatment plant's area. Secondly, the surface stratum of the soil is 'inhabited' by a vast number of 'local' microorganisms whose number depends on such factors as way of cultivating, dampness, soil structure, chemism, etc. Once new microorganisms that are found in raw sewage get introduced, antagonisms between them and the “local” soil microorganisms

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begin. According to Balicka [3] this antagonism results from changes in environmental reaction, the range of anaero-andaerobiosis and the production of antibiotic substances which are a survival weapon in the fight between saprophytes and pathogenic species. There is also a mutual dependence between plants and the soil microflora. A considerable growth of saprophytic microflora creates unfavourable conditions for the development of foreign microflora, e.g. in sewage. A very positive influence of rhizosphere on eliminating or preventing the growth of foreign microflora was also observed [1,2,3]. Studies by Balicka and Sobieszczański showed that an efficient retention of sewage microorganisms by the soil depends of the following:

1. Depth of soil stratum,
2. Soil structure,
3. Mechanical composition,
4. Amount and frequency of irrigation,
5. Soil dampness.

According to Boćko [5], the number of bacteria in 1g of dry matter in a meadow not fed with sewage does not exceed 1 million, but doubles after irrigating it with a single dose of sewage (30mm) and exceeds 7 million at the depth of 20 cm after feeding a triple dose of 90 mm. In his studies of in-depth feeding of crops with wastewater Marcilonek [10] proved that coli titre in underground water is much higher (10^{-2} - 10^{-4}) than in the sewage used for irrigation (10^{-5} - 10^{-6}).

Studies by Boćko and Paluch [6] concerning the effect of sewage on underground water in the area of Osobowice wetlands in Wrocław showed no sanitary or chemical contamination. Available results of studies by foreign researchers connected with the elimination of microbiological contamination mostly refer to constructed wetlands with reed beds [7,11]. According to different sources, such treatment allows an average decrease in faecal coliforms from 95.3% to 98.9%.

The analysed research results acquired in a fully-operational treatment plant prove a very high efficiency of sewage treatment. Tests were carried out towards the end of the start-up period of the plant. One can ask about the efficiency of sewage treatment during further operation. It can only be expected that with time it will stay similar to that achieved in tests. As such type of a treatment plant is the first one built in this part of Poland further systematic studies are required. They should also answer the question of the influence which treatment plants like this have on the environment and on underground water in particular.

CONCLUSIONS

The following can be concluded from the research:

1. A plant-soil treatment plant is highly efficient in lowering coli titre in treated sewage, which cannot be compared to any othertypes of treatment plants.
2. A very high microbiological efficienfy of sewage treatment was also reflected in an unusual lowering of aerobic and biogenic indexes.
3. The studies should be continued. This would allow, among other things, to assess the influence of the treatment plant on the environment, including underground water situated below it.

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Krzysztof Kuczewski, Joanna Kercel-Cwalińska, Edmund Solecki, Iwona Nowak
Institute of Agricultural Building,
Agricultural University
Pl. Grunwaldzki 24, 50-363 Wrocław, Poland

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