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# CHAPTER II

Marek Kalenik, Maciej Cieśluk

# SEWAGE TREATMENT IN GRAVEL WITH ASSISTING DOLOMITE LAYER

## Introduction

The sewage economy in numerous villages in Poland and small cities is not well organized. The most common method of removing sewage from apartment and farm buildings is collecting sewage in the septic tank, then transporting it in a sewage truck to a sewage treatment plant, sometimes on a field or to a ditch. Such a sewage system is expensive in the exploitation, the septic tanks are often leaky and improperly exploited. Sewages and sludge, carried away on field without disinfection, create a big sanitary risk because of the presence of pathogenic bacteria and eggs of parasites.

Expansion of the country water supply system and increase of the sanitary facilities standard in flats evoked the increase of the sewage amount in households. The construction of cumulative systems to collect and neutralize sewage is impossible in many cases because of buildings dispersion, disadvantages of the terrain topography and big investment costs. In these conditions a small sewage treatment plant can be an alternative.

Small sewage treatment plants on country areas are recommended to apply on terrains where the buildings are very dispersed, so the construction of sewage systems is economically ungrounded. Sewage can be carried away to ground if comes from detached houses, located outside of the underground water intake protection zones and when the quantity of sewage does not exceed 5,0 $m^3 \cdot d^{-1}$ (ROZPORZĄDZENIE MINISTRA ŚRODOWISKA [ORDER OF THE MINISTRY OF ENVIRONMENT] 2006). There is also assumed an optimal unit quantity of sewage on one inhabitant: in small settlement units (village) $q$ = 120 $dm^3 \cdot d^{-1}$ in big settlement units (city) $q$ = 200 $dm^3 \cdot d^{-1}$ (PN-EN 752-4, 2001).

The purpose of the elaboration is to assess the effectiveness of sewage treatment in the ground bed (gravel) with assisting layer (dolomite) under subsurface sewage disposal field.

## The small sewage treatment plants and technologies apply in them

On account of the applied technology of sewage treatment, small sewage treatment plants can be divided on (KALENIK 2007):

- soil treatment plants – where the sewage is initially treated in mechanical way in septic tanks and, as next, the sewage are cleaned thoroughly, directly in ground bed (subsurface sewage disposal field) or in filter layers made of ground material (sandy filter) (PN-EN 12566-3, 2007),

- soil-plant treatment plants - where the sewage is initially treated in mechanical way in septic tanks and, as next, the sewages are being cleaned thoroughly in filter layers made of ground with reed, willow or grass growing on the surface of them,
- container treatment plants - small containers gathered in blocks, basing on the technology of active sludge or bio-filter.

The small sewage treatment plants with subsurface sewage disposal field are being built in well permeable grounds (gravels, sands) where the maximum level of the ground water is at least 1.5 m below the sewage seepage level. (ROZPORZĄDZENIE MINISTRA ŚRODOWISKA [ORDER OF THE MINISTRY OF ENVIRONMENT] 2006). The purpose of this is to clean thoroughly the sewage in the aeration zone, to stop the bacteria and viruses as well as to prevent contamination of the natural environment. In fact, the small sewage treatment plants with subsurface sewage disposal field should be built on the areas where the distance between the sewage seepage level and maximum ground water level is at least 2.5 m. The recent investigations point that during the exploitation of subsurface sewage disposal fields, the humidity conditions of ground change within them depending on the sewage seepage method being used (KALENIK, BŁAŻEJEWSKI 1999, KALENIK 2002, KALENIK, KOZŁOWSKI 2007). Depending on the sort of ground, its hydraulic load by sewages and impervious layer floor inclination, the ground water level is raising up, reducing the real aeration zone (SROKA, KALENIK 1999, KALENIK 2000) in which occur the oxygen processes of thorough cleaning. Whereas the small sewage treatment plants with the sandy filter are being built in slightly permeable ground (clay, silt) or if the ground water level is shallow under the ground surface. Small container sewage treatment plants in the technology of active sludge or bio-filter can be applied independently of hydro-geological conditions or landform features of area.

The easiest and cheapest system is a septic tank cooperating with subsurface sewage disposal field. This system is easy in construction and exploitation, it does not require qualified service or technical and laboratory supervision. It can be operated by a household owner, appropriately trained.

A subsurface sewage disposal field is a device serving to introduce the sewage, initially treated in a septic tank, to ground. During filtering by natural layers of ground, the sewage are being cleaned in biological processes under the influence of oxygen bacteria and other microorganisms which take the oxygen from the ground air. Small solid and colloidal suspensions are being stopped on the surface of sand grains. Some part of sewage is being taken by plant roots, some raises toward the ground surface thanks to the ground capillarity and evaporates, the remaining infiltrates into ground waters. The arrangement of devices for the individual sewage disposal with subsurface sewage disposal field is showed in Figure 1. The sewage flows through a gravitational house sever (1) from the apartment building to the septic tank (2), where should be kept for ca. 2 - 3 days, but no less than 1 day. From the septic tank, the sewage flows to a distribution box (3) which directs them to a perforated distribution pipe (5), finished with ventilation pipes (4). Then, the sewage spills out in the sewage seepage bed (7) through the holes in perforated distribution pipes (5) and further infiltrates into the ground.

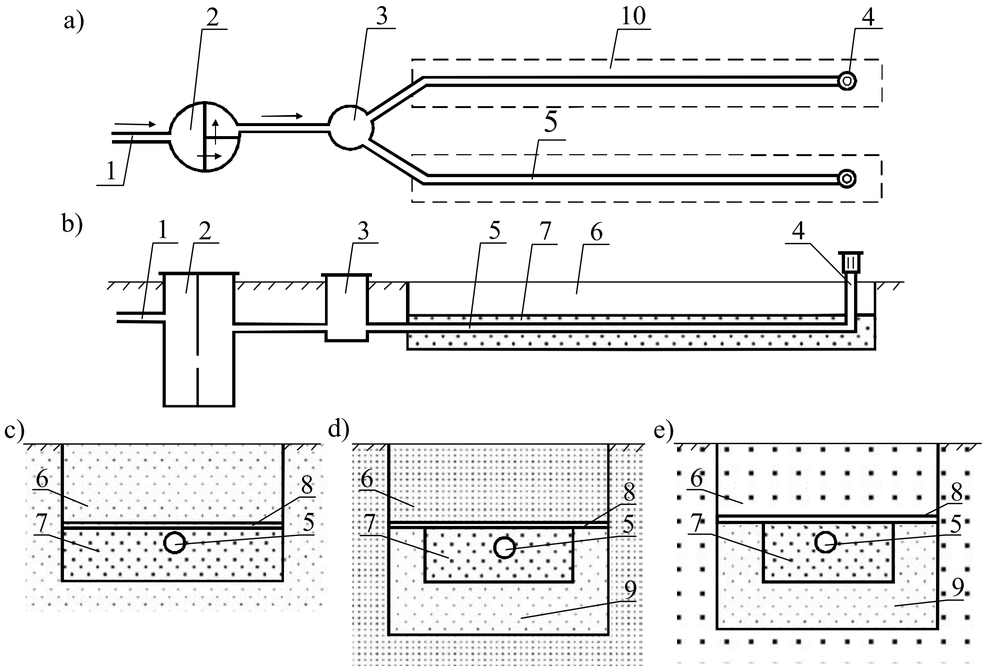


Fig. 1. Scheme of the subsurface sewage disposal field (KALENIK 2009): a) horizontal projection, b) longitudinal cross-section, c) cross-section of drainage in average-permeable ground, d) cross-section of drainage in slightly-permeable ground, e) cross-section of drainage in easily-permeable ground, 1- supplying sewage pipeline, 2-septic tank, 3-distribution box, 4-ventilation pipe, 5-perforated distribution pipe, 6-subsoil, 7-seepage bed, 8-barrier material, 9-assist layer , 10- sewage infiltration surface.

In the septic tank an initial mechanical sewage treatment occurs, which must reduce the value of $BOD_5$ at least of 20% and the content of solid suspension at least about 50% (ROZPORZĄDZENIE MINISTRA ŚRODOWISKA [ORDER OF THE MINISTRY OF ENVIRONMENT] 2006). It is so, because too big content of solid suspension in a filtering sewage accelerates a silting-up of the ground under subsurface sewage disposal field, what – as a result - diminishes the period of correct operation of the device. In the septic tank, there occur sedimentation and flotation processes stopping solid pollutants, as well as biological processes of anaerobic decomposition of sludge gathered at the bottom of the container. The general capacity of the septic tank cannot be smaller than 2.0 $m^3$ (PN-EN 12566-1:2004/A1, 2006). If the capacity is smaller than 4.0 $m^3$, two-chamber septic tanks should be used, whereas if greater - three-chamber, if septic tanks are not equipped with filter baskets. As a filling of the filter basket, a ceramist or pozzuolana is being used. In order to limit the suspension outflow from the septic tank, the bottom edge of the three-way pipe, the filter basket or the shield should be plunged in the sewage at 0.4 m. Once or twice a year the sludge gathered at the bottom of the container should be removed from the septic tank.

Perforated distribution pipes are made of stiff PVC pipes of the minimum internal diameter of 100 mm, in which round holes of the diameter 8.0 - 10.0 mm spaced in 20-cm intervals are bored. The slope of the distribution pipe is 5.0 - 10 ‰. The spacing of the pipes is assumed from 1.5 m to 2.0 m, and the arrangement depth of the pipes - 0.8 - 1.2 m. Length of the pipes should not exceed 20.0 m. To provide the ventilation of the seepage bed, ventilation pipes with the holes arose minimum 0.5 m above the level of the land are being installed on the ends of the distribution pipes (KALENIK 2009).

The seepage bed consists of breakstone or rinsed gravel of the diameter of 15.0 - 40.0 mm. The bed's thickness is equal 30.0 - 35.0 cm, its width - 50.0 - 120.0 cm. The separating layer (8, Fig. 1), protecting the seepage bed before silting, can be made of filtrating needled cloth or 5.0-cm layer of straw. (KALENIK 2009).

The construction of subsurface sewage disposal field in a low permeable ground or in ground containing considerable amounts of decay, hummus or peat should be avoided. After filtering in such bed, there remain some organic compounds in the sewage and moreover the drowning of the seepage bed occurs. This phenomenon should be avoided by decreasing of permissible unit hydraulic load of the subsurface sewage disposal field and by applying under the seepage bed an assisting layer which will extend the time of presence of the sewage in the layer deprived of organic compounds.

The sewage, initially cleaned in the septic tank, is not safe on account of bacteriological protection. Bacteria and eggs of parasites are removed in 99% together with sedimentation sludge (HARTMANN 1999). In the accessible scientific and technologic literature, there is little of a publication concerning the effectiveness of sewage treatment in ground bed under subsurface sewage disposal field (REED I IN. 1989, RETTINGER 1993, WILHELM I IN. 1994, SCHWAGER, BOLLER 1997, SIEMIENIEC, KRZANOWSKI 2001, VAN CUYK I IN. 2001). Currently carried investigations on the effectiveness of sewage treatment in the ground bed of coarse sand (KALENIK, GRZYB 2001), dust sand (KALENIK, GRZYB 2003), gravel (KALENIK, AMBROZIAK 2005), as well as with assisting layers of coarse sand (KALENIK 2008) and of mineral ash (KALENIK, WILKOWSKA 2008) point out that the kind of the ground bed affects the effectiveness of sewage treatment.

## Conditioning of research

To measure the effectiveness of sewage treatment in the ground bed under subsurface sewage disposal field, there was built a measurement stand in the form of a tight container of the size: length 1.20 m, height 1.70 m, width 0.20 m (Fig. 2). The container was made of plastic plates, fastened in metal frames. The sewage was being pumped by a pump from the container through a delivery pipeline to a perforated distribution pipe of the diameter of 100.0 mm laid on a ground bed layer made of stones of the diameter of 20.0 - 40.0 mm. The pump was turned on and off by a programmer. The size of the seepage bed layer is: length 0.50 m, width 0.20 m, height 0.20 m. The sewage is filtered to the seepage bed layer through a hole of the diameter of 8 mm placed in the bottom of the perforated distribution pipe. After filtering through the seepage bed layer, the sewage is filtered through an assisting layer into the ground bed. The assisting layer was made of dolomite and the ground bed - of gravel. The researches were carried out for two assisting layers of the thickness of 0.10 m and 0.20 m. The gravel layer thickness amounted to 1.30 m. In a bottom of the measurement stand three holes were made, which enabled an outflow of the filtered sewage through the assisting layer (dolomite) and ground bed (gravel) to collecting vessels. The container was being filled by layers of the thickness of 5.0 cm, thickened by compacting.

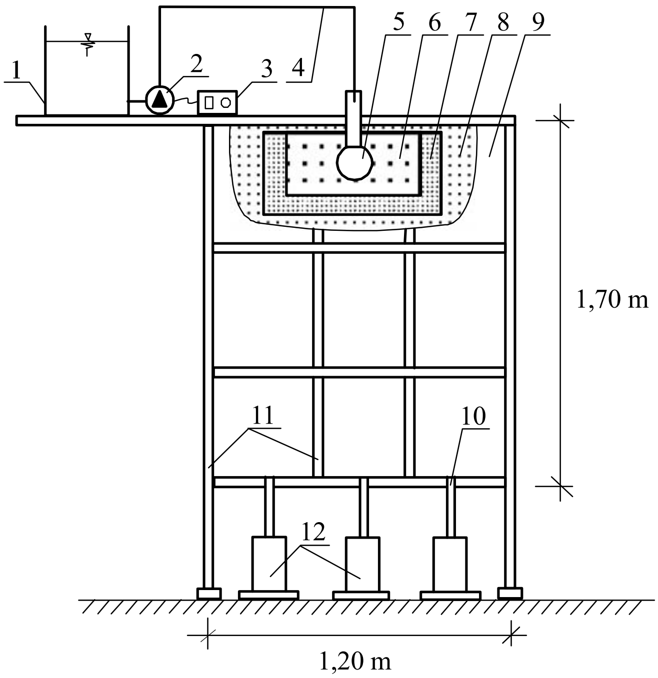


Fig. 2. Scheme of the measuring stand:
1-tank, 2-pump, 3-programmer, 4-delivery pipe, 5-perforation distribution pipe, 6-seepage bed, 7-assist layer (dolomite), 8-ground bed (gravel), 9-transparent plastic plate, 10-sewage outflow, 11-metal frame, 12-collecting vessel.

To researches, synthetic sewage was used, prepared according to PN-C-04616/10 (1987). The synthetic (raw) sewage was being dosed three times a day and its daily dose had been defined depending on the kind of the ground bed and minimal acceptable hydraulic load of ground by sewage, according to Polish recommendations. (CUGW 1971, TABERNACKI I IN. 1990). Before introducing the raw sewage at the ground bed (gravel) with assisting layer (dolomite), as well as after filtering them through the same layers, the following indicators of sewage contamination were determined (ROZPORZĄDZENIE MINISTRA ŚRODOWISKA [ORDER OF THE MINISTRY OF ENVIRONMENT] 2006): solid suspensions, $BOD_5$ and COD, and additionally total nitrogen, total phosphorus, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen. The contamination indicators in the sewage were determined once a week, taking into consideration the time of the sewage filtration through the ground bed (gravel) with the assisting layer (dolomite).

The content of individual fractions of the ground graining was determined by sieve analysis. The investigation was made on three samples and the obtained results showed that it was gravel (KALENIK, AMBROZIAK 2005). The filtration coefficient of gravel was determined in Wiłun apparatus ITB-ZW-K2. The measurement was made for six samples. For the examined gravel, the filtration coefficient (*k*) amounts to 0.005 $m \cdot s^{-1}$.

If the kind of ground (gravel) and its filtration coefficient (0.005 $m \cdot s^{-1}$) are known, the daily dose of sewages can be determined - 3.0 $dm^3$ - related to the length of the perforated distribution pipe, according to the Polish recommendations (CUGW 1971, TABERNACKI I IN. 1990). The hydraulic load of the distribution pipe, according to Polish recommendations, relates to 1 m of its length and for gravel amounts to 15,0 $dm^3 \cdot m^{-1} \cdot d^{-1}$. The daily dose of sewages was divided into three doses, 1.0 $dm^3$ each, and they were being applied to the seepage bed at 7, 13 and 19 o'clock.

The synthetic (raw) sewage was being prepared every sixth day and the indicators of contamination were being determined at the beginning, in the middle and at the end of the dosing period, then they were being averaged (Table 1). The solid suspension was determined by the gravimetric method. The $BOD_5$ was determined by the electrochemical Sensomat method of Lovibond. The COD was determined by the titration with potassium dichromate. Total nitrogen, nitrite nitrogen and total phosphorus was determined in the Hach spectrophotometer. Ammonia nitrogen and nitrate nitrogen was determined by the colorimetric method.

## Physical and chemical indicators of sewage

The carried-out research of the effectiveness of sewage treatment in ground bed made only of gravel (KALENIK, AMBROZIAK 2005) shows (Table 1) that the solid suspensions are not being removed in satisfactory degree and do not fulfill the obligatory recommendations (ROZPORZĄDZENIE MINISTRA ŚRODOWISKA [ORDER OF THE MINISTRY OF ENVIRONMENT] 2006). However, the $BOD_5$ and COD indicators fulfill them.

The solid suspensions removing effectiveness fluctuated between 50% and 56% and amounted to 53% on average. However, the effectiveness of decreasing of the $BOD_5$ indicator fluctuated between 98.4% and 99.5%, of the COD indicator - between 84.7% and 88.1% and on average amounted to 98.7% and 86% respectively. The total phosphorus in the cleaned sewage appeared in trace amounts and its medium effectiveness of decreasing amounted to 98.3%.

Table 1

Physical and chemical indicators of raw sewage and treated sewage in ground bed of gravel (mean values) (KALENIK, AMBROZIAK 2005)

| Indicators | Unit | Raw sewage | Treated sewage | | | |
|---|---|---|---|---|---|---|
| | | | 9 week | 10 week | 11 week | 12 week |
| Solid suspensions | [$mg \cdot dm^{-3}$] | 172.00 | 86.00 | 75.00 | 80.00 | 80.00 |
| $BOD_5$ | [$mg\ O_2 \cdot dm^{-3}$] | 109.70 | 0.60 | 1.80 | 2.10 | 1.20 |
| COD | [$mg\ O_2 \cdot dm^{-3}$] | 308.00 | 47.00 | 45.10 | 45.30 | 36.50 |
| Total phosphorus | [$mg\ P \cdot dm^{-3}$] | 1.70 | 0.00 | 0.06 | 0.02 | 0.04 |

The analysis of the results presented in the Table 2 allows to state that after filtering the raw sewage through the gravel with the dolomite assisting layer, the content of the solid suspensions, $BOD_5$, COD and total phosphorus in the cleaned sewage decreased.

The ground bed with dolomite assisting layer of the thickness of 0.10 m started to work properly after six weeks, however the ground bed with the assisting layer of the thickness of 0.20 m - after four weeks. Under the seepage bed, a bacterial jelly of the thickness of 2.5 cm formed, which is a site of bacteria and microorganisms. The temperature in the room for all the research period was stable and amounted to 14°C.

Table 2

Physical and chemical indicators in raw and cleaned sewage in ground bed of gravel with dolomite assisting layer (mean values)

| Indicators | Unit | Raw sewage | Cleaned sewage | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Assisting layer thickness | | | | | |
| | | | 0,10 m | | | 0,20 m | | |
| | | | 7 week | 8 week | 9 week | 5 week | 6 week | 7 week |
| Solid suspensions | [$mg \cdot dm^{-3}$] | 117.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| $BOD_5$ | [$mg\ O_2 \cdot dm^{-3}$] | 213.0 | 1.5 | 1.8 | 1.5 | 1.3 | 1.4 | 1.3 |
| COD | [$mg\ O_2 \cdot dm^{-3}$] | 261.0 | 34.8 | 34.5 | 30.1 | 29.8 | 26.5 | 27.1 |
| Total phosphorus | [$mg\ P \cdot dm^{-3}$] | 2.5 | 0.88 | 0.65 | 1.20 | 1.48 | 1.58 | 1.03 |

For the layer of the thickness of 0.10 and 0.20 m, the solid suspension removing effectiveness amounted to 100%. A big amount of solid suspension introduced into the ground bed causes its quick silting-up (ŁOMOTOWSKI 1999). As a result, the bed permeability coefficient decreases and then – a life of sewage treatment plant with subsurface sewage disposal field.

The $BOD_5$ removing effectiveness for the layers of the thickness of 0.10 m and 0.20 m amounted to 99% on average. Next the $BOD_5$ decreasing effectiveness for the layer of the thickness of 0.10 m fluctuated between 86% and 88% and amounted to 87% on average, however for layer of the thickness of 0.20 m fluctuated between 88% and 90% and amounted to 87% on average.

The total phosphorus in the all period of researches was being removed, because in the raw sewages it occurred in small amounts. The total phosphorus removing effectiveness for the layer of the thickness of 0.10 m fluctuated between 52% and 74% and amounted to 63% on average, however for the layer of the thickness of 0.20 m fluctuated between 37% and 59% and amounted to 48% on average. The lower effectiveness of the total phosphorus removing for assisting layer of the thickness of 0.20 m is caused by the bed saturation with phosphorus.

The analysed indicators: solid suspensions, $BOD_5$ and COD fulfilled the Polish recommendations concerning the introducing of cleaned sewage into ground (ROZPORZĄDZENIE MINISTRA ŚRODOWISKA [ORDER OF THE MINISTRY OF ENVIRONMENT] 2006).

## Forms of nitrogen in sewage

The carried-out research on the effectiveness of sewage treatment in the ground bed made only of gravel (KALENIK, AMBROZIAK 2005) shows (Table 3) that the total nitrogen and ammonia nitrogen was decreasing in satisfactory degree. The nitrate nitrogen quantity grew several dozen times, however the nitrite nitrogen in the cleaned sewage occurred in trace amounts. The removing effectiveness of the total nitrogen amounted to 26% on average and this of ammonia nitrogen - 99%.

Table 3

Forms of nitrogen in raw sewage and clened sewage in ground bed of gravel (mean values) (KALENIK, AMBROZIAK 2005)

| Indicators | Unit | Raw sewage | Cleaned sewage | | | |
|---|---|---|---|---|---|---|
| | | | 9 week | 10 week | 11 week | 12 week |
| Total nitrogen | [mg N·dm$^{-3}$] | 31.90 | 23.30 | 23.30 | 23.30 | 24.3 |
| Ammonia nitrogen | [mg N-$NH_4$·dm$^{-3}$] | 10.70 | 0.00 | 0.06 | 0.00 | 0.005 |
| Nitrate nitrogen | [mg N-$NO_3$·dm$^{-3}$] | 0.03 | 5.20 | 4.80 | 5.10 | 4.50 |
| Nitrite nitrogen | [mg N-$NO_2$·dm$^{-3}$] | 0.0019 | 0.0035 | 0.0027 | 0.0081 | 0.0022 |

Analysis of results presented in the Table 4 allowed to state that after filtering the raw sewage through gravel with dolomite assisting layer, the content of the total nitrogen, ammonia nitrogen and nitrite nitrogen decreased in the cleaned sewage. However, increase of the nitrate nitrogen occurred.

Table 4

Forms of nitrogen in raw sewage and cleaned sewage in ground bed of gravel with dolomite assisting layer (mean values)

| Indicators | Unit | Raw sewage | Cleaned sewage | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Assisting layer thickness | | | | | |
| | | | 0,10 m | | | 0,20 m | | |
| | | | 7 week | 8 week | 9 week | 5 week | 6 week | 7 week |
| Total nitrogen | [mg N·dm$^{-3}$] | 31.8 | 20.4 | 20.5 | 20.9 | 18.0 | 17.6 | 17.4 |
| Ammonia nitrogen | [mg N-$NH_4$·dm$^{-3}$] | 4.2 | 0.150 | 0.150 | 0.120 | 0.050 | 0.110 | 0.095 |
| Nitrate nitrogen | [mg N-$NO_3$·dm$^{-3}$] | 0.3 | 64.38 | 61.52 | 40.54 | 44.38 | 41.85 | 41.78 |
| Nitrite nitrogen | [mg N-$NO_2$·dm$^{-3}$] | 0.0082 | 0.002 | 0.002 | 0.001 | 0.0 | 0.0 | 0.0 |

The total nitrogen removing effectiveness for the layer of the thickness of 0.10 m fluctuated between 34% and 36% and amounted to 35% on average, however for the layer of the thickness of 0.20 m fluctuated between 43% and 45% and amounted to 44% on average. Next, the ammonia nitrogen removing effectiveness for the layer of the thickness of 0.10 m fluctuated between 96% to 97% and amounted to 96,5% on average, however for the layer of the thickness of 0.20 m fluctuated between 97% to 99% and amounted to 98% on average. The nitrite nitrogen in the cleaned sewage for both layers occurred in trace amounts, however the nitrate nitrogen amount grew several dozen times. The big quantity of the nitrate nitrogen in the cleaned sewage proves that in the ground bed a nitrification occurs.

## Summary

In the ground bed made only of gravel, the indicators $BOD_5$ and COD are being removed in appropriate amount according to the current recommendations (ROZPORZĄDZENIE MINISTRA ŚRODOWISKA [ORDER OF THE MINISTRY OF ENVIRONMENT] 2006). However, the solid suspensions are not being removed in satisfactory degree and do not fulfill the current recommendations. Only after using the dolomite assisting layer in the gravel ground bed the solid suspensions have been totally removed from the cleaned sewage.

In the carried-out experiment it is possible to state that the variability of the dolomite assisting layer thickness between 0.10 and 0.20 m has a small influence on the sewage cleaning effectiveness. However, one should emphasize that a better cleaning effectiveness was obtained for the dolomite layer of the thickness of 0.20 m. Filtering the sewage through the ground bed with assisting layer of the thickness of 0.20 m, comparing to the layer of the thickness of 0.10 m, resulted for the cleaned sewage in increasing of the $BOD_5$ reduction effectiveness on 1% on average, COD - on 2 %, total nitrogen - on 9 %, ammonia nitrogen - on 1.5 %. However, the total phosphorus reduction effectiveness decreased on 15%. As the obtained differences are lower than the accuracy of determination of the individual indicators, it is possible to acknowledge them as little significant. Hence, the application of the assisting layer of the thickness of 0.10 m is sufficient. The very good effectiveness of removing solid suspensions from the raw sewage in gravel with dolomite layer can be the reason of fast silting-up of the subsurface sewage disposal field. Thus, the septic tank should be designed in such way that there could be removed as big amount of suspensions from sewage as possible.

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**Marek Kalenik, Maciej Cieśluk**
Division of Water Supply and Sewage Systems
Department of Civil Engineering and Geodesy
Warsaw Agricultural University
ul. Nowoursynowska 159, 02-776 Warsaw, POLAND
e-mail: marek_kalenik@sggw.pl