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CP G.03.01:2016

SYSTEMS OF COMMUNAL WASTEWATER NATURAL BIOLOGICAL TREATMENT IN REED BED FILTERS

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SYSTEMS OF COMMUNAL WASTEWATER NATURAL BIOLOGICAL TREATMENT IN REED BED FILTERS

Key words: reed bed filters, natural/extensive biological treatment, horizontal and vertical flow reed bed filters, design, construction, execution, operation, tests, macrophytes

Preamble

1 DEVELOPED by the International Association of River Keepers ”Eco-Tiras” with participation of university professor Dr. Eng. Dumitru UNGUREANU, Dr. Chem.Olga COVALIOVA

2 ACCEPTED by the Technical Committee for Technical Rules and Standards in Construction CT-C 09 „Works and networks of water supply and sewerage”, minutes no. 02 of 06.07.2016.

3 APPROVED and ENFORCED by order of the Ministry of Regional Development and Constructions no. 96 of 21.07.2016 (official Gazette of the Republic of Moldova, 2016, no. 247-255, art. 1251), effective from 05.08.2016.

4 DEVELOPED FOR THE FIRST TIME.

Contents

Introduction

The development and implementation of small capacity wastewater treatment designs is regulated by NCM G.03.01-2012 “Small capacity wastewater treatment plants".

The purpose of this Code of practice is to help the technical experts (designers, construction contractors, operators, supervisors of compliance with the requirements related to environmental protection, public health, quality in construction, public self-administration of rural areas, etc.) to ensure treatment of wastewater in agglomerations with the conventional number of residents under 5000, according to the European Council Directive no. 91/271 of 21 May 1991 concerning urban wastewater treatment and Government Decision no. 950 of 25.11.2013.

This Code of practice is focused on one of the relatively new technologies and techniques of natural/extensive treatment of wastewater - treatment systems in constructed wetlands and, in particular, macrophytes planted filters or horizontal and vertical flow phyto-filters (reed bed filters).

Extensive systems are based on self-purification in aquatic and soils systems, mainly by sedimentation, filtration and biological and sunlight degradation/decomposition. The biological processes of self-treatment of wastewater are possible due to the vital activity of microorganisms, particularly bacteria attached or fixed on a solid media.

Biotreatment in constructed wetlands reproduce the self-treatment processes of natural ecosystems, which involve a number of possible means, taking into account the diversity of macrophytes and soils:

- open water pond systems, such as natural biological ponds;

- energetic plants irrigation systems;

- soil subsurface wastewater flow systems - filters planted with macrophytes with horizontal and vertical flow – reed bed filters (phyto-filters), which are the main focus of this Code.

Extensive biological wastewater treatment systems by definition occupy larger areas than the intensive ones (activated sludge reactors, biological filters and various modifications and combinations thereof, systems which use artificially grown suspended and/or fixed microflora), which are applied to larger, urban agglomerations. However, the extensive treatment procedures usually require lower investment costs, and the operating conditions are lighter, more flexible and energetically economical. Finally, these systems do not need a large number of highly qualified workers and technicians, compared to intensive systems.

This document describes the extensive treatment systems, in particular, the phyto-filters and the recommended procedures for design, implementation and operation of their components.

Along with other sources of information, this Code takes into account the adapted to the conditions of Kaliningrad region of the Russian Federation German standard DWA A 262 “Principles of calculations, construction and operation of biological treatment of municipal wastewater in macrophyte planted filters" (Akut Umweltschutz Burkard Ingenieure und Partner. Berlin/Biesental, 2015).

CODE OF PRACTICE IN CONSTRUCTION

Works and networks of water supply and sewerage systems.

Systems of communal wastewater natural biological treatment in reed bed filters.

1 Scope

1.1 This Code of Practice covers the natural biological treatment of municipal wastewater in reed bed filters (phyto-filters), in particular planted with reed/cane or cattail; it refers to individual units, located both, in and outside rural areas: farms, private homes, summer camps, nursing homes, schools, kindergartens, social and administrative buildings etc., as well as to settlements with conventional population of up to 5000 inhabitants; in case of availability of favorable conditions and appropriate technical and economic ground, superior capacities can also be accepted [3, 6, 12, 16, 20, 22, 28-31].

1.2 The technical recommendations of this Code of Practice cover the phyto-filters designed for autonomous biological treatment of domestic wastewater and possibly of a mixture of this with industrial wastewater with similar organic content load, originating mainly from food industry.

1.3 Phyto-filters may serve either as autonomous treatment facilities, as distinct facilities within a treatment plant and/or, if necessary, as final or additional treatment units, if high quality standards of the effluent are required.

1.4 The phyto-filters can remove of suspended solids (SS) and organic pollutants, expressed in BOD, from wastewater, and, under favorable conditions (wastewater temperatures of over $12 \div 15^0$C), can perform nitrification of ammonia nitrogen.

1.5 The phyto-filters can also perform disinfection of wastewater - the destruction of pathogenic microorganisms, viruses and parasite eggs, but at present no specific recommendations can be submitted on disinfection efficiency because of lack of data [4, 9].

Also, the use of phyto-filters cannot guarantee the elimination of phosphorus compounds from the wastewater in order to prevent eutrophication of surface waters. This requires an additional treatment phase, preferably of chemical precipitation, but this process does not fall within the scope of this Code.

2 Regulatory references

NCM A.01.04-96	Rules for drafting regulatory documents
NCM A.07.02-2012	Procedure of developing, endorsing, approving and the framework content of design documents in constructions. Main requirements and provisions
NCM G.03.01-2012	Small capacity communal wastewater plants
NCM G.03.02-2015	Exterior sewerage networks and facilities
СНиП 2.04.02-84	Водоснабжение. Наружные сети и сооружения
SM SR EN 752:2011	Swererage networks outside the buildings

SM SR EN 1085:2011 Wastewater treatment. Vocabulary

3 Terms and definitions

The terms and definitions used in this Code referr to in the standard SM SR EN 1085: Wastewater treatment. Vocabulary.

4 General provisions

4.1 This Code of Practice is developed as an additional material to NCM G.03.01, chapter 7.2. „Biological treatment of wastewater“, and covers the natural biological treatment of wastewater (p.7.2.2). This Code of Practice is based on the recent results of scientific research and practical application of natural wastewater treatment systems in phyto-filters (reed bed systems) in the world and in the country, referred to in English language literature as "constructed wetlands", and contains the necessary methodological guidance for the design, implementation and operation of this type of autonomous facilities.

4.2 The Code of Practice covers the extensive biological wastewater treatment, which have the advantage of reduced capital costs, are easier to operate, more flexible and in, some cases, more energy efficient. These systems do not need a large number of highly qualified workers and technicians, compared to intensive ones. The described systems are recommended for treatment systems the capacity of which does not exceed 5,000 conventional inhabitants, with very rare, exclusive exceptions.

4.3 The design of reed bed filters will consider the groundwater level, the floodability of the area, the soil permeability and the geotechnical conditions (rocky soils, areas with landslides, etc.).

4.4 The design of reed bed filters shall also consider the topography and the availability of land. The two-step vertical-flow phyto-filters require a level difference of at least 4 m between the point of entry into the treatment plant and the point of discharge into the water body. This difference may reach even 6 m for larger units. On the other hand, in case of horizontal-flow filters, including a series of a grille followed by a settler and a filter, a level difference of at least 1 m can be provided.

4.5 The recommended shape of filters top view is close to the square. The maximal area of a filter must not exceed 500 m^2 [1, 2] to avoid shortcomings in the distribution of wastewater on the surface of phyto-filters.

The following describes the autonomous systems of extensive biological treatment using phyto-filters and the recommended procedures are given related to design, construction and operation of their components.

5 Phyto-filters. Concept and practical application

5.1 The biological treatment systems with bio-filters/constructed wetlands reproduce the treatment processes of natural ecosystems. The high heterogeneity and diversity of plants and soils, the types of wastewater flow involve a wide variety of possible means, of which the systems with water flow under the aerial surface of phyto-filters - horizontal and vertical flow reed planted filters are preferable.

5.2 Phyto-filters involve various treatment mechanisms, such as: a) physical, by filtering through the porous material in the filter and its root system (removal of suspended solids - SS); b) chemical, through precipitation, absorption, ultraviolet radiation (death of pathogenic viruses and bacteria) and redox reactions (removal of metals); c) biological, due to development of free or fixed bacteria, which decompose organic matter (BOD), nitrification in aerobic zones and denitrification in anaerobic zones [3-5].

5.3 The treatment of wastewater in phyto-filters is performed through aerobic biological treatment, which takes place in the filter medium. No renewal or backwashing of the filtering layer is performed. Instead, the sludge accumulated on the surface of the filters must be periodically drained.

5.4 The wastewater treatment plants with phyto-filters are a set of beds/platforms arranged in parallel and/or in series.

5.5 The phyto-filters are the most reliable method of natural biological treatment of wastewater from rural areas with small agglomerations. Two types of phyto-filters/reed bed filters are distinguished according to the direction of flow of treated wastewater:

a) vertical flow filters;
b) horizontal flow filters.

5.6 The most suitable option for the design is selected after a preliminary analysis, with the following starting points:

a) the purpose and the extent of water treatment;
b) where will the treated wastewater be discharged;
c) climate conditions;
d) topography;
e) soils, geological and hydrogeological characteristics of the location for the treatment plant.

The economic, institutional and political, environmental, socio-cultural and land availability issues will also be taken into account. Finally, the cost-effectiveness analysis should also be a selection criterion in selecting the best option according to SM SR EN 752.

5.7 When determining/establishing the feasibility for implementation of a design of wastewater treatment plant with phyto-filters, the following should be taken into account [6]:

- reaching a consensus among stakeholders on the need to develop the project;

- thorough analysis of the situation in order to identify any problems related to implementation of phyto-filters;

- developing solutions to the identified problems, setting the design criteria, design of the treatment plant components taking into account previous experience and knowledge of researchers and experts in the field;

- assessing the developed solution options in order to select the best one and implementation of the concept;

- developing the regulation for acceptance of works, protocols for startup and exploiation (operation and maintenance) of the treatment plant [7-11];

- developing the monitoring program to assess the operational condition and performance of the treatment plant;

5.8 The following criteria shall be considered when selecting the site for the phyto-filters [2, 12-14]:

- distance and access to the sewerage system;

- the flow rate of wastewater to be treated;

- distance to the electricity grid;

- access to transport;

- distance to the settlement;

- soil structure;

- the effluent discharge point and the distance to it;

- public health status;

- the legal conditions etc.

5.9 The basic data characterizing the treated water to be considered in the design are summarized as follows [6, 12, 15, 17, 18]:

- meteorological data: in dry conditions, during rainfall;
- population: total and connected to the sewerage system;
- organic load (BOD) of wastewater from industry or economic operators and other parameters including COD, SS, TN (total nitrogen), TP (total phosphorus), variation in concentrations of pollutants.

5.10 In order to define the initial data for the design of the treatment plant, a campaign of sampling and testing of wastewater samples should be carried out, determining at least the following indicators [2, 16, 18-20]:

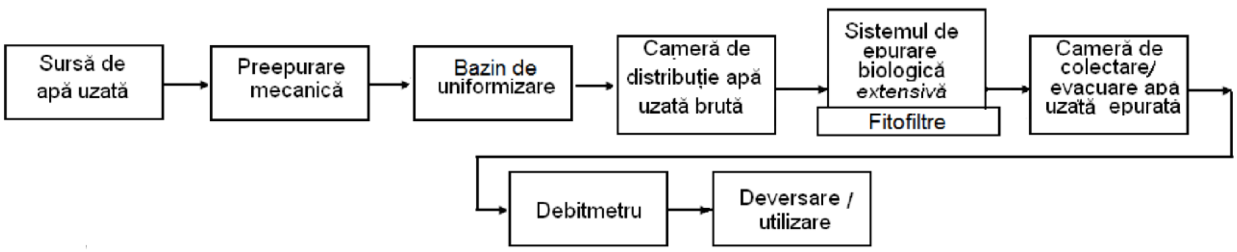
- temperature (0C);
- pH;
- electroconductivity (mS/cm);
- suspended solids (SS, mg/l);
- chemical oxygen demand (COD, mg/l);
- biochemical oxygen demand (BOD5, mg/l);
- total nitrogen (TN, mg/l);
- Ammonia nitrogen (NH4-N, mg/l);
- Total phosphorus (TP, mg/l).

To evaluate the negative impact of industrial wastewater, the following additional indicators are recommended to be included:

- oils and fats;
- heavy metals such as Cd, Cr, Pb, Hg, Zn, etc.;
- other metals such as Al, Cu, Fe, etc.;
- other indicators, such as NO2, NO3, sulfides, sulfates, cyanides, etc.

6 Wastewater treatment technological shemes

6.1 The technological scheme of the wastewater treatment plant within the phyto-filters (Fig.1) must contain a preliminary phase of coarse pre-treatment, consisting of dense screens and grease traps. For the dense screen, if used one unit, a bypass channel shoud be provided in order to prevent clogging of the grille and allow any inspections and repairs.



Wastewater source ---Mechanical pre-treatment --- Equalization tank ----Wastewater distribution system ----Extensive biological treatment system (phyto-filter) ---Treated wastewater collection/drainage chamber ----Flow meter -----Discharge/use

Fig. 1 Technological chart of extensive biological wastewater treatment in reed bed filters (macrophyte planted filters)

6.2 An equalization tank for leveling the flow and concentrations must be added to the scheme in order to cope with big daily fluctuations or in case of periodic overload of vertical flow phyto-filters.

6.3 Primary settlers may not be included in the technological chart of the treatment plant if the efficiency of primary settling by gravitational sedimentation is below 40% [4, 19] and treatment in vertical flow phyto-filters is expected.

6.4 The wastewater treatment consists of several technological stages that must ensure the discharge of effluent, which quality is in accordance with the current legislation.

6.5 Wastewater treatment consists of removing suspended and non-miscible with water solids, separable by gravity, in a first phase, followed by removal of colloidal, dissolved biodegradable organic matter by the process of biological treatment in phyto-filters while partially removing bacteriological pollutants (pathogens).

6.6 The technological units along the wastewater flow of the reed bed plant can include (all or part of):

- screens;
- by-pass chanel for the whole treatment plant or for a specific technological unit, if deemed necessary;
- wastewater flow meter;
- grease trap;
- flow distribution chambers;
- primary settler;
- equalization tank;
- wastewater pumping station;
- reed bed filters with corresponding vegetation;
- intermediary pumping station for the wastewater partially treated in the first phase, if the phyto-filters are provided with two or more phases;
- technological pipelines and connecting channels;
- treated wastewater collection chambers (or pits);
- pipelines (or channel) for transportation of the effluent to the receiving water;
- effluent discharge oulet into the receiver.

6.7 The treatment units and related auxiliary facilities of a low capacity wastewater treatment plant may also include:

- administration building, which may include the laboratory for chemical and biological testing in the treatment plant;
- sanitary, heating, ventilation facilities;
- mechanical workshop;

- access road;

- roads, alleys and interior platforms;

- fences and gates;

- electricity supply;

- electric power, lighting and protection utilities;

- automation facilities and measurement and control devices;

- power generators (as a backup for electricity source);

- telephone/telecommunication facilities:

- embankments, bank protection works, riverbed works, if the site is located in the floodplain etc .;

- green spaces;

- guardian cabines.

6.8 The number of similar or identical technological units is recommended to be a minimum of 2. If n=1, a bypass shall be provided [2, 17].

6.9. The grease trap and the primary settler are in some cases independent technological units. They can be grouped into one technological object such as, for example, a multi-chamber septic tank. There are also compact screenning facilities (screens and sieves) that retain solids and separate grease.

6.10 The list of technological units presented in 6.6 represents a general set of components of a treatment plant. Depending on the peculiarities of the technological scheme, one or several facilities may not be included, but also others may be added. Thus, depending on site slope, the pumping station may not be included in the scheme, if the wastewater flows through the plant units by gravity.

7 Application of wastewater treatment systems in phyto-filters

7.1 The phyto-filters are designed and constructed so that the hydrophytic vegetation, typical for "wetlands", contributes to wastewater treatment in a more efficient manner than natural wetlands. They represent an environmentally friendly alternative for secondary and tertiary biological treatment processes for communal waters [18].

7.2 For municipal wastewater the phyto-filters may follow after conventonal treatment processes as suplimentary post-treatment of wastewater. Different types of phyto-filters can effectively treat the wastewater at primary, secondary or tertiary phases. The phyto-filters may also be provided as one, two or more split units, which increases both the degree of treatment and the safe operation of tthe plants (see Fig. 2 and 3). Through the phyto-filters organic pollutants (COD, BOD), suspended solids (SS), nutrients (nitrogen and phosphorus compounds), pathogens, heavy metals and other toxic and hazardous substances are removed from the wastewater [21].

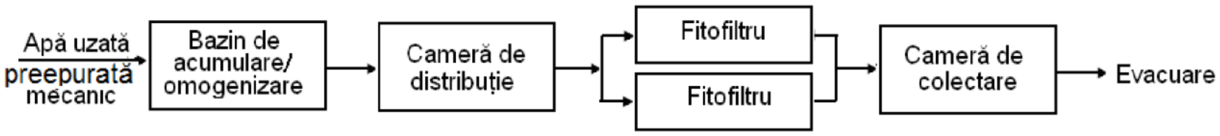


Fig.2. Technological chart of natural/extensive biological treatment in one-phase phyto-filters

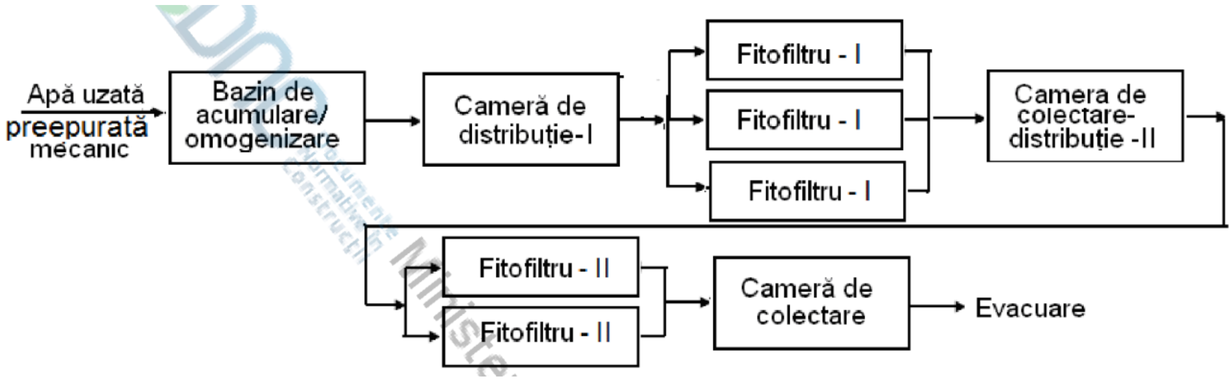
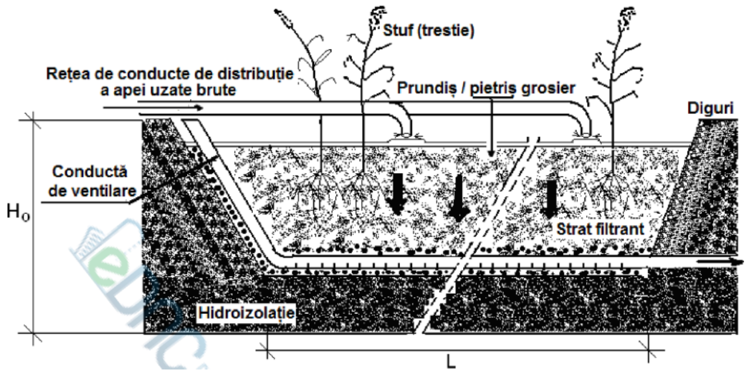


Fig. 3. Technological scheme of natural/extensive biological treatment in two-phased phyto-filters

7.3 The major difference between phyto-filters and other filtering systems is that phyto-filters in the filtering medium/layer are planted with hydrophites with dense roots, which serves as a way for the transfer of oxygen from the atmosphere.

7.4 Depending on the configuration and the slope of the treatment plants' site, phyto-filters may or may not require pumping of wastewater. They can be provided for secondary or tertiary treatment after a preliminary phase of mechanical treatment in septic tanks or other settling-fermentation utilities and after compact modular biological/artificial intensive treatment facilities.

7.5 Of the many types of natural/extensive biological phyto-filtering facilities, which are divided according to the flow paths, two main categories can be mentioned: free water surface systems and subsurface systems. The second category of facilities - phyto-filters with wastewater flow through the filtering layer below the surface - has become the most popular in the practice of wastewater treatment. These, in their turn, are subdivided into 2 types, which differ in terms of direction of movement of the water flow through the porous environment of the filter layer, built of gravel and sand where the water-loving plants are rooted. Thus, horizontal and vertical flow filters are distinguished (Fig.4 and 5) [20, 22].



7.6 The sub-surface filters are more suitable for the autonomous treatment of wastewater as there is no direct contact between the water column and the atmosphere and there is no danger of multiplying insects, which does not affect public health. The inside environment of the filtering layer of horizontal flow phyto-filters is predominantly anoxic or anaerobic. Oxygen is provided/supplied through the root system of emerging plants and consumed/used by the biofilm developed/fixed directly to the roots and rhizomes, and is thus unlikely to get/to spread largely into the water column itself. As a consequence, such phyto-filters are better suited for removal of nitrates (denitrification) and less able to oxidize the ammonia nitrogen (nitrification) because oxygen availability is a limiting condition for the nitrification.

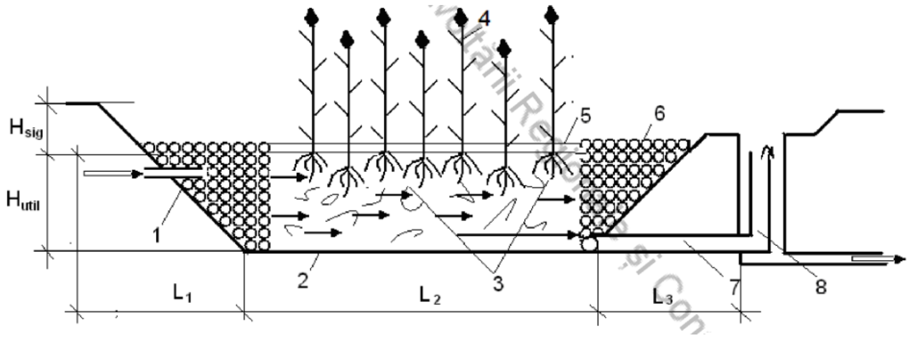


Fig.5. Horizontal flow phyto-filter: 1 - facility for uniform distribution of raw wastewater (gravel or stones gabion); 2 - waterproofing; 3 - filter layer combined with plants' root system; 4 - emerging macrophytes (reeds); 5 - sewage level; 6 - gabion drainage for uniform collection of treated wastewater (gravel or stones); 7 - discharge pipe; 8 - flexible hose for adjusting the water level.

7.7 Most phyto-filters are composed of the following zones (also see Tab.1):

Zone	Components	Functions
Wastewater inlet	Inlet infrastructure, raw wastewater distribution chambers	Distribution of water flow over the entire width at a minimum distance/range of 3-5 m
Macrophyte area	Porous filter layer, water, vegetation, islands, diverting baffles, flow dividers	To provide a filter layer with a high hydraulic conductivity; to provide an area for biofilm growth/development; help remove fine particles by sedimentation and/or filtration; provide adequate/favorable/suitable support for development of the root and rhizomes system of the emerging plants
Deep water area (from saturated filter layer)	Vegetation free water (non-vegetation area)	To reduce short-circuiting through reorientation of water flow routes; to reduce stagnant/dead areas; enable Ultraviolet disinfection of bacteria and pathogens; to ensure water flow habitat
Littoral zone	Littoral area	The littoral vegetation protects the embankments from erosion, coastal vegetation serves for sinking/breaking the wave action
Treated effluent discharge area	Collection device, outlet, embankment (shoulder), discharge infrastructure	Water depth control in phyto-filters; effluent collection without creating dead zones; ensuring access for sampling and monitoring of water flow

7.8 The goal/task of the biological treatment of wastewater is to optimize the contact of microbial species with the solid support (filter material), with the ultimate objective of bioconversion of pollutants into carbon dioxide, biomass and water. The phyto-filters have a number of characteristics making them attractive for water pollutants' management. These characteristics include the high productivity of plants, the high sediments' absorption capacity, high microflora oxidation speed associated with plants biomass and the large buffer capacity for nutrients and pollutants (see Tab. 2) [19, 23].

Table 2. Main pollutants removed in the phyto-filters

Pollutants	Removal processes
Biodegradable organic matter (expressed in CBO)	Biological degradation/decomposition, sedimentation, microbial assimilation
Persistent organic pollutants (including pesticides)	Absorption, volatilization, photolysis, biotic/abiotic decomposition/degradation
Suspended solids	Sedimentation, filtration
Nitrogen	Sedimentation, nitrification/denitrification, microbial and plant assimilation, volatilization
Phosphorus	Sedimentation, filtration, absorption, microbial and plant assimilation
Pathogens	Natural death, sedimentation, filtration, predation, UV irradiation, adsorption
Heavy metals	Sedimentation, absorption, assimilation by plants

7.9 Biological processes involved in phyto-filters' performance include photosynthesis, respiration, fermentation and microbial removal of nitrogen and phosphorus.

7.10 Precipitation of metals from wastewater in the form of insoluble compounds is performed through chemical processes. Exposure to light and atmospheric gases may lead to destruction of organic pesticides or pathogenic organisms. pH of the water and filter material of phyto-filters strongly influence the direction of many reactions and processes, including biological transformations, partition of the ionized and non-ionized forms of alkalis and acids, cation exchange, leaching of solids and gases [23].

7.11 The most important physical processes that lead to the removal of pollutants from wastewater are sedimentation and filtration.

7.12 The speed of chemical and biological processes depend on environmental factors, uch as temperature, dissolved oxygen and pH. The capacity of phyto-filters is limited both in terms of the wastewater flow and the total load of pollutants. The efficiency of all these processes (biological, chemical and physical) varies depending on the temperature and the hidraulic retention time. A longer retention time increases the removal of many impurities, although long retention times can have some drawbacks. The efficiency of treatment processes is higher at high temperatures (over 15^0C).

7.13 Horizontal flow phyto-filters are compatible with a more severe/harsher climate, while the vertical flow ones are more sensitive to cold. The previous experience shows that the first phase of vertical filters continues to properly/effectively treat the suspended matter and organic pollutants (BOD) during several weeks of cold (-15^0C), while the second phase freezes. Therefore the discharge of wastewater into the receiving water must be done from the first phase, bypassing the second phase. Freezing during low temperatures can be prevented by leaving mowed plants on the surface to form an insulating layer.

8 Vertical flow phyto-filters. Mode of operation and construction peculiarities

8.1 Vertical flow reed bed filtering systems are usually made up of at least 2 steps in series, each consisting of two or three parallel phyto-filters, which operate in alternating mode. The purpose of this alternation is to minimize clogging of filters by mineralization of the accumulated organic matter during the time of rest. The rest time required for the first phase is about 2 times the operating/supply time, which requires 3 beds in parallel. For the second phase the operating and the rest time are equal and thus two parallel beds are required (see Figure 3). The rotation of phyto-filters usually takes place after each 3-4 days. First phase filters are filled exclusively with gravel/pebbles, where the aeration processes by diffusion from the atmosphere are more intensive than in the sand [4, 9, 21].

8.2 The intermittent/discontinuous/periodic and alternative supply of phyto-filters improves the efficiency of wastewater treatment and helps increase the permeability of the filter material. In this respect the use of poorly pervious soils as filtering material is not suitable due to hydraulic considerations. Vertical flow phyto-filters are supplied from the surface by uniform dispersal over the entire area and the wastewater enters by slipping through the filter layer, where in the first phase the suspended solids are physically removed at the filter surface by filtration. A biological decomposition/degradation of soluble organic pollutants is performed by aerobic microbial biomass fixed on the solid support/unsaturated filtering layer and at the same time on the sludge layer deposited/accumulated on the filter's air surface. During the first phase, the BOD removal, but also some partial nitrification take place. The second phase completes the BOD removal and the nitrification takes place to the extent that oxygenation conditions, the pH and the temperature allow it.

8.3 Oxygenation, the main driver of an aerobic treatment, is ensured through regular supply due to the convection phenomenon by water movement through the filtering layer and atmospheric gaseous diffusion through air surface, when the filtering layer pores are empty/water free. In addition, an important role in oxygenation of filtering mass through diffusion is played by the drainage pipes, which are in contact with the atmosphere via the ventilation system (see Figure 4).

To enhance oxygenation and ensure the optimum use of the whole set of phyto-filters, each portion of wastewater must be distributed evenly over the surface of the filters. The aerobic conditions do not contribute to denitrification of these vertical phyto-filters. Removal of phosphorous is not fully achieved both because of the weak absorption capacity of the filter material (which is essentially of silica) and the negligible/low level of assimilation by plants, taking into account the applied loads. Decontamination/disinfection is also low due to reduced retention time of wastewater in vertical flow phyto-filters.

8.4 Clogging of the filter layer by the excessive increase of the bacterial biomass is prevented through autoxidation during the rest phase. This is why the vertical flow phyto-filters consist of several beds: usually three in the first phase and two in the second phase, placed in parallel and fed through alternation.

8.5 The role of macrophytes/reed in vertical flow phyto-filters in the first phase is mainly a mechanical one. They participate in the dense development of roots, starting from the nodes of rhizomes (underground stems) and piercing the layer of sludge on the surface of the filters. In addition, the stems and rhizomes create paths that extend to the root system and from there further to the filters' draining layer. Due to this phenomenon clogging of filters does not occur even when they are fed from raw, unsettled wastewater.

8.6 In the sludge accumulated on the surface of vertical flow phyto-filters a microbial biomass is developed, contributing to the mineralization of organic component in a proportion of about 65%, generating soil layer with a thickness growth rate of about 15 mm per year, which is also a good biofilter that retains good permeability. The cleaning action of this layer of soil complements the one of the basic filtration layer, creating the trend of increasing efficiency of treatment while the facility gets older.

9 Horizontal flow phyto-filters Operation and construction

9.1 The horizontal flow phyto-filters have a filter layer completely saturated with water due to a siphon system located at the outlet, which allows adjusting the height of the aquifer in the filter body. Some gabion-shaped structures located in inlet and outlet areas allow the uniform (almost homogeneous) allocation/distribution and collection of the treated wastewater. This type of phyto-filters is more susceptible to clogging than those with vertical flow, hence they must be fed with wastewater with a prior removal of suspended solids in settling-fermentation facilities located upstream or by providing a first phase of vertical flow phyto-filters.

9.2 In horizontal flow phyto-filters oxygenation only takes place with the contribution of oxygen brought in by the macrophyte plants' root system and, in a limited extent, by gaseous diffusion from the atmosphere through the upper unsaturated layer. Thus, the intake of oxygen per unit of surface of the horizontal flow filters is much smaller than that of vertical flow phyto-filters. This surface must be determined and modulated depending on the tasks and objectives assigned to horizontal flow phyto-filters, taking into account the degree of treatment achieved in upstream facilities.

9.3 The relatively low oxygen intake in horizontal flow phyto-filters limits the development of aerobic, heterotrophic and autotrophic bacteria, and consequently, the elimination of the BOD and, in particular, oxidation of nitrogen compounds. Therefore, horizontal flow filters are recommended as the second phase, after the vertical flow phyto-filters.

10 The role of the macrophytes

10.1 In addition to the aesthetics and mechanical role, macrophytes indirectly contribute to the degradation of organic pollutants contained in the raw wastewater: the growth of roots and rhizomes allows maintaining or adjusting the initial hydraulic conductivity of the filtering layer of the phyto-filters; the amounts of oxygen introduced by plant photosynthesis are transferred to the root tips, ensuring an aerobic environment in the surrounding areas; the growth of the root system increases both the fixing area of micro-organisms (biofilms) and the precipitation reactions; the root tissue and the exudate form some favorable niches for microorganisms' mobility, a phenomenon related to a well-known concept in agronomy referred to as "rhizosphere"; the plant metabolism related to the assimilation of nutrients, influencing treatment depending on the areas involved; the deciduous cover protects the surface from drying up in summer, thus contributing, through the developing bacteria, to organic matter mineralization; the summer evapotranspiration leads to a significant reduction in the flow of treated wastewater effluent/discharged into the receiving environment; in winter, the deciduous sheath mitigates the negative impact of low temperatures in the cold season.

10.2 Due to the root system of macrophytes in a more general manner the filtering medium of the phyto-filters has a high diversity of species (bacteria, protozoa, invertebrates) whose activity depends on the load of waste water and oxygen balance. All these organisms also participate as competitors and predators in reducing the pathogenic population, but this reduction also depends on the wastewater hydraulic retention time in the phyto-filters' body.

11 Technological design and sizing of the phyto-filter treatment plant buildings and facilities

The sizing of natural/exntensive biological treatment plants is performed taking into account the maximum daily flow of wastewater. The maximum hourly flow rate of wastewater is only used for pre-treatment units sizing.

The capacity of the treatment units is expressed in terms of mass loading or in the number of inhabitants connected to the sewerage. In the absence of measured data, the specific amount of pollutants reported per connected resident will be used, according to NCM G.03.01:
- COD - 120 g/(man day);
- BOD5 – 60 g/(man·day);
- Suspended solids (SS)- 65 g/(man·day);
- Nitrogen (N) - 8 g/(man·day);
- Phosphorus (P) – 3.3 g/(man·day).

For guidance purposes, the characteristics of wastewater entering into biological treatment plants, indicated in *Annex 1 to the Regulation on the requirements for collection, treatment and discharge of wastewater into the sewage system and/or in water bodies for urban and rural areas* can be used [24].

The quality of the treated waste water varies depending on the seasons and the temperature conditions respectively. The treatment units of phyto-filters allow obtaining a treatment efficiency according to the requirements [25] (also see Annex 3 [24]) expressed by effluent concentrations equal to:

- COD - 125 mg/l;
- BOD_5 – 25 mg/l;
- SS - 35 mg/l.

The actual performance of the phyto-filters is higher, but the removal of nitrogen and phosphorous, especially at temperatures below 15°C, is not guaranteed. The decrease of the pathogenic microflora is also limited, especially in vertical flow phyto-filters because of rapid transit of wastewater through the filter layer, but in any case a reduction of 2 log units is realistic. In horizontal flow phyto-filters a reduction of Coli bacteria by 2 log units in winter and up to 4 log units in summer is possible.

Pre-treatment is an important component of natural biological treatment process because it allows the main phases of biological treatment to work correctly and effectively. Anyway, regardless of the type of phyto-filters, the coarse screening of wastewater is compulsory, while for vertical flow phyto-filters fed by raw wastewater, other methods of pre-treatment (de-sanding, fat separation) in most cases can be omitted. If wastewater flows by gravity, the roughing must be performed in the adduction channel. When the treatment plant is fed by pumping, under pressure, it is recommended to install a basket screen at the pumps' reception tank, and have it equipped with surface lift mechanisms.

11.1 Preliminary mechanic treatment (pre-treatment) of wastewater

11.1.1 General issues

11.1.2 The preliminary mechanical treatment phase includes the installations and devices which help retain coarse solids, suspended matter and floating matter (fats, oils, hydrocarbons, etc.).

11.1.3 To catch coarse solids from the wastewater entering the treatment plant (branches, leaves, pieces of paper, textile, etc.), screens and/or sieves must be used. In order to deal with eventual clogging of the screens or sieves bypass mechanisms should be provided.

11.1.4 To retain coarse suspended solids (coffee grounds, remains of seeds of fruits and vegetables) and floating matter (grease, oil, petroleum substances, etc.), grease traps alone or in combination with septic tanks are used.

11.1.5 When designing pre-treatment facilities and devices for natural biologic treatment plants, the respective recommendations and prescriptions for conventional treatment plants (the mechanical phase) shall be complied with.

Screens and sieves

11.1.6 The screens and/or sieves are placed at the inlet of wastewater into the treatment plant. If the wastewater is to be pumped, the screens and sieves should be put upstream of the pumping station.

11.1.7 Treatment plants for settlements with less than 5000 inhabitants, fine screens (b = 2÷3 mm) are usually provided with automated and mechanical cleaning and no service staff.

11.1.8 When calculating the amount of matter retained on the screen, specific average values shown in Table 3 shall be taken into account, but also to admit that these amounts may be several times higher; thus, a daily variation ratio of k = 2÷5 shall be considered [26].

Table 3. Specific average values of retained matter amounts

No.	Distance between the screen bars (interspaces), mm	Specific amount of retained matter, α, l/(oman) in mechanical treatment
1	0.5	25.0
2	3	20.0
3	4	18.0
4	6	15.0
5	10	12.0
6	16	8.0

11.1.9 If the water must be pumped, "basket" type screens can be used, which should be operable vertically for cleaning and located at the entrance to the pumping station or in the equalization tank.

11.1.20 The mechanical cleaning devices for matters retained on the screens can be automated depending on the loss of loading admitted at the passage of water through the bars of the screen (7÷25 cm). This is carried out through level sensors.

11.1.21 The matters retained on the screens are discharged in order to be buried, stored, fermented, composted with household waste or incinerated. They can be chopped or grinded using special mechanical devices located outside the technological flow (shredders) and re-returned into wastewater upstream or downstream of the screen.

11.1.22 shredding screens can be used instead of simple screens or sieves.

11.1.23 To reduce the amount of removed from screens solids, it is recommended to press and wash them in special facilities (inclined compactor). The humidity of pressed retained solids decreases from 80% to 55 ÷ 60%.

11.1.24 To achieve higher efficiency in removing coarse and suspended solids, fixed or mobile screens or sieves provided with inclined compactor, with continuous and automated functioning, are preferred. They should perform four important operations:

- retaining coarse bodies;
- extracting water from the screen and washing them of fine organic substances and particles;
- pressing the retained matter, decreasing their volume and humidity;
- transporting them off the treatment flow and storing in containers.

11.1.25 Depending on the daily amounts of retained matter, at least 2 bins or containers will be provided for the collection of these materials. The duration of accumulation of material retained in the container between two discharges shall not exceed 2 days to avoid their acid anaerobic fermentation, which causes smelly gas generation.

Equalizing of pollutants and loadings

11.1.26 The hourly variation of wastewater flows entering the treatment plant (influent) grows when the community from which these flows come is smaller. The hourly flow variation ratio can vary between between 3 and 10, according to [26].

11.1.27 Because the operation of the treatment plant and in particular of the biological phase (phyto-filters) is inadequate in the event of variations (shocks) of flow and pollutant concentrations, the equalization basin is absolutely necessarily.

The equalization tank is also necessary when bypassing of the treatment plant is not allowed, in order to accumulate wastewater during the revisions and repairs. The existence of the equalization tank allows first of all using of less powerful pumps with a smaller flow rate, and secondly, the supply of phyto-filters with a virtually constant flow rate.

11.1.28 Usually, the average daily maximum flow of wastewater through the equalization tank is comprised between 5 and 8 hours.

11.1.29 To prevent production of sediments in the equalization tank and achieve a good mixture, suitable for the operational volume of the tank mixing machines are provided; aeration devices fixed on the foundation plate of the tanks can be used for mixing (compressed air bubbling).

11.1.30 Equalization tanks are usually placed after the screens.

Grease traps

11.1.31 An important condition for the proper functioning of phyto-filters is the preliminary mechanical clearing of wastewater in order to remove/capture both coarse and fine suspended matter, to prevent clogging of the filter material, which could cause both odors and decommissioning of phyto-filters. Grease and oil separators and septic tanks can be used to this end.

11.1.32 Grease traps are designed to capture the floating materials with lower density than the density of the water and to discharge them into containers or pits located in places adjacent to separators.

11.1.33 Grease traps are placed before the primary settlers or prior to biological treatment phase, if primary settlers are not included in its technological scheme. Grease traps may also be integral with the primary settlers, for example, septic tanks.

11.1.34 The concept of grease traps must allow efficient and safe extraction of separated solids, grease and oils. These separators must be provided with devices for discharge of the floating matter layer, which is formed at the liquid surface, but also with the means for extracting of settled solids from the foundation plate.

11.1.35 For extracted from the trap grease and floating material separate storage tanks must be designeted with a capacity for 3÷7 days, which can be discharged once or twice a week to authorized landfills. If the separated grease and oils are recoverable, they must be stored in special containers and periodically transported to the nearest recovery entity.

11.1.36 Grease and oils extracted from wastewater must be handled under conditions complying with safety and hygiene rules.

Primary settlers

11.1.37 The primary settlers are designed to capture the suspended solids from wastewater. Primary settlers are placed after the screening step and prior to the biological treatment step.

11.1.38 In some technologically and economically justified cases, primary settlers may not be included in the technological scheme of the treatment plant, namely those phyto-filters with vertical flow.

11.1.39 Primary settlers must be present in the technological chart where biological treatment is performed in horizontal flow filters.

11.1.40 For small and very small capacity treatment plants, the following types of primary settlers should be used:

- septic tanks;

- multi-storied settlers (Imhoff type);

- vertical settlers;

- natural aeration clarifiers coupled with primary sludge fermenters.

11.1.41 The number of settler sections must be $n \geq 2$, and each of them should be able to operate independently. If a single section is necessary, a bypass shall be provided.

11.1.42 Primary settlers for small and very small plants are designed according to NCM 03.01.

The main design parameters for primary settlers are:

- wastewater flow ($Q_{or, max}$, m^3/s);
- solids sedimentation speed (Vsed, mm/s);
- water flow rate through the pool (v_{dec}, mm/s);
- settling times for the calculation flow (t^c_{dec}, h) and the control flow (t^v_{dec}, h).

11.1.43 The particle sedimentation speed is selected from Table 4, depending on concentration of suspended solids (SS) at the entrance to the treatment plant and on the required SS removal efficiency (εSS,%), according to [26].

Table 4. Efficiency of SS retention in the settler

SS retention efficiency in the settler, ε_{MS}, %	Initial concentration of SS, mg/l		
	MS < 200	200 < MS < 300	MS > 300
	Sedimentation speed, vsed, mm/s		
40-45	0.64	0.75	0.83
46-50	0.5	0.64	0.72
51-55	0.33	0.42	0.53
56-50	0.2	0.28	0.42<

11.1.44 In the design of vertical settlers, the superficial loading $v_{sed} = Q_{OR, max} / A_o$ is assumed to be equal to the current sedimentation speed v_{sed} indicated in Table 4 for the considered case.

11.1.45 Where longitudinal horizontal settlers (tiered settler troughs), the maximum water flow through the useful cross-section is 5 mm/s.

11.1.46 The recommended settling times corresponding to the calculation and check flows are as follows:

a) calculation flow – min. 1.5 hours;

b) check flow – min.1 hour.

Septic tanks

11.1.47 Septic tanks are tanks used for mechanical treatment of wastewater - grease separation and settling - from a small number of households, with usually up to 100 conventional inhabitants.

11.1.48 There are several types of septic tanks, depending on their construction particularities: with one, two or three sections, rectangular or circular. The recommended minimum capacity of a septic tank built on site, i.e. which is not manufactured in a factory, is 300 liters (one section).

11.1.49 The treatment efficiency of septic tanks can be considered:
- for suspended solids: 60÷70 %;
- for BOD_5: 15÷25 %;
- for faecal coliforms: 90 %.

11.1.50 The following parameters are recommended for sizing septic tanks:
- Hydraulic retention time: Ts = 3÷4 days;

- Specific volume: Vs = 225÷600 l/man;
- Minimum volume (first section): Vmin = 300 l;
- Safety height (distance between the water level and the tank cover): sh = 50 cm;
- The water depth in the tank: h = 1.2 ÷ 2.5 m (optimal 1.5 m);
- Height of the clarified water layer: ha = 0.5 ÷ 0.7 m (can reach up to 1.0 m);
- The number of discharges/emptying: n = 1 ÷ 2 times/year;
- Fresh sludge moisture: Wn = 95%;
- Fermented sludge moisture: Wn = 90 %;
- The specific amount of dry matter in the deposited sludge: p = 0.1 kg SU/(man-day);
- Number of served people: N = 5 ÷ 100 people;
- Specific weight of the sludge: γn = 1200 kg / m3;
- Daily volume of deposits: Vd· day = p · N · 100 / γn · (100 - Wn f), m3 /day;
- The volume of deposits that must be ensured between two emptyings, Tev = 183 ÷ 365 days, is: Vd = Tev · Vd· day, m3

For septic tanks with 2 and 3 sections, the following are recommended:
- the first section (fermentation chamber): V1 = min 2000 l; T1 = max 2 days; (V1 = 67% for septic tanks with 2 sections and V1 = 50% for septic tanks with 3 sections);
- the second section: V2 = ¼ V1, T2 = 1 day;
- the third section: V3 = ¼ V1, T2 = 1 day.

11.1.51 The reduction in the volume of deposits by anaerobic fermentation in septic tanks is about 25 - 30%.

11.1.52 The amount of fresh deposits formed in the fermentation chamber (first section) is considered a = 70 g / (man-days) at a humidity of 95%.

11.1.53 The maximum flow rate is 0.05 m/s.

11.1.54 Septic tanks must be fitted with vent pipes in order to avoid accumulation of fermentation gases.

11.1.55 Septic tanks are built with 2 or 3 chambers/sections (Fig 6 and 7). In 2-sections septic tanks the volume distribution is 2/3 and 1/3, and in those with 3 sections the distribution is ½, ¼ and ¼. The holes for wastewater passing between the chambers are placed at a third of the depth of the central volume of clear liquid.

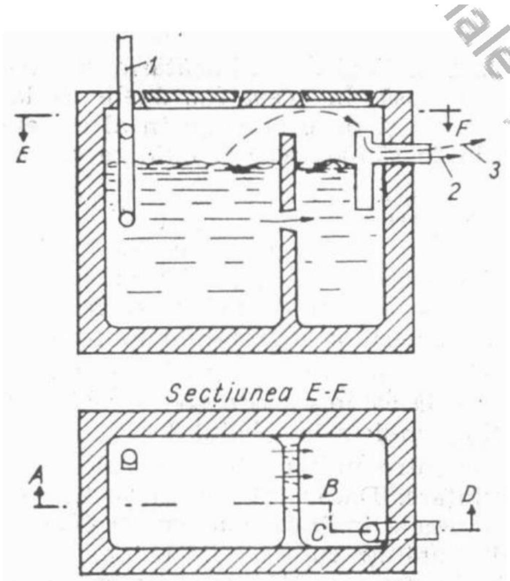


Fig.6. Two-sections septic tank: 1 – tube for wastewater discharge from households; 2 – cleared liquid; 3 – gases released from fermentation

The outlet tubes set the the level of wastewater in the whole tank. This tube must have its vertical part immersed to the third of the depth.

The sloping bottom of the last sections favors and helps sliding of deposited sludge to the first section, where anaerobic fermentation takes place.

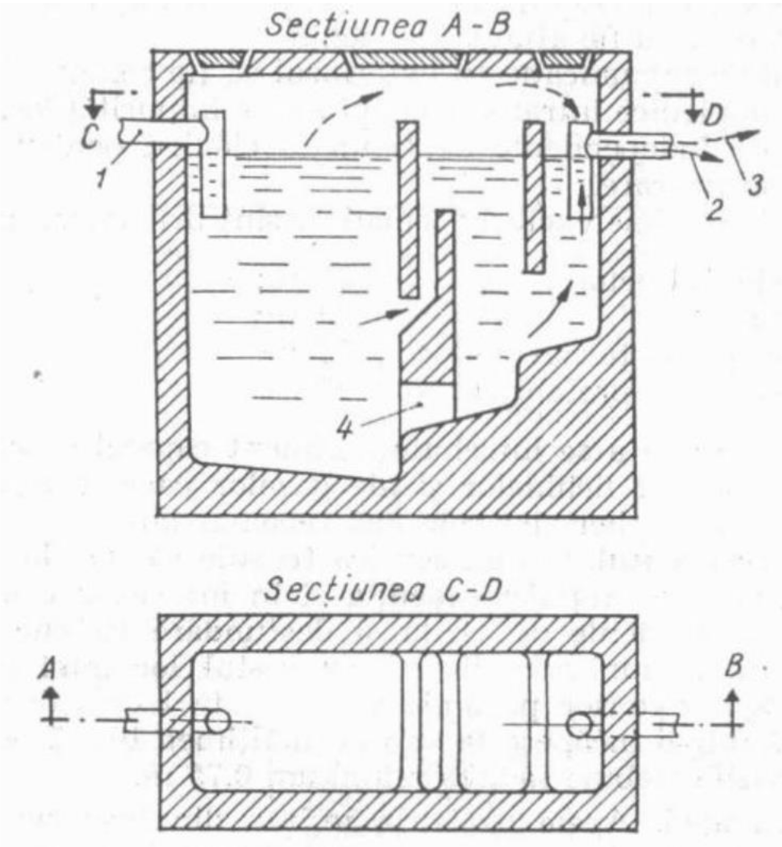


Fig.7. Three-sections septic tank: 1 – wastewater inlet zone; 2 – cleared liquid; 3 – gases released from fermentation

11.1.56 In terms of construction particularities, there are there types of septic tanks applied as appropriate:

a) Cylindrical septic tank of monolithic concrete; applies on land with the groundwater level close to that of the bottom of the tank (Fig. 8);
b) Septic tank of precast concrete tubes/rings is applied when the ground water level is under the level of excavation (Fig. 9);
c) Rectangular brick stone or stone tank applied in dry soil (fig.10).

If the foundation is on macroporous (loose soils) foundation, the soil must be treated as indicated in the geotechnical approval. It is recommended to perform mechanized excavation, usually without using horizontal stabilizers, with slopes up to the platform for casting the foundation plate. The slope angle is determined by the nature of the soil/land.

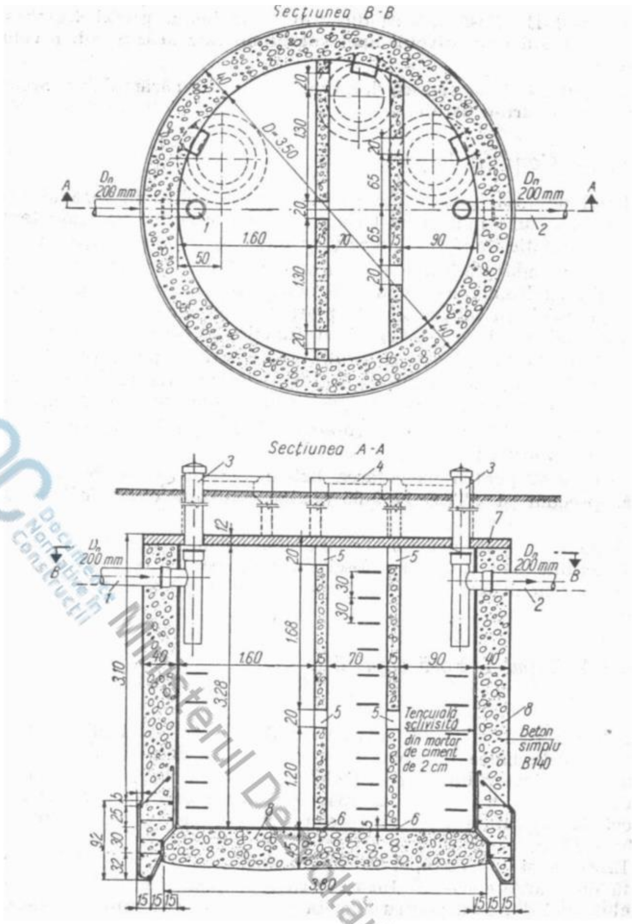


Fig.8. Circular caisson septic tank of reinforced concrete: 1 – inlet, cast iron drain pipe; 2 – outlet, cast iron drain pipe; 3 – cleaning basket; 4 – reinforced concrete or cast iron tap; 5 – passage holes 20 x 20 cm; 6 – holes 15 x 5 cm; 7 – reinforced concrete B140; 8 – simple concrete B140

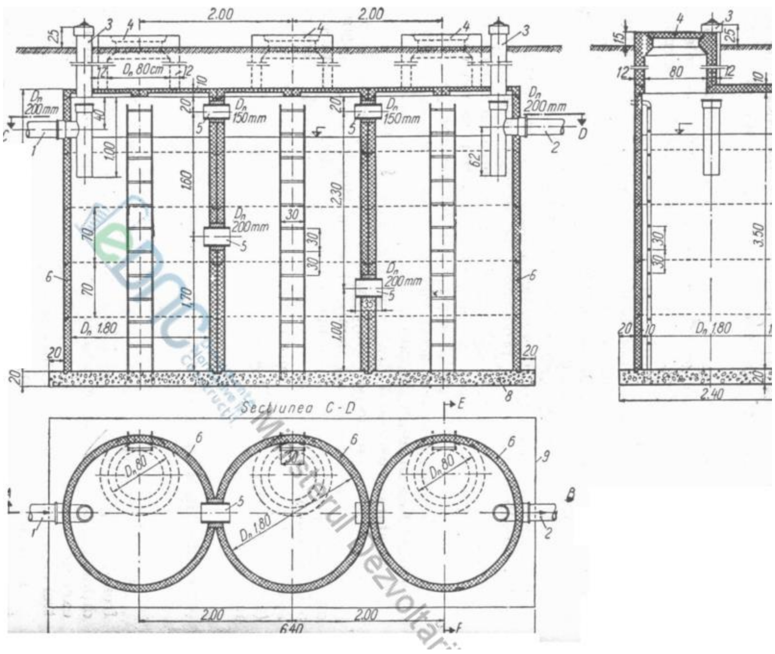


Fig.9. Septic tank of off-the shelf rings: 1 – inlet, cast iron drain pipe; 2 – outlet, cast iron drain pipe; 3 – cleaning basket; 4 – reinforced concrete or cast iron tap; 5 – concrete tube; 6 – precast concrete tubes B250; 7 – cement mortar; 8 – concrete B90; 9 - compacted clay ground boundary layer

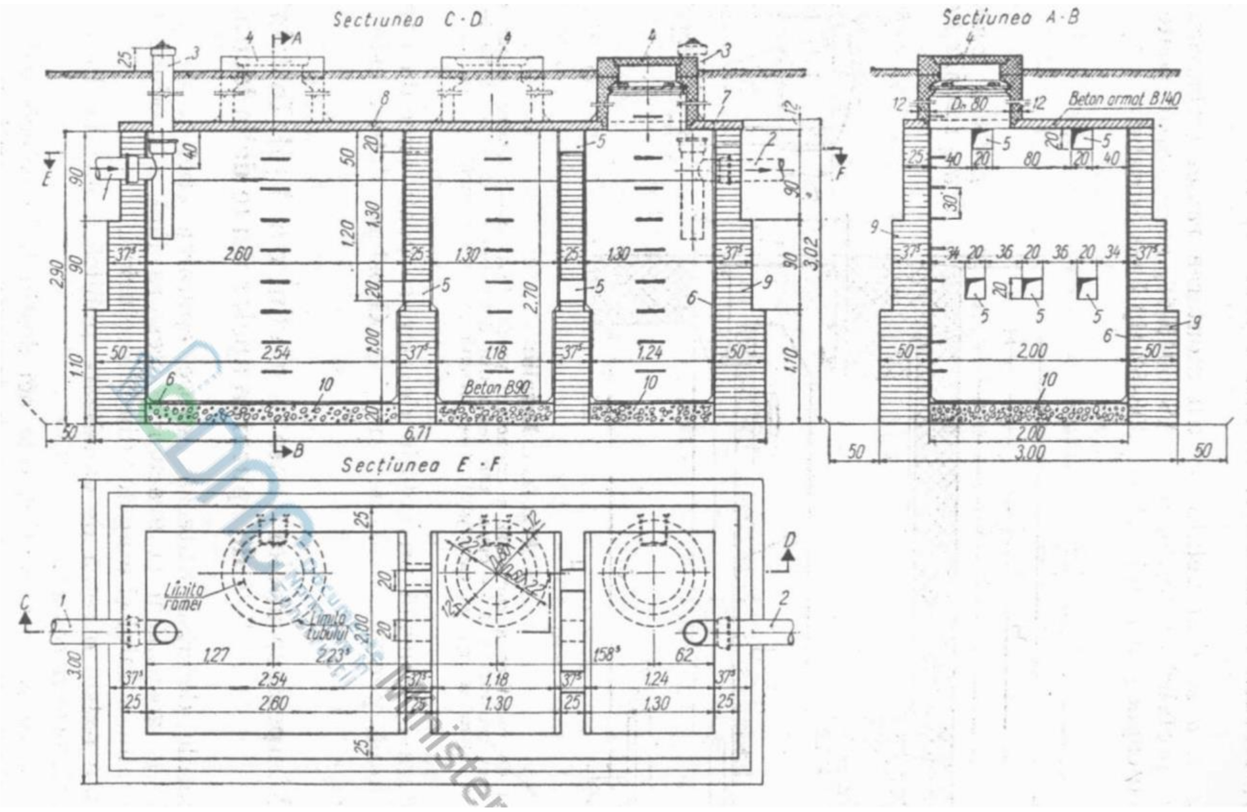


Fig.10. Brick stone rectangular septic tank: 1 – inlet, cast iron drain pipe; 2 – outlet, cast iron drain pipe; 3 – cleaning basket; 4 – reinforced concrete or cast iron tap; 5 – passage hole 20 x 20 cm; 6 - trowel plastering of 2 cm thick cement mortar; 7 - paperboard insulation; 8 - reinforced concrete B140; 9 - brick wall; 10 - Concrete B90

11.1.57 After execution of works urgent measures must be taken for commissioning and filling of the tank with water, so as to avoid keeping the sections dry for more than 10 days after termination.

11.1.58 Inlet and outlet into and from the septic tank should be done through tubes, the mouths of which are 0.70 m below the water level in order to avoid clogging of the hole by the floating sludge and oil formed on the water surface.

11.1.59 After completion of construction and its verification, the tank is filled with water up to the channel level. Thereafter, 0,5 – 1,00 m3 of sludge from another septic tank or from a simple cesspool is inoculated. 3-5 kg of lime is then added in lumps, to ensure the production of methane fermentation (alkaline) in the beginning, avoiding the production of hydrogen sulphide. If inoculation of sludge is not being performed, when committing it should be considered that the startup time to normal operation may take 6-8 months. To make this time shorter, it is recommended to commission the tank in the warm season.

11.1.60 Emptying of sludge from the septic tank is performed once a year, preferably in summer. During the emptying, 10-20% of deposited, fermented sludge must be left in the septic tank, in order not to interrupt the methane (alkaline) fermentation of the septic tank’s content. The fermented sludge is removed through the manholes using a vacuum facility (vacuum truck) and transported to the field or will be buried.

Imhoff tank;

11.1.61 Primary settling of wastewater in small and medium settlements or isolated objects (spa resorts, sanatoriums, etc.) that do not exceed 10 thousand m3/day can be carried out in multilevel settlers (also referred to as Imhoff or Emscher). In these wells, in the upper chamber with two V-shaped walls sedimentation takes place, and at in the inferior chamber, anaerobic fermentation of sedimented sludge occurs at ambient temperature (cold fermentation). The solids from the settler reaches the fermenter through a 0,25 m wide slot at the bottom trough of the upper chamber .

11.01.62 The settling troughs in cross section are formed of a rectangular cross section with b x h1 (Figure 11) and a triangular cross-section at the bottom, on the h2 depth. The walls of triangular section are designed with an inclination of 1.2: 1 for a quick slip of deposits to the lower floor/space through the slot from the top of the triangle. The lower edge of one of the inclined walls of the trough outruns the edge of the other inclined wall by 0.15 cm so that sludge particles and gas bubbles that rise from the fermentation process do not reach the settling space (trough). The width of the trough shall not exceed 3.0 m, and the depth (h1 + h2) is recommended of 1.2 - 2.0 m in order to achieve a uniform flow of the wastewater throughout the entire cross-section.

The entering of wastewater in and the clarified water out of the tank are performed in the same manner as in horizontal settlers through the channels provided across the width of the trough. In front of the intake trough at a distance of 0.5 - 0.7 m semi-submerged screens are provided to ensure uniform distribution of wastewater in the settler. At the end of the sedimentation zone a semi-submerged is also provided for capturing floating matter. On the outlet vertically adjustable sluices are provided to ensure a perfect horizontality for a uniform discharge of settled water.

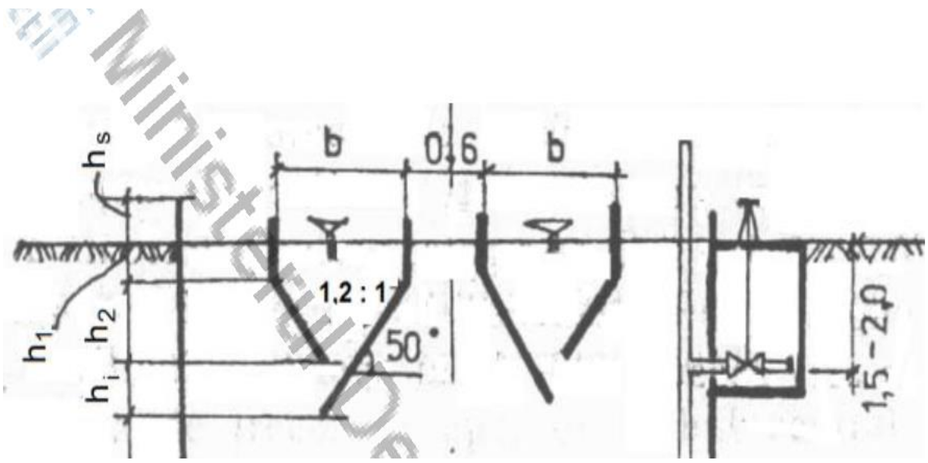


Fig.11. Imhoff tank with two settlings

11.1.63 The constructive elements of settling troughs are determined based on the following formula:
$n_{dec} = L_j^{total} / l_j$; $V_j = Q_c \cdot t_{dec}$; $L_j = V_j / A_j$; $A_j = b \cdot h_1 + 0,3\ b_2$,
where:
V_j is the volume of settling troughs, m3;
Q_c - calculation flow, high time, m3/h;
t_{dec} – settling time in settling troughs; the recommended time is min. 1.5 hours;
A_j – cross-section area of a settling trough, m2;

L_j^{total} – total length of the settling troughs, m;
l_j - the length of the trough from one tank with the diameter D, m; in tanks with diameters up to 6 m a single trough is provided, i.e. l_j = D, and in tanks with diameters up to 10 m two troughs are provided and therefore, l_j = 2D;
b – the width of the trough, m;
n_{dec} – number of Imhoff tanks with the diameter D.

11.1.64 The sedimentable suspended solids reaching the lower/septic chamber undergo an anaerobic fermentation process. The volume of fermentation space determined by the tank foundation plate placed 0.5 m below the lower edge of the settling trough is calculated using the equation:
$V_{ferm} = C \cdot N_{conv} / 1000$, m^3,
where: N_{conv} – conventional number of residents covered by the treatment plant;
C - specific fermentation capacity, l/man·year, which shall be adopted in accordance with Table 5.

Table 5. Specific fermentation capacities of Imhoff tank

Average winter temperature of wastewater, °C	Specific fermentation capacity, l/man-year
6	110
7	95
6.5	80
10	65
12	50
15	30

Since fermentation spaces are not heated, the fermentation time lasts 100-220 days.

11.1.65 When operating the Imhoff tank, the environmental conditions required for methane fermentation must be permanently monitored. This imply the following measures: to maintain a constant inside temperature, the tiered settlers are built entirely or partially underground, and the height difference is protected by earth filling; at the beginning of fermentation the process must be primed with fermented sludge or other type of inoculum in an amount of 10-25% of the volume of fermentation area; periodic destruction of the crust on water surface, formed of risen sludge particles together with fermentation gas, in order to avoid obstruction of the slots of settling troughs.

11.1.66 The fermented sludge is discharged through pipes with a diameter of 200 mm by the hydrostatic pressure of the water column in 1.5 - 2.0 m in the tank. The sludge is conducted to a neighboring pit with 2 compartments: one dry compartment, where the maneuvering valve is located, and a wet one, where the fermented sludge is discharged and then - to dehydration or transportation. For a smooth sliding of fermented sludge to the central part, where the lower end of the sludge pipe is located, the bottom of the fermentation chamber should be at an angle of at least 30°.

11.1.67 The total depth Imhoff tanks estimated at 8-10 m is determined by:

$$H_{total} = h_s + h_j + h_n + h_d, \text{ m}$$

where:
h_s – height of the safety space, above the tank water level, estimated at 0,40- 0,50m;
h_j - height of the trough ($h_j = h_1 + h_2$), under 2,0 m;
h_n - height of the neutral area, under 0,5 m;
h_d - height of deposits in the fermentation space.

11.2 Design of vertical flow phyto-filters

11.2.1 To achieve a uniform distribution of incoming wastewater all over the surface of vertical flow phyto-filter units, the supply must be done with a net flow rate much higher than the one entering the treatment plant. This requires supply through a storage-accumulation tank of a relatively long duration, followed by short periods of high feed rates for the filters. The filter supply by accumulation tanks connected by gravity or by means of a pumping station must produce an instantaneous flow, enough to provide a uniform distribution of wastewater and suspended matter contained therein over the entire surface (within the limits of a bed) - flooding of these beds and self-cleaning of distribution pipelines. Indicatively, a flow rate equal to or greater than 0.5 m^3/h for 1 m^2 of a supplied filter can ensure proper distribution provided that the wastewater distribution system is properly designed. The higher the specific flow for a square meter of surface, the better the distribution, as long as the upper/maximum flow rate of the supply flows does not exceed 1.5 $m^3/(m^2 \cdot h)$ [1]. Such a uniform distribution can be achieved by providing a large number of disperses (at least one point of the dispersion per 50 m^2 of filter surface).

11.2.2 As for the volume supplied by each batch, it must provide a layer of water with the thickness between 2 and 5 cm distributed as evenly as possible all over the surface of the phyto-filter/bed powered or operated. The instantaneous flow and the volume of supply batches are mutually related: the lower the supply volume, the greater the instantaneous flow in order to "soften" or wet the entire surface of the filter supplied in a short time.

11.2.3 A system of manual or automatic control valves must ensure the alternation of instantaneous flow and rest phase batches of each vertical flow phyto-filter unit in the first phase. This system is placed upstream of the intermittent supply unit (in batches).

11.2.4 The treatment system must be fitted with wastewater gauging/meters to allow assessing both the flow rates and the volumes of wastewater which is distributed to the phyto-filters. In the gravity supply system one metering device for counting butches is sufficient. When pumping/draining the wastewater, the duration of pumps operation may be metered, provided that they are calibrated correctly in their actual operating conditions.

11.2.5 The supply by gravity to vertical flow filters should be provided according to the following conditions and incorporating the following components:

- using of small diameter pipes and valves that can be eventually clogged/obstructed by suspended solids and greases should be avoided;

- the need to empty the storage tanks at a speed sufficient to drive the suspended solids;

- mechanical equipment to be provided, such as: self-priming siphons, on/off valves, valves with swinging flaps.

This equipment is typical for large instantaneous flow rates (calculated based on the loss of load in downstream wastewater distribution devices) and by consistency/stability of flow rates during/between emptying of the tank, especially towards the end of the operation of self-priming siphons. The emptying must be complete to avoid accumulation of suspended solids and formation of sludge in the tank. Between the supply phases (during the rest phase) the wastewater flow should be null.

11.2.6 In the supply of phyto-filters by means of pumping/pressure the pumps and connecting pipes must be adapted to the type of wastewater carried in them. The minimum nominal diameter of pumps and pipes is DN 60 mm [2]. At the same time, security devices must be available to protect pumps from hydraulic shocks, wastewater shortage, overpressure or obstruction/blockage due to clogging. Thermal insulation of hydraulic systems must be provided to avoid their freezing.

11.2.7 Pumping stations form an integrated body with the batch/intermittent supply systems, and the pumping rate must be as independent as possible of the waste water level in the catchment tank. The pumping station is equipped with at least two pumps, each of which is sized for different design supply flow requirements. The wastewater storage/accumulation tank should be equipped with an efficient ventilation to avoid buildup of gas, mainly hydrogen sulfide (H_2S). The foundation plate of the catchment tank of the pumping station must be provided with a slope to the sludge vessel.

11.2.8 As mentioned before, the distribution/allocation of raw wastewater should be done so that it occupies the entire surface of the vertical flow phyto-filter supplied by the fed batch and be uniform/homogeneous. The pipeline network that supplies the distribution points should be designed so as to allow full emptying and excluding stagnation of water in it, in order to avoid the deposition of suspended solids, odors and the possibility of frost. The set of equipment and fittings must be accessible for inspection and cleaning. The wastewater distribution system must operate at a self-cleaning rate of not less than 0.7 m/s of water discharge/transport.

11.2.9 For the supply of raw wastewater to vertical flow phyto-filters overflowing spillage distribution troughs or point/concentrated disperser can be used. The troughs require a high supply flow rate and is a system adapted to small areas of up to 50 m^2. Their disadvantage is the risk of accumulation of suspended matter in the vicinity at the entrance of the trough.

The raw wastewater distribution system with point/concentrated disperser is preferable if the number of supply/injection points is high enough. These are distributed in an accurate and symmetric manner to provide a uniform/homogeneous distribution. The system is calculated based on the thickness of the water layer and the area of filters to be supplied. At least one injection point for about 50 m^2 of filter surface will be considered. Anti-erosion devices will also be provided, such as plates resistant to erosion or gabions at the level of the point/concentrated dispersers.

To facilitate the drainage of the deposits/sludge layer accumulated on the surface of phyto-filters, when its thickness hinders a normal operation, it should be possible to temporarily dismantle the distribution pipes and the dispersers.

11.2.10 The distribution of wastewater on the surface of vertical flow filters in the second phase, where appropriate, just like in the first phase, should be made in a similar manner in order to ensure a uniform/homogeneous coverage of the entire filter surface for each portion. Given the low concentration of suspended solids in the wastewater that feeds the second phase and although the filter material is composed of sand and the filtration rate is lower, the number of dispersers/injection points in this phase must be increased compared to the first phase.

A homogeneous dispersion of partially treated wastewater can be provided by a network of unburied perforated pipes, given the risk of obstruction/plugging of holes by the plant roots and rhizomes of reeds.

The punctual/concentrated dispersers system is recommended if the number of injection points is rather high and if the flow of each disperser is sufficient to ensure a uniform/homogeneous distribution. In this case at least one injection point must be provided at 5 m^2 of the filter area.

11.2.11 As mentioned earlier, the number of parallel filters is determined by the ratio "supply phase/rest time", which is managed by alternation of supply to the filters. The first phase is generally composed of 3 filters, and the second one - only 2 filters.

The basic values of the area, recommended by specialized literature for designing vertical flow phyto-filters are as follows:

- total area - 2 ÷ 2.5 m^2/resident, including

- first phase surface (3 parallel filters) - 1.2 ÷ 1.5 m^2 /resident

- second phase area (2 parallel filters) – 0,8÷1,0 m^2/resident.

These values apply to permanent population. They were established so as to achieve necessary performance in the winter season, which is less favorable for biological treatment. Performances in summer season prove that the plants can withstand much larger loads, with the surface area reduced to 1 m^2/resident.

11.2.12 The first phase of the vertical flow phyto-filters consists of 3 layers of filter material - gravel/pebbles:

- The 30 cm upper filtering layer of fine gravel with granules of 20 to 80 mm;

- The 10-20 cm intermediate/transition layer of gravel with granules of 3 - 20 mm and a thickness of 10 -;

- The 10 - 20 cm drainage layer of gravel with granules of 20 - 60 mm.

The thickness of the first layer of 30 cm may be increased depending on the desired treatment degree.

11.2.13 The material of the upper layer of the second phase phyto-filter consists of sand. Its function is to retain suspended matter. If a high degree of nitrification is wanted, an additional layer of 30 cm of fine gravel with a particle size of 2 to 8 mm can be provided. The composition of siliceous sand must be predominantly of alluvial origin and it should contain particles not smaller than 80 μm to avoid the risk of clogging of the filter.

Thus, the following composition of second phase phyto-filter filling is recommended:

- The upper filter layer of alluvial sand with particle sizes of 0.25 mm <d10 <0.40 mm, the fine material content should not exceed 3% of mass, with the minimum thickness of 30 - 60 cm, depending on the desired treatment degree, with the content of limestone ($CaCO_3$) not exceeding 20% by mass;

- The intermediate/transition layer of gravel with the grain size from 5 to 10 mm and a thickness of 10 to 20 cm;

- The drainage layer of gravel with a grain size of 20 to 40 mm and a thickness of 10 to 20 cm.

The data on the composition of phyto-filters are shown in Table 6.

11.2.14 For the filling of phyto-filters in both phases, alluvial materials (smooth, round particles) are preferred. Whatever the granulation of alluvial material (gravel, sand) it should be thoroughly washed and contain less than 3% by mass of fine material (d <80 μm).

When assembling layers of filter material, to avoid their mixage and migration of particles the TERZAGHI rules must be followed with regard to conditions of granulometric transition. They provide for a granulometric composition of filters so that the diameter d_{15} of the filter material granules is at least 1/4 of d_{85} of the previous filtering layer, which would prevent the possibility of fine particles to pass through the lower layer.

The constructors must justify the choice of the granulometric composition of different filter materials available under these rules.

To help the builders, Figure 12 shows the distribution of diameters of the filter material granules recommended for vertical flow filters, according to recommendations [27]).

The transition layer in vertical flow filters is designed to prevent/avoid migration of upper layer granules of sand to the lower/drainage layer of coarse grain gravel. Thus, the grain size (granulometric composition) of the intermediate/transition layer depends mainly on these two materials, which composition is determined by applying the TERZAGHI rules. These rules establish the d_{50} of the transition layer relative to the lower draining layer and d15 relative to the upper filtering layer according to the following two inequalities:

d50 drainage/10 ≤ d50 transition ≤ d50 drainage/5

d15 transition ≤ d85 filtering

Table 6. Characteristics of filling (filtering) materials of phyto-filters

Type of phyto-filters	Layers	Filter material	Grain size, d, mm	Layer height, cm	Note
Single/mono vertical flow (one-phase)	- protecting - upper - intermediary - lower - drainage	gravel sand pebble gravel gravel	5-10 m 1-4 mm 0,2<d_{10}S0,4 mm 2-8 mm 16-32 mm 32-56 mm	5 cm > 30 cm > 20 cm > 10 cm > 15 cm	Non-uniformity ratio 3 < d_6o/dio —6
Vertical flow, 2 phases: - first phase - second phase	- Upper - intermediate - drainage - protecting - upper - intermediary - drainage	pebble fine pebble gravel Pebble fine sand pebble pebbles	20-80 mm 3-20 mm 20-60 mm 2-8 mm 0,25<d_{10}<0,4 mm 5-10 mm 20-40 mm	> 30 cm 10-20 cm 15-20 cm 30 cm 30-60 cm 10-20 cm 15-20 cm	
Single/mono horizontal flow (one phase)	- Distribution gabions - collection - Filtering	Gravel mixed	40-80 mm 5-20 mm (4-8 mm)	length > 0,75 cm 45-60 cm	
Mixed (2 phases) -1 phase, vertical flow -II phase, horizontal flow	- superior - intermediary - filter drainage - filtering (treatment)	Pebble and fine gravel sand	<%- 20-80 mm 3-20 mm 20-60 mm u 1-4 mm (6-12 mm)	> 30 cm 10-20 cm 15-20 cm 45-60 cm	

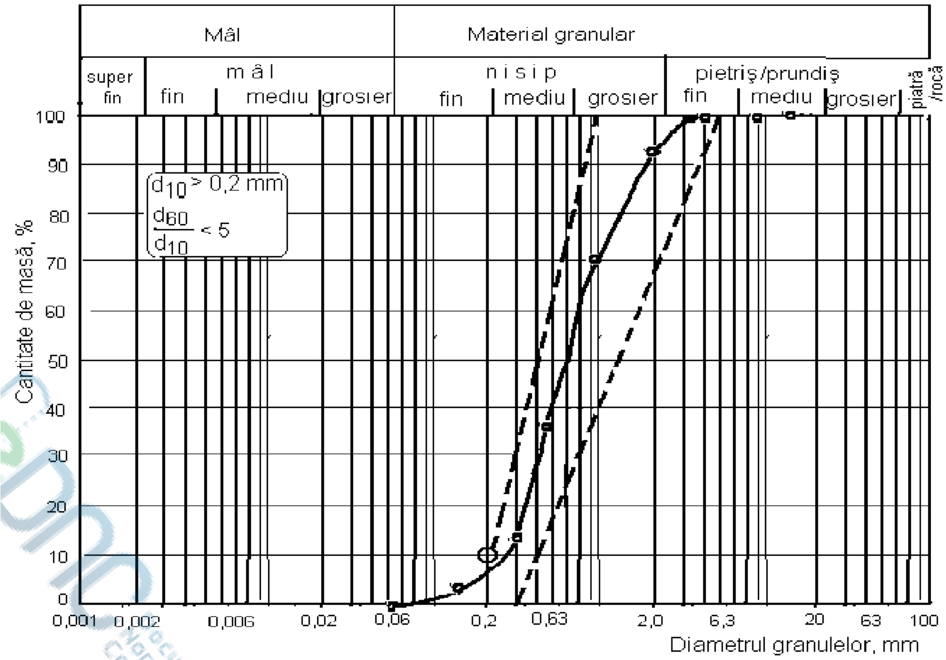


Fig.12. Distribution of granule material recommended for filling the phyto-filters

Below is an example of this rule for the transition layer between the second phase sand layer and the drainage layer of gravel with granules of 20÷60 mm at d_{50} of 40 mm (Fig.13).

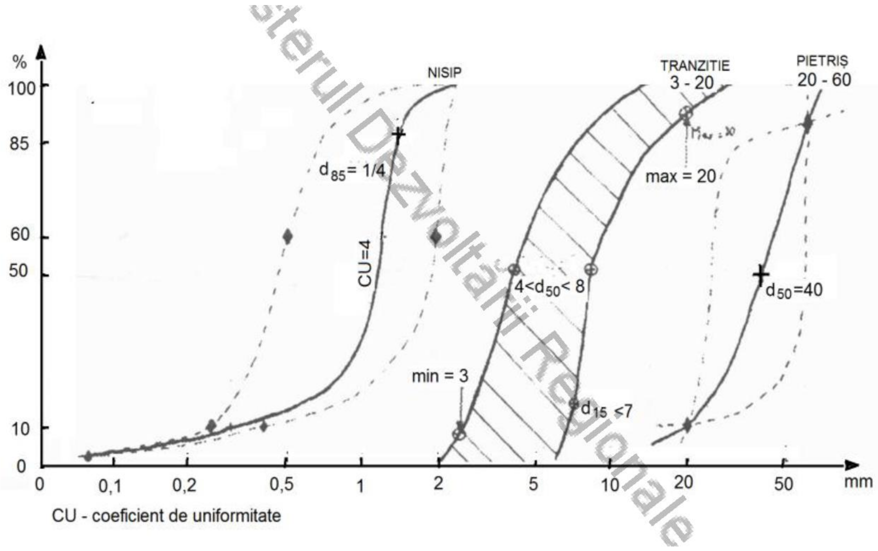


Fig.13. Dependency of transition layer on the filtering lower layer and the filtering upper layer

11.2.15 To collect the treated wastewater from the drainage layer of vertical flow phyto-filters, a system of slotted plastic tubes will be used, with a diameter of at least 100 mm and of a high resistance class, in order to avoid the risk of damage. The openings of the drains must have wide slits of 5 mm on one third of the circumference, placed at a distance of 15 cm from each other and oriented towards the bottom. The bottom of the filters must be laid on with a steady slope toward the collection drains to avoid water stagnation areas.

The ends of the drain pipes must be connected with the atmosphere air through solid tubes with mesh at the upper end so as to protect it from falling objects in ventilation ducts and drains. Use of right-angle fittings must be avoided. The diameter of ventilation tubes and their openings must correspond to diameter of drains. The drains must be accessible for inspection and cleaning.

11.02.16 Disposal of sludge from vertical flow phyto-filters of the first phase will be performed after every 10÷15 years. This sludge is well stabilized and is not fermentable. The cleansing of deposited and stabilized sludge layer can be performed using a shovel equipped with a basket to clean the ditches with a sharp edge or a tracked excavator for large surface filters. This requires sufficiently wide spaces for access of sludge transportation mechanisms (tractors with trailer or trucks). These access restrictions can be limiting factors for the actual areas of filters/beds. Inthis regard, building temporary ramps for the period of sludge discharge could be considered.

11.3 Design of horizontal flow phyto-filters

11.3.1 In horizontal flow phyto-filters, to prevent their clogging with suspended matter contained in the raw wastewater, primary/mechanical treatment is necessary.

The primary wastewater treatment can be provided in two ways:

a) providing septic tanks or primary settlers, combined with sludge digesters/fermenters. The presence of a septic tank or a settler-digester creates the risk unpleasant odors, which should be taken into account in their design, including the corrosion concern etc. Particular attention should also be paid to the location of the treatment plant, taking into account the prevailing wind direction;

b) providing vertical flow filters as a first phase. This solution is preferable because it allows simultaneous filtering of wastewater and sludge stabilization, while contributing to improving the secondary/biological treatment.

11.3.2 Normally, the wastewater supply to horizontal flow filters is continuous/uninterrupted, but use of an intermittent/discontinuous supply by gravity or by means of pumping stations can also be considered. These options are preferable for large surface filters and with distribution of water through several points.

For filters placed in parallel, it is necessary to place a distribution chamber between the primary settler and the grour of parallel filters to allow regulation of wastewater flows for each filter/bed.

11.3.3 In order for the wastewater streams to enter the bed in a uniform manner on the set of supply trench a distribution/repartition device must be provided. Two solutions can be provided for in this regard:

a) a channel with a strictly vertical overflow wall, slightly flooded under the water level in the filter, which distributes the wastewater across the full width of the filter (Figure 14);

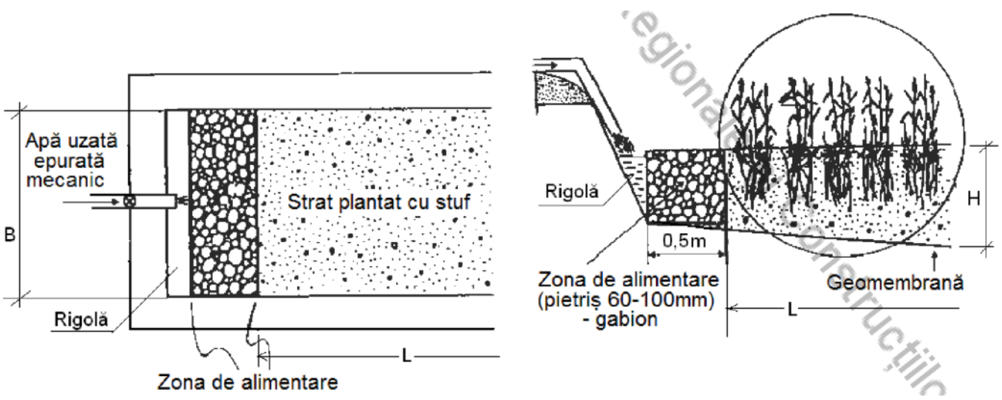


Fig.14. Horizontal flow supply through a channel

b) A plastic pipe line, located on the edge of the filter, with a large number of perforations / injection holes, so that the cross-sectional distribution of water is as even as possible (Figure 15).

This pipeline should not be buried in the filter material in order to avoid clogging of openings by reed plant roots.

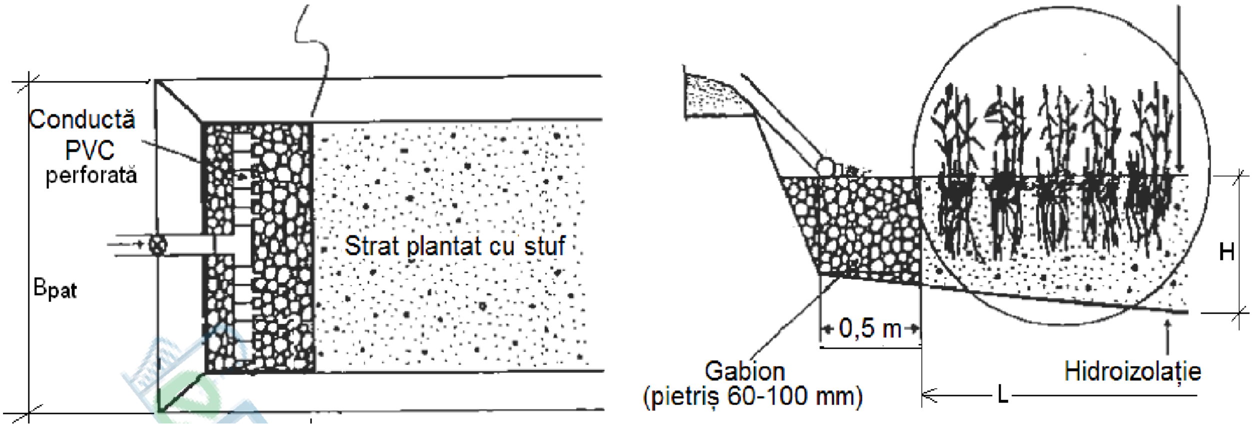


Fig.15. Horizontal flow supply by pipe line

11.3.4 The area of horizontal flow filters depends on loading of wastewater with pollutants. In the same way as for the vertical flow filters an empirical approach leading to sizing of filter surfaces in relation to the number of connected residents could be accepted also for the horizontal flow filters. Specific areas have been established for two types of previous stages treatment:

- if settler-digesters are used, the specific surface area is equal to 5 m^2/resident

- when vertical flow filters are used as a first phase of treatment - 2-3 m^2/resident.

11.3.5 Given that the area of phyto-filters is determined according to p.11.3.4, the bed geometry will be designed taking into account the permeability of the filter medium, whereby the water moves horizontally along the filter. This permeability can be approximated by the permeability of filling materials according to the Darcy's Law.

The equation expressing this approximation is as follows:

$$Q = A \cdot K_1 \cdot (dH/dL),$$

where:

Q is the daily flow rate expressed in m^3/s;

A – the surface of cross-section of the filter/bed in m^2:

A = H· B (H – height of the water layer on the filter and B – width of the bed);

K_1 – hydraulic conductivity of the native filter material in m/s;

dH/dL – hidraullic gradient (m/m) used conceptually, corresponding to the water level slope in its flow through the filter material: from the surface of the filter at the inlet to about 10 cm of the total height at the outlet level.

The maximum useful depth of the filters is 0.6 m. The 0.5% slope of the foundation plate is recommended to allow emptying the filter’s tank.

The K_1 values used for sizing the filters are of the order of values of filterability/permeability of the filter material, which is directly related to the granulometric composition of the filter material and which changes with the progressive clogging of the filler layer. For information, the sand with the characteristics described in p.11.2.13 has a permeability of the order of $5\ 10^{-4}$ m/s, and the gravel wit particles of 20-30 mm - 1 m/s.

11.3.6 The iterative calculation of the geometry of the phyto-filter bed will be made as follows:

- on the basis of the foregoing equation the cross-sectional area A is calculated, assuming the initial value of the hydraulic gradient dH/dL. Knowing the depth/thickness of the filtering layer (0.6 m) the B thickness is calculated; the L length is then deduced from the horizontal surface S. Then the height of water upon exiting the filter H = (dH/dl) L is determined;
- this calculation is then reiterated by varying the values dH/dL until an output water level of about 10 cm of the filter layer surface is established (Fig.16).

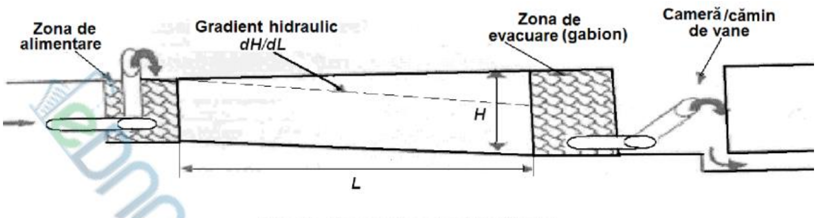


Fig.16. Geometria patului fitofiltrelor

Fig.16. Geometry of phyto-filter bed

Once the width of the cross-section has been established according to the flow rate of treated wastewater, it must be ensured that the wastewater will be distributed evenly at the level of the supply pipe line or the channel through as shown in p.11.3.3.

11.3.7 In horizontal flow filters supplied with settled wastewater it is recommended to use filter material with a grain size from 4 to 8 mm. For phyto-filters placed downstream of the vertical flow filters, a finer grain size can be used – from 1 to 4 mm. The acceptable grain size may be 6÷12 mm. The designers should pay attention to inherent difficulties caused by very fine filter materials, which may be irreversibly clogged and could not be washed in any way during the operation of phyto-filters, especially of those with horizontal flow.

11.3.8 The devices for drainage of treated wastewater should allow setting the level of water in the filtering layer at min 5 cm below the surface of the filling. The drain pipes of 100 mm in diameter are provided for the collection of treated wastewater into the drainage ditch/gabion. They may be replaced by a drainage ditch filled with large grains, from 60 to 80 mm, on the whole width of the filter. The drainage device can be equipped with a rotating angled plug and a flexible hose or tube with the top attached at different heights (Figure 17).

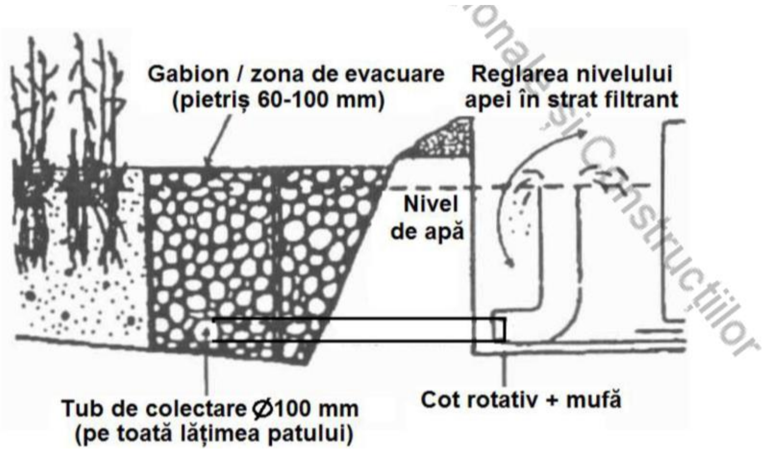


Fig. 17. Regulation of water level in the filtering layer upon exiting the horizontal flow filter

11.3.9 From the experience accumulated over the years 1980-2014 in different EU countries, the properly designed and built phyto-filters ensure the compliance with the EU Directive on urban wastewater treatment considering the removal of suspended solids (SS) and organic pollutants expressed in COD and BOD_5, these indicators showing degrees of treatment of over 80-90% in winter and summer seasons respectively.

As for the removal of nutrients (N and P), the single phase phyto-filters only provide partial reduction due to incomplete denitrification and dephosphorylation. The pathogens (coli-bacteria) are reduced by 1-3 log (logarithmic units).

A higher degree of biological treatment is provided by 2-phases filters: 1) vertical flow filters ("French" system) or 2) the "hybrid" system – with vertical flow filters in the first phase and horizontal flow in the second phase. This technology can insure the nitri-denitrification by removing nitrogen compounds, while for phosphorus removal and disinfection an advanced chemical treatment and express disinfection in maturation or ultraviolet ponds can be provided, where necessary [22].

12 Technical recommendations for construction of phyto-filters

12.1 The sealing of phyto-filters can be either natural, using a soil layer with low water permeability of K_s = 10.8 m/s at a depth of 0.3 m, or artificially, with geomembranes. The waterproofing must be tested for each bed by filling with water.

12.2 If waterproofing is ensured by a system with geomembranes, these should be opaque, resistant to attrition and UV radiation. They should provide a sufficient resistance against perforation by reed/cane roots. Usually, geotextiles should be able to protect the geomembrane against perforation both inside and outside of the filter. The maximum thickness of the geomembranes depends on the basic component: 1 mm for PVC and poly-propylene (PP), 1.5 mm for HDPE, 1.4 mm for EPDM and 3 mm for bitumen.

12.3 The selection of filters must be assessed in two phases:

- Selection based on information collected from quarries: grain size, content of fine material, content of limestone;

- On-site checking of supply conformity with information collected from the selected quarry, based on grain size and cleanliness measurements, and permeability estimation.

There are no particular requirements and precautions for pebbles, except that it must be washed and not be mixed with the soil when it is stored.

The sand filtration layer it is recommended to be placed in successive layers of 15 ÷ 20 cm in order to exclude any problems with stratification/migration.

Most precautions must be taken for the circulation of trucks and other heavy machinery in order not to damage the filter layers, drains and the geomembranes.

12.4 The macrophytes can be planted at any time except during frost or extreme heat. There must be a minimum density of 4 plants per m^2. Rhizomes can also be planted (2 knots) considering 5 pieces per m^2. Usually the moist part of the filters is planted, the other parts being eventually covered with expanding rhizomes as the wastewater flow increases and the wetted surface expands.

For horizontal flow phyto-filters it is recommended to leave the water level a few centimeters below the air surface of the filter layer during plant development (3 ÷ 4 months) to prevent weed growth.

12.5 Below a list of recommendations is presented concerning trials/tests at different phases, taking into account the peculiarities of the process of wastewater treatment in reed beds [7].

A. In the process of construction-installation works:

- soil investigations: geotechnical studies are carried out not long before execution of works;

- granulometric analysis of filter material;

- checking the joints of geomembranes;

- verification of conformity of location/position of supply and distribution facilities (levels and sizes/volumes) with the project, especially for gravity systems;

- checking the levels and compliance of flow rates with the pump operation curbs and the flows provided for in the project;

- checking the measuring and control devices.

B. Before commissioning:

- testing the operation of hydraulic installations of the plant when filling with clean water, at the same time checking the consumption of pumps and/or self-priming/self-priming siphons and checking the uniformity of distribution systems’ operation;

- tests/trials on roads and pipelines;

- leakage tests;

- checking the flatness of infiltration surfaces.

C. During the startup period:

- checking of wastewater distribution and fixing of horizontality flaws, if necessary;

- study of the development of the vegetation (survival rate, appearance etc.);

- supervision of formation of the shallow layer of sludge on the beds of the first phase of vertical flow filters;

- supervision of plant attachment and removal of weed;

- training of maintenance/operation staff.

D. During the period of observation/examination:

- Supervision of permeability, especially of horizontal flow phyto-filters and of vertical flow phyto-filters in the second phase;

- studying the development of vegetation;

- Supervising the sludge layer formation on the beds of the first phase of vertical flow phyto-filters;

- Adjusting the water level at the outlet of horizontal flow phyto-filters so that the water level as high as possible while avoiding the total flooding of the filtering layer.

E. Before discharge/cleaning of sludge:

- Chemical analysis of sludge: humidity, organic ratio: mineral, content of micro-elements to ensure compatibility with use of sludge on agricultural land.

13 Operation of phyto-filters

13.1 For operating the phyto-filters the designer will develop a detailed instruction on operation and maintenance of treatment plants, in particular in terms of the operating conditions in different macrophyte growing seasons. At the same time, due attention should be drawn to the indications referring to vital security and labor protection measures.

13.2 As in all treatment plants, the plants of this type should be subject to regular maintenance and supervision. All observations and interventions will be entered in the register of the treatment plant. Given the alternation established for the supply of vertical flow reed beds, at least a weekly examination is required [10,14]. Besides the manufacturer's recommendations, the main maintenance should concern pretreatment facilities, supplies and distribution of water for treatment.

13.3 The staff of the treatment plant should conduct the monitoring of the proper operation of phyto-filters according to the volume set out for traditional processes and technologies. In addition to these, measures of control specific to phyto-filters must be carried out, including:

- Regular analysis of the quality of wastewater treated in preliminary treatment plants by determining the concentration of suspended solids (SS) and biodegradable organic pollutants (BOD), which will allow to control the sludge formation and the need to drain it, while observing the sludge layer level;

- Control of ventilation (aeration) of the filter body, ensuring the prevention of clogging of the filter layer.

This should be performed by determining the content of ammonia in the treated water and the change in the value of water oxidation-reduction potential; ammonia concentration exceeding 10 mg/l indicates malfunctioning of the supplied water supply facilities and its drainage or burdening of phyto-filters, while the reduction in redox potential indicates insufficiency of oxygen, which can be the result of the organic or hydraulic overload of phyto-filters;

- Measuring and recording of wastewater flows using flow meters or measuring the operation time of pumps that pump the water from the catchment-uniformity or distribution tank. Table 7 shows the volume and the calendar plan of treatment plant operations.

Table 7. Volume and schedule of plant operation control [16]

Control activities		Frequency	
Control indicators	Control places	Time intervals	Seasons
Content of biodegradable organic pollutants - BOD	Pre-treatment facilities at outlet	Monthly	
Content of ammonia NH_4-N or the value of redox potential -rH	at the outlet of horizontal flow phyto-filters	Monthly	especially in spring
		For each phase or continuously (optionally)	
The flow of wastewater and the recirculation ratio, where appropriate	At the inlet of phyto-filters	Weekly	
Distribution of wastewater and discharge of treated water	At each phyto-filter	Weekly	

13.4. Technical maintenance and operation works for the facilities are shown in Table 8.

Table 8. Maintenance and operation works at phyto-filters wastewater treatment plants

Facilities	**Performed works**	**Frequency minimum**	**Note**
General works	Making of the operation report	Annually	Attaching the operation log
Pre-treatment	Visual inspection of the water levels, checking the functionality of the distribution and drainage facilities. Control of the ventilation system	Monthly	Leakage, clogging, preparing/discharge of sludge etc.
Catchment/uniformization tank with pumping stations	The functionality of pumps, recording of flow meters data or the operation time	Monthly	Automation system, entering data into the register
Wastewater distribution facility	Control of proper operation	Monthly	Cleaning, adjusting to required flows, where necessary
Phyto-filters	Visual inspection of the surface of filters, vegetation, checking for presence of backwater (increased water level), adjusting the discharge level of treated water	Monthly	Discharge of sludge, pulling of weed, cleaning of fallen leaves etc.
Treated wastewater discharge facility (drainage system)	Visual inspection of functionality	Monthly	Cleaning/washing of pipes
Control manhole	Sampling of treated wastewater	Monthly	Determining the SS, BOD, NH_4, pH, color, smell, temperature
Treated water discharge system	Visual inspection of the free flow of treated water	Annually/monthly	Cleaning, repair, construction and embankment strengthening

Additionally, provisions must be made for mowing and harvesting of vegetation (macrophytes), which during the frost season can be left on the surface of phyto-filters for protective insulating.

13.5 Strict technical operation requirements include:

- Supervision of water in reed beds;

- Control of wastewater levels according to operating instructions;

- Monitoring of phyto-filters in terms of treatment performance/efficiency of wastewater;

- Regular surveillance of treatment plant supply and discharge of treated wastewater, to be performed at least weekly.

13.6 The treatment plant maintenance requirements should include:

- Repair of embankments;

- Control of useful vegetation density;

- Removal/weeding of undesirable weed species;

- Repair of pipes and overflow ducts;

- Renewal of the filtering layer, as appropriate;

- Repair of fences or other auxiliary constructions;

- Pest control (rodents, mosquitoes).

13.7 Starting with the year following the planting, the trimming/harvesting of plants should be performed every year. If winters are harsh, it is recommended to leave the plants after harvesting /trimming, in order to provide thermal insulation of the phyto-filters when new branches emerge, so as not to damage them by stepping on them (generally before March).

As a precautionary measure, the reed stems below 30 cm will not be cut, in order to avoid water entering the plant tissue through the cutting section.

13.8 The sludge formed in the first phase of vertical flow phyto-filters must be removed once in 10 years. The content of solids in the accumulated sludge is in the range of 20- 30%, and the content of organic matter ranges from 35% in the lower, older layer, to 60% at the surface. The sludge removal must be carried out carefully to avoid damaging of the filtering layer of the phyto-filters by pulling the root system of reed/cane [11].

13.9 The instruction on operation of phyto-filters, usually developed by the designer, must contain the following:

- The operating mode of installations: continuous, periodic, through alternation (for several parallel phyto-filters);

- Measures to prevent and fix the stagnant backwater issues in filter layers;

- Measures to prevent the development/growth of foreign (unwanted) weed;

- Indications for the use of phyto-filters for treatment of wastewater from seasonal undertakings (campgrounds, boarding houses, camps, etc.) and, in particular, relating to the operation/maintenance off the season, to maintain the operating efficiency of phyto-filters;

- Preventive measures necessary to prepare for the winter in case of strong frosts;

- List of control and maintenance works indicated in p.p. 13.3 - 13.6;

- Macrophyte care/maintenance measures;

- Guidelines for the collection, treatment and disposal of coarse material and sludge from pre-treatment facilities;

- The maximum level of sludge in wastewater pre-treatment facilities and the required/necessary quality of pre-treated wastewater (e.g., SS and BOD_5), as well as measures to be taken when these parameters are exceeded.

ANNEX

(for information purposes)

Examples of calculation

Design of phyto-filters of an extensive biological treatment plant for a settlement of under 1,000 conventional residents with a specific flow of domestic wastewater equal to q_{spec} 120 l/pers/day. One-phase phyto-filters that will biologically treat the wastewater prior subject to mechanic pre-treatment are provided.

1. Quantitative characteristics of wastewater

Daily flows:

$$Q_{day,\ aver} = N_{res\ \cdot\ qspec} /1000 = 1000 \cdot 120 / 1000 = 120\ m^3/d$$
$$Q_{day,\ max} = Q_{day,\ aver} \cdot K_{day,\ max} = 120 \cdot 1{,}15 = 138\ m^3/d = 0{,}0016\ m^3/s$$
$$Qday,\ min = Qday,\ aver \cdot Kzi,\ min = 120 \cdot 0{,}7 = 84\ m^3/d$$

Hourly flows:

$$Q_{h,\ aver} = Q_{day,\ max} /24 = 5{,}75\ m^3/h = 1{,}6\ l/s$$
$$Q_{h,\ max} = Q_{or,\ aver.} \cdot K_{hr,\ max} = 5{,}75 \cdot 2{,}5 = 14{,}4\ m^3/h = 4{,}0\ l/s$$
$$Q_{h,\ min} = Q_{or,\ aver} \cdot K_{h,\ min} = 5{,}75 \cdot 0{,}38 = 2{,}2\ m^3/h = 0{,}61\ l/s.$$

2. Qulitative characteristics of wastewater:

a) Concentrations of main pollutants to be removed in phyto-filters:

- suspended solids (SS, mg/l), considering the efficiency of pre-treatment of 40%:

$$[SS] = a_{MS} \cdot 1000 / q_{spec} = 65 \cdot 1000 / 120 = 542\ mg/l \cdot 0{,}6 = 325\ mg/l$$

- chemical oxygen demand (COD, mg/l), considering the efficiency of pretreatment of 20%:

$$[COD] = a_{COD} \cdot 1000 / q_{spec} = 120 \cdot 1000 / 120 = 1000\ mg/l \cdot 0{,}8 = 800\ mg/l$$

- biological oxygen demand (BOD, mg/l), considering the efficiency of pretreatment of 20%:

$$[BOD_5] = a_{BOD} \cdot 1000 / q_{spec} = 60 \cdot 1000 / 120 = 500\ mg/l \cdot 0{,}8 = 400\ mg/l$$

b) Daily pollutant loading of wastewater stream (after pre-treatment):

- suspended solids (SS, mg/l);

$$G_{SS} = Q_{day,\ max} \cdot [SS] = 138 \cdot 325 / 1000 = 44{,}85\ kg/d$$

- chemical oxygen demand (COD):

$$G_{COD} = 138 \cdot 800 / 1000 = 110{,}4\ kg/d$$

- biological oxygen demand (BOD5):

$$G_{BOD5} = 138 \cdot 400 / 1000 = 55{,}2\ kg/d$$

3. Required treatment degree according to EU Directive:

Effluent of phyto-filters must comply with the following requirements:

$$COD \leq 125 \text{ mg/l}$$
$$BOD_5 \leq 25 \text{ mg/l}$$
$$SS \leq 35 \text{ mg/l}$$

The required treatment efficiency will be:

$$- \varepsilon_{CCO} = (800\text{-}125) / 800 \cdot 100 \% = 84{,}4 \%$$
$$- \varepsilon_{CBO5} = (400\text{-}25) / 400 \cdot 100 \% = 93{,}75 \%$$
$$- \varepsilon_{MS} = (325\text{-}35) / 325 \cdot 100 \% = 89{,}23 \%$$

A. Singe phase phyto-filters

1. The area of phyto-filters - air surgace of filters planted with macrophytes (reeds or rush).
a) Calculate the area of horizontal flow filters, based on the specific area of 5 m^2 per resident (see p. 11.3.4):

$$A_{ff}^{\ horis} = 1000 \text{ x } 5 = 5000 \text{ m}^2$$

b) For vertical flow filters, the specific area is 2.5 m^2/resident (see p. 11.2.11):

$$A_{ff}^{\ vertic} = 1000 \text{ x } 2{,}5 = 2500 \text{ m}^2$$

2. Design of reed beds
a) Horizontal flow phyto-filters
The total area of horizontal flow filters $A_{ff}^{\ horiz} = 5000$ m^2, while from the recommended maximum area of 500 m^2 for a bed, determine the required number of beds/filters:

$$n_{ff}^{\ horiz} = 5000 : 500 = 10 \text{ beds.}$$

The cross sectional area of horizontal phyto-filters is calculated based on the Darcy law (p.11.3.5):

$$A_s = Q_{day,\ max} / K_l\ (dH/dL),\ m^2$$

By substituting these values and adopting $Q_{day,\ max} = 0.0016 / 10 = 0.00016$ m^3/s according to the number of beds; K_l - the hydraulic conductivity of the filter layer, while taking account of clogging of the pores of suspended solids and biofilm formed in the filtering layer, equal to 1.8·10-4 m^3/s; dH/dL=0.1, we obtain:

$$A_s = 0{,}00016 / 1{,}8 \cdot 10\text{-}4 \cdot 0{,}1 = 9{,}0 \text{ m}^2$$

Considering the thickness of 0.6 m of the filter layer (p. 11.3.5), the width of the phyto-filters will be equal to:

$$B_{ff} = 9{,}0 / 0{,}6 = 15{,}0 \text{ m,}$$

while their length, based on the air surface of phyto-filters equal to 500 m^2 of each bed will be:

$$L_{ff}^{\ horiz} = 500 / 15 = 33 \text{ m.}$$

Thus, the size of a horizontal phyto-filter in plane will be 15 x 33 m, with the ratio of 1: 2,2 (oblong beds).
b) Since the filtering will be held vertically through the 0.8 m thick filter layer, the design of the vertical flow phyto-filters will take into account the air surface equal to 2500 m^2 = 1000x2,5
Same number of beds equal to 10 and the area of each bed will be:

$$A_{ff}^{\ vert} = 2500 / 10 = 250 \text{ m}^2$$

Similarly we adopt the thickness of a bed of 15 m and then the width of the beds will be equal to:

$$L_{fv} = 250 / 15 = 17 \text{ m,}$$

with a ratio of 17: 15 = 1 : 0.9 (almost square beds).

B. Two-phase phyto-filters

<u>The ”French” system</u>
The French system alternative to the single phase phyto-filters is a series of vertical flow phyto-filters with 2 phases - with intermittent/periodic supply of 3 parallel filters in the first phase and 2 phyto-filters in the second phase.

Treatment of raw wastewater without pre-sedimentation is considered, because the filter layer of the first phase filters consists of large grain pebble, which allows filtering wastewater containing suspended solids. As these are retained in the upper part of the first phase filters, forming a sludge layer, which under aerobic conditions and under intermittent flooding of filters is subject to a good aerobic stabilization of the putrescible organic matter and accumulates, allowing for its drainage from the surface of filters with a frequency of once every 10-15 years.
The phyto-filters are designed assuming a specific surface in m^2 per one conventional inhabitant, considering the thickness/depth of the filter layer of 0.8 m.

Design of the first phase of vertical flow phyto-filters:
a) For vertical flow phyto-filters, the first phase is calculated considering the specific area of 1.2–1.5 m^2/resident (11.2.11):

$$A'_{fv} = 1{,}5 \cdot 1000 = 1500\ m^2.$$

In the design of filter beds, a configuration of 2 parallel groups of 3 beds is considered, i.e. 6 beds in total. In such case, for each bed there is $A_{bed} = 1500 : 6 = 250\ m^2$. The standard size of a filter bed of 15 x 17 m (15 x 17 x 6 = 1530 m^2)> 1500 m^2 are adopted, i.e. the total area is increased by about 15%.

b) The area of second phase vertical flow phyto-filter is calculated based on the surface area of 0.8-1.0 m^2/resident (p. 11.2.11):

$$A''_{fv} = 1.0 \cdot 1000 = 1000\ m^2.$$

In the design of the second phase filter beds, a configuration of 2 parallel groups of 2 beds is also considered, i.e. 4 beds in total. In such case, for each bed there is $A_{bed} = 1000 : 4 = 250\ m^2$. The standard size of a filter bed of 15 x 17 m (15 x 17 x 4 = 1020 m^2) > 1000 m^2 is adopted, i.e. the total area of the second phase phyto-filters is increased by about 10.2%.

c) The distribution of wastewater on the surface of vertical flow filters is provided considering the provisions of p. 11.2.9. Thus, distribution pipes with the diameter of 60 mm is provided for the first phase phyto-filters.

Dispersers are provided to disperse the wastewater considering the computation for one disperser per 50 m^2 and for the second phase filters - the pipes are perforated, based on the calculation of a hole per 5 m^2.
- The number of first phase phyto-filters' dispersers:

$$n'_{disp} = A''_{fv} / 50 = 1728 / 50 = 35 \text{ dispersers}$$

For 6 beds, for each of them

$$n^{bed}_{disp} = 35 / 6 = 6 \text{ dispersers (per } 250\ m^2)$$

- Number of openings in the wastewater distribution pipes on the surface of second phase phyto-filters:

$$n''_{holes} = 1152 / 5 = 230 \text{ holes or slits of 2 cm}$$

For 4 beds, for each of them

$$n^{bed}_{holes} = 230 / 4 = 58 \text{ holes or slits of 2 cm.}$$

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