Phytofilter – environmental friendly solution for purification of surface plate from urbanized territories

O Ruchkina\textsuperscript{1} and I Shchuckin\textsuperscript{2}

\textsuperscript{1} Doctor of Technical Sciences, Professor of Department of Heating, ventilation and water supply and sewerage, Perm National Research Polytechnic University, Russian Federation, Perm
e-mail: xgogax@mail.ru

\textsuperscript{2} Senior Lecturer of Department of Heating, ventilation and water supply and sewerage, Perm National Research Polytechnic University, Russian Federation, Perm
e-mail: shchukin-is@yandex.ru

Abstract. It is proved, that phytofilters are environmental friendly solution of problem of purification of surface plate from urbanized territories. Phytofilters answer the nowadays purposes to systems of purification of land drainage. The main problem of it is restrictions, connecter with its use in the conditions of cold temperature. Manufactured a technology and mechanism, which provide a whole-year purification of surface plate and its storage. Experimentally stated optimal makeup of filtering load: peat, zeolite and sand in per cent of volume, which provides defined hydraulic characteristics. Stated sorbate and ion-selective volume of complex filtering load of ordered composition in dynamic conditions. Estimated dependences of exit concentrations of oil products and heavy metals on temperature by filtering through complex filtering load of ordered composition. Defined effectiveness of purification at phytofiltering installation. Fixed an influence of embryophytes on process of phyttogeneration and capacity of filtering load. Recommended swamp iris, mace reed and reed grass. Manufactured phytofilter calculation methodology. Calculated economic effect from use of phytofiltration technology in comparison with traditional block-modular installations.

1. Introduction

Problem of removal and purification of surface plate (SP) is one of the most popular issues of urbanized terrains. Today for purification of land drainage there exist installations of mechanical and physical-and-chemical treatment. Together with moderate effectiveness of purification this installation have high construction and exploitation estimate, what limits the possibility of it extensive use.

Up-to-date systems of purification of surface plate have to answer following purposes: ability to purify wide range of pollutions; environmental friendliness of constructing and exploitation; maximal energy- and resource-saving; aesthetic visual appearance; ability to re-use the land drainage as a source of technical quality water supply. Installations of mechanical and physical-and-chemical purification of land drainage not in full answer following purposes.
Perspective growth option for purification systems land drainage is usage of bioengineered installations as of phytofilters, which are well known in world practice as raingardens, bioretention filters, stormwater biofilters (information about a principles of phytofiltration and structures of phytofilters is described in works [1–3]). Statistics of foreign investigations testify that these installations have high technological effectiveness in condition of low-cost construction and exploitation. Nevertheless on the territory of Russian Federation phytofilters nowadays have low distribution. One of the reasons of it are the limits on exploitation of phytofilters in the low temperature conditions (less than +10 °C), when there is low trend of plants activity and soil microorganisms [4, 5]. This is very important for territories with mild climate, which are characterized the existence of winter season with below zero temperatures and icecap, because, at first, conversion times with near-zero temperature last long and, at second, on that period there appears significant quantity of land drainage.

2. Solution for sustaining high effective work of phytofilter and storage purified surface plate in the cold periods

For the purpose of sustaining high effective work of phytofilter in the periods of near-zero temperatures there is offered induction in composition of resin charge components, which are sorbate and ion-selective – peat and zeolite.

The chase of zeolite as an addition to resin charge components is conditioned of its moderate cost on the one hand, and on the other hand high sorbate and ion-selective abilities in relation to hydrocarbon and heavy metals, which is proven by a large body of researches [6, 7].

Also there is known a positive influence of addiction of zeolites in soil, which influence on plant growth by means of keeping of air-and-water balance of soil [8].

High sorbate size of fen peat related to oil products and heavy metals is mentioned in work [9]. Peat besides its sorbate of oil products and heavy metals capabilities is a source of organic components for plants and soil microorganisms.

Thus in the cold periods purification from dissolved solids is achieved by the processes of sorbate and ion exchange on pointed out materials and in the period of vegetation of plant there take place its phyto- and bioregeneration due to absorption, transformation, stabilization and degradation of cumulated elements under the influence of plants and microorganisms, progressing in resin charge and rhizosphere. Besides the growth of root and top of plants enables the regeneration of void space and therefore capacity of resin charge. Thus the sustainable high quality of SP purification in the whole year is achieved and also long period of work of resin charge before renewal is achieved.

We offer engineering-and-technical solution of storage purified surface plate purposely to its re-use [10]. Realization of solution is provided by use of inert hard-grained bulk material (HGBM), for example, gravel and break-stone, situated under phytofilter (Figure 1). The use of HGBM with water-proof fundament for storage purified SP is cheaper than traditional solutions – reservoirs made of steel, plastic or fiberglass. Besides this construction isn’t fracture-prone while frost-heaving phenomenon of watered soils and freezing of water in intergranular space.

3. Laboratory investigation of phytofiltration and phytoregeneration processes

For investigation of processes of phytofiltration and phytoregeneration was developed pilot lab phytofiltration mechanism. Filtering columns (Figure 2) are made of soil pipes made PolyVinylChloride, 160 mm diameter 1 m height with load of fixed composition. Columns were filled layer-by-layer like this: 100 mm – sand, 300 mm – complex load ; zeolite; sand in 1:2:7 proportion to volume; 100 mm – gravel 5–20 mm, 100 mm – gravel 20–40 mm. Substantiation of composition and chemical properties of complex filtering load is written in work [11]. Investigations in dynamic conditions have shown high sorbate and ion-selective capacity of complex filtering load (Table 1).
Figure 1. Engine for purification and storage of land drainage:
1 – settling chamber or filter (optional); 2 – treatment unit;
3 – bowl, filled with discharged water; 4 – resin charge; 5 – plants; 6 – reservoir with hard-grained bulk material;
7 – hard-grained bulk material; 8 – drain-pipe; 9 – impenetrable fundament; 10 – flow-metering mechanism; 11 – drill-hole; 12 – deep-water pump.

Table 1. Results of investigation of sorbate and ion-selective capacity of complex filtering load of given composition in dynamic conditions.

| Contaminator     | Oil-prod. | Cu   | Al   | Pb   | Fe    |
|------------------|-----------|------|------|------|-------|
| Sorbate (ion-selective) | 40.08     | 0.505| 1.708| 0.738| 0.933 |
| volume, mg/g (meq/g) |           | (0.016) | (0.061) | (0.007) | (0.049) |

In the filtering columns were planted common reed grass (*Phragmites comminis*), mace reed (*Typha latifolia*) and swamp iris (*Iris pseudacorus*), 3 columns with plant of every type. Signed types were chosen on the fundament of carried out analysis of 15 plants, which are wide-spread in midlatitudes and meeting next requirements: hydrophil, heavy root system, unpretentiousness, cold resistance. Also there were concerned 3 control columns without plants.

For giving synthetic brine of land drainage individually in every column was used additional reservoir volume of 50 litres and deep-water pump.

As a source of water for watering and preparation of synthetic brine was used centralized aqueduct. For purifying faucet water from pollutions, which could affect the result of experiment (suspended solids, iron compounds, hardness, free chlorine) was foreseen three-level filtration system, containing filters of mechanical, sorbate and ion-selective purification. Filtered faucet water got tanked into supply tank with volume 50 litres, from which it was pumped by deep-water pump through the spreader pipe into filtering columns with period once twenty-four hours when timer signals. The volume of sprinkling water was 1.5 litres for every filtering column. Excesses of water, which were filtered by the installation were poured in aqueduct. For sampling of purified water were foreseen flexible PolyVinylChloride hoses in the bottom of columns.

For the purpose of plats life support was foreseen the system of illumination with fluorescent lamps OSRAM FLUORA 36W (4 pieces) This lamps a made special for growing up plants and have optimal spectrum of illumination. Switching on and switching off the lamps was automatically by timer. Duration of photoperiod was 14h per day-and-night cycle. Scheme and exterior of phytofiltration mechanism is depicted on Figure 2 and 3.
Figure 2. Scheme of pilot phytofiltration mechanism:
1 – giving of municipal water; 2 – filtration system; 3 – consumption tank; 4 – deep-water pump;
5 – timer, that controls watering; 6 – timers, that controls illumination; 7 – system of water conveying;
8 – drop bottle; 9 – fluorescent lamp; 10 – clear tube h=250 mm.; 11 – phytofiltering column;
12 – timber framing; 13 – sampling hose; 14 – ready-made outflow tube; 15 – water remove in canalization

Figure 3. Exterior of pilot phytofiltration mechanism

Phytofiltration effectiveness was investigated by giving in filtering columns surface plate imitator,
which contains oil products and heavy metals in concentrations, which are showed in Table 2. In every
column in the 7 week period was given 350 litres of SP imitator, which is 70% of year volume of land
drainage in condition of rainfall intense 600 mm per year and square of impenetrable water-gathering territory 40 times bigger than phytofilters square. Samples collection of effluents with determination of degree purification from pollutants took place after giving every 50 litres of SP imitator.

**Table 2. Composition of surface plate imitator**

| Parameter                      | Reagent for preparation SP imitator               | Concentration, mg/litres |
|-------------------------------|--------------------------------------------------|--------------------------|
| Suspended materials Oil products, mg/litres | Sweepings form car road, bolted through bolt № 008 blend of naphtha Nefras (Нефрас mineral thinner) C2-80/120 and industrial oil H-20A in 1:1 volume proportion Fe, Cu, Pb, Al | 500, 30, 0.3, 0.5, 0.4 |

Results of work of pilot phytofilter mechanism are represented in Table 3.

**Table 3. Range and central case of concentrations of pollutants in effluents after phytofiltering columns**

| Plant type (column numbers) | Range of concentrations of pollutants in effluents, mg/litres | Average concentration in effluents, mg/litres |
|-----------------------------|-------------------------------------------------------------|---------------------------------------------|
| Mace reed (1-3)             | Susp. mat. 5.2–13.6, 0.43–1.21, Cu 0.003–0.006, Al 0.01–0.05, Pb 0.1–0.13 | Fe 0.075                                    |
| Reed grass (4-6)            | Susp. mat. 6.9–10.2, 0.273–0.618, Cu 0.001–0.009, Al 0.01–0.08, Pb 0.068–0.17 | Fe 0.086                                    |
| Swamp iris (7-9)            | Susp. mat. 5.8–13.2, 0.227–1.34, Cu 0.002–0.006, Al 0.01–0.02, Pb 0.1–0.14 | Fe 0.051                                    |
| Control (10-12)             | Susp. mat. 6.2–16.8, 0.49–1.36, Cu 0.002–0.007, Al 0.01–0.03, Pb 0.152–0.161 | Fe 0.093                                    |
| MAC 1*                      | Susp. mat. 0.05, Cu 0.001, Al 0.04, Pb 0.006 | Fe 0.1                                      |
| MAC 2**                     | Susp. mat. 0.1–5, Cu 0.1–4, Al 1–10, Pb 0.2–1 | Fe 2–20                                     |

*Maximum Allowed Concentration in Russian Federation commercial fishing branch
**Maximum Allowed Concentration in European Union [12]

On the fundament of analysis results of work of pilot phytofiltration mechanism (Table 3) following conclusions were made. Effectiveness of purification of surface plate from suspended materials was amounted 97.2–98.9 %, oil products 95.5–98.9 %, Cu – 97–99.3 %, Al – 80–86.4 %, Pb – 66–86.4 %, Fe – 87.5–97.5 %. The opportunity of drain of surface plate after phytofiltration in the water object is determined by national directives to content of pollutants in water basin. Purified surface plate suits European Union directives to discharge in water basin. For surface plate gathering after phytofiltering in water basins intended to commercial fishing on the territory of Russian Federation there needs deep additional cleaning from oil products and heavy metals with use of absorbent carbon.

According to offered concept of phytofilter work in the conditions of mild climate, cleaning from salted oil products and heavy metals in the periods of cold temperatures is carried out by the sorbate
and ion-selective processes in complex filtering load. For determinaion of purification effectiveness in the cold temperature conditions filtration of SP imitator through the sorbate column at temperature +2 °C, +8 °C and +20 °C took place. Exit concentrations after filtering at pointed out temperatures are shown in Figure 4.

![Figure 4. Dependence of exit concentrations on temperature](image)

In condition of falling temperature from +20 °C to +2 °C effectiveness of purification from heavy metals have lowered at the level of 4.8–10.6 %, from the oil products – 5.5 %.

For evaluating the speed of phytoregeneration of filtering load there were analyzed dynamics of fluctuations of oil products concentration and motile form of heavy metals in root layer of filtering load in the period of 2 months after breaking the giving surface plate imitator.

Filtering load selection was made from near-root layer of plants, as nearly as possible to the roots.

The results of investigation of phytoregeneration of filtering load under the influence of embryophytes are shown in Figure 5.

There is ascertained that average speed of lowering of the concentration of heavy metals in columns with swamp iris was made – 8.33 mg/kg/month, Al – 4.39 mg/kg/month, Pb – 2.83 mg/kg/month, Fe – 7.77 mg/kg-month, in columns c reed grass: Al – 2.85 mg/kg-month, Pb – 0.58 mg/kg-month, Fe – 7.67 mg/kg-month.. The decrease of concentration of heavy metals in filtering load in columns with mace reed wasn’t signed.

Decrease in oil products in filtering load was seen in all columns: with mace reed at 192.41 mg/kg-month, reed grass at 249.3 mg/kg/month, iris at 137.27 mg/kg-month, at control column – 113.60 mg/kg-month. Decrease of oil products concentration in control columns is explained by its degradation by soil microorganisms and vapor of floats. However all columns with plants have shown more than control columns extract of oil products from the load. This can be explained by degradation of oil products by the plants and by stimulation effect by rhizosphere microorganisms, going on at the plant’s root layer.

Aiming at determine calculated water volume, which could be accumulated in the volumetric unit hard-grained bulk material, was experimentally estimated water return of river roundstone and granite macadam of different fraction.

Water return of investigated materials more or less didn’t depend on fraction and worked out at the average 450 litres/m³ (321 litres/t) for granite macadam and 400 litres/m³ (250 litres/t) for river roundstone.

On the fundament of undertaken studies was developed calculation methodology of phytofilter, which allows depending on square and type of surface of well field, quality of off-taken surface plate,
consumers directive to quality and quantity of purified rain waters to define its overall dimensions, periodicity of renewal of filtering load, volume of tank accumulation of purified waters.

4. Economic effect from the use of phytofiltering technology and technical solution on storage purified land drainage in hard-grained bulk material

Offered phytofiltering technology was adopted in the process of production of design and estimate documentation in project “Purifying installations for cleaning land drainage for “Yugovskiy integrated plant of milk products””. Economic effect from the use of phytofiltering technology in compare with traditional block-modular installations, estimated by method of life cycle cost estimate equaled 27.09 million of rubles. This effect was reached by lowering cost on handling purifying installations, lowering periods of renewal of sorbate mechanism of additional cleaning, absence of costs for transfer of waste water.
For economic justification of carried technical solution on storage purified land drainage in hard-grained bulk material was carried out calculation materials costs and labor for storage 50 m³ phytofilter purified rainwater (Figure 6). Calculation was carried out in prices for 2nd quarter of 2016 year on virtue of catalogues of producers, price of 1 t of gravel of 40–600 mm fraction is 350 rub, pit gravel – 800 rub, water return of pit gravel is 450 litres/m³, gravel – 400 litres/m³.

Calculation has shown that costs of organizing of storage of purified land drainage in comparison with offered solution is lower for 50.8 – 276.8%.

5. Conclusion

Manufactured technology of phytofiltration for purification of surface plate, inclusive of conditions of mild climate zone and species composition of plant in temperate latitudes. Developed technical mechanism, which provides the whole-year purification of land drainage and its storage in order to its next re-use. (Patent of Russian Federation No. 2540620).

Experimentally defined optimal composition of filtering load: peat 10 %, zeolite 20–40 %, sand 50–70 % of volume, which provides specified technical characteristics – speed of free-flow filtering 0.3 m/h in condition of head of liquid 0.3 m. Sorbate and ion-selective volume of complex filtering load specified composition in dynamic conditions equaled: oil-products – 40.08 mg/g, Cu – 0.505 mg/g, Al – 1.708 mg/g, Pb – 0.738 mg/g, Fe – 0.933 mg/g.

Estimated dependences of exit concentrations of oil products and heavy metals from temperature, while filtering through complex filtering load specified compositions.

On the fundament of experimental investigations estimated effectiveness of purification at phytofiltering installation: from suspended materirals – 97.2–98.9 %, oil products – 95.5–98.9 %, Cu – 97–99.3 %, Al – 80–86.4 %, Pb – 66–86.4 %, Fe – 87.5–97.5 %.

Estimated influence of embryophytes: swamp iris (Iris pseudacorus), reed grass (Phragmites communis) and mace reed (Typha latifolia) on the process of phytoregeneration and capacity of filtering load. Experimentally defined the speed of phytoregeneration of filtering load from heavy metals and oil products. Swamp iris has made – 8.33 mg/kg-month, Al – 4.39 mg/kg-month, Pb – 2.83 mg/kg-month, Fe – 7.77 mg/kg-month, in columns c reed grass: Al – 2.85 mg/kg-month, Pb – 0.58 mg/kg-month, Fe – 7.67 mg/kg-month, oil products 249.3 mg/kg-month in condition of plant population 50 plants/m2. Determined that effectiveness of regeneration of capacity by plants has down trend like this: swamp iris > reed grass > mace reed.

Manufactured phytofilter calculation methodology, which helps in condition of specified characteristics to calculate needed square of phytofilter, operating time before filtering load renewal, to define volume of hard-grained bulk material for purified water storage.

Economic effect from the use of phytofiltering technology in compare with traditional block-modular installations, estimated by method of life cycle cost estimate equal 27.09 million of rubles.

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