THEORETICAL FOUNDATIONS OF NATURAL WATER TREATMENT BY FILTRATION

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Abstract
One of the urgent problems of today is the purification of drinking water and the supply of high-quality drinking water to the population. It is established in Article 24 of Chapter 6 of the Decree of the Republic of Uzbekistan No. ORQ-784 dated 22.07.2022 on drinking water supply and wastewater disposal. According to the resolution, it is envisaged to carry out the preparation and supply of drinking water and the technological stages of drinking water preparation in water facilities, taking into account the quality of water in the water body, the capacity of the facility and its geographical location. In finding optimal solutions for the technological processes of drinking water preparation in water facilities, proposals and considerations were made on the optimal selection of materials used as fillers in rapid filters and the provision of high-quality and required drinking water to the population

Keywords: Rapid filters, fillers, standard, size, pressure, granularity, loading.

Introduction

The quality of water intended for drinking, household, and technical purposes is determined by the presence and concentration of various dissolved and undissolved mineral and organic substances. This quality is evaluated through the combined assessment of its physical, chemical, bacteriological, and biological characteristics. In the Republic of Uzbekistan, the requirements for drinking water quality are regulated by the Uzbekistan State Standard "Drinking Water: Hygienic Requirements and Quality Control" — UzDSt 950:2011. For water used in industrial enterprises, the quality standards are set according to specific sectoral regulations and technical specifications, which may vary depending on the field of application. One of the widely used methods of improving water quality is disinfection by bactericidal radiation. This method inactivates microorganisms present in the water by exposing them to ultraviolet rays with bactericidal properties, particularly with wavelengths in the range of

2200–2800 Å, which are proven to be most effective in microbial destruction. Such treatment is often used as an additional step in water purification after mechanical and chemical filtration. In water treatment practice, multi-layer filters are frequently applied. In principle, these filters are similar to single-layer filters, but the filtering medium consists of several layers made from different materials, each designed to capture particles of specific sizes. The process in which water flows through a layer of filtering material is called filtration.
Filtration serves to clarify water by capturing suspended solids, colloidal particles, and other fine impurities. The filter medium is typically composed of a porous, fine-grained material capable of retaining these particles. Quartz sand is the most common filtering material due to its high porosity, mechanical strength, chemical resistance, and stability against dissolution in water.
Slow sand filters are used for purifying water with fine particles without chemical additives. These filters are filled with fine quartz sand, and filtration occurs at relatively low rates. For example, if the concentration of suspended solids in water does not exceed 25 mg/L, the filtration rate is maintained at around 0.2 m/h; if the concentration reaches up to 50 mg/L, the rate is reduced to 0.1 m/h to ensure proper removal efficiency.
However, in modern practice, rapid filters are more commonly used for large-scale water treatment. The principle of operation of rapid filters involves pre-treating water with chemical reagents (coagulants and flocculants) to aggregate fine particles, followed by filtration through a bed of quartz sand. This approach significantly increases the rate of filtration while maintaining high water quality standards.

Materials and methods

A filter is defined as a basin or tank filled with a filtering medium and equipped with devices for supplying raw water, collecting filtered water, and washing the filtering medium. Multi-layer filters are, in principle, similar to single-layer filters; however, the filter bed consists of several layers of materials arranged in a specific sequence. The materials used in the filter may differ in grain size, density, and chemical composition. In the treatment of fresh groundwater, disinfection is often considered the only required process, since such water typically contains fewer impurities than surface water.
The degree of filtration depends on the size of suspended particles in the water, the granularity of the filter medium, and the type of filtration facility used.
At the bottom of the filter, a drainage system is installed. Above the drainage layer, a supporting medium — usually gravel or small stones — is placed, with the grain size decreasing progressively from bottom to top. Above this supporting layer lies the filtering medium, typically composed of quartz sand, with particle size decreasing from bottom to top.

During operation, the filter remains filled with water, ensuring continuous contact between the water and the filtering medium.
The filtration capacity is expressed in terms of filtration rate, defined as the height of the water column passing through the filter per unit of time (m/h). In slow sand filters, uncoagulated water is filtered through a layer where a biological and mechanical film forms on the surface of the filtering medium, trapping suspended particles. In this process, no chemical reagents are used, and water is clarified purely by mechanical and biological means. Filtration rates for slow sand filters typically range from 0.1 to 0.3 m/h.
The operational cycle of a slow sand filter consists of three main stages:
Formation of the filtering film (1–2 days) — during this time, a layer of biofilm develops on the surface of the sand, improving filtration efficiency.
Normal operating period (1–2 months) — during which filtration continues at stable efficiency until clogging occurs.
Filter cleaning (washing) — performed when the hydraulic resistance becomes too high.
In modern water supply systems, rapid filters are more widely used for large-scale purification. The principle of rapid filtration involves pre-treating water with chemical reagents (coagulants) and then filtering it through quartz sand. Suspended matter in the water adheres to the sand grains due to the adhesive properties imparted by the coagulation process, allowing effective removal.
For household and drinking water supply, the filtering layer in rapid filters usually consists of quartz sand with a grain size of 0.7–0.8 mm and a thickness of about 0.7 m. The supporting gravel layer prevents the sand grains from entering the drainage system.
In operation, if the water level in the reservoir is higher than in the filter, water flows through by gravity. If the opposite is true, water is supplied under pressure, and the filter operates as a closed pressure vessel. Raw water is introduced into the filter via special “pockets” or troughs, passes through the layers of sand and gravel, and is collected by drainage pipes.
Filter washing is carried out in the reverse direction — from bottom to top — by supplying water at a higher flow rate. This upward flow expands the filter bed, loosening trapped particles and carrying them away. The resulting wash water is collected in special troughs and discharged into the sewer system.

Results

All filters used in the study are reinforced concrete basins consisting of two layers. The lower layer is solid, while the bottom of the upper layer is perforated, and the two are separated by empty drainage channels. Filtered water passes through these drainage channels into a chlorination unit and then flows into a contact basin.

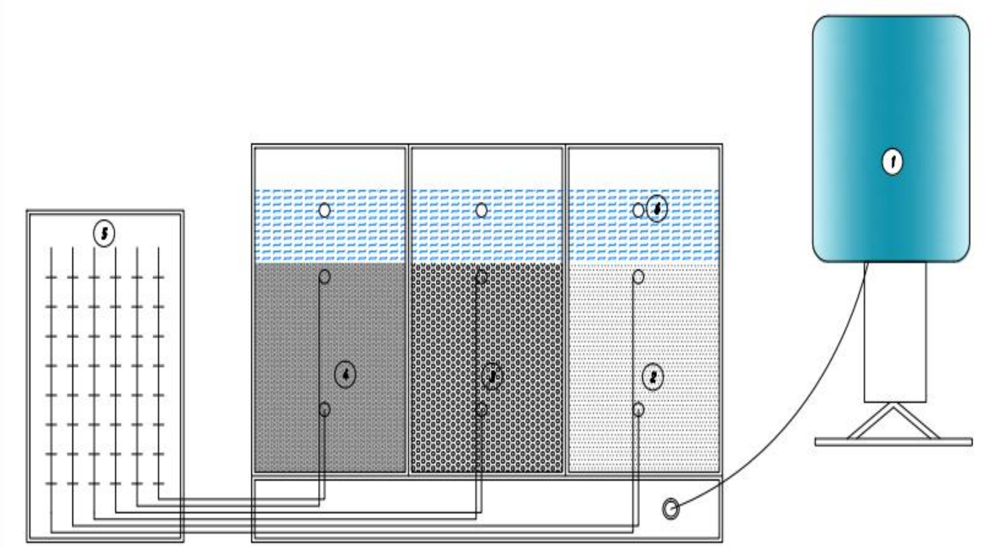
When backwashing of the filter is required, water is forced under pressure from the drainage channel in the reverse direction. This process removes accumulated films and deposits from the surfaces of sand, gravel, and other filtering media. In the upper layer, a bed of gravel and crushed stone is placed, over which the filtering layer of sand is deposited.

For slow, single-flow, and rapid filters, backwashing is performed by supplying water onto the sand surface, whereas for double-flow filters, water is introduced from below. The diameter of the gravel and crushed stone used should not exceed 2–40 mm to ensure proper hydraulic performance and prevent clogging.

Various design options exist for water treatment filters intended for different operating conditions. For example, in laboratory experiments, porcelain, crushed expanded clay (ceramsite), and quartz sand fillers were tested for permeability using a specialized laboratory apparatus (Figure 1). These experimental tests were conducted to assess filtration efficiency under controlled conditions.

In large-grain pressure filters, the pressure loss in the filter bed must be considered: up to 15 m for pressurized drainage channels, and 3–3.5 m for open-type filters. In open filters, the water layer should be maintained at least 1.5 m above the surface of the filter bed to provide sufficient head for filtration.

To eliminate trapped air in the water supplied for filter backwashing, venting devices such as shut-off valves or automatic air release structures are installed in the piping system. Vent chimneys have diameters of 75–150 mm, while those in drainage channels are typically 50–75 mm in diameter. These features are essential for maintaining uninterrupted operation and ensuring the effective cleaning of the filter media.



1 – Water tank, 2 – Porcelain filler, 3 – Quartz filler, 4 – Sand filler, 5 – Piezometer indicator panel, 6 – Outlet for filtered water.

Figure 1. Laboratory apparatus for experimental studies on water filtration using different fillers.

Filtration coefficient

$Q = \omega kJ$; (1)

$k = \frac{Q}{\omega J}$; (2)

$Q = V/t$; (3)

here:

Q- water consumption; V- water volume; t- water flow time

$Q -$ suvning iste'moli; $V -$suvning hajmi; $t -$ suvning oqib o'tish vaqti

J= h1-h2; (4)

bu yerda:

J- pressure difference; h1, h2- piezometric height;

$\omega = a \times b$; (5)

Here:

ϖ- area of the device;

ϖ= a×b=25×15= 375=0.0375 m2

Porcelain (porcelain)

$$Q = V/t = 0.7/33 = 0.021\ l/s$$

J= h1-h2= 0.03 m

$$k = 0.000021/0.0375 \times 0.08 = 0.018\ m/\ sek$$

Stone

$$Q = V/t = 0.7/34 = 0.02\ l/s$$

J= h1-h2= 0.05 m

$$k = 0.00002/0.0375 \times 0.042 = 0.0127\ m/\ sek$$

Crushed expanded clay (ceramsite)

$$Q = V/t = 0.7/38 = 0.018\ l/s$$

J= h1-h2=0.04 m

$$k = 0.000018/0.0375 \times 0.04 = 0.012\ m/\ sek$$

Quartz

Q= V/t= 0.7/39= 0.0179 l/s

J= h1-h2= 0.035 m

k= 0.0000179/0.0375×0.03=0.016 m/ sek

Sand

$$Q = V/t = 0.7/41 = 0.0172\ l/s$$

J= h1-h2= 0.045 m

$$k = 0.0000172/0.0375 \times 0.039 = 0.0117\ m/\ sek$$

Discussion

The aggregation and stabilization of particles present in natural waters can be achieved only through chemical pretreatment. For rapid filter units to operate effectively, they must receive natural water that has undergone such initial chemical treatment. The principle of operation of high-rate rapid filters has been described in the scientific literature as D. Mins' hypothesis, named after the researcher who contributed significantly to the development of the theoretical foundations for the filtration of natural waters using rapid filter systems.

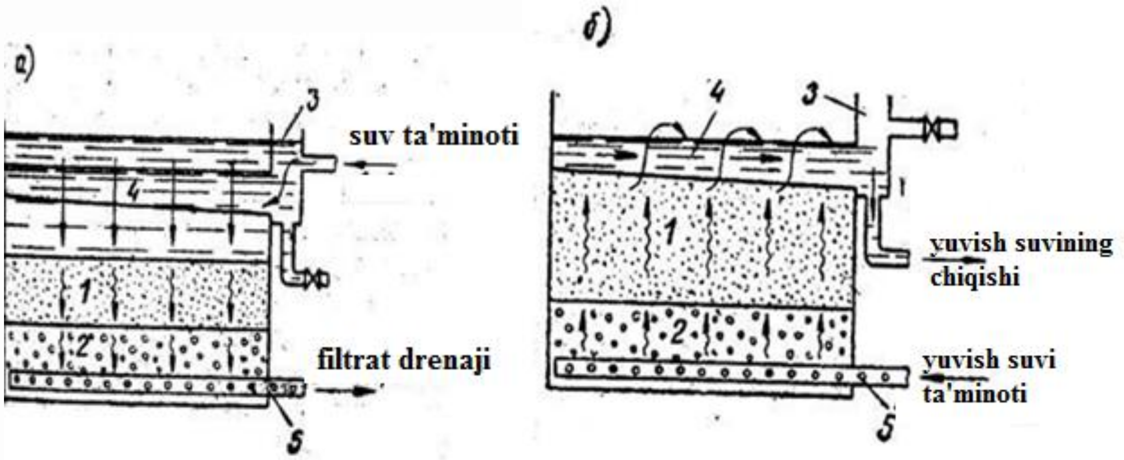
During filtration, dispersed particles present in the water are retained within the pores of the filter bed. As this process continues, the hydraulic resistance of the filter bed gradually increases. At a certain point, the energy of the water flow in the upper part of the bed becomes insufficient to overcome this resistance. As a result, the filtration rate decreases, or, in some cases, particles previously trapped in the pores of the bed detach and are carried away by the water flow into the filtrate, leading to deterioration in water quality.

When such a situation occurs, the filter must undergo washing (cleaning of the filter bed) — a process also referred to as regeneration. The term "regeneration" is derived from the Latin regeneratio, meaning "restoration." In water treatment technology, regeneration refers to restoring the original properties of the filter bed by reversing the direction of water flow through it.

During regeneration, the velocity of the water flow is typically 5–10 times higher than during normal filtration. The primary purpose of filter washing is to remove the particles trapped within the pores of the filtering medium. When water is supplied from the bottom upwards, the bed expands — a phenomenon known as bed expansion. The effectiveness of regeneration is directly related to the degree of bed expansion achieved.

In standard practice, regeneration cycles in rapid filter units are performed once or twice per day. Therefore, considerable attention is paid to minimizing the frequency and complexity of regeneration procedures. In many cases, the cleaning process is enhanced by introducing compressed air into the filter bed, or by using mechanical agitators to increase the dislodging of trapped particles.

Figure I.1.3 presents a schematic diagram of a rapid filter unit. These filters are typically rectangular or trough-shaped in design and are constructed from prefabricated reinforced concrete elements for durability and ease of assembly.



a – Filtration process; b – Washing (regeneration) process of the filter bed; 1 – Filter bed composed of filtering medium; 2 – Supporting layer composed of gravel; 3 – Water supply network; 4 – Water distribution trough; 5 – Drainage network.
Figure 2. Schematic diagram of a rapid filter unit.

The schematic diagram of a rapid filter unit is shown in Figure 2. In operation, raw water is supplied to the distribution trough of the filter and flows downward through the sand filtering layer and the gravel supporting layer. As the water passes through these layers, suspended particles are removed, and the filtered (purified) water — known as the filtrate — is collected in the drainage network located at the bottom of the unit. From there, it is directed either to consumers or to clean water storage reservoirs.

For washing (regeneration) of the filter bed, the appropriate valves in the supply and drainage networks are adjusted, and the filtration process is stopped. Washing water (the regenerant) is then supplied from the bottom upwards, flowing through the gravel supporting layer and the sand filtering layer. The backwash water exits the unit through the overflow trough and is discharged into the external drainage network.

During regeneration (see Figure 2b), the flow rate of washing water is set several times higher than the filtration rate to ensure proper expansion of the bed and complete removal of trapped particles. This increased velocity is critical for achieving effective cleaning of the filtering medium and restoring its original filtration capacity.

Conclusion

A filter unit design filled with locally available materials for the effective treatment of natural waters was developed. This construction ensures both structural reliability and cost-effectiveness, making it suitable for widespread use in local water supply systems.

Laboratory-scale studies demonstrated that pressure filter units achieve more efficient purification of natural waters when operated in an “upflow” (bottom-to-top) mode. Under these conditions, the filtration duration ranged from 10 to 18 hours, with a removal efficiency for fine dispersed particles between 85.5% and 95%. The particle retention capacity of the filter bed was found to be 2.0–2.5 times higher compared to the "downflow" (top-to-bottom) method, reaching values of up to 20 kg/m³ in the experiments.

When operating filter units filled with locally sourced materials, the following key technological parameters are recommended:

3.1. Calculated filtration performance of the filter unit surface: 20–25 m³/m²·h. Recommended particle size ranges for the local filtering material:

Minimum particle diameter: d_{min} = 0.5 mm

Maximum particle diameter: d_{max} = 2.0 mm

Equivalent particle diameter: d_e = 1.3 mm

Filter bed height: h = 1.6 m

3.2. Water filtration regimes:

Initial filtration rate (v_β): 42–54 m³/m²·h

Final filtration rate (v_o): 6–12 m³/m²·h

3.3. Regeneration of the filter bed should be carried out in two stages, ensuring complete removal of trapped particles and restoration of the filtering capacity.

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