Ministry of Education and Science of Ukraine
Kharkiv National Automobile and Highway University

Department of Ecology

S. S. Dushkin

LECTURE COURSE

WATER SUPPLY, SANITATION AND WATER QUALITY IMPROVEMENT

Kharkiv
KhNAHU
2025

UDC 628.1-3

BBK

Dushkin S.S. Course of lectures in the discipline ‘Water supply, sanitation and water quality improvement’ / Dushkin Stanislav Sergeyevich: A course of lectures. Kharkiv: KhNAHU - 139 p.

The course of lectures is developed in accordance with the requirements of the educational and professional programme ‘Ecology and Environmental Protection’ of the first (bachelor's) level of higher education in the speciality 101 Ecology for a classroom load of 32 hours (16 lectures).

The content of the lectures corresponds to the work programme of the academic discipline OK 34 ‘Water supply, sanitation and water quality improvement’ 2022.

CONTENT

Lecture No. 1
THE IMPORTANCE OF WATER RESOURCES AND PROBLEMS OF WATER SUPPLY

Lecture plan

1. The importance of water resources
2. Problems of water supply

1.1 The importance of water resources

Water is the basis of life on our planet. No living organism can exist without water, and its unique properties make it possible for biological systems, climatic processes and human economic activity to exist. However, despite its vital importance, humanity today faces numerous challenges in the area of water supply.

More than 70% of the planet's surface is covered by water, but only 2.5% is fresh water, most of which is unavailable for use because it is in glaciers or underground sources. This creates a serious imbalance between the needs of the population and the available resources. Climate change, pollution, unsustainable use and rapid population growth are exacerbating the problem

Water is the lifeblood of the Earth. Its physical and chemical properties, including the ability to store heat, dissolve various substances and participate in chemical reactions, are the basis for the functioning of biological and ecosystem processes. It plays a key role in climate regulation: it transfers heat through ocean currents, forms clouds that produce precipitation, and ensures the carbon dioxide cycle. Water resources support biodiversity. Rivers, lakes, oceans and swamps are home to billions of organisms that form complex ecosystems. Water regulates the climate balance, reducing temperature fluctuations and helping to maintain stable conditions for life. Thus, the importance of water goes far beyond mere use - it is the foundation on which environmental sustainability and economic development are built.

Water, when used sustainably and equitably, can be a source of peace and prosperity. But when water is scarce, polluted or difficult to access, food security can be undermined, livelihoods can be lost and conflicts can arise.

Approximately half of the world's population now experiences acute water shortages for at least part of the year. One quarter of the world's population faces ‘extremely high’ levels of water scarcity, using more than 80% of the annual renewable freshwater supply. In low-income countries, poor ambient water quality is mainly due to poor wastewater treatment, while in higher-income countries, runoff from agriculture is the most serious problem. Record extreme rainfall is on the rise worldwide, as is the frequency, duration and intensity of meteorological droughts.

Climate change is projected to intensify the global water cycle and further increase the frequency and severity of droughts and floods.

Well-developed water management systems contribute to sustainable development and prosperity by ensuring a reliable water supply and efficient distribution of water to key economic sectors, including agriculture, energy, industry, and businesses and services. Likewise, safe, affordable and well-functioning water and sanitation systems are essential to the prosperity of societies.

However, the effects of climate change, geopolitical instability, pandemics, mass migration, hyperinflation and other crises can exacerbate inequalities in access to water. In most cases, the poorest and most vulnerable populations are the most affected, putting them at risk of losing their well-being and livelihoods.

According to the UN, the largest consumer of fresh water is agriculture, followed by industry and then households, regardless of the development of countries (Fig. 1.1).

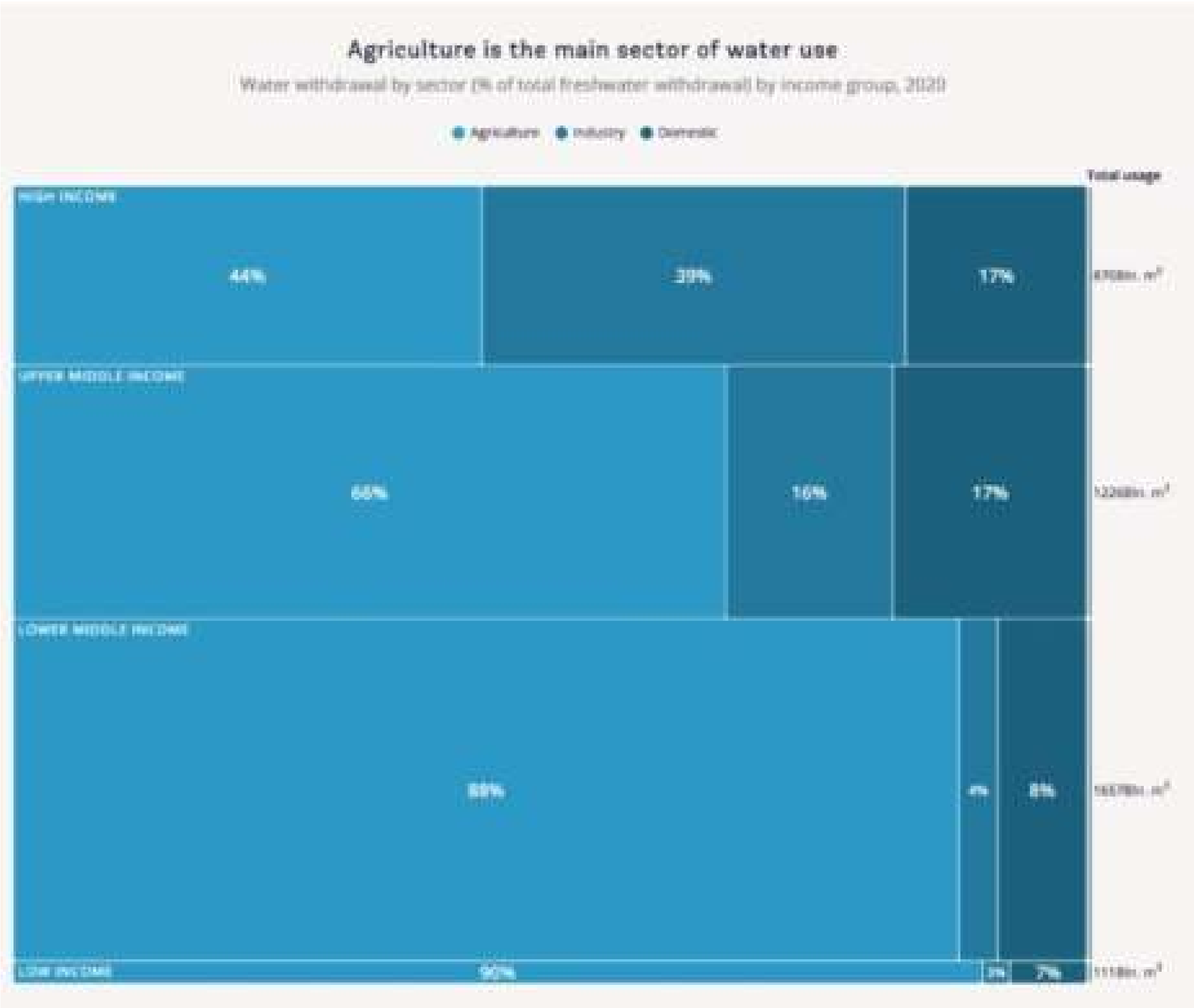


Figure 1.1 - Fresh water intake by consumer groups depending on income

Agriculture

Agricultural production is critically dependent on access to and availability of water resources. It is one of the most vulnerable sectors to climate risks, as agriculture consumes about 72% of the world's fresh water.

Since 1961, the area of irrigated land has more than doubled: from 139 million hectares to over 328 million hectares as of 2018. At the same time, about 40% of global agricultural production comes from irrigated land, which accounts for only about 20% of all agricultural land.

Climate change, including rising temperatures, erratic precipitation and extreme weather events, is affecting water resources, contributing to an increase in pests and diseases of crops and livestock, and increasing the frequency of floods and droughts.

Climate change has both direct and indirect negative impacts on crops. The direct impact is manifested in the loss of crop yields, and the indirect impact is the spread of pests, diseases and insufficient water supply.

Industry

Industry has a complex interaction with water resources, as water consumption and freshwater pollution have a significant impact on ecosystems, while at the same time industry itself depends on access to water. Water scarcity, quality, and availability pose serious risks to business operations. For example, almost 70% of companies surveyed by CDP said that water problems could seriously affect their business. Increased treatment costs, compliance with stricter environmental standards, and problems with access to water can have a significant impact on companies' profitability.

The conventional linear model of water use in industry (direct-flow water supply), which involves the intake, use and discharge of wastewater, does not usually involve reuse or recycling. However, there are many proven technologies available today that can reduce water abstraction and consumption or enable water reuse and recycling.

Reuse, recycling and resource recovery from wastewater have become recognised ways of addressing water availability issues. Industrial wastewater can be a sustainable source of energy, nutrients and by-products. This creates a win-win situation where emissions are reduced and demand for fresh water is reduced at the same time. The implementation of such approaches contributes to the sustainability of water use in industry, reduces environmental impact and ensures sustainable production.

Households

Water resources play an important role in the daily life of households, providing basic needs for drinking water, cooking, hygiene and sanitation. However, the traditional model of household water consumption usually involves a linear approach: abstraction, use and disposal of wastewater, which does not promote water conservation, reuse or recycling.

Today, there are a variety of technologies and methods that allow households to use water more efficiently, reducing consumption and promoting reuse. These include:

- installation of water-saving equipment;
- introduction of rainwater harvesting systems for technical needs;
- reusing grey water (from baths and washing machines) for irrigation or technical needs.

Efficient use of water in households not only reduces costs but also helps to reduce the pressure on natural water resources. For example, the use of modern equipment can reduce water consumption by 30-50%, and the introduction of water reuse systems can reduce the amount of wastewater that needs to be treated.

Rational water use in households has a significant potential to reduce overall freshwater demand, which is an important step towards sustainable water management and environmental sustainability.

1.2 Problems of water supply

Water availability is an indicator that reflects the availability of water resources for the needs of the population, industry, agriculture and other areas of activity in a certain territory. It takes into account the amount of water available from natural sources (rivers, lakes, groundwater) per unit of population or territory over a certain period of time, usually a year. It is measured in cubic metres of water per capita (m^3/year). A level of 1,700 m^3/year per person is considered sufficient for basic needs. Less than 1,000 m^3/year indicates a water shortage.

Key factors affecting water availability:

- natural conditions: climate (precipitation, evaporation); size and condition of water bodies; availability of groundwater;
- socio-economic conditions: population density; level of industrial and agricultural development; efficiency of water resources use;
- environmental factors: water pollution; changes in ecosystems due to human activity.

Approximately half of the world's population currently faces acute water shortages for at least part of the year. While some regions experience water scarcity for only a few months, others suffer from acute shortages all year round (Fig. 1.2).

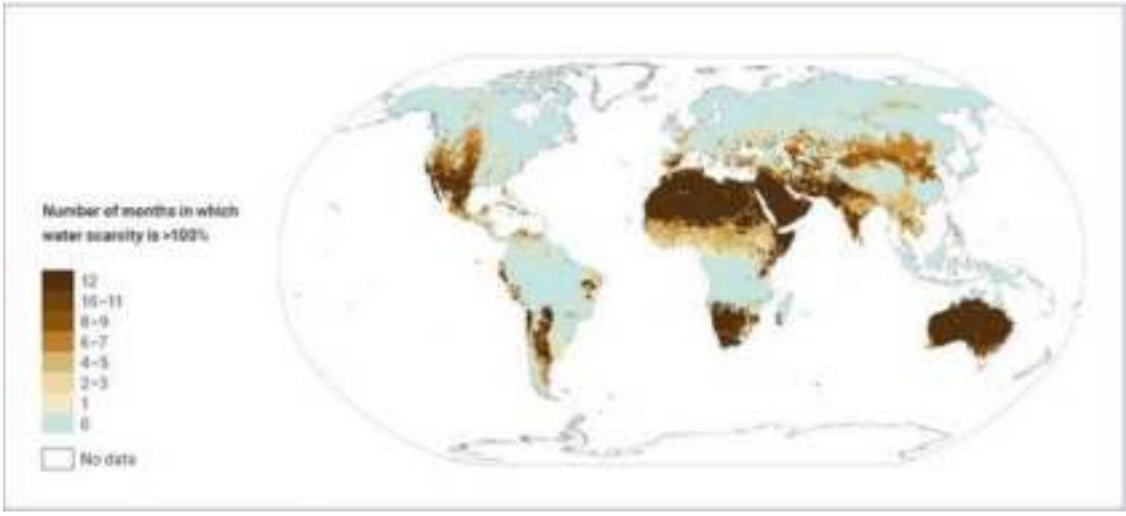


Figure 1.2 - Number of months in a year with severe water shortages
(water demand to availability ratio >1.0)

This problem is particularly relevant for arid and semi-arid regions, where natural water scarcity is compounded by increasing demand for water due to population growth, urbanisation and climate change. In terms of natural disasters, floods and droughts are among the most devastating water-related disasters (Fig. 1.3). Acute water scarcity limits access to clean water for drinking, agriculture, industry and other sectors, significantly affecting the welfare of the population and the economic stability of the regions.

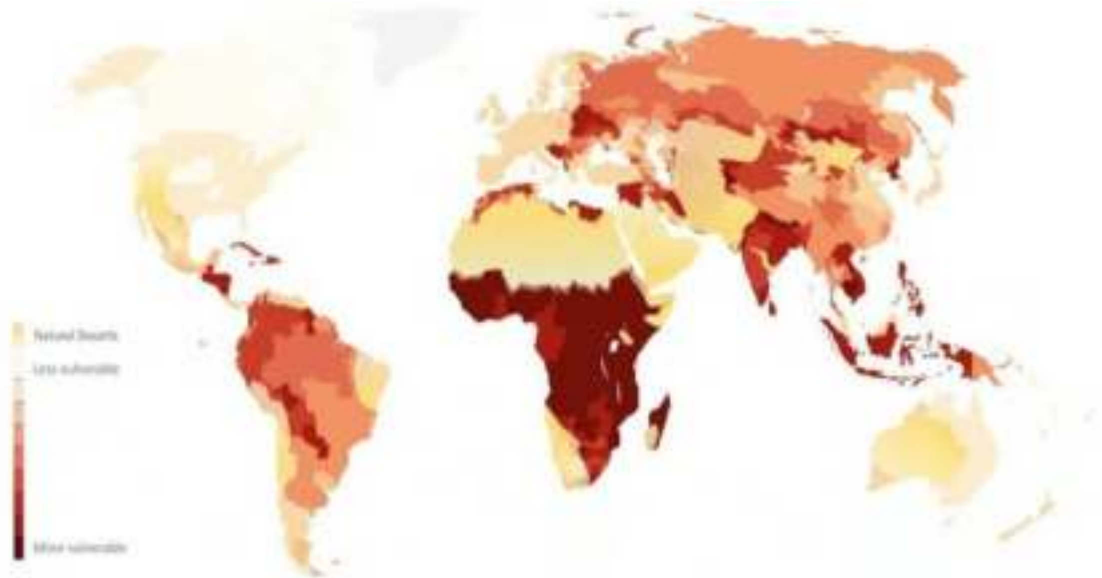


Figure 1.3 - Regions vulnerable to drought

In general, only 0.3% of the total fresh water volume is technically available for use.

The world's water resources are extremely unevenly distributed around the world. The following countries are the most endowed with water resources: Brazil (8233 thousand km^3), Russia (4508 thousand km^3), the USA (3051 thousand km^3), Canada (2902 thousand km^3), and China (2840 thousand km^3) (Fig. 1.4).

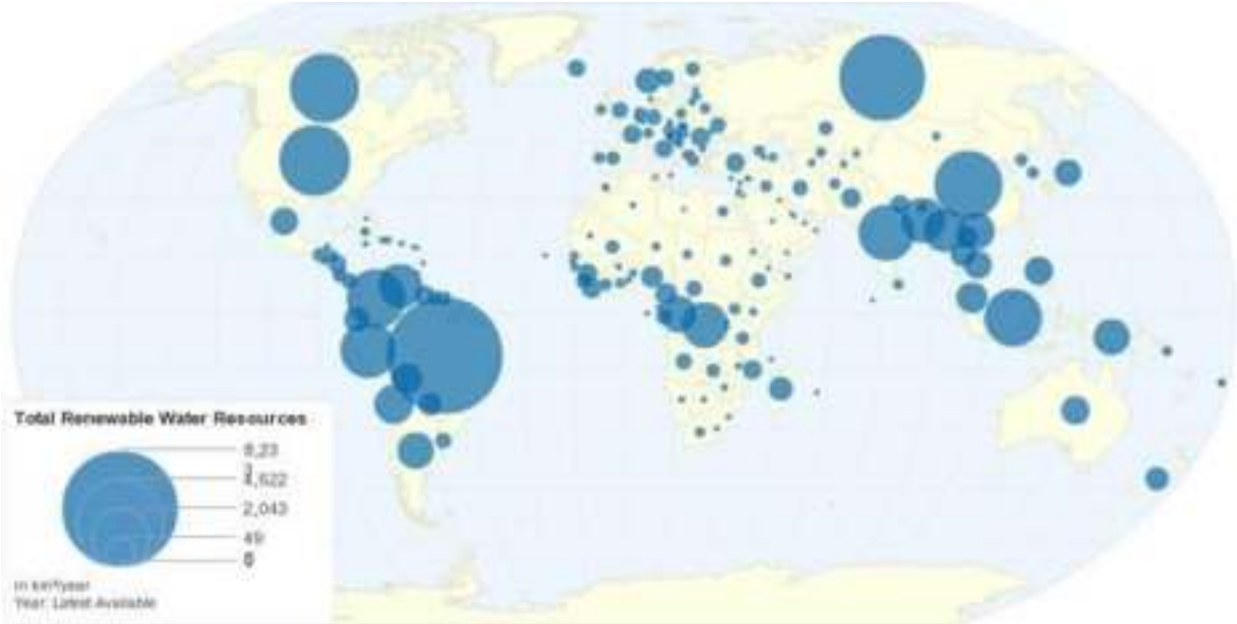


Figure 1.4 - Water resources by country (km^3/year)

The highest per capita water resources are in French Guiana (609,091 m^3), Iceland (539,683 m^3), Guyana (315,858 m^3), Suriname (236,893 m^3), and Congo (230,125 m^3), and the lowest in Kuwait (6.85 m^3), the United Arab Emirates (33.44 m^3), Qatar (45.28 m^3), the Bahamas (59.17 m^3), Oman (91.63 m^3), and Saudi Arabia (95.23 m3).

In the post-Soviet space, the situation is as follows: Turkmenistan (97.1%), Moldova (91.4%), Uzbekistan (77.4%), Azerbaijan (76.6%), and Ukraine (61.9%).

Ukraine is a water-scarce country, with a water supply of 1,000-1,200 m^3/year. The main sources are river water, groundwater and artificial reservoirs. About 80% of river runoff is generated outside Ukraine (in particular, in the Dnipro, Dniester and Siverskyi Donets basins).

Water supply is affected by the variability of local runoff over time. For example, in low-water years, it is 29.7 km^3. Uneven distribution of runoff throughout the year. Spring runoff accounts for up to 70 per cent of the water supply in the north and northeast and up to 90 per cent in the south of Ukraine.

Ukraine has significant groundwater resources, with a projected balance sheet resource of 21.0 km^3/year. Groundwater discharge varies from 30 mm (Polissya), 40-50 mm (Volyn-Podillya) to 0-5 mm (Black Sea region, Steppe Crimea) in the southern direction. In the Ukrainian Carpathians, groundwater runoff amounts to 100-120 mm, with the highest in the Crimean Mountains at 500 mm. Groundwater runoff moduli also decrease from north to south, from 3-1.5 l/s*km^2 to 0.5 l/s*km^2 or less. The total amount of groundwater runoff is estimated at 500-550 m^3/s, which is 30% of the total runoff from the country

Planning the distribution of water resources (Water Resource Allocation [1]) has long existed in many countries and is becoming increasingly important as water scarcity increases, and it also contributes to the resolution of international, regional and local conflicts over water access. Water allocation planning is one of the ways to effectively manage a country's water resources, determining how much water can be used from groundwater and surface water sources, while ensuring the sustainability of the resource and protecting water-dependent ecosystems.

Water safety planning is recognised by many countries as the most effective modern practice of sustainable management of drinking water quality and safety (Water Safety Planning [2]) based on risk analysis and assessment, with measures to control such risks at all stages of drinking water supply: from the source to the consumer's tap.

Today, proactive management is becoming more widespread and developed in many countries. Countries such as Australia, Canada, Germany, Japan, Singapore, the United Kingdom, the United States and the International Water Association (IWA) were the first to actively implement a water security plan (WSP), and their experience was used to prepare the WHO Guidelines. It should be noted that in the European region, the implementation of WSP has received significant support from the Protocol on Water and Health, and since 2010, the WHO approach and recommendations on planning and sustainable management of water and sanitation safety have been a priority area for the implementation of the Protocol on Water and Health. It should be noted that, thanks to the European experience in implementing the WSP and the financial, technical and humanitarian support of the EU and European countries, a pilot WSP implementation project has been launched in Ukraine.

Control questions

1. What is the importance of water for life on Earth?
2. Why is there a shortage of fresh water?
3. Which sector of the economy consumes the most water?
4. What is water availability?
5. What is the situation with water availability in Ukraine?
6. What factors influence water availability?
7. What are the consequences of climate change for water resources?
8. What international organisations deal with water supply problems?
9. Which countries have the largest reserves of fresh water?
10. Which countries are experiencing the greatest water shortage?
11. What is water security planning?
12. What measures can be taken to preserve water resources?

13 What is the role of citizens in solving the problem of water scarcity?

Link:

1. https://www.oecd.org/content/dam/oecd/en/publications/reports/2015/04/water-resources-allocation_g1g507d6/9789264229631-en.pdf
2. https://www.who.int/teams/environment-climate-change-and-health/water-sanitation-and-health/water-safety-and-quality/water-safety-planning

Lecture No. 2
SANITARY AND ENVIRONMENTAL REQUIREMENTS FOR DRINKING WATER QUALITY

Lecture plan

1. Assessment of water quality in terms of environmental safety
2. Requirements for the safety and quality of drinking water and its production control
3. Measures to improve the environmental status of surface water sources

2.1 Assessment of water quality in terms of environmental safety

Natural waters include land waters (surface and underground) and sea waters. These waters are used for various purposes: domestic, drinking, municipal, fishery, industrial, medical and other. In addition, when using water for human needs, we should not forget about the protection of living organisms that live in water.

Water quality criteria are characteristics of water composition and properties that determine its suitability for specific types of water use. Water quality is judged by a set of indicators. This set of indicators may differ for different users and depends on the requirements that each user has for the composition and properties of water.

Water quality indicators are a set of biological, chemical and physicochemical characteristics of water (trophic, saprobic, salinity, hardness, hydrogen index, concentration of dissolved substances, etc.)

Thus, the quality of natural waters is their state represented by a set of indicators that reflects the needs of users in the composition and properties of water.

Assessment of natural water quality is the determination of its suitability for practical purposes; it is carried out on the basis of state standards and regulations.

If the assessment consists of several scores (categories), then it describes the degree of water purity or pollution, for example: very clean, clean, fairly clean, slightly polluted, moderately polluted, etc.

To assess water quality, not only the values of indicators are required, but also their norms, which are the quality standard. The main quality standards are the maximum permissible concentrations (MPC) of the quality standards include sanitary and hygienic pollutants, which are part of the sanitary standards, and fishery pollutants, which are part of the fishery standards. In addition, the quality standards also include indicatively safe exposure levels (ASEL), approximate permissible levels (APL) and average lethal concentrations (LC50) pollutants.

ASEL and APL substances are introduced temporarily until MPCs are developed for them. Average lethal concentrations are used when it is necessary to assess the permissible content of a mixture of pollutants in water. In these cases, the criterion is 0.01 LC50: 1) by the method of detailed analysis; 2) by the method of complex indices (indicators); 3) by the methods of bioindication and biotesting as a habitat for living organisms.

The method of detailed analysis is to compare the measured (calculated) value of each indicator (from the entire set) with its standard (MPC). The score is two-point: if at least one indicator does not meet the standard, the water is considered dirty; otherwise, it is clean.

The peculiarity of water quality assessment using the composite index method is that the value of the composite index is calculated for the entire set of indicators (or part of it), and a verbal generalised description of the water is given on the appropriate scale (the assessment has several points).

When implementing the above two methods, either sanitary and hygienic or fishery methods are most often used MPC. However, depending on the user's needs, other standards (environmental, departmental, industrial, etc.) may also apply.

It should be noted that today, when assessing the ecological status of water bodies, sanitary or fishery water quality standards are often used. The disadvantage of this is that when developing sanitary and hygienic standards, water is considered as a subject for satisfying human needs, not as a habitat for aquatic life, and when developing fisheries standards, only fish and other species of aquatic life that are human food are considered, i.e. in both cases, human needs and health are considered first.

The current regulations do not allow assessing water as a habitat for aquatic organisms, so bioindication and biotesting are used. These methods assess the quality of water based on the reaction of living organisms: bioindication based on hydrobiological observations in natural conditions, and biotesting in laboratory conditions.

2.2 Requirements for the safety and quality of drinking water and its production control

In order to provide the population in the area of hostilities or other emergency situations with drinking water of adequate quality, in accordance with the Decree of the President of Ukraine of 24 February 2022 No. 64 «Pro vvedennia voiennoho stanu v Ukraini», an order is introduced № 683 Pro zatverdzhennia Derzhavnykh sanitarnykh norm i pravyl «Pokaznyky bezpechnosti ta okremi pokaznyky yakosti pytnoi vody v umovakh voiennoho stanu ta nadzvychainykh sytuatsiiakh inshoho kharakteru» [1]. These norms are applied under martial law and during emergencies of a different nature in a particular territory for a certain period of time by the decision of the relevant regional or local commission on technogenic and environmental safety and emergencies. The following terms are used in these

Sanitary and Epidemiological Standards (DSanPiN) in the meanings given in the Water Code of Ukraine [2], Laws of Ukraine«Pro zabezpechennia sanitarnoho ta epidemichnoho blahopoluchchia naselennia» [3], «Pro pytnu vodu, pytne vodopostachannia ta vodovidvedennia» [4] and other regulatory acts in the field of drinking water supply to the population.

Tap drinking water and drinking water from bottling points (hereinafter referred to as drinking water) must meet the requirements of the State Sanitary Norms and Rules in terms of epidemic and radiation safety «Hihiienichni vymohy do pytnoi vody, pryznachenoi dlia spozhyvannia liudynoiu» [5], approved by Order of the Ministry of Health of Ukraine No. 400 dated 12 May 2010, registered with the Ministry of Justice of Ukraine on 1 July 2010 under No. 452/17747, for other indicators - hygiene standards in accordance with the Annex [6] to these DSanPiN.

Requirements and methods of water quality control are standardised in the DSTU 7525:2014 Voda pytna: vymohy ta metody kontroliuvannia yakosti [7]. This standard implements the provisions of the Law of Ukraine «Pro pytnu vodu ta pytne vodopostachannia», DSanPiN 2.2.4-171-10 «Hihiienichni vymohy do vody pytnoi, pryznachenoi dlia spozhyvannia liudynoiu», basic requirements of the Council Directive 98/83/EC of the European Union of 03.11.1998 on the quality of water intended for human consumption, the WHO Guidelines for the Quality of Drinking Water of 2011 and the Commission's Alimentarius document «Zahalnyi standart na rozfasovani u pliashky/upakovani pytni vody (vidminni vid mineralnykh vod)» CODEX STAN 227-2001.

The specifics of Ukraine's drinking water supply are mostly based on surface sources.

Depending on the quality of water, there are five classes of water, which are described in Table 2.1.

Table 2.1 - Water class depending on water quality

Water class	I class	II class	III class	IV class	V class
Water quality	Very clean	clean	polluted	dirty	very dirty

Water bodies are considered to be suitable for domestic drinking water supply in terms of environmental safety if

- the general requirements for the composition and properties of water for drinking water supply are not violated;

- the following conditions are met:

$$C \leq MPC, \quad (2.1)$$

where C is the content of impurities in the water body, g/m³

and

$$\sum \frac{C_i}{MPCi} \leq 1 \qquad (2.2)$$

where Ci and $MPCi$ – appropriate concentration of limiting additives.

Centralised water supply to the population is provided by water utilities, which purify natural water (surface and groundwater) to drinking quality.

There are also water bottling points whose activities are regulated by the Water Code of Ukraine, which establishes the general principles of water resources use and protection. The Code defines the rules for conducting economic activities related to water bottling, the Law of Ukraine «Pro osnovni pryntsypy ta vymohy do bezpeky ta yakosti kharchovykh produktiv», the Law of Ukraine «Pro pytnu vodu», Order of the Ministry of Healthcare of Ukraine No. 400 of 12.05.2010 on approval of the State Sanitary Norms and Rules «Hihiienichni vymohy do vody pytnoi, pryznachenoi dlia spozhyvannia liudynoiu».

Bottled water can be either table water (drinking) or mineral water (in Ukraine, water is considered mineral if its mineralisation exceeds 1 g/l and the therapeutic effect of its main components has been proven. Mineral water is characterised by effects that are different from those of drinking water. Such effects depend on the specifics of its composition. If there are no such effects, the water is considered mineralised). Bottled mineral waters are divided into the following types: natural table water, diluted table water, natural medicinal table water, diluted medicinal table water and natural medicinal water. They are classified depending on their total mineralisation. Regulatory documents define standards for natural mineral water and the conditions for its storage, processing and use: DSTU 878–93 «Vody mineralni pytni. Tekhnichni umovy», DSTU 42.10-02–96 «Vody mineralni likuvalni. Tekhnichni umovy», DSTU 878:2006 «Vody mineralni pryrodni fasovani». Companies engaged in the extraction of mineral water from natural sources and subsequent bottling for sale must obtain permits.

International standards governing the quality of mineral drinking water: CODEX STAN 227–2001, CODEX STAN 108–1981, Rev.1–1997. WHO recommends that all countries adopt these standards as national standards, but compliance is voluntary.

All regulatory documents specify which indicators should be monitored in drinking water and set maximum permissible standards for their content. And if DSTU and DSanPiN contain almost identical indicators and maximum permissible standards, which differ only by a few items, the latter EU directive [8] has already been expanded with new toxin names. It includes such indicators as vinyl chloride, epichlorohydrin, bisphenol A, haloacetic acids, microcystins and per- and polyfluoroalkyl substances. In Ukraine, they are currently not controlled, although they pose a danger to human health. However, as a result of European integration, we have to reach the same level of control over drinking water as in European countries. This means that when considering possible options for equipping laboratories, it is better to focus on European water quality and safety indicators.

Learn more about methods for determining organic pollutants in the webinar «Suchasni metody vyznachennia orhanichnykh zabrudnykiv pytnoi vody zghidno vymoh DSanPiN 2.2.4-171-10 [9])».

2.3 Measures to improve the environmental status of surface water sources

The main measures to improve the environmental status of surface water sources include the following:

- treatment of water generated by surface runoff from urban areas, construction of drainage systems in cities and rural areas;
- Improvement of sanitary protection zones;
- improvement of water protection and coastal protection strips of water bodies;
- protecting drinking water intakes from the harmful effects of livestock and poultry farms and other agricultural facilities that are potential sources of water pollution;
- clearing riverbeds and strengthening river banks and reservoir bottoms;
- state monitoring of water bodies used as water supply sources.

Water treated according to the traditional scheme contains about 70% organic matter.

Control questions

1. Assess the water quality in terms of environmental safety.
2. What are the hygienic requirements for drinking water quality?
3. What are the proposed requirements of the Sanitary and Epidemiological Standards for the quality of drinking water?
4. What is the physical adequacy of the mineral composition of drinking water?
5. How is the water toxicity index determined?
6. What is the specificity of drinking water supply in Ukraine?
7. What measures improve the ecological condition of surface water sources?
8. What methods are used to assess the quality of natural water?
9. What classes of water are distinguished by quality?
10. What is mineral water and what are its types?
11. What measures should be taken to improve the quality of drinking water?
12. What are comprehensive water quality indices?
13. What are the advantages and disadvantages of different methods of water quality assessment?

14. Why is it important to assess water quality not only from the point of view of human needs, but also from the point of view of ecology?

15. What are water quality criteria

Link:

1. https://zakon.rada.gov.ua/laws/show/z0564-22#Text
2. https://zakon.rada.gov.ua/laws/show/213/95-%D0%B2%D1%80#Text
3. https://zakon.rada.gov.ua/laws/show/4004-12#Text
4. https://zakon.rada.gov.ua/laws/show/2918-14#Text
5. https://zakon.rada.gov.ua/laws/show/z0452-10#n25
6. https://zakon.rada.gov.ua/laws/show/z0564-22#n35
7. https://online.budstandart.com/ru/catalog/doc-page?id_doc=61154
8. https://zakon.rada.gov.ua/laws/show/994_963#Text
9. https://www.youtube.com/watch?v=LxfIzv7UrNU&list=PLe9Tazc2AK9oLcj24loU5wRSJpkmu_t7t&t=1s

Lecture No. 3
SOME ASPECTS OF THE PROBLEM OF WATER AND TERRORISM

Lecture plan

1. Some aspects of the 'Water Security Plan'
2. Water supply security plan
3. Addressing water quality issues

The availability of fresh water is a crucial factor in security, including the avoidance of conflict of all kinds. In many regions of the world, water scarcity contributes to permanent conflict. Water issues are characterised by an unconventional combination of socio-economic, political, legal, international and domestic, military and civilian aspects. This makes them a very specific type of new transboundary challenges and security threats.

There are 263 water basins on the planet that are located on the territory of more than one country. They cover about half of the Earth's surface area, home to 40% of the world's population. In addition, two-thirds of the so-called 'large marine ecosystems' are shared by several countries. There are many examples in human history of conflicts over access to water resources, which underscores the importance of their joint management and sustainable use.

The Pacific Institute has for many years maintained an open database called the Water Conflict Timeline, which is one of the best in the world on the subject. This database tracks all known and recorded conflicts where freshwater has been a key factor, a conflict trigger, or where water resources and infrastructure have been used as a weapon or have been the victim of conflict. The Institute's experts on development, environment and security have developed a classification of such conflicts according to their nature: conflicts aimed at controlling water resources to meet their own needs (state or non-state actors); conflicts in which water is used as a military tool, for example, flooding territories or blocking water supplies; conflicts in which water is used as a political tool, for example, to put pressure on other countries or groups; hydro-terrorism, where water resources are the object of terrorist actions; conflict This classification helps to better understand the nature of water-related conflicts and facilitates the search for solutions.

The international community, aware of the danger and reality of deteriorating water supply systems, pays serious attention to creating a system of reliable resistance to terrorist threats.

Attacks on civilian infrastructure critical to human health and well-being are a violation of the Geneva Conventions. In particular, the use of water as a means of warfare or attacks on civilian water infrastructure, such as water supply or water treatment plants, or attacks on dams and irrigation systems are war crimes under the 1977 Protocols. Articles 51 and 54 of Protocol I to the 1977 Geneva Convention prohibit indiscriminate attacks on civilian populations and civilian infrastructure and protect infrastructure that is crucial to the survival of the civilian population. This international law states: "It is prohibited to attack, destroy, displace or render useless objects essential to the survival of the civilian population, such as foodstuffs, agricultural land for food production, crops, livestock, drinking water installations and supplies, and irrigation systems, which are operated with the specific purpose of depriving the civilian population or the opposing party of their life support, whether for the purpose of starving the civilian population, forcing them to leave the country, for any reason, or forcing them to move."

The law also states that the military must avoid attacking such objects in order "not to leave the civilian population with such insufficient food or water as to cause starvation or to compel it to move" (Protocol I, Article 54), while Article 56 of Protocol I and Article 15 of Protocol II prohibit attacks on infrastructure "containing dangerous forces", including explicitly "dams" and "levees", if such attacks "may result in the release of dangerous forces and consequent serious loss of civilian life".

3.1 Some aspects of the 'Water Security Plan'

FBI Director Robert Mueller made a statement: "Poisoning food and water could be an attractive tactic in the future. A successful attempt could result in thousands of casualties, spread fear among the population and undermine public confidence in food and water." Thus, terrorism is not only limited to direct armed conflicts or attacks, but can also be targeted at vital human supplies such as food and water, which can have a much wider impact on a larger number of people - up to thousands (rather than small groups) in the case of armed terrorism.

One of the main concerns with water supply systems is that they are diverse and spatially dispersed over large geographical areas. Water is consumed through drinking and cooking, and inhaled as an aerosol in showers. On the other hand, water is used for sanitary and economic purposes (e.g. in factories, restaurants). Therefore, water systems are extremely vulnerable to several physical, chemical and biological threats that can affect the system's ability to deliver safe water. Drinking water and wastewater systems contain components that are easy to access and difficult to protect (treatment plants, pumping stations, and distribution systems, including risers and miles of distribution or collection mains).

Chemical and biological contaminants in water can infect people through various routes of exposure.

Chemical water pollution poses a significant threat to human health and safety.

- Sulphur mustard is a well-known chemical warfare agent. Its complexity is largely due to the fact that it is not a naturally occurring substance in the environment and was introduced as a chemical warfare agent in World War I.

- Organophosphorus nerve agents: Nerve agents have been widely used as chemical weapons since the first half of the 20th century. They are the most toxic chemicals known, including sarin (GB), tabun (GA), soman (agent GD) and agent VX.

Biological water contamination: Biological threats are classified into two main categories - pathogens and toxins.

The Centers for Disease Control and Prevention (CDC) has divided biological warfare agents into three categories:

- Category A: agents of the highest priority; these include organisms that pose a serious threat to national security because they can be easily transmitted from person to person and spread easily. Category A agents typically result in high mortality rates and have the potential for serious public health consequences. They can also cause social upheaval and panic, and they require great public health preparedness and action. Common diseases/agents associated with this category are: tularemia (Francisella tularensis); plague (Yersinia pestis); anthrax (Bacillus anthracis); smallpox (Variola major); botulism (Clostridium botulinum toxin); viral haemorrhagic fevers (filoviruses and arenaviruses).

- Category B: Second priority agents. These are agents that are relatively easy to spread. They result in low mortality rates but moderate morbidity rates. Some related diseases/agents: Typhus (Rickettsia prowazekii); Cu-fever (Coxiella burnetii); SARS (Burkholderia mallei); Brucellosis (Brucella spp); epsilon toxin (Clostridium perfringens); viral encephalitis (alphaviruses); melioidosis (Burkholderia pseudomallei); ornithosis (Chlamydia psittaci); ricin toxin (Ricinus communis);

staphylococcal enterotoxin B (Staphylococcus spp.); water safety threats (Vibrio cholerae, Cryptosporidium parvum); food safety threats (Salmonella spp, E. coli O157:H7, Shigella).

- Category C: Third priority pathogens. These include emerging pathogens that may be engineered to spread in the future. These pathogens are widely available, easy to produce and disseminate, and may have a high potential to increase morbidity and mortality. Common pathogens in this category include Nipah virus and hantavirus.

Researchers of water terrorism, systematising the available information, identify two main areas of destructive use of water: water as a weapon; water as a goal. The main areas of destructive use of water are shown in more detail in Fig. 3.1. In the first case, it is primarily about using the destructive power of large masses of water, such as the destruction of the Kakhovka hydroelectric power station (Fig. 3.2), or water treatment facilities. The 1995 accident at the pumping station of the Dykaniv sewage treatment plant in Kharkiv (Fig. 3.3) shows how dangerous this is from an environmental and sanitary point of view.

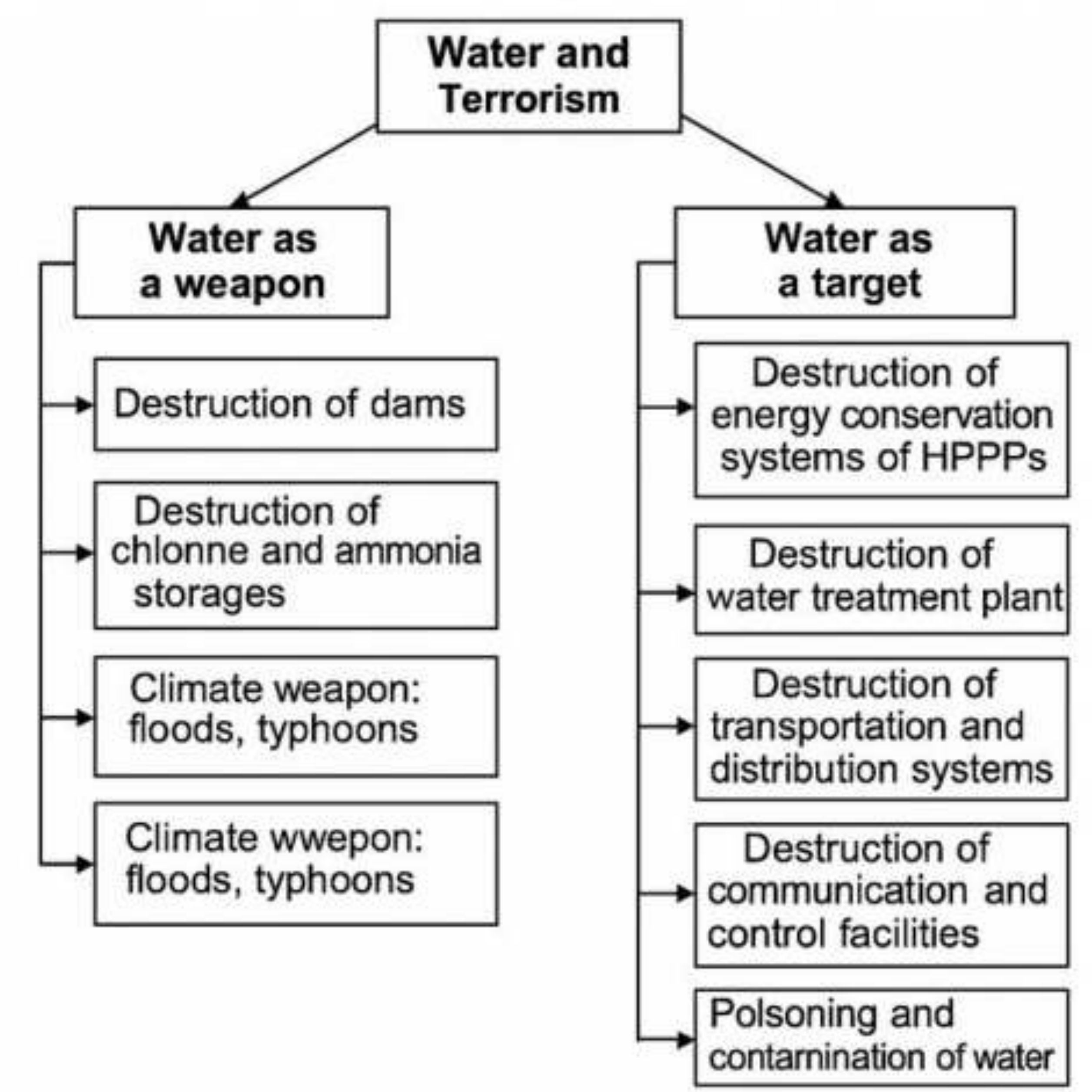


Figure 3.1 - Main areas of destructive water use

Figure 3.2 - Consequences of the destruction of Kakhovka HPP

Figure 3.3 - Consequences of the accident at the Dykaniska pumping station, 1995

A potential threat, such as that posed by the Kyiv HPP dam, is unique, as the Kyiv reservoir, in addition to a huge mass of water (about 4 billion tonnes), contains another 90,000 tonnes of radioactive sludge formed after the Chornobyl accident in 1986.

In the second case, we are talking about the destruction of energy saving systems of water and wastewater utilities, water treatment facilities, water transportation and distribution systems, destruction of communications and control facilities, and water poisoning and contamination (Fig. 3.4).

Figure 3.4 - Destruction of water supply systems as a result of Russian shelling

The armed ‘military’ aspect is the highly toxic reagents used for water purification: liquid chlorine, etc.

3.2 Water supply security plan

The water supply security plan includes:

1. Sufficiency, reliability and effectiveness of the physical protection system of water supply facilities.

2. Availability of special equipment and material and technical reserves (materials and equipment) to restore the damaged.

3.1 Water intake facilities at surface sources are unlikely targets for terrorist attacks due to their large size and massiveness.

3.2 Intake structures at boreholes are highly vulnerable due to their compact size and usually spatial association with the first lift pumping station.

3.3 Trunk pipelines are highly vulnerable due to their long length (making them difficult to physically protect) and the presence of large above-ground sections.

3.3 Addressing water quality issues

It can be performed under the following conditions:

1. Continuous monitoring of possible places of possible introduction of a poisonous substance, biological pathogenic agent or radioactive agent.

2. Prompt detection in tap water in case of suspicion of their use with simultaneous warning informing the population.

3. Daily operational control of the quality of natural, drinking and waste water in all settlements of Ukraine, including in emergency situations, can be carried out

with the help of a mobile chemical and bacteriological laboratory based on a photometer and bacteriological equipment.

The global problem of 'Water and Terrorism', which Ukraine is currently facing directly, requires urgent solutions to counter the current threats of destruction and destruction of the complex and expensive system of centralised water supply and sewerage.

It is necessary to supplement the National Programme 'Drinking Water of Ukraine' for 2022-2026 (draft of 02.07.2021, reviewed on 15.02.2022) with the task 'Protection against Terrorism and Sabotage', which, in particular, should provide for the immediate equipping of water and wastewater utilities with facility protection systems and operational water quality monitoring systems, including on-line monitoring systems.

Control questions

1. Why is the availability of fresh water considered the most important security factor?

2. What aspects make water issues a specific type of cross-border security challenge and threat?

3. Why are attacks on civilian water-related infrastructure considered a violation of the Geneva Conventions?

4. Why are water supply systems considered extremely vulnerable to threats, and how is this related to their structure?

5. What are the main aspects of a "Water Security Plan"?

6. What are the main areas of destructive use of water?

7. How do you know the main components of the Water Security Plan?

8. What is the classification of terrorist groups on the issue of 'Water as a Target'?

9. What is the degree of vulnerability and recovery of water supply facilities?

10. What are the solutions to the problem of water quality?

11. What are the main global problems of the concept 'Water and Terrorism'?

12. The main directions and prospects for improving the environmental safety of water use.

13. Environmental and legal responsibility for violation of water legislation.

14. Improving the structure of water management.

15. Conceptual directions of ecological and economic optimisation of water use.

16. Current trends and problems of providing the population with drinking water.

17. Sanitary and epidemiological aspects of water supply to the population.

18. Environmental safety of water use.

Lecture No. 4
WATER SUPPLY SOURCES

Lecture plan

1. General information about water supply sources
2. Surface sources of water supply
3. Underground sources of water supply

4.1 General information about water supply sources

Sources of water supply for centralised water supply systems include surface and groundwater, as well as precipitation. For technical water supply of industrial enterprises, it is possible to use treated wastewater and storm water.

The water supply system may use several sources with different characteristics.

The choice of a source is one of the most important tasks in the construction of a water supply system, as it largely determines the nature of the system itself, the presence of certain facilities in it, and, consequently, the cost of construction and operation.

The water supply source must meet the following basic requirements:

- Ensure that the required quantities of water are obtained from it, taking into account the growth of water consumption in the future development of the facility;
- ensure uninterrupted water supply to consumers;
- to provide water of the quality that best meets the needs of consumers or allows achieving the required quality through simple and inexpensive water treatment;
- ensure that water can be supplied to the facility at the lowest cost;
- have such a capacity that water extraction from it does not disturb the existing ecological system.

The correct decision on the choice of a water supply source for each specific facility requires a thorough study and analysis of the water resources of the area where the facility is located. Almost all natural water sources used for water supply purposes can be classified into two main groups:

1) surface sources - seas or their separate parts (bays, straits), watercourses (rivers, streams, canals), reservoirs (lakes, ponds, reservoirs, waterlogged quarries), swamps, natural groundwater outlets (geysers, springs), glaciers, snowfields;
2) underground sources - groundwater basins, aquifers.

4.2 Surface sources of water supply

Surface water sources are subject to natural processes such as blooming, fouling and overgrowth. Water bloom is an intensive reproduction of planktonic organisms of plant (phytoplankton) and animal (zooplankton) origin in the upper water layers. The most massive development of plankton occurs in spring, summer and autumn, especially in lakes and reservoirs. Rivers with high water velocities bloom much less and less frequently. When water is taken during the flowering period, water intake structures are covered with a layer of gel-like, mucous mass. In spring and autumn, phytoplankton is mainly represented by diatoms, and in summer - by blue-green algae. Fouling, i.e. the deposition of small aquatic organisms on hard surfaces under water, including water intake devices and the inner surface of gravity pipes, is a factor that significantly complicates water intake from water sources. The qualitative composition and intensity of fouling depend on the physical and chemical properties of the water in the water sources.

Surface water sources are characterised by relatively high turbidity, organic matter and bacteria content, and low salt content (except for sea water and some lakes). The quality and quantity of water from surface sources depends heavily on the amount of precipitation, snowmelt, and surface contamination. Water from surface sources must be treated for drinking purposes.

In addition, each type of surface water source has its own characteristics related to climatic, geological, meteorological, hydrological, topographical, biological and other factors. Naturally, not all of these factors affect the condition of the source to the same extent, so a detailed study of these factors is required to ensure the correct selection and design of the water intake facility in each case.

4.2.1 Rivers

Rivers are natural open water flows that flow through the channels they have created. In their natural (unregulated) state, rivers should be assessed as water supply sources primarily on the basis of hydrological factors, including the quantity and quality of runoff, total discharge, water levels and their fluctuations, ice conditions, floods and their fluctuations, flow velocity, sediment quantity and quality, and channel structure. Topographic and geological factors must also be taken into account.

For regulated rivers as sources of water supply, in addition to the above factors, hydrographic conditions, i.e. the shape of the coastline formed as a result of regulating the river flow, meteorological factors, i.e. wind direction and strength, and biological factors, i.e. water blooms, duration of blooms, presence of plankton and aquatic vegetation, should also be taken into account.

Surface water sources have a variety of feeding and flow regimes.

For most rivers, rain, snow and glacial water are the main sources of supply.

During dry periods of the year and during the ice-out period, groundwater is the source of water for rivers. Rivers typically have several sources of supply, with one or two of them predominating, varying by season. Plain rivers are characterised by groundwater and partly rainwater in summer and winter; snow as a result of snowmelt in spring; and rainwater in autumn.

River flow and discharge vary depending on the season and along the length of the river, from the headwaters to the mouth. Typically, runoff and discharge increase with an increase in the catchment area, so water flows in the river are different for different streams and settlements.

The presence of marshes in the basin of rivers, lakes and reservoirs helps to reduce the maximum flow, while preventing a sharp decrease in flow during the low-water period, when rivers are fed mainly by groundwater. In other words, marshes play a buffering role in the quantitative variation of river flows over the seasons.

Due to the unevenness of runoff over the seasons, a very important characteristic of the river's water regime is the long-term average flow, as well as its maximum and minimum values, which must be taken into account when selecting and designing water intake structures.

The speed of water movement in a river and fluctuations in water levels largely depend on the shape of the riverbed cross-section, its slope, planform, and aquatic vegetation.

Water movement in the river is turbulent. Near a concave bank, masses of water move downwards, eroding the banks, and near a convex bank, they move upwards, washing it out. This pattern of river flow should be taken into account when choosing the design and location of the water intake.

Water velocities in rivers are distributed unevenly across the live section - vertically they decrease from the surface to the bottom, and horizontally - from the middle of the river to the banks. For a river channel with a live cross-section W, through which flow Q passes, the average velocity V is:

$$V = \frac{Q}{W} \qquad (4.1)$$

Usually, the average river velocity does not exceed 5 m/s, but local velocities can vary significantly from this value, and instantaneous velocities at certain points can exceed 2 or more times.

4.2.1.1 Ice phenomena

The process of freezing on rivers is as follows. As the air temperature drops, river water gradually cools. The first ice crystals appear near the banks, in the shallows, i.e. in places with low speeds and depths where water cools faster. As they freeze to the shore, they form strips of ice attached to the shore, the so-called shorelines. Simultaneously with the formation of ice floes, soot appears on the rivers.

The fat is transparent crystals up to several millimetres thick in the form of needles and thin plates that float on the water surface and look like spots of fat frozen on the water from a distance. Snow that falls on a supercooled water surface forms a snowflake.

Due to the turbulent nature of the flow, the water temperature is continuously mixed and levelled throughout the river. As the water is supercooled, crystals of in-water ice form. One of its types is shuga, which is intra-water and bottom ice that has floated to the river surface.

The ice pack can be in motion and create a snow drift, or it can be stationary. The accumulation of ice under the ice cover leads to the formation of jams. Ice jams are formed in places of river flow distortion, abrupt changes in depths, and channel narrowing. At air temperatures below 0°C during the autumn ice drift, large ice floes can linger in places of river narrowing, near islands, on bends and shoals. The gradual stopping and freezing of ice floes results in the formation of ice drift. On small rivers, ice formation occurs quietly, most often by splicing the banks.

The nature of the ice regime divides rivers into four groups: with stable ice, unstable ice, some ice phenomena, and no ice phenomena.

The duration of ice cover on rivers varies widely and depends primarily on the climatic conditions of the areas through which they flow.

To characterise ice drift events on rivers, a score is used:

- 1 point - small amount of ice (up to 25% of the live cross-section), ice drift up to 3 days without formation of jams, all ice is transported in the upper water layer;

- 2 points - medium amount of mud (up to 50% of the live cross-section), mud drift for up to 7 days with the formation of mud jams and mud transport in the upper half of the live cross-section of the stream;

- 3 points - a large amount of mud (up to 90% of the live section), mud run for more than 7 days with the formation of mud jams and mud transport over the entire live section.

The period of ice drift and its nature for rivers is usually established on the basis of long-term observations.

The period of ice drift and its characteristics for rivers are usually determined on the basis of long-term observations.

4.2.1.2 River sediments

River sediments are solid mineral particles carried by the flow and forming channel and floodplain deposits. River sediments are formed from the products of

weathering, denudation and erosion of rocks and soils.
Water erosion, the destruction of the earth's surface under the action of flowing water, is the most active process that enriches rivers with sediments. It is divided into slope and channel erosion.

Slope erosion is the erosion and washing away of soils and rocks by snow and rainwater flowing down the slope.

Channel erosion is the erosion of bedrock and riverbeds and valley slopes by water flows in river channels.

River waters erode the banks and bottom of the channel. However, the sediments that arrive as a result of these processes are only part of the river sediments, and a certain proportion of them are the products of the erosion of sediments that were previously deposited in the channel and were brought from the surface of the basin.

The intensity of water erosion depends primarily on the energy of flowing water and then on the resistance to erosion of the surface over which this water flows.

Destruction of vegetation cover (deforestation, excessive grazing, fires), improper ploughing of the surface (along slopes) and cultivation of soils without observing agrotechnical rules that provide for the preservation of soil structure can lead to increased erosion, local soil washout, the emergence of gully erosion and, ultimately, to increased turbidity of rivers.

Basic definitions and characteristics of river sediments

River sediments are usually divided into suspended and bedded sediments depending on the nature of their movement in the flow. Sediments are also divided into transit and channel-forming sediments. Small particles are mainly transported to the river mouth in transit. Larger particles, depending on the hydraulic properties of the flow, are either transported by the flow in a suspended or entrained state, or are retained in separate sections of the river, only to start moving again when the hydraulic properties of the flow change. Thus, the channel is constantly being reshaped. Obviously, most of the suspended sediments are transitory, and most of the flying sediments are channel-forming.

The amount of sediments (in kilograms) carried by the river through a cross-section per unit of time is called the sediment discharge. The total amount of sediment carried by the river through a cross-section over a certain period of time (day, month, year) is called the sediment discharge for that period and is usually expressed in tonnes. The sediment discharge module is the sediment discharge from 1 km^2 per year. An important characteristic of sediments is their granulometric composition, i.e. the distribution of a given fraction.

The amount of suspended sediments contained in a unit volume (1 m^3) of water is called turbidity. Turbidity is expressed in g/m^3.

4.2.1.3 Channel deformations

Channel deformations - erosion or sedimentation of the bottom and banks. The physical cause of channel deformations is an imbalance of sediments in certain sections of the river channel. A change in sediment flow along a non-flowing section is inevitably accompanied by channel deformations: an increase in sediment flow along the river corresponds to channel erosion, while a decrease in sediment flow is accompanied by an increase in the bottom elevation (sediment accumulation). Channel deformations are divided into vertical (predominantly changes in the channel bottom elevation) and horizontal (transverse channel displacement). Usually, these two types of channel deformations occur simultaneously.

Channel deformations can be periodic (reversible) and directed (irreversible). Periodic channel deformations include changes in the channel that are repeated over time, and changes in the bottom elevation are reversible. These channel deformations are observed during the movement of bottom ridges, the development of eddies, etc. Directional channel deformations are expressed in unilateral changes in the channel, for example, in the case of unidirectional erosion or deposition of river sediments. Irreversible deformations are deformations associated with the construction of reservoirs.

Depending on the type of channel deformation, all rivers can be divided into three main groups:

- wandering rivers - significant changes in river channels, changes in depths at rifts (there are no such rivers in Ukraine);
- non-permanent rivers - relatively small and slow changes in the riverbed, river movement downstream does not exceed 70-100 m (Dnipro, Dniester);
- permanent - flow in stable, low-destructive rocks at low speeds and carry a small amount of sediment.

4.2.2 Lakes and reservoirs

When assessing lakes and reservoirs, the same factors are taken into account as for rivers. For reservoirs, the same factors are additionally analysed as for regulated rivers.

There are 3 main levels (horizons) and 4 volumes:

levels:

1. forced backwater level (FBL) or forcing horizon - the water surface level of the reservoir that exceeds the NBL, which, when designing a hydraulic structure with a known flow capacity, is determined based on the area of the reservoir and the maximum possible water inflow. Exceeding this level can lead to overflowing over the crest of the dam and other emergency situations;

2. normal backwater level (NBL) - the optimal highest water level of the reservoir that can be maintained for a long time by the backwater structure;
3. Dead volume level (DVL) or reservoir operating horizon - the water surface mark corresponding to the maximum emptying of the reservoir.

Volumes:
1. Volume or total volume of the reservoir - this value is equal to the sum of the dead and useful volumes;
2. forcing capacity or regulating capacity of the reservoir - part of the volume of the reservoir between the FPR and NPR marks, designed to reduce the maximum flow through the hydraulic structure during spring floods or rain floods;
3. useful volume of the reservoir - the part of the reservoir volume between the marks of the optimal highest level of the horizon (NPR) and the level of maximum operation of the reservoir (RMO);
4. dead volume of the reservoir - the volume of the reservoir below the mark of the horizon of operation of the reservoir (RMO).

4.3 Underground sources of water supply

Underground sources of drinking water supply are groundwater, interlayer water (unconfined and confined), surface water, infiltration coastal water and springs.

Groundwater (GW) is water contained in the strata of rocks in the upper part of the Earth's crust in a liquid, solid, or vapour state.

GW that moves under the influence of gravity is called gravitational or free, as opposed to water that is bound and held by molecular forces - hygroscopic, film, capillary and crystallisation. Layers of rock saturated with gravitational water form aquifers. The first permanently existing unconfined aquifer from the earth's surface is called the groundwater horizon. The entire space from the earth's surface to the groundwater table is called the aeration zone, in which water seeps from the surface. In the aeration zone, on separate disconnected layers of rock with lower filtration capacity, temporary accumulations of groundwater called surface water are formed during the groundwater recharge period. Aquifers lying below groundwater are separated from it by layers of impermeable (water-resistant) or low-permeability rocks and are called interlayer water horizons. They are usually under hydrostatic pressure. The recharge area of interlayer water is located in places where water-bearing rocks come to the surface (or in places where they are shallow); recharge also occurs through the flow of water from other aquifers (Fig. 4.1).

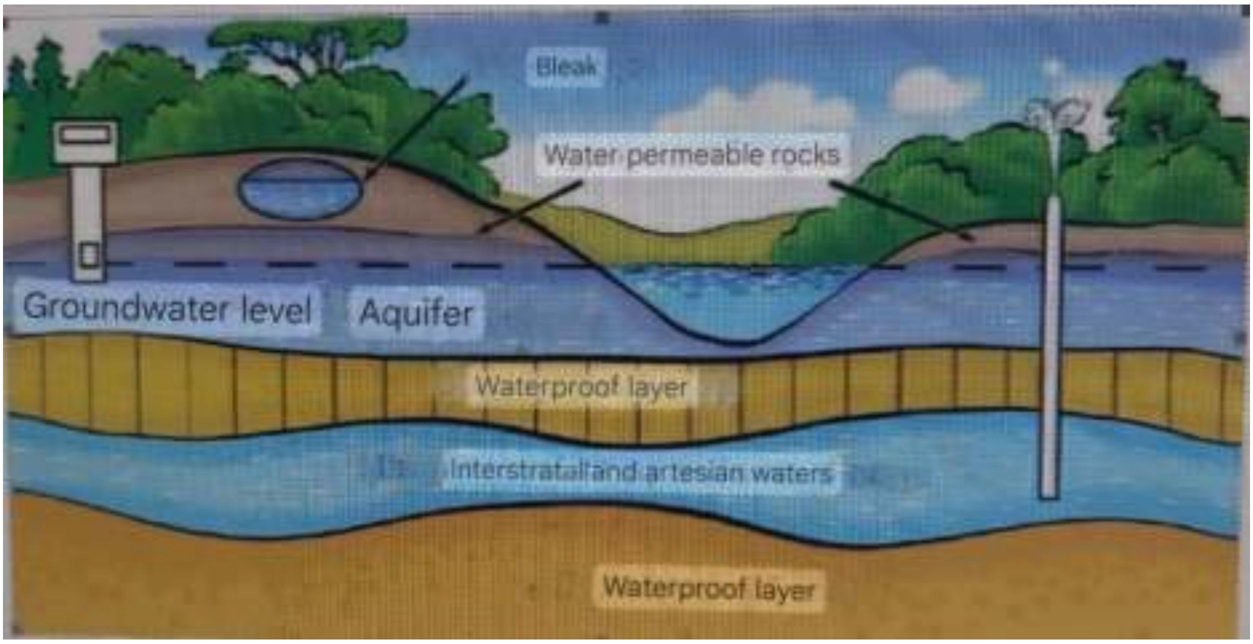


Figure 4.1 – Diagram of groundwater occurrence

There are several types of groundwater based on its origin:

- Infiltration water is formed by rainwater, meltwater and river water seeping from the ground surface. In terms of composition, it is mainly hydrocarbonate-calcium and magnesium. When gypsum-bearing rocks are leached, sulphate-calcium waters are formed, and when salt-bearing rocks are dissolved, chloride-sodium waters are formed;
- Condensation water is formed as a result of water vapour condensing in the pores or cracks of rocks;
- sedimentary waters are formed in the process of geological sedimentation and usually represent altered buried waters of marine origin - sodium chloride, calcium-sodium chloride, etc.

Depending on the nature of the voids in water-bearing rocks, PV are divided into pore waters - in sands, gravel and other clastic rocks; fissure (vein) - in rock formations (granites, sandstones) and karst (fissure karst) - in soluble rocks (limestones, dolomites, gypsum, etc.).

Water located at different depths from the earth's surface is referred to by different names. It is called surface water if the depth of the water is up to 4 m; groundwater - at depths of up to 10 m; soil water - at depths of up to 40 m; artesian water - at depths of more than 40 m.

The speed at which water flows depends on the structure of the rocks through which it flows. All rocks are divided into water-resistant and water-impermeable rocks in relation to water:

- water-impermeable: gravel, sand, sandy loam, pebbles, limestone, fissured chalk;

- water-resistant: granite, limestone, clay, dense sandstone.

Surface water is a certain accumulation of water on the surface of low-permeability or water-resistant rocks that are included in the thickness of the water-permeable layer. Just like groundwater, surface water, being close to the surface, can become contaminated and unsuitable for drinking water supply.

Groundwater (unconfined water) is located in the first water-resistant layer (counting from the surface). In wells, it is located at the same level as underground water. Groundwater moves in the direction of the slope of the water-resistant underlying layer. Most often, such water is suitable for drinking water supply and is not polluted in natural conditions. However, groundwater pollution can occur from the soil: the closer the water is to the surface, the greater the likelihood of its pollution from economic facilities and settlements located above it.

Unconfined waters do not completely fill the aquifers and have a free surface. An example of unconfined waters is the water in the aquifers exposed by wells K1 and K2 (Fig. 4.2). The water in these wells is at levels that coincide with the groundwater levels. Unconfined groundwater from the first aquifer surface (the layer exposed by well K1 in Fig. 4.1) is called soil water. Soil water is characterised by high pollution, so when used for water supply purposes, it is usually purified.

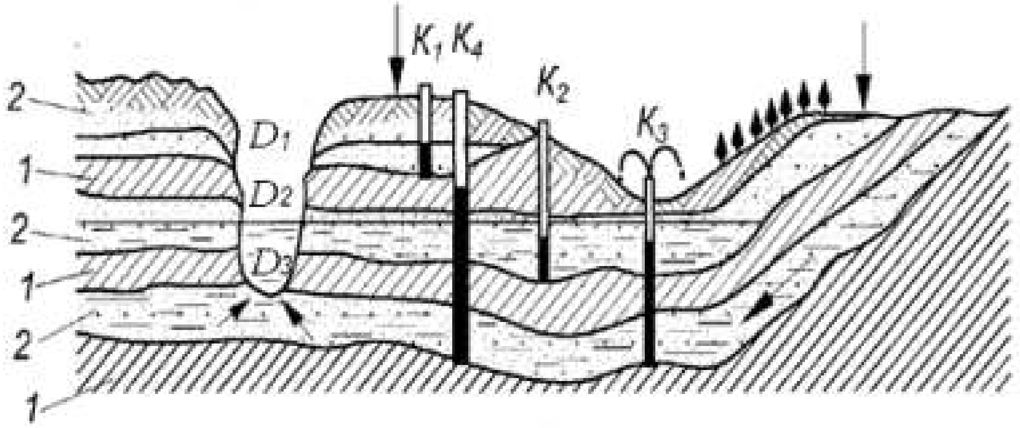


Figure 4.2 – Diagram of groundwater formation and occurrence:
1 – water-resistant rocks; 2 – water-bearing rocks; K1 – K4 – wells;
D1 – D3 – springs

Pressurised (artesian) waters completely fill the aquifers. An example of artesian water is the water in the aquifer exposed by wells K3 and K4 (Fig. 4.3). Artesian water is usually of high quality and in most cases can be used for domestic and drinking purposes without purification.

In a well that opens up a confined aquifer, the water rises to the piezometric line. If the piezometric line is above the ground, water flows out of the well (well

K3 in Fig. 4.2). These wells are called self-flowing.

The water level established in a well in the absence of water withdrawal is called static. The static level of unconfined water coincides with the level of groundwater, and that of confined water coincides with the piezometric line (Fig. 4.3).

When water is pumped out of a well, its level decreases, and the more intense the pumping, the greater the decrease. This level is called dynamic.

The water levels and piezometric lines established around wells when pumping water from them (in cross-section, they have a convex upward shape) are called depression curves. The area bounded by the depression curves is called a depression funnel.

Non-pressure and pressure waters can reach the surface (springs, wells). The outlet of non-pressure waters is called a descending (downward) spring, and the outlet of pressure waters is called an ascending spring. Spring water is of high quality and can also be used for water supply purposes without purification.

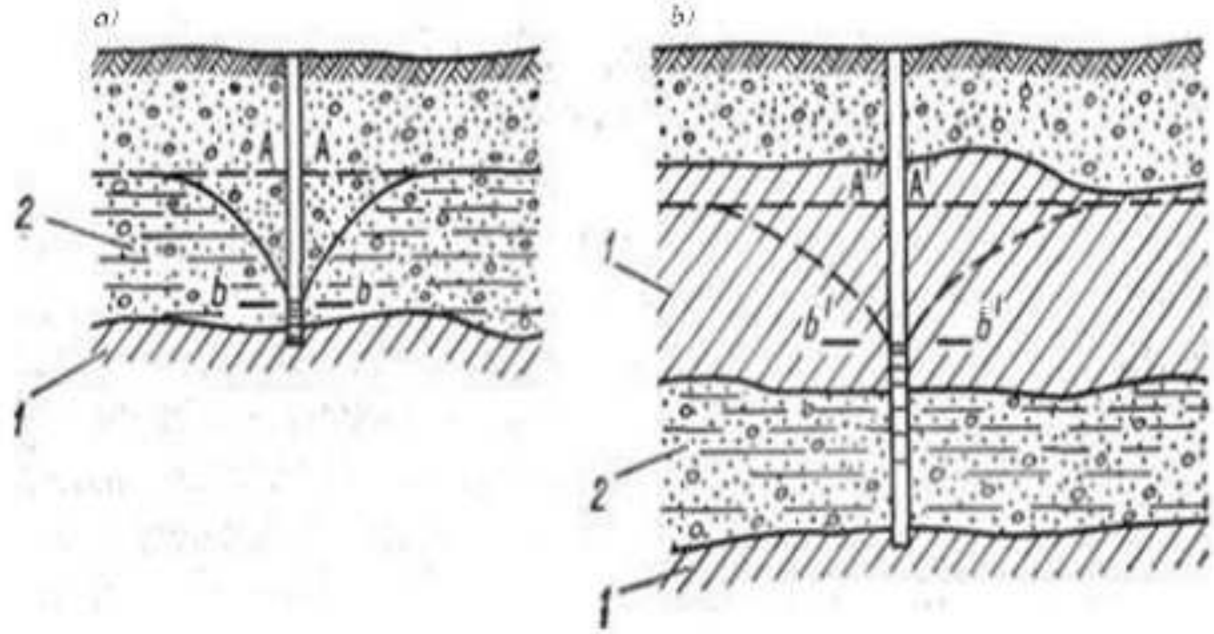


Figure 4.3 – Depression funnels:
a – non-pressurised water; b – pressurised water; 1 – water-resistant rocks;
2 – water-bearing rocks; A-A – static level;
A‘-A’ – piezometric line in the absence of pumping;
b-b and b‘-b’ – dynamic levels

When choosing a water supply source, it is necessary to consider the quality of the water in it and its capacity, consumer requirements for water quality, technical and economic considerations, and other factors.

Control questions

1. What are the main sources of water supply for centralised water supply systems?

2. What criteria determine the choice of water source?

3. What are surface water sources? Give examples.

4. What natural processes are characteristic of surface water sources?

5. Why does water from surface sources need to be purified for drinking?

6. What is water blooming, and what factors influence it?

7. What differences in river flow are characteristic of different seasons of the year?

8. How do wetlands affect river flow in different seasons of the year?

9. What is the average annual river flow, and why is it important?

10. What is channel erosion, and how does it differ from slope erosion?

11. How does the movement of water in a river affect its channel and banks?

12. What are ice phenomena, and how do they form on rivers?

13. What are river sediments, and how are they formed?

14. How do you distinguish between suspended and bedload river sediments?

15. What is a depression funnel, and how is it formed?

16. What types of groundwater exist, and how do they differ in terms of characteristics?

17. What is groundwater, and how does it differ from artesian water?

18. What is artesian water, and in what cases can it be self-flowing?

19. What are the main factors to consider when choosing a water source?

Lecture No. 5
WATER INTAKE STRUCTURES

Lecture plan

1. General information about water intake structures for water intake from underground sources

1.1 Water intake wells

1.2 Mine wells

1.3 Horizontal water intakes and capture chambers

2. General information on water intake structures for water intake from surface sources.

2.1 Water intake structures of the coastal type.

2.2 Channel-type water intake structures.

2.3 Special water intake structures

5.1 General information about water intake structures for water intake from underground sources

The choice of the type of groundwater intake facility depends mainly on the depth of the groundwater and the thickness of the aquifer.

Groundwater intake facilities can be divided into four types:

- water intake wells;
- mine wells;
- horizontal water intakes;
- capture chambers.

Water intake wells are used to receive non-pressure and pressure groundwater that lies at a depth of more than 10 m. Water intake wells are the most common type of water intake facilities for water supply systems in cities, rural areas and industrial enterprises.

Mine wells are used to receive groundwater that lies at a depth of no more than 30 m.

Horizontal water intakes are arranged to receive groundwater at a shallow depth (up to 8 m), with a low aquifer thickness.

Capturing chambers are used when it is necessary to use spring water for water supply purposes.

5.1.1 Water intake wells

Water intake wells are constructed by drilling boreholes in the ground, the walls of which are supported by steel casing. As the well is deepened, the diameter of the casing is reduced. As a result, the well acquires a telescopic shape (Fig. 5.1).

Concentric gaps between individual casing pipes are filled (tamped) with cement mortar. In rocky soils, well walls are not cased with casing. A brick, concrete, or reinforced concrete chamber is built over the top of the water intake well. A filter is installed in the lower part of the well, consisting of an over-filter, water intake (filtering) and sedimentation parts.

Water intake wells can be equipped with the following types of filters: hole filters; slotted filters; mesh filters; wire filters; gravel filters.

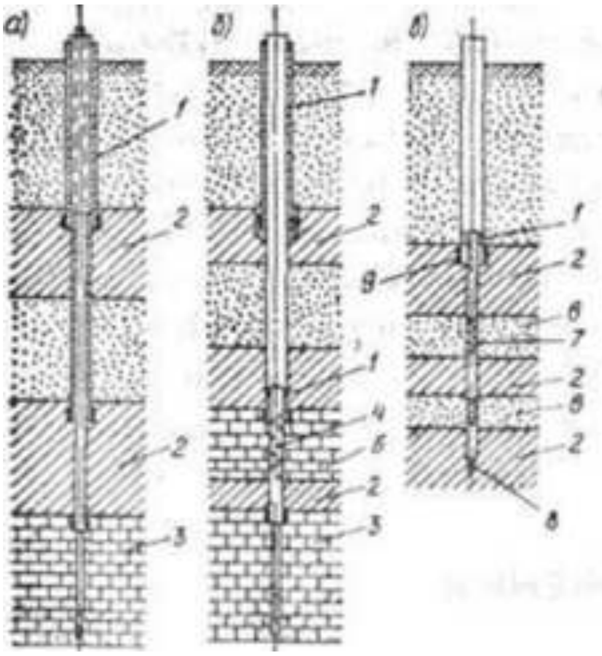


Figure 5.1 - Schemes for the arrangement of water intake wells:
a and b - when taking water in fractured rocks;
c - the same, in sands; 1 - cement mortar between the pipe space; 2 - clay, 3 - hard fractured rocks, 4 - perforated pipes;
5 - limestone; 6 - aquifer sand; 7 - filter; 8 - cork; 9 – shoe

Depending on the required flow rate and capacity of the aquifer, one or more water intake wells are arranged perpendicular to the direction of groundwater flow (Fig. 5.2).

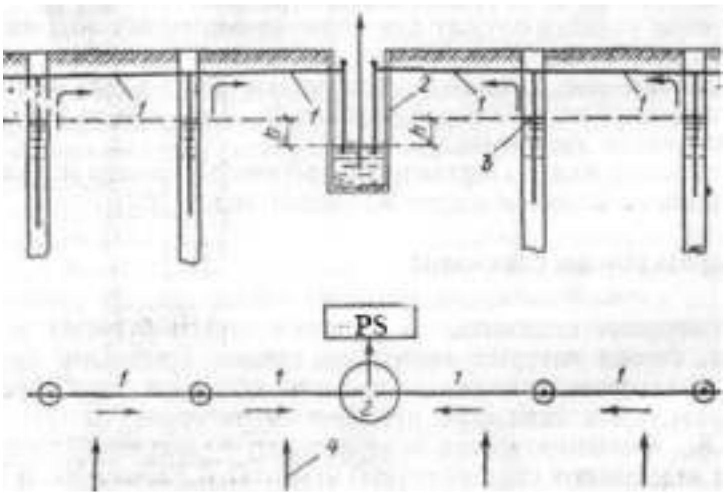


Figure 5.2 - Scheme of water intake wells location
1 - self-priming or siphon pipeline; 2 - collecting well; 3 - dynamic water level; 4 - direction of groundwater flow; water intake wells

The method of extracting water from wells depends on the depth of the dynamic water level. If the water flows out on its own, it is withdrawn from the wells by gravity to a collection tank, from which it is pumped out by pumps. In case of relatively shallow occurrence of the dynamic water table, groundwater is discharged from the wells through gravity or siphon pipelines 1 to the collection well 2, from which it is pumped out by pumps (Fig. 5.2).

The use of siphon pipelines allows to reduce the depth of the collecting pipelines. When the dynamic level 3 is deep (more than 20 m from the ground surface), each water intake well is equipped with a pump.

5.1.2 Mine wells

Mine wells can be made of concrete, reinforced concrete, brick, rubble stone and wood. Most often, mine wells are constructed by lowering them, so they are usually round in plan. Wooden wells, which are made in the form of a log house, have a square shape in plan.

To receive water, the bottom of mine wells is arranged in the form of so-called reverse filters by backfilling coarse-grained materials in layers with a gradual increase in grain size from the bottom up (Fig. 5.3).

Water inlets are created in the side walls of concrete and reinforced concrete wells by laying pipes in them during concreting.

In brick and rubble wells, through seams that are not filled with mortar serve as water inlets.

In case of fine-grained soils, it is advisable to make V-shaped or inclined holes in the walls of mine wells (gravity filters), filling them with sand or gravel as in the case of return filters. Such loading is not washed into the well.

To increase the flow rate of mine wells, the area of the bottom filter is increased by expanding their base. A significant increase in the flow rate can be achieved by arranging radially located horizontal tubular filters Such water intakes are called beam filters.

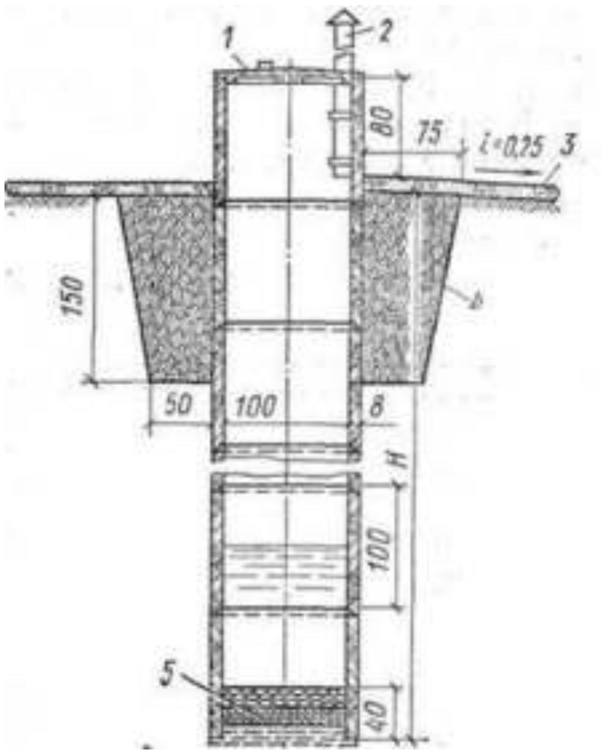


Figure 5.3 - Mine well made of reinforced concrete rings:
1 - reinforced concrete cover; .2 - ventilation asbestos-cement pipe with a diameter of 150 mm; 3 - pavement with crushed stone rammed into the ground, 10 cm thick, 4 - clay lock; 5 - return filter

Around the wells, it is recommended to make a clay castle and a pavement of cobblestones on a sandy foundation. The walls of the well should be built at least 0.8 m above the ground. This prevents clogging of the well and surface runoff from entering it.

To obtain significant water flow rates, several mine wells are arranged perpendicular to the direction of groundwater flow. The water from each well is discharged through siphon and sometimes gravity lines to a collecting well, from which it is pumped to a treatment plant or to consumers.

5.1.3 Horizontal water intakes and capture chambers

Horizontal water intakes are made of reinforced concrete, concrete or ceramic pipes with round or slotted holes. For horizontal water intakes, it is advisable to use oval pipes with a larger intake surface area (Fig. 5.4).

To prevent soil particles from being washed into the intakes, they are covered with filtering sand and gravel. To prevent contaminated surface runoff from entering the intakes, a clay cushion is placed on the ground above them.

The simplest horizontal water intakes can be made of short pipes with gaps at the joints, brick or rubble masonry without mortar, etc.

For inspection and cleaning of horizontal water intakes, manholes are arranged every 50 to 150 m along their length.

The use of spring (well) water for water supply purposes (key capture) is carried out using capture chambers. To capture the water of the ascending keys, capture chambers are arranged as mine wells, placing them above the water outlets, and to capture the water of the descending keys, capture chambers are made with water intake through the side walls. To increase the water intake surface, capture is carried out in the form of horizontal water intakes.

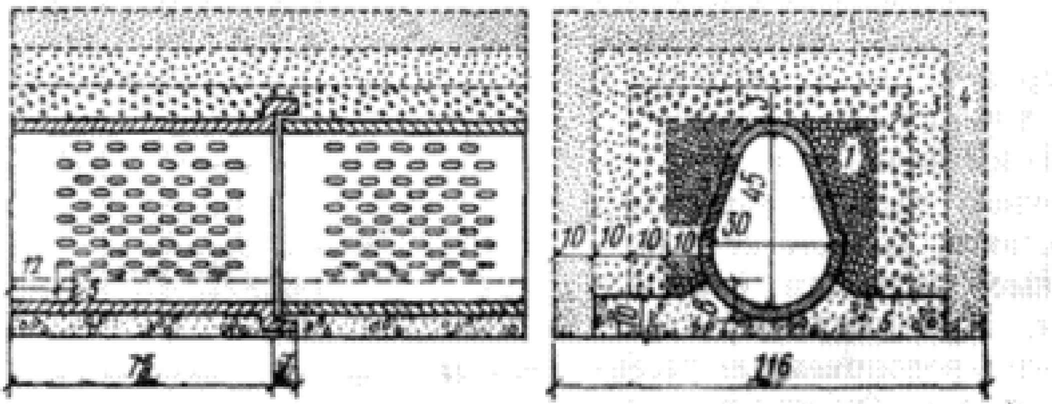


Figure 5.4 - Horizontal water intake from reinforced concrete pipes of ovoid cross-section:
1 - layer with grain size of 12-15 mm; 2 - the same, 5-7 mm;
3 - the same, 1.5-2 mm, 4 - the same, 0.4-0.6 mm; 5 – concrete

5.2 General information on water intake structures for water intake from surface sources.

Facilities for receiving water from surface sources should ensure uninterrupted supply of water of the best possible quality to consumers at different times of the year. This task is achieved by the correct choice of their location (in plan and depth), their type and design.

The location of the water intake structure should be chosen as close as possible to the consumer, in a stable part of the water body, in the area of least pollution of the water body (on rivers - above settlements, industrial enterprises and wastewater discharge sites), outside the areas of possible formation of ice jams and ice jams, outside areas of intensive movement of bottom sediments and taking into account the possibility of organising a sanitary protection zone. In addition, the location of water intake structures on rivers is chosen taking into account the type of channel process (the nature of channel changes).

The depth position of the water intake point on the river should be determined on the condition that the distance from the bottom of the ice cover (in winter) to the top of the intake windows is at least 0.2-0.3 m, and the distance between the river bottom and the bottom of the intake windows, which is necessary to prevent sediment from entering the water intake structure with water, is at least 0.7-1.0 m.

During the period of ice freezing, water supercooled to a temperature of minus 0.02-0.05 °C crystallises on suspended soil particles, forming anchor ice, which is transported by currents over long distances. Such ice-laden streams often create emergencies at water intake facilities, completely blocking their intake openings. To protect water intake structures from deep ice, the following measures should be taken

- locate water intake structures in places where there is no accumulation of ice (ice jams);
- reduce the speed of water flow through the intake openings;
- heat the intake grates by supplying warm water;
- arrange floating weirs and boxes enclosing inlets (Weirs are floating devices (rafts, nets, barriers) that are installed in front of inlets to trap ice, ice debris or other obstacles. They effectively protect structures from blockage, especially in winter, when there is a risk of deep ice formation or accumulation of ice drift);
- to arrange water inlet buckets, etc.

Clogging of water intake openings can also be removed by cleaning the grates with scrapers or by flushing with reverse water flow.

Water intake structures on rivers can be divided into the following types by design

- bank (separate or combined with a pumping station);
- channel (with gravity lines);
- special (bucket, infiltration, from mountain rivers, mobile, floating, etc.).

5.2.1 Water intake structures of the coastal type

Bank-type water intake structures are arranged on relatively steep river banks. A schematic diagram of this type of water intake is shown in Fig. 5.5.

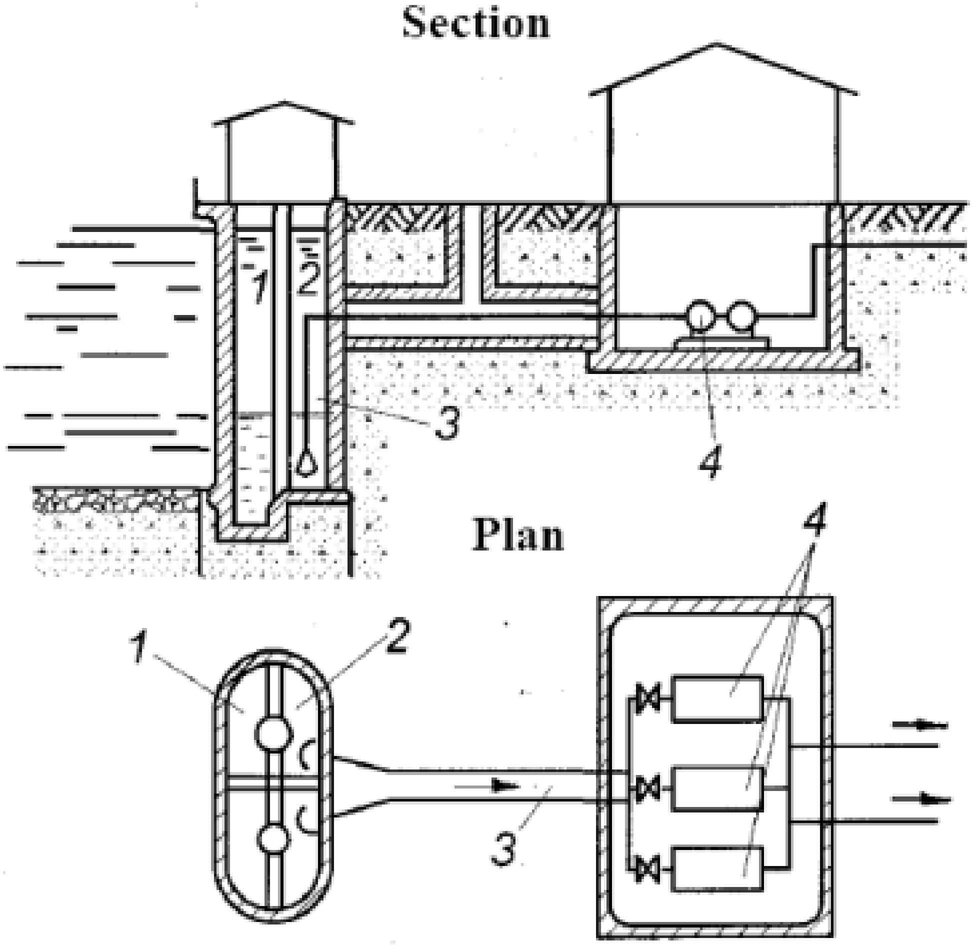


Figure 5.5 - Schematic of a separate onshore water intake structure:
1 - intake chamber; 2 - suction chamber;
3 - suction pipes; 4 - pumps.

The intake structure consists of a water intake well and a pumping station. Along the front, the intake well is divided into separate sections, the number of which is assumed to be two or the number of suction lines. Each section of the water intake well is divided by a partition into two chambers: intake 1 and suction 2, where the suction pipes 3 of pumps 4 are lowered. Water from the river enters the intake chamber through openings equipped with removable grilles on the outside and throttle or gate type gates on the inside.

The grating is made of vertical steel rods with a rectangular or round cross-section. The gap between the rods of the grating is 40-50 mm. The dimensions of the grating are determined from the condition of water passing through the gaps between the rods at the highest flow rate at a speed of 0.2-0.6 m/s.

In case of heavy water contamination and the presence of a sludge, lower velocities are used.

If the water level in the river fluctuates greatly, the inlets are made in two or three tiers. The upper openings are used to collect the upper, relatively clean layers of water during floods. In the openings of the partition between the intake and suction chambers, a 1.0-1.5 mm thick wire mesh with mesh sizes ranging from 2x2 to 5x5 mm is installed. Large water intake structures are equipped with rotating screens with continuous flushing. Filtering the water through the screens and meshes ensures its preliminary purification and prevents damage to the equipment.

The top of the water intake well should rise above the highest water level (HWL) by at least 0.5 m. A pavilion is constructed above the well, from which the equipment is controlled.

Separate water intake structures of the coastal type (performed relatively less frequently than those combined with pumping stations.

Since in most cases combined water intake structures are built on loose soils, they are constructed with a common bottom for the intake well and the sedimentation plant.

5.2.2 Channel-type water intake structures

Water intake structures of the channel type are arranged for relatively gentle banks, weak soils and shallow water depths in the river. They consist of a headworks, gravity lines, a bank well and a pumping station. Water flows into the bank well via gravity lines. Further movement of water is similar to its movement in a coastal water intake.

In some cases, instead of installing a head, a coastal intake is combined with a pumping station that is placed directly in the riverbed. This type of in-stream intake is called a crib intake.

The headworks are used to secure the ends of gravity lines and receive water from the source. The headworks can be flooded all the time, flooded only in floods, or not flooded.

On non-navigable rivers, headgates of any design can be used. In this case, preference should be given to the simplest structures: in the form of pipe sockets extended into the riverbed, or other designs.

On the rivers used for logging individual logs (the so-called ‘mills’), ordinary headwaters are built (in the form of wooden log cabins).

On navigable and rafting rivers, only reinforced concrete or concrete headwaters in a steel casing are designed, thus eliminating the possibility of damage by ships or anchors. Non-sinking headwalls are in the form of bridge piers with icebreakers.

Gravity lines are made of steel, reinforced concrete or asbestos-cement pipes, or in the form of reinforced concrete galleries.

The number of threads should be at least two. Gravity lines should be laid with a slope towards the coastal well or in the opposite direction, depending on the direction of flushing of these lines. The water velocity in gravity lines should be at least 0.7 - 0.9 m/s to avoid clogging. It is advisable to clean gravity lines from deposits by direct or reverse flushing with water. For this purpose, water intake facilities should have the necessary equipment.

If gravity lines are long and the river bank is high, it is advantageous to replace them with siphon lines, which have a much lower depth of installation.

Coastal wells of channel-type water intakes are similar in design to the intake wells of coastal-type water intakes.

At water levels significantly exceeding the NRW and the corresponding profile of the river bank, windows can be used for water intake.

5.2.3 Special water intake structures

If deep ice forms in the river or if the water is highly turbid, it is advisable to draw water from an artificial bay, the so-called bucket, rather than directly from the river. The size of the buckets is determined by the condition of deep ice floating or suspended solids falling out.

The flow rate in them is assumed to be 0.05-0.2 m/s.

Buckets can be of the downstream type (Fig. 5.6, a), where the bucket mouth is located upstream, and of the upstream type (Fig. 5.6, b), where the mouth is located downstream.

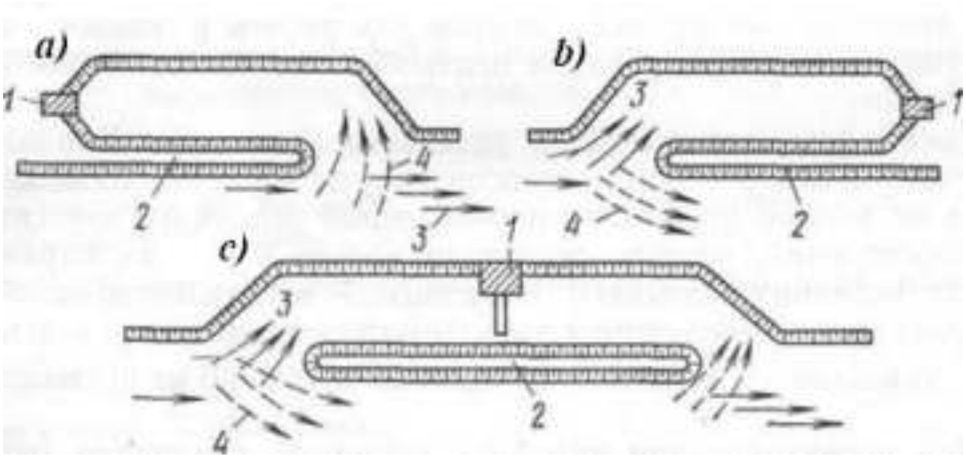


Figure 5.6 - Schemes of water intake buckets:
1 - intake structure; 2 - dam; 3 - surface flows; 4 - bottom flows

Buckets with a bottom inlet receive mainly bottom jets, while buckets with a top inlet receive surface jets. Therefore, it is advisable to use the first type of bucket for deep ice control, and the second type of bucket for water clarification.

Paired buckets (Fig. 5.6, c) are used to combat deep ice and to clarify water at different times of the year.

The buckets can be dug into the river bank or placed in the riverbed. In the latter case, the bucket is enclosed by dams. The design of water intake structures for buckets does not differ from that of conventional river intake structures.

Infiltration water intake structures are wells, mine wells or horizontal water intakes located along a river with sandy or sandy-gravel banks. These intakes take river water that filters through the soil. Infiltration water intake structures are advisable to use when it is necessary to obtain good clarified water and on rivers with intensive deep ice formation.

Mobile or floating water intakes are used for temporary water supply systems. A mobile water intake is a lightweight pumping station that can move according to changes in the water level in the river along an inclined rail track laid on the bank. At floating water intakes, pumping units are placed on floating vessels: barges, pontoons, etc.

The advantages of mobile and floating water intakes are the independence of water intake from fluctuations in the water level in the river and the possibility of their quick installation. However, they also have significant disadvantages, such as the need for flexible pipeline connections, as well as difficult operating conditions in winter and during floods.

Two types of water intake structures can be used to draw water from reservoirs:

- combined with dams, spillways or spillways;
- free-standing.

Water intake structures at reservoirs should provide the possibility of water intake from different depths, taking into account its quality.

Control questions

1. What types of water intake structures are used to take water from underground sources?
2. What are the main functions of water intake structures for groundwater sources?
3. What is a water intake well and when is it used?
4. What is the design of the water intake well? List the main elements.
5. What types of pumps are used in water intake wells?
6. What is a mine well? What are its advantages and disadvantages?
7. Under what conditions is it advisable to use mine wells for water intake?
8. How is water quality ensured in mine wells?
9. What is horizontal water intake? Where is it usually used?
10. What is the role of capture chambers in groundwater abstraction?

11. What are the advantages of horizontal water abstraction compared to wells and boreholes?

12. What are the main types of water intake structures used for water intake from surface sources?

13. What is the peculiarity of designing water intake structures for surface sources?

14. What is a coastal water intake? Under what conditions is it used?

15. What is the difference between a coastal and a channel water intake?

16. What are the special water intake structures? In what cases are they used?

Lecture No. 6
WATER SUPPLY SYSTEMS AND SCHEMES

Lecture plan

1. Water supply systems
2. Water supply schemes
2.1 Water supply schemes for settlements
2.2 Water supply schemes for industrial enterprises

6.1 Water supply system

A water supply system is a set of facilities, engineering networks and equipment that ensures the supply of water in the required quantity and quality. The main components of the water supply system:

Sources of water supply:

- natural (rivers, lakes, underground aquifers, artesian wells);
- artificial (reservoirs, tanks).

Water intake facilities - designed to take water from a source (e.g., pumping stations).

Water treatment systems - purification of water to the required quality (filtration, disinfection, softening).

Water supply networks:

- pipelines for transporting water to consumers (mains, distribution networks);
- water towers or reservoirs to maintain a stable pressure.

End users: population, industrial enterprises, agriculture, municipal facilities.

A general water supply system is designed to use treated water for production needs. However, the capacity of a drinking water source is not always sufficient to withdraw the required amount of water for production needs. In addition, the design of several separate industrial water supply systems is necessary to supply water to individual production units at different pressures.

Fire-fighting functions are performed by combined water supply systems for domestic and fire-fighting purposes. The choice of designing combined or separate water supply systems is based on the results of technical and economic calculations.

Group water supply systems are designed to supply water to several cities or settlements. The cost of a group water supply system is less than the total cost of individual systems for each facility, both in terms of capital expenditure and operating costs.

All water supply systems can be classified according to the following criteria:

- By purpose: water supply systems of settlements (cities and towns); agricultural water supply systems; industrial water supply systems, which are distinguished by industry sectors (water supply systems of thermal power plants, water supply systems of metallurgical plants, etc.

- by the functions performed: household drinking; household fire-fighting; household production; fire-fighting.

- According to the use of natural sources, the following water supply systems are distinguished: water supply systems in which water comes from surface sources (river, lake, sea); water supply systems in which water comes from underground sources; water supply systems of mixed supply.

- By the method of water supply, water pipelines are: gravity (gravitational); with mechanical water supply (by pumping water with pumps).

Production water pipelines are divided into the following types according to the method of water use: direct-flow systems (systems with a single use of water); recycling systems; systems with water reuse.

6.2 Water supply schemes

Schemes are a structural model of the location and interaction of elements of water supply or wastewater systems in a certain area. They are developed taking into account: geographical conditions; water sources; number and location of consumers; volume and type of wastewater.

Main types of schemes:

- centralised - one system serves a large number of consumers (cities, large industrial complexes);
- decentralised - separate systems for individual facilities or districts (rural areas, private houses).

6.2.1 Water supply schemes for settlements

The composition of the facilities is determined primarily by the turbidity and colour of the source water and the capacity of the treatment plant. Most often, a water treatment plant is located in close proximity to a water supply source. The treated water is collected in clean water tanks.

The most common scheme for small settlements is the extraction of drinking quality groundwater (Fig. 6.1). Water is taken from the aquifer using a borehole and fed into a water tower. As soon as the tower tank is full, the pump in the well is automatically or manually switched off and no water is supplied to the tower. Water is supplied to the network from the tower, which provides the required pressure and flow rate. When the water level in the tower tank reaches the minimum level, the pump in the well is switched on again and water fills the tank. Water intake wells and the tower are usually located directly next to the mains. This is the scheme envisaged for the first phase of the water supply system.

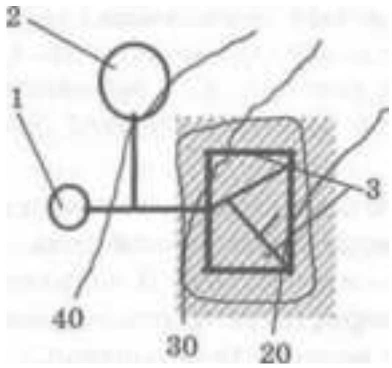


Figure 6.1 - Scheme of water supply with drinking water intake from an underground source:
1 - well; 2 - water tower; 3 - water supply network

A water treatment plant between wells and reservoirs is only provided if the water quality does not satisfy consumers. Clean water reservoirs store large volumes of water, which are needed to regulate the unevenness of water supply to the network and ensure uniformity of supply. Water pipes transport water to the water supply network, which directly distributes it to consumers.

The water supply scheme of a large settlement most often contains the following elements (Fig. 6.2 and 6.3):

1. A surface water body (river, lake, reservoir, pond, etc.) used as a source of water supply;

2. A water intake structure designed to take water from a water body;

3. Pumping station of the first lift (PS-1), which pumps water from the reservoir to water treatment facilities;

4. Water pipelines transporting water from PS-1 to the water treatment plant;

5. Drinking water treatment facilities (DWTF);

6. Clean water tanks (CWT) - designed to store regulated water volume, fire reserve and process water volume for the auxiliary needs of the treatment plant;

7. Pumping station of the second lift (PS-2) - designed to pump drinking water from the treatment plant to the distribution network of the settlement;

8 Water pipelines for transporting water from PS-2 to the distribution network of the settlement;

9. The boundary of the settlement's urban area;

10 The ring water distribution network of a settlement is designed to distribute water evenly over the area of the settlement;

11. Water tower (WT) - designed to store a regulated volume of water in case of differences in NS-2 supply and water consumption by the settlement;

12. Nodal wells of the ring network for the placement of shut-off valves;

13. Industrial enterprise (PE);

14. Pipeline for supplying industrial water to the PP;

15. Water intake of process water;

16. Water intake wells;

17. Collecting collector.

Fig. 6.2 shows the scheme of water supply to a settlement in case of water intake from a surface source. The water is taken by means of a water intake facility, ensuring that it is of high quality and pre-treated to remove the largest impurities. The type of water intake structure is selected depending on the type of source, water quality, hydrogeological, geological, topographic conditions, shipping, etc. NS-1 takes water from the intake structures and pumps it to the treatment plant, where it is clarified, discoloured and disinfected.

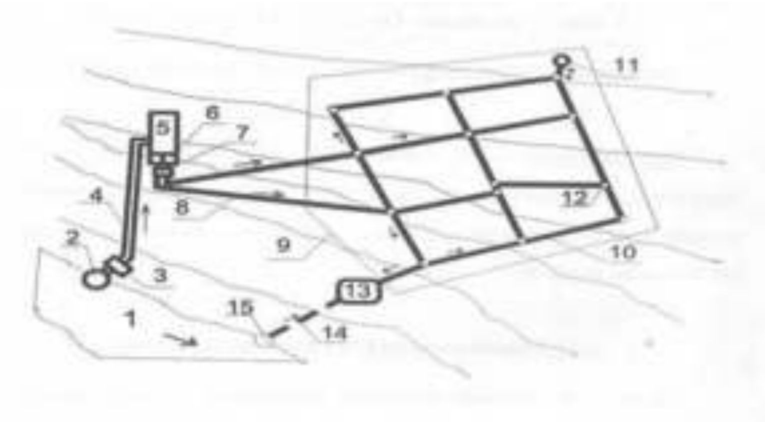


Figure 6.2 - Scheme of water supply to a settlement in case of water intake from a surface source

Figure 6.3 shows the scheme of water supply to a settlement when water is abstracted from an underground source. The water is abstracted through several wells and supplied to the WSS.

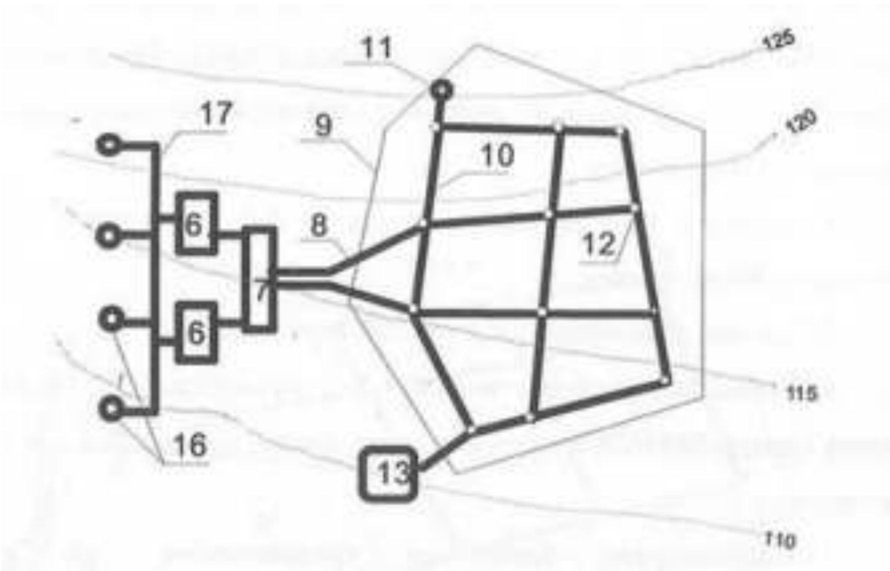


Figure 6.3 - Scheme of water supply to a settlement in case of water intake from an underground source

6.2.2 Water supply schemes for industrial enterprises

The industrial water supply scheme may include the following elements:

- water intake facility (designed to take water from a natural source);
- NS-1 (designed to supply water to a settling pond or directly to the water supply system);
- Settling pond (used for preliminary water treatment; if necessary, supplemented with water clarification facilities, etc;)
- RWP (designed to store a certain amount of water and create pressure for a number of consumers in the event of a system outage);
- storage pond (designed to accumulate and store water);
- NS-2 (designed to create additional pressure);
- Pumping station of the third lift (PS-3) (designed to lift water into the storage tank of the water tower);
- WB (purpose - to provide the required head to consumers);
- chemical water treatment plant (chemical water treatment);
- water pipelines of an industrial enterprise;
- Shut-off and control equipment designed to provide switching in the network, pressure regulation and measurement of parameters;
- storage facilities (tanks, reservoirs, tanks, etc.).

The location of the water supply system elements on the diagram, their design options, and capacity depend on the characteristics of the enterprise and the natural source.

The direct-flow scheme can be used if there is a powerful water source close to the facility (up to 3 km away). Figure 6.4 shows a direct-flow water supply scheme for an enterprise. Pumping station 4, which is located near the water intake structure 5, supplies water for production needs through network 2 to workshop 1. Pumping station 4 supplies water to an independent network 7 for the household and fire-fighting needs of the village 6 and workshops 1. The water is pre-treated at the treatment plant 3

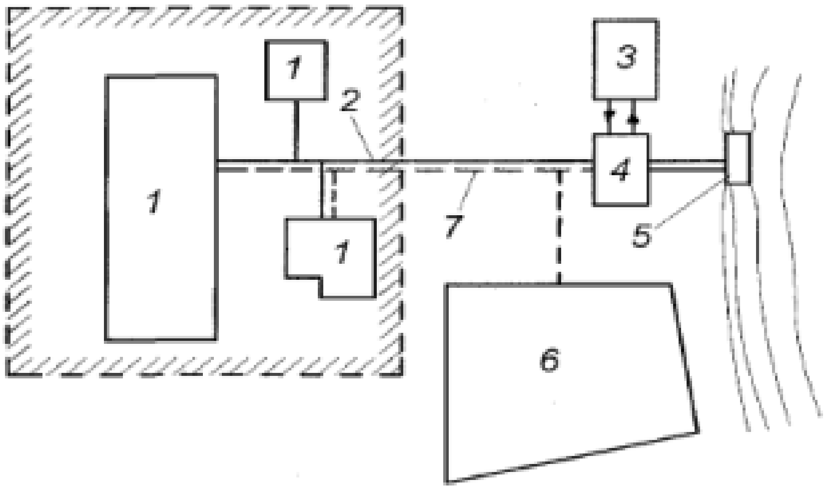


Figure 6.4 – Scheme of direct-flow water supply to the enterprise

At a number of enterprises (chemical, metallurgical, etc.), water is used for cooling purposes and is hardly polluted, but only heated.

If there is a consumer of process water with a high consumption rate whose discharge water can satisfy other consumers in terms of quantity and all parameters, then a water reuse system is used in these cases. This system operates in a direct-flow mode, but only the amount of water required by the consumer with the highest consumption is taken from the source, and the rest of the consumers use its wastewater.

This system reduces the amount of natural water withdrawn and wastewater discharged, and reduces the cost of the entire water supply system.

The water recycling scheme is applied if the company includes at least one consumer that meets two conditions:

- The total water consumption of this consumer is equal to or greater than the water consumption of all other consumers;
- the quality of the large consumer's wastewater meets the technological requirements of the other consumers.

The water reuse scheme has the following advantages compared to the direct flow scheme

- Reduction in the amount of water taken from a natural source;
- Reduction in the amount of wastewater discharged;
- lower operating costs than the direct-flow scheme.

The disadvantages of the water reuse scheme are:

- narrow range of application;
- not all of the company's production facilities allow the use of wastewater;
- the need for extensive networks.

Recycling systems offer great opportunities to reduce the cost of water supply, reduce fresh water consumption and discharge of contaminated wastewater. These systems can also use the part of the process water that is contaminated with relatively easily removed impurities. After treatment, the water is reused (Fig. 6.5).

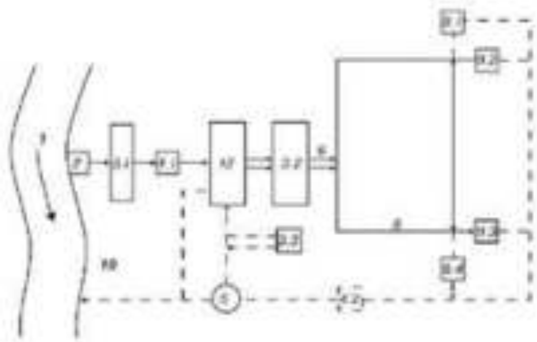


Figure 6.5 - Flow diagram of the industrial water supply system:
1 - source; 2 - water intake facility; 3.1 - NS-1; 3.2 - NS-2;
3.3 - NS-3; 4.1 - natural water treatment facilities; 4.2 - industrial wastewater treatment facilities; 5 - RCF; 6 - water pipelines; 8 - industrial water supply network; 9.1-9.4 - water consumers at the enterprise; 10 - discharge water line of the PP; 12 - cooling devices for process water

In such recycled water systems, to compensate for irrecoverable water losses in production, cooling plants (evaporation from the surface, wind, etc.), wastewater treatment plants, and water losses discharged to the sewerage system, water is recharged from water sources (continuously or periodically). The amount of water added is 5-10% of the total amount of water circulating in the system.

Recycling systems are used at enterprises with advanced production. The possibility of their use is due to the fact that from 70 to 80% of the water passing through the process plants is only heated in the cooling systems and can be reused.

Advantages:

- A significant reduction in the volume of water taken from a natural source compared to the two previous schemes;
- Reduced costs for the construction and operation of the system;
- high level of wastewater treatment.

Disadvantages:

- Limited application: for large and medium-sized enterprises;
- the need for extensive networks.

According to the technical conditions, the use of this system may be necessary because the debit of the available natural water source is insufficient for direct water supply.

The need for recycling systems is also driven by environmental requirements. The use of recycled water systems helps to reduce the amount of polluted water discharged into water bodies.

Drainless technical water supply systems.

Recirculating wastewater systems are the most environmentally efficient, as they completely avoid discharging wastewater into natural water bodies. Such systems use a repeatedly treated mixture of industrial and domestic wastewater that meets all the necessary technical, economic and sanitary and hygienic standards. This results in significant water savings and minimises the negative impact on the environment (Fig. 6.6).

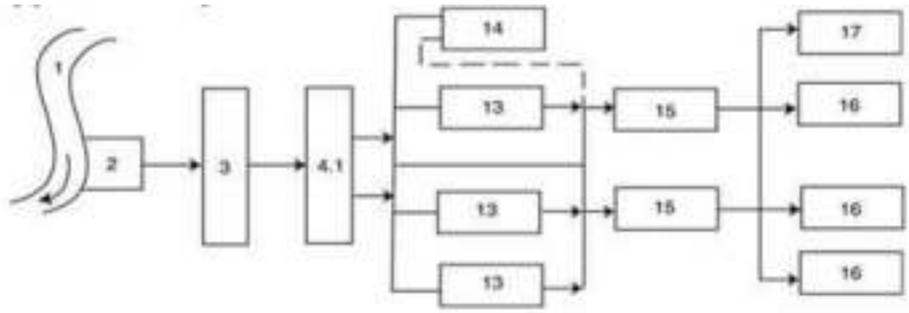


Figure 6.6 - Drainless technical water supply systems:
1 - source; 2 - water intake facility; 3 - NS-1;
4.1 - natural water treatment facilities; 13 - discharged water;
14 - CWS; 15, 16 - water consumers; 17 - sludge management

Drainless water supply systems are the most modern and environmentally friendly types of systems. They can be built by developing and combining the designs of existing systems of the enterprise. The modification involves partially changing the network configuration and incorporating wastewater and sludge treatment or disposal facilities into the system.

The principle of operation of wastewater systems is as follows: after water is taken from a natural source and passed through water intake 2, pumping stations 3 and natural water treatment plant 4.1, the water enters the clean water pipelines, which supply the main consumers of the ‘clean’ cycle. Part of the water is supplied to water treatment plant 14 and directed to consumers with higher water requirements. Wastewater from clean cycle customers is also sent here. The other part of the wastewater, which has not been treated, goes to the consumers of the ‘dirty’ cycle, while the prerequisite is that the total capacity of the discharged water 13 is sufficient to meet the needs of the consumer group 15. Consumers of the ‘non-return' cycle are separated into a group 16 and supplied with water through a non-return network, while residual insoluble elements are accumulated in the sludge 17 management facility.

Positive aspects:

- high environmental friendliness of the system;
- practical implementation of the implementation of the principles of lean technologies in production.

Disadvantages:

- high cost of facilities;
- high operating costs.

In practice, there are often combined water supply systems with different schemes depending on the specifics of production, local conditions, water balance, etc. In some cases, the main recycled water supply scheme is accompanied by a direct-flow system to supply consumers who do not use recycled water for one reason or another. The direct-flow water supply system is often combined with domestic and fire-fighting water supply. Under certain conditions, heated clean water from the systems of individual workshops can be used to make up for losses in recycled water supply workshops or to supply plants that are allowed to use heated water.

Thus, the choice of water supply system depends on the type of source, water quality and the adopted water supply scheme.

Control questions

1. Name the elements of the water supply system.
2. What is a centralised water supply system and what are its advantages and disadvantages?
3. What are the most common sources of water supply in Ukraine?
4. What is the water consumption rate and what does it depend on?
5. What is the difference between surface and groundwater sources?
6. What are the main tasks of pumping stations in water supply systems?
7. What is the need for water improvement for drinking purposes?
8. What international organisations are involved in monitoring the state of water resources?
9. Name the main challenges in the field of water supply at the global level.
10. What is a combined water supply scheme and when is it used?
11. How can the efficiency of water consumption in industry be improved?

Lecture No. 7
WATER SUPPLY NETWORKS

Lecture plan:

1. Water Supply Networks
2. Routing of the water supply network
3. Calculation of Water Supply Networks

7.1 Water Supply Networks

In the water supply networks of medium and large cities, there is usually a distinction between the main network (diameters greater than 300 mm) and the distribution network (diameters between 100…300 mm).

Water mains are pressure (or non-pressure) pipelines designed to transport water between individual structures, for example, from a second-stage pumping station to the water supply network.

To ensure the reliability of water supply, the number of water main lines must be at least two. These are connected by bypasses, expansion joints are installed to accommodate thermal deformations, and check valves are installed (usually at the pumping station) to ensure one-way water flow.

Water mains must meet the following main requirements:

- Have sufficient capacity to supply the required amount of water at the required pressure;
- Construction and operational costs must be minimized;
- Ensure reliable and uninterrupted operation.

Meeting these requirements is achieved through the correct selection of the network type and its components.

When designing a water supply network, the following tasks must be solved:

- Selection of the network type;
- Layout of the network and choice of tower location;
- Selection of pipe materials for the network;
- Determination of design flows for all sections of the network;
- Determination of diameters for all sections of the network;
- Calculation of head losses in the networks;
- Determination of piezometric elevations at network nodes and construction of piezometric lines;
- Determination of the required height of the water tower and pump head for supplying water to the network;
- Construction of the water supply network and selection of equipment.

The type of water supply network is chosen based on consumer requirements. Considering the required reliability, water supply networks can be:

- Dead-end or branched networks;
- Looped (closed) networks;
- Combined (mixed) networks.

In the event of an accident on the main sections of a dead-end (branched) network, the water supply to the following sections is stopped. In the event of an accident on the main sections of a ring network, the emergency section is disconnected, but water is supplied to other sections.

The number of hydraulic shocks is reduced in a ring network. But the ring network has a higher cost because it is longer. Therefore, a ring network is designed in cases where it is necessary to ensure uninterrupted water supply (domestic drinking networks, combined domestic drinking and fire-fighting networks, industrial networks, fire-fighting networks).

Dead-end networks are designed in cases where the continuity of water supply is not crucial (for small settlements, industrial water supply systems).

7.2 Routing of the water supply network

The rationality of network routing and their geometric outline in the plan affect the technical and economic performance indicators.

The routing of the water supply network is determined by taking into account the following factors:

- planning of the water consumption facility, location of individual water consumers, driveways, shapes and sizes of residential areas, green spaces;

- natural and artificial obstacles during pipe laying (rivers, canals, ravines, railway tracks);

- the terrain.

When tracing water supply networks, it should be assumed that the main lines should evenly cover the water supply facility. They should follow the main directions of water flow. In addition, it is necessary to ensure the supply of water to individual areas and large enterprises by the shortest routes, but in no less than two directions. Main lines should be laid in areas with the highest geodetic marks perpendicular to obstacles. The distance between longitudinal main lines and main crossings should be within 300÷800 m. Distribution networks are routed along roads so that the distance between them is within 250÷300 m. Given the significant length of water supply networks, experts conclude that it is advisable to divide water supply networks into smaller subsystems – sectors.

After tracing the water supply network on the terrain with the highest geodetic marks, a water tower is installed.

The choice of material and strength class of pipes for water mains and water supply networks should be made based on the results of hydraulic calculations, taking into account sanitary conditions, soil and water aggressiveness, as well as pipeline operating conditions. For pressure water mains and networks, non-metallic pipes should generally be used: reinforced concrete pressure pipes, asbestos-cement water pipes, polyethylene pipes, and cast iron pressure pipes. Steel pipes can also be used for water mains.

7.3 Calculation of water supply networks

o determine the design flow rates in individual sections of the water supply network, it is necessary to determine the actual water flow rates in the network nodes. If the number of water distribution points is small and the flow rate at each point is determined, then the design scheme can take into account all these flow rates, which is not possible when calculating networks with a large number of points.

Consider a section of such a network. The point of water withdrawal from the network will be called a node, and the line between two nodes will be called a network section. Let water enter node 3 from the pumping station and move through the network in a given direction, as shown in Fig. 7.1.

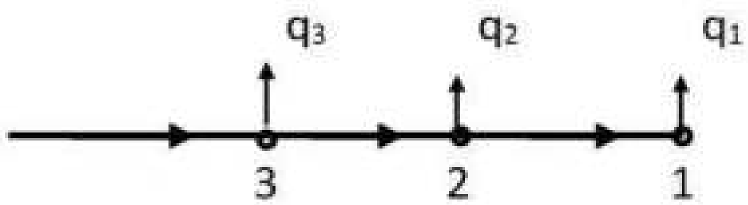


Figure 7.1 - Scheme of water disassembly from a dead-end network
q1, q2, q3 - nodal water flows

Then the water consumption at each site is determined by the formulas

$$q_{1\text{-}2} = q_1; \quad (7.1)$$

$$q_{2\text{-}3} = q_1 + q_2; \quad (7.2)$$

$$q_{н.ст.} = q_1 + q_2 + q_3, \quad (7.3)$$

For sections of urban water supply networks with distribution network connections, the actual water withdrawal from the network will look like the one shown in Figure 7.1.

Water consumption that is taken from individual nodes is called concentrated consumption. An actual network abstraction scheme will have a very large number of concentrated flows.

To reduce the number of network calculations, a simplified scheme of water consumption from the network is used. For this purpose, it is assumed that water is evenly drawn from a unit length of the network. The flow rate per unit length is called the specific flow rate and is determined by the formula

$$q_{sp.} = Q / \sum l, \quad (7.4)$$

where Q – is the total water consumption in the network for the design mode, l/s;
$\sum l$ – total length of lines, m.

When determining the specific consumption, individual consumers should be taken into account in the form of concentrated sampling. Then the specific consumption will be determined by the formula

$$q_{sp.} = (Q - Q_{con}) / \sum l, \quad (7.5)$$

where Q_{con} – is the total concentrated consumption of the city, l/s.

In cities, specific consumption is determined separately for each district.

The hydraulic calculation is performed only for the main network, so the total $\sum l$ only the length of the main lines is taken into account. In this case, the value of the sum $\sum l$ the length of mains that provide only water transportation, but not water discharge (sections that pass through undeveloped areas, sections that transport water in transit) should not be included. In the case of unilateral water withdrawal from a section of the main network, the total amount of $\sum l$ only half the length of this section is taken into account.

When calculating the network, the specific flow rate is determined for individual design hours (hour of maximum water consumption, hour of maximum water consumption in case of fire, hour of maximum water transit to the tower for networks with counter reservoirs).

The actual water distribution scheme is shown in Figure 7.2.

The flow rate that is evenly distributed along the length of the section is called the path flow rate.

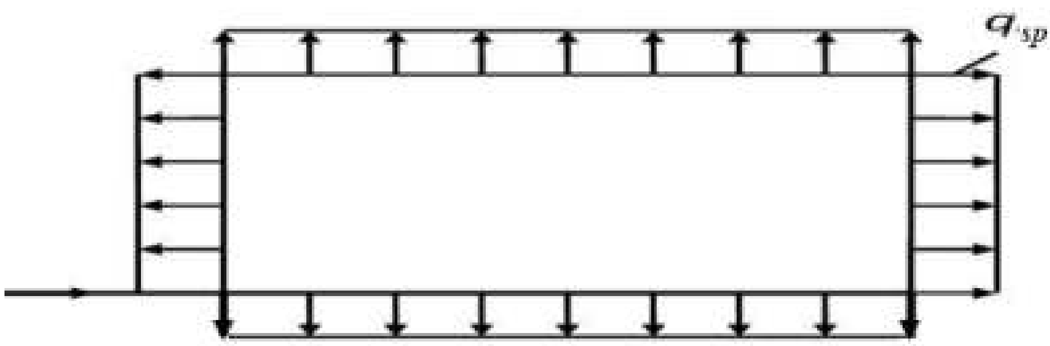


Figure 7.2 - Scheme of actual water discharge from the ring water supply network

The road consumption is equal:

$$Q_r = q_{sp.} \times l_{ar.}, \tag{7.6}$$

where $l_{діл}$ – length of the plot.

If the entire city network is divided into sections and travel costs are determined for each section Q_r, then for the entire network, the total travel costs$\sum Q_r$ can be determined by the formula

$$\sum Q_r = Q - Q_{con}, \tag{7.7}$$

where $\sum Q_r$ – the amount of travel expenses;
Q – total water consumption in the network;
Q_{con} – concentrated consumption.

If the actual scheme of water extraction from the network is replaced by uniform extraction, then variable flows will pass through its sections. The initial node of the section receives a flow rate of Q_r, which is completely disassembled in this section, as shown in Fig/ 7.3, A. If a transit flow also passes through this section, it will remain at the end of the section (Fig. 7.3, B).

It turns out that it is necessary to determine the head loss for variable water flows.

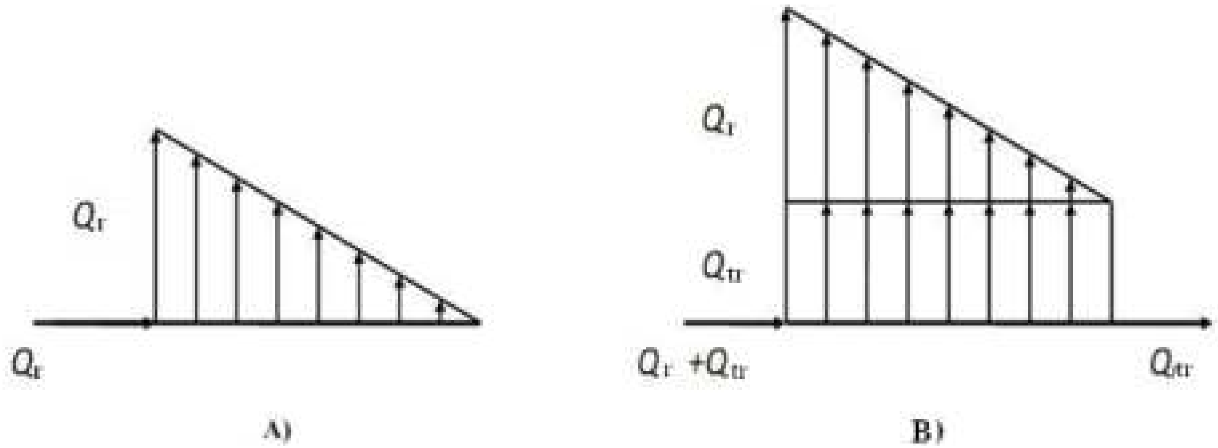


Figure 7.3 - Design schemes of water withdrawal in the network:
Q_{tr} is the transit flow rate; Q_r is the road flow rate

When determining the head loss in a section with a variable flow rate, the equivalent flow rate is taken as the design flow rate, i.e. a constant flow rate at which the same head loss is observed as at other flow rates:

$$Q_{eq} = \alpha \cdot \times Q_{r.}, \tag{7.8}$$

where α – a coefficient that takes into account the length of the plot.

If we take the middle section of the network rather than the end section, then the calculated flow rate will be determined by the formula

$$Q_{ar} = Q_{tr} + \alpha\cdot\times Q_{r}.. \quad (7.9)$$

The equivalence coefficient α depends on the ratio between the value of transit costs and road costs, and is taken within the range of 0,5÷0,58. As the value of Q_{tr}/Q_{r}. coefficient α is approaching the value ofα=0,5, and with a decrease to α=0,58. To simplify calculations, the following values are assumed α=0,5. Then the calculated flow rate of the site Q_{calc} is determined by the formula

$$Q_{calc} = Q_{tr} + 0{,}5\cdot\times Q_{r}. \quad (7.10)$$

If we replace the uniformly distributed water withdrawal from a section with withdrawals at the beginning and end of the section, i.e., nodal flows, then all the travel time in the sections is replaced by two equal concentrated flows at the beginning and end of the section. Values of nodal water flows Q_{n}. are determined by the formula

$$Q_{n}. = 0{,}5 \times\cdot Q_{r}. \quad (7.11)$$

For nodes to which more than one section is connected, the nodal costs are determined by the formula

$$Q_{n}. = 0{,}5\times\Sigma Q_{r}, \quad (7.12)$$

where ΣQ_{r} – the sum of the travel costs of the sections connecting to the node.

Given that the value of specific consumption for a particular urban area is a constant value, it is possible to determine the value of the expenditure Q_{n} without determining the journey time Q_{r} according to the formula

$$Q_{n}. = 0{,}5\times\cdot q_{sp}\ \Sigma l, \quad (7.13)$$

where Σl – the sum of the lengths of the sections that are connected to the node.

For nodes located on the border of two districts, nodal costs are determined by the formula

$$Q_{n}. = 0{,}5\times q'_{sp}(\Sigma l' + 0{,}5\times\Sigma l_{3}) + 0{,}5\times q''_{sp}(\Sigma l'' + 0{,}5\times\Sigma l) \quad (7.14)$$

where $q^{/}_{sp}$ – specific consumption of the first district;

$q^{//}_{sp}$ – specific consumption of the second district;

$\Sigma\ l^{/}$ – is the sum of the lengths of the plots that are connected to the node and located in the first district;

$\Sigma\ l^{//}$ – is the sum of the lengths of the plots that are both connected to the node and located in the second district;

$\Sigma\, l$ – is the sum of the lengths of the plots that are connected to the node and are located on the border between districts.

Thus, the final design scheme for water withdrawal from the ring network, taking into account nodal flows, is shown in Fig. 7.4.

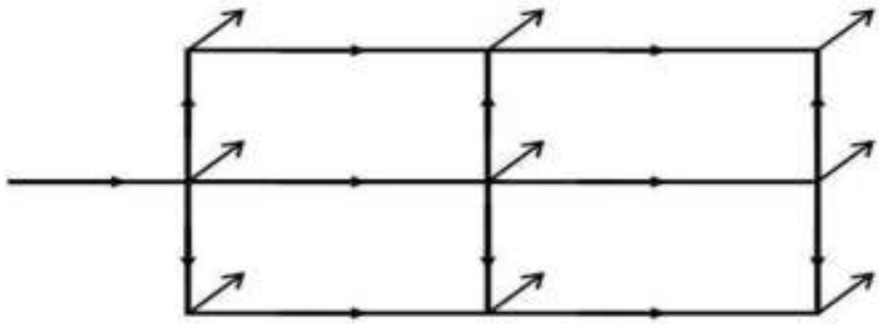


Figure 7.4 - Design scheme of water separation from the ring water supply network

The calculation scheme allows you to determine the flow rates in the sections, the calculation should start from the nodes where the water flows converge. The diameters of these sections can be determined from the known calculated flow rates. The water flow rate is determined by the formula

$$Q = v \times w = (\pi D^2/4) \times v = 0{,}785D^2 \times v, \quad (7.15)$$

$$D = (4Q/\pi \times v)^{0{,}5} = (1{,}27 \times Q/v)^{0{,}5}, \quad (7.16)$$

where Q is the water flow rate;
v is the water velocity;
w is the cross-sectional area;
D is the diameter of the section.

Taking into account the tightness of the pipelines, the maximum water velocity Vmax in metal pipes is assumed to be Vmax = 8 m/s, and in non-metallic pipes - Vmax = 4 m/s. However, this speed is dangerous, as it increases the likelihood of a water hammer. Therefore, the actual velocity should be less than the maximum.

As the speed decreases, the diameter increases, and therefore the cost of the site. But as the speed of water movement in the pipes decreases, the energy consumption for lifting water decreases, because the pressure loss in the pipelines decreases.

Control questions

1. What types of networks are distinguished in the water supply systems of medium and large cities?
2. What are the main requirements for water pipes?
3. What is the main and distribution network?
4. Why are check valves installed in water pipes?
5. Why should the number of water pipes be at least two?
6. What factors are taken into account when tracing the water supply network?

7. What does "dividing the network into sectors" mean and why is it important?

8. How are the main lines located in relation to the terrain?

9. Why is a water tower located on the highest geodetic level?

10. What materials are recommended to be used for pressure water pipes and why?

11. What is the concentrated flow rate and how is it taken into account in the calculations?

12. How is the specific water consumption for urban areas determined?

13. What is the path water consumption and how is it calculated?

14. How is the equivalent flow rate determined for a variable flow area?

15. How are nodal water flows determined for individual sections of the network?

16. How is the flow rate at nodes located on the border of two districts taken into account?

17. What is the transit flow rate and how does it affect the calculation of the section?

18. What pipe diameters are recommended depending on the speed of water movement?

19. Why should the water velocity not exceed the maximum values, even in metal pipes?

Lecture No. 8
HYDRAULIC CALCULATION OF WATER SUPPLY NETWORKS

The most common formula used in hydraulic calculations for water pipes made of steel and cast iron pipes is Pavlovsky's formula:

$$h = 0{,}0014822\frac{Q^2 L}{D^{5,33}} \qquad (8.1)$$

where h is the head loss along the length, m; Q is the flow rate per second, m^3/s; L is the length of the pipeline, m; D is the internal diameter of the pipes, m. The formula takes into account normal pipe contamination (n = 0.012 (roughness coefficient).

The above formula can be represented as:

$$h = AKLQ^2 \text{ or } h = sQ^2 \text{ when } V \geq 1{,}2 \text{ m/s } K = 1, \qquad (8.2)$$

where A - specific resistance $\left(A = \frac{0{,}0014822}{D^{5,33}}\right)$; s - specific resistance of a section with a length of L, or the head loss module for a given section, equal to AKL.

Specific resistance depends only on the material and diameter of the pipes. For steel and cast iron pipes A and K, see Table 8.1.

Table 8.1 - Summary table for finding A, K and V

D,m	Specific resistance A for Q in m^3/s (for q in $l/s \cdot 10^{-3}$)				D, m	Specific resistance A for Q in m^3/s (for q in $l/s \cdot 10^{-3}$)			
0,050	12900				0,250	2,41			
0,075	1480				0,300	0,911			
0,100	319,4				0,350	0,401			
0,125	97,2				0,400	0,196			
0,150	36,7				0,459	0,105			
0,200	7,92				0,500	0,0598			
V, m/s	0,2	0,25	0,3	0,35	0,4	0,45	0,5	0,55	0,6
K	1,41	1,33	1,28	1,24	1,20	1,175	1,15	1,13	1,115
V, m/s	0,65	0,7	0,75	0,8	0,85	0,9	1,0	1,1	1,2
K	1,10	1,085	1,07	1,06	1,05	1,04	1,03	1,015	1,0

The main factors determining the diameter of a section of the water supply network are the calculated flow rate and velocity:

$$D = \sqrt{\frac{4Q}{\pi V}} \Leftrightarrow V = \frac{4Q}{\pi D^2} \Leftrightarrow Q = \frac{\pi D^2 V}{4}, \qquad (8.3)$$

where D is the internal diameter, m; V is the average economic velocity, m/s; Q is the design flow rate, m^3/s. To simplify calculations, you can use the table of limit flow rates compiled by M. M. Abramov based on the formulas of L. F. Moshnin (Table 8.2).

Table 8.2 – Limit flow rates

D, mm	Marginal economic costs, l/s		Maximum economic speeds, m/s	
	minimum	maximum	minimum	maximum
100	–	5,4	–	0,71
125	5,4	9,0	0,45	0,73
150	9,0	15,0	0,51	0,85
200	15,0	28,5	0,48	0,91
250	28,5	45,0	0,53	0,92
300	45,0	68,0	0,64	0,96
350	68,0	96,0	0,71	1,00
400	96,0	130,0	0,76	1,04
450	130,0	168,0	0,82	1,06
500	168,0	237,0	0,86	1,21
600	237,0	355,0	0,84	1,26
700	355,0	490,0	0,93	1,27
800	490,0	685,0	0,98	1,36
900	685,0	882,0	1,07	1,38
1000	882,0	1120,0	0,12	1,46
1100	1120,0	1390,0	1,22	–
1200	1390,0	–	1,22	–

The amount of pressure loss at local supports is taken into account by introducing a coefficient of 1.05 - 1.10 depending on the number of fittings and valves on the pipeline.

When calculating a newly designed ring network, the diameter and flow rate are unknown for each section, i.e. the total number of unknowns is equal to twice the number of sections. The number of possible equations is determined by the condition that the sum of the linear (path) and node losses for a given node is equal to zero:

$$\sum q + Q = 0, \tag{8.4}$$

where q is the flow rate in the pipelines leading to the node, and Q is the node flow rate taken from the network at a given point (Q_n або $Q_n + Q_r$).

For each closed circuit or ring, the algebraic sum of head losses in all sections comprising the ring is equal to zero (considering losses in sections where water moves clockwise as positive and losses in sections where water moves counterclockwise as negative): ΣH = 0.

The total number of equations is less than the number of unknowns, and the task of calculating a ring network is indeterminate. As a result, in practice, a ring network is calculated using the method of gradual approximation using various practical techniques.

The calculation procedure is as follows:

- determine the path and concentrated costs and 'estimate' them at the nodes;

- distribute transit costs across individual sections while maintaining equality. In doing so, take into account the location of individual consumers to whom water must be supplied by the shortest routes, as well as the approximate equality of transit costs along the main parallel mains;

- based on the planned (calculated) costs of individual sections according to the average hydraulic slope or economic speeds, determine their diameters;

- based on the costs and diameters, find the head losses h while maintaining equality Σh = 0. За relatively arbitrary initial distribution of costs in most rings Σh ≠ 0, but Σh = Δ h - inconsistency;

No.	Section No	Section length *l*, m	Diameter D, mm	Specific resistance $A \cdot 10^{-6}$	preliminary distribution of costs					
					q, L/s	*v, m/s*	*k*	$S = A \cdot k \cdot l \cdot 10^{-3}$	$h = \frac{S \cdot q^2}{1000}$	$S \cdot q \cdot 10^3$
1	2	3	4	5	6	7	8	9	10	11

- redistribute water consumption across individual branches while complying with the condition by transferring the binding consumption Δq from some branches to others. The network is balanced several times in succession until the imbalance across the ring is reduced to approximately 0.3–0.5 m.

1 correction			
Δq, L/s	*q, L/s*	$h = \frac{S \cdot q^2}{1000}$	$S \cdot q \cdot 10^3$

- the binding flow rate Δq for each ring is found from the equation:

$$\Delta q_i = \frac{\Delta h_i}{2\sum (sq)_i}, \tag{8.5}$$

where s and q are the resistance and flow rate of the sections that make up the ring.

When linking the ring of the water supply network, positive linking costs should be added to the positive costs of the lines and subtracted from the negative costs, and negative costs should be done the other way around. So, the linking costs are written opposite each section of the ring with a plus or minus sign.

When determining the balancing flow rates of lines belonging to two adjacent rings, it is necessary to take into account the balancing flow rates of adjacent rings: thus, if $\Delta h>0$, then Δq should be directed counterclockwise.

Control questions:

1. What is the hydraulic calculation of a water supply network?
2. Define concentrated, specific, route and calculated flow rates.
3. Give the sequence of hydraulic calculation of a ring water supply network.
4. Define network connection and give methods for determining it.

Lecture No. 9
PRESSURES IN WATER SUPPLY NETWORKS

Lecture plan:

1. The concept of necessary and actual pressures in water supply networks.
2. An unfavourable node in the network and its location.
3. The nature of piezometric lines in a system with a tower at the beginning of the network.
4. The nature of piezometric lines in a system with a counter-reservoir for domestic and drinking water consumption.

9.1 The concept of necessary and actual pressures in water supply networks

In order to supply consumers with water, it must be delivered at a certain pressure, which depends both on the design of the network and on the geometric height of the consumers above the ground. Let us consider a house with internal water distribution units (Fig. 9.1).

In order for the water to rise to the highest sanitary appliance 'b', the pressure in unit "A" must be sufficient to lift the water to the specified height and to the spout, and, in addition, it must ensure that all pressure losses are overcome on the way from unit 'A' to the consumer.

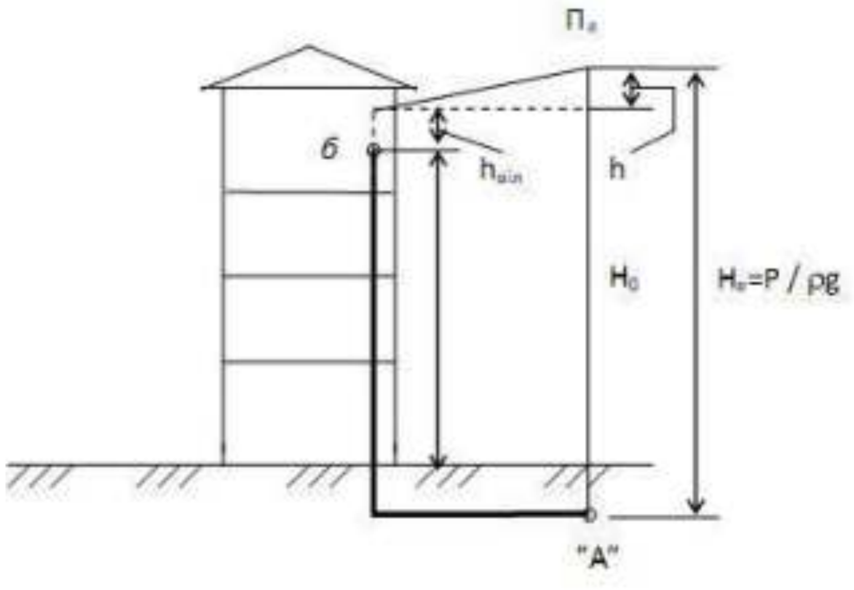


Figure 9.1 – Diagram of water supply to a house:
$h_{віл}$ – free head; h – total head loss; H_0 – geometric height;
$H_в$ – free head; P – water pressure in the pipeline

The required pressure is determined by the formula

$$H_н = H_0 + h + h_{віл.},\qquad(9.1)$$

where H_0 is the geometric height of the rise to the water distribution unit;

h is the total head loss in the pipelines from unit 'A' to the water consumption unit;

hfree is the free head that must be provided before the water distribution taps for pouring;

$H_н$ – minimum pressure required for normal water supply.

If the pressure in the street main is not less than the required Hн, then water

will flow to the appliances directly from the street network. The pressure in the street main at the connection point of the internal water supply system is called free pressure

For a known pressure P in the street main, the free pressure or height to which the water will rise in a piezometric tube, if installed at this node, is determined by the formula

$$H_в = P/(\rho \times g),\qquad(9.2)$$

where P is the water pressure in the pipeline;

Z is the absolute elevation;

ρ is the density of water;

g is the acceleration due to gravity.

The piezometer value is determined by the formula

$$П = Z + P/(\rho g),\qquad(9.3)$$

where Z is the ground surface elevation.

If the pressure P is measured in kg/cm2, then the free head is

$$H_в \cong 10\ P\ м.вод.ст.\qquad(9.4)$$

If the pressure value P is measured in MPa, then the free head is

$$H_в \cong 100\ P.\qquad(9.5)$$

When designing a water supply system, the value of free head Hv is taken to be equal to the value of the required head Hn:

$$H_в = H_н.\qquad(9.6)$$

Obviously, the value of Hn depends on the number of floors in the building. According to the standards for single-storey buildings, the free head must be at least 10 m, and for buildings with more floors, 4 m is added for each floor. Then the head is determined by the formula

$$H_н = 6 + 4 \times n,\qquad(9.7)$$

where n is the number of floors in the building.

9.2 Disadvantageous node in the network and its location

All nodes of the water supply network must have the necessary pressure during normal operation. If all buildings in the city have the same number of floors, the required free pressure for them will be the same. It is impossible to ensure equal pressure at all nodes of the network. If the required free pressure is ensured at the node located in the most unfavourable place, then the following condition will be met at any other node:

$$H_в > H_н \quad .(9.8)$$

Such unfavourable nodes may be the highest and most remote nodes from the point of water entry into the network. In general, to ensure the necessary pressure in the most unfavourable or critical node, it is necessary to ensure the highest piezometric mark at the node where the water pipes are connected to the network.

To determine the critical node, it is necessary to check the most remote nodes, determine the piezometric mark at the connection node of water pipes $П_{1(i)}$, in relation to these nodes using the formula

$$П_{1(i)} = Z_i + H_{н.i.} + \sum h_{i\text{-}1}\ , \quad (9.9)$$

where Z_i – geodetic mark of the i-th node;
$H_{н.i.}$ – the minimum pressure required at node i;
$\sum h_{i\text{-}1}$ – total head losses along the route from node i to the node where the water mains connect to the network.

The node for which the maximum piezometric elevation was determined is critical or unfavourable.

The critical node determines not only the pressures in the networks, but also the pressures for other structures. Let us consider the path of water flow from the unfavourable node to the water pipe connection node (Fig. 9.2). Let the profile look as shown in Fig. 9.2.

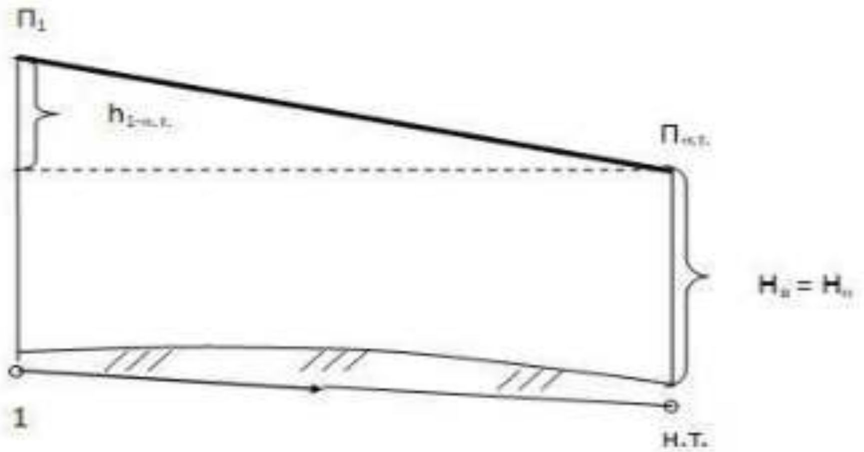


Figure 9.2 – Piezoelectric line from node 1 to critical node
$П_1$ – piezometric mark in the node 1; $П_{н.т.}$ – piezometric mark in unfavourable node; $H_н$ – required pressure;. $H_в$ – free pressure;
$\sum h_{1\text{-}н.т.}$ – pressure loss in the section from node 1 to the unfavourable node

At the critical node, the required pressure is equal to the free pressure.

$$H_в = H_н \qquad (9.10)$$

In order for water from node 1 to reach the critical node, the piezometric head at node 1 must be greater than the head at the critical node by the amount of head loss along the path from node 1 to the critical node, i.e.

$$П_1 = П_{н.т.} + h_{1\text{-}н.т.} = Z_{н.т.} + H_{н.н.т.} + h_{1\text{-}н.т.} \qquad .(9.11)$$

where $П_{н.т.}$ – piezometric mark at the critical node;

$h_{1\text{-}н.т.}$ – pressure loss from node 1 to the critical node;

$Z_{н.т}$ – geodetic mark at a critical node;

$H_{н.н.т}$ – required pressure at the critical node.

The slope of the line connecting the piezometer mark in node 1 with the piezometer mark in the critical node shows the head loss in the network for a given period. Considering that the highest water consumption occurs during peak hours, the maximum head losses will also be observed at this time of day.

The required pressure at node 1 can be provided in two ways:

- second lift pumps,
- second lift pumps and a water tower installed at node 1, provided that $Z_1 > Z_{н.т.}$.

In the first case, the piezometric mark at node 1 is the starting point for determining the head of the second lift pumps. In this case, the network and water pipes are not separated, so the piezometer mark at the location of the second lift pumps is determined by the formula

$$П_н = Z_{н.т.} + H_{н.н.т.} + h_{1\text{-}н.т.} + h_{вод}, \qquad (9.12)$$

where $h_{вод}$ – pressure loss in water pipes.

Then the pressure of the pumps Hn will be determined by the formula

$$H_н = (Z_{н.т.} - Z_н) + H_{н.н.т.} + (h_{1\text{-}н.т.} + h_{вод}), \qquad (9.13)$$

where $Z_н$ – marking of the axis of the second lift pumps,

$H_н$ – pump pressure.

The considered scheme of water supply to the network without a water tower is designed for uniform water withdrawal from the network, which occurs in water supply systems of industrial enterprises or in domestic and drinking water supply systems with insignificant unevenness of water consumption. The operation of pumps in a network without a water tower is regulated by changing the head, which is determined by the Q-H characteristic of the pump. When using such a pump operation scheme, excess electricity consumption may be observed.

9.3 The nature of piezometric lines in a system with a tower at the beginning of the network

Systems with regulating tanks are most commonly used. Depending on the

location of the water tower, water supply systems are classified as follows:
- with a tower located at the beginning of the network;
- with a tower located at the end of the network (network with a counter-reservoir);
- with a tower located in the middle of the water supply area.

If the highest geodetic marks of the area are located at the beginning of the network, a water supply network with a water tower at its beginning is designed. This is necessary to reduce the height of the water tower. Let us consider the profile of a water supply system with the highest marks of the area at its beginning (Fig. 9.3).

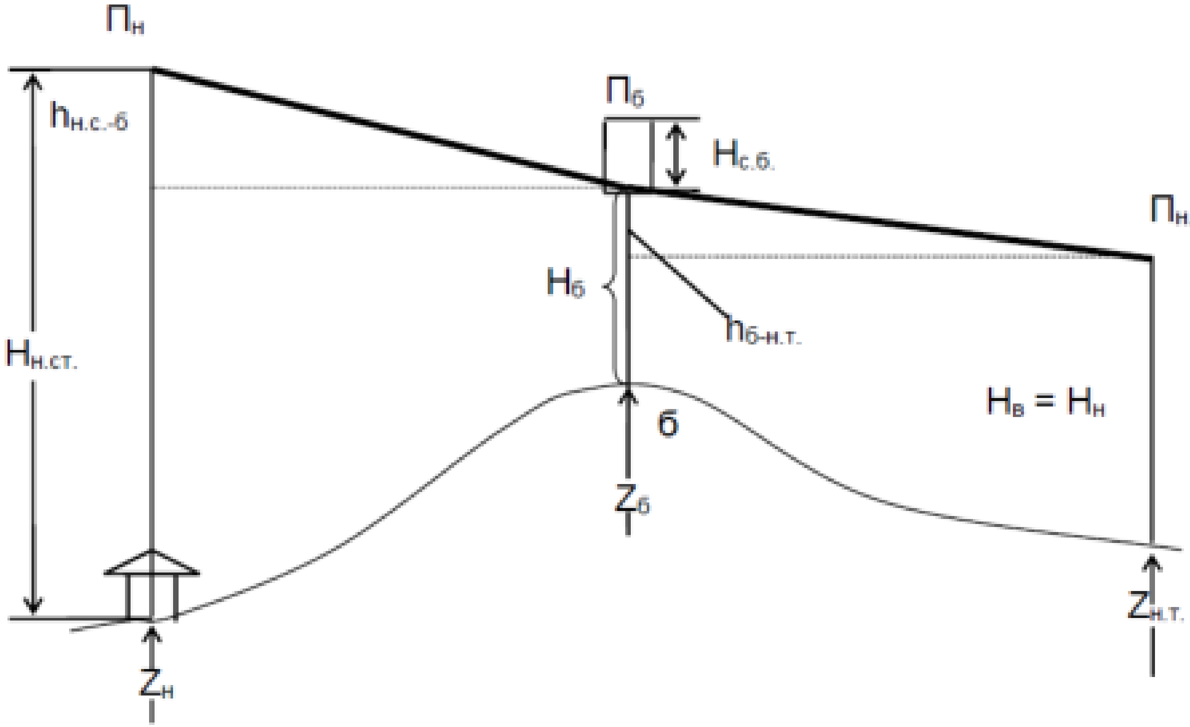


Figure 9.3 – Piezoelectric lines in a system with a tower located at the beginning of the network

$П_б$ – piezometric mark at the connection point of the water tower;
$Z_б$ – geodetic mark at the connection point of the water tower;
$H_б$ – height of the water tower; $h_{б\text{-}н.т}$ – pressure losses on the way from the tower to the critical node; $H_в$ – free pressure;
$H_{н.ст.}$ – pressure near the pumping station

The piezometric mark of the critical node is equal to:

$$П_{н.т.} = Z_{н.т.} + H_{н.н.т.}. \qquad (9.14)$$

The piezometric mark at the connection point of the water tower will be:

$$П_б = Z_б + H_б . \qquad (9.15)$$

On the other hand

$$П_б = П_{н.т.} + h_{б\text{-}н.т.} = Z_{н.т} + h_{б\text{-}н.т} + H_{н.н.т} . \qquad (9.16)$$

Then

$$Z_б + H_б = Z_{н.т} + h_{б\text{-}н.т} + H_{н.н.т.}, \quad (9.17)$$

Where

$$H_б = H_{н.н.т.} + h_{б\text{-}н.т} - (Z_б - Z_{н.т.}). \quad (9.18)$$

Formula (9.18) shows that as $Z_б$ increases, the height of the tower $H_б$ decreases. If $H_б \leq 0$, a pressure tank is installed instead of a tower.

If there is a tower, the pressure in the water supply network also changes. This change in pressure is explained not only by the change in head losses in the network, but also by the change in the water level in the water tower tank. Maximum water consumption can be observed not only when the tank is empty, but also when it is full. Then the piezometric lines will be located as shown in Fig. 9.4.

If water consumption is less than the calculated maximum, the gradient of the piezometric line will decrease and will be zero when consumption stops. On the graph, the piezometric line will rotate around points δ_1 and δ_2 or around an intermediate point between them. Thus, the piezometric lines for all hours will lie between the horizontal line and the line with the maximum gradient. If the piezometric line is calculated for the hour of maximum water consumption, then the piezometric marks at the network nodes will satisfy condition (9.8).

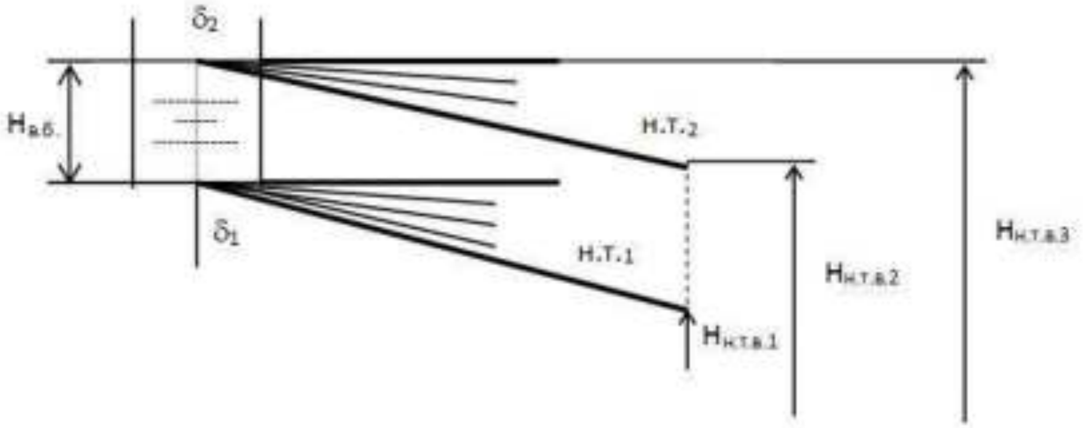


Figure 9.4 – Pressure fluctuations in the network at different water tower tank fill levels:

$\delta_1 \div \delta_2$ – water levels in the tank; н.т.1, н.т.2 – unprofitable nodes;

$H_{н.т.в.1} \div H_{н.т.в.3}$ – required pressure at an unfavourable node

Free heads in domestic and drinking water supply networks should not exceed 45 m, as all fittings in internal water supply systems are designed for a maximum pressure of 0.45 MPa.

Free heads in network nodes must meet the following condition

$$45 \geq H_в \geq H_н. \quad (9.20)$$

The required pump pressure for such a system with an empty tank is determined by the formula:

$$H_{н} = П_{н} - Z_{н} = П_{б} + h_{нс\text{-}б} - Z_{н} = H_{б} + h_{нс\text{-}б} + Z_{б} - Z_{н}, \qquad (9.21)$$

or

$$H_{н} = П_{нТ} + h_{б\text{-}нТ} + h_{нс\text{-}б} - Z_{н} = H_{н.нт} + h_{б\text{-}нТ} + h_{нс\text{-}б} + Z_{нТ} - Z_{н}. \qquad (9.22)$$

When the tank is full, the pump pressure is determined by the following formulas

$$H_{н} = H_{б} + h_{нс\text{-}б} + H_{вб} + Z_{б} - Z_{н}, \qquad (9.23)$$

$$H_{н} = H_{н.нТ} + h_{б\text{-}нТ} + h_{нс\text{-}б} + H_{вб} + Z_{нТ} - Z_{н}. \qquad (9.24)$$

9.4 Characteristics of piezometric lines in a system with a counter-reservoir for domestic and drinking water consumption

The operating mode of a network with a counter-reservoir differs from that of a network with a tower at its beginning. Such a system is designed on the assumption that the highest points of the terrain are located at the opposite end from the point where the water pipes connect to the network. Let us consider the differences between the operating modes of water supply networks with a tower located at the beginning (Fig. 9.5, A) and at the end of the network (Fig. 9.5, B).

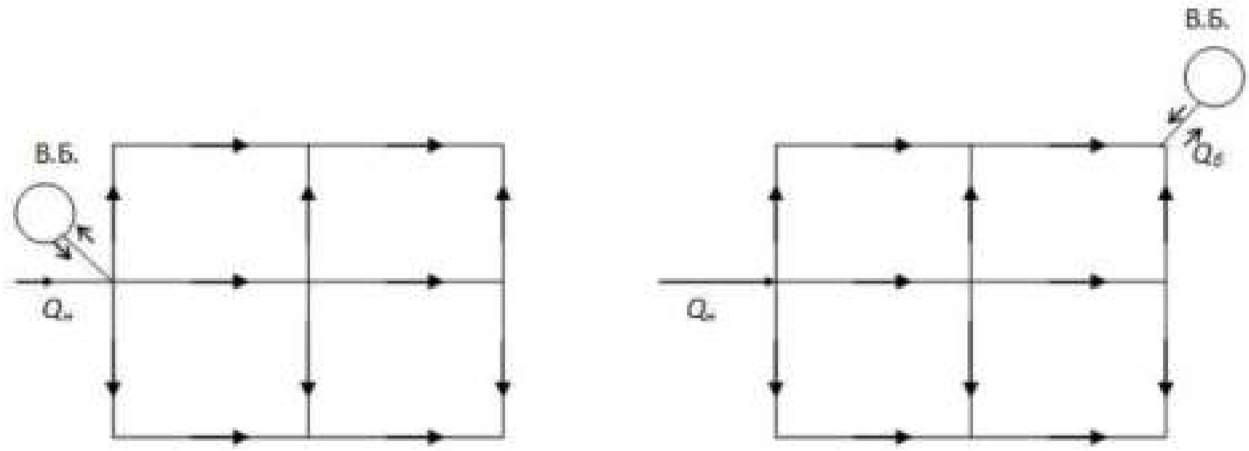


Figure 9.5 – Water supply diagrams:
В.Б. – water tower; $Q_{Н}$ – water supply from the pumping station;
$Q_{В}$ – water supply to the tower

For different values of water consumption supplied to the network from the pumping station $Q_{Н}$ and expenses consumed by the city $Q_{м}$ the following situations are possible:

– $Q_{н} > Q_{м}$ – water enters the tower, i.e. $Q_{в} = Q_{н} – Q_{м}$;
– $Q_{н} < Q_{м}$ – water is consumed from the tower, i.e. $Q_{в} = Q_{м}$ - .

In systems with towers located at the beginning of the network, water distribution zones are not formed because only the flow that is fully consumed by consumers always enters the initial node of the network.

In water supply systems with a counter-reservoir, the network is supplied from two sides, as shown in the diagram (Fig. 9.6).

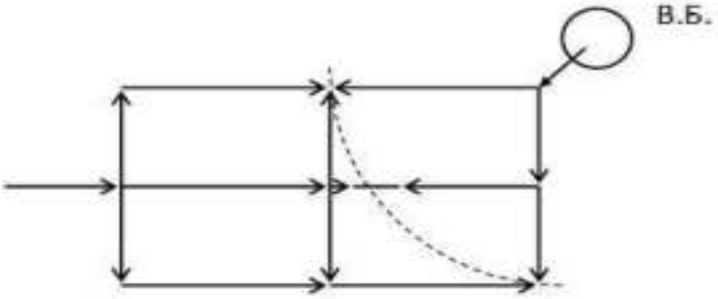


Figure 9.6 – Diagram of a water supply network with a counter-reservoir at the time of maximum water consumption

The flow rates from the pumps and the tower per calculated hour are determined according to the combined schedule of water consumption and supply by the pumps.

For known values $Q_н$ and $Q_б$ It is possible to determine the boundaries of the supply areas from the pumps and the water tower. With two-way supply, the location of the piezometric lines also changes. Let us consider what the piezometric lines look like in a water supply system with a counter-reservoir (Fig. 9.7).

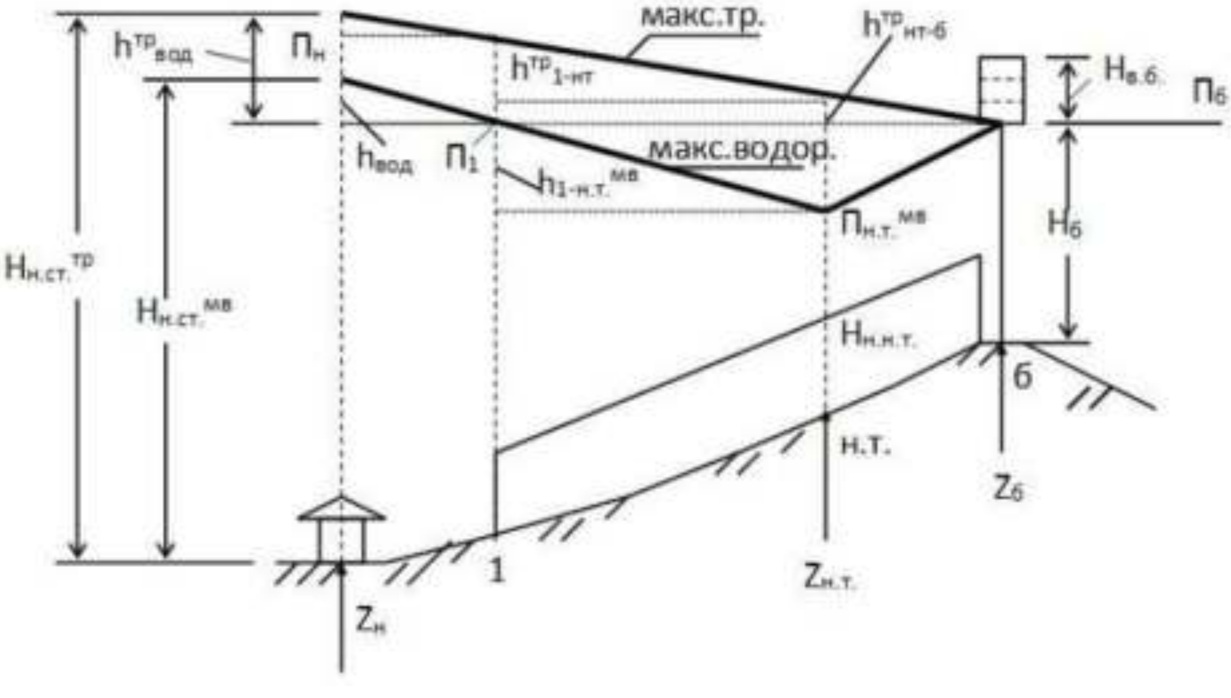


Figure 9.7 – Piezoelectric lines in a system with a counter-reservoir

макс. тр – maximum water flow mode in the tower; макс. водор. – maximum water consumption mode; $h^{TP}_{вод}$ – pressure losses in water pipes during water transit to the tower; $h^{TP}_{1-нт}$ – pressure losses in water pipes from the connection point of water pipes to the critical point during transit; $h^{макс}_{1-нт}$ – pressure losses in water pipes from the connection point of water pipes to the critical point during maximum water consumption; $h^{TP}_{нт-б}$ – pressure loss in water pipes from the critical node to the tower during water transit to the tower

The lowest piezometric marks will be observed at the boundary of the supply zones, and the critical node will be the one located at this boundary and relative to which the maximum piezometric mark is determined at the water pipe connection node.

The required head at the critical node is equal to the free head. In order for water from the tower to enter the critical node, the head at node ‘b’, as shown in Fig. 9.7, must exceed the piezometric mark at the critical node by an amount of $h^{ТР}_{нт-б}$. However, water from the pumping station must be supplied at a pressure sufficient to maintain pressure at the critical node. $П_{н.т.}$. Для забезпечення роботи системи вежа повинна мати висоту

$$Н_б = П_б - Z_б. \qquad (9.25)$$

To ensure the system works properly, the tower must be of sufficient height.

$$П_б = П_{нт} + h_{НТ-б} = Н_{н.н.т} + h_{нт-б} + Z_{нт},. \qquad (9.26)$$

Then the height of the tower

$$Н_б = Н_{н.н.т} + h_{НТ-б} + Z_{нт} - Z_б = Н_{н.н.т.} + h_{нт-б} - (Z_б – Z_{нт}). \qquad (9.27)$$

Formula (9.27) shows that the higher the Zб mark, the lower the height of the water tower will be. Pump pressure $Н_{нм}$ at maximum water consumption and an empty tank will be equal to

$$Н_{нм} = П_{нм} - Z_н = П_{н.т.м} + h^{макс}_{1-нт} + h_{максвод} - Z_Н \qquad (9.28)$$

The operating mode of a network with a counter-reservoir during hours of minimum water consumption differs from the operating mode of a network with a tower located at the beginning of the network. If the tower is located at the beginning of the network, then when water consumption decreases, the excess water flows to it without entering the network. The location of the piezometric lines does not change, but their slope decreases. In a system with a counter-reservoir, excess water supplied by second-stage pumps flows into the tower when water consumption decreases, passing through the entire network. In this case, the piezometric line takes on a uniform slope along its entire length towards the water tower, and its appearance will be the same as when the tower is located at the beginning of the network.

The hour of maximum transit is determined by the combined water consumption and water supply schedule.

During this time, the sections of the network near the supply boundary will experience higher consumption than during the hour of maximum water consumption. This leads to an increase in pressure losses in the network, as well as an increase in the length of the water flow and the required pressure of the second lift pumps when water transits to the tower. Therefore, the calculation of the network with a counter-reservoir is performed not only at maximum water consumption, but also at maximum transit.

If the water tower is located in the middle of the water supply area, the network operating mode and piezometric graphs remain similar to the graphs constructed for the network scheme with a counter-reservoir, but the supply zone from the tower on the graph will be two-sided.

If the tower is located near the node to which water is supplied, the amount of water coming from the tower tank may be insufficient to form a supply zone. In this case, the piezometric line profile for the network will be the same as in networks with a tower at their beginning.

Control questions:

1. How to determine the required free head in the water supply network?
2. How to determine the critical node?
3. For what purpose is the tower installed at the highest points of the terrain?
4. What explains the one-sided slope of the piezometric line in a network with a tower at its beginning?
5. What factors influence the required head in a water supply network for domestic and drinking water consumption?
6. How are piezometric marks determined at nodes in a water supply network?

Lecture No. 10
GENERAL INFORMATION ABOUT WASTEWATER AND SEWAGE SYSTEMS

Lecture plan:

1. General information about wastewater
2. General information about sewage systems (water drainage)
3. General requirements for the composition and properties of wastewater discharged into centralised water drainage systems

Water disposal (sewerage) is a complex of equipment, networks and structures designed for the organised collection and removal of contaminated wastewater through pipelines outside populated areas or industrial enterprises, as well as its treatment and neutralisation before disposal or discharge into a water body.

Water disposal (sewerage) facilities include residential, public, industrial, office and special-purpose buildings equipped with internal water supply and sewerage systems, as well as newly built, existing and reconstructed cities, urban-type settlements, rural and suburban settlements, resorts, industrial enterprises, combines and industrial areas.

Wastewater is water that has been used for domestic, industrial or other purposes and has been contaminated with additional impurities that have changed its original chemical composition and physical properties, as well as water that flows from populated areas and industrial enterprises as a result of precipitation or street watering..

9.1 General information about wastewater

Wastewater is divided into three main categories: domestic, industrial and rainwater.

Domestic wastewater includes water from kitchens, toilets, showers, baths, laundries, canteens, hospitals, as well as utility water generated during cleaning of premises. It comes from residential and public buildings, as well as from domestic premises of industrial enterprises. By the nature of the pollution, it can be faecal, contaminated mainly with physiological waste, and domestic, contaminated with all kinds of domestic waste.

Urban wastewater is a mixture of domestic wastewater from residential and public buildings and industrial enterprises, as well as industrial wastewater from communal and domestic services, public catering, local and food industries. In addition to organic and mineral impurities, domestic wastewater contains biological impurities consisting of bacteria, including pathogenic ones, and is therefore potentially dangerous.

Industrial wastewater includes water used in technological processes, which does not meet quality requirements due to its degree of contamination and must be removed from the territory of enterprises. This also includes water pumped to the surface during the extraction of minerals. Industrial wastewater from some industries may contain toxic substances, heavy metal salts and radioactive elements.

Industrial wastewater is mainly polluted by production waste that has a certain value. In order to reduce the degree of pollution of industrial wastewater, it is necessary to strive to improve technological processes at industrial enterprises aimed at reducing the amount of waste and utilising it in the production process.

Rainwater is formed as a result of atmospheric precipitation. It is divided into rainwater and meltwater, which comes from melting ice and snow. A distinctive feature of rainwater runoff is its episodic nature and sharp unevenness. Water from washing and watering streets, as well as from fountains and drains, is similar in quality to rainwater in terms of contaminating impurities and is removed together with it.

During precipitation, rainwater becomes saturated with dissolved gases, atmospheric dust and aerosols, and as it flows off, it washes away dust, debris, petrol, oil and other contaminants from the surfaces of roofs, inner courtyards and driveways. Rainwater, which contains mainly mineral pollutants, is less hazardous in sanitary terms than domestic and contaminated industrial wastewater, and is therefore discharged into reservoirs without treatment.

Atmospheric water flowing from polluted areas of industrial enterprises sometimes contains impurities specific to a given production, for example, chemical and oil refineries, leather enterprises, meat processing plants, coal depots, etc. Such water should be treated. In practice, when installing sewage systems in populated areas and industrial enterprises, it is necessary to take into account the discharge of a mixture of domestic and industrial water or a mixture of domestic, industrial and rainwater. The composition of this mixture can be very diverse and depends on the concentration and nature of the pollution in industrial water.

To determine whether water is contaminated with pathogenic bacteria, it is tested for the presence of a specific type of bacteria - Escherichia coli (E. coli), which is a typical representative of the intestinal microflora. Escherichia coli, while not a pathogenic bacterium itself, serves as an indicator that the water is contaminated with the aforementioned secretions and, therefore, may also contain pathogenic bacteria. To assess the degree of bacterial contamination of water, the coli titre (E.

coli titre) is determined, or the smallest volume of water in millilitres that contains one E. coli bacterium.

Contamination of industrial wastewater consists of residues of processed raw materials and reagents used in the technological process. It is not possible to provide any typical characteristics of these waters, so their composition and properties are studied in each individual case. The most characteristic and dangerous pollutants are extracted substances (mainly petroleum products), phenols, synthetic surfactants, heavy metals (mercury, zinc, iron) and organic substances. Pollution of reservoirs with wastewater from agricultural fields is increasing sharply due to the use of pesticides.

When considering the composition of wastewater, one of the key concepts is the concentration of pollutants, i.e. the mass of pollutants per unit volume of water, usually calculated in mg/l or g/m3.

Based on their physical state, wastewater pollutants are divided into: insoluble impurities, colloidal particles and soluble particles.

Insoluble impurities are found in water in the form of large suspended particles (with a diameter of more than tenths of a millimetre) and in the form of suspensions, emulsions and foam (particles with a diameter ranging from tenths of a millimetre to 0.1 micrometres). In wastewater, they can be in a coarse-dispersed (in the form of large suspended particles) and finely dispersed (suspension, emulsion and foam) state.

According to the accepted analysis method, the part of insoluble substances in wastewater retained on a paper filter is called suspended solids. Their mass is determined after drying at a temperature of 105°.

Depending on the size of individual particles (degree of dispersion) and their density, suspended solids can precipitate as sediment, float to the surface of the water or remain in a suspended state. For most particles in water in a finely dispersed state, due to their small size, the forces of resistance of the medium compared to the force of gravity are very large, so such particles practically do not settle and remain in a suspended state.

Precipitating substances are undissolved substances that fall to the bottom of the vessel in the form of sediment after 2 hours of settling in laboratory conditions: the content of settling substances is expressed by volume in ml/l or by mass (after drying the precipitated suspension at 105° and subsequent weighing) in mg/l.

Colloidal particles with a diameter of 0.1 to 0.001 micrometres; The chemical composition of colloidal and dissolved substances in domestic wastewater is influenced by proteins, fats, carbohydrates from food products, as well as the composition of tap water, which usually contains one or another concentration of

hydrocarbonates, sulphates, chlorides and sometimes iron. The colloid content in domestic wastewater is
30-40% of the suspended solids content. In addition to nitrogen, organic substances in wastewater contain carbon, sulphur, phosphorus, potassium, sodium and chlorine in the form of salts, as well as iron.
Soluble particles are found in water in the form of molecularly dispersed particles with a diameter of less than 0.001 micrometres; they do not form a separate phase, and the system becomes single-phase - a true solution.

9.2 General information about the sewerage (water drainage) system

The drainage system refers to the combined or separate drainage of three categories of wastewater. It consists of the following elements: internal sewerage systems of buildings, external intra-quarter sewerage networks, external street sewerage networks, pumping stations and pressure pipelines, treatment facilities and facilities for discharging treated wastewater into reservoirs.

Sewerage systems can be classified according to the following criteria: depending on the inflow of wastewater, pressure, wastewater discharge scheme, routing scheme, purpose, sewerage basins, and wastewater removal method.

Depending on the requirements for surface wastewater treatment, the composition of industrial wastewater pollutants, climatic conditions, terrain, and other factors in populated areas, one of the following sewerage systems is selected: combined (Fig. 10.1,a), separate (complete or incomplete) (Fig. 10.1,b), semi-separate or combined (Fig. 10.1,c).

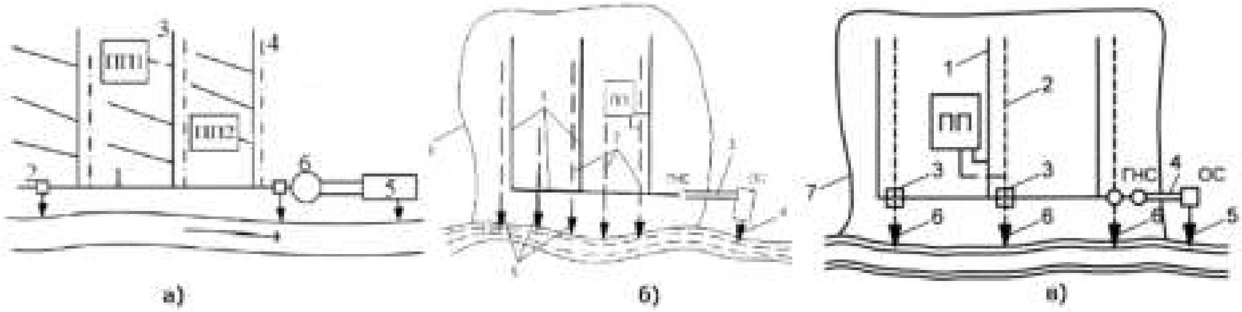


Figure 10.1 – Drainage systems:
a) combined, b) fully separate, c) semi-separate

All these systems are conventionally referred to as combined sewer systems and involve the collection and transportation of wastewater through closed (usually underground) systems consisting of pipes and channels.

Combined sewer system (Fig. 10.1,a: 1 - main drainage collector; 2 - storm drains; 3 - industrial and domestic network; 4 - rainwater network, 5 - municipal treatment facilities; 6 - main pumping station; PP1, PP2 - industrial enterprises) -

Wastewater of all categories is delivered to treatment facilities via a single underground network, because during periods of heavy rainfall, the flow of wastewater is very high and the concentration of pollutants is low, so some of the wastewater is discharged without treatment through special devices - storm drains.

Separate (Fig. 10.1,b: 1 - domestic network; 2 - industrial and storm water network; 3 - pressure pipelines; 4 - discharge of treated domestic and industrial wastewater; 5 - discharge of atmospheric and conditionally clean industrial wastewater; 6 - city limits; GNS - main pumping station; WWTP – wastewater treatment plant; PP – industrial enterprise) - domestic wastewater is sent to wastewater treatment plants, rainwater is sent to the nearest watercourses. In a separate sewerage system, different types of wastewater containing different types of pollution are discharged through separate networks. In a fully separate sewerage system, at least two networks are installed. The network for the discharge of domestic wastewater is called the domestic network. The network for the discharge of atmospheric water is called the rainwater or drainage network.

Semi-separate (Fig. 10.1,c: 1 – domestic network; 2 – industrial rainwater network; 3 – water collection chambers; 4 – pressure pipelines; 5 – discharge of treated wastewater; 6 – storm drains; 7 – city limits; GNS – main pumping station; OS – treatment facilities; PP – industrial enterprise) - two separate networks and a collector that intercepts wastewater. In the separation chambers, the discharge of rainwater into reservoirs and contaminated water for treatment is regulated. In a semi-separate sewerage system, at the intersections of independent sewerage networks for the discharge of different types of wastewater, there are water collection chambers that allow the most polluted rainwater to be discharged to the domestic network at low flow rates and then to the treatment plant via the collector; and during heavy rainfall, relatively clean water is discharged into reservoirs.

Water drainage system (sewerage) refers to a technically and economically sound design solution for an approved sewerage system, taking into account local conditions and the development prospects of the sewerage facility. Each sewerage system can be implemented using various technical methods for tracing networks and collectors, determining their depth, the number of pumping stations, the number and location of treatment facilities, etc.

Sewerage schemes for cities and industrial complexes can be centralised, decentralised and district (regional). In a centralised scheme, wastewater from all sewerage basins is directed individually or through several collectors to a single treatment plant for the entire city, located downstream of the city, along the river.

Decentralised sewerage network schemes are used for sewerage in large cities in both rugged and very flat terrain. In this case, a regional sewerage system with independent treatment facilities is set up.

District (regional) drainage network schemes are used for several closely located settlements and enterprises in industrial and densely populated areas. These schemes provide for one large-capacity treatment plant instead of a large number of small treatment facilities serving individual objects. This makes it possible to reduce capital and operating costs for wastewater treatment, reliably protect open water bodies from pollution within the densely populated part of the area, and rationally use its water resources.

The street network of cities is highly branched and covers large areas (Fig. 10.2), from which wastewater is mainly discharged by gravity. For this purpose, the territory of a populated area is divided into sewerage basins. A sewerage basin is a part of the sewerage territory bounded by watersheds.

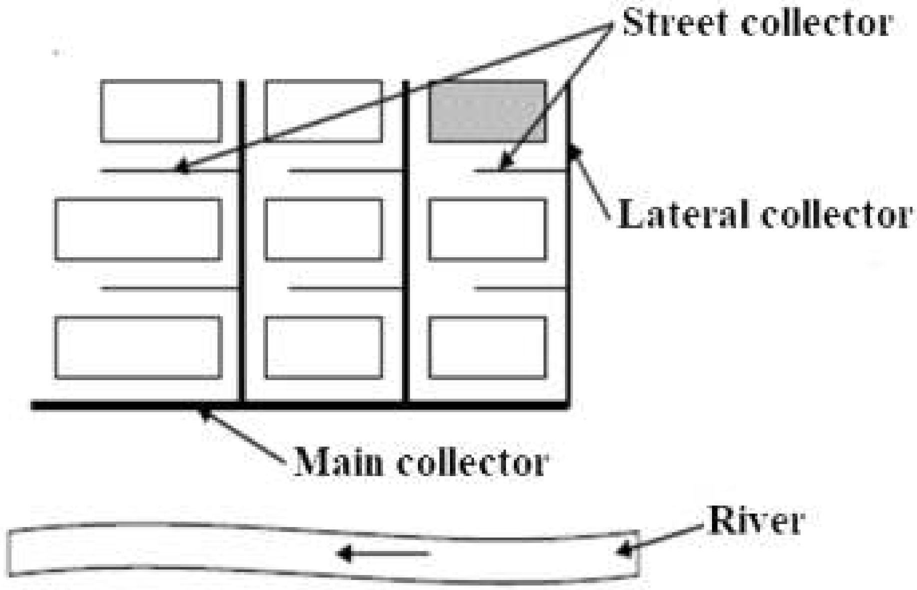


Figure 10.2 – Diagram of sewerage system in a settlement

A section of the sewerage network that collects wastewater from one or more sewerage basins is called a sewer. Collectors are divided into:

- sewerage basin collectors that collect wastewater from the sewerage network of one basin;
- main collectors that collect wastewater from two or more sewerage basin collectors;
- off-site (or diversion) collectors, through which wastewater is discharged in transit (without connections) outside the sewerage facility to pumping stations, treatment plants or to the point of discharge into a water body.

In large cities with a well-developed urban network, large collectors are often called canals. The sewerage network and collectors must always be accessible for inspection, flushing and clearing of blockages, for which purpose manholes are arranged on them. Collectors intersect with rivers, ravines and railways by means of culverts, crossings and overpasses. Collectors are laid with a slope in low-lying areas, along the thalwegs of rivers and ravines.

If it is necessary to raise wastewater to higher levels, sewage pumping stations are arranged to pump water through pressure pipelines. Depending on the purpose, sewage stations are divided into:

a) local - for pumping wastewater from one or more individual, unfavourably located buildings or residential areas;

b) district - for pumping wastewater from individual districts or sewerage basins;

c) main - pumping the main part or the entire volume of wastewater from a sewered settlement or industrial enterprise.

Wastewater treatment plants are designed to treat, dispose of, and disinfect wastewater and sludge; they consist of complexes of treatment and auxiliary facilities interconnected by utilities into a single technological scheme. Treatment plant complexes are selected depending on the concentration, qualitative and quantitative characteristics of pollutants, as well as on the requirements for treated water under local conditions. The channel through which the treated wastewater is discharged from the treatment plant to the reservoir and which is equipped with a device for mixing this water with the reservoir water is called an outlet. Collectors in front of pumping and treatment plants also have outlets for discharging wastewater into a water body without treatment in case of an accident; these outlets are called emergency outlets.

Drainage schemes for settlements

The sewerage network layouts of cities, towns or industrial plants depend on the topography, ground conditions, location of wastewater treatment plants, concentration and type of wastewater pollution, as well as planning factors and other conditions (above and below ground obstacles). Due to the wide variety of local conditions, the possible sewerage network layouts are very diverse (Fig.10.3).

In the initial period of sewerage construction, when there was little wastewater and no strict requirements for its treatment were imposed, the sewerage basin collectors were routed along the shortest route perpendicular to the water body, unless this was prevented by the terrain. This scheme of the sewerage network is called perpendicular (Fig. 10.3,a). At present, this scheme is used in areas with a pronounced slope to the water body to discharge atmospheric and uncontaminated industrial wastewater.

If the collectors of individual basins of the perpendicular scheme are intercepted by a main collector that runs parallel to the water body, then this sewerage network scheme is called intersecting (Fig. 10.3,b). The intersecting scheme is recommended for areas with a pronounced slope to the river to discharge all three categories of wastewater.

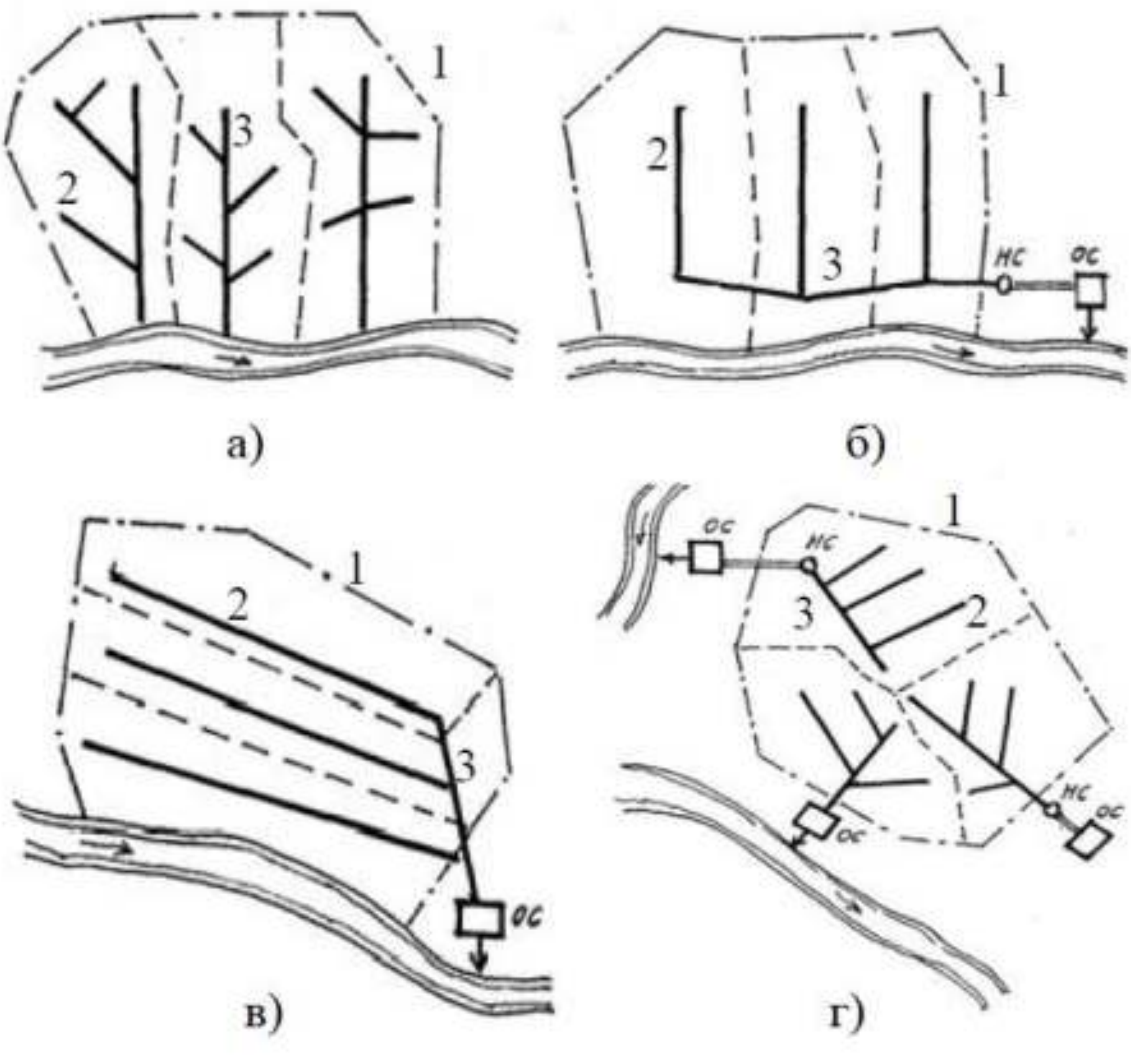


Figure 10.3 - Drainage schemes:
a) perpendicular, b) intersecting, c) belt or zone, d) radial or decentralised; 1 - city limits, 2 - street network, 3 – collectors

An area consisting of several separate terraces with significant elevation differences can be divided into zones (belts) that are sewered independently. Such a sewerage network scheme is called a belt or zone network (Fig. 10.3,c). The wastewater from the upper zone can flow by gravity to the treatment plant, and only the wastewater from the lower zone is pumped directly to the treatment plant or to the upper zone collector, which reduces operating costs. The sewerage network scheme shown in Fig. 10.3,7 is called radial or decentralised.

9.3 General requirements for the composition and properties of wastewater discharged to centralised sewage systems

First and foremost, the centralised wastewater system accepts consumer wastewater that does not lead to disruption of the operation of wastewater networks and treatment facilities, safety of their operation and can be treated at the treatment facilities of the centralised wastewater system in accordance with the requirements of the Rules for the Protection of Surface Waters from Pollution by Wastewater, approved by the Cabinet of Ministers of Ukraine on 25 March 1999, No. 465.

Secondly, wastewater that is accepted into centralised sewage systems should not contain

- combustible impurities and dissolved gaseous substances capable of forming explosive mixtures;
- substances that can clog pipes, wells, grates or be deposited on their surfaces (garbage, soil, abrasive powders and other coarse suspensions, gypsum, lime, sand, metal and plastic shavings, fats, resins, fuel oil, brewer's grains, bread yeast, etc;)
- substances that are not subject to biological degradation;
- substances for which no MPCs have been established for water bodies or toxic substances that interfere with biological wastewater treatment, as well as substances for which analytical control methods have not been developed;
- Hazardous bacterial, viral, toxic and radioactive contaminants;
- biologically harsh synthetic surfactants (hereinafter referred to as SAS) with a primary biodegradation rate of less than 80%.

Waste water should not:

- have a temperature above 40 °C;
- have a pH below 6.5 or above 9.0;
- have a chemical oxygen demand (COD) higher than the biochemical oxygen demand for 5 days (BOD5) by more than 2.5 times;
- have a BOD that exceeds the BOD specified in the design of the treatment plant of the centralised wastewater disposal system of the relevant settlement;
- create conditions for harming the health of personnel servicing the centralised wastewater system;
- make it impossible to utilise sewage sludge using methods that are safe for the environment;
- contain pollutants in excess of permissible concentrations.

If the consumer carries out production processes that require wastewater treatment before discharge to the centralised water disposal system and wastewater treatment in accordance with Annex 1 to the Rules, as well as in case of systematic discharge of excessive pollution, discharge of wastewater to the centralised water disposal system without prior treatment at local treatment facilities is not allowed, except in the cases provided for.

It is prohibited to discharge sewage sludge containing pollutants prohibited for discharge into the centralised sewage system without prior neutralisation and disinfection at local treatment facilities with mandatory disposal or burial of the resulting sewage sludge.

If the quantitative and qualitative indicators of the consumer's wastewater significantly change during the day, and the concentration of pollutants exceeds the DC, the consumer must install special averaging tanks and devices that ensure uniform discharge of wastewater throughout the day.

Control questions:

1. What is a sewerage network and what are its main functions?
2. How was the path of collectors determined in the initial period of sewerage construction?
3. What is a perpendicular sewerage network layout?
4. Under what conditions is a perpendicular sewerage network layout used?
5. What categories of wastewater are distinguished in sewage systems?
6. What is the difference between the perpendicular and intersecting schemes of the sewerage network?
7. How does the terrain affect the choice of the sewerage network scheme?
8. Why are the requirements for wastewater treatment increasing in modern conditions?
9. How does the main collector interact with individual basin collectors in a cross-sectional scheme?
10. What are the main stages of sewerage network design?
11. Why were collectors originally built perpendicular to the water body?
12. How does atmospheric wastewater affect the operation of the sewerage network?

Lecture No. 11
THE STRUCTURE AND COMPOSITION OF INTERNAL AND EXTERNAL SEWAGE

Lecture plan:

1. Internal sewage and its main elements
2. External sewage and its main elements
3. External and internal gutters of buildings

The sewerage system (Fig. 11.1) consists of internal building sewers, yard sewers, external sewers, pumping stations, treatment plants and wastewater outlets into water bodies.

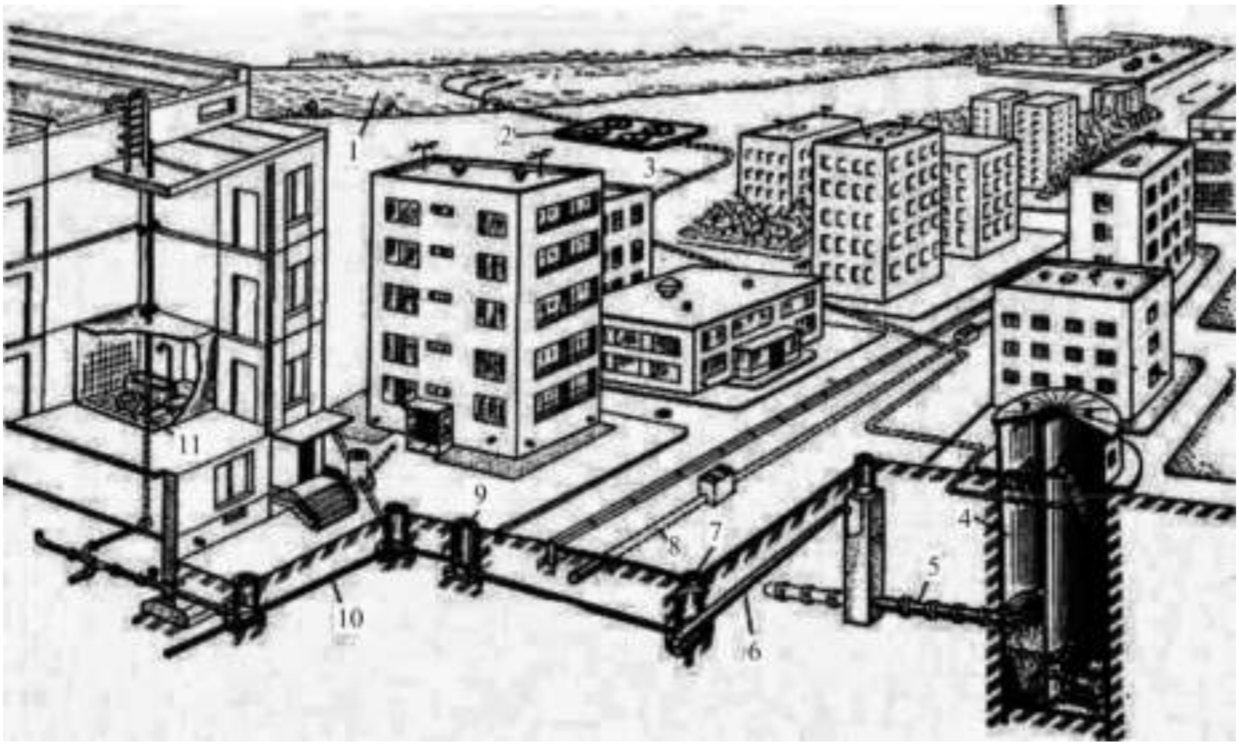


Figure 11.1 - Centralised sewerage system:
1 - reservoir; 2 - treatment plant; 3 - pressure pipeline;
4 - pumping station; 5 - collector; 6 - street network; 7 - manhole; 8 - drainage network; 9 - control well; 10 - yard network; 11 - internal sewage system of buildings

The movement of wastewater inside a building (residential, industrial, etc.) begins with the internal pipeline network. From plumbing fixtures, contaminated water flows through drainage pipes to the sewer riser, and then through the outlet to the external sewer network. Depending on the location of the pipelines in the territory of a settlement or enterprise, this system is called a yard, block or factory network.

Rainwater sewers are used to dispose of rain and melt water. As a rule, it is routed along the shortest distance to the outlet.

The external storm sewer system consists of open rainwater ditches and trays, rainwater inlets (rainwater inlets), a closed network of pipes, storm drains and outlets. Water enters the closed stormwater network through inlets - round or rectangular wells covered with metal grates that allow water to pass through and trap anything that could clog the sewer network (Fig. 11.2).

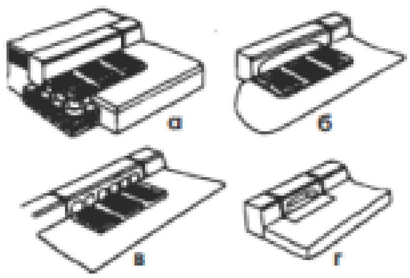


Figure 11.2 - Layout of rainwater inlets on the carriageway:
a) open with a rectangular grate in the tray; b) combined with a grate in the tray and a hole in the curbstone; c) combined with a grate in the tray and a cast-iron curbstone extension; d) closed with a hole in the curbstone at a distance of 50-80 m from each other.

Ceramic, concrete and reinforced concrete pipes are used for the stormwater network. The smallest diameter of gravity-flow stormwater networks is 250 mm for the street network and 200 mm for the intra-quarter network. Rainwater is discharged into water bodies mainly within the city or at industrial enterprises. For sanitary and aesthetic reasons, rainwater should be released below the water level in the river. Stormwater outfalls on the network allow the most polluted portions of rainwater to be sent for treatment.

11.1 Internal sewage system and its main elements

An internal sewerage system is a system of pipelines and engineering equipment that ensures the organised collection of wastewater at the point of generation and the transport of contaminated wastewater outside the building to external networks. If necessary, the internal sewerage system may include local pumping or local wastewater treatment facilities.

Internal sewage systems are divided by: the method of collection and disposal of contaminants, characteristics of wastewater, service area, availability of special equipment and network ventilation.

According to the characteristics of the wastewater, internal sewage systems can be domestic, industrial and rainwater (gutters). Domestic sewage systems dispose of contaminated water after washing dishes, food, laundry, sanitary and hygienic procedures, as well as faecal wastewater containing liquid and solid human excretions. The industrial sewage system discharges industrial wastewater generated in the technological process outside the building. Internal gutters (rainwater drainage) drain rain and melt water from the roof of buildings.

By service area, there are combined and separate sewage systems. Combined systems are used in cases where the mixing of different wastewater does not produce toxic, explosive or other substances that impede the safe transport and treatment of wastewater. Separate sewerage systems (e.g. domestic and industrial) should be installed at enterprises if industrial wastewater requires local treatment.

Internal sewerage systems can be simple, i.e. without special equipment, and with special equipment (e.g. local wastewater pumping or treatment plants before discharge to external networks).

These sewage systems remove pollution in a liquid state (wastewater). Solid waste, garbage is removed through garbage chutes, which also belong to the sewerage system (solid waste sewerage).

The internal sewerage system consists of the following main elements: wastewater inlets, hydraulic valves, internal sewerage network (floor outlets, risers, horizontal sections and outlets) (Fig. 11.3).

Wastewater receivers are made in the form of open vessels or funnels that collect contaminated water and discharge it into the sewerage network. In most cases, wastewater receivers are sanitary appliances (sinks, sinks, washbasins, bathtubs, shower trays, bidets, toilets, urinals); devices for receiving industrial wastewater (trays, ladders, receiving grids, pits, funnels, etc.); drainage funnels designed to collect and drain rain or melt water from the roof.

Hydraulic traps (siphons) are placed after every sanitary device, except for those that have them in their design (toilets, ladders, urinals). A water seal (a layer of water 50-70 mm high) traps harmful gases in the sewage system, preventing them from entering the room. The water layer is formed in the bend of the pipeline in U-shaped traps, or between two cylinders in bottle-type traps. Since siphons can become clogged, they are provided with holes that can be closed with covers, which allows cleaning the siphons and the pipework near them.

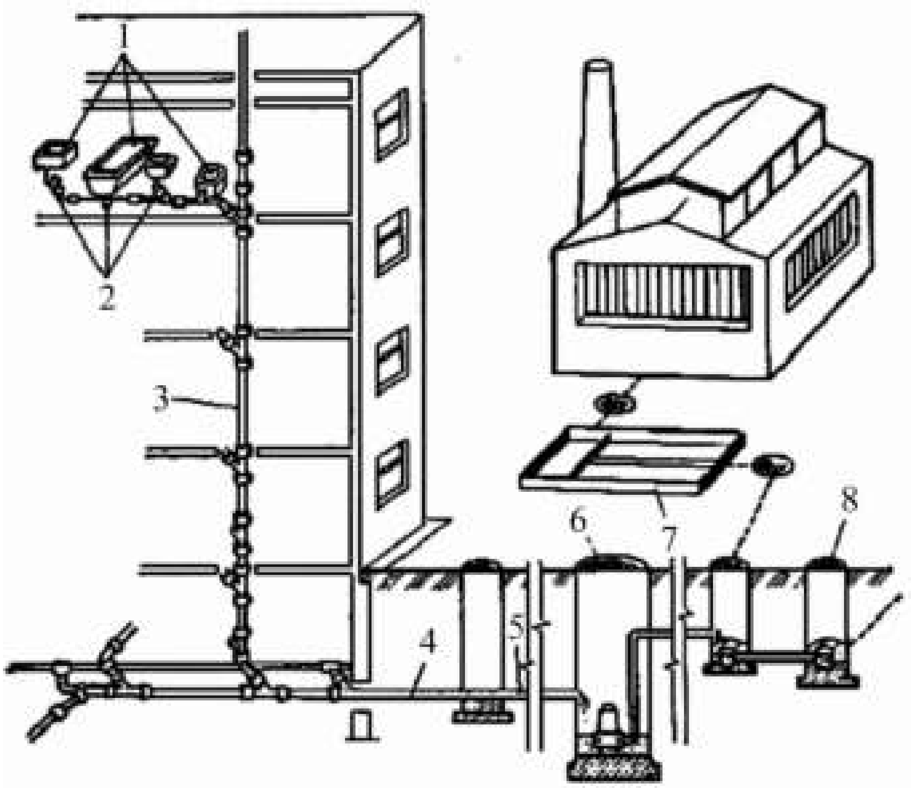


Figure 11.3 - Elements of the internal sewerage system:
1 - wastewater inlets; 2 - hydraulic valves; 3 - internal sewerage network; 4 - outlets; 5 - yard network; 6 - local wastewater pumping plant; 7 - local water treatment plant; 8 - street network well

Floor drainage pipes connect sewage inlets to risers. They are installed in the locations of a group of sanitary appliances, closer to those appliances that receive the most contaminated and least diluted wastewater. The risers are installed openly near the walls or hidden in grooves and special shafts. The upper part of the riser in the form of an exhaust pipe is brought out to a height of at least 0.7 m above the roof of the building, which ensures ventilation of the network and prevents ‘breakdowns’ of hydraulic valves in devices. The diameter of the exhaust pipe must match the diameter of the riser. To control and clean the internal sewerage network, it is necessary to install inspections and cleaning stations.

The required diameters of the outlet pipes and risers are determined depending on the number of receiving devices and the second flow rate of wastewater (Table 11.1).

The internal sewerage system ends with an outlet that is connected to a well located outside the building.

Table 11.1 - Estimated wastewater flow rates and diameters of outlet pipes from individual sanitary fixtures and equipment

Device	Estimated flow rate, dm^3/s	Outlet pipe diameter, mm
Toilet	1,60	100
Washbasin	0,15	50

Shower	0,20	50
Sink	0,30	50
Single compartment sink	0,60	50

Water from each group of appliances is collected and discharged to the street network separately. Premises requiring sewage facilities are placed in compact groups. Sanitary facilities are usually placed one under the other. Wastewater collection devices are rarely installed in basements. Sanitary equipment is allowed to be installed in basements if the depth of the external sewerage network is below the basement floor level and the edges of the sanitary devices are above the level of the nearest manhole.

11.2 External sewerage system and its main elements

A sewerage pipeline system is designed in residential areas and enterprises to carry wastewater from internal sewerage systems to street networks. Depending on the location of the pipelines in a settlement or enterprise, this system is called a courtyard, neighbourhood or factory network.

A courtyard network serves one or several houses, a neighbourhood network serves a much larger group of houses within a neighbourhood, and a factory network is laid on the territory of an enterprise (Fig. 11.4).

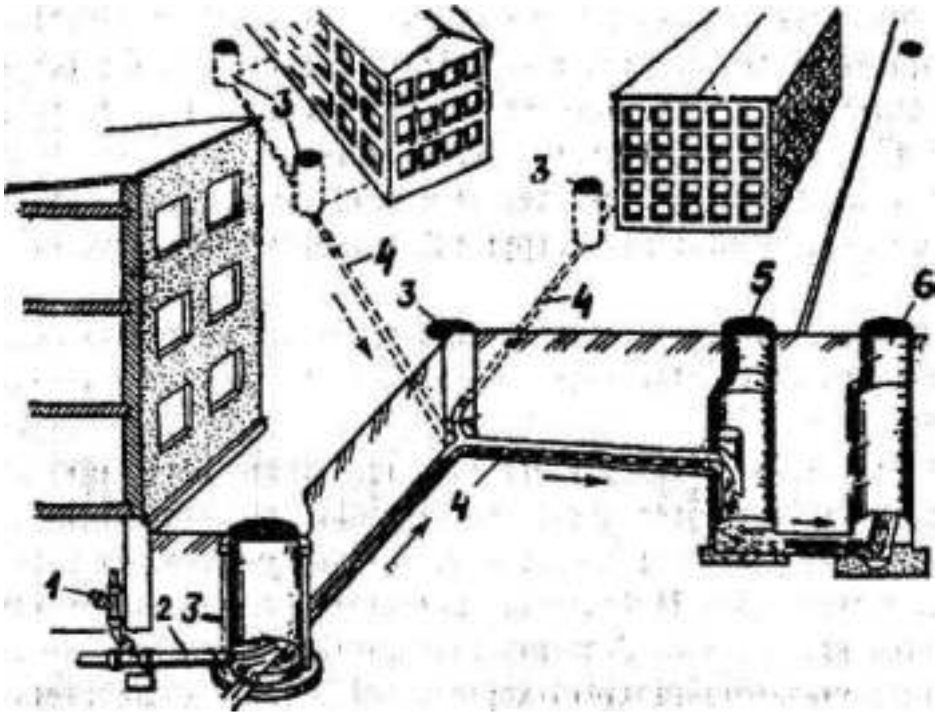


Figure 11.4 – Courtyard sewerage network:
1 – cleaning; 2 – outlet; 3 – courtyard well; 4 – courtyard networks;
5 – inspection well; 6 – street network well

Courtyard, neighbourhood and factory networks are laid using ceramic, asbestos-cement, concrete, reinforced concrete and plastic pipes. Metal pipes are used only under special conditions (for example, in subsiding soils). Sewerage network pipelines are usually laid parallel to buildings, connecting all the outlets of the internal sewerage networks of these buildings. The distance from the wall of the building is taken to be at least 3.5–5.0 m so that the foundation of the building is not damaged during excavation work. Further drainage of wastewater is carried out by gravity flow along the shortest route to the control well, and then to the street collector of the external sewerage system of the settlement.

Manholes on networks are installed at points where outlets from buildings are connected, side connections are made, pipe diameter and slope change, the line turns in the plan, and at elevation changes. Inspection wells are located on straight sections at a distance of no more than 35 m from each other for pipes with a diameter of 150 mm and 40-50 m for pipes with a diameter of more than 150 mm. To monitor the composition of wastewater discharged into the municipal sewerage system, an inspection chamber is installed at the end of the courtyard sewerage system at a distance of 1.0-1.5 m from the red line of development. Quite often, a drop is made in it, since the depth of the street collector is usually much greater than that of the courtyard networks (Fig. 11.4).

11.3 External and internal gutters of buildings

Rain and melt water from the roof of a building is removed by discharging water from overhangs and eaves through organised drainage through external or internal gutters (Fig. 11.5).

External gutters (downspouts) (Fig. 11.5, a) consist of gutters that collect water from the roof slope and downpipes with a funnel that discharge water onto the pavement near the building (Fig. 11.6). The water flows down the driveways into a rainwater inlet and then into the external stormwater network (Figure 11.7). In winter, gutters freeze and meltwater is not completely removed, which leads to the destruction of building structures due to their moisture. External gutters increase the cost of roof maintenance, they are not durable and are time-consuming to repair. Therefore, they are used in buildings where it is not possible to organise internal drainage, or in low-rise buildings with a small roof area, mainly in the southern regions.

Internal gutters (Fig. 11.5, b) are discharged through pipelines located inside the building. They operate reliably in all seasons and require minimal maintenance. Internal gutters are widely used in the construction of buildings with flat roofs.
Water from internal gutters is discharged to the external stormwater or general sewerage networks through a closed outlet (Fig. 11.5, b). Gutters shall not be connected to the domestic system. It is allowed to discharge rainwater into the industrial sewerage system of uncontaminated or recycled water. In the absence of a sewerage system, the discharge is provided in trays near the building - an open discharge (Fig. 1.5, c).

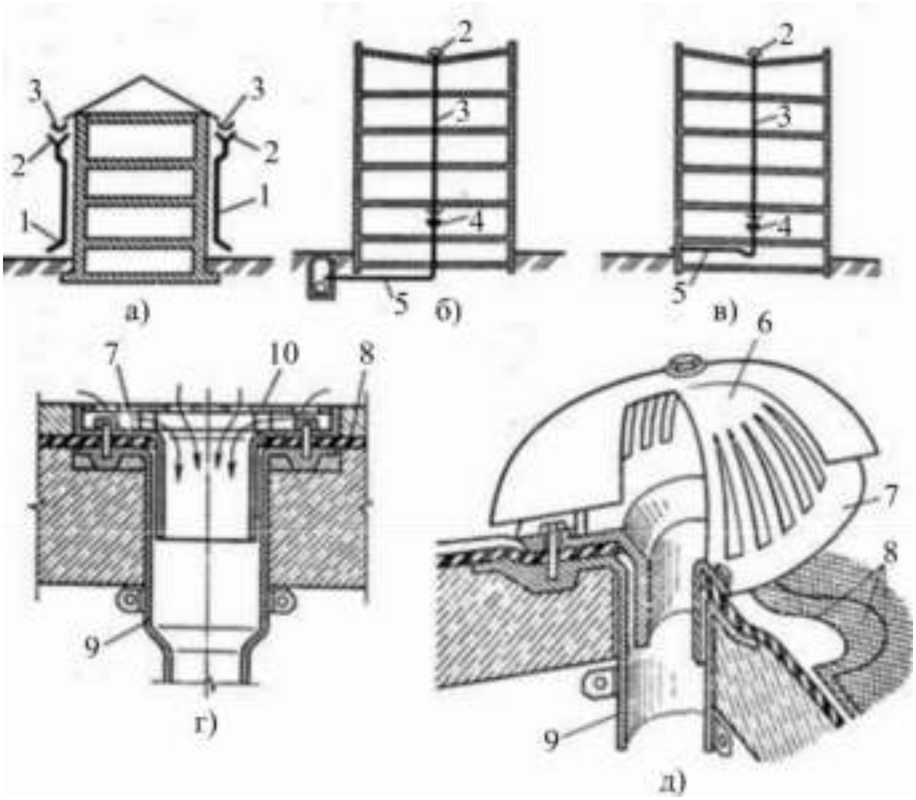


Figure 11.5 - Building gutters:
a - external gutters; b, c - internal gutters; d, e - downspouts; 1 - downpipe;
2 - downspout; 3 - gutter; 4 - cleaning device; 5 - outlets;6 - cap; 7 - frame;
8 - waterproofing; 9 - body; 10 - grille

Figure 11.6 - Complete set of external drainage:
1 - gutter; 2 - gutter plug; 3 - funnel; 4 - universal gutter outlet; 5 - fastening of the gutter pipe (clamp); 6 - holder for the gutter; 7 - gutter outlet funnel; 8 - gutter pipe elbow; 9 - gutter pipe; 10 - corrugated drain elbow

Internal gutters consist of atmospheric water receivers - gutters, risers, outlet pipes connecting gutters to risers, outlets, and cleaning devices.

Gutters with an open outlet at negative outside temperatures are equipped with a water seal, which prevents the penetration of cooled air and freezing of the gutter in the cold season. In buildings with negative temperatures, gutter heating devices are provided (warm air supply, electric heating).

Internal gutters are made of pressure cast iron, asbestos-cement, and plastic pipes. The drainage funnels consist of a body that is arranged in the ceiling, a frame under which the waterproofing is installed, a cap or a grid for trapping debris. The upper part of the funnel (hood, grate) has openings with a cross-sectional area not less than twice the cross-section of the outlet to reduce the resistance to movement and water backup in front of the funnel. The funnels must be sealed to the roof to prevent atmospheric water from seeping in and damaging the slab. For this purpose, a waterproofing layer is bolted between the body and the frame and filled with mastic on top.

Water from the internal gutters can be discharged to the building pavement (open outlets) or to the rainwater or general sewerage system (closed outlets).

Open outlets (Fig. 11.7) are made in the form of a steel or cast-iron pipe that comes out of the building wall (overhang of at least 150 mm) at a height of at least 150 mm from the tray, which prevents soil erosion near the building. To prevent the outlet from freezing in winter, the gap between the wall and the pipe 1 is filled with a layer of thermal insulation 3 (mineral wool) with a thickness of at least 50 mm. In areas with an estimated temperature below -5°C, open outlets are equipped with a water seal 4, which prevents cold air from entering the riser and thus freezing.

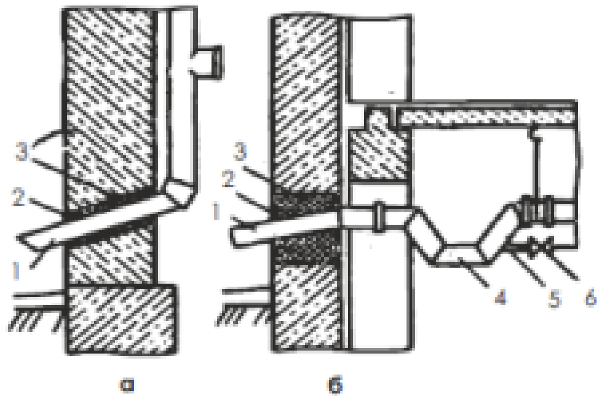


Figure 11.7 - Open gutter outlets:
a) without water seal; b) with water seal; 1) outlet pipe; 2) cement screed;
3) thermal insulation layer; 4) water seal; 5) meltwater drainage pipe; 6) tap

From the building, contaminated wastewater (domestic, industrial and atmospheric) is transported separately or jointly from the external (underground) sewerage network to the treatment plant for treatment and further disposal.

Control questions:

1. What is a sewage system?

2. What are the main elements of a centralised sewerage system?
3. What is internal sewage?
4. What are the functions of the external sewage system?
5. What is the purpose of a two-level sewerage network?
6. What is a rainwater drainage system?
7. What does the internal sewage system include?
8. What types of wastewater are discharged by the internal sewage system?
9. What are the main elements of the internal sewage system?
10. What are wastewater receivers?
11. What is a riser in the sewerage system?
12. What is domestic sewage?
13. What is the purpose of industrial sewage?
14. What is a combined sewerage system?
15. When is it advisable to use a separate sewage system?
16. Why is it important to place sanitary facilities under each other?
17. What are local wastewater pumping plants?
18. What are inspections and cleaning in the internal sewerage system?
19. What is the street sewerage network?
20. What is a manhole?

Lecture No.12
EXTERNAL DRAINAGE SYSTEMS

Lecture plan:
1. Arrangement of pipelines and collectors for the drainage network
2. Collectors and channels
3. Structures on the sewerage network

12.1 Arrangement of pipelines and collectors for the drainage network

Pipelines and collectors of external networks that are laid in different hydrogeological conditions, at different depths and operate in gravity and pressure modes must have a sufficiently long service life, be reliable in operation, economical and industrial in construction. This is achieved through the correct choice of pipe material, the design of their butt joints, effective insulation and the construction of reliable foundations.

The following requirements are imposed on the structures of external networks:

- Strength - pipes and butt joints must be able to withstand the pressure of bulk soil, loads from moving vehicles, and internal water pressure without deformation;
- watertightness (tightness) - groundwater (infiltration) should not enter the network through the pipe walls and joints and water (exfiltration) should not leak out of the network in excess of the established standards;
- smooth internal surface is necessary to reduce resistance to water movement;
- ensuring the lowest cost of materials and the minimum amount of scarce materials.

In accordance with DBN B.2.5-75:2013, pipes in accordance with DSTU B.2.5-25, DSTU B.2.5-32, DSTU B.2.5-46, DSTU B.2.5-47, DSTU B.2 .5-48, DSTU B B.2.5-49, DSTU B B.2.5-50, DSTU B B.2.5-55, DSTU B B.2.5-57, DSTU B B.2.5-63, DSTU B B.2.7-141, DSTU B B.2.7-151, DSTU B B.2.7-178, DSTU BBI-12666-1 for sewer pipelines:

- gravity - non-pressure reinforced concrete, concrete, ceramic, cast iron, asbestos-cement, plastic pipes and other pipes made of corrosion and abrasion-resistant materials or lined with such materials;
- pressure pipes - pressure reinforced concrete, asbestos-cement, cast iron, steel and plastic pipes and other pipes made of corrosion- and abrasion-resistant materials or with an internal protective lining made of such materials.

Ceramic non-pressure pipes are manufactured in accordance with DSTU 286-82 from plastic refractory clay with a bore D = 150-600 mm (DSTU B V.2.5-57:2011).

Ceramic pipes must meet the following characteristics:

- have at least five grooves on the outside of the barrel end and the inside of the bell with a depth of at least 2 mm;
- be waterproof and withstand an internal hydraulic pressure of at least 0.15 MPa during testing;
- have water absorption not exceeding 7-8 %;

- have a uniform, gap-free coating of chemically resistant glaze on the outer and inner surfaces.

Ceramic pipes are the most durable in the construction of drainage networks, especially in cases where groundwater is aggressive. However, the disadvantages of these pipes are a large number of butt joints and material fragility. It is not recommended to use these pipes in subsiding soils. They do not take dynamic loads well, so these pipes are not used on roads with heavy traffic and in shallow burials.

Asbestos-cement non-pressure pipes are manufactured according to the technical conditions of DSTU 1839–80 with smooth ends D = 100–400 mm, and special couplings are produced for their connection. These pipes have a smooth surface, are practically waterproof, are easy to process (sawing, folding, drilling), their mass is 3.5 times less than cast iron pipes. The considerable length of the pipes reduces the number of butt joints when laying networks, but they have a strong fragility and ability to abrasion.

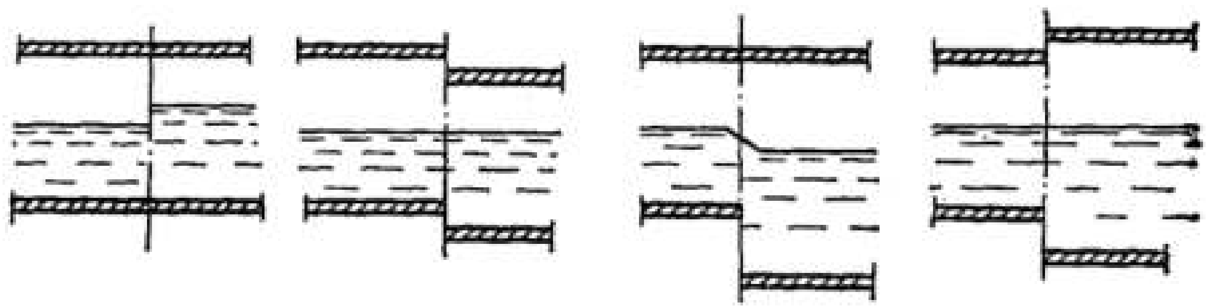
The use of this type of pipe is impractical on high-speed streams carrying a large amount of coarse mineral suspension (sand, slag, glass cullet). Asbestos-cement pipes are supplied complete with connecting couplings and sealing rings. When testing pipes and couplings must withstand a hydraulic pressure of at least 0.4 MPa, and pipes and couplings of the highest quality category - at least 0.6 MPa.

Cast iron non-pressure pipes (DSTU B V.2.5–25:2005) are manufactured according to DSTU 6942–98 with a diameter of 50–150 mm with a socket joint and are also used for laying sewer networks (with separate justification). Cast iron pressure pipes are manufactured from gray cast iron according to DSTU 9583–75, are used in the construction of external pressure networks.

The advantages of cast iron pipes include their high mechanical strength and durability, and the disadvantages include fragility and high metal consumption.

Reinforced concrete pressure pipes are manufactured with a diameter of D = 500–1600 mm by the methods of vibro-hydropressing according to DSTU 12586–83 and centrifugation, with socket joints on rubber seals. Pipes manufactured by the method of vibro-hydropressing, depending on the calculated internal pressure in the pipeline, are divided into four classes, and pipes manufactured by the method of centrifugation are divided into three classes: I - for a pressure of 1.0 MPa; II - for a pressure of 1.0 MPa; III - for a pressure of 0.5 MPa.

In engineering practice, two methods of connecting pipes are used: "shelyga in shelyga" and "by water levels". Fig. 12.1, a and b show the schemes of connecting pipelines of the same diameter, and Fig. 12.1, c and d - of different diameters. When connecting pipelines "sheliga in sheliga" (Fig. 12.1, a and c), the upper parts of the pipe arches, called sheligas, are connected. If the pipes are connected "by water levels" (Fig. 12.1, b and d), then the calculated water levels are connected in height. The most common idea is that pipelines of the same diameter should be connected "by water levels", and those of different diameters - "sheliga in sheliga".



a) *b)* *c)* *d)*

Figure 12.1 – Connection diagrams of sewer pipes:
a, c - pipe to pipe; b, d - by water levels

12.2 Manifolds and channels

In all-alloy, separate, combined and production sewage systems both in our country and abroad, collectors and channels of large cross-sections built of brick at the end of the 19th and beginning of the 20th centuries have been successfully operated for a long time. The main elements of brick collectors of any cross-section are identical: the upper forming part is called a vault, the lower part is called a tray. The trays are laid in a foundation, which is brought to half their height on the sides of the collectors (Fig. 12.2). The foundation structure consists of a preparation, a slab and a chair. The preparation is made of crushed stone, gravel or concrete; the slab is made of concrete or reinforced concrete. The thickness of the slab and the brand of concrete are determined by calculation depending on the stability of the soil and the dimensions of the channel. The side part of the collector is called a chair. Its width is determined by static calculation.

Brick collectors of circular cross-section (Fig. 12.2, a) with a diameter of 600-1800 mm with a regular or expanded seat, and for large sizes - semi-elliptical (tent) cross-section, better meet the static operating conditions with good quality bricks, are durable and well resist the aggressive action of groundwater and wastewater. However, their design is massive, they are not industrial and expensive, their construction requires high-quality straight and wedge-shaped bricks, as well as a lot of cement (approximately the same amount as is required for the manufacture of a reinforced concrete pipe of the same diameter). For this reason, as well as due to the impossibility of mechanizing the work, their construction has been discontinued. With the transition to industrial methods of prefabricated construction of collectors from large-sized prefabricated reinforced concrete elements of factory production (blocks, pipes, rings and tubing), collectors are given the shape of a round and rectangular cross-section. The chair, slab and vault are sometimes combined in one volumetric element.

Fig. 12.2, b shows a combined collector of prefabricated reinforced concrete elements of the base and vault, resembling a brick collector in shape. Prefabricated collectors are 35-50% cheaper than brick and reinforced concrete collectors made on site.

Rectangular collectors are used for the construction of domestic and storm sewers, as well as for laying underground communications. Four elements are used for the construction of one- and two-section collectors: external wall blocks 1.8 m long, floor slabs up to 4 m wide, bottom slabs up to 2.6 m wide and middle wall blocks. Collectors of various cross-sections (from 2x2 to 3x4 m) are assembled from such blocks. Special blocks or trapezoidal inserts are used to arrange smooth turns. However, rectangular channels no longer meet the modern requirements of industrial construction and do not provide the necessary water tightness in the butt joints.

The main structure of large sewer collectors and drains should be round reinforced concrete non-pressure pipes, and for pressure ones - reinforced concrete pressure pipes, manufactured by the method of vibro-hydropressing and centrifugation. The transition from rectangular channels to round long pipes of large diameter allows you to increase the throughput of channels by up to 10%, reduce installation costs by up to 30-50% and ensure water tightness of the joint.

The use of long pipes with a flat base (Fig. 122, d) allows them to be laid directly on concrete preparation and significantly reduces the consumption of reinforced concrete, since there is no need to arrange a chair. The laboriousness of the work on laying long pipes with a flat base turned out to be 2 times less than when arranging a channel from round pipes.

When constructing collectors in areas of old and limited development at a depth of 6 m and below, it is advisable to lay them using the method of closed shield tunneling.

Collectors are assembled with a circular cross-section from trapezoidal or segmental reinforced concrete blocks - tubing. When tunneling with shields of old structures, trapezoidal tubing was used, the width of which usually did not exceed 300–350 mm, and their number along the processing ring was 16–20 pcs. Mechanized shields of new unified designs allow strengthening the walls of tunnels with enlarged tubing in the form of segments 700–800 mm wide with a number of 6–8 pieces per processing ring. Tubing and segments are made of concrete grade 400 on granite crushed stone with a grain size of no more than 40 mm. To ensure water resistance and increase durability in the channels of tubing, an internal reinforced concrete jacket of monolithic reinforced concrete grade 400 on granite crushed stone is arranged (Fig. 12.1, e), and when constructing a channel in water-saturated soils, in addition, waterproofing is provided. The sleeve tray is reinforced with cement grade 500. If it is necessary to lay a collector of a much smaller diameter than the smallest diameter of the tunnel shield in a tunnel made by the shield method, a tray made of monolithic concrete or prefabricated concrete elements laid on bitumen mastics is arranged inside the block processing of the tunnel after the installation of a reinforced concrete waterproof sleeve. In all cases, one should not strive to reduce the collector cross-section to the calculated one (if this does not violate its hydraulic regime) for the expediency of further development of the sewerage system.

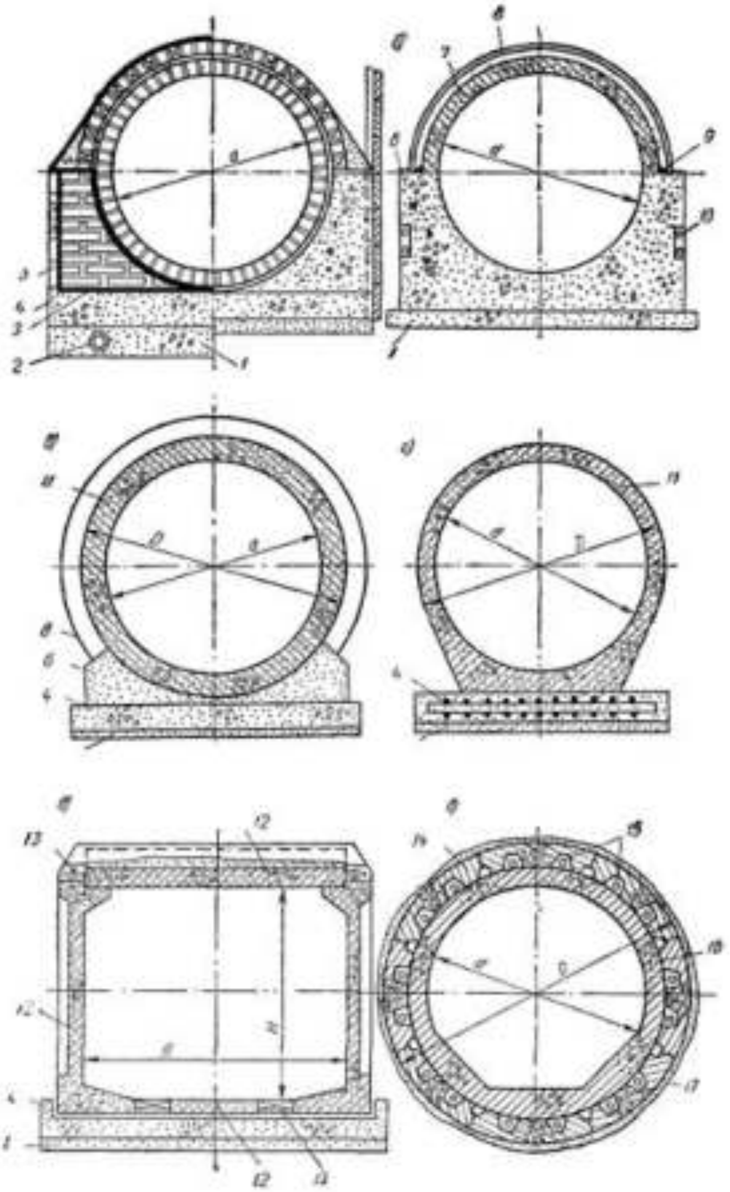


Figure 12.2 – Collectors:
a – brick; b – combined with a semicircular overlap;
c, d – from reinforced concrete pipes; d – rectangular from blocks; e – from tubing, made by the shield penetration method; 1 – preparation; 2 – drainage;
3 – waterproofing; 4 – slab; 5 – chair; 6 – concrete base from prefabricated elements; 7 – reinforced concrete vault; 8 – belt for sealing joints;
9 – bitumen; 10 – belt for fastening blocks; 11 – pipe; 12 – blocks;
13 – monolithic places; 14 – tubing; 15 – steel studs, d = 30 mm;
16 – waterproof jacket; 17 – cement mortar pumped behind the tubing

12.3 Structures on the sewer network

Manholes and chambers are constructed on sewer networks.

Manholes can be inspection, connecting, turning, overflow and flushing according to their purpose. They are installed: in places of change of diameters, slopes, direction, connection of tributaries, when arranging overflows.

Sewer lines should be laid straight between manholes.

The calculated velocity of the wastewater should be such that it increases with the flow. A decrease in the calculated velocity (but not less than the minimum) is allowed only after overflow manholes.

The calculated velocity of the wastewater in the side connections should be less than in the main collector.

Linear manholes are installed on straight sections of sewer networks of all systems after 35-500 m, depending on the pipe diameter (Fig. 12.3).

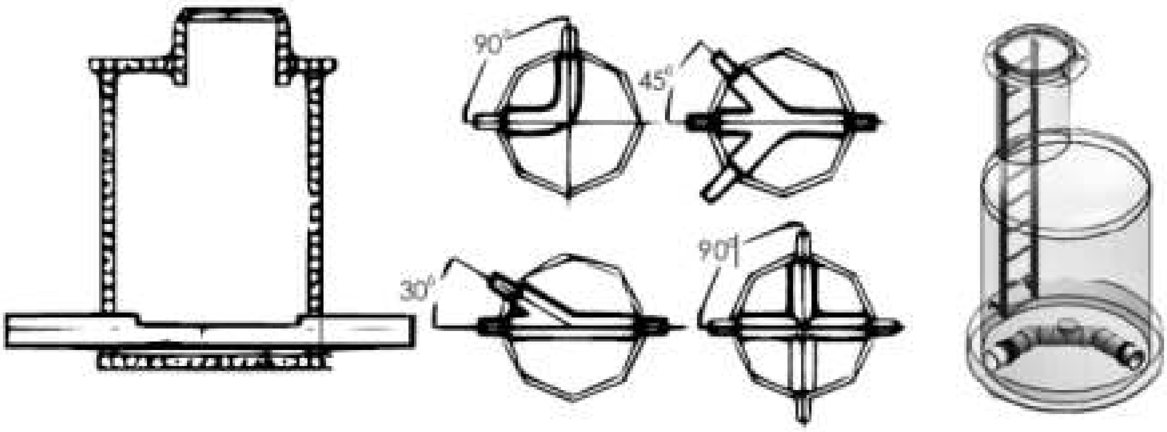


Figure 12.3 – Pipeline layout diagram in linear wells

Flushing wells are provided in those areas of the sewer network where sedimentation in the pipes is possible.

Differential wells (Fig. 12.4) are constructed in places where pipes are connected at different depths, which occurs when connecting side tributaries to the main sewer network, when arranging differentials due to a sharp change in the terrain and when it is necessary to reduce the speed of wastewater flow through the network.

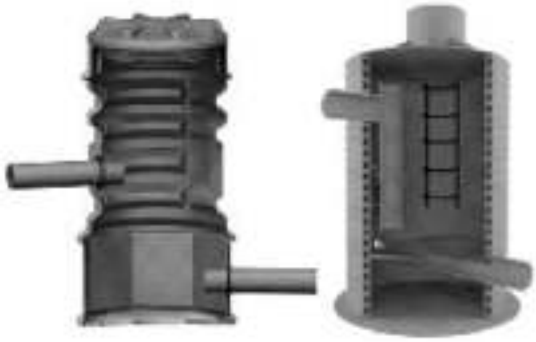


Figure 12.4 – Overflow wells

Connecting inspection wells (Fig. 12.5) are installed at the junctions of sewer lines. They provide a three-stage filtration process.

Stages of the filtration process:

1. Basket with a fine mesh of 0.35 mm for collecting coarse debris;
2. Solid sedimentation zone;
3. Separator of floating particles (fats).

Technical characteristics:

– installation depth from 900 mm to 1600 mm thanks to the telescopic cover D = 600 mm;

– two types of execution: with a polymer cover for pedestrian areas and with a cast-iron cover for the carriageway;

– rainwater collection area up to 1000 m;
– connecting pipes DN 150.

Figure 12.5 – Drainage inspection connection well

Inspection wells are installed in front of the red building line from the side of the houses at the points of connection of the yard, quarter or industrial network to the street.

Wells on pressure pipelines are installed if it is necessary to place valves, outlets and other fittings in them.

Sewer lines should be laid straight between the wells. The calculated speed of movement of the wastewater should be such that it increases with the flow. A decrease in the calculated speed (but not less than the minimum) is allowed only after the differential wells. The calculated speed of movement of the wastewater in the side connections should be less than in the main collector.

Chambers are constructed on all sewer systems at the points of connection of several large-diameter sewer lines into one collector. Precast reinforced concrete chambers can be round and rectangular.

Turns in wells and chambers are made along smooth curves with a radius of at least three pipe diameters of the largest size and, as an exception under limited conditions, at least two diameters. Turns of collectors with a diameter or height of 1.2 m and more are allowed to be arranged outside inspection wells along curves with a radius equal to at least five diameters or five times the width of the channel, with the installation of inspection wells at the beginning and end.

The angle between the connecting and outlet pipe must be at least 90o, since sharp turns of flows in wells create additional local supports.

In wells, pipes are connected using open trays made along smooth curves.

When sewer collectors intersect with domestic and drinking water supply, the latter is laid above the sewers by 0.4 m vertically in the light. When it is impossible to comply with this requirement and it is necessary to lay the water supply below the sewer collector, steel pipes are used for the water supply, and cast iron pipes for the collector. It is also possible to lay the water supply in a protective casing with a length of at least 5 m in each direction from the intersection in clay soils and 10 m in those that filter, and the sewer pipe in this area must be metal.

Gravity pipelines often intersect with various natural and artificial obstacles. Natural obstacles include streams, rivers, ravines, etc.; artificial ones include roads and railways, underground collectors, pipelines for various purposes, cables, pedestrian crossings, subway lines and other structures.

The design of the intersection depends on the mutual elevation (difference in elevation) of the pipeline and the obstacle. If the pipeline directly intersects with an obstacle, that is, the pipeline and the obstacle are located at the same level or their difference is insignificant, then the intersection is made in the form of a dyke - a pressure pipeline connecting two gravity pipelines.

The dyke consists of the following main elements: pressure pipelines, upper and lower chambers. Pressure pipelines of the dyke are made of at least two strands of steel pipes with reinforced anti-corrosion insulation. Their diameter must be at least 150 mm. Both threads must be working. Only at low costs is it allowed to install a culvert with one working and one reserve pipe.

The culvert is laid in a trench along the bottom of the channel. The angle of inclination of the ascending part of the culvert should not exceed 20°. The depth of the underwater part of the pipeline should be taken not less than h = 0.5 m to the top of the pipe, and within the fairway on navigable rivers not less than h = 1 m. The distance between the culvert pipes in the light should be not less than b = 0.7–1.5 m (depending on the diameter and other features of the culvert installation).

Crossings under railways and highways are used: for roads passing in deep excavations - culverts, and in other cases - gravity.

Crossings of the culvert type under roads are laid with the same calculation, construction and operation conditions as culverts under rivers.

Gravity-type crossings are made of steel, cast iron or pressure reinforced concrete pipes of the same diameter as the supply manifold. Crossings under tracks have the following designs: steel pipe without casing (casing); pipe in a monolithic concrete or reinforced concrete chair; pipe in a casing-casing; open tray in a gallery or tunnel. Pipes in a monolithic chair under roads are laid with shallow embedment and an open method of production of works. A crossing in the form of a pipe in a casing is laid by the method of pushing through using hydraulic jacks or horizontal drilling. In places of crossing, the pipeline route should be straight and cross the roads at an angle close to a right angle.

Pipeline crossings over railways and motor roads of the first and second categories, as well as over city highways should be provided in casings (boxes) or tunnels.

The depth of the pipeline from the sole of the rail or the road surface depends on the method of production of works. So, with the open method, this is a distance of at least 1 m to the top of the pipe or casing, while with the closed method (pushing, puncture, horizontal drilling, shield tunneling) - at least 1.5 m to the top of the casing. When arranging transitions, it is advisable to provide shut-off valves in the upper and lower nearest wells, which allows you to turn off the transition for prevention or repair.

Overpasses are arranged when crossing deep ravines or dry valleys with gravity pipelines, the marks of the tray of which significantly exceed the marks of the bottom of the obstacle being crossed. Structurally, the overpass is a bridge on high supports, along which a gravity pipeline is laid from long metal and reinforced concrete pipes in an insulated box - casing. The box is insulated with slag, expanded clay, mineral wool. The overpass is simpler in design than a culvert, and can also be used as a pedestrian bridge. Instead of inspection wells, inspections are arranged on the pipeline for cleaning pipes, and in front of the overpass - an emergency release, the device of which is coordinated with the sanitary and epidemiological service. Pressure drainage pipelines, which are laid, as a rule, in two lines, when crossing rivers and ravines, are suspended in insulated boxes to the spans of existing bridges.

Control questions:

1. What are the main requirements for the structures of external drainage networks?
2. What materials are used to manufacture gravity pipelines?
3. How do asbestos-cement pipes differ from cast iron pipes in terms of characteristics?
4. What are the advantages and disadvantages of cast iron pipes?
5. How are reinforced concrete pressure pipes classified depending on the calculated internal pressure?
6. What types of connections are used for pipelines of different diameters?
7. What is a "tray" in the collector design?
8. What are the differences between the designs of brick and reinforced concrete collectors?
9. What are the advantages of round collectors made of long pipes?
10. What methods are used to lay collectors in old-built areas?
11. What are tubings and for what structures are they used?
12. How is the watertightness of tubing channels ensured?
13. What are the main types of wells used in drainage systems?
14. In what cases are differential wells installed?
15. What is a drainage inspection connecting well, and what are its functions?
16. What are the requirements for connecting pipes in wells?
17. In what cases are inspection wells used?
18. What is a chamber, and why is it installed on a sewer network?
19. What features should be taken into account when turning collectors in chambers?
20. What is a culvert, and when is it used?
21. What elements are included in a culvert?
22. What are the requirements for pipeline crossings over highways and railways?
23. What is an overpass, and in what cases is it used?
24. How is water supply pipelines laid when they intersect with sewer collectors?

Lecture No. 13
WASTEWATER TREATMENT

Lecture plan:

1. Mechanical wastewater treatment

1.1 Screens

1.2 Sand traps

1.3 Settling tanks

2. Biological wastewater treatment

2.1 Biological wastewater treatment in natural conditions. Irrigation fields and filtration fields

2.2 Biological wastewater treatment facilities in artificially created conditions

13.1 Mechanical wastewater treatment

Wastewater entering wastewater treatment plants contains contaminants of mineral origin (sand, clay, dissolved salts, etc.); biological origin (human waste products, etc.); harmful chemicals (industrial wastewater); and pathogenic bacteria.

Wastewater treatment involves removing all of the above contaminants and preparing the water to a relatively clean state. Requirements for the physical and chemical state of wastewater when discharged into surface water bodies are regulated by state sanitary norms and rules, and by local authorities depending on the quality of the water in the surface water body where the wastewater is to be discharged.

Wastewater treatment facilities perform mechanical, chemical and biological treatment. All contaminants removed during treatment also undergo specific treatment at sludge treatment facilities.

Mechanical cleaning involves removing mineral contaminants from wastewater that are in an undissolved and suspended state, as well as foreign objects floating in the wastewater.

Mechanical methods can remove up to 60% of undissolved impurities from domestic wastewater.

In recent years, preliminary aeration has been used to intensify the process. This method can increase treatment efficiency to 75%.

During mechanical wastewater treatment, solid and suspended particles are separated from the medium. This is a preliminary stage of preparing wastewater for discharge or reuse, during which the medium is prepared for biological or physical-chemical treatment.

The main mechanical methods of wastewater treatment at enterprises or in sewerage systems:

Straining. This is the primary stage of water treatment, during which wastewater is passed through screens to remove fibres and insoluble impurities.

Settling - suspended particles are removed from the wastewater. The method is based on the action of gravitational forces - contaminants sink to the bottom of the settling tank.

Filtration - separation of suspended solids by passing wastewater through a fine-mesh screen or porous materials (anthracite, quartz sand, gravel or other material).

Centrifugation of wastewater in hydrocyclones - separation of solid particles in a stream of rotating media.

After mechanical water treatment, wastewater sludge is dewatered, which also consists of several stages:

Preparatory. Preliminary dewatering of wastewater sludge is carried out using filter presses by conditioning with organic flocculation - aggregation of sludge using flocculants. This helps to increase the water yield of the sludge.

Main. The layer of solidified particles obtained after the preliminary stage of wastewater sludge dewatering is covered with quicklime and converted into granules. During the reaction, the temperature of the layer of solidified particles rises to + 80 °C. This promotes dewatering and disinfection of the sludge.

Final stage - final dewatering of sewage sludge by mechanical action (centrifugal force, discharge or pressure) on the layer of solidified particles.

Main elements of mechanical structures очищення стічних вод від забруднень: решітки; пісколовки; відстійники.

13.1.1 Screens

Screens are the first element of all technological schemes. They are used for mechanical retention of large impurities larger than 5 mm. Depending on their design features, they are divided into movable, stationary and combined with crushers.

Depending on the size of the openings, screens are divided into: coarse screens (openings 30–200 mm); medium screens (openings 10–30 mm); fine screens (openings 1–10 mm).

Grates are used to remove large floating contaminants from the wastewater. Grates can be movable or fixed. They are installed at an angle of 65-75° to the horizon. During operation, wastewater treatment grates must be regularly cleaned of accumulated contaminants.

Primary coarse cleaning of wastewater takes place on the grates – foreign objects and large floating contaminants (paper, rags, leaves, etc.) are removed. The wastewater then flows into sand traps.

13.1.2 Sand traps

Sand traps are designed to retain heavy mineral impurities (mainly sand) contained in wastewater. They are usually installed upstream of sedimentation tanks. The use of sand traps is justified by the fact that when mineral and organic impurities are removed together in sedimentation tanks, significant complications arise during the removal of sludge from the tanks and its subsequent fermentation in methane tanks.

Sand traps are designed to retain sand with a grain size of 0.15–0.2 mm and a hydraulic size of 13.2–24.2 mm/s. The principle of operation of sand traps is based on the fact that under the action of gravity, particles with a specific weight greater than that of water fall to the bottom.

To retain sand at treatment plants, several types of sand traps are used, which differ in the direction and nature of fluid movement: with horizontal rectilinear fluid movement; horizontal sand traps with circular fluid movement; with helical fluid movement in a circle (tangential sand traps); with horizontal screw motion of fluid (aerated sand traps); vertical.

13.1.3 Settling tanks

Depending on their purpose in the treatment plant process flow diagram, settling tanks are divided into the following types:

1. Primary settling tanks, designed to clarify wastewater after screens and sand traps (installed upstream of biological treatment facilities).

2. Secondary clarifiers, designed to separate sludge mixture after aeration tanks or to retain excess biofilm after biofilters.

3. Tertiary clarifiers, designed to clarify biologically treated wastewater after treatment with coagulants.

Depending on the operating mode, there are periodic and continuous action clarifiers. Periodic action clarifiers are usually used for small flows or periodic wastewater inflow. These clarifiers are metal or reinforced concrete tanks with a conical bottom. The dimensions of a periodic settling tank are determined by the wastewater flow rate and the kinetics of suspended solids precipitation. Continuous settling tanks are usually used in municipal treatment plants, where treatment is carried out at any wastewater flow rate.

Suspended solids contained in wastewater consist of particles of various sizes, whose hydraulic size varies significantly and represent a polydisperse, aggregatively unstable system. The particles are heterogeneous, have good adhesive properties and the ability to agglomerate during sedimentation. A distinction is made between agglomeration (coarsening) of particles under conditions of diffusion coagulation (which occurs when colloidal systems are destroyed, the particle sizes of which do not exceed 0.1 μm) and orthokinetic or gravitational flocculation.

For the bulk of coarse particles with sizes of 1–1,000 μm, flocculation is decisive. Due to their adhesive properties, particles agglomerate when they collide with each other under conditions of compressed precipitation, which causes a change in their shape, size, density and, as a result, the rate of precipitation. This phenomenon is called gravitational or orthokinetic coagulation.

Depending on the design features and direction of wastewater flow in the structure, sedimentation tanks are divided into horizontal, vertical and radial.

The type of sedimentation tank is selected based on the accepted technological scheme for wastewater treatment and sludge processing, the capacity of the structures, the sequence of construction, the number of units in operation, the terrain, geological conditions, and the groundwater level.

Horizontal sedimentation tanks are used when the treatment plant's capacity exceeds 15,000 m^3/day, radial tanks are used for capacities exceeding 20,000 m3/day, and vertical tanks are used for capacities up to 20,000 m^3/day.

13.2 Biological wastewater treatment

Biological wastewater treatment is based on the ability of various groups of microorganisms to destroy soluble organic substances contained in wastewater during their life cycle, contained in wastewater, i.e. to use dissolved organic pollutants in wastewater as food, as a result of which they obtain energy for their life activities, and the wastewater is freed from these pollutants.

Biological treatment can be carried out using the following methods:

- in conditions close to natural ones;
- in artificially created conditions.

Biological treatment in conditions close to natural ones consists in adapting, with the help of technical means, natural biocenoses of soils or water bodies to receive wastewater and naturally biologically oxidise organic substances contained in wastewater.

Facilities for biological treatment of wastewater in conditions close to natural ones are divided into facilities in which the treated wastewater is filtered through a layer of soil (filtration fields and irrigation fields) and facilities that are water bodies (bioponds) filled with treated wastewater. In the first type of facilities, oxygen is supplied mainly through its direct absorption by microorganisms from the air. In the second type of facilities, oxygen is supplied mainly through re-aeration or artificial aeration. However, the low intensity of natural biochemical processes, the large area of the structures and climatic conditions limit the widespread use of biological wastewater treatment methods in filtration fields, irrigation fields and bioponds.

Aerobic biological treatment structures in artificially created conditions include biofilters and aerotanks. A biofilter is a tank with filtering material, the surface of which is covered with a biofilm (a colony of microorganisms

capable of sorbing and oxidising organic substances and wastewater). An aerotank is a tank in which the wastewater to be treated is mixed with activated sludge (a biocenosis of microorganisms that are also capable of absorbing organic substances from wastewater).

The principle of treatment in these facilities is the same as that underlying natural treatment methods. However, the ecological systems of biofilters and aerotanks differ significantly from their natural counterparts in terms of the extreme conditions in which the biocenoses exist and the ability to maintain optimal conditions for the biocenosis organisms to live (organic matter load, temperature, pH, amount of dissolved oxygen, etc.). All this together ensures a high intensity of biochemical processes in these structures.

In water treatment practice, the term ‘biological wastewater treatment’ usually refers to aerobic biological treatment processes that occur under the action of aerobic microorganisms in the presence of dissolved oxygen in water. The ability of microorganisms in the biological film and activated sludge to consume compounds of various chemical compositions and their high adaptability to changing environmental conditions allows for the effective treatment of wastewater from organic compounds contained in domestic wastewater, as well as biologically oxidisable substances contained in industrial wastewater. Today, biological wastewater treatment in biofilters and aerotanks is the main, most effective and economically viable method of treating municipal and many categories of industrial wastewater.

13.2.1 Biological wastewater treatment in natural conditions. Irrigation fields and filtration fields

Methods of wastewater treatment in soil are based on the soil's ability to self-purify. Soil self-purification is determined by its absorption capacity, which is understood as the soil's ability to retain soluble, colloidal and insoluble impurities. Due to the mechanical absorption capacity, which is related to the porosity of the soil, insoluble impurities in wastewater, including bacteria and helminth eggs, are retained. Thanks to chemical absorption capacity, anions that form insoluble compounds with soil cations (e.g. phosphates) are removed from the water. The biological absorption capacity of soil consists in the use of organic and mineral impurities in wastewater by soil organisms.

The soil biocenosis is a complex community of bacteria, fungi, actinomycetes, algae, protozoa, worms and insect larvae. Biologically, the most active layer of soil is 20 cm deep.

When wastewater is filtered through the soil layer, a microbial film develops in it, the biocenosis of which consists of wastewater microorganisms and soil micro-populations that have adapted to the specific conditions that arise in the soil when it is irrigated with wastewater. At the same time, the total number of bacteria increases several times. It is believed that the main part of the bacterial population of irrigated fields consists of natural soil inhabitants, and most of the bacteria introduced into the soil with wastewater die off under the influence of various physical, chemical and biological factors.

It has been calculated that from the moment it enters the fields to the moment it enters the drainage system, each portion of wastewater has contact with the soil for at least 6–12 days. This, as well as the developed active surface of the soil and the large mass of microorganisms in it, explains the high efficiency of wastewater treatment achieved in irrigation and filtration fields.

Different types of wastewater pollutants penetrate the soil layer to different depths. Bacteria, viruses and helminth eggs are retained in the uppermost layer. Organic matter and ammonium nitrogen penetrate slightly deeper, and chlorides and nitrates penetrate even deeper. It has been established that surfactants are poorly absorbed by the soil and are therefore able to penetrate very deep layers, entering the groundwater. In addition, surfactants reduce the possibility of substances concentrating on the surface of soil particles, in other words, they reduce its absorption capacity. In the presence of surfactants, bacteria, viruses and helminth eggs are able to penetrate deeper layers of soil.

The most important factor causing rapid oxidation of wastewater impurities is oxygen. Good aeration is achieved only in the upper layer of the soil with a depth of 20–30 cm, which is why the most intensive mineralisation of organic substances occurs here. Along with heterotrophic bacteria, fungi also actively participate in the oxidation of organic substances. The photosynthetic activity of algae developing in the uppermost layer of the soil contributes to its aeration. In the well-aerated top layer of soil, nitrification processes occur intensively. The solid substrate, which is soil, and its special physical and chemical conditions reduce the harmful effects of ammonium nitrogen, creating the possibility of symbiotic life of heterotrophic and nitrifying bacteria. Nitrate is a highly mobile ion that freely penetrates deep into the soil, enabling the oxidation of residual concentrations of organic matter through the process of denitrification.

Wastewater treated in irrigation fields or filtration fields, subject to permissible hydraulic loads, is almost completely free of pathogenic bacteria and helminth eggs. However, the sanitary condition of the soil deteriorates significantly. Non-spore-forming pathogenic bacteria remain in the soil for a relatively short time, but the spores of a number of pathogenic bacteria and helminth eggs remain viable for years. For these reasons, it is recommended to grow crops that are not consumed raw, mainly grasses, on irrigation fields.

The degree of wastewater treatment in irrigation and filtration fields is significantly reduced in winter due to the slowdown and even cessation of biological processes at low temperatures. During this period, fields of all types function mainly as wastewater storage facilities through surface freezing.

The methods of biological wastewater treatment in irrigation fields and filtration fields are significantly inferior to aerotanks and biofilters in terms of the intensity of biochemical processes, but in terms of the quality of treated water, they are comparable, and in some cases provide more effective treatment than in artificially created conditions, especially from biogenic elements. The disadvantage of natural treatment methods is the large area of land required for the construction of fields, as well as the seasonality of their operation.

Industrialised countries have almost completely abandoned the treatment of wastewater in irrigation and filtration fields, due to: the gradual accumulation of biologically non-oxidisable pollutants in the soil; the introduction of substances into the soil with wastewater that have a detrimental effect on soil flora and fauna; the high cost and difficulty of acquiring land around populated areas for treatment, and the sharp increase in energy costs when such facilities are located far from populated areas; the sanitary unreliability of both the facilities themselves and the agricultural products grown on them; practically complete absence of technological control and management of wastewater treatment processes in the soil; well-established serial production of small treatment plants of any capacity for wastewater treatment in artificially created conditions; standardisation of the construction of large treatment facilities using intensive methods of wastewater treatment and disinfection.

13.2.2 Biological wastewater treatment facilities in artificially created conditions

Biological treatment facilities include aerotanks, biofilters, as well as artificially created biopónds, secondary clarifiers, anaerobic reactors and areas for sludge disposal sites.

Aerotanks are the main structures for aerobic biological wastewater treatment. They operate on the basis of activated sludge, a special biological sediment consisting of microorganisms capable of decomposing organic compounds.

The main elements of aerotanks

Reservoir: a large container where treatment takes place.

Aeration system: provides air supply to support the life of microorganisms.

Mixing zone: for uniform mixing of activated sludge with wastewater.

Principle of operation

Wastewater enters the aeration tank reservoir. Oxygen-enriched air is supplied to the water through the aeration system. Active sludge containing microorganisms processes organic pollutants, converting them into carbon dioxide, water and biomass. The treated water is sent to a secondary clarifier to separate the sludge.

Types of aerotanks

Complete oxidation: for deep water purification.

Classic aerotanks: provide standard purification.

Aerotanks with denitrification: allow the removal of nitrogen compounds.

Advantages of aerotanks

High efficiency in removing organic pollutants.

Compact design compared to natural ponds.

Can be combined with other technologies.

Biofilters: principle of operation and design

Biofilters are structures in which wastewater is purified by passing it through a loading material covered with a biofilm of microorganisms.

Main elements of a biofilter

Filling material: a layer of gravel, crushed stone or synthetic materials where the biofilm is formed.

Water supply system: evenly distributes wastewater over the surface of the filling.

Aeration system: provides oxygen for microorganisms.

Principle of operation

Wastewater enters the biofilter and is evenly distributed over the loading surface. As the water passes through the loading, microorganisms on the biofilm absorb and decompose the contaminants.

The treated water is collected at the bottom of the structure and sent to a secondary clarifier.

Types of biofilters

Classic biofilters: with natural materials (gravel, crushed stone).

Contact biofilters: with modern synthetic materials (plastic granules, nets).

Drip biofilters: for uniform irrigation of the bed.

Advantages of biofilters

Simple design and operation.

Ability to treat large volumes of wastewater.

Energy efficiency (lower energy consumption compared to aerotanks).

Secondary clarifiers are structures for separating activated sludge or other suspended particles from treated wastewater. They are the final stage of aerotank or biofilter operation.

Main elements of a clarifier

Tank: reduces the flow velocity of water for particle sedimentation.

Sludge collection mechanisms: remove settled sludge from the bottom of the tank.

Water collection devices: for collecting treated water from the surface.

Principle of operation

Wastewater from aeration tanks or biofilters enters the tank.

Under the action of gravity, solid particles settle to the bottom.

The purified water is collected and sent for further use or discharge into a reservoir.

The settled sludge is pumped for treatment or reuse in aeration tanks.

Advantages of secondary clarifiers

Reduction of suspended solids in water.

Possibility of reusing activated sludge.

Increased overall efficiency of the treatment system.

Review questions:

1. What types of pollutants can be found in wastewater?
2. What is mechanical wastewater treatment and what are its main tasks?
3. What are the main methods of mechanical wastewater treatment that you know?
4. What types of sedimentation tanks are there, depending on their purpose?
5. What is the difference between primary and secondary sedimentation tanks?
6. What is biological wastewater treatment and what is it based on?
7. What methods of biological treatment do you know?
8. What is the difference between biological treatment in natural and artificially created conditions?
9. What are the advantages and disadvantages of irrigation fields and filtration fields?
10. What structures are used for biological wastewater treatment in artificially created conditions?
11. What is an aerotank and how does it work?

Lecture No. 14

TREATMENT AND DISPOSAL OF SEWAGE SLUDGE

Lecture plan

1 Types of sewage sludge, their general characteristics

2 Tasks and essence of sewage sludge treatment methods

3 Sludge thickening and concentration

4. Sludge disinfection and disposal

14.1 Types of sewage sludge, their general characteristics

Wastewater sludge (or slurry) is solid particles formed during the wastewater treatment process at treatment plants. They are produced as a result of sedimentation, filtration or other methods of removing pollutants from water. The main sources of these sediments are domestic, industrial and rainwater wastewater. Depending on the conditions of formation and separation characteristics, sludge is classified as primary or secondary.

Primary sludge includes coarse impurities that are in the solid phase and are separated from water by mechanical treatment methods such as screening, sedimentation, filtration, flotation, and centrifugal precipitation. Secondary sludge includes impurities that are initially present in water in the form of colloids, molecules and ions, but form a solid phase during biological or physical-chemical water treatment or primary sludge treatment.

Waste generated during the treatment of industrial wastewater at industrial enterprises, which includes wastewater sludge, is divided into four toxicity classes according to the degree of danger, depending on the place of its formation, appearance and consistency: extremely dangerous; highly dangerous; moderately dangerous; low danger.

This classification of the danger of chemical substances is based on their MPC in soil according to the calculated toxicity index.

Four classes of sludge are also distinguished according to their impact on the environment, which can be identified with the previous ones: toxic unstable organic and mineral sludge; toxic stable mineral sludge; inert unstable organic sludge; inert stable mineral sludge.

To justify the technology for processing and utilising sludge, information is needed on the various properties of sludge, including:

- sludge density ρ, kg/m3 – its mass per unit volume;
- concentration of the solid phase by volume (volume concentration) – the ratio of the volume of the solid phase to the initial volume of the analysed sediment sample;
- concentration of the solid phase by mass (mass concentration), characterised by the ratio of the mass of the solid substance to the initial mass of the selected sediment sample;
- specific concentration of solid phase mass, kg/m3;
- sediment moisture content in fractions of a unit or in percent, characterised by the ratio of liquid mass to total wet sediment mass;
- sediment ash content – characterises the content of non-volatile mineral impurities;
- granulometric composition of the solid phase of sediments;
- thermophysical characteristics of sediments;
- the chemical composition of sediments has a significant impact on their water yield. Thus, alkalis, compounds of iron, aluminium, chromium, and copper promote the intensification of sludge dewatering and reduce the consumption of chemical reagents for their coagulation before dewatering, while oils, fats, nitrogenous compounds, and fibrous substances, on the contrary, have an adverse effect on the sludge dewatering process. In addition, the sludge has a high level of bacterial contamination. It contains all the main forms of bacterial contamination (causative agents of stomach and intestinal diseases, helminth eggs, etc.), which poses a risk of infection;
- other indicators, including the calorific value of organic matter in sludge, electrical conductivity and electrokinetic properties of sludge, specific surface area, friability, volatile matter yield, chemical incombustibility, fuel properties of sludge, drying kinetics, the ability of sludge to compact in a centrifugal field and by filtration, etc.

Main types of sludge:

- Raw sludge: Formed during primary treatment when solid particles settle at the bottom of the sedimentation tanks.
- activated sludge: This is the biomass of microorganisms that is formed during biological treatment.
- stabilised sludge: Obtained after treating sludge, for example, in the process of anaerobic or aerobic fermentation, to reduce its volume and hazard.

14.2 Tasks and essence of sewage sludge treatment methods

The essence of sludge treatment is to meet the following requirements:

- sludge must not contain sources of harmful effects on the environment;
- sludge must not contain sources of disease for humans and animals;
- the aggregate state of solid sludge particles must correspond to the method and means of its disposal or elimination (in liquid, concentrated or dried form).

The main task of wastewater sludge treatment is to obtain a final product whose properties would ensure its disposal or minimise damage to the environment, and is carried out with the aim of reducing the volume of sludge and its disinfection.

The technological processes of wastewater sludge treatment can be divided into the following main stages:

- compaction (thickening);
- stabilisation of the organic fraction;
- conditioning;
- dewatering;
- thermal treatment;
- utilisation of valuable products;
- disposal of sludge.

14.3 Sludge thickening and concentration

Compaction is the most common method of reducing the volume of sludge. During the activity of microorganisms, the amount of activated sludge continuously increases, while excess activated sludge is formed, which is separated from the recirculation (which is sent to aeration tanks). Given the high humidity of excess activated sludge (up to 99.2–99.7%), it is necessary to compact it.

Usually, excess activated sludge is compacted, in some cases, a mixture of activated sludge and raw sludge, and quite rarely, raw sludge. Anaerobic fermented and aerobically stabilized sludge can also be compacted. Since the humidity of the compacted sludge decreases sharply, the volume of structures during its further processing also decreases.

The choice of the optimal compaction scheme is significantly influenced not only by the type of compactor, but also by the properties of the activated sludge.

3.1 Gravity compaction

Reducing the volume and humidity of sediments by gravity is achieved by their prolonged settling. The compaction of excess activated sludge is carried out in accordance with the laws of limited sedimentation of the suspension; its duration is 9–12 h, the humidity of the compacted sludge is 97%.

In the process of compacting activated sludge, only free water is removed. Compaction of activated sludge leads to a sharp increase in its specific filtration resistance and to an increase in the amount of bound water, which does not allow its humidity to be significantly reduced.

The mixture of sludge from aeration tanks is compacted faster than activated sludge from secondary clarifiers. Activated sludge from aeration tanks for incomplete biological treatment is compacted faster and better than from aeration tanks for complete biological treatment.

It has been established that the degree of sludge compaction depends on the duration of its stay in the compaction zone and the pressure in it. The duration of sludge stay in the compaction zone is determined by the dry matter load per unit surface of the sludge thickener – the specific surface load, measured in kg of dry matter per 1 m2 of the water surface per day. The specific surface load for gravity sludge thickeners is taken within 20–30 kg/m^2.day.

The process of compaction of excess activated sludge is negatively affected by the same factors that lead to a deterioration in the performance of secondary clarifiers: the release of gases as a result of sludge decay due to denitrification or changes in the temperature of the sediment.

Radial-type sludge thickeners are usually used, i.e. conventional radial clarifiers. At low-capacity stations, vertical sludge thickeners are used, which are arranged on the basis of conventional primary vertical clarifiers with a central pipe.

For vertical sludge thickeners, the estimated duration of compaction of excess activated sludge from secondary clarifiers is 10–12 h, from the lighting zone of aeration tanks-clarifiers – 16 h, from aeration tanks for incomplete biological wastewater treatment – 3 h. The humidity of the compacted activated sludge is 98%.

Radial clarifiers have certain advantages over vertical ones and allow compaction of sludge to a humidity of 97.3%. The estimated duration of compaction of sludge in radial clarifiers is: 5–8 h – for a mixture of sludge from aeration tanks; 9–11 h – for activated sludge from secondary clarifiers; 12–15 h

– for activated sludge from the lighting zone of aeration tanks-clarifiers.

The operation of sludge thickeners can be intensified both by improving the properties of the compacted sludge (by chemical coagulation or heat treatment), and by equipping the sludge thickeners themselves with rod mixers.

Preliminary heat treatment leads to the destruction of the hydrate shell that envelops solid particles of the sludge, as a result of which the process of its compaction is significantly intensified. After the sludge is aged at a temperature of 70-90°C for 30 minutes, it is compacted in a thermogravimetric sludge thickener to a humidity of 96.7% for 30-60 minutes. By design, a thermogravimetric sludge thickener is similar to a conventional vertical sludge thickener, inside which is placed a chamber for heating the sludge with steam. To prevent heat loss, sludge thickeners are arranged closed and insulated.

Among the advantages of the structure, it should be noted that simultaneously with compaction, sludge sterilization also occurs in it. However, due to the high cost of the process, thermogravimetric compactors have found application only in technologies for sludge utilization as a feed additive.

14.3.2 Flotation sealing

During flotation compaction of sediments, the release of moisture from the structural voids of activated sludge is intensified at the level of surface phenomena. Air, introduced in the form of small bubbles, interacts with bound water on the surface of sludge particles, displacing and transferring it to a free state. The use of flotation allows for 10–20 min. to achieve the same degree of sludge compaction as after its gravitational compaction for 2 hours.

Excess activated sludge is fed to the upper part of the chamber, and the working fluid saturated with air is fed to the lower part. The working fluid is treated wastewater after secondary settling tanks or sludge water leaving the flotation chamber. Sludge and working fluid are evenly distributed over the area of the chamber using radial distribution pipes with holes with a diameter of 5–10 mm, which are arranged on top in sludge pipes, and on the side in working fluid pipes (the liquid exit velocity from the holes should be 0.7–1.0 and 1.8–2.3 m/s, respectively). Sludge water is removed from the lower part of the flotation chamber. Sludge accumulating on the surface is periodically (after 3–4 hours after reaching a humidity of 94.5–95%) discharged to the sludge discharge tray using a spiral scraper. The height of the working zone of the flotation chamber (between the sludge and working fluid distribution pipes) is taken as 2–3 m, and its volume is determined by the duration of the stay of the mixture of sludge and working fluid in it (taken as 40–60 min.). The height of the sludge layer is usually taken as 0.3–0.7 m; the same height should be the protective zone between the sludge and the sludge distribution pipes. The volume of the sludge water zone (between the working fluid distribution pipes and the sludge water discharge holes) should be 20–40% of the volume of the working zone, but its height should be at least 1 m. The actual concentration of suspended solids in the sludge water is 80–100 mg/dm3.

In addition to excess activated sludge, other types of sediments and their mixtures are subjected to flotation compaction.

Pre-treatment of sediments with flocculants allows you to reduce the moisture content of the treated sludge from 95–96% to 94–95% and increase the efficiency of dry matter retention to 95–99%.

The main advantages of flotation sludge thickeners compared to gravity ones are a shorter duration of the compaction process, their smaller size, lower humidity of the compacted sludge and its significantly smaller volume, which allows to reduce the volume of structures for further sludge treatment. However, flotation sludge thickeners also have significant disadvantages: high electricity consumption by flotation pumps, a certain complexity of design and operation, the need to place flotation sludge thickeners in a building for convenient operation in winter.

14.3.3 Centrifugal seal

Centrifugal compaction of sludge suspensions is carried out in compact high-performance separators or centrifuges. The speed of separation of suspensions is 1000 times higher than with gravitational compaction.

Separators with disc inserts have found application. After entering the separator and entering the space between the plates, sludge particles are exposed to the action of two components of centrifugal force: a force acting perpendicular to the plate surface and pressing the particles to it, and a force directed along the plate, under the action of which the particle slides down the plate. The clarified sludge (fugate) moves upwards in the space between the plates and is removed through the upper annular gap. The compacted sludge, which slides off the separator plates, is collected in the sedimentation space and is continuously discharged through small-diameter nozzles in the wall of the drum body.

Self-unloading separators are divided into two main groups: with continuous and pulsating sediment removal. In separators with continuous sediment removal, the latter is removed together with part of the liquid phase through nozzles in the form of a concentrated heavy fraction.

In separators with pulsating sediment removal, the latter is thrown out of the drum when the moving element moves, which opens the unloading slots on the periphery of the drum.

When completely unloaded, the sediment supply to the separation is periodically stopped, the unloading slots of the drum are opened, and all its contents, i.e. the separated sediment and the liquid phase, are thrown into the receiver.

The main design factors that significantly affect the efficiency of the separation process: the drum rotation frequency, the dimensions of the drum and plates, the distance between the plates.

The use of plate separators allows you to compact the sludge to a concentration of 40–60 g/^{dm3} with an average dry matter retention efficiency of 97%. However, even with preliminary filtration of sludge through sieves or drum screens, the operation of separators is greatly complicated due to frequent clogging of the separator nozzles. Sludge compaction in centrifuges has not found wide application due to the formation of a large amount of poorly dewatered sludge, although this method allows obtaining compacted sludge with a concentration of 60–70 g/dm^3 with a dry matter retention efficiency of 85–93%.

14.4 Decontamination and disposal of sludge

Municipal sewage sludge contains a significant number of microorganisms (including pathogenic ones), viruses, helminth eggs, salmonella, and therefore is dangerous in terms of sanitation and infection. In this regard, the sludge must be disinfected.

4.1 Thermal and biothermal disinfection

Disinfection of liquid sediments by heating to a temperature of 100 °C with exposure for several minutes ensures the death of helminth eggs and the death of pathogenic microorganisms. At temperatures of 52–56 °C for 5 minutes. many pathogenic bacteria die, at a temperature of – 62–74 °C and an exposure duration of about 30 minutes. viruses die. Disinfection and helminthization of raw, mesophilically fermented and aerobically stabilized sediments should be carried out by heating them to 60 °C for at least 20 minutes. However, as the results of the studies have shown, for complete neutralization of pathogenic bacteria and helminth eggs at a temperature of 60 °C, the duration of exposure should be at least 4 hours. Neutralization of sediment with an exposure duration of 20 minutes. is ensured at temperatures above 75 °C.

Deworming of sludge, i.e. destruction of helminth eggs, is carried out both in liquid and mechanically dehydrated sludge. Liquid sludge is the easiest to deworm: hot steam is introduced into it and the entire mass of sludge is mixed to heat it to a temperature of 60-65 °C.

Biothermal treatment (composting) of sewage sludge. The effectiveness of the biothermal process depends on the physicochemical composition of the sludge, the conditions of the vital activity of microorganisms, the type of fillers, the conditions of aeration, homogenization and heat and mass transfer. The composting process consists of two phases. The first phase lasts for 1–3 weeks and is accompanied by intensive development of microorganisms, and the temperature of the sludge rises to 50–80 °C. At the same time, the sludge is disinfected and its mass is reduced.

The second phase - compost maturation - is longer. It lasts from two weeks to 3–6 months. and is accompanied by the development of simple and arthropod organisms, a decrease in temperature to 40°C and below. An increase in the ambient air temperature intensifies the process of decomposition of organic matter.

14.4.2 Chemical decontamination of sediments

Chemical disinfection of sediments is carried out in case of their further use in agriculture as organic fertilizer. Ammonia, thiazone, formaldehyde and urea are used for chemical disinfection of sediments. The residual content of these substances in the sediments prevents the reactivation of pathogenic microorganisms and maintains the stability of the sediments.

14.4.3 Sediment removal

Wastewater sludge disposal is used in cases where disposal is impossible or economically inexpedient.

Incineration is one of the most common methods of wastewater sludge disposal, which is the most effective means of ensuring maximum reduction in the volume of sludge and its disinfection. Incineration of wastewater sludge allows for the complete elimination of the organic part of the sludge; the inorganic part remaining after incineration has a minimal volume and is completely sterilized.

Control questions

1. What is sewage sludge?
2. What are the main sources of sewage sludge formation?
3. What types of sewage sludge are divided into depending on the conditions of formation?
4. What is primary sludge?
5. What is secondary sludge?
6. How are sewage sludge classified by toxicity?
7. What are the main indicators that characterize sewage sludge (density, humidity, etc.)?
8. How does the chemical composition of sludge affect its water yield?
9. What is the main task of sewage sludge treatment?
10. What are the main stages of sludge treatment?
11. What does the technological cycle of sewage sludge treatment include?
12. What are the main methods of sludge compaction?
13. What is the essence of gravity compaction?
14. What are the advantages of flotation sludge compaction compared to gravity?
15. How is sludge compaction carried out in centrifuges?
16. What methods of sludge decontamination are used in modern technologies?
17. What is thermal sludge decontamination?
18. What stages does the process of biothermal sludge composting include?
19. What is chemical sludge decontamination used for?

20. What are the advantages and disadvantages of sludge incineration as a method of their elimination?

Lecture No. 15
SAMPLING, PRESERVATION AND STORAGE OF SAMPLES FOR LABORATORY AND TECHNOLOGICAL ANALYSIS OF WATER

Lecture plan:

1. Requirements for water sampling
2. Preservation of water samples
3. Devices for sampling and preparation of water samples

15.1 Requirements for water sampling

The current Instructions for sampling, preparation of samples and soil were approved by Order No. 30 of the State Emergency Service of Ukraine dated 19 January 2016. It establishes the procedure for sampling and preparation of samples.

There are specific requirements for water sampling, according to which:

- the water sample taken for analysis must reflect the conditions and location of its collection;
- sampling, storage, transportation and handling must be carried out in such a way that there are no changes in the content of certain components or in the properties of the water;
- the volume of the sample must be sufficient and must correspond to the analysis method used.

Depending on the purpose of the analysis, different types of sampling are distinguished. For example, single or serial sampling is used.

In the case of single sampling, a sample is taken once at a specific location and the result of a single analysis is considered. This method is used in rare cases when the results of a single analysis are sufficient to judge the quality of the water being tested.

A simple sample is obtained by collecting the entire required amount at once.

A mixed sample is obtained by combining simple samples of equal volume taken from the same place several times in succession at regular intervals or collected simultaneously from different places of the object under investigation.

An average sample is usually prepared by mixing equal parts of samples taken at regular intervals.

If these conditions are not met, a so-called average proportional sample is prepared by mixing different volumes of simple samples, taking into account the different concentrations of the component to be determined in the simple samples being mixed. For example, preliminary studies have established that the concentration of a certain component in the middle part of the reservoir is half that near the right bank and three times less than near the left bank. Then, the average proportional sample is prepared by mixing volumes of water from the middle part of the reservoir (V1), near the right (V2) and left (V3) banks in a ratio of V1 : V2 : V3 = 1.00 : 0.50 : 0.33. The average proportional sample characterises the average chemical composition of water over a certain period of time; it is not recommended to prepare it for more than one day.

Sampling water from rivers and streams. Water samples are taken at the fastest flow points - the fairway, unless a specific task is set. Samples should not be taken from stagnant water in front of or immediately behind a dam or in dead arms. When mixing the waters of two rivers or river water with wastewater, samples for analysis should be taken at points where the water masses are completely mixed, which are determined by special hydrological studies. Samples are taken at a depth of 20-30 cm from the water surface. From large rivers, samples are taken at specific sections of the water area and depths, depending on the purpose of the analysis.

Sampling from reservoirs, lakes and ponds. Water samples are taken at fixed points located throughout the water area, usually at two depths: near the surface (0.2-0.5 m) and near the bottom (0.5 m). At intermediate depths, samples are taken depending on thermal stratification and in the case of special studies.

The frequency of sampling depends on the physical and geographical characteristics of the water body and its anthropogenic load. In addition, it is also determined by the importance of the water body for economic activity and the conditions of its exploitation. Based on a complex of various factors that influence the formation of the chemical composition of surface waters in Ukraine, the points and frequency of hydrochemical observations are divided into four categories (Table 15.1).

Table 15.1 – Programme of hydrochemical observations at water bodies in Ukraine

Sampling frequency and number of observation points	Category of point			
	I	II	III	IV
1	2	3	4	5
Daily	Programmes A, B, C, D, E, F, Y, S			
Every ten days		Programmes A, C, D, E, F, Y, S		
Monthly			Programmes A, B, C, D, E, Y	
During major hydrological phases				Programmes A, B, C, D, E, Y

Note: A - temperature, hydrogen index (pH), dissolved oxygen (O_2), oxygen saturation percentage (% O_2), biochemical oxygen demand (BOD_5), suspended solids, flow rate, water level;

B - hydrogen sulphide (H_2S); C - colour, transparency, odour, carbon dioxide (CO_2), hardness, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), bicarbonates (HCO_3), sulphates (SO_4^{2-}), chlorides (Cl^-), phosphates (PO_4^{3-}), total phosphorus (Ptotal), silicon (Si), mineralisation; D - nitrate nitrogen (NO_3^-), nitrite nitrogen (NO_2^-), ammonium nitrogen (NH_4^+); E - chemical oxygen demand (COD), phenols, petroleum products, anionic synthetic surfactants (ASPAR), chromium-6 (Cr(VI)); F - organochlorine pesticides (OCP): α-HCH, γ-HCH, DDT, DDE, HCB, trifluralin; Y - manganese (Mn_2^+), total iron (Fe), copper (Cu^{2+}), zinc (Zn^{2+}); S - permanganate oxidisability (PO).

Water sampling for chemical analysis is performed in a specific sequence. The label of each sample must indicate: the sampling point in accordance with the Observation Programme; the section, vertical, horizon; the filtering and preservation of the sample (e.g., filtered, 12 cm3 of nitric acid), the used filter is attached to the sample; the type of analysis. The accompanying documents must be filled out legibly, in full, without errors or corrections. Measurements are taken directly at the water body, and the results are recorded in form KG-9.

The procedure for checking, taking water samples and analysing them is approved by Resolution of the Cabinet of Ministers of Ukraine No. 828 of 21 August 2019.

15.2 Preservation of water samples

The purpose of preserving water samples is to preserve the components determined in the water and its properties in the state in which they were at the time of sampling. At the same time, it is necessary to comply with the conditions set for their preservation (Table 15.2).

Table 15.2 – Conditions for preserving water samples

Component	**Sample preservation conditions**
Aluminium	Samples are taken in acid-washed bottles. The determination is carried out, if possible, no later than 2 hours after sampling; 5 ml of HCl is added per 1 litre of sample (if necessary).
BOD	Cannot be preserved; samples are stored at a temperature of 3-4 °C; processed no later than one day after collection.
Suspended solids	Samples should not be preserved; testing should be carried out no later than one day after collection. Store at a temperature of 3-4 °C.
Taste and odour	Samples cannot be preserved; samples cannot be taken in plastic bottles. The determination must be carried out no later than two hours after sampling.
Humic substances	Samples cannot be preserved; they must be processed no later than three days after sampling.
Iron	Total iron content: add 25 ml of HNO_3 solution per 1 litre of water.

Odour	Samples cannot be preserved; testing must be carried out no later than two hours after sampling, but no later than the end of the sampling day.
Nitrates	The determination is carried out on the day of sampling or by adding 1 ml of H2SO4 per 1 litre of sample. The sample is cooled to 3-4 °C or 2-4 ml of HCl_3 is added per 1 litre of sample.
Chlorine	Samples cannot be preserved; they are collected in dark glass containers, protected from sunlight and shaking. The determination must be made immediately after sampling.
Alkalinity	Samples cannot be preserved. Determinations are carried out immediately at the sampling site. The bottle is filled to the top with the sample and analysis begins no later than 24 hours later.

The determination must be carried out:

- immediately at the sampling site or in a laboratory, if it is located near the sampling site;
- as soon as possible, no later than 2 hours after sampling;
- on the same day; analysis shall commence on the day of sampling, no later than 12 hours after sampling.

15.3 Devices for sampling and preparation of water samples

An important stage in water analysis is sampling. Water sampling devices are used for sampling water – various designs of bathometers and glasses and bottles with caps that can be closed. Pumps with suction cartridges can be used.

For stationary observations, water samples for chemical analysis should be taken at a depth of 0.2-0.5 m. In deep channels and weak currents, it is more appropriate to take samples at different depths. Samples are mainly taken with a 10-litre enamel bucket. The bucket is used to fill vessels for determining the pH, oxygen and carbon dioxide content in the water, to record the oxygen dissolved in the water, and to fill bottles for subsequent analysis in the laboratory. Samples for determining the concentrations of petroleum products, phenols, surfactants, heavy metals, and pesticides are taken in separate bottles.

Special devices are also used to take samples at different depths - various types of bathometers. A bathometer must meet the following requirements:

- water passing through it must not be retained in it;
- it must close tightly;
- the material of the sampler must be chemically inert.

In practice, horizontal, flip-type and automatic bathometers are widely used. The Molchanov bathometer (Fig. 15.1) is used to collect water samples to determine the pesticide content:

Figure 15.1 – Molchanov's batometer

Sampling at significant depths (20-30 m) is carried out using Rutner's batometer (Fig. 15.2):

Figure 15.2 – Router's batometer

Polyethylene and glass containers are used to store samples. Before use, the containers are washed with concentrated acid and rinsed with tap water. The main requirements for containers are strength, resistance to dissolution and tightness of closure. Samples are preserved when sampling for unstable components. These samples are analysed no later than 3 days after sampling. Samples are stored at a temperature of 3–5 ºC in a refrigerator. In winter, at temperatures below 0 ºC, the sampled sample is transferred to a warm room where the analysis is carried out.

The devices commonly used in the third stage – preparation of water samples – are typically standard laboratory equipment (centrifuges, extruders, extractors, evaporators), which are used to separate and concentrate samples, increasing the sensitivity and selectivity of the subsequent analysis. It is also possible to use flowinjection concentrating attachments that operate in automatic mode, such as the PPI-M and PPI-N types, in the sample preparation process. Special sample preparation devices are used to increase the selectivity of the analysis and eliminate interfering influences. Examples of such devices are autoclave modules for chemical sample preparation of the MKP-04 and MKP-05 series, which include a thermostat for heating 6 or 10 autoclaves, a set of autoclaves themselves with fluoroplastic reaction chambers, and devices for controlling the heating and cooling temperature regimes. The MKP-04 and MKP-05 analytical autoclave sample preparation modules with resistive heating are currently the most technically advanced and affordable chemical sample mineralisation equipment available to domestic users.

Microwave autoclave mineralisers from Perkin Elmer (Fig. 15.3) and SEM (USA), Milestone (Italy), and Prolabo (France) are widely used in global analytical practice. Microwave autoclave mineraliser from Perkin Elmer (USA).

Figure 15.3 – Microwave autoclave mineraliser

Another example of sample preparation equipment is the FK-12M ultraviolet chamber for express preparation of water samples, which works by photolytic oxidation of interfering organic compounds under the action of UV radiation.

The next and most important stage of the technological cycle of eco-analytical control of water is quantitative analysis, which is mainly carried out on universal stationary laboratory equipment using various measuring instruments (chromatographs, spectrophotometers, spectrometers, spectrographs, etc.).

Among the wide variety of technical means of water control, special attention should be paid to a group of devices that are currently becoming increasingly important and widely used – devices based on electrochemical methods of analysis. From a practical point of view, their use in water monitoring has a number of significant advantages. First of all, they are portable and relatively easy to maintain, which allows analyses to be performed not only in laboratory conditions, but often directly at the sampling site. Another advantage is their high cost-effectiveness: low reagent consumption (mainly for auxiliary purposes), low equipment cost (several times, and sometimes dozens of times cheaper than chromatographic and spectral instruments). At the same time, as a rule, the high specificity and sensitivity of the analysis is maintained.

In the modern domestic market of eco-analytical equipment, electrochemical devices (ED) are mainly represented by pH meters, ion meters in combination with ion-selective electrodes, conductometers and oximeters. Electrochemical devices based on the principles of potentiometry have the best characteristics.

Control questions

1. What are the requirements for water sampling, types of water sampling?
2. What is water sample preservation and what are the conditions for their preservation?
3. Instructions for sampling and preparing water samples for chemical and hydrobiological analysis.
4. General rules of operation and safety precautions for those working in a chemical laboratory. Chemical glassware.
5. Sampling, storage and transportation of water samples.
6. Determination of organoleptic indicators of water quality (smell, taste, colour, turbidity).
7. Determination of water pH by potentiometric method.
8. Neutralisation method. Preparation and standardisation of working solutions.
9. Determination of water acidity and alkalinity.
10. Determination of carbonate acid forms and carbonate hardness of water.
11. Determination of total water hardness, calcium and magnesium ion content.
12. Determination of the content of sulphate ions in water.
13. Determination of the content of chloride ions in water by the Moore method.
14. Conductometric method for determining the salt content of water.
15. Determination of the content of total iron.
16. Determination of the content of mineral nitrogen-containing substances in water.

16\. Determination of the content of sodium ions by the potentiometric method.

18. Determination of permanganate oxidisability of water using the Kübel method.
19. Determination of dissolved oxygen content in water using the Winkler method.

Lecture No. 16
ORGANISATION OF WATER QUALITY AND PROPERTIES CONTROL

Lecture plan:

1. Methods and regulatory requirements for water quality assessment
2. Key elements of laboratory and production control at treatment facilities
3. Key points in the technological chain for sampling for analysis
4. Laboratory and production control system at treatment facilities
5. Safety precautions when performing hydrochemical work

16.1 Methods and regulatory requirements for water quality assessment

When assessing water quality based on the results of chemical analysis of samples, it should be remembered that the Resolution of the Cabinet of Ministers of Ukraine 'On the recognition of sanitary legislation acts as invalid and not applicable on the territory of Ukraine' dated 20 January 2016 No. 94-r, sanitary legislation acts issued by the central executive authorities of the Ukrainian SSR and the USSR, including their officials, which approved sanitary, sanitary-hygienic, sanitary-anti-epidemic, sanitary-epidemiological, anti-epidemic, hygienic rules and norms, state sanitary-epidemiological standards and sanitary regulations.

Assessing water quality based on the results of chemical analysis of samples requires a clear understanding of the purposes for which it is performed. Accordingly, regulatory documents or methodologies governing the content of chemical components in water are selected. For example, it is incorrect to compare the results of chemical analysis of water samples taken from a river or lake with a regulatory document relating to drinking water. After all, drinking water undergoes appropriate technological preparation, so to speak, it becomes a product that is 'prepared' at a water supply station from water taken from a natural water body. The essence of this treatment is to purify natural water to the level required for drinking water. Therefore, it is advisable to evaluate the chemical analysis data of water samples from a water body in accordance with the regulations concerning water supply sources or from an environmental or other perspective.

The quality of water in water bodies that have already become or may become water supply sources is assessed in accordance with DSTU 4808:2007 'Sources of centralised drinking water supply. Hygienic and environmental requirements for water quality and selection rules'. In this standard, the range of chemical, microbiological and hydrobiological indicators of water quality in centralized drinking water supply sources (separately for surface and groundwater) is divided into four classes: Class 1 – excellent, desirable water quality; Class 2 – good, acceptable water quality; Class 3 – satisfactory, acceptable water quality;

Class 4 – mediocre, limited suitability, undesirable water quality.

The quality of water from the water supply network, wells and source catchments, bottled water, from bottling points or from drinking fountains. The quality of drinking water in Ukraine is regulated by two main documents: State Sanitary Rules and Regulations DSanPiN 2.2.4-171-10 'Hygienic requirements for drinking water intended for human consumption' and DSTU 7525:2014 'Drinking water. Requirements and methods of quality control'.

The quality of water in water bodies at points of domestic and cultural-domestic water use. The quality of water in water bodies used for domestic and cultural purposes is assessed in accordance with the 'Hygienic requirements for the composition and properties of water in water bodies at points of domestic and cultural water use', which are Appendix 11 to the 'State Sanitary Rules for the Planning and Development of Settlements' (DSP 173-96), approved by Order of the Ministry of Health of Ukraine No. 173 of 19 June 1996, as amended by Order of the Ministry of Health of Ukraine No. 952 of 18 May 2018.

Water quality of water bodies used for fisheries. In order to establish the water quality of water bodies used for fish farming, the "Environmental Safety Standards for Water Bodies Used for Fish Farming Regarding Maximum Permissible Concentrations of Organic and Mineral Substances in Sea and Fresh Water (Biochemical Oxygen Demand – BOD5, Chemical Oxygen Demand – COD, suspended substances and ammonium nitrogen)", approved by Order of the Ministry of Agrarian Policy of Ukraine No. 47 dated 30 July 2012. This document specifies the maximum permissible concentrations of organic and mineral substances (BOD_5, COD, suspended solids, NH_4^+, PO_4^{3-}) for: marine waters; natural fresh waters; fish ponds.

By Resolution of the Cabinet of Ministers of Ukraine dated 19 September 2018 No. 758 approved the 'Procedure for State Water Monitoring,' which implements the provisions of the European Union Water Framework Directive regarding the environmental monitoring of water bodies based on hydromorphometric, hydrobiological, and hydrochemical indicators.

The 'List of pollutants for determining the chemical status of surface and groundwater bodies and the ecological potential of artificial or significantly altered surface water bodies' with 45 indicators was approved by Order of the Ministry of Ecology and Natural Resources No. 45 dated 6 February 2017.

State water monitoring is carried out to ensure the collection, processing, storage, summarisation and analysis of information on the state of water bodies, to forecast changes in it and to develop scientifically sound recommendations for decision-making in the field of water use, protection and restoration of water resources. State water monitoring is an integral part of the state environmental monitoring system.

16.2 Key elements of laboratory and production control at treatment facilities

Laboratory and production control is divided into several elements:

- control of water quality at treatment facilities;
- control of water quality at all stages of treatment, including water supplied to consumers;
- control of the quality of reagents delivered to the station;
- control of the technological parameters of feed materials;
- control of the quality of mixing, dissolving and dosing of reagents.

16.3 Key points in the technological chain for sampling for analysis

Samples for analysis at stations with a full range of water treatment facilities are taken at the following points:

- before the mixer or at water intake points (raw water, not treated with reagents);
- at the end of the mixer (water treated with chlorine, coagulants, lime and other reagents);
- at the end of the reaction chambers (water containing coagulated flocs of suspension);
- after each sedimentation tank or clarifier (clarified water);
- before filters and contact clarifiers;
- after each filter or contact clarifier (filtered water);
- in clean water tanks (purified water that has undergone secondary chlorination, ammoniation and other types of treatment);
- in water pipes through which purified water is supplied to consumers.

16.4 Laboratory and production control system at treatment facilities

The laboratory and production control system at treatment facilities consists of the following groups:

- sampling; determination of physical indicators and physical and chemical properties of liquids; determination of nitrogen content in various forms (total, nitrites, nitrates, etc.), phosphates, sulphides and chlorides;
- wastewater sludge analysis laboratory, consisting of the following groups: sampling; quantitative analysis of suspended solids and activated sludge; analysis of the chemical composition of sludge, activated sludge, sand, and waste;
- a sanitary and hygienic assessment laboratory, consisting of the following groups: bacteriological; helminthological; hydrobiological;
- a group for the technological assessment of the operation of a specific

treatment facility.

16.4.1 List of analyses performed in treatment plant laboratories

The list of analyses performed in treatment plant laboratories is as follows:

The first laboratory must perform all physical and chemical analyses that provide information about the concentration and daily amount of pollutants entering the treatment plant and assess the suitability of wastewater for biological treatment. In addition, the first laboratory prepares data on the efficiency of treatment at individual facilities and the station as a whole, as well as on the characteristics of treated water.

The second laboratory analyses the quantity and quality of waste, sand, raw sludge from primary sedimentation tanks, sludge fermented in methane tanks and dried on sludge beds, and activated sludge.

The third laboratory performs bacteriological, helminthological and hydrobiological studies of samples received from wastewater, sludge fermented in methane tanks and dried on sludge beds, activated sludge (in aerotanks) or films (in biofilters); treated wastewater and reservoirs at the point of discharge of treated water.

The technological assessment group collects all the results of analyses provided by analytical laboratories and processes them; measures or controls operational measurements of wastewater, sludge, activated sludge, steam, compressed air and electricity consumption; calculates the specific characteristics of the main parameters (aeration intensity, specific consumption of electricity, air, steam, etc.), working loads by volume, surface area per sludge, etc.

16.4.2 Material and technical support for laboratory and production control

The minimum dimensions of the laboratory premises are as follows: chemical room 20 m², weighing room 6 m², bacteriological room 20 m² with a medium storage and washing room 10 m², storage room 6-10 m², head's office 8-10 m², a cloakroom is desirable.

Laboratories must be equipped with:

- water supply and sewage systems;
- electricity;
- heating and ventilation systems;
- laboratory furniture and equipment;
- reagents (storage);
- first aid kit.

It is desirable to have a side table in the laboratory with a set of hand tools: pliers, wire cutters, vices, rasps, files, drills, a blowtorch, and foot warmers.

It is desirable to have large heating devices: a thermostat, a drying cabinet and an autoclave. These devices should be located near the entrance.

16.5 Safety precautions when performing hydrochemical work

When performing hydrochemical work, it is necessary to strictly adhere to safety regulations, a detailed description of which is provided in the relevant instructions. Even when working very carefully, it is possible to cut your hands with glass, burn yourself with hot objects, acids, alkalis, or get corrosive reagents in your mouth. Therefore, everyone working in the laboratory must know and follow safety rules, be able to use heating devices, glassware, reagents and solutions, and be attentive and careful while working.

Employees in a hydrochemical laboratory must wear a lab coat and have two towels – one for hands and one for dishes. The same towel cannot be used to wipe hands and dishes, especially when working with harmful substances. It is necessary to keep hands clean and wash them every time a certain substance gets on them.
Ventilation in the laboratory and fume cupboard must be monitored, and work must not be carried out if ventilation is poor.

A first aid kit must be installed in an accessible place in the laboratory, which must contain individual packets, cotton wool, boric acid in crystal form and in solution (2%), iodine tincture, BF-6 glue, potassium permanganate, acetic acid solution (2%), adhesive plaster, burn ointment, sodium bicarbonate solution (5%), ammonia, tweezers, scissors, eye wash cup, etc.

Rules for working on water (necessary to know when taking samples). The most dangerous work is on water bodies during the ice drift and unstable ice cover. Persons taking samples on water must be able to swim and row. In the event of an accident on water, it is important to remember that you must immediately get rid of unnecessary items and clothing; do not swim from an overturned boat to the shore, but hold on to the boat and swim to the shore with it; to prevent the rescue boat that has approached from capsizing, do not climb into it over the side, but do so from the stern.

Working with glass. Chemical glassware is usually thin-walled, so you need to be careful with it, because if you're not careful, you could get hurt. Chemical glassware should be held carefully in your hands, without squeezing it too tightly with your fingers. When washing dishes with brushes or glass sticks, be careful not to puncture the bottom or sides.

When cutting glass tubes, sticks, or opening ampoules, protect your hands with a towel. In the event of a small cut with glass, remove the glass splinters, wash the blood around the wound with a cotton swab moistened with a solution of potassium permanganate, apply iodine and bandage or cover with adhesive tape. For small cuts, cover the wound with BF glue (for treating microtraumas).

For deep arterial wounds, after removing the glass, tightly bandage the arm above the cut with a tourniquet, wipe the blood around the wound, apply several layers of sterile gauze, then a thick layer of absorbent cotton wool, and call a doctor.

Working with electrical appliances. When working with electrical appliances (electric hotplates, lighting devices, pH meters), prevent sparking of contacts, carefully insulate electrical wires, and prevent water from getting into them. Place asbestos or a ceramic plate under the electric hotplate. All malfunctions should be repaired only after disconnecting the power supply. If the power supply to the laboratory is interrupted, all electrical appliances must be turned off. Leave one control lamp on.

Working with reagents. It is very important to know the chemical compounds that a hydrochemist has to deal with.

When working with liquid acids, it is important to remember that they can cause severe chemical burns that are difficult to heal. Particular care should be taken when transferring acids from large containers. Bottles containing acids and other liquids should be placed in woven baskets and stored in special racks. When transferring and diluting large quantities of fuming acids (hydrochloric acid, nitric acid), wear a respirator or cover your nose and mouth with a gauze bandage moistened with a soda solution, and be sure to wear safety goggles. Small quantities of acids may only be transferred in a fume hood.

When diluting acids, always remember that the acid should be added to water, not vice versa.

If strong acids (nitric, hydrochloric, sulphuric, chromic mixture) come into contact with the body, the affected area should first be washed with plenty of water and then with a 5% solution of sodium bicarbonate. In case of hydrofluoric acid burns, the affected area should be thoroughly rinsed with water for 4-6 hours until the white surface of the burn turns red. Then, a freshly prepared paste of magnesium oxide in glycerine should be applied to the affected area.

For alkali burns, the affected area should also be washed with plenty of water, followed by a 2% solution of acetic acid.

When dissolved in water, alkalis heat up significantly, so they should be dissolved in porcelain dishes – first concentrated solutions, and after cooling, diluted to the required concentration.

If an alkaline solution of iodic acid gets into the mouth, rinse the mouth first with water, then with a 2% solution of boric acid until the soapy taste in the mouth disappears, and then again with water. Then lubricate the mouth with edible fat.

If a solution of silver nitrate enters the mouth, it must be rinsed with a large amount of sodium chloride solution.

Cases of poisoning with reagents in laboratories where all safety measures are in place are extremely rare, but they cannot be ruled out, so it is necessary to know how to provide first aid before the doctor arrives.

In case of poisoning, the following substances should be administered to the victim's stomach:

- soapy water, magnesia, soda, limestone water, milk, liquid flour dough, mucous decoctions in case of acid poisoning (hydrochloric, sulphuric, acetic, oxalic);
- citric acid, 5% acetic acid in case of alkali poisoning (caustic alkalis, potash, ammonia, soda);
- egg white, large quantities of milk in case of salt poisoning (silver nitrate, nitrates, copper salt, mercury, lead);
- starch with water, astringent tinctures, strong tea or coffee in case of iodine poisoning.

When working with reagents and solutions, always remember that pipettes should only be filled with solutions of acids, alkalis and other substances using a pear or a balloon pipette. Work with harmful and poisonous substances must be carried out only under conditions of ventilation, observing all safety precautions.

Work with heating devices. All heating devices must be installed on a heat-insulating stand. Careless handling may result in burns from the appliance itself, heated glassware, crucibles, etc., so do not pick up hot dishes with bare hands. Usually, heated objects are taken with tongs, flask holders, or a towel tourniquet, but it is more convenient to use rubber oven mitts.

It is necessary to closely monitor the operation of heating appliances, without leaving them unattended.

Fire extinguishers, asbestos, koshma, sand, and a fire hydrant must always be available in the laboratory. Only substances or materials that are water-soluble or heavier than water may be extinguished with water. It is absolutely unacceptable to extinguish oil, kerosene, etc. with water.

In case of first-degree burns (redness), the burned area should be immersed in a solution of potassium permanganate, the concentration of which is higher the more severe the burn. You can also use ointments for burns.

In case of second-degree burns (blisters), treat the burned area with potassium permanganate or a 5% tannin solution.

In case of third-degree burns (tissue destruction), cover the wound with a sterile dressing and call a doctor.

Control questions

1. What are the main elements of laboratory and production control at

wastewater treatment plants?

2. What are the main points of the technological chain for sampling analyses?

3 What are the types of sanitary and environmental analysis of water?

4. What is the schedule of laboratory and production control used at sewage treatment plants?

5. What is the system of laboratory and production control at treatment plants?

6. What is the nomenclature of analyses used in the laboratories of treatment plants?

7. What is the material and technical support for laboratory and production control?

8. What regulatory documents govern the quality of drinking water in Ukraine?

9. What is controlled at the stage of reagent dosing in the water treatment process?

10. What is the purpose of quality control of reagent mixing?

11. At what points in the technological chain is water sampling carried out for analysis?

12. Why is it important to take water samples before and after each filter?

13. What are the main analyses carried out to assess the quality of water in wastewater treatment plants?

14. Why is it important to analyse the composition of sludge in wastewater treatment plants?

15. Why is it important to provide the laboratory with ventilation systems?

16. What rules should be followed when working with acids?