Vladimir Kolesnikov
Elena Vilson

MODERN DEVELOPMENT OF OPERATION PROCESSES OF SEWAGE PURIFICATION AT COMBINED INSTALLATIONS

“To recommend the materials of the book for usage during designing and construction of the water disposal systems in settlements, cities and industrial enterprises”.

Minutes No. 101 of the Academic Council
of the State Unitary Enterprise of the Academy of Public Services
after K.D. Pamfilov of September 28, 2004.

Rostov-on-Don, 2006

UDK 628.16; 628.32
BBK 38.761.2
K60

Vladimir Kolesnikov, Elena Vilson
K60 Modern development of operation processes of sewage purification at combined installations: Edited by Academician of Housing and Public Services V. K. Gordeev-Gavrikov – Rostov-on-Don: Yug Publishing House, 2006. – 213pp.

ISBN 5-88094-069-1

The volume contains the abridged consideration of the principles of the sewage biochemical purification. The modern methods of biodegradation of pollutants in aerobic and anaerobic installations of biological purification are considered. The theoretical and practical aspects of the combined works (CW) operation are stipulated; the CW have been designed in the Rostov-on-Don Scientific Research Institute of the Academy of Public Services after K.D. Pamfilov and will enable to solve the most burning issues of the sewage purification, including purification of concentrated and strong sewage. The results of research in integrated purification of sewage from organic substances and biogenic elements are given. The calculation algorithms of the CW and the examples of the process flow schemes for the 5 – 100,000 m^3/day household sewage purification installations are presented, as well as designing solutions for purification of industrial wastewater. The volume is illustrated with well-chosen visual materials.

The volume is intended for researchers, engineers and technicians, trained in the field of water purification and environment preservation. It may be used as an additional material to the textbooks by students and post-graduates of the following specialities: “Water Supply and Disposal” and “Engineering Protection of Environment”.

The authors’ sincere acknowledgements for active assistance in writing the volume to Academician of Housing and Public Services V. K. Gordeev-Gavrikov (Chapter 7.1., 7.3.), D.Sc. in Chemistry S.V. Kalyuzhnyi (Chapters 3.1; 4.3; 5.4; 5.5), D.Sc. in Physics and Mathematics V.A. Vavilin (Chapters 6.1., 6.2., 6.3.), Candidate of Technical Sciences A. N. Kochetov (Chapters 11.4).

CONTENTS

INTRODUCTION

Wastewater is generated as a result of man's household and industrial activity. In one way or another it gets into waters of closed reservoirs, rivers, seas and oceans where a whole variety of harmful substances concentrates produced by man voluntarily or involuntarily.

Utilization and neutralization of sewage is one of the most important ecological problems of nowadays. A great number of different techniques have been worked out in this field based on physicochemical or biochemical processes of harmful sewage components degradation.

Intensive construction of drainage systems in Europe began in the 19th century, however centralized sewage disposal led to local growth of water reservoirs contamination. Therefore as early as in 1861 a law on sewage purification from faecal and decomposing substances before their discharge into rivers was adopted in England. The earliest sewage detoxication methods – the ones of soil purification - were elaborated in Russia in the middle of the 19th century. Such methods are based on soil's ability to self-purify. Such purification occurs in irrigated or filtration fields. Sewage utilization in agriculture and its purification are united in one process in irrigated farm fields. However alienation of considerable areas of fertile lands is necessary in order to purify sewage under natural conditions. Purification efficiency reduces in winter time owing to slowing down of biological processes at low temperatures. Household sewage contains a large amount of pathogenic bacteria and helminth eggs, more than 50 per cent of which maintain viability in soil and on vegetables over a long period of time. Therefore use of natural biological purification installations decreases both in our country and in some industrially developed foreign countries.

Biological purification progresses intensively under artificially created conditions. This process can be controlled and regulated and thus intensified.

It was the possibility of regulation of purification efficiency that led to creation of diverse techniques which effectiveness is determined with the ecological factor – achieved purification efficiency and the economic factor - purification costs. Generally any level of purification efficiency can be achieved based on the principle of microorganisms' metabolism, but application of this or that technology can be limited with its cost which depends on the amount of power consumed and the number of service personnel employed, particularly when sewage treatment installations operated.

Biological filters characterized with reliable operating modes and low power consumption prevailed in construction of sewage treatment installations before 1970s. However, experience showed that they operated most steadily when organic substances are oxidized by 50-70 %.

In 1980s installations with biological filters and stabilizers for purification of sewage in small settlements were produced in Yugoslavia and Bulgaria. But they did not become widespread due to insufficient purification, “swelling” of the biomass and its removal from the settling zone. Biological filters include submersible filters consisting of reservoirs with horizontal shafts on which different mechanisms are fixed to form the immobilized microflora. These installations do not ensure high purification efficiency corresponding to contemporary demands, including demands to biogenic substances removal. When the organic substances flow or hydraulic load sharply increases untreated sewage may slip through those filters.

Aeration installations where sorption and destruction is carried out by microorganisms (active sludge) suspended in the treated sewage water may ensure high and stable quality of purification. At the same time aerotanks, oxidizing ducts and aerated lagoons have the following drawbacks: considerable power consumption (0,4 – 0,6 kW.h per 1 m^3 of city sewage); insecurity of blast blowers, high pressure fans and mechanic aerators during sustained operation; deterioration of purification efficiency in winter time due to the treated liquid cooling when aerated with cool air. Lately multisectional installations with active sludge have been spread throughout the world that purify sewage from organic pollutants and transform nitrogen compounds simultaneously. The combination of aerobic and anaerobic zones permits to accomplish nitrification and denitrification processes. But these installations are not efficient enough for the majority of settlements and towns in the middle and northern parts of Russia as low temperatures of the primary sewage in a cold season (12 – 17^0C) which tend to decrease during the process (by 2 – 5^0C on the average) make negative impact on the nitrifying bacteria activity. These installations efficiency is insufficient for some cities in the southern part of Russia as well (for Stavropol, Cherkessk, Krasnodar, etc.) due to the relatively low content of organic substances in sewage (BOD_{comp} varies from 100 to 130 mgO_2/dm^3), thus it is difficult to receive volatile fatty acids in the amount sufficient for intensification of denitrification and biological dephosphorization processes. Lately more interest has been shown abroad to periodic reactors (batch-reactors) that permit to achieve high purification efficiency during complete oxidation. However static installations operation demands additional power inputs for sewage pumping-over and frequent switching between aeration systems. Up to one thousand pathogens may occur in 1 dm^3 of air drawn through the aerotank as a result of droplet entrainment. The drainage treatment installations personnel find themselves in the enhanced risk atmosphere. Pathogenic microflora may maintain its viability over a long period of time and get to settlements (sanitary-hygienic zones do not serve as sufficient barriers) under the definite combinations of air humidity, air temperature and wind direction.

Industrially developed countries have necessary conditions for effective operation of sewage treatment installations. The majority of European countries are situated in favourable climatic conditions facilitating best performance of biochemical processes in sewage treatment installations. Russia is in a more complicated situation as in some areas of the country the air temperature in a cold season may decrease to – 50^0C. Stoppages and breakages are not uncommon in power supply systems. Besides, purified water quality specifications are more rigid in Russia than in EEC countries.

Due to the growth of cities some new problems emerge: new sewers are to be laid, power consumption of sewage delivery to treatment installations increases. In our opinion, one of the up-to-date problem-solving techniques of sewage purification in large settlements is partial or complete decentralization of water disposal systems. However this method is difficult to apply in some cases due to the complex process of alienation of considerable areas for construction of bulky sewage treatment installations and impossibility of meeting the area requirements to sanitary-hygienic zones. **Sewage treatment installations in future must have minimum dimensions and be ecologically safe when located within the city boundaries; the treated sewage quality must enable its utilization for the city technical needs.**

Shortage of naturally clean water and high demand for water in industry determine the necessity to continue working on further development of purification systems.

In the present context the development of new technological concepts providing high and stable quality of sewage purification is a pressing problem in high demand. This volume contains theoretical provisions, analysis of the existing methods of biological purification, results of laboratory and shop research of the combined installations and works elaborated in the Rostov Scientific Research Institute of the Academy of Public Services after K.D. Pamfilov that in our opinion meet the contemporary demands to sewage treatment quality. This volume contains the results of research in integrated sewage treatment as well.

The developed combined sewage treatment works are new regarding some technical concepts and their novelty has been confirmed with patents taken out in Russia, America and Canada. The combination works were awarded the Gold medal of the 1996 International Inventions Salon in Brussels.

Chapter 1. GENERAL NOTIONS OF SEWAGE IMPURITIES

1.1. Sewage Types

The term “sewage” can be used generally to denote water produced as a result of man’s economic and household or industrial activity. Sewage water is divided into the following five types according to the dominating pollutant types: household sewage, industrial wastewater, agricultural sewage (field flow and sewage from stock-farms), mine and pit water and surface flow.

Household Sewage

Sewage waters of this type are produced as a result of man’s household activity. Every man is ascertained to produce the following amount of contaminating substances per day: 65g of suspended matters, 75g of BOD_{20} organic matters, 8g of ammonia nitrogen (NH_4^+), 3,3g of phosphates (P_2O_5), 9g of chlorides, and 2,5g of surface active substances /17/. In order to determine the pollutant concentration in the household sewage the per person contamination rate value *a* [g/day] should be divided by the water disposal rate value *q* [dm^3/day]: C= (a 1000)/q, (mg/dm^3).

Industrial Wastewater

Industrial wastewater is produced at industrial enterprises; its composition is varied and depends on the production type. Industrial wastewater is divided into conditionally pure sewage, exclusively thermally polluted sewage and produce-polluted one. The latter can be classified according to the pollutant types depending on the enterprise type, materials being processed, feedstock and output types (see Table 1.1). The wastewater diversity is divided into three groups according to the types of impurities they contain – mineral, organic and organic-mineral ones. Industrial wastewater containing mineral impurities mainly is received from engineering industry, machine-building industry, enterprises producing fertilizers and construction materials. Industrial wastewater containing organic impurities is generated at food industry enterprises (meat, dairy, fish, packing, sugar, etc. industry), tanning enterprises. Industrial wastewater with organic-mineral impurities is generated at textile and pharmaceutical enterprises, oil refineries.

Surface Flow of Settlements

This type of flow is formed with rainwater, melt water and water intended for watering. The following major factors determine the flow quantity and the pollutant composition: precipitation intensity and duration, the total area of the catch basin, climatic conditions, relief and surface type. Suspended matters of organic and mineral origin, oil products, biogenic matters, heavy metals prevail in this type (see Table 1.2.).

Agricultural Sewage

Agricultural sewage is divided into sewage from stock-farms and field flow. The first one contains a large quantity of organic impurities up to 10 thousand mg/dm^3. This type of sewage is characterized with nitrogen content up to 1,5 g/dm^3 and phosphorus content of 0,06 – 0,10 g/dm^3 (household sewage contains 25-30 mg/dm^3 nitrogen and 6-8 mg/dm^3 phosphorus). The second type of sewage contains substances used as fertilizers and anti-vermin agents (nitrogen, phosphorus and potassium compounds, pesticides). The biogens and pesticides concentration depends on the amount of fertilizers and pesticides applied, as well as on the accurate conditions of storing of fertilizers and pesticides (see Table 1.3, Table 1.4).

The legend for Table 1.1. Type of industry: A – nonferrous metallurgy, B – ferrous metallurgy, C – by-product coking industry, D – engineering industry, E – oil refinery, F – synthetic chemistry, G – textile industry, H – tanning industry, I – meat-processing industry, J – diary industry. Ingredients concentration values, in mg/dm^3: 1 – ones; 2 – tens; 3 – hundreds; 4 – thousands; 5 – tens of thousands; 6 – hundreds of thousands; + - possibility of occurrence.

Table 1.1

Main Types of Industrial Wastewater Pollutants

Pollutant Type	Type of Industry									
	A	B	C	D	E	F	G	H	I	J
1	2	3	4	5	6	7	8	9	10	11
Suspensions: Mineral	5–6	3–4	3–4	+	2	–	–	–	–	–
Organic	–	–	–	–	–	+	3	4–5	4	3
Dissolved Inorganic:										
Chlorides	–	0–2	3– 4	–	3	1– 3	2– 3	4	3– 4	–
Sulphates	–	2–4	–	–	2–3	3	–	3–4	–	–
Phosphates	–	–	–	–	–	–	1–3	1–2	0–2	1–2

1	2	3	4	5	6	7	8	9	10	11
Cyanides	4	0-3	0-3	+	–	–	–	–	–	–
Copper	2	–	–	1–3	–	–	+	–	–	–
Manganese	+	–	–	+	–	–	+	–	–	–
Chromium	–	–	–	2–3	–	–	1	2	–	–
Lead	0–5	1	–	1	–	–	–	–	–	–
Zinc	0–4	–	–	+	–	–	–	–	–	–
Cadmium	+	–	–	0–3	–	–	–	–	–	–
Dissolved Organic:										
Surfactants	–	–	–	–	–	0–2	2	0–2	–	–
Phenols	–	0–1	3–4	–	–	0–2	–	0–2	–	–
Oil products	–	–	–	+	3–5	–	–	3	–	–

Table 1.2

Large Cities Surface Flow Composition Values

Surface Flow Composition	Pollutants Concentration in a Filtered (Unfiltered) Sample, mg/dm^3
Suspended Matters	(750)
BOD comp.	25 (60)
Total Nitrogen	3.8
Organic Nitrogen	1.2
Total Phosphorus	1.0
Organic Phosphorus	0.45
Oil Products	15
Chlorides	75 (90)
Sulphates	110
Synthetic Surfactants	0.5
Copper	0.15 (0.23)
Lead	0.2 (0.5)
Zinc	1.2 (3.0)
Iron	3.0
Nickel	0.09 (0.14)

Table 1.3

Stock-Farms Sewage Chemical Composition

Sewage Composition	Pollutants Concentration, mg/dm^3	
	Hog-Breeding (10 thous. heads)	Cattle-Breeding (10 thous. heads)
Suspended Matters	12400	8600
Total Nitrogen	1000	1300
Polyphosphates	400	300
Sulphates	400	400
Calcium	200	300

Table 1.4

Nitrogen, Phosphorus and Pesticides Removal from Agricultural Lands

Physiographic Zone	Nitrogen, kg/ha	Phosphorus, kg/ha	Pesticides, kg/ha
Steppe Zone:			
Irrigated Lands	2.2 – 22.5	0.17 – 1.1	0.145
Non-irrigated Lands	2.0	0.03	–
Mixed Forests:			
Irrigated Lands	–	–	0.035
Non-Irrigated Lands	3.98	0.09	–

Mine and Pit Water

Mine and pit water is generated in production and processing of mineral products. It is often characterized by high degree of mineralization, acid reaction, large amount of mining elements dissolved or suspended (Table 1.5).

In order to determine the sewage composition a large amount of different chemical, physicochemical and sanitary bacteriological analyses are to be made. The main tasks accomplished on the basis of the above-mentioned analyses are: assessment of sanitary and toxicological properties of the water; determination of the exact area of the water usability;

determination of the fouling factor, pollutant character and water purification method, as well as determination of methods of water purification processes control and purification installations operation control; assessment of separate installations performance and the purification technological flow chart on the whole; the reservoir state control.

Table 1.5

Chemical Composition of Some Mine and Pit Waters (mg/dm^3)

Deposit	Mn	Fe	Co	Ni	Cu	Cd	Pb	Zn
Sulphide Deposit (Western Altai)	15	30	0.3	0.05	16	0.5	0.2	125
Gold Mine (South African Republic)	4	3	3.5	15.9	5.4	0.05	0.29	26

1.2. Organic Impurities in Sewage

In general organic substances in household sewage include urea, proteins, fats, carbohydrates and their decomposition products, different organic acids and synthetic surfactants. The distinctive feature of household sewage is the relative stability of its composition as water disposal systems receive from a dweller a definite average quantity of pollutant substances (g/day) determined according to the Construction Norms and Specifications 2.04.03-85.

Industrial wastewater may be polluted with specific organic substances depending on the production type, for example, with oil and oil products, phenols, lignin, different organic acids, synthetic surfactants. The largest amount of synthetic surfactants is contained in industrial wastewater received from textile, tanning and oil industries.

Composition of organic impurities that may be oxidized by microorganisms in their metabolism is defined as biochemical oxidability. One part of the used organic substances is consumed by microorganisms for their energy needs and the other part is used for the cellular element synthesis. Some of the pollutants used for energy needs are oxidized by microorganisms to final decomposition products which composition depends on the type of the component being oxidized, oxidation-reduction conditions and acid-base conditions of the medium: CO_2, H_2O, NH_4^+ (NH_3), SO_4^{2-}, (H_2S), HPO_4^{2-} generally (compounds that are reduced by microorganisms under anaerobic conditions are given in parenthesis). The oxidation products – metabolites – are withdrawn from the cell out into the environment. Many microorganisms use oxygen as acceptor of electrons and protons to accomplish metabolism. The amount of oxygen needed by microorganisms for the complete cycle of energy generation reactions and synthesis is defined as BOD – Biological Oxygen Demand. The BOD value is determined analytically from the difference between the oxygen concentration value in the primary water sample being analyzed and the value fixed in 5 or 20 days of metabolism of microorganisms (in the latter case the BOD value is said to be complete value). The BOD value is considered to have been determined correctly if by the end of the incubation process 3 to 5 mg O_2/dm^3 remains in the phial. Oxygen dissolubility in water under air pressure is determined with its temperature, at 20°C 9,17mg O_2/dm^3 is dissolved in distilled water. Thus the maximum BOD value at this temperature will make 6,17mg O_2/dm^3. If there are many organic pollutants in the analyzed sample and microorganisms need a large amount of oxygen for organic oxidation the method of the primary sample dilution is used. The method consists in mixing one part of the water being analyzed and several parts of diluting water, then oxygenating the mixture to the highest degree, pouring into incubation phials and keeping it in the thermostat at 20°C. When calculating the BOD value the dilution degree is taken into account and shown as a ratio, for example, the 1:100 ratio means that for one part of the water being analyzed 99 parts of diluting water are used. If the definite BOD value at 60-times dilution makes 4mgO_2/dm^3 then, consequently, the BOD value of the water being analyzed is 240mgO_2/dm^3.

1.3. Mineral Impurities in Sewage and Dissolved Gases

Inorganic impurities in sewage consist of piped water-specific salts and salts generated as a result of metabolic reactions in human organisms, phosphates and ammonium salts in particular. Industrial wastewater may contain high concentrations of specific mineral substances: tin, copper, lead, zinc, cadmium, different acids, etc. Mineral pollutants containing suspended substances are mainly represented with sand and clay particles getting into household sewage when washing fruit and vegetables, tidying rooms up, etc. The type and quantity of mineral pollutants in industrial wastewater depends on the type of the economic activity of the enterprise. They may be similar to household pollutants or specific ones, like scale, cement kiln dust, etc.

The occurrence of dissolved gases indicates progressive biochemical processes in sewage. Dissolved oxygen indicates a rather high degree of purification, ammonium (or ammonia) ions and sulphur compounds indicate the progressive process of protein ammonification where sulphur occurs as sulphate ions under aerobic conditions and reduces to hydrogen sulphide or sulphide-ion under anaerobic conditions, methyl hydride indicates the progressive methanogenic process under anaerobic conditions.

1.4. Biological Impurities in Sewage

The microflora of household sewage is represented by microorganisms excreted from man's intestines, washed off his body and surrounding objects. Everyday physiological egesta contain several trillions microbes including colibacilli, lactobacilli, enterococci, fungi, protozoa, helminth eggs. Industrial wastewater may contain specific biological pollutants – yeast, fungi, actinomycetes (pharmaceutical, food and other industries). Infectious diseases caused by pathogenic bacteria, virus, protozoa or parasites that get into the water reservoir with untreated or insufficiently treated water represent the typical and most common health hazard in connection with potable water. If there are sick people with progressive diseases or disease carriers in settlements then faecal pollution leads to occurrence of pathogens in water. Peroral ingestion of such water (as drinking water) or contacting it when washing or bathing and even inhaling water vapour may cause contamination. Such pathogens include Salmonella spp., Shigella spp., Escherishia coli, Vibrio cholerae, Uersinia enterolitika, Salmonella tichi, etc. A sanitary and bacteriological analysis of water is carried out in order to determine the epidemiologic danger or safety of natural and purified sewage water for man. Many pathogens are defined with the corresponding methods but it is more simple and effective to carry out the analysis on bacteria that indicate faecal contamination or insufficient purification or disinfection of water. In order to serve as indicators those bacteria have to meet the following criteria: be available in faecis of men and haematothermal animals in large amounts;

be detected with simple methods; not be able to develop in natural water; their purification efficiency and methods of removal must be analogous to those for pathogens of water origin. Till recently the sanitary and bacteriological analysis of water quality was based on determination of two factors – total microbial count (TMC) and coli-bacteria count. The first one shows general semination of water with aerobic saprophytes, the second one estimates possible occurrence of pathogenic microorganisms in water. The analysis result is represented as coli index – the number of bacteria per liter of water or as coli-titer – the smallest amount of water (in cm^3) containing one collibacillus. Coli-titer =1000/coli index. At present the range of indicating microorganisms has been enlarged, Escherishia coli, bacteria tolerant to high temperature and other coli-forming bacteria, faecal streptococci, sulphate-reducing clostridia spores and coliphages have been added to the main indicating microorganisms list.

Chapter 2. THEORETICAL PRINCIPLES OF BIOLOGICAL DEGRADATION AND TRANSFORMATION OF POLLUTANTS

2.1. Principles of Biological Degradation

The method of biological purification is the most economically efficient and sometimes the only one available among the employed methods of industrial wastewater and household sewage purification. The technology of biological purification is based on utilization of active sludge or a biofilm representing an accumulation of live and dead microorganisms which serve as the beginning and source of destructive biochemical processes. The common feature of all microorganisms is their small size that varies from micrometer fractions to several micrometers. A gram of bacterial mass contains 10^{12} bacteria cells. Notwithstanding their small sizes they however have considerable specific weight in animate nature. They evolve up to 95 per cent of the total amount of carbon dioxide generated in nature. Microorganisms can be found everywhere in soil, water, air. Their main habitats are soil and water, as well as bodies of plants, animals and men. They densely inhabit the digestive system and mucous membranes. The first scientific description of microorganisms was made by Anton Levenguk (1632-1723); in 1683 he discovered the third world of the animate nature called the protists. This world includes organisms that are poorly morphologically differentiated unlike plants and animals, the majority of them being monadiforms. Protists are divided into two groups of higher and lower protists based on the cellular organization peculiarities. Lower protists include bacteria and cyanobacteria. According to their shape bacteria are further subdivided into the ball-shaped ones (cocci), rod-shaped or cylindrical ones (bacteria, bacilli) and twisted ones (vibrios and spirilla). There are labile and static bacteria forms. They move by means of flagella. They are divided into several groups according to the flagella position type – into the monotrichia having one flagellum at the cellular pole, the lophotrochia having flagella fascicles at the cellular pole and on the peretrichia having flagella all over the cellular surface.

A microbial cell contains up to 80-85 per cent of water and 15-20 per cent of dry matter which is a mixture of organic and mineral compounds. The chemical compounds ratio is different and depends on the microorganism type and age. A part of water in the cell is free and another part is bonded - incorporated into proteins, fats and carbohydrates molecules. Free water serves as organic and mineral substances solvent. All nutrients cannot enter the cell except with water and metabolism products (metabolites) are withdrawn with water as well. The amount of proteins in the cell depends on its age; proteins make up 50-80 per cent of the cellular dry matter on average. Proteins are high-molecular polymeric compounds with amino acids as monomers. Amino acids are able to polymerize. Proteins include polypeptides with more than 50 amino acids in the chain. Proteins perform the following functions – the construction function: they take part in formation of cellular membranes and organelle as well as that of extracellular structures (exoenzymes); the catalyst function: all enzymes (substances that accelerate spontaneous chemical transformations) are proteins in their chemical composition; the motor function: the one being performed with specific contracting proteins taking part in all types of movement (flagella beating); the transportation function: proteins attach chemical elements or biologically active substances and transfer them through the membrane to different cellular tissues and organs; the energy supply function: proteins provide the cell with energy, complete proteolysis of one gram of protein gives 17,6 kJ of energy. Carbohydrates make up to 5 per cent of the cellular dry matter. Carbohydrates perform the following functions: the construction function and the energy supply function, carbohydrates are structural components of cellular membranes; they are also the main energy source. When one gram of carbohydrate is oxidized 17,6 kJ of energy is evolved; carbohydrates are main nutrient reserves, that is food and energy reserves. Lipids make up to 5 per cent of the cellular dry matter; they include fats, oils, waxes – water-insoluble organic substances that may be withdrawn from the cell by means of organic solvents (ether, chloroform, benzol). Fatty acids are components of lipids. They perform the construction function in the cell – they form the cellular membranes; the energy supply function of fats consists in releasing 38,9 kJ of energy when one gram of fat disintegrates completely. Mineral salts make up to 2-14 per cent of the cellular dry matter. The majority of inorganic substances are represented either as ions or as insoluble salts. Potassium, sodium and calcium are important among the ions. The alkalescent reaction of the cell medium is supported with a specific buffer space mainly formed with phosphoric acid anions and phosphoric acid salts. The cell also includes such microelements as molybdenum, cobalt, nickel, manganese, etc.

2.2. Classification of Microorganisms according to the Type of their Existence

Bacteria constantly need nutrients both when growing and at rest transforming them during the metabolism process into construction materials for the cellular element synthesis and into energy necessary for the cellular element synthesis, motion, possible luminescence, etc. A growing cell needs a large amount of energy which is consumed during the biomass synthesis, reproduction of DNA proteins and cell walls and other volatile processes. An adult cell needs 7 times less energy. It mainly uses it for renewal of DNA protein and other components. In the anabiosis state metabolism goes on, however very slowly. Then the cell mainly needs energy to withdraw decomposition products and to synthesize DNA protein. Microorganisms may exclusively utilize the chemical reactions energy (oxidation-reduction reactions) and electromagnetic energy (light of the definite wavelength); other energy types are not available for them. All bacteria are divided into two large groups according to the type of energy being used by them: chemotroths and phototroths correspondingly. Chemotrophs occupy the major place in the biological degradation technology of sewage pollutants treatment, and further on the classification of these very organisms is considered. Chemotrophs are divided into two large groups according to the character of the oxidizable substance: lithotrophs utilizing energy during oxidation of non-organic substances (that is non-organic substances donate protons and electrons); organotrophs receiving energy during oxidation of organic substances (organic substances donate protons and electrons). The type of carbon necessary for the cellular element synthesis determines the reference of chemotrophs either to the group of heterotrophs (microorganisms that synthesize their cellular element from organic carbon) or to the group of autoratrophs (microorganisms that synthesize their cellular element from the CO_2 carbon). If microorganisms utilize dead organic substance they are called saprophytes, if they utilize organic substance – part of the hosting cell they are called parasites (pathogens or morbific organisms). Chemotrophs are called aerobes if free oxygen diluted in water is proton (electron) acceptor, chemotrophs are called anaerobes if bonded oxygen (an element of compounds like nitrates or sulphates) or an organic substance which is the product of the incomplete biological degradation of the substratum (primary nutrients, metabolites) is proton (electron) acceptor. The prokaryote type of existence is determined taking into consideration the above-mentioned peculiarities and represented in Table 2.1 /18/.

Table 2.1

Prokaryote Type of Existence

Energy Source	Electron donor (Deoxidizer)	Carbon Source	Type of Existence	Representatives
Oxidation-Reduction Reactions	Non-Organic Substances (H_2; H_2S; NH_3; Fe^{2+})	CO_2	Chemolitho–autotrophia	Nitrifying, Carbothionic, Hydrogen, Iron Bacteria
		Organic C	Chemolitho–heterotrophia	Methane-Generating and Hydrogen Bacteria
	Organic Substances (Proteins, Carbohydrates, etc.)	CO_2	Chemoorgano-autotrophia	Elective Methylotrophs
		Organic C	Chemoorgano-heterotrophia	Majority of Prokaryotes

2.3. General Notions about Metabolism

All microorganisms receive energy and nutrients as a result of metabolism. Metabolism is a succession of different transformations to which the substances inside the cell are subject. The cell absorbs nutrients from the surrounding environment with its entire surface. The nutrients must be soluted and their molecules sizes must be considerably less than the cell size for ions and small molecules to enter the cell easily. Macromolecules are sometimes larger than the cell and in order to enter it they must disintegrate subject to hydrolysis which is a spontaneous process. However if the substance is not readily soluble the hydrolysis process can be prolonged. This process is accelerated by means of catalysts. The cell synthesizes these catalysts – exoenzymes – and they withdraw to the environment. The way exoenzyms act is shown in Fig. 2.1.

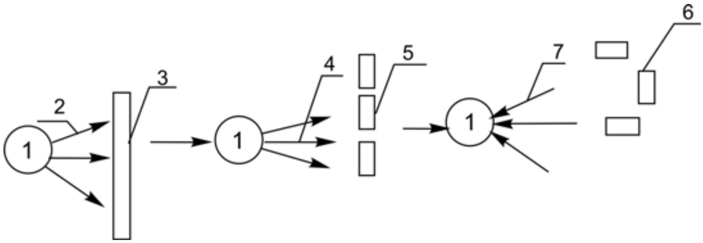


Fig. 2.1. Exoenzyms Activity Chart

1 – bacteria cell; *2* – cellulase exoenzym catalyzing the cellulose hydrolysis – *3* into cellobiose *5; 4* – cellobiase exoenzym catalyzing the cellobiose hydrolysis into glucose *6* entering the cell due to the passive transportation mechanism or transported with the transferase exoenzym – *7*

The protein hydrolysis into organic acids and amino acids under exoenzyms influence can be presented in the following way:

$$RCO – NHR + H_2O \rightarrow R – COOH + H_2N\ R$$

In bacteria cells the enzymic hydrolysis products are subject to transformations via a series of consecutive enzymic reactions. These reactions of intracellular transformations of substances are called the metabolic fate. To make it simpler the metabolic fate is divided into two branches – the energy branch (the substratum degradation) and the synthetic branch (the cellular element formation). The destruction processes liberate energy and the synthesis processes consume it. Nutrients disintegrate into small fragments during the cell process called degradation, decomposition or catabolism, then they transform into a series of organic acids and phosphorous ethers – this is the intermediary metabolism process or amphibolism. These two stages evolve energy. The different low-molecular compounds resulting from the amphibolism process form the basis for the synthesis of cell constitutive components called the cellular construction blocks – they are amino acids, sugar phosphates, organic acids and other metabolites. These construction blocks form polymeric macromolecules – nucleic acids, proteins, reserve substances, the cell wall components, etc., in other words all those molecules that constitute the cellular element. The synthesis stage consumes energy and is called anabolism.

All processes of metabolites transformation inside the cell are catalyzed with intracellular enzymes – endoenzymes.

The term for ferments or enzymes is derived from the Latin word "fermentum" meaning leaven or mold. Enzymes are proteins. The reaction catalyzed with an enzyme begins with the bonding of the metabolite (that is, the substratum) with the enzymatic protein. Alongside with enzymes some low-molecular organic compounds, the so-called coenzymes and prosthetic groups, take part in the bonding and further transportation of the substratum separate fragments – methyl groups, amino groups, hydrogen, etc. The substances bonding a substratum fragment on a protein and then separating to transfer this fragment on another enzymatic protein to another compound are called coenzymes (carriers). The low-molecular compounds firmly bonded with the enzyme and not subject to separation during the process of the bonding and transportation of the substratum fragments are called the enzymes prosthetic groups. Enzymes possess specific qualities in comparison to non-organic catalysts: they accelerate chemical reactions acting tens and hundreds times faster than non-organic catalysts. For example, the reaction constant of the hydrogen peroxide (H_2O_2) decomposition catalyzed with ions of ferrous iron equals 56, the reaction constant of the same reaction when it is catalyzed with the enzyme is $3{,}5x10^7$; the reaction constant of urea decomposition under the acid influence equals $7{,}6x10^{-6}$ while the reaction constant of the enzymic decomposition is $5x10^7$. The enzymic effect is connected with the intensive decrease of the activation energy. Thus when the hydrogen peroxide is disintegrated with ions of ferrous iron the activation energy makes 46 kJ/gram-molecule, during enzymic decomposition it equals 7kJ/gram-molecule, the metabolite chemical transformation on the enzyme occurs at usual temperature. Thus enzymes ensure the progress of those reactions which would progress without them at very high temperatures impossible for living organisms. For example, the oxidation of ammonia nitrogen to free nitrogen progresses at the temperature of 600 – 700°C; the enzymes are characterized by the substratum specificity (they interact with only one metabolite and its transformation product) and action specificity (they catalyze only one of all different transformations that the given metabolite is subject to). The enzyme identifies the substratum while bonding it. The bonding is fulfilled in the definite part of the enzyme molecule called the catalytic centre. The steric characteristics of the substratum (its shape) and the charges distribution in its molecule serve as indicators during identification of the substratum with the enzyme.

The substratum and the enzyme fit each other as a key fits the key-hole in the lock (see Fig.2.2) /18/.

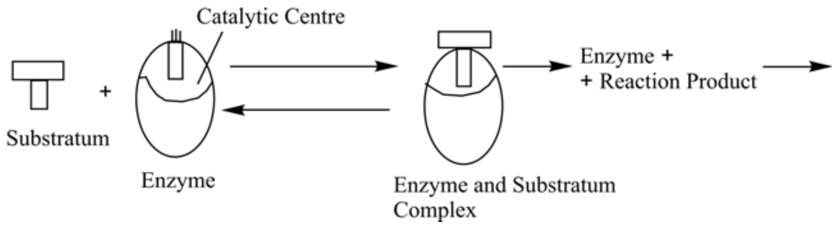


Fig. 2.2. Substratum Bonding with an Enzyme
("the Key-and-Keyhole" Hypothesis)

The changeability of catalytic activity of some enzymes that is subject to regulation is a very important characteristic of these enzymes. This regulation is a possible explanation of utter coordination of all metabolic transformations. Such enzymes identify not only the substratum metabolite (by means of their catalytic centre) but the final product of this very biosynthesis fate as well (by means of another centre). These enzymes have the second bonding centre – the regulatory centre. The enzyme catalytic activity is regulated by effectors. It is raised by positive effectors and reduced by negative effectors. The metabolites which will interact with the final products of the given reaction can be referred to positive effectors and the final products of enzymic transformation can be referred to negative effectors. Thus the concentration of metabolites acting as effectors determines the activity of enzymes and thus the transformation velocity. Effectors have nothing in common with the enzymes substrata in their substance. They differ from substrata in their steric qualities. Thus allosteric effectors are spoken about and the center responsible for their regulation is called the allosteric centre (See Fig.2.3.) /18/.

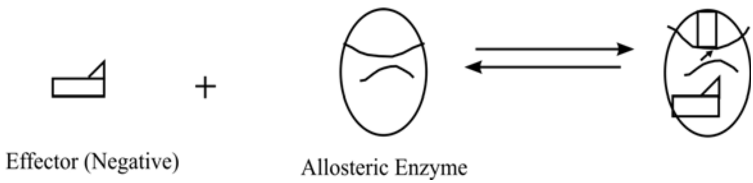


Fig. 2.3. Bonding of an Effector by an Allosteric Enzyme

2.4. Population Growth in Nutritious Medium

The microorganisms' growth in a static medium is shown by means of kinetic growth curves (see Fig. 2.4.) /11/. Generally not a separate species but a microorganisms community, that is a population, is being studied.

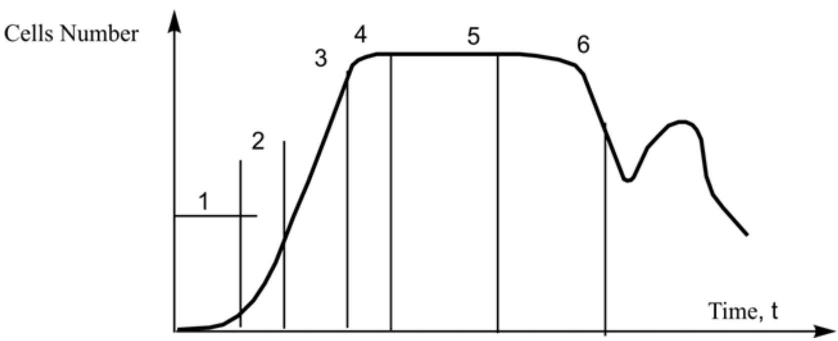


Fig. 2.4. Kinetic Curve of Microorganisms Growth in a Static Medium

1.– The primary phase (lag-phase) includes the interval between the points of inoculation and achievement of the maximum growth velocity. The duration of this phase depends on the extent to which the nutritious medium is appropriate for the given microorganism population and on the age of the inoculum. 2.- The exponential growth phase is characterized by the sufficient amount of nutritious matter and low concentration of metabolites. It is characterized by the constant maximum cell division rate. 3.- Logarithmical growth phase. In a closed system the exponential phase cannot develop infinitely and it transforms into the linear growth phase or logarithmical growth phase characterized by the linear culture growth which is proportional in time. In the logarithmical phase metabolites are accumulated gradually. 4.- The linear growth phase is replaced by a short-term period when the culture growth rate slows down. It is the growth deceleration phase which is influenced by the metabolites accumulation that inhibits the cell growth. 5.- The stationary phase is characterized by the long-standing and steady culture growth. The substratum exhausts gradually, metabolites are accumulated thus intensifying the inhibition of the cell growth still more, and the number of the new emerging cells equals that of the dying-off cells. The cell lysis begins in this phase (lysis is enzymatic hydrolysis of the dying-off cells). 6.- The complete lysis phase. If the system substratum exhausts completely or the metabolites accumulation becomes significant and limits the cell growth then the growth stops and the dying-off process begins to prevail accompanied by the complete lysis as a rule. This phase is called the dying-off phase. During the lysis process a certain amount of nutritious elements appears in the system and is used by stable organisms so some cell growth is possible even during the dying-off of the bacterial culture. It is possible because the exoenzymes of the dead cells continue to act as they are chemical substances (in some foreign literature this effect is called the postmortem activity). Then the metabolites accumulation finally inhibits the cell growth and complete lysis occurs.

2.5. Static Parameters of Culture Growth Curve

When choosing a sewage purification scheme technologists are first of all interested in the following four indicators: the microorganisms growth rate, that is the increase (doubling) of the cell number in the definite period of time, μ (1/t); - the biomass increase or economic coefficient (the biomass amount received from one gram of the substratum) – y, (biomass gram/ substratum gram); - the substratum oxidation rate (biological degradation velocity) – p, (substratum mg /sludge gram per hour); – latent period or lag-phase duration /12/.

Let us consider every indicator in detail.

The microorganisms' growth rate

The change of the cell number N in the given period of time has been experimentally established to be connected with the initial number of cells,

$$dN/dt = \mu N,$$

where μ is the proportion ratio called the specific microorganism growth rate, $\mu = dN/Ndt$, if we use the value of the biomass concentration instead of the cell number (the biomass value is taken for its dry matter, in grams per liter of bacteria culture) then we may write

$$\mu = \frac{x_1 - x_0}{x_1(t_1 - t_0)},\ 1/t,$$

where x_0 and x_1 are the concentration of microorganisms values at the beginning and at the end of the experiment correspondingly, g/dm^3; t_o and t_1 – the time values for the beginning and the end of the experiment correspondingly. The reciprocal value to the specific growth rate is called the biomass age θ, $\theta = 1/\mu$ and is evaluated in time units, for example, in days, hours, etc.

The microorganism growth rate in real conditions hardly ever can reach maximum values and depends on the limiting substratum concentration in the system and its affinity to the microorganism nature; it is defined according to the Moneau equation:

$$\mu = \frac{\mu_{max} S_1}{S_1 = Ks},\ 1/t,$$

where: μ_{max} is the maximum microorganism growth rate, $1/t_1$; S_1 is the substratum concentration in the fermenter (an apparatus for microorganisms cultivation), mg/dm^3; Ks – the substratum affinity constant assumed to be equal to the substratum concentration value at which the growth rate $\mu=0{,}5\mu_{max}$ (is determined experimentally or on the basis of the reference literature).

As the growth process and the growth rate of bacteria cells are affected by the environmental conditions like temperature, pH, dissolved oxygen concentration, etc. the Moneau equation is supplemented by factors taking into consideration the influence of abiotic factors and determined experimentally or on the basis of the reference literature.

The biomass yield economic coefficient based on the substratum concentration

The economic coefficient "y" determines the amount of biomass formed when the BOD substratum concentration decreases from the initial value down to the final value:

$$y = \frac{\Delta x}{\Delta S} = (x_1 - x_0)/(S_0 - S_1)\text{, g/g}$$

is evaluated in grams of the biomass divided by grams of the oxidized substratum, g/g.

The substratum consummation rate

The substratum consummation rate p is the change of the substratum concentration in the time unit divided by the biomass concentration value:

$$\rho = \frac{S_0 - S_1}{x_1 \Delta t} = \frac{\Delta S}{x_1 \Delta t} = \frac{\Delta x}{y x_1 \Delta t} = \frac{\mu}{y}\text{, g/g h}$$

The latent period duration

The lag phase allows considering the microorganisms qualities (like the new enzymes synthesis velocity, etc.) or the affinity of the given nutritious medium to the given community (type) of microorganisms. It is determined as a period between the moment when the population achieves the definite density N and the moment when the population would achieve the same density if exponential or logarithmical culture growth began right after the culture placement in the nutritious medium.

2.6. Flowing Cultivation of Microorganisms

It has already been mentioned that in stationary conditions the bacteria cells growth decreases gradually as a result of it being inhibited by metabolites and of the nutritious substratum exhausting, thus this method would not be efficient for sewage purification in practice. It is used in preliminary laboratory research in order to determine the substratum oxidation rate in different population growth phases which ensures the correct choice of the optimum mode of sewage purification. In sewage purification practices the flowing cultivation of microorganisms is used when the substratum is constantly introduced into and the metabolites are constantly withdrawn from the purification installation. Generally the flowing cultivation can be performed by means of the process of complete displacement (bioreactors-displacers) or during the process of complete mixing (bioreactors-mixers or chemostats).

The ideal displacer is a bioreactor in which the substratum and biomass are delivered centrally to the beginning of the installation. When sewage is treated the initial sewage serves as a substratum for microorganisms; the population of microorganisms forming the bacteria mass is called active sludge in this case. In the displacer the active sludge is distributed through the sewage amount and forms the sludge mixture that is withdrawn centrally at the end of the installation. The sludge mixture moves inside the installation due to displacement of the previously supplied portions with newly supplied ones. In displacers the nutrients concentration decreases along the installation due to their consummation with bacteria cells and the biomass concentration increases due to the growth of bacteria cells number. The substratum consummation rate (pollutants oxidation rate) also changes - it decreases along the installation because in the beginning of the installation the easily oxidized substances prevail, and as the sludge mixture moves through the installation the not-readily oxidized substances begin to dominate in pollutants. The changes in the substratum concentration, bacteria mass and oxidation rate in a displacer is shown in Fig. 2.5.

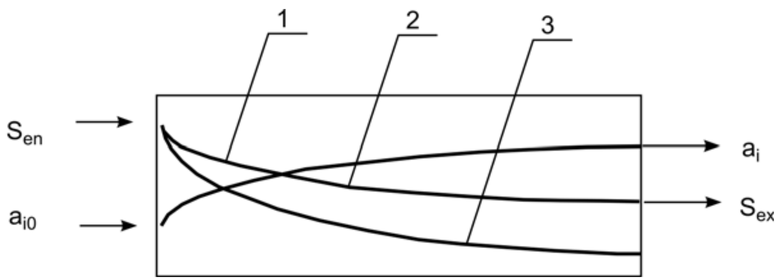


Fig. 2.5. Characteristics of Changes in Substratum Concentration *S* (*Curve 1*), Active Sludge Concentration *a* (*Curve 2),* Substratum Oxidation Rate ρ (*Curve 3*)

In the chemostat which is an ideal mixing bioreactor the substratum and bacteria mass are delivered and discharged uniformly along the installation. The complete mixing of sewage with active sludge ensures the equalization of active sludge concentrations and biochemical oxidation rates throughout the installation. The characteristics of changes in biological oxidation parameters are shown in Fig. 2.6.

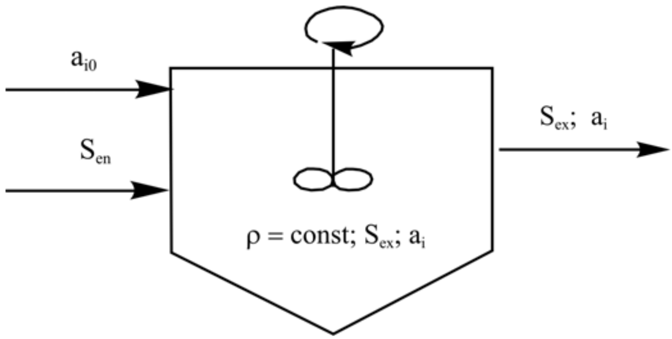


Fig. 2.6. Characteristics of Changes in Biological Oxidation Parameters in a Mixing Reactor

Water flow Q (m^3/day) divided by the reactor volume V(m^3) is called the dilution rate or dilution ratio D: D = Q/V, (1/t). If active sludge were not returned into the reactor after sludge mixture leaves it, the reciprocal value of the dilution rate would make the sludge age Θ, (t).

The dilution rate D determines the decrease of sludge concentration in the bioreactor due to its removal, that is $da_i/dt = D a_i$, the increase of the sludge concentration over a certain period of time due to its growth is determined by its growth rate: $da_i/dt = \mu a_i$. In order to preserve the biomass concentration at a certain level in the installation it is necessary to keep the amount removed from the installation equal to the amount of the growing sludge, D = μ. If D > μ the biomass is carried out, if D < μ the biomass is accumulated and the amount of the growing biomass $da_i/dt = (\mu - D)a_i$ μ. In stable conditions (μ = D) taking the biomass flow rate the substratum concentration (residual pollutants concentration) may be defined as follows:

$$D = \frac{S_1 \mu_{max}}{Ks + S_1} \Rightarrow S_1 = \frac{DKs}{\mu_{max} - D}, \ t^{-1}$$

When operating sewage purification installations the necessary sludge age value is supported by removing of the excess of the biomass only but not of the entire biomass amount.

Chapter 3. IMPORTANCE OF MICROORGANISMS FOR POLLUTANTS TRANSFORMATION

3.1. Carbohydrates Transformation

Carbohydrates serve as the energy and nutrients substratum for microorganisms both in aerobic and anaerobic conditions. In aerobic conditions extracellular compound carbohydrates (polysaccharides) are exposed to hydrolysis, this process being catalyzed with specific exoenzymes. During the process of hydrolysis polysaccharides disintegrate into glucose which enters the cell under the influence of enzymes – transferases (or as a result of passive diffusion). Glucose is further oxidized in the cell evolving energy that is saved in the form of ATP /21/. Carbon dioxide and water are oxidation products that are withdrawn from the cell into the environment. Be sides, the bacterial cell uses glucose molecules as "construction blocks" for cellular polysaccharides molecules. The biological degradation process in aerobic conditions may be presented in the following chart:

$$\text{carbohydrate} \rightarrow C_6H_{12}O_6\downarrow \ \rightarrow \ \text{the cell polysaccharides} + \underbrace{CO_2 + H_2O}_{\downarrow}$$

ATP molecules   Into the environment

Fermentation (biological oxidation of carbohydrates in anaerobic conditions) in its strict sense includes the energy-receiving processes when the hydrogen liberated from the substratum is finally transported onto organic acceptors. Oxygen does not take part in fermentation processes; as Pasteur said, fermentation is life without oxygen. Mainly carbohydrates are fermented but many bacteria types are capable of fermenting different organic acids, amino acids, etc. Polysaccharides are hydrolyzed into monosaccharides outside the cell, the process being catalyzed with exoenzymes; monosaccharides are transformed in the cell, the biochemical reactions being catalyzed with endoenzymes. Microorganisms accomplish fermentation in anaerobic conditions, carbohydrates being degraded not into complete oxidation products (carbon dioxide and water, as in aerobic conditions) but into organic compounds that are withdrawn and accumulated in the environment. Each type of microorganisms oxidizes carbohydrates into definite organic substances according to its fermentative composition. Depending on the type of prevailing or especially typical separated products the following types of fermentation are defined: alcoholic, lactic acid, propionic acid, formic acid, butyric and acetic fermentation, as well as methane-generating fermentation. For example, alcohol is generated as a result of oxidation of carbohydrates with yeast, that is why this type of fermentation is called alcoholic fermentation:

$$\text{Polysaccharides} \xrightarrow{\text{exoenzymes}} C_6H_{12}O_6 \xrightarrow{\text{endoenzymes}} 2CH_3CH_2OH + 2CO_2.$$

Alcoholic fermentation occurs in an acid medium (pH ≈ 6), yeast is stable when sugar concentration is high (about 76%) but alcohol concentration must not exceed 17%. Alcoholic fermentation occurs when highly concentrated industrial wastewater is purified (wastewater from sugar refineries, yeast plants, hydrolysis plants, etc.). When glucose, lactose, malic acid are oxidized with propionic acid bacteria propionic acid is generated.

The final product of biological degradation of carbohydrates during butyric fermentation is butyric acid. The fermenting bacteria inhabit sewage, water reservoirs, manure, and soil. Butyric fermentative agents are obligatory anaerobes. Butyric fermentation is divided into genuine butyric fermentation, acetone-butanol fermentation, fermentation of pectin substances. Butyric fermentation occurs in compliance with the following equation:

$$\text{Polysaccharides} \longrightarrow 4C_6H_{12}O_6 \longrightarrow 3CH_3CH_2CH_2COOH + CH_3COOH + 8CO_2 + 8H_2O.$$

Genuine butyric fermentation generates acetic acid apart from butyric acid, when pH is less that 5.5 butyl alcohol and acetone are generated instead of acetic acid.

Pectin substances (intercellular substances contained in any vegetable material, insoluble and capable of swelling) are fermented in compliance with the following equation:

$$\text{Pectin} \rightarrow \text{monosaccharides} \rightarrow CH_3CH_2CH_2COOH + CO_2 + H_2O.$$

Methane fermentation is accomplished with methane-generating bacteria, obligatory anaerobes. This type of fermentation was discovered by Volta in 1776. Methane-generating bacteria inhabit the sediment formed during the sewage purification process. The biogas evolved during anaerobic fermentation is a mixture of 50-80% of methane, 20-50% of carbon dioxide, insignificant quantities of hydrogen sulphide, nitrogen, oxygen, ammonia, carbon protoxid. Having access neither to oxygen nor to any other more preferable electron acceptors as regards energy (nitrates, sulphates, sulphur, etc.), microorganisms have to utilize organic carbon for this purpose, generating finally the most heavily reduced carbon compound existing in nature – methane. In the same time the other part of organic carbon donates electrons during its oxidation to carbon dioxide (the other main component of biogas) /8/. Methane-generating organisms utilize acetic acid and H_2 as carbon sources because they cannot decompose complex organic compounds; thus methane fermentation is the last stage of the preceding fermentation types: first other fermentative organisms ferment carbohydrates into fatty acids, alcohols, CO_2 and molecular hydrogen (this fermentation stage occurs when $pH<6$ and is called the acid fermentation stage), then the received fermentation products are processed with methane-generating bacteria. Methane fermentation occurs when $pH>7$ and is called the alkaline fermentation stage. Thus organic substances degradation during methanogenesis is a multi-stage process in which carbonic bonds are destroyed gradually as a result of activities of different groups of microorganisms.

According to the contemporary points of view anaerobic transformation of any complex organic compound into biogas undergoes five consecutive stages (Batstone et al., 2002): - the disintegration stage when complex cellular compounds disintegrate into separate biopolymers - proteins, lipids, polysaccharides, etc.; - the hydrolysis stage; - the fermentation stage; - the acetogenic stage (the duration of this stage generation is 5-12 hours); - the methane-generating stage leading to the final product of compound organic substances degradation – methane (the duration of generation of the methane-generating alkali fermentation stage is 7-10 days).

The hydrolysis stage presupposes disintegration of complex biopolymer molecules (proteins, lipids, polysaccharides, etc.) into simpler oligomers and polymers: amino acids, carbohydrates, fatty acids, etc. Hydrolysis is accomplished with exogenous enzymes evolved into the intercellular medium with different hydrolytic microorganisms. These enzymes activity leads to generation of relatively simple products which are actively utilized with hydrolytic organisms themselves and other bacteria groups at further methanogenesis stages /8/. The hydrolysis phase during methane fermentation is closely connected with the fermentation phase (acidogenic phase), hydrolytic bacteria accomplishing both phases and being sometimes united with fermentative bacteria /15/.

During the fermentation stage the generated monomers are further fermented into even simpler substances – low-molecular acids and alcohols generating carbonic acid and hydrogen as well. Fermentative or zymotic bacteria represent a complex mixture of many types of microorganisms, the majority part of them being obligatory anaerobes and performing best of all in the acidity range of pH 4,0 – 6,5 /13/. The anaerobic bacteria of the *Bacteroides, Clostridium, Butyrivibrio, Eubacterium, Bifidobacterium, Lactobacillus* genera and some other bacteria dominate /4/. The main characteristic of fermentative bacteria is their ability to utilize the same substrata as used with hydrolytic bacteria, that is the products of polymer compounds hydrolysis and sewage monomers, but in lower concentrations.

Generally the stage of fermentative bacteria activity considered as regards the periodic process is accompanied by acute decrease of carbohydrates concentration in the medium, decrease of the pH value of the medium, increase of total concentration of volatile fatty acids. The qualitative and quantitative composition of the fermentation products at this stage may change considerably depending on the sewage type, temperature, pH, Eh and other conditions. So, for example, when the delivery of substratum into the reactor increases drastically the excessive quantities of volatile fatty acids and hydrogen may be generated thus decreasing the pH and Eh values. Accumulation of volatile fatty acids and alcohols is extremely objectionable as their decomposition may serve as the limiting stage in the process /8/. The fermentative bacteria alongside with proteins, carbohydrates and fats metabolize phenol, nitrogen- and sulphur-containing compounds /8/.

At the acetogenic stage the main direct predecessors of methane are generated: acetate, hydrogen, carbonic acid. The obligatory proton-reducing or obligatory-syntrophic bacteria decompose the acidogenic phase products and as a rule need hydrogen-utilizing partners. The corresponding reactions for these bacteria are given in Table 3.1. Presently several obligatory proton-reducing bacteria utilizing fatty acids have been described (Boone and Bryant 1980; McInerney et al, 1979).

Table 3.1.

Anaerobic Oxidation of Reduced Substances with Obligatory Proton-Reducing Bacteria and Change of Gibbs Free Energy

Reaction Types	$\Delta G_0'$ kJ/gram-molecule
Without H_2 – utilizing methanogens	
$CH_3CH_2CH_2COO^- + 2H_2O \rightarrow 2CH_3COO^- + H^+ + 2H_2$	+48.1
$CH_3CH_2COO^- + 3H_2O \rightarrow CH_3COO^- + H^+ + 3H_2 + HCO_3^-$	+76.1
$C_7H_6O_2^- + 7H_2O \rightarrow 3CH_3COO^- + HCO_3^- + 3H_2$	+54.0
With H_2 – utilizing methanogens	
$CH_3CH_2CH_2COO^- + HCO_3^- + H_2O \rightarrow 4CH_3COO^- + CH_4 + H^+$	–39.4
$CH_3CH_2COO^- + 3H_2O \rightarrow 4CH_3COO^- + 3CH_4 + H^+ + HCO_3^-$	–102.4
$4C_7H_6O_2 + 19H_2O \rightarrow 12CH_3COO^- + 3CH_4 + HCO_3^- + 13H^+$	–190.8

The complicated process of organic substances degradation in anaerobic conditions is *finished with methane-generating archae or methanogens*. They are considered to be a separate branch of microorganisms' evolution and were formerly called archaebacteria (Balch et al., 1979). They are obligatory anaerobes and oxidation-reduction potential of their growth medium is 330mV and less (Pavuter & Hungate, 1968). The methane-generating microorganisms are divided into psychrophiles, mesophiles and thermophiles. The most favourable conditions for methanogens is pH 6.6-7.6 and constant pressure and temperature parameters, as well as absence of light.

Methanogens may utilize a limited number of substrata as energy and hydrogen sources – eight on the whole: carbonic acid summed with hydrogen, formate, hydrogen protoxid, methanol, acetate, mono-, di- and trimethylamines (Table 3.2). The main reactions of methane generation and changes of Gibbs free energy are given in Table 3.2. It is evident that it is due to the small value of ΔG_0 that a relatively slow growth of methanogens at the given substratum is observed. The most important one is acetate that generates more than 70% of methane when complex organic substances are decomposed. Acetate is followed by carbonic acid + hydrogen, formate, methanol, methylamines, methylcarbolamin, carbon oxide /8, 20/.

As methane-generating archae transform 90-95% of utilized carbon into methane, only 5-10% of carbon is used for the biomass growth. Due to the above-mentioned peculiarity up to 80-90% of organic substances decomposing while the methane-generating consorcium develops transform into gas.

All types of methane-generating organisms may be conditionally divided into 3 subgroups depending on the type of the substratum used /4/. The organisms of the first subgroup utilize $H_2 + CO_2$, the majority of methane-generating archae belongs to this group, some of them are also able to utilize formate. The second subgroup is represented by methanogens utilizing acetate. Reaction 3 from Table 3.2. may be performed with the representatives of two genera *Methanosarcina* and *Methanosaete* (former *Methanothrix)* exclusively, acetate being the only growth substratum of very close affinity for the latter. The *Methanosarcina* biomass doubles in 20-30 hours, the *Methanosaete* biomass doubles in 200-300 hours. Presently three species of *Methanosaete* have been described: two mesophile species *M. soehngenii* (Huser et al., 1980) and *M. concilii* (Patel, 1984) and one thermophile species *M. thermoacetophila* (Nozhevnikoba and Chudina, 1984). *Methanosaete* are the determining group of methanogens during liquid waste purification and are able to utilize acetate in very small concentrations thus ensuring the profound flow purification. *Methanosarcina* may be referred to the third subgroup; they are able to utilize all methanogenic substrata known at the moment except formate. The most preferable substratum for them is methanol and the least preferable one is acetate to which they have less affinity than *Methanosaete* do.

Table 3.2.

Main Methane-Generating Reactions and Changes of Free Energy

Main Methane-Generating Reactions and Changes of Free Energy	$\Delta G_0'$ kJ/gram-molecule	No.
$4H_2 + CO_2 \rightarrow CH_4 + H_2O$	–130,4	1
$4CHCOO^- + 4H^+ \rightarrow CH_4 + 2H_2O + 3CO_2$	–119	2
$CH_3COO^- + H \rightarrow CH_4 + CO_2$	–32,5	3
$4CH_3OH \rightarrow 3CH_4 + CO_2 + 2H_2O$	–103	4
$4CH_3NH_3^+ + 2H_2O \rightarrow 3CH_4 + CO_2 + 2NH_4^+$	–74	5
$2(CH_3)_2NH_3^+ + 2H_2O \rightarrow 3CH_4 + CO_2 + 2NH_4^+$	–74	6
$4(CH_3)_3NH_3^+ + 6H_2O \rightarrow 9CH_4 + 3CO_2 + 4NH_4^+$	–74	7
$4CO_2 + 2H_2O \rightarrow CH_4 + 3CO_2$	–185,5	8

3.2. Transformation of Organic and Non-Organic Nitrogen Compounds

Nitrogen organic compounds include proteins, amino acids, urea. Proteins concentration in sewage may be considerable. Proteins are disintegrated with chemoorganoheterotrophs and serve as a nitrogen and carbon source for biosynthesis of their cellular element, as well as an energy source for these organisms. Proteins may be disintegrated both in aerobic and anaerobic conditions. Disintegration of proteins begins outside the cell from the protein hydrolysis process, peptone being the hydrolysis product.

The hydrolysis process is accelerated under the influence of exoenzymes. Peptone enters the cell where it is oxidized to fragments of amino acids (utilized by the cell as "construction blocks"), to ammonia, carbonic acid and water; the intercellular processes are catalyzed with endoenzymes. The process of biological decomposition of amino acids into ammonia withdrawn into the environment is called ammonification (it is useful to remember that if the pH value is less than 9 then nitrogen in the form of ammonium prevails in water). Thus when proteins are disintegrated the ammonium nitrogen concentration in the system increases. Ammonium nitrogen accumulates in the purified water as well as a result of decomposition with the urea microorganisms: $CO(NH_2)_2$ (the product of proteins decomposition in man's and animals' organisms) $CO(NH_2)_2$ NH_4^+. In its turn ammonium nitrogen is the substratum component for aerobic microorganisms – chemolithoautotrophs that utilize ammonium salts nitrogen as a protons donor. The process of ammonium nitrogen transformation – nitrification – is accomplished with nitrifying microorganisms Nitrosomonas and Nitrobacter; the first transform ammonium nitrogen into nitrite nitrogen: $NH_4^+ \rightarrow NO_2^-$, the latter transform nitrite nitrogen into nitrate nitrogen during their metabolism: $NO^-_2 \rightarrow NO^-_3$. The following conditions are necessary for the nitrification process: available ammonium nitrogen; available dissolved oxygen (not less than 2 mg/dm^3 preferably); available CO_2. Nitrification is accomplished after the ammonification process has finished and has accumulated carbonic acid in the system. The following conditions are optimum for nitrification: the pH value ranging from 7,5 to 8,5; temperatures ranging from 20 to 25^{o}C; the organic substance sludge load must not exceed 0,05-0,2 BOD_{comp}/kg in the system (with complete nitrification at the first value and partial nitrification at the latter value).

Nitrate nitrogen utilizes elective anaerobes - denitrifying chemoorganotrophs - during its metabolism. The process of nitrate nitrogen transformation into nitrogen gases is called denitrification. Denitrification is accomplished according to the following reaction equation:

$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$.

Denitrifying organisms utilize organic substances as electrons and protons donors and bonded oxygen (that is nitrate oxygen) as an electrons and protons acceptor; oxygen is fixed with hydrogen and forms water and nitrogen transforms into nitrogen gases and redistributes between water and atmosphere according to the nitrogen partial pressure in the air. Denitrification is possible only if there is oxygen deficiency: being elective anaerobes denitrifying organisms utilize oxygen as a protons acceptor (that is, they switch to respiration) when there is sufficient amount of dissolved oxygen. The following conditions are necessary for denitrification: oxygen concentration of not more than 2mg/dm^3; nitrates available in the system; available readily disintegrated organic substances.

3.3. Transformation of Fats and other Carbohydrates

Fats hydrolyze in aerobic conditions into glycerin and fatty acids; the process is carried out outside the cell and accelerated under the influence of specific exoenzymes. Microorganisms utilize fats as a carbon and energy substratum.

$$\text{Fats} \xrightarrow{\text{exoenzymes}} \text{Glycerin + Fatty Acids} \xrightarrow{\text{endoenzymes}} CO_2 + H_2O + \text{cellular element}$$

Fats oxidation is 98% possible in aerobic conditions. In anaerobic conditions humous acids enter the environment besides CO_2 and H_2O. Besides bacteria fats are actively decomposed with actinomycetes and mycelial fungi. Microorganisms oxidize such complex substances as paraffin, caoutchouk, oil products, etc. as well. Oil products undergo biological degradation in aerobic conditions, they disintegrate into CO_2 and H_2O, organic acids are accumulated in the medium as well – they are the incomplete degradation products - valerian acid, acetic acid, citric acid, etc. Synthetic carbohydrates are very difficult to decompose; they accumulate polluting the environment.

The growth and biological activity of producers are determined with the environment factors in many respects. The main factors roles and methods of their management are given in Table 3.3.

Table 3.3

Main Environmental Factors Determining the Intensity of Microorganisms Metabolism

Factor	Factor's Role when Cultivating	Methods of Managing the Factor
1	2	3
Nutrients Composition and Concentration	Ensure metabolism of chemical reactions	Optimizing of the composition; the process continuity; multi-stage process taking into account the demand for producer at different phases
Products and Inhibitors Concentrations	Decelerate biochemical processes	Withdrawal of the metabolite. Dilution in order to decrease the inhibitor and other substances concentration.
pH	Optimizes the velocity of biochemical reactions	Regulation by adding an acid or alkali
Temperature	Optimizes the velocity of biochemical reactions	Cooling or heating of substrata
Osmotic Pressure or Environment Activity	Determines the life boundaries	Optimizing of nutrients concentration in media, maintenance of its constant level by dilution or concentration of the medium
Dissolved Oxygen Content	Ensures metabolism for aerobes, serves as a protons acceptor, inhibits the anaerobes development	Aeration intensity is controlled, anaerobic processes are accomplished in an oxygen-free medium by purging of carbonic acid or adding reducers

1	2	3
Carbon Dioxide Content	A carbon source for autotrophs; some heterotrophs need and some of them decelerate metabolism when carbon dioxide is available	Purging with carbonated gas medium, mixing promotes evolving
Mixing of the Medium	Uniform distribution of nutrients	Mechanical mixing, bubbling, circulation, aeration
Medium Viscosity	Determines the nutrients differentiation and mixing of the producer cells	Nutrients composition and biomass concentration are controlled. Viscosity affects mixing and aeration

Chapter 4. GENERAL ASPECTS OF USING MICROORGANISMS IN AEROBIC AND ANAEROBIC PURIFICATION OF SEWAGE

4.1. The Principles of Pollutants Biodegradation in Biofilters

At present, there exist different installations for biodegradation and transformation of organic and mineral substances in aerobic or anaerobic conditions. These installations are divided into plants with immobilized (fixed) microflora and plants with free-swimming microflora according to the type of contact between the treated water and colonies of microorganisms. Now there are many modifications combining both purification mechanisms in one installation. The basic variants of contemporary installations are classic biofilters, aerotanks and anaerobic bioreactors.

Aerobic biodestruction of organic pollutants in biofilters is accomplished by means of filtering sewage through the feed that gradually absorbs organic substances (pollutants) and sewage microorganisms. Thus, a so-called bioorganic-mineral complex forms which is called a biofilm in the biological purification technique. The surface of one kilogram of biomass occupies the area of 4000 m^2 . Immobilized (fixed) microorganisms absorb the substratum (nutrients) from sewage washing the feed. During metabolism they accelerate by means of exoenzymes the process of hydrolysis of complex substances to simpler ones with molecules smaller than those of bacteria. Hydrolysis products diffuse into the cell where they are further oxidized under the influence of endoenzymes in order to receive energy and simpler compounds utilized as construction blocks of cellular element. The oxidation products composition depends on the substratum composition and specific diversity of the biofilm-forming bacteria; carbonic acid and water are obligatory, sulphates, phosphates, ammonium nitrogen and nitrate nitrogen may be available in different quantities, as well as the incomplete decomposition products – different organic acids /21/. The metabolites that have not been utilized as construction materials enter the purified water. During the process of metabolism of microorganisms the bioorganic-mineral complex thickens. Some part of the microorganisms of the biofilm eventually dies off and loses their absorptive abilities. Both dead and live microorganisms that are washed out with the liquid flow from the filter body are withdrawn from the feed with the purified water when the biofilm thickness exceeds the critical value of 3 to 7 mm. If the biofilm thickness is more than 2-3 mm there exist aerobic and anaerobic zones in the biofilter (see Fig. 4.1.).

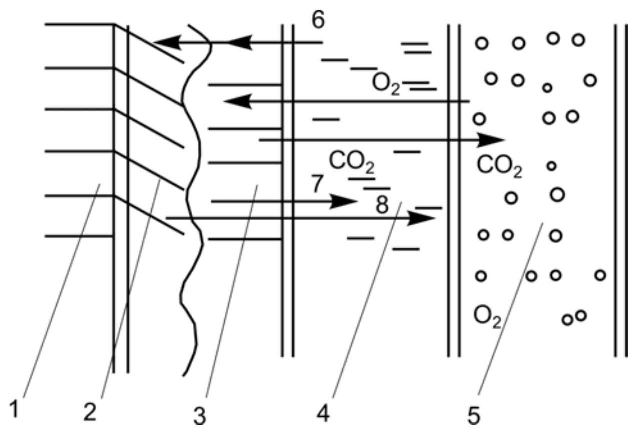


Fig. 4.1. Chart of Pollutants Biodestruction with Biofilm:
1 – feed; *2* – anaerobic layer of biofilm; *3* – aerobic layer of biofilm; *4* – liquid sewage; *5* – air layer; *6* – pollutants (substratum); *7*– metabolites of microorganisms of aerobic layer; *8* – metabolites of microorganisms of biofilm anaerobic layer

The specific content of the bacteria biofilm includes bacteria, actinomycete and protozoa. Fungi, worms, lower crustacea are available in insignificant quantities. The biofilm structure depends on its thickness (which is in its turn determined and limited with the hydraulic load on the biofilter and sewage composition) and on biofilters' height as well. The influence of the biofilm thickness and biofilter's height on the specific diversity of microorganisms is connected, first, with the oxygen diffusion and second, with the fact that the organic substratum concentration changes throughout the biofilter height. As a rule, the higher biofilter layers have the higher load of organic carbon as compared with the lower layers and oxygen is mainly consumed for oxidation of organic pollutants. In lower biofilter layers the load of organic substances on the biofilm decreases, carbonic gas and ammonium nitrogen (products of oxidation of nitrogen-containing organic substances) accumulate. Thus, the optimum conditions for the process of nitrification are ensured. If the biofilm thickness is more than 2-3mm anaerobic zones begin to form in its interior part. If the treated water contains nitrates that are an energy substratum for denitrifying microorganisms the favourable conditions for the process of denitrification are created.

4.2. Principles of Pollutants Biodegradation in Aerotanks

In aerotanks the microorganisms' population, the active sludge, is suspended in the treated sewage liquid. Bacteria, actinomycete and protozoa are the main participants of the purification process, algae and insects are not available, as a rule, and fungi and lower crustacea are available in insignificant quantities. Bacteria play the leading part in destruction of sewage organic substances. The increased portions of sludge in the aerotank as compared to its natural growth volume as a rule lead to starvation of bacteria cells in active sludge that enables fuller assimilation of incoming nutrients. According to the data by L.I.Gunter the pollutants consumption with active sludge corresponds to the formula:

$$p = 795\,\mu + 20{,}2 \text{ mg } BOD_5 \text{ g/h}.$$

If the growth rate vanishes then pollutants consumption corresponds to fasting metabolism (maintenance of living functions); the higher the specific growth rate and sludge growth, the more intensively destruction of organic pollutants progresses /2/. However when the sludge portion exceeds the critical amount its existence conditions aggravate drastically: the quantity of nutrients decreases, the conditions of mass transport of nutrients and oxygen deteriorate, metabolites accumulate, sludge growth reduces increasingly, the time of sludge presence in the system increases – sludge ages, the number of dead cells increases in it, it loses its activity.

In flowing systems operating on natural growth of biomass the growth will decrease until the specific growth rate of the culture equals the nutritious medium growth, thus the system regulates itself. Self-regulation also takes place in the aerotank and develops as a change in fermentative activity of cells. The purification process in the aerotank may be conditionally divided into four phases. The first phase is the phase of absorption of organic pollutants on the surface of active sludge flakes. It is the shortest stage of about 30 minutes duration. The second phase is the one of biodegradation of readily oxidized organic compounds, carbohydrates for example, when microorganisms receive the sufficient amount of energy further utilized for reactions of biosynthesis of cellular element. The process of biooxidation of organic substances during the second stage may be schematically presented with the following equation:

$$C_xH_yO_z + O_2 \rightarrow CO_2 + H_2O + \Delta H$$

(ΔH is the expression of energy evolved during organic substances oxidation). The second phase duration is 1 hour approximately. Nitrification is not observed as a rule during the second phase. The third phase includes biodegradation of heavily oxidized organic substances (proteins, fats, etc.). Active biosynthesis of cellular element progresses during the third phase and leads to an increase in the total quantity of biomass (in the water purification techniques this process is called active sludge growth process). The newly synthesized substance is determined by an empirical formula $C_5H_7O_2N$. The biosynthesis process may be schematically described with the following equation:

$$C_xH_yO_z + NH_3 + O_2 \rightarrow C_5H_7O_2N + CO_2 + H_2O.$$

The organic substratum transferring into the new cells amounts to 65%. This is a long-duration phase that can be from 3 to 20 hours long depending on the biooxidability rate of organic pollutants. Nitrification develops intensively during this phase. The fourth phase is the final one, the phase of sludge endogenous respiration. It is also called the phase of self-oxidation of sludge cellular element. The endogenous respiration process may be schematically presented with the following equation:

$$C_5H_7O_2N + O_2 \rightarrow CO_2 + H_2O + NH_3 + \Delta H.$$

The division of aerotanks processes into phases is rather relative, however, they have formed the basis for different systems and schemes of purification. Accomplishment of the first two phases is typical for incomplete biological purification (BOD_{comp} of the purified water is 15-20 mg O_2/dm^3). Accomplishment of the first three phases enables to complete biological purification (BOD_{comp} of the purified water is 5 mg O_2/dm^3). Accomplishment of all four phases is typical for prolonged aeration with complete oxidation of pollutants and partial self-oxidation of active sludge cellular element.

4.3. Principles of Biodegradation in Anaerobic Reactors

Sewage purification in anaerobic reactors is accomplished with a specific microorganism population – anaerobic sludge. Until recently utilizing methane fermentation has been considered appropriate for sewage sediments treatment exclusively because the process duration (several days) presupposes the considerable sizes of available reactors. In 1980s numerous researches have shown that in certain conditions formation of granular sludge is possible in bioreactors thus enabling the biodestruction with this type of sludge to finish in several hours (6-14); so this method can be used for sewage purification (Lettinga et al., 1980; Hulshof Pol, 1989; Alphenaar, 1994). However, this method hardly can be considered an alternative to aerobic biodegradation of organic substances as it is expedient when the initial pollutants concentration exceeds 2000 mgO_2/dm^3 (BOD_{comp}). Anaerobic purification may be used as the first stage of biological purification of highly concentrated sewage water with further purification and aftertreatment of sewage in aerobic conditions.

Formation of biomass aggregates is the result of microbiological, chemical and physical processes occurring at the boundary of division between the liquid and solid phases (Lettinga et al., 1980; Hulshof Pol, 1989; Alphenaar, 1994).

Formation of granular biomass in the UASB-reactor and other reactors with suspended sedimentating biomass (hybrid, ABR, AF, AFB reactors) is a unique phenomenon of self-organization of methanogenic microbial population (Lettinga et al., 1980; Guiot et al., 1988; Yoda et al., 1989). The acetate-utilizing methanogens have exactly those morphological peculiarities that enable them to create formed structures with other bacteria or mixed colonies.

There is no exact morphological classification of granular methanogenic biomass yet. Taking into consideration intermediate forms three main types of granules are determined (de Zeeuw, 1988): - A type: compact spherical or disk-shaped thick granules consisting of Metanosaete filaments. They usually form if the substratum with high content of volatile fatty acids is available, including pre-acidified sewage under two-stage anaerobic treatment (Hulshof Pol, 1989; Kalyuzhnyi et al., 1996;) - B type: big and not so thick spherical granules containing different types of microorganisms, Metanosaete filaments basically, often fixed to inert particles. They form when wastewater from diary industry plants (Kalyuzhnyi et al., 1997a) and breweries or non-alcoholic beverage plants (Kalyuzhnyi et al., 1997b) is treated; - C type: small and somewhat loose roundish granules, Methanosarcina basically. They form in systems with high loads, with high acetate loads in particular, for example, in manure flow (Kalyuzhnyi et al., 1998) or in vinic flow at low temperatures (Gladchenko, 2001).

There are pores of different sizes on the surface of all types of granules that serve for substratum transportation and biogas withdrawal. When counted the concentration of microorganisms in granules turned out to vary from 1 to $4x10^{12}$ cells per gram of granules dry matter (Duborguier et al., 1988), including methanogens in the amount of up to 10^{10} cells per gram of granules dry matter (Kalyuzhnyi et al., 1996).

Electron-microscopic study of granules internal composition showed that archae of the *Methanosaete* genus formed a considerable part of the microbial biomass of granules (Duborguier et al., 1988; Kalyuzhnyi et al., 1996). Wiegant suggested the “spaghetti theory” explaining the granule formation on the basis of *Methanosaete* (Wiegant, 1988). According to this theory Methanosaete filaments form microscopic bunches (joints, balls). A large number of morphologically various bacteria forms, often colonies, are inside the granules between the Methanosaete filaments. Bunches of Methanosaete filaments often leave the boundaries of already formed granules and may break thus forming new compact rod-shaped granules that develop further, grow and become spherical or disk-shaped. Due to a thick layer of glycocalyx microscopic colonies of Methanosarcina form a pseudo-parenchyma, other bacteria living in its intercellular spaces. Other authors think also that Methanosaete aggregates may serve as secondary nuclei for granules formation (Yoda et al., 1989). Hulshof Pol, a researcher from Holland, came to the conclusion that as no feed was entered into UASB-reactors, microparticles of inert organic and non-organic substances served as centers or nuclei for initiation of granules formation, as well as readily forming sediment bacterial aggregates from inoculum sludge, Methanosaete being the dominating organism in granules (Hulshof Pol, 1989).

The main advantage of granules is their sufficiently high density and ability to form sediment. The density of granules decreases with the growth of their sizes and they disintegrate into smaller particles (Beefting, 1987). Electron-microscopic analysis has shown availability of intercellular polymers as capsules on the surface of granules, as well as that of fibers. These polymers may include proteins, liposaccharides, substances forming cellular walls and lyzed cells capsules. The mineral composition of granules varies widely (Hulshof Pol, 1989).

One of the most important characteristics of anaerobic sludge is its methanogenic activity; its value can help to calculate theoretical organic load on the reactor (or on the known amount of sludge) per day and thus optimize its performance and to prevent its overloading, especially in the launching period. Methanogenic activity depends on the sewage composition: the more volatile fatty acids in the initial substratum, the higher methanogenic activity. The more complex the treated sewage composition is, the more acidogenic microorganisms are contained in granules and the lower the value of specific methanogenic activity is. According to the data of Hulshof Pol (Hulshof Pol, 1989), in the mesophile conditions (30 ^{o}C) the value of specific methanogenic activity of sludge reached 1kgCOD/kgBA/day for non-preacidified substrata and 2,5 kgCOD/kgBA/day for sewage containing a mixture of volatile fatty acids. For thermophilic granules grown at 55 ^{o}C on the acetate and butyrate mixture and consisting of *Methanosaete* mainly the activity value reached 7,3 kgCOD/kgBA/day (Wiegant and de Man, 1987). The granules methanogenic activity may decrease even if the conditions of their decomposition are very sparing.

The process of anaerobic purification of sewage is influenced with the phase and chemical substratum composition, the pH value of the medium, availability of toxic substances, hydrodynamic and temperature conditions.

Sewage water is classified into sewage with low concentration (1-5 kgCOD/m^3), concentrated sewage (5-20 kgCOD/m^3) and highly concentrated sewage (more than 20 kgCOD/m^3). The substratum concentration value determines the value of biomass growth per volume unit during sewage purification. Using the value of the biologically decomposable part of COD flow one may determine the expected methane yield and vice versa, the methane volume value may give the expected value of COD of the treated flow. COD decrease by 64g theoretically corresponds to formation of 1 gram-molecule of methane (1g COD=0,35 dm^3 of methane in normal conditions) (Kalyuzhnyi et al., 1988). A considerable content of suspended substances affects the anaerobic reactors performance negatively. Thus, for example, there is a danger of forcing of active biomass flocculi from the reactor increasing the sewage treatment time and complicating the installation design. It is advisable to carry out the preliminary treatment of sewage with insoluble substances and solid particles to prevent swelling and destruction of active granules, sludge flotation and floating, such treatment including settling or acidogenic phase hydrolysis. The volatile fatty acids concentration influences greatly the microbial composition of granules. When 1g/dm^3 of acetate was contained in the model flow the granules were observed to develop in the thermophilic conditions, the *Methanosarcina* genus dominating (Kalyuzhnyi, 1990). When the volatile fatty acids concentration is less than 200 mg/dm^3 thick granules of regular shape form (Hulshof Pol, 1989). It was observed that on the media with saccharides as their main substratum granules developed faster and they had larger sizes (up to 5 mm in diameter) as compared to volatile fatty acids substrata. It was accounted for by the fact that the biomass growth rate was higher on carbohydrates than on volatile fatty acids (Hulshof Pol, 1989).

The best inoculum for anaerobic reactors is granular sludge from reactors operating on the same flow. Fermented sludge from municipal methane tanks is often used as inoculum when launching reactors. The stable performance of anaerobic reactors depends greatly on the pH value and its stability, pH 7.0 – 8.0 being the optimum range.

The surge capacity of the reactor liquid phase is also important. The larger the capacity is, the more effectively the reactor medium opposes the sudden changes of pH in the system. When the reactor is performing stably the pH value is maintained spontaneously due to mutual balance between the acidification and alkalization processes. Acidification occurs as a result of generation of volatile fatty acids first of all, as well as of formation of hydrogen sulphide and carbonic acid when CO_2 is hydrated. Alkalization of the medium occurs by means of consumption of volatile fatty acids and deaminization of nitrogen-containing compounds /8/.

The growth of methanogenic population cells depends on receipt of nutrients including organic substances and mineral salts. The C/N ratio is very important, its optimum value varies from 20/1 to 100/1. It is connected with the activity and vital functioning of microorganisms of the methanogenic consorcium (Lettinga and Hulshof Pol, 1992). Besides, the calcium ions of 100-200 mg/dm^3 concentration were shown to stimulate the methanogenic activity of anaerobic sludge and ions of 250 mg/dm^3 concentration and more (McCarty, 1964) were shown to inhibit it. Sodium is an integral mineral component for microorganisms' growth and granules development. Microelements (especially iron, cobalt, nickel, manganese) available in the medium were shown to have a strong and positive impact on the granules formation process (Guiot et al., 1988).

The methanogenesis process intermediates (hydrogen, volatile fatty acids) and associated products intermediates (ammonia, hydrogen sulphide) may serve as inhibitors. The simplest method to eliminate the toxic affect of substances is replacement of the toxic liquid phase in the reactor or its dilution /8/.

The hydrodynamic conditions in the reactor determined with treated sewage flow rate are important for formation of granules and granular sludge development.

The regulation of the flow schedule is especially important when the reactor is launched and granular biomass forms and accumulates in it. Because of many observations of launching of laboratory reactors inoculated with dispersed sludge a general pattern of changes in sludge amount was marked. At first the mass decreases by 25-75 % as a result of small particles and cells washout (Alphenaar, 1994; Hulshof Pol, 1989), that is why it is prohibited to increase considerably the flow rate at this stage of launching. Usually during the first month the duration of the liquid presence in the reactor approximates 24h. As the biomass concentration grows in the reactor the flow rate and organic load increase gradually. Specific methanogenic activity of sludge grows gradually reaching the constant level at the time of stabilization of the methanogenic population.

The appropriate mass transport inside the reactor is the obligatory condition for intensive progress of the anaerobic conversion process, which is necessary for effective transport of substrata to microorganisms, elimination of local aggregates of intermediates and fast distribution of fresh flow inside the reactor.

The methane-generating processes may progress at certain temperatures, the main temperature ranges are the following three: the psychrophilic conditions progressing at temperature less than 20 ^oC, the mesophilic conditions progressing at temperature of 20 - 45 ^oC and the thermophilic conditions progressing at temperature of 45 – 70 ^oC. The temperature conditions influence the process velocity without influencing the final product composition. The higher the temperature is, the higher biochemical processes velocities are, so the thermophilic processes are as a rule 2-3 times faster than the mesophilic ones (Mkinerni et Briant, 1990; Tanala et al., 1984). However, notwithstanding the high velocities of processes in thermophilic reactors the received profit is often not large enough to compensate the cost of additional power consumption necessary for maintenance of optimal temperatures for this process.

One more drawback is a relatively poor species composition of microflora that accounts for less stability of the thermophilic conditions as compared to the mesophilic ones. While the mesophilic conversion combines both reasonable velocities of the process (due to the more varied species composition of microflora) and lower energy consumption (sewage water's temperature is 15-25 ^oC in the majority of cases). Lately anaerobic psychrophilic treatment has attracted certain interest; sewage is treated at the flow temperature that seldom differs much from the environment temperature. However low fermenting temperatures cause certain difficulties at the moment of launching of the reactor, which may be overcome if the reactor is launched in the mesophilic conditions and then transferred to lower temperatures /8/.

Kinetic parameters for some of the main substrata as well as for the main groups of microorganisms and for anaerobic sludge on the whole are shown in Tables 4.1 and 4.2 /8/. Kinetic parameters of growth form the direct basis for main technological principles of anaerobic purification.

Low values of specific methanogenic activity of the methane biocenosis taken on the whole (see Table 4.2) demand high biomass concentration inside the reactor for intensive purification. The considerable difference in growth rates and metabolism rates of acidogenic and methanogenic microorganisms is often critical as well (Table 4.2) as it sometimes leads to the so-called “souring” of anaerobic fermentation at the disbalance of development of both populations. Low rates of the biomass dying-off are an important technological advantage of anaerobic sludge as compared to aerobic sludge because they enable to keep anaerobic sludge (especially granular sludge) for a sufficiently long period without delivery of sewage to the reactor which is principal for seasonal industries (Kalyuzhnyi et al., 1991).

Table 4.1

Numerical Values of Kinetic Parameters
for Some Substrata of Anaerobic Fermentation

Substratum Type	Temperature, ^oC	Y, kgBA/kg COD	μ_m, day^{-1}	K_s, $kgCOD/m^3$	b, day^{-1}
Glucose	37	0.173	5.19	0.023	0.8
Acetate	25	0.05	0.235	0.869	0.011
Acetate	30	0.054	0.259	0.333	0.037
Acetate	35	0.04	0.365	0.154	0.019
Propionate	25	0.051	0.5	0.613	0.04
Propionate	35	0.042	0.403	0.032	0.01
Butyrate	35	0.047	0.733	0.005	0.027
Higher Volatile Fatty Acids	20	0.12	0.462	1.58	0.015
Higher Volatile Fatty Acids	25	0.12	0.558	1.27	0.015
Higher Volatile Fatty Acids	35	0.12	0.8	0.68	0.015

Table 4.2

Numerical Values of Kinetic Parameters for Different Groups of Microorganisms

Substratum Type	Temperature, °C	Y, gBA/kg COD	μ_m, day^{-1}	K_s, kgCOD/m^3	b, day^{-1}
Acidogens	35	0.15	2.0	0.2	0.4
Methanogens	35	0.03	0.1 – 0.4	0.05	0.02
Anaerobic Population on the Whole	35	0.04 – 0.08	0.1 – 0.4	0.1	0.03

Low energy output of methane biocenosis reactions account for low growth of biomass during anaerobic wastewater purification. During the glucose methanogenesis the overall reaction is:

$$C_6H_{12}O_6 \rightarrow 3CH_4 + 3CO_2 + \text{biomass} + \text{heat}$$

Only 8 % of energy is utilized for biomass growth, 3% constitute heat loss and 89 % transfer into methane /8/. In anaerobic processes only 0.1-0.2 kg of sludge forms for every removed BOD kilogram. Thus, in anaerobic processes considerably lower growth of microorganisms' biomass practically cancels the problem of sludge treatment and utilization, besides this biomass loses water well.

Treatment of excessive anaerobic sludge makes no problem at all. High initial content of dry matter (up to 100g/dm^3), high ash percentage and stability, good water-losing qualities and, as a rule, its small quantities enable to dewater sludge without reagents either by means of centrifuges, belt filter-presses and other mechanisms or at sludge beds (under high loads). Anaerobic sludge forming during purification of food industry wastewater is a high quality organic-mineral fertilizer, which may be used without particular limitations. Anaerobic sludge in itself does not contain pathogens and thermophilic sludge is rich in vitamin B_{12}, so it can be used as a food additive to fodder of livestock /6/.

Granular sludge of high quality from many installations is successfully utilized as an inoculum for launching of new plants using the same flows.

The low energy output during methane fermentation accounts, in particular, for the important characteristic of microorganisms of methane biocenosis: the ability to do without any substratum for a long time (for months) and reestablish its activities fast after nutrition resumes /8/.

Chapter 5. STUDY OF EXISTING INSTALLATIONS OF BIOLOGICAL PURIFICATION

5.1. Biological Filters (Aerobic Conditions)

A biological filter is a sewage purification installation filled with feed; sewage water filters through this feed and a biofilm forms on its surface. The difference between the sewage and the air temperatures guarantees the continuous ventilation of the atmospheric air through the filter feed thus constantly ensuring the oxygen concentration sufficient for the microorganisms' activity.

The feed is the most important part of the filter. According to the feed type, all biofilters are divided into two categories – with volumetric feed and flat feed. In biological filters with volumetric feed crashed solid rock, pebble, slag, haydite is used, in filters with flat feed plastic is used that is capable of withstanding the temperature of 6 – 30 ^{o}C without losing its durability.

The filter's flow capacity is determined first of all with the following factors: the area of the biofilm surface and the free access of oxygen to the biofilm. The more the area of the biofilm surface is and the easier oxygen obtains access to it, the higher the filter's flow capacity is. According to the filters' common classification there are the following types of biofilters with volumetric feed – trickling biofilters, high-rate biofilters and multistage towers, and the following types of biofilters with flat feed – with rigid filling feed, rigid block feed and soft feed.

According to the reference data not only is the intensity of degradation of heavily oxidized organic substances in biofilters not less than in aerotanks, but sometimes it is even higher (Table 5.1) /19/. Biofilters are used to purify household sewage and industrial wastewater. For example, wastewater from a wood rosin plant, shale thermal processing plant, production of dimethylterephthalate, ethylene oxide, chloroprene rubber has been purified by means of trickling biofilters with the 1,5m high feed and natural aeration. Pollutants concentration in the primary sewage was from 320 to 580 mg/dm^3 and did not exceed 25 mg/dm^3 in the treated water. The oxidizing capacity of trickling biofilters varied from 400 to 580 BOD_{comp} per 1 cubic meter of the installation per day. When the biofilter height was 4m and the purification efficiency from 250 to 25 mg/dm^3 BOD_{comp}, the oxidizing capacity was 7-9 g BOD_{comp} per 1 m^3/day /22/.

The research of the St.Petersburg University of Architecture and Civil Engineering (SPUACE) showed that biofilters treated wastewater from a meatpacking factory and a diary plant more stably than aerotanks. The above-mentioned wastewater contains highly concentrated readily decomposed organic substances, lactose for example, that leads to development of filamentous bacteria causing the sludge “swelling” and preventing stable performance of the final settler. In biofilters the development of filamentous bacteria and colonies of lower fungi in the feed upper part may lead to the feed sludging, however, it can be prevented by means of raising the hydraulic load (due to the increase of recirculation ratio) and decrease of the mixture BOD value (in this case the experienced development of lower fungi colonies turned out to stop) /19/. The research to determine the influence of the wastewater pH value on stability of biofilters performance is also interesting. S.M. Shifrin and his colleagues (1981) showed that a diary plant wastewater pH was 4,6 – 9,4 , the value being determined with whey and discharge detergent solution; acid and alkali wastewater influenced the biofilm composition leading to intensive growth of filamentous bacteria in particular. However, no deterioration in biological filters performance was observed. The preliminary neutralization of the primary wastewater to pH 7 did not enhance the purification efficiency. Neither was deterioration in biological filters performance observed when unclarified wastewater with suspended substances concentration up to 450 mg/dm^3 was delivered The removal of excessive biofilm increased 2-3 % as compared to purification of clarified wastewater /19/.

In an ordinary biofilter the processes of nitrification and gentrification may progress alongside with biodegradation of organic substances. The biocenosis of the biofilter upper part has high organic loads, that is why in this part of the biofilter a biofilm forms that consists of heterotrophs oxidizing organic substances intensively. As wastewater moves along the feed sorbing organic substances, the organic load on the biofilm decreases and the conditions for autotrophs – nitrifying microorganisms form, these bacteria transforming ammonium nitrogen into nitrite and nitrate nitrogen. If the biofilm thickness exceeds 4-5mm the biofilm inner layer is depleted of oxygen and anaerobic heterotrophs develop in anaerobic conditions, including denitrifying microorganisms that transform nitrate nitrogen into molecular nitrogen and other volatile forms of nitrogen.

Trickling biofilters are usually designed in a rectangular shape with sewage driven from above onto the feed surface by means of distribution mechanisms of different types (Fig. 5.1).

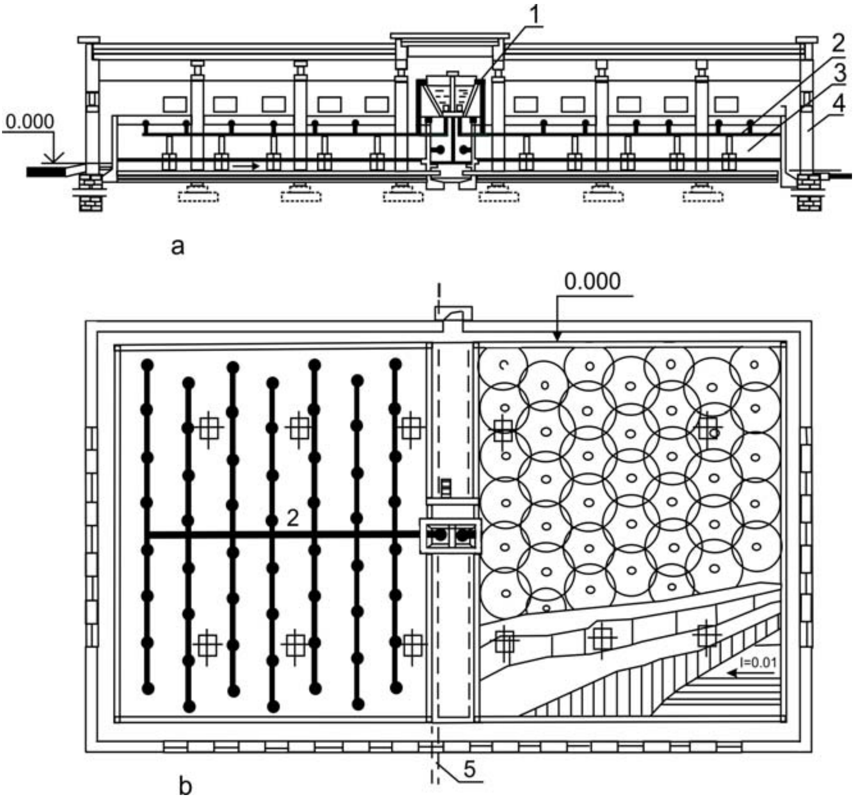


Fig. 5.1. Trickling Biofilter
a – Cross Section; *b* – Plan; *1* – Dosing Tanks for Wastewater;
2 – Sprinklers; *3* – Feed Material; *4* – Biofilter Walls;
5 – Wastewater Delivery into Biofilter.

The filtering layer may be composed of crushed stone or gravel (25 to 80mm in size) or of separate structures consisting of spatial plastic elements /23/. Relatively small linear dimensions determine the considerable value of the specific surface (150-250m^2/m^3) predetermining high rates of pollutants removal, while utilizing large-sized feed decreases the possibility of the installation sealing. These filters do not require mandatory aeration; the air comes through the holes of the feed-supporting grate on the filter bottom. In order to increase the purification efficiency, especially when the flow varies considerably, it is advisable to ensure the recirculation of the already treated sewage through the installation. The biofilm is washed out during the biofilter performance. The excessive amount of the biofilm is to be assumed as 8g dry matter/(man day). The humidity of the biofilm removed from the biofilter is 96%. Final settling tanks are installed to retain the biofilm. When the sewage BOD_{comp} is more than 220 mgO_2/dm^3 the recirculation of sewage should be foreseen. The recirculation ratio is:

$$n = \frac{L_{tn} - L_{cm}}{L_{cm} - L_{ex}}; \; L_{cm} = K_{bf} L_{ex} \; K_{bf} = L_{en}/L_{ex.}$$

Such biofilters may be utilized for both organic pollutants removal and accomplishing of the nitrification process, the latter case requiring installation of the biofilter of the 1^{st} and the 2^{nd} stages. The Handbook on Modern Purification Techniques and Equipment for Natural Water and Sewage (Danish Cooperation for Environment in Eastern Europe) recommends utilizing biofilters for preliminary purification of highly concentrated sewage /16/. In this case, an installation with the 2 kg BOD/m^3 day load may be operated if plastic feed is used.

Trickling biofilters may ensure up to 80 % BOD decrease, BOD concentration may be less than 30 mgO_2/dm^3 in treated sewage (Construction Norms and Regulations 2.04.03-85, par. 6.129 shows that BOD_{comp} pollutants residual concentration may be assumed as 15 mgO_2/dm^3) and ammonium nitrogen concentration may be less than 2 mg/dm^3.

The trickling biofilter disadvantages becoming apparent during operation are: the possibility of the feed sludging; susceptibility to temperature fluctuations; impossibility to achieve low BOD values of purified sewage even when organic load is low; relatively high capital outlays.

High-rate biofilters (aerofilters) have higher oxidizing capacity than trickling filters that equals 0,75 – 2,25 kgBOD/(m^3 day) and is conditioned with better air renewal and non-sludging of feed which is achieved by means of utilizing the 40-70 mm large feed, increase of the feed operating height to 2-4m and hydraulic load to 10-30 $m^3/(m^2 day)$ /16/ (Fig.5.2).

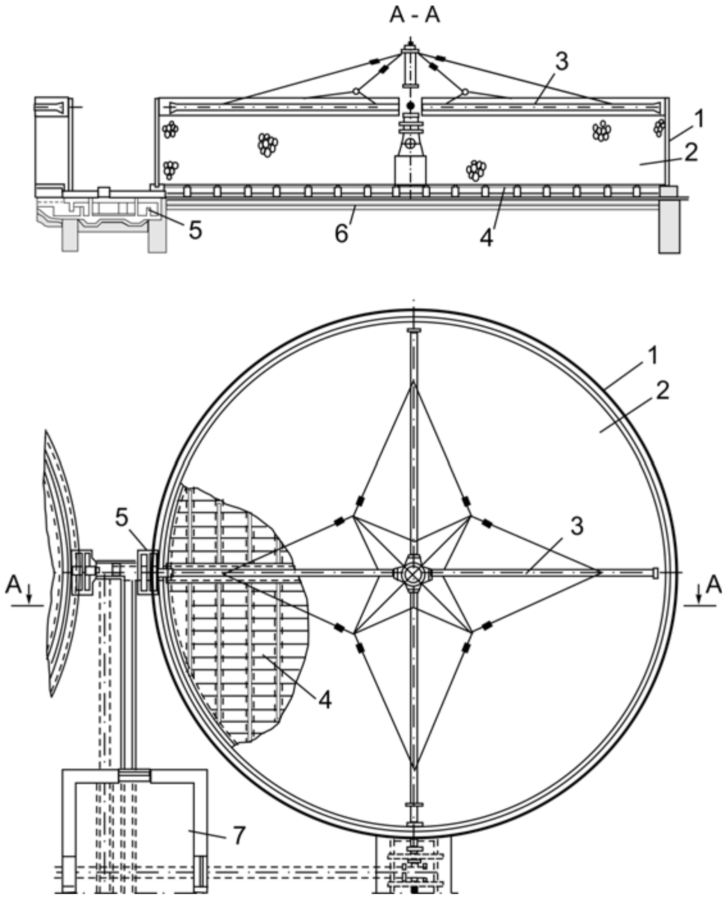


Fig. 5.2. High-Rate Biofilter
1 – Body; *2* –Feed; *3* – Reactive Sprinkler; *4* – Drain Grate;
5 – Hydraulic Gate; *6* – Uniform Bottom; *7* – Air-Ventilation Chamber

High-rate filters may have natural and mandatory aeration; filters using the latter type are called aerofilters. The excessive amount of the biofilm removed from high-rate biofilters should be assumed as 28 g dry matter/(men day), the biofilm humidity being 96 % /17, 23/.

The high-rate biofilters parameters are calculated in the following order:

– the K ratio is determined: $K = L_{en}/L_{ex}$; - the biofilter height H, the hydraulic load and air consumption values are determined using the value T of the average winter temperature of sewage and the found value K (Table 38 of Construction Norms and Regulations 2.04.03 – 85);

– for purification without recirculation these parameters should be assumed according to the nearest larger value of K, for purification with recirculation – according to the smaller value of K. For purification without recirculation, the biofilter area is determined according to the formula:

$$f = \frac{Q}{q}, \text{ m}^2.$$

For purification with recirculation, the allowable BOD_{comp} of the mixture of incoming and recirculated sewage delivered to the biofilter is determined – L_{cm}; in this case, the biofilter area is determined according to the following formula:

$$f = \frac{Q}{q}(n+1), \text{ m}^2.$$

Recirculation is used when the sewage BOD_{comp} is more than 300 mgO_2/dm^3.

When the high-rate biofilters parameters for sewage with temperatures lower than 8 and higher than 14 °C are calculated $K = 10^{\alpha F + \beta.}$

where $F = HB^{0,6}K_T/q^{0,4}$: is the criterion complex; $K_T = 0,2x1,047^{T-20}$ is the constant of the air consumption; α and β are coefficients assumed depending on the specific air consumption and the criterion complex value.

Anthracite, sand, shale, pumice may be used as the feed material, the diameter of particles being 4-8 mm usually. The direction of the water flow may be both downward and upward.

If the aerofilter parameters are calculated taking into consideration the nitrification process, the following parameters are determined: ammonium nitrogen load in kg of NH_4-N/m³ feed per day (0,3 – 2,0 kg of NH_4-N/m³ feed per day) and hydraulic load – 3 – 15 m³/m² per hour. If the aerofilter is correctly designed the BOD_5 pollutants removal may reach 90% and more (BOD_5 of the treated water being less than 20 mgO_2/dm^3 and the suspended substances concentration being 25 mg/dm³ and less).During the nitrification process the ammonium nitrogen concentration in the treated water is less than 2 mg/dm³, the suspended substances concentration is less than 15 mg/dm³. Power consumption for operation of aerated filters is comparable to power consumption for operation of active sludge systems. The excessive biomass is to be aftertreated in order to prevent unpleasant smells. Aerofilters have inconsiderable susceptibility to temperature fluctuations and stable quality of the purified water.

Filters with flat feed.

In order to increase the biofilter flow capacity the flat feed with 70-90 % porosity is used. The effective surface for biofilm formation makes up 60 to 250 m^2/m^3 of feed. This is the main fundamental difference of flat feed biofilters from volumetric feed biofilters (Fig. 5.3).

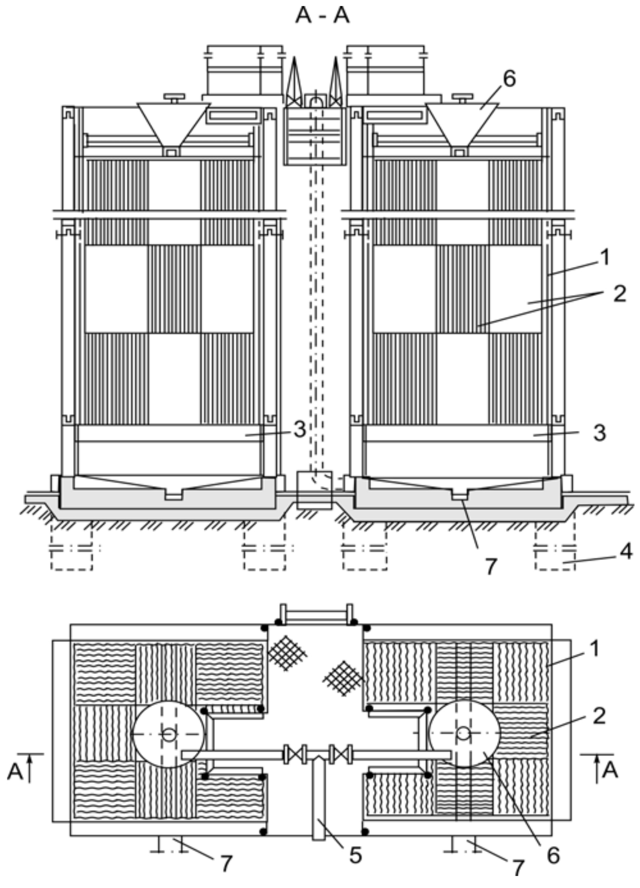


Fig. 5.3. Flat (Plastic) Feed Biofilter with 200 m^3/day Flow Capacity
1 – Body of Asbestos Cement Sheets on Metal Frame; *2* – Plastic Feed; *3* – Grid; *4* – Concrete Column Supports; *5* – Supply Pipe; *6* – Reactive Sprinkler; *7* – Discharge Chutes

The method of calculation of the flat feed biofilters parameters was suggested by Prof. Yu.V. Vorontsov who introduced the notion of criterion complex $\eta = PHK_T/F$.

Where: P is the feed material porosity, in %; H is the biofilter height, in m, assumed depending on the required purification degree, but not less than 3 – 4 m; K_T is the temperature constant of oxygen consumption, $K_T = 0{,}2 \cdot 1{,}047^{T-20}$; T is average winter temperature of sewage; F is the amount of BOD_5 organic pollutants per day per unit of the surface area of the biofilter feed material, g/(m^2 day),

$$F = \frac{L_{en} q_n}{S_{sp}}.$$

Where: S_{sp} is specific surface of the feed material, m^2/m^3; q_n is hydraulic load, m^3/m^3 of feed per day.

The criterion complex values depending on the pollutants residual concentration L_{ex} are given in Table 5.1.

Table 5.1

The Criterion Complex Values Depending on L_{ex}

L_{ex}, mgO_2/dm^3	η	L_{ex}, mgO_2/dm^3	η
10	3.30	35	1.60
15	2.60	40	1.45
20	2.25	45	1.30
25	2.00	50	1.20
30	1.75		

The biofilter height may be calculated according to the L_{ex} value: when L_{ex} = 11 mg/dm^3, $H = 3F/PK_T$.

When calculating the biofilter parameters first the criterion complex is determined according to Table 5.1, then the value of $F = PHK_T/\eta$ is determined; then the allowable hydraulic load $q_n = FS_{sp} / L_{en}$ is determined at the initial value of L_{en} and the value of structural specific surface S_{sp}; then the biofilter feed material volume, the number of biofilters and their construction dimensions are determined with the given value of daily discharge Q m^3/day and calculated value of q_n.

The calculation parameters for flat feed biofilters are given in Tables 5.2 and 5.3 for blocks with 93 – 96 % porosity; S_{sp} = 90 – 110 m^2/m^3; L_{en} = 200 – 250 mg/dm^3.

Table 5.2

Allowable Hydraulic Load on Flat Feed Biofilters

Required Purification Efficiency, %	Hydraulic Load, $m^3/(m^3$ of Feed, m day), at Layer Height, m							
	3				4			
	and Average Winter Temperature of Sewage, °C							
	8	10	12	14	8	10	12	14
90	6.3	6.8	7.5	8.2	8.3	9.1	10	10.9
85	8.4	9.2	10	11.0	11.2	12.3	13.5	14.7
80	10.2	11.2	12.3	13.3	13.7	16.4	16.4	17.9

The flat feed biofilter is as a rule placed in a closed space. The allowable BOD_{comp} value of the incoming sewage is 250 mg/m^3 during complete biological purification and is not limited during incomplete biological purification.

Table 5.3

Allowable Organic Load on Flat Feed Biofilters

BOD_5 of Treated Water, mg/dm^3	BOD_5 $g/(m^3day)$ Load, at Feed Layer Height, m					
	3			4		
	and Average Winter Temperature of Sewage, ^{0}C					
	10–12	13–15	16–20	10–12	13–15	16–20
1	2	3	4	5	6	7
15	1150	1300	1550	1500	1750	2100

1	2	3	4	5	6	7
20	1350	1550	1850	1800	2100	2500
25	1650	1850	2200	2100	2450	2900
30	1850	2100	2500	2450	2850	3400
40	2150	2500	3000	2900	3200	4000

However, the hydraulic load range for flat feed biofilters recommended in Construction Norms and Regulations 2. 04.03. – 85 and ensuring the stability of purification efficiency may be somewhat enlarged. According to the end of the 1970s – beginning of the 1980s research a biofilm with stable composition was shown to form easily on the feed surface when hydraulic load was changed from 5 to 120 $m^3/(m^2$ day); the purification efficiency being 60% at large values of hydraulic load (Porcalowa Petra, 1978). The Japanese scientists when studying superhigh-rate biofilters with the 10-40 circulation ratio and 150 – 250 m^3 /(m^2 day) hydraulic load (Endo/ I, Tamura T, 1980) supported these data.

According to the data by S.V. Yakovlev and Yu.V. Voronov (Biological Filters, 1982) the change of hydraulic load within the range of 10 – 32 (m^3/ m^2 day) does not considerably influence the biofilm microflora. When the load is more than 32 $m^3/(m^2$ day) the decrease in the number of rotifera and worms was observed alongside with the decrease in the number of large forms and increase in the amount of smaller forms of ciliates.

The reference literature review established that already in the 1970s experiments on purification of unclarified sewage by means of plastic feed biofilters proved it was possible to achieve the quality of the treated water close to that of the water purified by means of complete biological oxidation installations with active sludge (according to the data by Ya.A. Karelin et al., Sewage Purification Installations in Eastern Europe Countries, 1977). The disadvantage of this method is the necessity of large 20-times recirculation of sewage enabling to complete biological purification due to the liquid aeration with the air oxygen during the sprinkling of the biofilter feed.

For high-rate biofilters recirculation may be necessary and useful to achieve the 50-70% purification efficiency and unprofitable at higher efficiency percentage as the increase of the recirculation ratio above the established limits may lead only to insufficient increase of the purification efficiency.

The comparative assessment showed that flat feed biofilters productivity and efficiency were larger than those of volumetric feed biofilters. If the oxidizing capacity of a trickling biofilter was 0,15 – 0,25 kg/(m^3 day) and of a high-rate biofilter is 0,6 – 0,7 kg/(m^3 day), the oxidizing capacity of a flat feed biofilter might achieve 1,9 kg/m^3 day. The best economic results were obtained when flat feed biofilters were used for incomplete biological purification. For example, the American researchers data showed that within the BOD value range from 3 to 14 kg/m^3 day the BOD value decreased by 53% on average, in other words the taken BOD oxidizing capacity achieved 7kg/(m^3) when treating wastewater from freezing factories and pulp and paper mill. S.V. Yakovlev when processing numerous biofilters researches results received the similar data. According to the reference data (S.V. Yakovlev, T.A. Karyukhina, 1980) the oxidizing capacity during incomplete biological purification (50 – 80%) may reach 3 – 16 BOD_5/(m^3 day). Thus, we can say that the maximum values of the feed oxidizing activity are achieved when the BOD_5 purification efficiency is 50 – 70%. The increase of the purification efficiency value above 70% is connected with considerable increase in the biofilter dimensions and power consumption.

The biofilters-stabilizers developed by the Sewage Department at the St.Petersburg University of Architecture and Civil Engineering (former SPUACE) represent a modification of flat feed biological filters (Fig. 5.4).

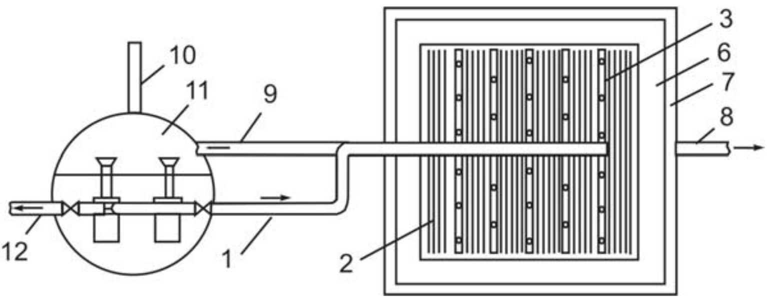


Fig. 5.4a. Biofilter-Stabilizer Chart. Operation Chart

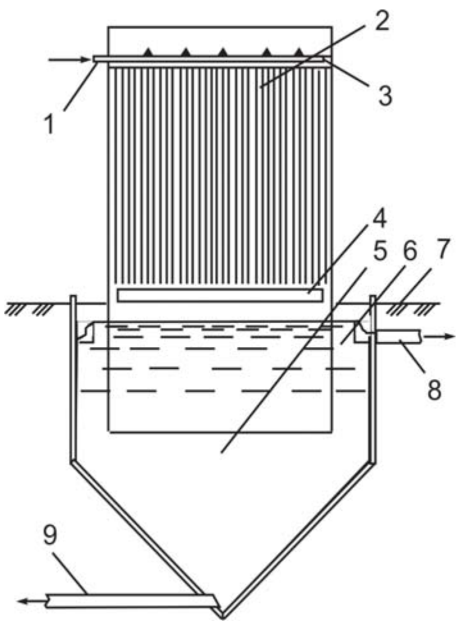


Fig. 5.4b. Biofilter-Stabilizer Chart. Sectional View
1 – Liquid Supply Pipe; *2* – Biological Filter with Plastic Feed; *3* – Sewage Distribution System; *4* – Ventdoors; *5* – Stabilizer; *6* – Settling Zone; *7* – Gathering Chute; *8* – Discharge Pipe for Treated Liquid; *9* – Discharge Pipe for Recirculated Mixture; *10* – Primary Sewage Supply; *11* – Pumping Station; *12* – Discharge Pipe for Excessive Stabilized Biomass

The effect of oxygen high concentration in the filtrate was the foundation for development of these installations. The biofilm was simultaneously established to continue consuming dissolved oxygen in the final settling tank.

The main point of biofilters-stabilizers performance is achievement of integrated purification of sewage and simultaneous stabilization of the excessive biomass by means of repeated return of the biofilm to the filter together with the circulating liquid. It is possible only when porosity of the feed material is sufficient for prevention of its sludging.

A biofilter-stabilizer consists of a biological filter and a stabilizer beneath it. The stabilizer has a circumferential settling zone. A perforated rolled vinyl film is hung in vertical stripes in 50 mm and serves as feed material. The feed material has the following characteristics: porosity –

98%, specific surface - 66 m^2/m^3. The feed is capable to sustain practically any organic load without the risk of sludging and enables natural aeration while operating.
The biochemical purification in the given installation is accomplished both with the biofilm immobilized on the feed and the circulating excessive biofilm.

The installation operates in the following way. The primary sewage is supplied into the receiving tank of the pumping station together with the recirculated liquid from the lower part of the stabilizer and the excessive biofilm. The mixture is piped onto the distribution mechanism of the biological filter. When the sewage passes through the feed the treated liquid is aerated with oxygen. This oxygen is utilized in the stabilizer for oxidation (mineralization) of the excessive biofilm and tertiary treatment of sewage. The required quantity of the dissolved oxygen is regulated by means of changing of the recirculation degree and the intensity of sprinkling the feed. The purified sewage is clarified in the settling zone and removed from the installation. Suspended, colloid and dissolved pollutants are oxidized in the biofilter-stabilizer; the growing biomass is mineralized there as well. Thus, no primary and final settling tanks, as well as stabilizing structures for the excessive biomass, are necessary when these installations are used. The biofilter-stabilizer is serviced with one pump; its operation can be easily automated (S.M. Shifrin et al., 1981).

The biofilter-stabilizer performance was tested for several years in different operation modes when treating wastewater from diary factories. The biofilter oxidizing capacity was 1000-3300gBOD_{comp}/(m^3 day), the purification efficiency was 97-98,5%, BOD_{comp} of the purified liquid was 13-28 mg/dm^3. The installation operated in the mode of complete oxidation of the excessive biomass at the biomass concentration of 1-1,5g/dm^3 in the stabilizer. The dissolved oxygen concentration in the liquid flowing down the feed was 5,5-7,2 mg/dm_3. The biomass stabilization period was 6 to 15 days. The results of testing of the installation proved higher oxidizing capacity of the biofilter-stabilizer as compared to that of high-rate biological filters of ordinary design.

Based on the results of operation testing of biofilters-stabilizers the installation designers (S.M.Shifrin, G.V. Ivanov, B.G. Mishukov, Yu.A. Feofanov, 1981) recommend to assume the design parameters as follows: the oxidizing capacity 1000 gBOD_{comp}/(m^3 day), the feed height 2-4m. Vertical stripes of perforated vinyl film make up the biofilter feed; the distance between stripes is 50mm. The recirculation ratio is determined depending on the conditions of oxygen supply for the process of excessive biomass mineralization in the stabilizer according to its growth. The quantity of oxygen removed from 1m^3 of sewage during its single flow through the biological filter is 4-6g/m^3. The biomass stabilization period is 10 days; its concentration in the stabilizer is 1-2g/m^3. The stabilizer settling zone is designed for 1,5 hours of treated sewage presence.

5.2. Aerotanks

The aerotank complete purification of sewage from organic substances subject to biodegradation consists of several stages. The first stage is adsorption of pollutants with active sludge, it is the fastest stage of about 30 minutes duration; the following two stages are those of biodegradation of readily oxidized and heavily oxidized adsorbed substances, the latter type is oxidized in 8-24 hours; the final stage is regeneration of the initial activity of sludge. After the adsorption process is over the sewage is generally purified from pollutants but microorganisms of active sludge continue biochemical oxidation of adsorbed substances, in other words, the initial activity of sludge is restored – the regeneration process goes on. The regeneration process may be accomplished directly in the aerotank or in a separate installation – in a reactor, which as a rule does not differ from an aerotank in its structure.

Aerotanks are classified according to their main characteristics: according to the hydrodynamic mode they are divided into aerotanks-displacers, aerotanks-mixers and aerotanks with distributed intake of sewage; according to the active sludge regeneration type they are divided into aerotanks with separate regeneration and aerotanks without separate regeneration; according to active sludge loads they are divided into high-rate aerotanks (incomplete purification aerotanks), ordinary and low-rate aerotanks (aerotanks of prolonged aeration); according to the number of purification stages they are divided into one-, two- and multi-stage aerotanks. The term "purification stage" comprises a part of the general biochemical system where the specific active sludge culture is maintained; according to the sewage supply mode, they are divided into flow and half-flow aerotanks, aerotanks with variable operating level and contact aerotanks.

According to the reference data, the technological process in aerotanks-displacers does not enable to use the operating capacity of the installation to the sufficient extent, besides, the purification process and, consequently, the treated water quality is subject to considerable fluctuations.

Corridor aerotanks with diffuser canals (Fig. 5.5) commonly known in sewage purification practices are difficult to operate, cumbersome and requiring considerable capital and time investments during construction. Besides, the susceptibility of this installation to overloads drastically diminishes its application for industrial wastewater purification (Ya.A. Karelin, D.D. Zhukov et al., 1973). Aerotanks-displacers are used for purification of household and industrial wastewater with pollutants concentration of not more than BOD_{comp} 500 mg/dm^3.

It is preferable to use aerotanks-displacers when there are no sudden fluctuations of sewage flow and toxic substances concentrations.

In aerotanks-mixers doses of supplied sewage liquid almost immediately mix with the entire amount of purified sewage and active sludge enabling to distribute dissolved oxygen and organic load on active sludge uniformly (Fig. 5.6).

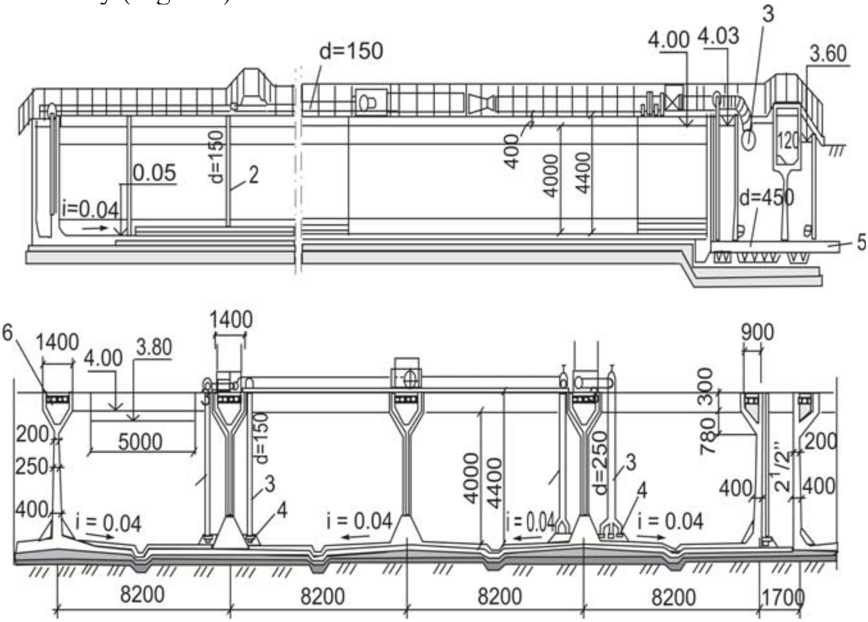


Fig. 5.5. 4 m Deep 4-Corridor Aerotank

1 – Upper Distribution Duct for Primary Sewage Clarified in Primary Settling Tanks; *2* – Diffusers Standpipes; *3* – Main Air Pipe; *4* – Diffuser Plates; *5* – Unloading Pipe; *6* – Duct for Clarified Sewage By-Passing from Upper Distribution Duct into Lower Distribution Duct.

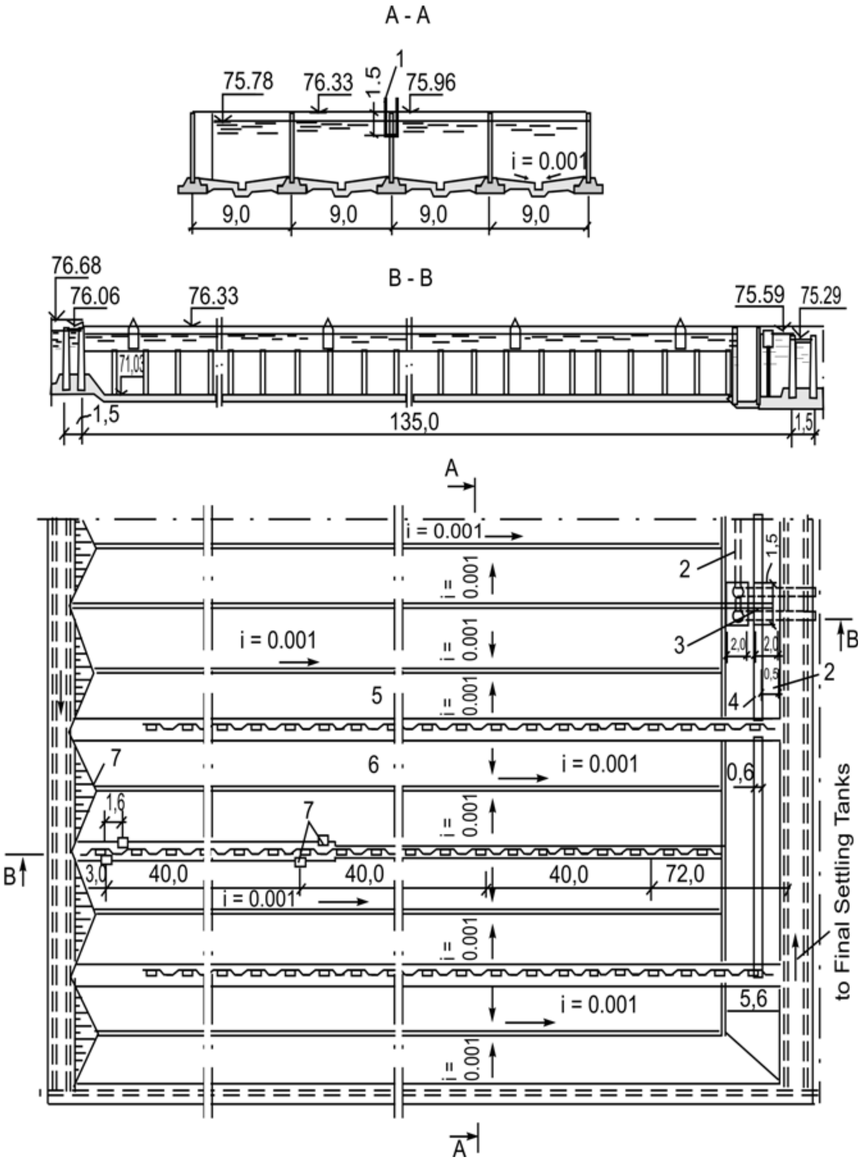


Fig. 5.6. Aerotank-Mixer

1 – Distribution Chute; *2* – Unloading Pipe for Aerotanks and Final Settling Tanks; *3* – Chamber for Unloading Gates; *4* – Active Sludge Chute; *5* – Regenerators; *6* – Aerotanks; *7* –Sluice Gates.

It is possible to ensure the installations operation under high loads in the given mode. The technological peculiarity of a classic installation is distributed intake of the mixture of sewage and active sludge along the longitudinal wall of the aerotank and the similar discharge of it out from the opposite side. The high degree of dilution of the incoming sewage with purified water of the aerotank enables to deliver sewage with high concentration of pollutants; it is expedient to use this type of installations for purification of concentrated industrial wastewater with BOD_{comp} up to 1000 mg/dm^3. The disadvantage of aerotanks-mixers is the possibility of pollutants "channeling" into already purified water.

If the general irregularity ratio of sewage delivery into the aerotank does not exceed 1,25, the aerotank volume is determined based on the average daily flow of sewage; if the irregularity ratio is larger, the aerotank volume is determined based on the average hourly flow of sewage into the aerotank during aeration in the maximum flow period. The amount of the circulating active sludge is not taken into account when the aerotank volume is determined. The aeration duration is determined according to the Construction Norms and Regulations 2.04.03–85, formulas 48 and 50. The sludge dose is determined during precommissioning or based on the experience of similar installations performance of purification of sewage with similar composition, taking into consideration final settling tanks operation. Approximately the sludge dose may be assumed according to the data of Table 5.4.

Table 5.4

Approximate Values for Sludge Dose Depending on the Aerotank Type and BOD_{comp} Pollutants Concentration

Sewage BOD_{comp}, mg O_2/dm^3	Sludge Dose in g/dm^3 Depending on Aerotank Type		
	Aerotanks without Regenerators	Aerotanks-Settlers	Aerotanks with Regenerators
Below 100	1.2	3	–
100 – 150	1.5	3.4	–
150 – 200	1.8	3.7	$a_{aer} \approx 1.5$ g/l $a_{reg} \approx 4$ g/l
Above 200	1.8 – 3	4 – 5	

The main characteristic enabling to divide all aerotanks into high-rate and low-rate ones is oxidizing capacity, that is the BOD_{comp} value of sewage removed from $1m^3$ of the aerotank daily. Oxidizing capacity depends on BOD_{comp} load per 1g of dry ash-free matter of active sludge and its quantity per g/dm^3. Usually sludge load during incomplete biological purification makes up from 500 to 2000 mg/g day, during complete biological purification of sewage sludge load varies from 200 to 500mg/g day, when this value is less, nitrification is possible (for complete nitrification the sludge load value must be 50 -100mg/g day). In high-rate aerotanks purification completes in 0,5-2 hours; as a result of it hydraulic load is more than 20 m^3/day per 1 m^3 of the installation and daily BOD_{comp} sludge load is more than 0,8kg/kg when the purification efficiency reaches 70-95%. 80-85% of sludge under high loads is made up with organic substances and 60-65% of mineralized sludge is made up with them. Increase of the ratio of nutrients amount to the active microorganisms amount in high-rate aerotanks raises the intensity of oxidation as compared to aerotanks with low loads on active sludge or mineralized sludge (high sludge age) where the process is inhibited with deficiency of nutritious matter for microorganisms. The excessive nutrients delivery into aerotanks results in prevailing of the logarithmic phase of microorganisms' growth, considerable biomass growth and availability of high concentrations of ammonium nitrogen in purified sewage.

In order to diminish the installation dimensions it is possible to achieve high load per volume unit of the installation by means of increase of active sludge load, first, while maintaining the amount o f the operating sludge dose. The disadvantage of this method is incomplete biodegradation of sewage organic substances resulting in the impossibility to achieve the high value of sewage purification efficiency (when BOD_5 is not more than 10-15mg mgO_2/dm^3) at sludge loads of more than $1gBOD_5$ per 1g of sludge daily. Besides, increase of loads deteriorates the active sludge quality when treating many types of industrial wastewater, resulting in gradual loss of its sedimentating ability and failure of the installation. Second, when maintaining the previous sludge load the active sludge concentration in the system is increased - it helps to create an aeration installation of high efficiency unlike high-rate installations. Usually long-term compacting of active sludge in final settling tanks leads to oxygen deficiency and decrease in sludge activity. In order to prevent oxygen deficiency sludge mixture is circulated several times and thus aerated with the air oxygen, but it is a power-consuming method.

Sufficiently high doses up to 6-8 g/dm^3 may be maintained in aerotanks-settlers. The design peculiarity of this type of installation is combining of the aerotank with the final settler (Fig. 5.7).

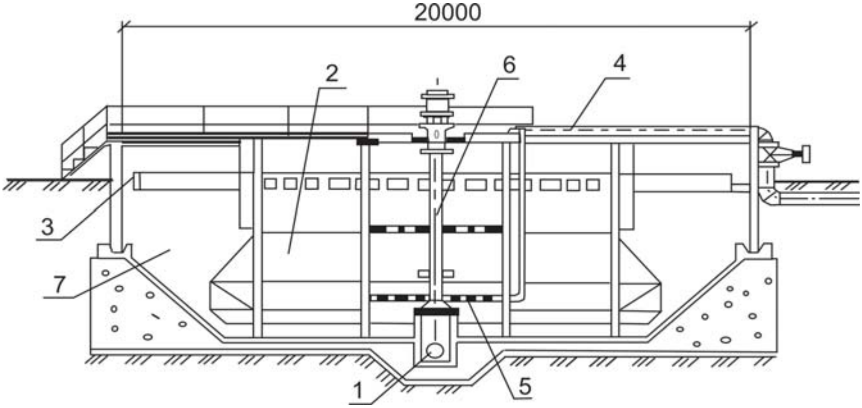


Fig. 5.7. Radial Aerotank-Settler

1 – Sewage Delivery Pipe; *2* – Aeration Zone; *3* – Chute for Clarified Water; *4* – Air Pipe; *5* – Circular Perforated Aerator; *6* – Disperser-Mixer; *7* – Settling Zone

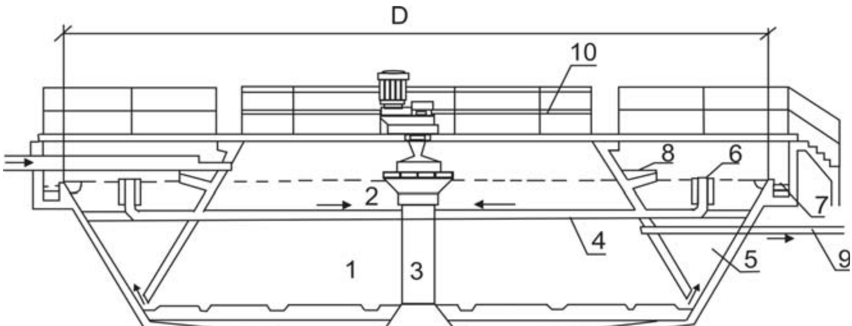


Fig. 5.8. Compact Installation Chart for 1500 – 3500 men.

1 – Aeration Zone; *2* – Aerator; *3* – Lifting Pipe; *4* – Discharge Pipe; *5* – Settling Zone; *6* – Floating Substances Discharge; *7*, *8* – Discharge and Delivery Chute Correspondingly; *9* – Excessive Active Sludge Discharge; *10* – Servicing Bridge.

The mixture aerated with oxygen is delivered from the aeration zone of the aerotank-settler to the settling zone where the dispersion medium and dispersed phase (active sludge) are separated. The positive factor of the aerotank-settler performance is formation of an active sludge layer in the settling zone in the form of a suspended filter, which promotes effective phase separation due to trapping of small sludge flakes. The thickest sludge flakes sedimentate in the lower part of the settling tank, get into the circulation flow of the sludge mixture and return into the aeration zone, thus, active sludge circulates from one zone into another and the dissolved oxygen concentration is not less than 1 mg/dm^3 throughout the entire depth of the settling zone.

The disadvantage of many existing designs of aerotanks-settlers consists in instability of the suspended filtering layer of sludge in the settling zone, which depends on the sewage flow and composition fluctuations. Any deviation of the flow rate from the optimal one leads either to excessive concentration of the filtering layer or to its washout accompanied by removal of active sludge with purified water. Besides, the suspended filtering layer state is influenced with the cyclic change in sludge parameters. For example, at meat and diary enterprises the sludge index decreases after the night shift with delivery of small amount of pollutants, sludge compacts into flakes; sludge “swells” after the morning shift when the equipment is washed and a large amount of pollutants is discharged (S.N. Shifrin, G.V. Ivanov, B.G. Mishukov, Yu.A. Feofanov, 1981).

Table 5.5. contains load values for some types of aeration installations.

Table 5.5.

Active Sludge Load Range for Aeration Installations
(According to the Data by Domestic and Foreign Researchers)

Installations and Technological Processes	Aeration Duration, h	Volumetric Load, BOD_{comp} /m^3 day	Sludge Dose, g/m^3	Sludge Load, kg BOD_5 per 1 kg of sludge per day	Sludge Age, day/sludge index, cm^3/g
1	2	3	4	5	6
Low Pollutants Load					
Aerotanks of Prolonged Aeration	10–30	0.3–1.2	3–12	0.05–0.12	25–30

1	2	3	4	5	6
Circulation Irrigation Canals	48–60	0.1	1–2	0.04–0.08	25–50/ 40–80
Aerated Ponds	180–250	0.025	0.5	0.05	–/–
Medium Pollutants Load					
Ordinary Aerotanks	6–8	0.6	2–4	0.12–0.3	2–5/–
Aerotanks with Regeneration	5–6	1.5	2–4	0.5	
High-Efficiency Aerotanks	3–5	2.5	3.5–8	0.3–0.5	–/–
High Pollutants Load					
Speed Aeration	3.2–4	1.5	1.5–3.5	2–5	–/–
Modified Aeration	3.4–4	1.5	1.5–3.5	2–5	0.5–2/ 80–200
Super-Activization	0.8–1	6	1.5–2	3.5–5	–/–

The calculation of parameters of aerotank-settlers should be made according to the technique of the Scientific Research Institute of Water Supply and Purification, which presupposes determining of the optimal sludge dose at which the cumulative volume of the aeration and settling zones will be minimum. The aeration duration t is determined according to the formula:

$$t = \frac{L_{en} - L_{ex}}{a_i (1 - S)\rho}, \text{ h;}$$

Depending on the primary sewage BOD_5 value the following oxidation rate is assumed:

BOD_5 of the primary sewage, mgO_2/dm^3:	100	150	200	300	400	500
Oxidation rate, $mgBOD_5$/g of sludge per hour	16	18	20	22	23	24

The optimal active sludge concentration in the aeration zone depends on the initial BOD_5 and the aeration-settler depth, it may be determined either taking into account the performance results of existing sewage purification installations or according to the formula:

$$a_0 = \frac{-t\alpha\beta + \sqrt{t\alpha^2 h\beta}}{h\beta - t\beta^2} \text{ , g/dm}^3.$$

Where: α and β are empirically determined coefficients, $\alpha = 2$; $\beta = 0{,}2$; h is the depth of the aeration zone.

The ash value of sludge is assumed to be 0.3 in this case. The settling zone depth is designed to equal the aeration zone depth. The boundary of the suspended layer of active sludge is defined on the level of not less than one half of the installation height. The cross-section area of the settling zone ω, m^2, is determined according to the following formula at this level:

$$\omega = KQ / 3{,}6\nu \text{ , m}^2.$$

Where: K is hour irregularity coefficient; Q is average hour sewage flow, m^3/h; v is allowable velocity of the upward liquid flow at the level of the boundary between the liquid and the suspended layer, determined according to the formula:

$$\nu = \frac{\alpha - \beta a_0}{3{,}6} \text{ , mm/sec.}$$

The velocity of the sludge mixture ascent (without taking into account circulating sludge flow) in the lower and entry parts of the settling zone is assumed to be 3 - 4 mm/sec. The circulating active sludge flow, m^3/h makes:

$$q = Q\frac{a_0}{a_b - a_0} \text{ , m}^3 / \text{h}$$

Where: a_b is the sludge concentration in the suspended layer, g/dm^3, assumed depending on a_0:

a_0, g/l ….2	3	4	5	6	7	8
a_b, g/l ….3	4,2	5,5	6,4	7,2	7,9	8,7

The sludge bunker area plan, F, m^2, is determined according to the formula:

$$F = \frac{(Q+q)a_0}{u a_b}$$

Where: u is allowable velocity of sludge sedimentation in the sludge bunker assumed to be not more than 10 mm/sec.

5.3. Aerotanks with Variable Operating Level of Liquid

Aerotanks operating in the contact mode have been known since the end of 1960s. Their performance consists of the following operations: 1 – stopping of the sewage delivery; 2 – shutdown of the aeration system; 3 – settling of the sludge mixture; 4 – removal of the purified water; 5 – removal of excessive sludge; 6 – actuation of the aeration system; 7 – feeding of the system with sewage liquid; 8 – aeration of the sewage and active sludge mixture. Initially contact aerotanks were widely used in laboratory scientific research experiments. It may be accounted for utmost simplicity of their maintenance, uniformity of the technological mode and relative easiness of the received data interpretation. The mode of pollutants concentration decrease in contact aerotanks is in many aspects similar to the flow aerotanks-displacers mode, the only difference being the purification efficiency depending at constant sludge doses on the distance covered with the given sewage portion from the intake point in the aerotanks-displacers and on the time since the beginning of aeration in contact aerotanks.

At present contact aerotanks are widely used abroad, their contemporary name being batch reactors (SBR).

In the Handbook on Modern Purification Techniques and Equipment for Natural Water and Sewage (2001, by a joint team of Russian and Dutch specialists) the SBR was shown to be a periodic process in which the operations of aeration and settling were performed successively; it was necessary to avoid the instable flow of sewage, if it was impossible, the number of operating reactors should be increased in order to ensure continuous flow of sewage into purification installations and stable performance of the given technique.

The typical operational cycle of batch reactors consists of the following operations: filling – 2,5 hours; aeration – 0,5 hours; settling – 0,5-1,5 hours; emptying – 0,5-1,5 hours; downtime – 0,6 hours. The Handbook states that the process of partial denitrification is typical for the SBR when the installation operates in the settling and emptying mode. This fact accounts for the relatively effective decrease of the nitrate nitrogen concentration (less than 8 mg/dm^3). The typical BOD_5 value of the effluent (purified water) is 15 mgO_2/dm^3. The concentration of the suspended matters in purified sewage varies as the tank empties. The fact must be taken into account when determining the sludge age – the main operating characteristic of the system. When the sludge age is high and sludge organic load is low nitrification is possible in the reactor. The absence of necessity to have a final settling tank and return sludge pumps, the high degree of stability against sewage flow fluctuations are the advantages of the system. The main disadvantage is that the aeration system must be designed for periodic operation.

The biological batch reactors - one-tank bioreactors – are designed for biological purification of sewage by means of freely floating active sludge (Fog. 5.9, 5.10).

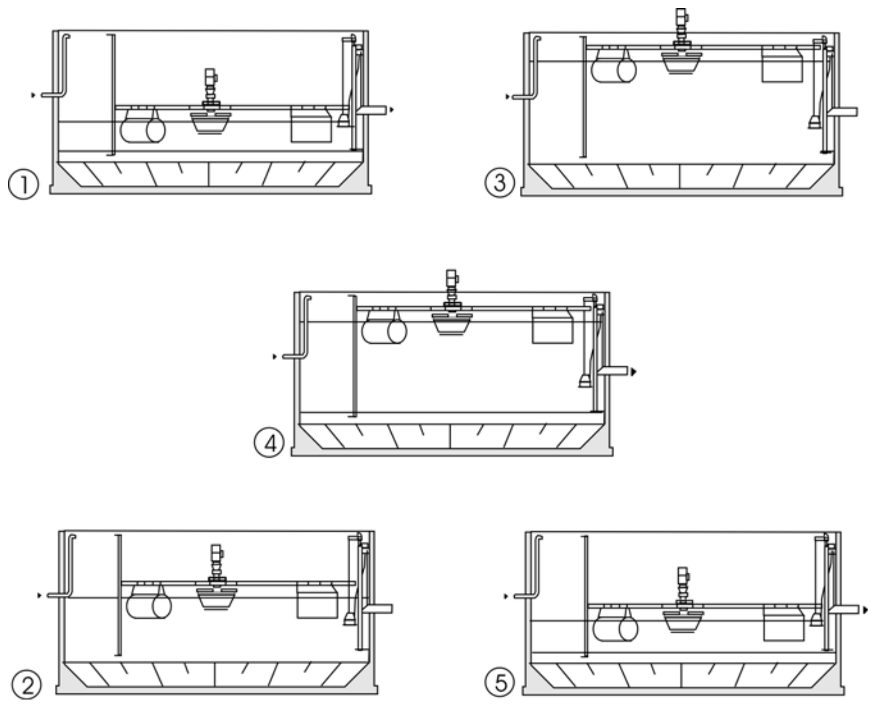


Fig. 5.9. Operation Principle of One-Tank Reactor

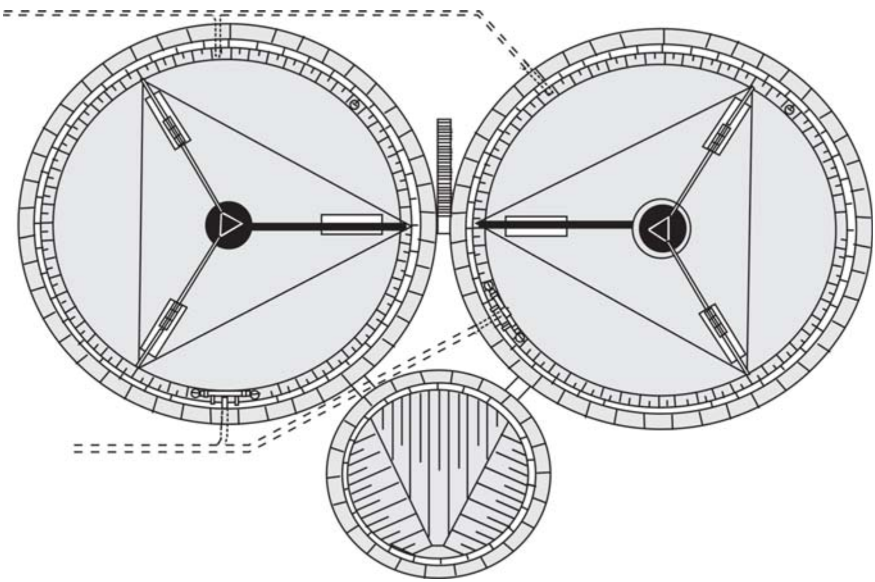


Fig. 5.10. Sludge Tank

A joint German-Bulgarian firm "Testech" elaborated these installations. More than 20 years of operating experience of this company are supported with performance of more than 500 stations. Due to specially developed batch principle, the system is capable to operate with any type of sewage and irrespective of any irregularity of sewage flow.

Every one-tank reactor is realized as a neutralizer, aerotank and a final settling tank, in other words, the normal operation includes the succession of filling, aeration, settling and decantation. The sewage purification cycle progresses as follows: 1 – filling and mixing, sewage is delivered into the one-tank reactor and mixed with active sludge (at the low turbine speed) in anaerobic conditions; 2 – filling and mixing, sewage continues to flow in conditions of mixing and aeration (at the high turbine speed); 3 – aeration, sewage does not flow any more, but mixing and aeration continue (the turbine may continue to operate irregularly in order to finish nitrification or to save power); 4 – settling, mixing and aeration stop (settling progresses in ideal conditions); 5 – decantation and removal of excessive sludge, there is no mixing, about 30% of the reactor volume is decanted through a special drain system, excessive active sludge is drawn from the system into the sludge compactor and the one-tank reactor is ready to accept the next sewage portion.

The bioreactor design may be adapted to any tank shape, but it is reasonable to use round bioreactors in order to avoid formation of stagnant zones. Aeration is accomplished with a surface turbine aerator consisting of an aerator (a centrifugal rotor), an electric motor and a reduction gear. When the rotor rotates, fins throw water to the tank rim and the hydraulic-jump wave intensively transports oxygen into water. Liquid is sucked to the rotor from beneath, thus oxygen aerates the entire bioreactor intensively. Utilizing of a surface aerator on pontoons guarantees easy maintenance and usage of only one installation.

5.4. Anaerobic Bioreactors

The most common classification of anaerobic reactors is based on the macrostructure shape of the methanogenic biomass in them. According to this principle, all designs may be divided into reactors with suspended-sedimentating biomass (sludge) and fixed biomass (biofilm) (Kalyuzhnyi et al., 1991).

The first type includes such reactors as: anaerobic lagoons, contact reactor, reactor with upflow through anaerobic sludge (UASB), reactor with expanded and suspended bed of granular sludge (EGSB), baffled reactor (ABR). The second type includes such reactors as: biofilter with upflow (AF), biofilter with downflow and stationary fixed biofilm (DSFF), reactor with fluidized bed of biofilm carrier (AFB), rotating biocontactor, hybridized reactors combining two reactor designs (for example, AF and UASB).

Upflow Anaerobic Sludge Blanket (UASB)

In the 1970s when studying processes going on in anaerobic reactors of the second generation with upflow (AF) Lettinga and his colleagues found out that microorganisms forming a methane population were able to form aggregates – thick easily sedimentating granules 1-3mm in size (Lettinga et al., 1980) (Fig. 5.11).

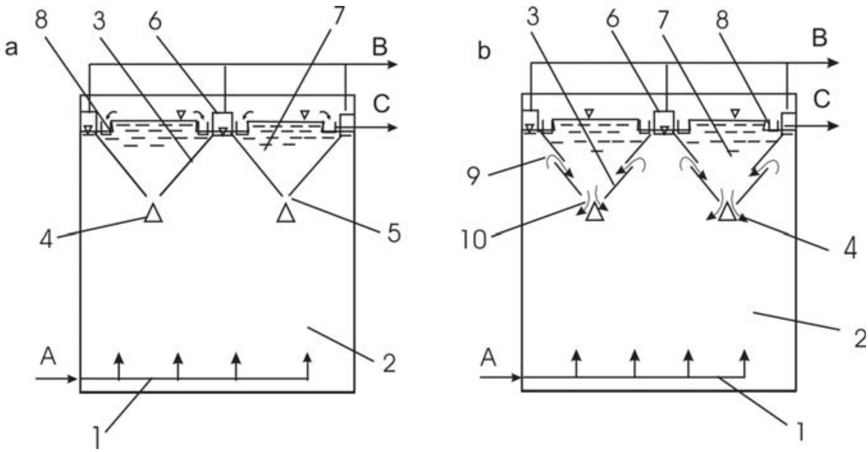


Fig. 5.11. UASB-Reactor
a – Simplest Design; *b* – “Biothane” Design;
1 – Distribution System; *2* – Fermentation Zone; *3* – Gas-Guiding Baffle;
4 – Deflector; *5* – Slot (Entry into Settling Zone); *6* – Gas-Collecting Duct;
7 – Settling Zone; *8* – Water-Collecting Chute; *9* – Separate Entry into Settling Zone; *10* – Separate Exit from Settling Zone; *A*– Primary Sewage; *B* – Biogas;
C – Purified Sewage

These granules mainly consist of methanogens, of the *Methanosaete* genus first of all, forming tight brushwood-like or ball-like structures. Based on the discovered effect Lettinga suggested a new design of a reactor with upflow of sewage through a blanket of anaerobic sludge. In this design granulation and retention of sludge is caused by means of a special inbuilt gas - and sludge-separating mechanism in the upper part of the reactor.

Sludge is retained in the reactor due to two factors: high sedimentating capacity of sludge granules and utilization of a special inbuilt gas- and sludge-separating mechanism in the upper part of the reactor (there is no need to use an additional separately standing settling tank). The phenomenon of granules formation spontaneously occurs in anaerobic reactors with upflow of sewage containing readily decomposed organic substances (volatile fatty acids, sugars) without toxic components and maintenance of optimal conditions for methanogenic bacteria vital activity. If there are large amounts of protein pollutants in sewage, inoculation of the reactor with granular sludge is necessary, the process intensifying formation of granules. There are two zones different in their characteristics and sludge concentrations, as well as in hydrodynamic conditions, in the fermentation zone of the operating UASB-reactor.

The first zone is made up with a compact bottom bed of sludge particles with the dry matter concentration of 50-100 g/dm^3. In this bed the sewage drawn through the distribution system from the reactor bottom is purified. The forming bubbles of biogas come through the sludge bed, thus ensuring its mixing. Above the lower bed there is the zone of intensive turbulent movement of a three-phase system: of liquid, sludge and biogas. An intensive exchange of sludge particles goes on between the upper and lower layers. The sludge particles transfer from the lower layer to the higher one due to the gaslift effect caused with upflows of biogas and due to sludge flotation. The upflow is effectively separated in a gas-separating mechanism consisting of tapered caps of gas-collectors and guide baffles-deflectors that separate the fermentation zone from the clarification zone.

Biogas bubbles are separated from the upflow of sludge mixture on the surface of phase separation under the gas-collecting cap. The degassed sludge is mainly returned to the fermentation zone. Sewage comes through slots between gas-collecting caps and deflectors and gets into in-built settlers formed with outer surfaces of gas-collecting caps.

Expanded Granular Sludge Bed (EGSB)

One of the directions of further development of the UASB-reactor design was connected with intensification of mass transfer between the sludge granules and treated flow. Lettinga suggested a concept of reactor with an expanded bed of granular sludge in the second half of the 1980s.

The main difference of the EGSB-reactor from the UASB-reactor is a higher velocity of upflow (5-12 m/h) ensured with the flow recirculation. EGSB-reactors are widely spread in Holland. Utilization of such a high velocity of upflow made it possible to treat wastewater with low concentrations from different industries at a wide range of temperatures (Lettinga & Hulshof Pol, 1992) (Fig. 5.12).

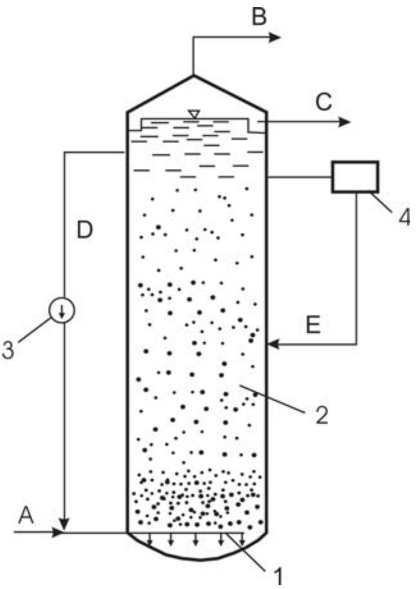


Fig. 5.12. Reactor with Fluidized Bed of Carrier Particles
1 – Distribution System; *2* – Bed of Carrier Particles;
3 – Device for Removal of Excessive Biofilm; *A* – Primary Sewage; *B* – Biogas;
C – Purified Sewage Water; *D* – Recirculation of Sewage;
E – Return of Carrier Particles.

Anaerobic Baffled Reactor (ABR)

A baffled reactor was developed by Bachman and McCarty in the 1980s in order to simplify the design of the UASB-reactor (Bachman et al., 1985). The advantages of the baffled reactor as compared to the UASB-reactor are a simple design and absence of necessity in gas- and sludge-separating mechanisms. The reactor is a rectangular reservoir divided with parallel vertical baffles into several parts. The sewage moves by turns bottom-up ant top-down going through a forming layer of biomass granules (flocculi) in every part.

Anaerobic Filter (AF)

A biofilter is the first anaerobic reactor with fixed biomass. The biomass is retained in the biofilter not only in the form of flocculi and granules situated in the feed material cavities, but in the form of the biofilm fixed to the carrier surface as well (Young & McCarty, 1977). As the flows of liquid and biogas are codirectional, there is no considerable mixing in the reactors and the hydraulic mode is close to an ideal displacement mode. In modern installations mainly flat plastic articles are used (formerly such volumetric materials as gravel, crushed stone, slag, etc. were used) (Young & McCarty, 1977).

Hybridized Reactors

Numerous researches in the 1980s convincingly showed that in order to retain biomass in the AF-reactor effectively it was not necessary to fill its entire volume with feed material: a layer of 25-40% of the reactor operating height was enough, this layer being in the reactor upper part. Thus, not only 60-75% of the expensive feed material is saved but all drawbacks of classic anaerobic biofilters (sludging of the lower layers, channeling of pollutants) are wholly removed as well. The similar design (an anaerobic biofilter with incomplete feed) was in details studied by the Canadian researchers (Kennedy & Guiot, 1986). There biomass was forming both in the reactor lower part (with granular sludge totally corresponding to the UASB-reactor biomass) and on the carrier surface and in cavities. These processes are leading to the increase of flocculated sludge retention efficiency. Active carbon and other floating carriers may be used as feed material. As an example of an improved hybridized reactor the so-called hybridized baffled reactor (HABR - Hybridized Anaerobic Baffled reactor) may be named, this type being studied in works by Tilche & Young, 1987; Boopathy & Tilche, 1991.

Downflow Stationary Fixed Film (DSFF)

Van den Berg and Kennedy (Van den Berg & Kennedy, 1982; 1983) studied the given system from both theoretical and technological points of view. They managed to show convincingly that in case of downflow the surface characteristics of feed material played the most important role as they determine the biofilm development. From this point of view, burnt gault and soft feed materials with inner porosity are the best feed materials. The peculiarity of the given design is that methanogenic biomass may be retained for a long period of time only in the form of biofilm in downflow conditions, this biomass ensuring up to 95% of the bioreactor activity (Van den Berg & Kennedy, 1983).

Anaerobic Fluidized Bed (AFB)

The reactor with a fluidized bed of the biofilm carrier has the highest efficiency of all reactors with fixed biofilm. Fluidization is a process when the small carrier particles are driven into the state similar to a liquid as a result of a fluidizing agent – a liquid or a gas - passing through it. Fluidization with upflow of the treated liquid is used as a rule in anaerobic purification systems. The forming biogas upflow also contributes to fluidization. The contact area between the active biomass and unprocessed waste grows (Switzebaum, 1982; Van den Berg, 1984). Dissolved and fine liquid wastes are treated by means of such reactors. However, erection of such installations demands considerable expenses allocated for the fluidized bed maintenance (Van den Berg, 1984).

Comparison of Anaerobic Reactors Designs

The diversity of sewage composition and characteristics does not enable to compare unambiguously the qualitative and quantitative characteristics of different anaerobic reactors designs. Depending on the sewage peculiarities and local climatic and social-economic conditions, practically any of the above-described systems may prove to be optimal.
The major parameters of main designs of anaerobic reactors are given in Table 5.6. Granular sludge reactors have been certainly prevailing as applied to purification of sewage containing readily decomposed organic pollutants. When treating industrial wastewater the purification efficiency of the anaerobic reactor complies as a rule with norms and standards of reception into sewage. In some cases of overload of the city sewage purification installations aerobic aftertreatment of effluents already treated in anaerobic conditions may be necessary.

Table 5.6

Major Parameters of Main Anaerobic Reactors Designs (Mesophilic Mode)

Reactor Type	Average Biomass Concentration in Reactor, kg/m^3	Specific Surface of Feed, m^2/m^3	Minimum Concentration Limit in Flow, kg COD/m^3	Capacity, kg COD/ m^3/day	Minimum Treatment Period, h
1	2	3	4	5	6
Traditional Methane Tank	0.5–3	–	10	0.5–5	192–240

1	2	3	4	5	6
Contact Reactor	5–10	–	2–3	3–8	24
UASB-Reactor	20–40	–	0.3	10–25	2–3
EGSB-Reactor	25–40	–	0.3	30–40	1–2
Anaerobic Biofilter	5–20	70–300	0.3	10–15	8–12
DSFF-Reactor	3–15	60–200	1–2	10–12	24
Hybridized Reactor	20–30	70–300	0.3	15–25	2–3
Reactor with Fluidized Bed	10–40	1000–3000	0.3	30–40	0.5

5.5. Current State of Anaerobic Sewage Purification

The first design of anaerobic reactor utilizing the biomass retention principle, a contact reactor namely, was suggested both in the USSR and abroad approximately at one and the same time (the 1950s). However, if it was practically not used in the USSR, in Western European countries it was immediately spread for food industry wastewater purification and was constantly perfected. Of modern anaerobic reactors designs the anaerobic filter was the first to be used – the industrial installations appeared in 1972. The first industrial UASB-reactor was erected in 1977 at Breda sugar-refinery (Netherlands) and has been operating since that time. At present more than 1700 anaerobic reactors have been assessed (Totzki, 1998) to operate in the world, but a detailed database founded on a survey of 16 largest designers of anaerobic techniques included 1215 industrial reactors in 65 countries of the world by the end of the 20th century (Frankin, 2001). The biggest construction growth was stated in 1992-1997 when about 100 reactors were built annually in the world. At present about 60 reactors are built every year. It is accounted for the fact that the majority of large industry enterprises in developed countries already has anaerobic purification facilities and the number of reactors grows basically due to those being built in developing countries and East European countries. Table 5.7 shows that more than 70% of all anaerobic reactors have been built in countries ranking among the top ten. It is comforting that first intensive anaerobic reactors for industrial wastewater treatment are also being built in the CIS countries.

Table 5.7.

Built Anaerobic Reactors Assignment to Countries
(Total – 1215, Frankin, 2001 Database with New Data Added)

India	150	Germany	94	Mexico	27	Other, incl.	376
Japan	122	Brazil	82	Canada	26		
USA	108	France	49	Taiwan	25	Russia	5
Holland	98	China	36	Philippines	22	Ukraine	1

Table 5.8 contains all built reactors assigned to their design types. It is obvious that granular sludge reactors prevail considerably. They have been especially prevailing during the latest ten years. It is interesting that the former leader (UASB-reactor) is being “cannibalized” with its more perfect modification – EGSB-reactor: 50% of the total number of reactors built in past 3 years belonged to this very type.

As regards the sewage type, the anaerobic technique has been spread in breweries and soft drinks production mostly (Table 5.9).

Table 5.8.

Built Anaerobic Reactors Assignment to Designs Type

Built Anaerobic Reactors Assignment to Designs Type (Frankin, 2001)	Number of Built Reactors	% of the Entire Number	Reactors Built in 1990-1996, %	Reactors Built in 1997-2000, %
1	2	3	4	5
EGSB	198	16	8	50

1	2	3	4	5
Low-Speed (Lagoons/ Contact Reactors)	187	15	12	8
UASB	682	56	68	34
Biofilters	54	4	4	3
With Fluidized Bed	16	1	2	1
Hybridized	12	1	1	2
Other Design	66	5	6	3

Table 5.9

Built Anaerobic Reactors Assignment to Fields of Industry Producing Wastewater (Frankin, 2001)

Industry Field	Number of Reactors	%
Breweries and Soft Drinks Production	329	27
Fermentation and Distillation	208	17
Chemical	63	5
Pulp and Paper	130	11
Other Food Industry	389	32
Filtrates of Solid Domestic Waste	20	2
Other	76	6
Total in Database	1215	100

Chapter 6. ANALYSIS OF METHODS OF NITROGEN AND PHOSPHORUS REMOVAL

6.1. Removal of Nitrogen and Phosphorus Compounds

In untreated industrial wastewater, nitrogen may be component of both organic and mineral compounds. For example, in industrial wastewater from food industry enterprises the majority of nitrogen (60-70 %) is available in the form of ammonium nitrogen. The allowable value of nitrogen concentration in treated sewage is regulated and depends on the type of compound comprising nitrogen. The allowable concentration of ammonium nitrogen in sewage discharged into surface reservoirs of fresh water in Russia is 0,5 mg/dm^3, of nitrite nitrogen – 0,08 mg/dm^3, nitrate nitrogen – 9,1 mg/dm^3. Discharging into water of nitrogen in higher concentrations than the above-mentioned ones promotes eutrophication of the reservoir. During biodegradation of organic substances in sewage purification installations forms of nitrogen transform and nitrogen is assimilated with microorganisms, however, purified sewage may contain up to 20 – 25 mg/dm^3 of total nitrogen and 15 – 20 mg/dm^3 of ammonium nitrogen without utilizing specific methods of nitrogen forms removal.

Nitrogen compounds may be removed by both physicochemical and biological means. Table 6.1. contains methods of influencing different nitrogen forms in order to decrease nitrogen concentration in treated sewage.

Table 6.1

Methods of Nitrogen Forms Removal

Method	Removal of Nitrogen Forms, %			
	Removal of Organic Nitrogen	Removal of Ammonium Nitrogen	Removal of Nitrate Nitrogen	Removal of Total Nitrogen
1	2	3	4	5
Aeration (Air Stripping).	Irremovable	60–98 (pH > 11)	Irremovable	50–90
Chlorination	Irremovable	80–100	Irremovable	80–95

1	2	3	4	5
Adsorption with Active Carbon	50–90	Irremovable	Irremovable	80–95
The Same with Prechlorination	50–90	80–100	Irremovable	80–95
Ion Exchange by Means of: – Synthetic Resins – Zeolites	80–95 Insignificantly	85–98 85–98	75–90% Irremovable	70–95 80–95
Electrolysis	Insignificantly	70–95	Irremovable	80–95
Ozonization	Insignificantly	80–95	Irremovable	80–95
Chemical Reduction	Insignificantly	–	50–90	80–95
Coagulation	30–70	5–15 (with Lime)	Irremovable	20–30
Electrodialysis	100	40	40	35-40
Reverse Osmosis	60–100	60–85	50–85	80–90
Assimilation with Algae	Partial Ammonification	Partial Assimilation with Cells		50–80
Assimilation with Bacteria	The same	40–70%	Limitative Effect	30–70
Nitrification	Limitative Effect	Oxidation To Nitrates	–	– to 70
Denitrification	–	–	80–98%	70–95
Soil Filtration	Oxidation to Ammonium Nitrogen	Oxidation To Nitrates	Denitrification	40–90
Oxidation Ponds	Ammonification	Partial Nitrification	Denitrification	20–40%

Physicochemical Methods of Sewage Purification from Nitrogen Compounds

Nitrogen Air Stripping

This method represents a modification of the aeration process used for removal of gases from water. Ammonium ions are in an equilibrium state with ammonia (a volatile compound) in sewage, when the pH value increases to 11,5, the equilibrium shifts to ammonia generation:

$NH_3 + H_2O \rightarrow NH_4OH \rightarrow NH_4^+ + OH^-$, which is air stripped at the water purification station at temperature above 15 ^{0}C. The technique is realized in the following way: lime is added into sewage in the amount corresponding to 10,5-11,5 pH of sewage, then both water and air are drawn to cooling towers. Ammonia moves into the air and gets into the atmosphere. The nitrogen removal efficiency may reach 95 %. This method is simple and reliable, however, it is expensive, the efficiency decreases at low temperatures, pipe precipitation with calcium carbonate is possible, further decrease of pH is necessary, the atmosphere is endangered.

Chlorination

When water containing ammonium nitrogen is chlorinated, a mixture of monochloramine, dichloramine, trichlorated and molecular nitrogen forms depending on the system pH value, Cl_2 and ammonium nitrogen concentrations. The fullest degree of removal is reached at the following ratio: $Cl:NH_{4(N)}^+$ = 7,6:1 and 10:1 at pH 5–8 (free nitrogen and dichloramine are reaction products). At the ratio of $Cl:NH_{4(N)}^+$ = (4-5):1 and high pH value monochloramines form mainly, when pH is less than 4 and chlorine concentration is high, toxic trichlorated nitrogen is generated. As all compounds of chlorine and nitrogen are toxic to some extent the chlorination process is carried to formation of N_2. Excessive chlorine is removed through granular active carbon.

Adsorption with Active Carbon with Prechlorination

Active carbon is used to remove organic substances, including nitrogen-containing compounds. Active carbon does not sorb ammonia and ammonium salts, however, its sorptive ability as regards chloramines is rather high (is must be noted that in this case we speak about chemisorption):

$$2NHCl_2 + C^* + H_2O \rightarrow N_2\uparrow + 4HCl + CO^*$$

$2NH_2Cl + CO^* \rightarrow N_2\uparrow + H_2O + 2HCl + C^*$

$C^* + Cl_2 + H_2O \rightarrow 2HCl + CO^*$.

Where C* is active carbon; CO* is surface oxides on carbon.

Chlorine must be entered into water directly before it comes onto feed; it promotes CO generation and chloramines adsorption. According to the given reaction equations acid enters the medium, pH of the treated water decreases, consequently, before being discharged water must be alkalized in order its pH reaches the minimum allowable value – 6,5.

During the chlorination-adsorption process 86-91% of ammonium nitrogen is removed on the average, its concentration in water decreasing from 12 to 0,7 – 1,8 mg/dm^3. Free chlorine and all chloramines are removed during the process. The maximum filtration rate is 15 m/h. The necessary contact with chlorine takes 25 minutes. The approximate chlorine dose is 110 – 150 mg/dm^3.

The advantages of this method are full transformation of ammonia into volatile nitrogen forms, low capital costs, simultaneous water decontamination. However, the growth of chlorides concentration in treated water is observed.

Ion exchange

Utilizing ionites enables to accomplish direct purification of sewage from nitrogen compounds. Nitrates are removed by means of synthetic anion-exchange resins, fro example, by means of dualite ALO2-D, amberlite IR-45, AV-17, Ede-10P in OH^- and Cl^- - forms. Chloride- and sulphate-ions in sewage decrease selectivity of ionites as regards nitrate-ions. For the mentioned anionites in the Cl^- -form the selectivity range looks in the following way during adsorption from neutral solutions: $Cl^- < NO_2^- << NO_3^- <= SO_4^{2-}$. Thus, selective removal of nitrate-ions is possible on sulphate forms of anionites. When organic substances are available in sewage, they are sorbed and (COD) concentration decreases from 33–40 mgO_2/dm^3 to 18–25 mgO_2/dm^3. The anionite operating capacity achieved while passing 360 m^3/m^3 (before the nitrate-ion slips into the filtrate in the maximum allowable concentration) is 580 equiv/m^3, nitrate-ions concentration in treated water being 5–10 mg/dm^3. In real conditions, it is possible to purify not the entire amount of sewage from nitrates, but only some part of it. In this case, the filtration cycle duration grows. The filtration rate may be sufficiently high and make 50-70 m/h when the filtration cycle lasts 12 hours. Anionites are easily regenerated with solutions of sodium, potassium or ammonium sulphates. The regenerant saturated with potassium or ammonium nitrate during recirculation is a valuable fertilizer. The method efficiency is rather high, for example, ion exchange enables to decrease the nitrate concentration from 30–70 mg/dm^3 to 0,1–0,5 mg/dm^3. In order to remove ammonium nitrate from sewage successive filtration through strong-acid cation-exchange resin and anionite are used. In order to purify sewage from ammonium nitrogen synthetic organic cation-exchange resins are used. Numerous researches in the field of enrichment of animal food additives with biogenic elements have shown that ammonium nitrogen is sorbed well with zeolites; the matrix lattice has remanent negative charge which is compensated with cations with large ionic radius and low charge (sodium, potassium, calcium, barium, rubidium, caesium). These cations are situated inside the lattice and determine ion-exchange properties of zeolites. In order to remove ammonium nitrogen it is promising to use zeolites with silica concentration up to 80 %, clinoptilolite for example, in this case the optimal sewage pH value is 4 - 8. Organic substances in sewage decrease adsorption capacity of zeolites by 25 %, that is why ion exchange is performed after preliminary clarification, filtration and biological purification. Ion exchange is accomplished by means of filtration through ion-exchange material. The filtration rate is chosen based on 6-10 minutes interaction of feed material with sewage water, usually filtration rate is 5-10 m/h. Clinoptilolite is regenerated with 8% solution of sodium chloride combined with lime.

Electrolysis

In order to remove ammonium nitrogen by means of electrolysis the sewage preliminarily purified from suspended substances is mixed with seawater and electrolyzed in a cell with graphite electrodes. As a result, H_2 forms on the cathode and in the $Mg(OH)_2$ solution which is used for additives coagulation and bonding of nitrogen and phosphorus into double salt $MgNH_4PO_46H_2O$ Cl_2 forming on the anode disinfects water.

Sedimentation of ammonium nitrogen in the form of metalammoniumphosphate may be accomplished also when magnesium, calcium, copper, iron, manganese salts are added to the treated water. It is expedient to use this method when phosphates are available in water. It is useful to bear in mind that when manganese salts are used the lowest values of $MgNH_4PO_46H_2O$ solubility are observed when pH is 10,7.

Ozonization is used to remove ammonium nitrogen in the alkali medium.

Chemical reduction is used to remove nitrites and nitrates, green vitriol being used as reducer:

$$NO_3^- + 2Fe^{2+} + H_2O \rightarrow NO_2^- + 2Fe^{3+} + 2OH^-$$

$$NO_2^- + 6Fe^{2+} + 5H_2O \rightarrow NH_3 + 6Fe^{3+} + 7OH^-,$$

copper is used as a catalyst.

Biological methods of sewage purification from nitrogen compounds

The analysis of the numerous reference data and the authors' own research testify to impossibility of complete simultaneous removal of nitrogen and phosphorus compounds in a one-sludge system in one and the same installation, as it is necessary to alternate the aerobic zone with the anaerobic one during biological removal of phosphorus, the anaerobic period must take not less than 3-4 hours and it leads to oppression of obligatory aerobes. Besides, metabolism of microorganisms is inhibited in anaerobic conditions and nitrates presence, these microorganisms accomplishing the process of biological dephosphorization.

Nitrogen in some form is necessary for all biological processes to synthesize the cell proteins and nucleic acids. When sewage is purified from nitrogen, assimilation of inorganic nitrogen compounds with bacteria and algae, bacterial nitrification and denitrification are used (Fig. 6.1). The first step in nitrogen compounds transformation is formation of ammonium nitrogen from organic substances. This process is called ammonification and is accomplished with enzymes produced with microorganisms. Nitrogen is used for the growth of microorganisms and thus part of inorganic nitrogen transfers into newly forming bacteria cells. Microbiological research proved the dry matter nitrogen concentration in a bacteria cell to be 11-13%. Steady accumulation of nitrifying bacteria progresses at high sludge age and sufficiently high temperature; ammonium nitrogen is oxidized first into nitrite nitrogen and then into nitrate nitrogen. This process is called nitrification and progresses only when oxygen is available. The formed nitrate nitrogen may be used for oxidation of organic substances; it reduces to free nitrogen air stripped into the atmosphere during aeration. It is a multi-stage process. First nitrate nitrogen reduces into nitrite nitrogen and then into nitrous oxide (N_2O) and finally into molecular nitrogen; this process is called denitrification and it progresses without oxygen but when readily oxidized organic substances are available.

Ammonification — Nitrification — Denitrification

Organic Compounds Nitrogen ⇄ Ammonium Nitrogen → Nitrates → Molecular Nitrogen

Fig. 6.1. Transformation of Nitrogen-Containing Compounds

Nitrification

Nitrification is accomplished with nitrifying microorganisms, of the Nitrosomonas and Nitrobacter genera mainly. Metabolism of these aerobic chemolythoautotrophic microorganisms is very much susceptible to the environmental factors. First of all, the optimal mode of nitrification depends on the dissolved oxygen concentration, pH value, temperature of treated water, substratum (ammonium ions) concentration. The given microorganisms utilize inorganic carbon as the only source of carbon. Active sludge contains only 1-2 % of nitrifying bacteria.

The dissolved oxygen is the electrons acceptor in reactions of biochemical oxidation of ammonium nitrogen, energy for cellular element formation is evolved during the transport of these electrons (the empirical formula is - $C_5H_7NO_2$), this energy also supports the microorganisms' functions. The necessary amount of oxygen may be determined using stoichiometric relationships in oxidation-reduction equations of ammonium nitrogen transformation into nitrite nitrogen and nitrite nitrogen transformation into nitrate nitrogen:

$$55NH_4^+ + 76O_2 + 109HCO_3^- = C_5H_7NO_2 + 54NO_2^- + 57H_2O + 104\,H_2CO_3$$

$$400NO_2^- + NH_4^+ + 4H_2CO_3 + HCO_3^- + 195O_2 = C_5H_7NO_2 + 3H_2O + 400NO_3^-$$

The general equation of oxygen demand for oxidation of ammonium nitrogen into nitrate nitrogen and growth of cellular element will look as follows:

$$NH_4^+ + 1{,}83O_2 + 1{,}98HCO_3^- = 0{,}021C_5H_7NO_2 + 1{,}041H_2O + 0{,}98NO_3^- + 1{,}88H_2CO_3.$$

Thus, the demand in oxygen for oxidation of 1mg of ammonium nitrogen into nitrate nitrogen is 4,2mg and the biomass growth will make 0,2 mg. The relationship of the specific growth rate of nitrifying microorganisms to the dissolved oxygen concentration is determined with the corresponding ratio:

$$K_{OC}: \ K_{OC} = C_O/(K_O+C_O),$$

where C_O is the dissolved oxygen concentration in treated water; K_O is the half-saturation constant equal to 2 mgO_2/dm^3. The minimum oxygen concentration for nitrification is 1,5 mg/dm^3, however, the oxygen concentration increase above 2mg/dm^3 will give no technological effect but increase operating costs.

The intensity of nitrification and the microorganisms growth rate μ_N depend on the pH value. As the pH value is in its turn connected with hydrocarbonate alkalinity, we can judge by the reaction equation that alkalinity decreases throughout the nitrification process, thus neutralizing nitric acid that is the process product that forms in the amount of 2 equivalents per 14 g of nitrogen – or 0,14 equivalent /g of N approximately. Decrease of the pH value inhibits nitrification as nitrifying microorganisms are not tolerant to acids, though they produce acids. The best nitrification results are received when the pH value is 7–9, the pH value of 8,4 is considered optimal. The relationship of the pH value to the hydrocarbonate alkalinity concentration may be determined with the following expression:

$pH = pK_1 - lg[H_2CO_3]/[HCO_3^-]$.

The American researchers found out the type of the relationship of the specific growth rate of nitrifying microorganisms to the pH value when the pH value is less than 7,2 /56/:

$\mu_N = \mu_{Nmax}$ (1- 0,833(7,2 - pH), when pH is more then 7,2 the expression in parentheses equals 1; μ_{Nmax} is the maximum growth rate of nitrifying microorganisms. In the Reference Manual to Construction Norms and Regulations 2.03.04 – 85 the KpH ratio has different values depending on the pH value:

pH	6	6,5	7	7,5	8	8,4	9
KpH	0,15	0,31	0,5	0,6	0,87	1	1,23.

The growth rate of nitrifying microorganisms depends also on the medium temperature, for example, in the monograph “Nitrogen Control and Phosphorus Removal in Sewage Treatment” (1987) a table of relationship of the maximum growth rate of microorganisms to the temperature is given which may help to state that for Nitrosomonas inhabiting active sludge at T = 12^{O}C, μ_{Nmax} = 0,4 day^{-1}; at 16^{O}C, μ_{Nmax}= 0,57 day^{-1}; at

20^OC, μ_{Nmax}= 0,71 day^{-1}; for Nitrobacter: at 8^OC, μ_{Nmax} = 0,25 day^{-1}; at 21^OC, μ_{Nmax}=0,34 day^{-1}.

In the Reference Manual to Construction Norms and Regulations 2.04.03 – 85 the Kt ratio values are given taking into account the influence of the liquid temperature:

^OC	10	15	20	25	30
Kt	0,32	0,56	1,0	1,79	3,2.

The specific growth rate depends on the limitative substratum concentration as well, the relationship looking as follows:

$$\mu_N = \mu_{Nmax}\, N/(N + K_S),$$

where N is the limitative substratum concentration, mg/dm^3; K_S is the Moneau constant, which is also called the affinity to substratum constant or the saturation constant; it determines the substratum concentration value at which the microorganisms' growth rate equals the half of the maximum value. The saturation constant depends on the temperature value, this relationship was established experimentally and represented in the form of the following equation by the American researchers /56/: K_S = 100,051T - 1,158 mg/dm^3.

Thus, taking into consideration all constant values the specific growth rate of nitrifying microorganisms depending on the given process conditions may be determined according to the following equation:

μ_N = 0,47[e0,098 (T-15)][(1-0,833 (7,2-pH)][N/(N+100,051T-1,158)][Co/Co+Ko], day^{-1}.

For example, at T= 20^0C, pH = 7,0; N = 2,5 mg/l; Co = 2,0 mg/l; Ko = 1,3 mg/l: μ_N = 0,3 day^{-1}.

The specific growth rate of microorganisms determines the duration of sludge presence in the system - the sludge age (Θ), $\Theta = 1/\mu_N$, day. The energy coefficient during nitrification is not large, thus determining the low specific growth rates of autotrophic microorganisms. That is why it is important to maintain the constant high sludge age in order to accomplish stably the nitrification process. The sludge age is determined with the ratio of the total sludge amount in the system to the rate of its removal from the system, however, when calculating nitrification parameters only the aerobic sludge amount must be taken into consideration. The specific growth rate of nitrifying microorganisms is very much susceptible to the temperature mode. The relationship of the sludge age sufficient for nitrification to the treated sewage temperature is shown in Fig. 6.2.

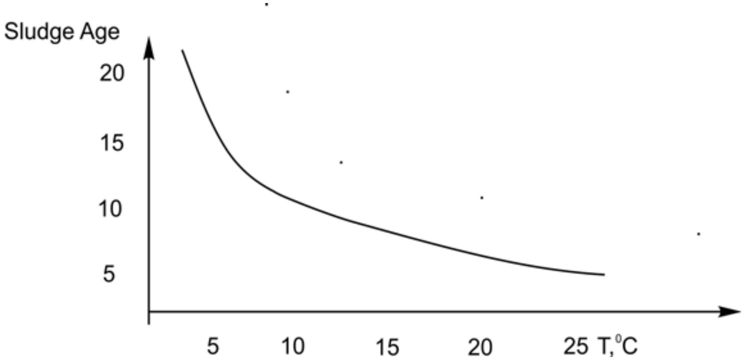


Fig. 6.2. Sludge Age Necessary for Nitrification
(according to the Data of the Handbook on Modern Purification Techniques and Equipment for Natural Water and Sewage, 2002)

The nitrogen balance of its transformation in bioreactors may be represented with the following equation:

$C^F_{N\text{-}NO3} = C^P_{N\text{-}NH4}{}^+ + C^E_{N\text{-}NH4}{}^+ - C^a_{N\text{-}NH4}{}^+ - C^T_{N\text{-}NH4}{}^+$, mg/dm^3,

where $C^F_{N\text{-}NO3}{}^-$, mg/dm^3 is the concentration of nitrate nitrogen formed during nitrification; $C^P_{N\text{-}NH4}{}^+$ is the total nitrogen concentration (of organic and ammonium nitrogen) in primary sewage, mg/dm^3; $C^E_{N\text{-}NH4}{}^+$ is the concentration of ammonium nitrogen entering the sewage in the process of endogenous respiration, mg/dm^3.

In the arotank-nitrificator the heterotrophic microorganisms concentration considerably exceeds that of the autotrophic microorganisms, that is why the main amount of ammonium nitrogen entering the system in the process of endogenous respiration is connected with self-oxidation of heterotrophic microorganisms which die-off rate is 0,08 day^{-1},

$C^E_{N\text{-}NH4}{}^+ = (a_i V K_1 K_2 K_3)/Q$, mg/dm^3,

where a_i is the ash-free matter sludge dose, g/dm^3; V is the aeration zone volume of the aerotank-settler, m^3; K_1 is the die-off rate constant of heterotrophic sludge, day^{-1}; K_2 is the decomposition degree of the ash-free matter of sludge assumed according to the value of the liquid temperature multiplied by the sludge age value (TΘ), for example, at TΘ = 200, the ash-free part of sludge decomposition will make 0,32, at TΘ = 600 – 0,42, at TΘ = 1000 – 0,46; K_3 = 0,09 g_N/g_{sludge} is the ammonium nitrogen amount entering the system during self-oxidation of bacteria; $C^{a}_{N\text{-}NH4}{}^{+}$, mg/dm^3 is the assimilated nitrogen concentration during the metabolism of microorganisms,

$C^{a}_{N\text{-}NH4}{}^{+} = 14/113(Y_S)$ (Len – Lex) mg/dm^3; Y_S – specific sludge growth, $Y_S = 0{,}4/(1+0{,}06\Theta)$, $mg_{sludge}/mg_{BODcomp}$; $C^{T}_{N\text{-}NH4}{}^{+}$ is the ammonium nitrogen concentration in the treated water, mg/dm^3.

Nitrate nitrogen is removed during dissimilation reduction – denitrification. Many bacteria – elective anaerobes – use bonded nitrate oxygen for respiration and reduce nitrate with isolation of molecular nitrogen or nitrous oxide N_2O. Gaseous nitrogen forms transfer from the treated water into the atmosphere during aeration. Denitrifying microorganisms are chemoorganoheterotrophs and need organic carbon for respiration. When primary sewage is used as the organic nutritious medium, the BOD_5 organic substances concentration in the denitrificator must be not less than by 20 % higher than the chemically bonded oxygen concentration, or in other words, the following condition must be maintained: $BOD_5 = 4C_{N\text{-}NO3}$. The total amount of organic substances entering the denitrificator must make up:
$QC + qC_1 = 4C_{N\text{-}NO3}Q_1$,
where Q, m^3/day; C, mg/dm^3 is the volume and concentration of the organic substances of sewage delivered from the aerotank-settler to the denitrificator; q, m^3/day; C_1, mg/dm^3 is the volume and concentration of the organic substances in clarified sewage used as the source of organic carbon; Q_1, m^3/day is the total amount of sewage in the denitrificator,
$Q_1 = Q + q$, m^3/day, then
$q = Q(4C_{N\text{-}NO3} - C)/(4C - C_1)$, m^3/day.
If primary or clarified sewage is used as the carbon substratum carrier, the available ammonium nitrogen must be taken into account. Its residual concentration may be calculated after denitrification (C^{D}_{N}) according to the following:

$C^{D}_{N} = (QC^{T}_{N\text{-}NH4} + q\,C^{P}_{N\text{-}NH4})/Q_1 - C^{a}_{N\text{-}NH4}$, mg/dm^3,
where C^{D}_{N} is the ammonium nitrogen concentration after the denitrificator, mg/dm^3; $C^{T}_{N\text{-}NH4}$ is the ammonium nitrogen concentration in treated sewage from CW, mg/dm^3; $C^{P}_{N\text{-}NH4}$ is the ammonium nitrogen concentration in primary sewage, mg/dm^3; $C^{a}_{N\text{-}NH4}$ is the concentration of ammonium nitrogen assimilated during denitrification, mg/dm^3. When free floating sludge is used for denitrification the installation volume is determined with the treated

sewage volume multiplied by the time of its presence in the denitrificator, which in its turn depends on the nitrate reduction rate. During biochemical evolution denitrifying microorganisms preserved and developed such type of metabolism when the oxygen liberated from the organic substratum is transferred to the bonded nitrate oxygen. In this case, nitrates are electrons acceptors and nitrate nitrogen reduces to molecular nitrogen and other gaseous forms. Denitrifying microorganisms are chemoorganoheterotrophs according to their metabolism type; they utilize organic substances for both receiving energy (as a result of the oxidation-reduction reaction accompanied with transport of protons and electrons) and synthesizing cellular element. Theoretically, the demand of an organic substance may be determined with the stoichiometric coefficients of the corresponding reaction equations. For example, if we consider methanol as the energy carbon substratum and take into account that denitrification progresses in two stages, we may equate the following reactions:

Stage 1: $NO_3^- + 0,33CH_3OH = NO_2^- + 0,67H_2O$

Stage 2: $NO_2^- + 0,5CH_3OH = 0,5N_2 + 0,5CO_2 + 0,5H_2O + OH^-$, the total nitrate nitrogen transformation is achieved as a result of the process that may be represented as the result of addition of the given reaction equations: $NO_3^- + 0,833CH_3OH = 0,5N_2 + 0,833CO_2 + 1,167H_2O + OH^-$. In this equation methanol is the electrons donor and nitrates are electrons acceptors. It may be shown when the equation is divided into the following oxidation-reduction half reactions:

$NO_3^- + 6H^+ + 5e^- \rightarrow 0,5N_2 + 3H_2O$ and

$0,833CH_3OH^- + 0,833H_2O \rightarrow 0,833CO_2 + 5H^+ + 5e$.

Nitrates receive electrons and the algebraic sum of the nitrogen charge decreases, consequently, it is the electrons acceptor; the carbon source, methanol, loses electrons oxidizing to CO_2, consequently, it is the electrons donor. Theoretical demand of methanol for metabolism energy needs is 1,9 mg/mg $N\text{-}NO_3$. The necessary amount of methanol for cellular element synthesis may be theoretically determined according to the following equation:

$NO_3 + 1,08CH_3OH + 0,24H_2CO_3 = 0,056C_5H_7NO_2 + 0,47N_2 + 1,68H_2O + HCO_3^-$

The methanol consumption with consideration of the biomass synthesis increases to 2,47. It was established that complete denitrification was possible when the methanol to nitrate nitrogen ratio was 3 mg/mg.

Notwithstanding the fact that methanol may be acknowledged the ideal carbon substratum as it does not contain nitrogen and is a readily oxidized substance, the product cost and organization expenses are large enough and make us look for alternative sources of carbonic nutrition. Expediency of any substratum may be determined with the technological parameter – denitrification velocity – besides the economic component of the process evaluation. The denitrification velocity in its turn determines the design dimensions of the installation, which also influence the process cost. It is natural that the process progresses most effectively when an easily decomposed organic substratum is used, for example, methanol, ethanol, organic acids. In the Reference Manual to Construction Norms and Regulations 2.03.04-85 the maximum values of denitrification velocity are given when methanol or ethanol is used, the values equaling 58,8 and 44,9 mgN-NO_3/(gh) correspondingly. As the maximum denitrification velocities refer to the optimal mode of the process (with the temperature of about 30^{0}C, pH = 7,0–7,5) that is not reproduced in real conditions as a rule, the denitrification velocity decreases and changes for the given substratum types mainly within the range of 6,0 – 11 mgN-NO_3/(gh). When studying the denitrification process at operating sewage purification installations in Florida, Zemaitis showed that wastewater from breweries might substitute methanol if used in systems with suspended sludge.
It was established that denitrification velocity was 9,16–10,4 mgN-NO_3/g_{sludge}h when wastewater from a brewery was used as a carbonic substratum and 7,5 mgN-NO_3/g_{sludge}h when methanol was used. Christensen (California) found out that organic acids might be used as a carbonic nutrition alternative to methanol, a mixture of volatile acids in wastewater from intermediate nylons factory being most efficient for denitrification, in particular. Denitrification velocity reached 15 mgN-NO_3/g_{sludge}h at 20^{0}C and 4,17 mgN-NO_3/g_{sludge}h at 10^{0}C. These velocities are comparable to those achieved when methanol was used. Central Cjntra Costa Sanitary District's Advanced Treatment Test tested treacle as a methanol substitute, the maximum denitrification velocity was achieved at 16^{0}C in the reactor with a suspended sludge bed and made up 1,5 mgN-NO_3/g_{sludge}h. When clarified sewage was used as carbonic nutrition, denitrification velocity made up 2,9 mgN-NO_3/g_{sludge}h, according to the data of the researchers from New-Jersey the maximum velocity of nitrate nitrogen removal (ρ^d, mgN-NO_3/(g_{sludge}h)) changes depending on the temperature and makes up at 10^{0}C – 2,08;

15^0C – 3,33; 20^0C – 6,25 and at 25^0C – 8,3 mgN-NO_3/(g_{sludge}h).

The most applied scheme of the active sludge installations, which simultaneously remove nitrogen and phosphorus compounds, is the 4-section Bardenpho scheme (Fig. 6.3). In order to accomplish denitrification effectively the influent sewage carbon is used as well as carbon forming as a result of the endogenous biomass decomposition. Ammonium passes through the first anoxic zone and then transforms into nitrites and nitrates in the first aerobic zone. The nitrates often return to the first anoxic zone and also pass to the second anoxic zone for additional denitrification assisted with endogenous carbon. In the second aerobic zone, molecular nitrogen evolves into the atmosphere. The simplified calculation of the 4-section Bardenpho scheme (according to Metcalf & Eddy, 1994) is given below.

On conditions that the nitrates returned to the anoxic zone have been completely denitrified and neglecting nitrogen assimilation, the recirculation (of sewage and recycle sludge) ratio *R* is written as follows:

$$R = \frac{(NH_4^+ - N)_0 - (NH_4^+ - N)_e}{(NO_3^- - N)_e} - 1$$

where $(NH_4^+ - N)_0$, $(NH_4^+ - N)_e$ are the influent and effluent ammonium nitrogen concentrations (mg/dm^3) correspondingly; $(NO_3^- - N)_e$ is the effluent nitrate nitrogen concentration, (mg/dm^3).

As nitrifying bacteria may grow in the aerobic zone exclusively, the sludge presence time necessary for nitrification may be written as

$$\theta_c^{'} = \frac{\theta_c}{V_{aer}}$$

where $\theta_c^{'}$ and θ_c is the time of sludge presence in the Bardenpho system and in the traditional active sludge system necessary for nitrification, V_{aer} is the aerobic fraction share in the Bardenpho system.

From the mass balance equations in the traditional active sludge system, the sludge concentration value is determined according to the following equation:

$$X = \frac{\theta_c}{\theta} \frac{Y(S_0 - S)}{(1 + k_d \theta_c)}$$

From here, the full time of sludge presence in aerobic zones of the Bardenpho system may be calculated according to the following equation:

$$\theta_a = \frac{\theta_c' Y_h (S_0 - S)}{X_a (1 + k_d f_{VSS} \theta_c')}$$

where θ_a is the full time of sewage presence in aerobic zones (day), Y_h is the economic coefficient (Y_h = 0,55 mgVSS/mg BOD_5), $S_0 - S \approx S_0$ is the BOD amount consumed in the system, k_d is the endogenous biomass decomposition coefficient (day^{-1}), X_a is the active sludge concentration (mg/dm^3), f_{VSS} is the decomposable fraction X_a during aeration.

As the decomposable fraction changes with changes of θ_c' and k_d it will be more correct to write it down as follows:

$$f_{VSS} = \frac{f_{VSS}'}{\left[1 + (1 - f_{VSS}') k_d \theta_c'\right]}$$

where f_{VSS}' is the constant usually assumed to be between 0,75 and 0,8.

The time of presence in the anoxic zone is written down as follows:

$$\theta_{DN} = (1 - V_{aer}) \theta_a$$

where V_{aer} is the aerobic zones share.

The time of presence in the anoxic zone necessary for denitrification is in its turn written down as follows:

$$\theta_{DN}' = \frac{N_{Denit}}{U_{DN} X_a}$$

where N_{Denit} is the nitrate amount for denitrification (mg/dm^3), U_{DN} is the typical denitrification velocity (day^{-1}). If $\theta_{DN} \neq \theta_{DN}'$, calculations are made for different V_{aer} values.

According to the Metcalf & Eddy 1994 Handbook the following chosen parameters are calculated as follows:

the influent BOD concentration is 200 mg/dm^3, the influent ammonium nitrogen concentration is 25 mg/dm^3, the effluent ammonium nitrogen concentration is 1,5 mg/dm^3, the effluent nitrate nitrogen concentration is 5 mg/dm^3, the temperature is 15^oC:

Y_h = 0,55 mg VSS/mg BOD_5, k_d = 0,04 day^{-1} (15 ^oC),

$U_{DN} = 0{,}042 mgNO_3 - N / mgVSS\ day$, the dissolved oxygen concentration in aerobic zones is 2 g/dm^3,

X_a = 2500 mg/dm^3, θ_c = 8,9 day for denitrification,

$V_{aer} = 0,71$, $f'_{VSS} = 0,8$.

As a result, we receive according to the given equations

$$R = \frac{25 - 1,5}{5} - 1 = 3,7\,;\; \theta'_c = \frac{8,9}{0,71} = 12,5\,\text{day},$$

$$f_{VSS} = \frac{0,8}{1 + (1 - 0,8)\,0,04\ \text{day}^{-1}\,12,5\ \text{day}} = 0,73\,,$$

$$\theta_a = \frac{(0,55\,\text{mgVSS}/\text{mgBOD})\,(200\,\text{mg}/\text{dm}^3)(12,5\,\text{day})}{2500\,\text{mgVSS}/\text{dm}^3\left[1 + (0,04\,\text{day}^{-1})(0,73)(12,5\,\text{day})\right]} = 0,4\ \text{day} = 9,6\ \text{h}$$

$$\theta_{DN} = (1 - 0,71)(0,40) = 0,12\,\text{day} = 2,9\,\text{h}\,;$$

$$\theta'_{DN} = \frac{(25 - 1,5 - 5)\,\text{mg}/\text{l}}{(0,042\,\text{day}^{-1})(2500\,\text{mg}/\text{l})} = 0,18\ \text{day} = 4,3\ \text{h}.$$

6.2. Dephosphorization Methods

A traditional method of phosphorus removal from sewage is a chemical method of sedimentating phosphates by means of adding calcium, magnesium and iron salts. The biological method of phosphorus removal presupposes phosphorus assimilation with microorganisms of active sludge and its removal from the system with excessive sludge. Excessive sludge may be used as an organic fertilizer after it has been removed if it does not contain toxic compounds and pathogenic microorganisms. For traditional purification installations for household sewage treatment the total abundance of phosphorus compounds in the sludge mass (mg PO_4-P/dry matter mg) makes from 0,01 to 0,02 mg-P/mg (Yakovlev, Karyukhina, 1980). However, when the anaerobic stage is included into the traditional purification scheme it leads to several times increase of the amount of phosphorus assimilated with active sludge. When anaerobic and aerobic zones are alternated the bacteria of the *Acinetobacter* genus which have enhanced ability to accumulate phosphates (Matsuo, Mino, 1984) are attached to the microorganisms' population in active sludge.

Among the most well-known installation designs with active sludge that simultaneously remove carbon, nitrogen and phosphorus compounds one can single out the A^2/O process, the 5-section Bardenpho process and the UCT process (Fig. 6.3, 6.4).

The typical characteristics and comparison of these processes are given in Table 6.2.

The advantages and drawbacks of the biological purification installations with simultaneous removal of carbon, nitrogen and phosphorus compounds are given in Table 6.3.

The A^2/O process. The key factor for biological removal of phosphorus is the alternate presence of microorganisms in anaerobic and aerobic conditions. The anoxic zone with the time of microorganisms' presence of about 1 hour is necessary for denitrification which presupposes chemically bonded oxygen in the form of nitrates or nitrites entering the zone when sewage and sludge are recycled from the aerobic section. The effluent phosphorus concentration reaches the value of 2 mg/dm^3.

The Bardenpho process. The 5-section scheme includes the anaerobic stage, 2 anoxic stages and 2 aerobic stages. The second anoxic zone ensures additional denitrification with consumption of nitrate as the electrons acceptor produced in the aerobic section and organic carbon as the electrons donor in the oxidation-reduction reaction. At the final aerobic stage, gaseous nitrogen enters the atmosphere. This stage also ensures the minimum withdrawal of phosphorus into the final settling tank. The sludge and sewage mixture recirculates from the 1st aerobic zone into the anoxic zone.

The UCT process. This scheme is similar to the A^2/O process, however, the recycle sludge returns to the anoxic zone and the inner recycle is realized from the anoxic zone into the anaerobic zone. Thus, nitrates are not delivered into the anaerobic zone and phosphorus removal in the anaerobic zone improves. The effluent from the anoxic zone contains considerable BOD quantities but little nitrates quantities. The recycle from the anoxic zone ensures optimal conditions for fermentation.

Table 6.2.

Typical Parameters for Combined Removal of Carbon, Nitrogen and Phosphorus Compounds from Sewage (Metcalf & Eddy, 1994).

Parameter	Units	A^2O	Bardenpho Process	UCT
Ratio of Pollutants to Active Sludge Mass, (F/M)	kg BOD/ kg day	0.15–0.25	0.1–0.2	0.1–0.2
Time of Presence of Active Sludge, θ_c	day	4–27	10–40	10–30
Active Sludge	g/dm^3	3–5	2–4	2–4
Time of Presence of Sewage, θ	h			
Anaerobic Zone		0.5–1.5	1–2	1–2
Anoxic Zone 1		0.5–1.0	2–4	2–4
Aerobic Zone 1		3.5–6.0	4–12	4–12
Anoxic Zone 2			2–4	2–4
Aerobic Zone 1			0.5–1.0	
Active Sludge Recycle	% of effluent	20–50	50–100	50–100
Inner Recycle	% of effluent	100–300	400	100–600

Table 6.3

Advantages and Drawbacks of Biological Purification Installations with Simultaneous Removal of Carbon, Nitrogen and Phosphorus Compounds (Metcalf & Eddy, 1994).

Process	Advantages	Drawbacks
1	2	3
A^2/O	Excessive sludge contains high phosphorus concentration (3-5 %) and may be used as a fertilizer	Purification progresses poorly at low temperatures.

1	2	3
Bardenpho	The excessive sludge amount is minimum. Sludge contains high phosphorus concentration and may be used as a fertilizer. Total nitrogen concentration decreases to the minimum level.	The process demands larger dimensions of installations and power supplies than the A^2/O process. The primary settler reduces removal of nitrogen and phosphorus. The process progresses at high BOD/P ratios.
UCT	The installation has somewhat smaller dimensions that the Bardenpho installation.	The process progresses at high BOD/P ratios. Requires larger power supplies for inner recycles.

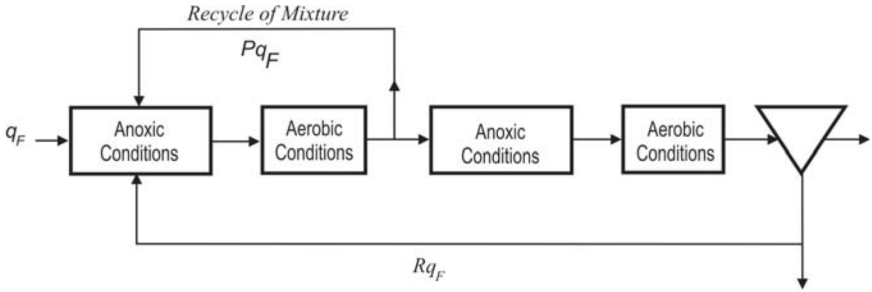
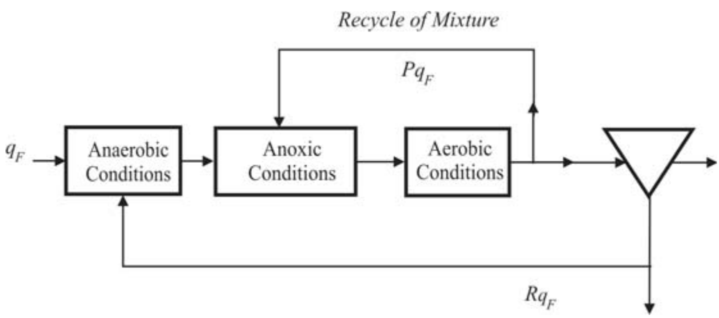
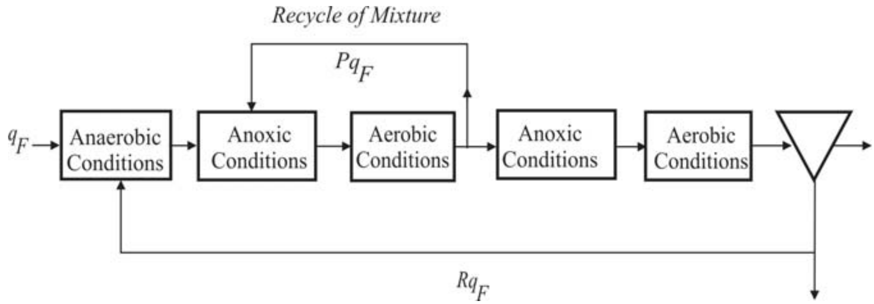


Fig. 6.3. Bardenpho Scheme for Removal of Nitrogen Compounds.

a



b



c

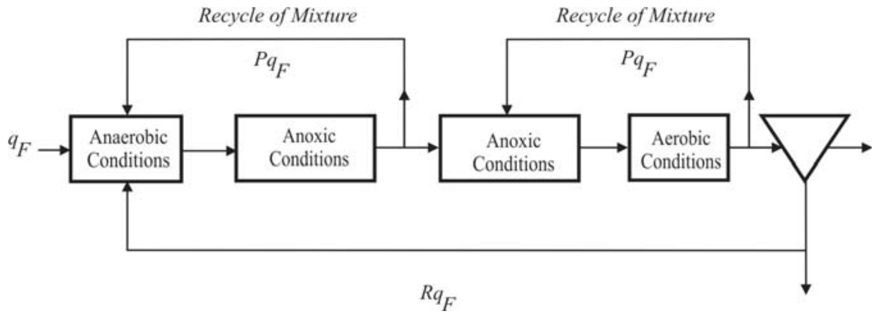


Fig. 6.4 (a, b, c). Three Most Well-Known Schemes for Simultaneous Removal of Carbon, Nitrogen and Phosphorus Compounds

As the research made on the experimental-industrial line by Moscow State Company “Mosvodokanal” have shown, the schemes given above and their comparative characteristics received abroad may not be used at purification installations of Russian cities without being adapted. The main reason for that is the insufficient quantity of biodegradable substances for simultaneous progressing of denitrification and dephosphorization. The specialists of Moscow State Company “Mosvodokanal” have managed to show that delivery of unclarified sewage into the aerotank anaerobic zone enables to reach higher purification efficiency as regards phosphorus but the instability of this process has been observed. The researchers have established the fact of possibility of combining the processes of denitrification and dephosphorization in different zones of one and the same installation at low concentrations of organic substances; in this case it is expedient to deliver active sludge from the aerotank anoxide zone into the aerotank anaerobic zone after denitrification to ensure stability of dephosphorization, thus competition between denitrifying bacteria and RAO-bacteria for substratum is removed. Thus, it must be noted that biological denitrification and dephosphorization may be accomplished at purification installations of Russian cities with specific low concentrations of organic compounds in sewage at high values of N/BOD and P/BOD ratios, however, the choice of a rational scheme must be done experimentally by specialists experienced in adjustment of installations of this type. Evidently, it is most expedient to introduce the biological dephosphorization scheme at high capacity purification installations. When purification installations service small settlements, the physicochemical dephosphorization scheme may be still actual.

6.3. Interactive Software for Calculation of Biological Installations Parameters

A working group under the aegis of the International Water Association (IWA) worked out a mathematical model of active sludge system (Activated…, 1986), where both organic substances oxidation and nitrogen compounds transformation were described. It was also taken into account that nitrogen and carbonic compounds might be dissolved or suspended.

The total pollutants concentration was divided into inert, heavily oxidized and readily oxidized fractions.
Dissolved oxygen concentration and alkalinity were also variable. In next 15 years the model popularity surpassed all expectations and there are several versions of it at present, the model taking into account accumulation of organic substance with microorganisms cells, in particular (Modelling and Microbiology…, 1999).

A simplified interactive program “Nitrogen” was suggested by Vassiliev and Vavilin (Vassiliev, Vavilin, 1990; Vavilin et al., 1993) for engineering calculations of the active sludge system parameters assuming the stationary system conditions. Different schemes of a multi-section aerotank were considered, optimal values of such parameters as relative section volumes and section distribution of flows were determined. The minimum reactor volume was determined according to the given effluent concentration of nitrogen compounds. The comparison of different schemes of multi-sectional aerotanks showed that the Bardenpho system turned out to be the most efficient one. However, this efficiency must be paid for with the energy consumed with pumps for sludge mixture. The purification efficiency values as regards nitrogen improve with increase of the sludge mixture recirculation ratio *P*. The choice of relative values of flows and section volumes influences the efficiency of nitrogen removal greatly. For all schemes optimal values of these parameters depend on the purification installations performance. It may be noted that the aerotank aerobic zone share must increase with increase of organic load and the anoxic zone share must decrease. The increase of the recycle sludge recirculation ratio *R* positively influences the nitrogen removal process, the influence increasing with increase of organic load. When evaluating the biological removal of phosphorus, cellular mechanisms of accumulating polyphosphates with microorganisms of active sludge must be considered (Vasiliev et al., 1994).

Chapter 7. BIOLOGICAL PURIFICATION INSTALLATIONS DESIGNED BY RSRI APS

7.1. Combined Installations Design and Operation Principle

A system of new types of sewage purification installations for settlements, cities and enterprises producing and processing agricultural products has been elaborated in the Rostov-on-Don Scientific-Research Institute of the Academy of Public Services according to the plans of scientific and research work and development of the Ministry of Housing and Public Services, Ministry of Agriculture and the State Committee for Housing of the Russian Federation. The main parts of the system are combined installations and works (CW) with characteristics of biofilters and aerotanks-settlers. In contrast to biofilters-stabilizers biofilters are not main elements in CW but only their components. A tank under the biofilter serves as an aerobic purification installation with active sludge. A system of water-jet aeration is realized in the CW making the installation's performance more reliable and economically profitable as compared to operation utilizing compressors and mechanical aerators.

An original technological solution of CW enables to ensure purification of household sewage and industrial wastewater. The CW design peculiarities are determined with their efficiency.

In order to purify concentrated and highly concentrated sewage and to remove biogenic elements if necessary, the technological scheme may be expanded with biocoagulators, anaerobic and aerobic reactors of specific design solutions, devices for physicochemical sewage treatment.

Combined works and installations consist of two main technological units – biofilters and aerotanks-settlers situated under biofilters /25, 26, 27, 28, 29/. Water-jet aeration is used in order to ensure the biological process of biodegradation of organic pollutants and biotransformation of inorganic pollutants with oxygen and maintenance of the aeration zone sludge in suspended state in the aerotank-settler. A mixing chamber and circulation pumps also constitute such installations. A CW scheme is represented in Fig. 7.1.

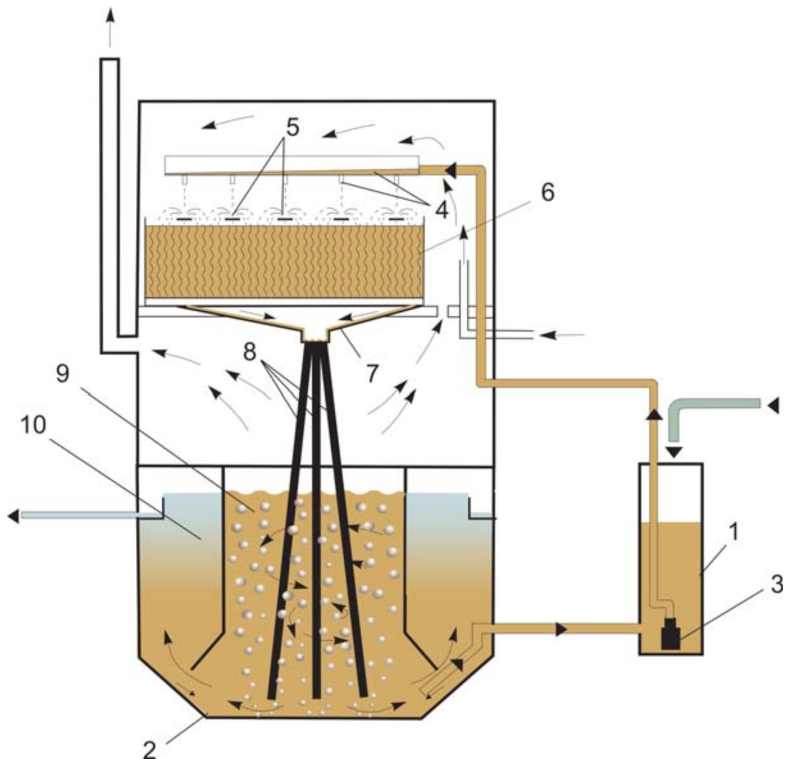


Fig. 7.1. CW Scheme

After preliminary mechanical treatment (separation of suspended solids and sands), sewage is drawn into mixing chamber (1) where sewage is mixed with the sludge liquid coming from aerotank-settler (2). The mixture of sewage and sludge is drawn with circulation pump (3) from the mixing chamber to the biofilter sprinkling system consisting of spouting chutes with outlet pipes (4) and of reflecting disks (5). The falling water jets are broken upon the disks, thus irrigating biofilter feed (6). The liquid leaving the biofilter is collected with tray (7) and delivered by air-stripping towers (8) to aeration zone (9) of the aerotank-settler.

When the liquid moves along the air-stripping tower a zone with reduced pressure forms in it and a vortex forms in the upper part of the tower into which air is sucked. The towers' specific position in the aeration zone (angles of inclination being different and distances from the lower ends of the towers to the bottom being 0,2-0,4 m) forms the movement of gas-liquid flows which ensures efficient mixing of the sludge mixture in the aeration zone alongside with emerging air bubbles. From the aeration zone the sludge mixture comes to settling zones (10) where it is separated. The main amount of sludge is compacted and discharged through slots between the aeration and settling zones into the aeration zone; the other part of sludge is drawn with the upflow of liquid and makes a layer of suspended sludge in the settling zone that traps small particles of pollutants and sludge, thus preventing removal of suspended substances and raising the sewage purification efficiency.

Thus, the CW aerotank-settler design peculiarity enables to maintain the sludge concentration of more than 4-6 g/dm^3 in the aeration zone at its high age, which is not typical for aerotanks of ordinary classic designs. Integrated purification may be accomplished in CW at sufficiently high sludge organic load. Purified water is removed through collecting chutes and treated further or discharged into a water reservoir.

Treated sewage is saturated with oxygen in the following ways: – when oxygen is dissolved in water during sprinkling of the biofilter feed with the mixture of sludge and sewage; - as a result of mass transfer during the biofilm outflow of liquid along the surface of the biofilter flat feed; - when treated water is saturated with the air oxygen in the aerotank due to additional dilution of oxygen in air-stripping towers and air bubbles rising.

The water-jet aeration is accomplished in CW at the definite liquid level above the towers' upper edges situated in the sump of the biofilter collecting tray and at the definite relationship of the towers' height over the liquid surface to the towers' depth; in this case vortexes appear with cores penetrating the pipe openings.

In water-jet aerators, the same principle is used as the one used in hydraulic air compressors. When the performance of hydraulic air compressors is studied the air leak-in value at minimum head values interests the researchers most of all in experiments with the hydraulic air compressor of the jet type, which head wall is a water-jet ejector /30/. According to the research data the volume ejection coefficient is $q_A/Q_x = 1,7 – 0,9$ (q_A is the air consumption, Q_x is the liquid consumption) at the maximum water-jet ejector efficiency of 0,68-0,76. The head loss in the ejector changes from 0,35 to 1,5 millicutter of water in this case.

The main air-entraining factor in both hydraulic air compressor installations and water-jet ejectors is the height and diameter of the tower where the water-air flow moves. In this respect, the research by M.I. Alexeyev is interesting /31/. When analyzed, the results of the theoretical determining of the air amount (q_A), that enters the vertical water sluices during free flow have shown the following: - for every standpipe diameter there exists a value of liquid consumption corresponding to the biggest q_A value, as the liquid flow rate increases with the growth of its consumption, but the sectional area of the air flow decreases simultaneously and, beginning with the certain value of the liquid consumption, the sectional area of the air flow will start decreasing; - the q_A value increases with increase of the standpipe height, as the average air flow rate increases and tends at the limit to V_{max}; – the ejecting capacity of the liquid stabilizes (stabilization of q_A) at the standpipe height equal to 90 values of standpipe diameters (L = 90 D). When the standpipe height increases further, the q_A value will change insignificantly. For the first time a mine apparatus (water-jet aerator) was used during wastewater purification at "Schwarze Pumpe" plant (Germany) in 1966 /32/.

7.2. Theory and Calculation of Combined Installations Parameters

The idea of combining positive features of biological filters (high oxidizing and mass-transfer capacity of immobilized microflora, vitality and low energy inputs for pollutants oxidation) and aerotanks-settlers (high purification efficiency, possibility of integrated mineralization of excessive sludge, possibility to create high sludge concentrations in the reaction volume) laid the foundation for elaborating combined installations and works.

CW is ideal mixing reactors: sewage is first mixed with active sludge in the mixing chamber, then it encounters the biofilter biocenosis, then it is entered uniformly and mixed with the aeration zone total volume and finally it is filtered through the suspended sludge layer in the settling zone. The CW design excludes untreated sewage channeling and ensures high purification efficiency. The total organization of the sewage purification process accomplished in the biofilter – aerotank-settler system enables to accomplish sewage purification in the prolonged aeration mode intended for complete oxidation of organic pollutants, biomass partial mineralization and nitrification.

Sewage organic pollutants are oxidized in biofilters with immobilized microflora. The operation conditions of the CW biofilters are specific and differ from the operation conditions of existing biological filters: the biofilter feed is sprinkled not with clarified sewage water but with a mixture of sewage and active sludge, thus the suspended substances concentration being 3 – 6 g/dm^3; the hydraulic load is 2-3 times larger than that of traditional high-rate biofilters and the feed is sprinkled continuously.

As existing sprinklers do not ensure uniform liquid distribution on the feed surface at constant liquid pressure in the supply net and they often get stopped, and as rotating reactive sprinklers do not ensure uniform sprinkling of the feed and are not reliable during long term operation, a new stationary device for the biofilter feed sprinkling was elaborated based on the principle of the liquid jets dropping and hitting a solid surface. When hitting the surface, a jet falls into a multitude of drops with different falling paths.

Not only the processes of adsorption and destruction of organic pollutants must go on in the CW biofilters with higher purification efficiency, but the processes of nitrification and denitrification must progress as well. With this purpose, a new type of rigid filling feed was elaborated and tested for low capacity installations. A combination of filling materials properties (a developed contact surface) and plate feed properties (prolonged contact time) enables to increase the biofilter specific role in the purification process, as well as to increase the air oxygen solubility in the liquid when passing through the biofilter.

In order to optimize the hydrodynamic mode of the liquid movement and formation of a developed biological mass the flat feed sheets must have a corrugated shape with waves perpendicular to the flowing down liquid and a rough surface.

A new type of flat feed has been elaborated enabling to increase the mass of the microflora immobilized on the material surface and to prevent the feed sludging. The increase of the biomass layer promotes development of nitrifying and denitrifying microorganisms in it.

In the CW design, aerotanks-settlers are intended for biodegradation of organic pollutants that have not been trapped with biofilters, for integrated mineralization of biomass and separation of sludge from purified water. During the periods of enhanced loads on sewage purification installations, the biofilter microflora with limited sorptive capacity for organic substances may not manage the removal of organic substances and the aerotanks-settlers active sludge operates at high organic loads.

Later on, when the CW starts to operate in a normal operating mode, organic pollutants are redistributed between the biofilter biocenosis and active sludge. The active sludge organic load decreases.

The main factors influencing the process of sewage biological purification are the primary sewage temperature and the environmental air temperature. The average sewage temperature in a cold season in Russian cities varies from 15 to 17 ^{O}C, the sewage temperature in medium-sized and small settlements is 9–14 ^{O}C. At the air temperature of -10, -20 ^{O}C the liquid temperature decreases by 1–3 ^{O}C during treatment in the aerotanks with ordinary aeration mode; in the aerotanks with prolonged aeration and overlapping boards – by 4–9 ^{O}C; it leads to deceleration or complete termination of the biochemical purification process. In countries with a hot climate high sewage temperatures and direct sunrays promote rising of the treated sewage temperature to 35 ^{O}C and above; the fact influences negatively the air oxygen solubility and the purification rate. Closed options of sewage purification installations partially solve the problem of the liquid cooling or heating. However, in our opinion, the increase of the oxygen utilization quotient is the main direction of optimization of the temperature operation mode of the installations. The CW design peculiarities enable to achieve the 20% value of the oxygen utilization quotient (theoretically, it is possible to increase this value to 30%) due to its repeated circulation together with treated sewage. This purpose is achieved in the following way (Fig. 7.1): the outer air comes in a natural way into the biofilter room and due to the air-entraining process in the air-stripping towers, it moves top down through the biofilter and towers and emerges in the aeration zone. Then the utilized air is either partially removed into the atmosphere or treated further, partially it is redistributed into the biofilter room to take part in the process of mass transfer.

As the sludge is provided with oxygen due to its dilution in the sludge liquid when the biofilter is sprinkled, when the liquid moves along the biofilter feed surface, as well as a result of air-entraining, mass transfer in towers and during air bubbles rising through the liquid layer, the necessary amount of the air oxygen is determined with calculation and ensured with the corresponding sewage circulating factor in the installation.

The hydraulic efficiency of the water-jet aerator is 0,6-0,65, which is close to the performance parameters of medium-sized bubble aeration. However, additional dilution of oxygen in the liquid during sprinkling and the liquid biofilm outflow along the CW biofilter feed surface ranks combined aeration among the best methods of pneumomechanical aeration. As the CW energy consumption is determined generally with the energy outlay necessary for achieving partial purification effect in aerotanks-settlers (30-40%), the specific energy rate in KWh/m^3, $KWh/kgBOD_{comp}$ is 2-3 times lower than that of well-known aeration installations. Besides, energy consumption of the installation complex also decreases due to decrease of energy outlay for treating of the utilized air.

Systems of sewage biological purification, as well as mass transfer equipment (scrubbers, gas absorbers, rectifiers) in chemical industry and aerobic fermenters in microbiological industry are based on the principle of packed or bubble columns. The new principle (CW) with considerably lower power consumption and a new type of rigid filling feed with higher mass transfer parameters presuppose creation of new installations for chemical and microbial synthesis. Using this principle in chemical industry will allow to decrease the height of the mass transfer equipment from 50-90 m to 15-20 m and to use fans and low-pressure pumps instead of high-lift pumps and high-pressure compressor assemblies.

Calculation Principles for Biofilter - Aerotank-Settler Block

Parameters of biofilters and aerotanks-settlers are calculated taking into account design peculiarities of the CW packaging, as well as the organic substances biodegradation kinetics in these installations. Kinetic data was received while processing the results of numerous experimental researches by the sewage purification laboratory of the Rostov-on-Don

Scientific-Research Institute of the Academy of Public Services under the direction of V.P. Kolesnikov, the author of the idea.

In order to ensure the high technological effectiveness of the purification process it is expedient to intend biofilters for 50-70% purification efficiency. The biofilter purification efficiency in fractions of the unit of total effect is determined according to the following formula:

$$E_b = \frac{\sigma \rho_b F m}{q(L_{en} - L_{ex})},$$

where σ, (g/cm²) is the average quantity of biomass forming on 1 cm² of dry matter of feed surface; ρ_b is the average oxidation rate of organic substances in BOD_{comp} g per 1g of dry matter of biomass per day for the assumed design temperature of the primary sewage in winter season; F is the surface area of the flat feed sheets, cm². This parameter is assumed for design reasons and according to the assumed flat feed sizes; m is the number of the CW sections; q is the treated sewage volume delivered to CW per day, m³/day; L_{en} and L_{ex} are organic substances concentrations in the primary and purified sewage correspondingly, $gBOD_{comp}/m^3$.
The calculation of the aerotank-settler's parameters is reduced to determining the volumes of the aeration and settling zones.

The necessary volume of one aeration section is calculated according to the following formula: W = qt/24m, m³,
where t is the time of the sludge liquid presence in the aeration zone:

$$t = (1 - E_b)(L_{en} - L_{ex})/a_i \ \rho_a, \ h;$$

where a_i is the sludge dose g/dm³; ρ_a is the average oxidation rate for organic substances in mg BOD_{comp} per 1 g of sludge dry matter per hour.

The settling zones parameters are calculated according to the hydraulic load q_{ssa}, m³/(m².h), taking into consideration the active sludge concentration in the aeration zone a_i, its index and J_i, cm³/g.

The settling zone hydraulic load value depending on the values of $a_i.J_i$ should be assumed according to Table 7.1.

Table 7.1

$a_i \ J_i$,	100	200	300	400	500	600
$q_{ms,}$ m³/ (m³ h)	5.6	3.3	1.8	1.2	0.8	0.7

Calculation of parameters of the CW combined aeration system

When designing the aeration system the intensity of the sludge aeration with oxygen and the turbulent conditions intensity in the medium must be taken into consideration; the sewage circulating factor (n) and the circulation pumps efficiency are determined based on these conditions. It has been established empirically that when the sludge mixture circulating factor exceeds 10, the sedimentating properties of sludge deteriorate. For combined installations intended for purification of household sewage with BOD_{comp} 120 – 300 mgO_2/dm^3, the sludge mixture circulating factor (n) varies from 3 to 8. Based on the (BOD_{comp}) pollutants concentration the circulating factor is assigned, the number of air-stripping towers is defined and the verifying calculation is made to compare the amount of oxygen dissolved in the system according to the adopted design solutions and the amount of oxygen necessary for oxidation of the given amount of organic pollutants.

Designing of the water-jet aeration elements begins with determining of the number of air-stripping towers Z according to the following equation:

$$Z = \frac{q\ n}{q_k m 24},$$

where q_k is the flow capacity of the air-stripping towers, m^3/h.

The verifying calculation of the oxygen balance is made according to the following formula:

$$b\ (1-E_B)\ q\ (L_{en}-L_{ex}) \le OC_T\ (K_B-K_A)\ Zm24 - [(C_{1q} + C_{2q})(n-1)],$$

where b is the specific oxygen consumption in aerotanks of complete oxidation assumed equal to 1,1 $gO_2/gBOD_{comp}$; OC_T is the oxidizing capacity of the air-stripping towers, gO_2/h; K_B is the coefficient allowing for the liquid aeration in the biofilter; K_A is the coefficient of influence of inclination angles of towers on their oxidizing capacity OC_T; C_1 and C_2 are the oxygen concentrations in purified water (assumed equal to 2 g/m^3) and sludge mixture coming from the aerotank into the mixing chamber (assumed equal to 1,5 g/m^3) correspondingly.

The left part of the equation designated as Q_1, the right part designated as Q_2, the design circulating factor of the sludge mixture (n) is specified according to the following ratio: $n_D = nQ_1/Q_2$.

The circulation pumps efficiency is determined according to the following equation:

$$q_P = q\ n_D/24,\ m^3/h.$$

7.3. Design Parameters of Combined Installations

The combined aeration system

The mass transfer processes between the gas – liquid phases in CW were studied in 1982-1984 at large-sized pilot installations.

According to the CW design solutions taking into account the rational installation height, the necessary height of passages between the aerotank and the biofilter tray and the sufficient depth of aeration tanks, the air-stripping height above the liquid level in the aerotank should be assumed equal to 2-2,5 m, the tower depth under the water level - 2-3,7 m.

The experimental research on determining the oxidizing capacity of air-stripping towers were made at their height above the water level of 2 m and the tower depth under the water level of 1; 1,5; 2 and 3 m.

The mass transfer coefficient (K_s) and the oxidizing capacity of air-stripping towers (OC_T) were determined utilizing the variable oxygen deficiency method: $K_s = \frac{138{,}18}{t_1 - t_0} \lg \frac{C_n - C_0}{C_n - C_t}$, h^{-1}, $OC_T = K_s C_{n1}\, \alpha w$, g/h,

where C_n is the equilibrium concentration of oxygen in the liquid (depends on the temperature), g/m^3; C_n = 11,25 g/m^3 is the equilibrium concentration of oxygen in tap water in standard conditions; C_0, C_t are the oxygen concentrations in the system at the beginning and at the end of the experiment, g/m^3; t_0, t_1 are the time indications of the experiment beginning and end, min.; α is the Paswer correction for the liquid temperature; w is the water volume assumed for the experiment, m^3.

The research was made on a model installation consisting of a reservoir (imitating the aerotank) with the volume capacity of 1,500 dm^3, a circulation pump, 37, 50 and 70 mm removable pipes with receiving chambers. Plexiglas windows were made to observe the character of bubbles movement in the reservoir. The amount of entrained air was measured by means of a revolving-vane analyzer. The reservoir water was preliminarily treated with sodium sulphate (7,9 g/g of oxygen) and cobalt chloride (1 mg/dm^3), thus the dissolved oxygen was bonded; then water was driven to the receiving chamber and further on to the air-stripping tower. The water flow was regulated by means of changing the pump capacity. The duration of the experiment was determined with the time of achievement of the equilibrium aeration of water. The mass transfer coefficients and oxidizing capacity of the d_y 50 and 70 mm towers in the air-stripping tower – aerotank system were calculated using the above-mentioned formulas; the corresponding curves were drawn (Fig. 7.2).

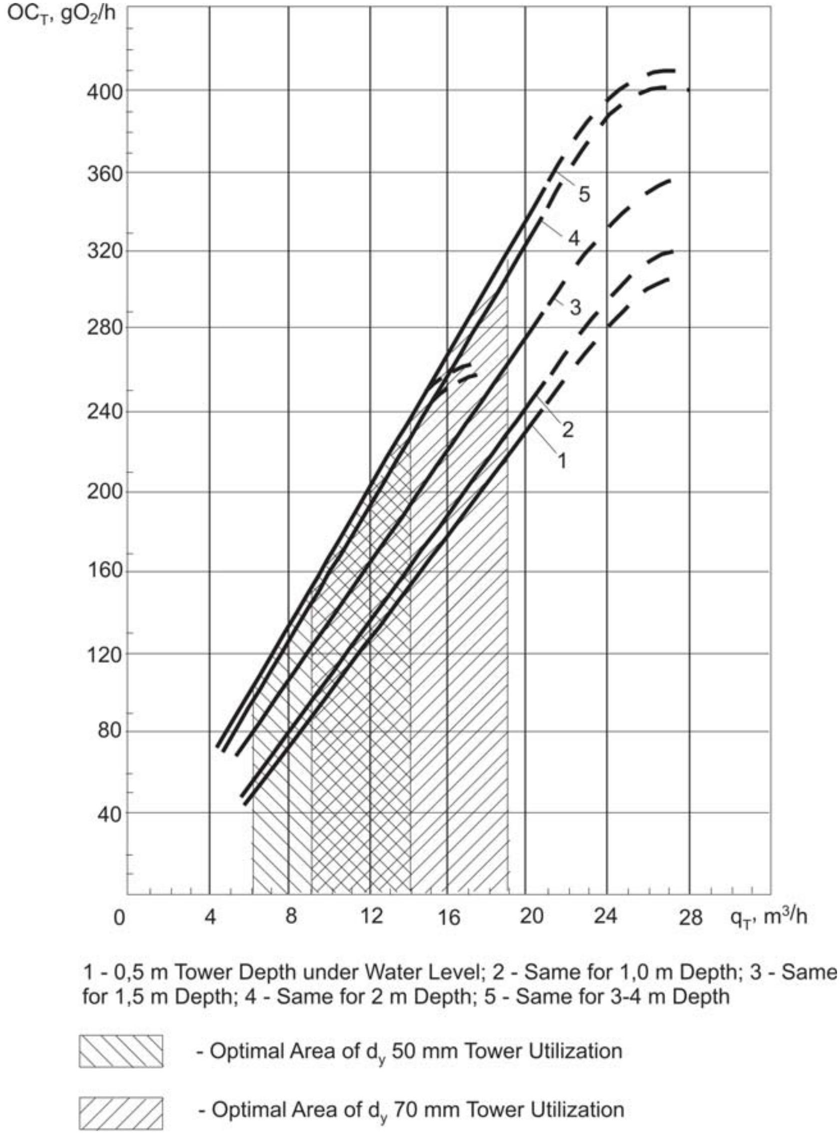


Fig. 7.2. Curve of Determining OC_T for d_y 50, d_y 70 Towers.

The mathematical processing of the practical data represented on the curve resulted in a formula showing the relationship of OC_T to the sewage flow delivered to one air-stripping tower q_T, and to the level of the tower depth under the water level in the aerotank - x. The above-mentioned relationship looks as follows:

$OC_T = q_T (a_1x^2 + a_2x + a_3) + a_4x^2 + a_5x + a_6$,

where a_i (i = 1..6) are the coefficients allowing for technical parameters.

When the air-stripping tower has the diameter within the range of 45-70 mm and its depth is within the range of 0,5 to 1,5 m the formula looks as follows:

$OC_T = q_T (0,4x^2 - 0,6x + 14,2) + 36,4x^2 - 34,6x - 37,8$;

When the air-stripping tower has the diameter within the range of 45-70 mm and its depth is within the range of 1,5 to 3,5 m the formula looks as follows:

$OC_T = q_T (-3,7x^2 + 18,8x - 6)+9,7x^2 - 47,8x + 44$;

When the air-stripping tower has the diameter within the range of 37-45 mm and its depth is within the range of 1,0 to 3,0 m the formula looks as follows:

$OC_T = q_T (-1,7x^2 + 8,7x + 8,7) - 0,84x^2 + 4,3x - 26,7$.

The above-mentioned different variants of calculating OC_T are made by means of a unified computer program developed taking into consideration the boundary conditions of the flow parameters of sewage (m^3/h) delivered to one air-stripping tower.

The limits of effective application of these formulas are calculated with the program depending on the tower diameter d in the following way:

$q_{min} = –3600d^2 + 582,4d – 14,1$

$q_{max} = –12200d^2 + 1715d – 41,3$

The liquid flow pattern in the air-stripping towers is determined based on Reynolds number Re according to the following formulas:

$Re_{min} = 4 (-3600d^2 +582,4d -14,1)/(\pi d \nu)$

$Re_{max} = 4 (-12200d^2 + 1715d - 41,3)/(\pi d \nu)$

where ν is the kinematic viscosity coefficient.

The data of the previous experiments has helped to establish the fact that the water aeration efficiency depends in many respects on the amount of oxygen dissolved in the liquid during the biofilter sprinkling. In order to determine the coefficient allowing for the liquid aeration in the biofilter (K_B), the model installation was supplied with a biofilter.

In this case, the water was circulated with a pump through the biofilter

– (d_y 37) air-stripping tower– aerotank system. The K_B value is the quotient of division of the amount of dissolved oxygen found in the reservoir during the operation of the biofilter – air-stripping tower – aerotank system by the oxygen amount in the reservoir during the operation of the air-stripping tower – aerotank system (Fig. 7.3).

For design reasons the water-jet aerator is executed as a bunch of air-stripping towers – several pipes erected at different inclination angles to the standing axis. However, such a position of towers decreases the amount of entrained air and consequently the oxidizing capacity of towers. The influence of the above-mentioned factor was tested at the model installation while determining the value of oxidizing capacity of removable d_y 50 mm towers at the inclination angles of 15, 25 and 40 degrees.

The data for the K_A calculation is given in Table 7.2.

The research was made in the following conditions:

the water volume in the reservoir – 1,8 m^3;

the tower height above the liquid level – 2 m;

the tower depth – 2 m.

Table 7.2.

Air-Stripping Towers Oxidizing Capacity Depending on Inclination Angle

Tower Inclination Angle to Standing Axis, degrees	Water Temperature, ^0C	Paswer Coefficient	Circulating Liquid Flow, m^3/h	Average Mass Transfer Coefficient, K_s	Oxidizing Capacity OC_T, gO_2/h
–	26,0	0,742	11,06	9,80	147,64
–	27,2	0,728	11,55	11,04	162,76
15	28,6	0,707	11,62	9,44	135,18
15	28,3	0,707	11,93	9,78	140,13
25	27,7	0,721	12,73	8,57	125,12
25	27,8	0,716	11,93	8,18	118,34
25	26,6	0,735	12,28	8,89	132,37
40	25,0	0,756	12,0	6,02	92,27
40	27,8	0,714	12,59	7,58	109,59

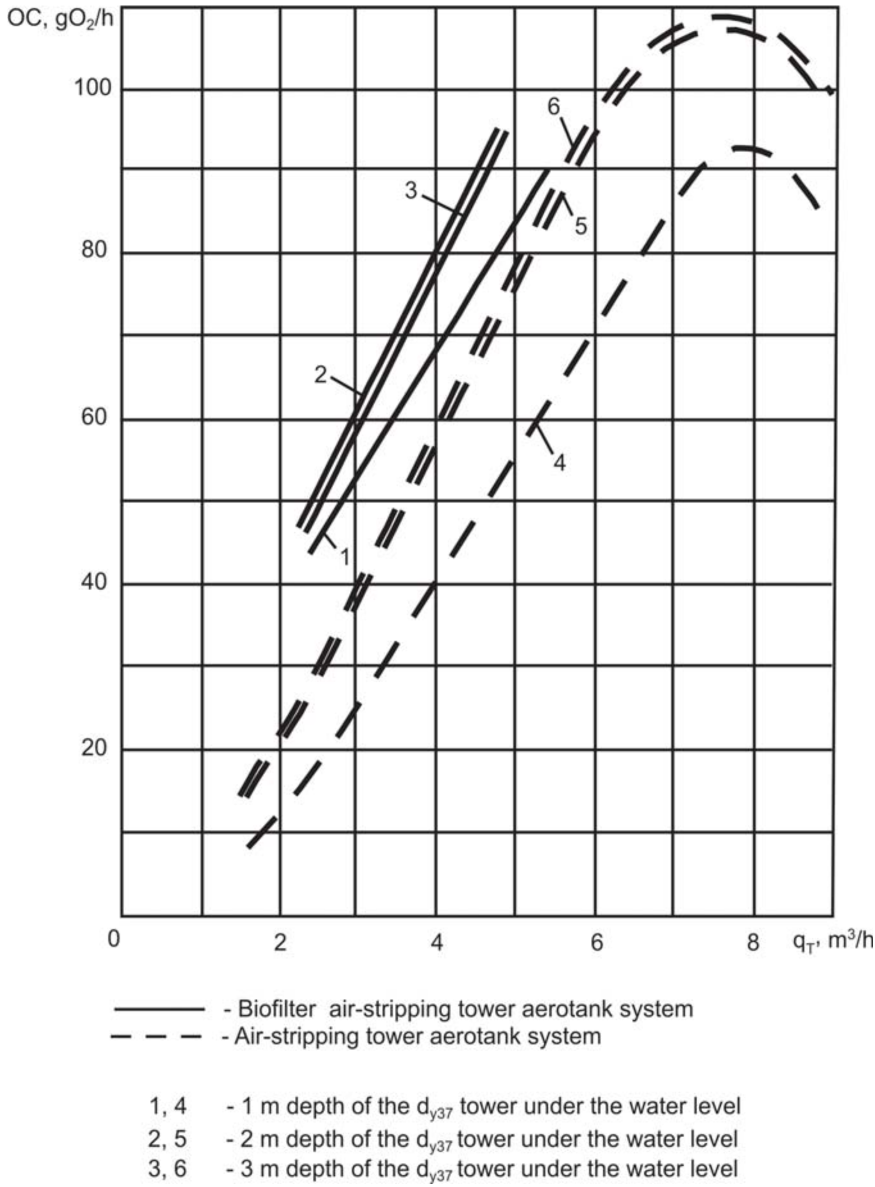


Fig. 7.3. Curve of Determination Oxidizing Capacity of Towers, with Biofilter incl.

The analysis of the research and observations results (Fig. 7.4; 7.5) enabled to find out the following:

Fig. 7.4. View of Air-Stripping Towers

Fig. 7.5. View of Aeration Zone

– Oxidizing capacity of air-stripping towers within the limits of their flow capacity changes in direct proportion to the liquid flow.
– The minimum limit of the tower flow capacity at which a vortex begins to form is 2 m^3/h for the d_y 37 mm pipes, 6 m^3/h for the d_y 50 mm pipes, 9 m^3/h for the d_y 70 mm pipes. The maximum design limit for the flow capacity of the liquid (taking into account the pipes biofouling and consequential decrease of their inner diameter by 1-2 mm) must be assumed equal to 6 m^3/h for the d_y 37 mm pipes, 14 m^3/h - the d_y 50 mm pipes, 19 m^3/h - the d_y 70 mm pipes. The water level above the upper edge of the tower depending on the circulating liquid flow is 2-10 cm.
– At equal flows of the liquid entering the towers the mass transfer coefficient value and the oxidizing capacity of the towers change when the tower depth increases from 0,5 m to 2 m. It may be accounted for with the fact that the efficiency of exchange between the gas-liquid phases increases with increase of partial pressure inside an air bubble and its path. When the tower depth increases, the oxidizing capacity stabilizes (the towers height in the experiment was fixed at the distance of 2 m above the water).

In the same time the amount of the air entrained per 1 m^3 of the circulating liquid decreases, thus, at the depth of 1 m it is 0,8-0,9 m^3/m^3; 2 m – 0,7-0,8 m^3/m^3; 3 m – 0,5-0,6 m^3/m^3.

– The height of the water-air jet leaving the end of the air-stripping tower is 0,5 – 0,7 m, the diameter of the majority of emerging bubbles varies from 3 to 5 mm. However, as the tower depth under the water level increases, large bubbles tend to appear in the system (up to 30 mm in the diameter). This phenomenon is evidently caused with small bubbles merging due to the pressure increase in the lower part of the tower.

- When the liquid was drawn to towers two types of vortexes formed – well developed and shapeless ones. The vortex type may change in the course of time, in other words, a shapeless vortex may change into a well-developed one and vice versa. Shapeless vortexes often form at maximum values of the towers flow capacity. The hydrodynamic mode of operation of other air-stripping towers, closely situated in the receiving chamber of the biofilter collecting tray, also influences the vortex shape. The highest air-entraining and oxidizing capacity values are typical for the air-stripping towers with well-developed vortexes.

- The K_B coefficient value should be assumed equal to 1,33. The value of the reducing coefficient K_A is determined according to the following formula:

$$K_A = 0{,}0116\alpha.$$

The further development of the water-jet aeration system may be developed further in compliance with the patent /31/, according to which guide projections in the form of spirals (Fig. 7.6) or evolvent recesses should be established in the upper part of the air-stripping towers (in the zone of the jet contracted cross-section formation). The projections enforce the clockwise air curling process and ensure the stability of well-developed vortexes formation. In order to decrease pressure inside the water-air flow the air-stripping towers are perforated in their lower parts, the diameters of these openings should increase top-down and the distances between them should decrease circumferentially and towards the tower bottom (Fig. 7.6). It prevents formation of large air bubbles in the aeration zone. Towers are placed evenly above the flat parts of the aeration zone bottom at the distance of 200-300 mm from it.

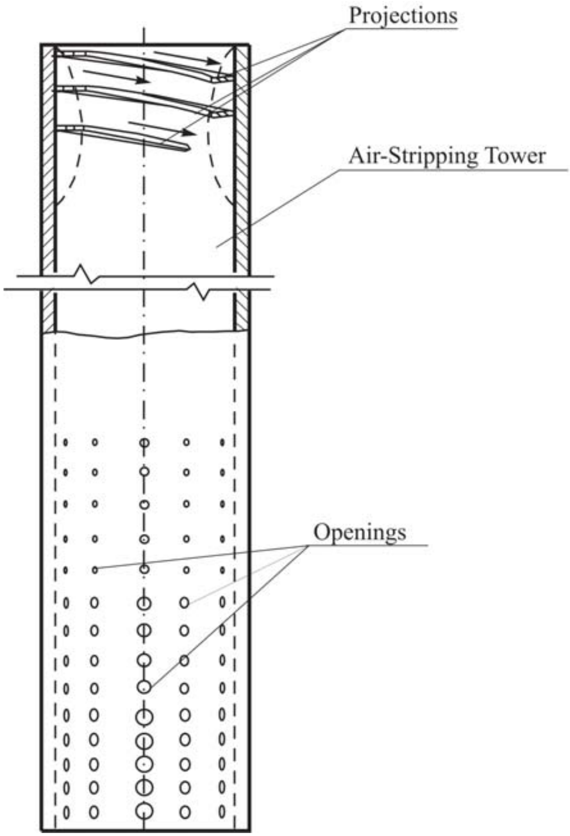
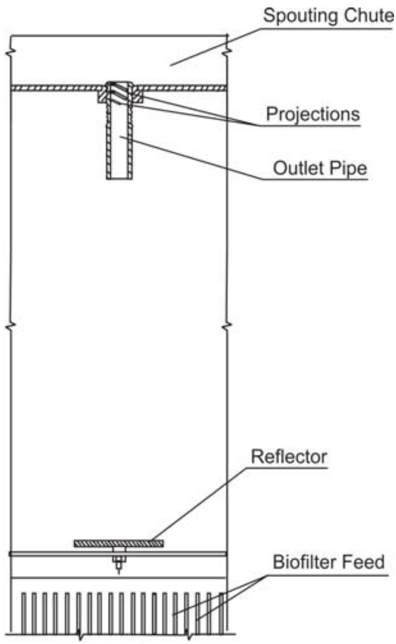


Fig. 7.6. Air-Stripping Tower Section

CW Boilers

In compliance with the patents the biofilter sprinkling system consists of spouting chutes with adjustment devices, outlet pipes and reflectors, the pipes being provided with inner guide projections in the form of spirals and established with consideration of possible change of the height of their overflow edge above the chute bottom /26, 33/.

In laboratory and industrial research the sprinkling system parameters were determined to ensure sufficient uniformity of the biofilter feed sprinkling, as well as simple and reliable operation of the system (Fig. 7.7 a, b).



a


b

Fig. 7.7. Sprinkling System

The sprinkling system is designed in compliance with the following conditions: the distance between spouting chutes is assumed according to the installation capacity and hydraulic load equal to 700-1,200 mm; the outlet pipes length must be 4-10 times larger than their diameters (if this value is less than 4, the falling jet is unstable, if it is more than 10, the jet looks like a continuous homogenous flow, thus decreasing the variety of the liquid drops reflection paths); the reflecting disks diameters should be assumed equal to 80-100 mm; the distance from the upper edge of the outlet pipe to the reflector is assumed equal to 1,000-1,500 mm.

The possibility of formation of developed biocenosis on the surface of the biofilter feed sprinkled with a mixture of sewage and sludge at enhanced hydraulic loads – 60-100-150 $m^3/(m^2$ day) was determined during half-industrial research in 1982 /34, 35/. The analysis of the research results showed that a stable mature biocenosis developed on the biofilter feed represented with plastic balls with sand glued onto their surface. In this case, the biofilm thickness considerably exceeded that of the pebble feed.

On average the biofilm weight (ten minutes after the balls stopped being sprinkled) was 0,07 – 0,08 g per 1cm^2 of the active area. The biofilm thickness and species composition mainly depend on the equivalent roughness of the feed surface, organic pollutants composition and concentration. According to the research data, corrugated asbestos cement sheets are rough enough. The sheets are placed in the biofilter in the vertical position perpendicular to the flowing down liquid; thus, the liquid film outflow along the sheets surface is ensured.

The specific amount of the biomass forming on the asbestos cement surface of the biofilter feed (g/cm^2) was determined at different hydraulic loads and oxidizing capacity (oxidation rate) for the half-industrial installation assembled on the purification installations of the Rostov-on-Don water intake and distribution facilities in 1984. When the biocenosis was forming, the biofilter feed was sprinkled with a mixture of sewage and sludge delivered from the installation aerotank. After the biocenosis formation the biofilter feed was sprinkled with sewage. The hydraulic loads were changed at constant sewage flow to the biofilter by means of specific devices – cylinders limiting the sprinkled area of the biofilter feed. During the research, the influence of the distances between the asbestos cement sheets on the purification stability was evaluated. The distances between the sheets were assumed to equal from 19 to 24-29 mm. The research results data is given in Tables 7.3 and 7.4.

Table 7.3

Data on Immobilized Biomass Amount on Asbestos Cement Sheets

Hydraulic Load, m^3/m^2 day	Water Concentration, dm^3/m^2 d	Distance of Asbestos Cement Sheets Samples to Feed Top, m	Forming Biomass Amount (Dry Matter), g/cm^2	Average Amount of Biomass, g/cm^2	Ash Value, %
85,7	0,0124	0,2 0,5 0,8	0,0050 0,0062 0,0064	0,0058	34–41
127,3	0,0183	0,2 0,5 0,8	0,0047 0,0059 0,0065	0,0057	34–39
190,9	0,0271	0,2 0,5 0,8	0,0038 0,0058 0,0059	0,0051	37–40

Table 7.4

Research Data on Determination of Biofilter Oxidizing Capacity

Influent Sewage Flow, m^3/h	Biofilter Hydraulic Load, m^3/m^2 day	Aerotank Liquid Tempera-ture, ^0C	Sewage BOD_5, mg/dm^3		Biomass Amount (Dry Matter) in Biofilter, g	Oxidizing Capacity of 1g of Biomass per day, $gBOD_5/g$ day
			Influent Sewage	Effluent Sewage		
0,5	85,7	19,0	196-208	30-44	5974	0,33
0,5	127,3	19,5	185-208	61-88	4021	0,36
0,5	190,9	19,2	193-204	80-124	2858	0,39

The following facts were established based on the analysis of the research results: - a more stable biocenosis layer forms on the rough surface of asbestos cement sheets than on a smooth surface on which at the hydraulic load of 190,9 m^3/m^2 day scours with a thin layer of biofilm were discovered (fig. 7.8., 7.9.); - the design hydraulic load for this type of feed must not exceed 150 m^3/m^2 day; - the biofilm layer thickness on the certain parts of the feed surface reached 7-10 mm. Sludging zones were observed during the research; when the distance between the flat feed sheets was decreased from 30 to 15mm, the number of such zones increased. Thus, the distance between the sheets must be assumed equal to not less than 20 mm; - while designing biofilters for operation under high hydraulic loads a verifying calculation of water concentration in liters per meter of the sprinkled surface must be done. The recommended value for water concentration is 0,013 - 0,026 dm^3/m d.

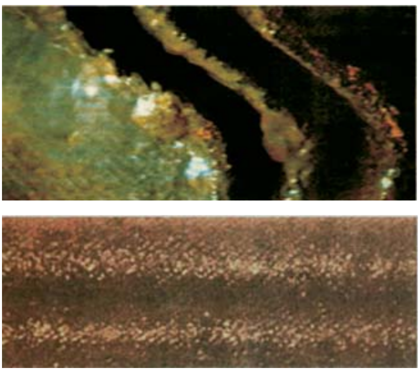


Fig. 7.8. View of Rough Feed Surface

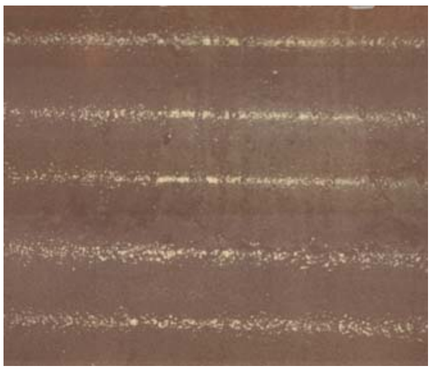


Fig. 7.9. Scours with Thin Biofilm Layer

In 1986 in village Severino of the Krasnodar Region combined installations for purification of the settlement sewage and fur farming waste were constructed. The results of the installations performance studies are given in Tables 7.5. and 7.6.

The organic pollutants oxidation rate in the biofilter was determined after the treated water and active sludge had been removed from the aerotank and it had been filled with the primary sewage in order to prevent the influence of the aerotank active sludge.

Table 7.5

Specific Amount of Biomass Forming on Biofilter Feed Surface and its Ash Value

Dates	Total Area of Samples Taken throughout the Sheet Height at Depths of 0,2; 0,6; 1 m, cm^2	Weight of Washed Biomass (Dry Matter), g	Amount of Biomass Forming per cm^2 of Asbestos Cement Sheets Surface, g/cm^2	Ash Value, %
18.06.85	828	4,748	0,0057	36,1
22.11.85	694	6,315	0,0091	45,5
27.03.86	460	3,171	0,0068	33,25

The average concentration of sewage pollutants in sewage on leaving the biofilter decreased in 2 hours by 49 BOD_5mg O_2/dm^3, in 4 hours – by 85 mgO_2/ dm^3, in 6 hours the concentration decreased from 126 to 17 mgO_2/ dm^3.

Table 7.6

Biomass Oxidizing Capacity

Asbestos Cement Sheets Surface Area in Biofilter, m^2	Biomass Amount (Dry Matter), g	Treated Liquid Volume, m^3	Liquid temperature, ^0C	Average Organic Pollutants BOD_5 Concentration, mg/ dm^3				Amount of Organic Pollutants Removed per Day, $gBOD_5$	Oxidation Rate $gBOD_5$ per 1g of Biomass (Dry Matter)
				Before Experiment	in 2 hours	in 4 hours	in 6 hours		
1182	80376	42,1	10,5	126	77	41	17	18356	0,228

The accomplished research laid foundation for specification of the following CW parameters being calculated: the specific biomass amount should be assumed to equal 0,007 g/cm^2; the oxidizing capacity of 1 g of biomass or the oxidation rate at the temperature of 10 ^{0}C should be assumed to equal 0,22 g BOD_5/(g day). At higher temperatures of the primary sewage, the oxidation rate is corrected.

In CW biofilters essentially all known peculiarities of microorganisms are used. There are zones where biocenosis develop in aerobic or anaerobic conditions and are represented with heterotrophic and autotrophic microorganisms. Microbiological research on the basis of the Microbiology Department of the Rostov-on-Don State University determined the prevailing microorganisms' cultures in the biofilter. The studies of the biofilter biomass enabled to identify the most typical biocultures according to the zones in which they prevail.

The microbiological research was accomplished in the following way: the biomass was sampled from the biofilter and inoculated with dilution of 10^2, 10^3, 10^4, 10^5, 10^6 in sterile Petri dishes on the meat infusion agar-agar, thrice for each dilution rate. Petri dishes were placed in a thermostat and in seven days the biocultures prevailing in the biofilter were determined and specific features were further defined more precisely. Microscopic results established a large amount of the following microorganisms in the biofilter: motile bacilli, aerobes, spore forming bacteria, gram-positive bacteria that might be identified as ammonifying microorganisms - Bacilus subtilus.

Specific filamentous microorganisms were widely available and unambiguously identified as Bacilus mycoides – aerobic ammonifying microorganisms forming typical populations resembling fungi mycelium that ammonified nitrogen-containing substances of most different structures: proteins, amino acids, amino sugars, nucleic sugars, amides, phosphatides, uric acid and urea. The first mineralization product of organic nitrogen was ammonia (at pH less than 8 nitrogen appeared in the form of ammonium mostly). In the biofilter lower part such microorganisms as oval, motile bacteria, non-spore forming bacteria, gram-negative bacteria were available in large amounts; they might be identified as Nitrobacter. In the biofilter upper part such denitrifying microorganisms as Micrococcus denitrificans were identified.

At present the materials assortment for the biofilter feed is being enlarged (glass fiber plastics, etc.) The new type of feed material was patented

/33, 36, 37/. The biofilter feed consists of corrugated sheets with fibrous elements (Fig. 7.10.).

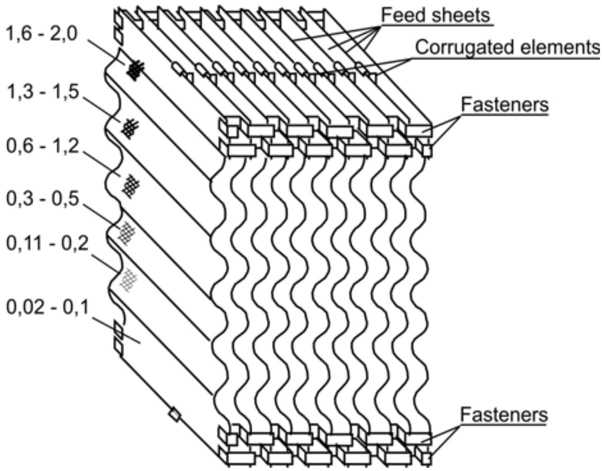


Fig. 7.10. Biofilter Feed of Corrugated Sheets with Fibrous Elements

The elements are fixed to the sheets with fasteners. Sheets are assembled into separate blocks by means of self-locking latches. Projections and recesses are provided on sheets, their equivalent roughness being minimum in the first lower zone - 0,02 – 0,1mm; in the second zone 0,11 – 0,2mm; in the third zone – 0,3 – 0,5 mm; in the fourth zone 0,6 – 1,2 mm; in the fifth zone – 1,3 – 1,5 mm, the equivalent roughness has the maximum value in the sixth upper zone – 1,6 – 2 mm. The zones with maximum roughness promote formation of developed biocenosis; in the same time, decrease of the equivalent roughness value in the medium and lower parts decreases the sheets cohesion and promotes removal of the excessive biomass.

Sheets of feed material are assembled into blocks directly during the CW assembling.

It is difficult to assess the biofilter contribution into sewage purification process at CW, as it depends on a large number of interrelated factors. However, the experience of CW operation showed that the design purification efficiency for purification of household sewage in flat feed biofilters should be assumed within 70%.

One of the main principles of the CW biofilters design is their reliability and effectiveness, which is especially important for purification of sewage from small remote settlements. Breaks in energy supply to small settlements are more probable than to larger cities, the problems of repair, replacement and qualified maintenance are more difficult to solve. In particular, the biofilter reliability depends on the feed material properties, so a new type of feed was developed that combines the properties of rigid filling feeds and volumetric feeds in compliance with the patents /38, 39/. The biofilter feed is made of ceramic ball-shaped elements with evenly placed recesses whose axes meet in the ball centre. Irrespective of the manner the balls are laid, some part of the recesses is always filled with the sludge mixture (Fig. 7.11.). A view of the biofilter feed of the 50 m^3/day installation in the "Energetic" recreation centre is given in Fig. 7.12. A longer contact between the sewage and the immobilized microflora and availability of active sludge in the feed enable to reach the sewage purification efficiency of 80-85% in the biofilter.

When the circulating pump is shut down, the humid conditions inside the biofilter feed are maintained due to a large number of vessels filled with the liquid, and bacterial cells inside the balls recesses receive oxygen due to the air oxygen diffusion, thus permitting to preserve the microflora vital functions during shutdowns up to 2 days long.

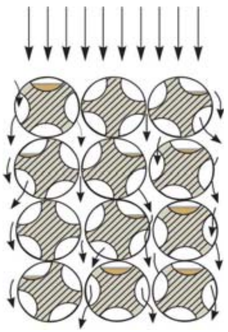


Fig. 7.11, 7.12. Biofilter Feed Made of Ball-Shaped Ceramic Elements

The research results on determination of the dissolved oxygen concentration in the sewage leaving the biofilter are given in Table 7.7 depending on the feed type.

Table 7.7

Dissolved Oxygen Concentration Data

Hydraulic Load, $m^3/m^2 h$	Dissolved Oxygen Concentration in Reservoir, mg/dm^3	Average Dissolved Oxygen Concentration, mg/dm^3			
		d = 50 mm Balls with d = 20 mm Recesses	d = 50 mm Balls with d = 25 mm Recesses	d = 50 mm Balls with d = 27 mm Recesses	50x50 mm Rashig Rings
2,2	1,04	8,32	8,48	8,76	8,16
6,2	1,04	8,28	8,40	8,48	8,16
7,5	1,12	8,04	8,15	8,24	7,78
8,5	2,16	7,04	7,75	7,96	7,47

The data analysis has shown that the mass transfer characteristics of the suggested feed are by 7 % higher than those of the rigid filling feed made of Rashig rings. The amount of liquid entrapped with 1 m^3 of the feed is 40 – 50 dm^3. That is why the utilization of the new feed type is effective in chemical and microbiological industry as well. In process testing of the feed at the “Energetic” recreation centre in the Krasnodar Region proved the high sewage purification efficiency of the biofilter (about 80%). During energy shutdowns in a warm season active sludge died-off in aerotanks in 8 hours, but due to the CW biofilter feed consisting of ceramic balls with recesses the technological operation of CW resumed in 1,5 – 2 days.

Aerotanks-Settlers

The specific conditions of organic substances biodegradation in aerotanks-settlers, especially in the periods of high organic sludge loads and enhanced hydraulic loads on installations, defined the necessity to research the peculiarities of the active sludge and oxygen concentrations distribution in the aeration and settling zones of CW aerotanks-settlers.

The research was accomplished in 1985 on existing installations built in village Severino in the Krasnodar Region on demand of the Ministry of Housing and Public Services of the Russian Federation /40/. The research results are represented in the chart (Fig. 7.13.).

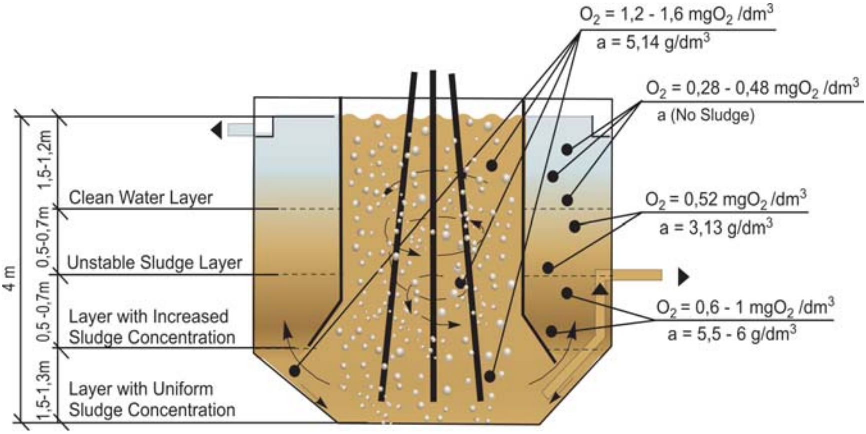


Fig. 7.13. Concentrations of Dissolved Oxygen and Active Sludge Doses in Different Zones of CW Aerotank-Settler

The microscopic research of the CW aerotanks-settlers made together with the Microbiology Department of the Rostov-on-Don State University established a large amount of the following microorganisms in the aerotank: motile bacilli, aerobes, spore forming bacteria, gram-positive bacteria that might be identified as ammonifying microorganisms - Bacilus subtilus. Specific filamentous microorganisms were widely available and identified as Bacilus mycoides – aerobic ammonifying microorganisms that ammonified nitrogen-containing substances of most different structures: proteins, amino acids, amino sugars, nucleic sugars, amides, phosphatides, uric acid and urea. In the aerotank such microorganisms as oval, motile bacteria, non-spore forming bacteria, gram-negative bacteria were available in large amounts; they might be identified as Nitrobacter.

The comparative characteristic of the oxidizing capacity values of the biofilter biocenosis and the CW aerotank-settler biocenosis

The oxidizing capacity of the biocenosis of the aerotank-settler reaction zone may be determined according to the following equation: $OCa = Ca – Cs$, mgC/dm^3 ,

where OCa is the oxidizing capacity of the aeration zone biocenosis, mgC/dm^3; Ca, Cs are the organic substances concentrations conversed to carbon in the treated sewage in the aeration zone of the aerotank-settler and in the settler correspondingly, mgC/dm^3.

The oxidizing capacity of the biofilter biocenosis is determined according to the following equation:

OCb = Ci – Ce, mgC/dm^3 ,

where OCb is the oxidizing capacity of the biofilter biocenosis, mgC/dm^3; Ci, Ce are the organic substances concentration conversed into carbon in the influent and effluent sewage in the biofilter, mgC/dm^3.

The dissolved organic substances concentration at different purification stages – Cos, mg C/dm^3 made up: Ca – 553,11 mg C/dm^3 ; Cs – 147,94 mg C/dm^3 ; Cos – 829,39 mg C/dm^3; Ce – 225,43 mg C/dm^3.

According to the above-mentioned data the biocenosis of the reaction zone of the aerotank-settler oxidizes 405,17 mg C/dm^3, and the biofilter biocenosis oxidizes 600,18 mg C/dm^3, that is 40,3 % and 59,7 % in percentage terms correspondingly.

The above-mentioned calculation data was compared to the received oxidizing parameters of the biofilter biocenosis and the biocenosis of the reaction zone of the aerotank-settler while considering the changes in organic substances BOD_5, mgO_2/dm^3 concentrations :

OCb = BOD_5i – BOD_5e; OCa = (BOD_5a – BOD_5s) – OCb,

where OCb and OCa are the oxidizing capacity of the biofilter biocenosis and that of the biocenosis of the reaction zone of the aerotank-settler correspondingly, mgO_2/dm^3; BOD_5i, BOD_5e are the organic substances concentration in the influent and effluent sewage in the biofilter correspondingly, mgO_2/dm^3; BOD_5a and BOD_5s are the organic substances concentration in the reaction zone of the aerotank-settler and in the settler correspondingly, mgO_2/dm^3.

The biofilter oxidizing capacity made 53 mgO_2/dm^3, and the oxidizing capacity of the reaction zone of the aerotank-settler made 40,0 mgO_2/dm^3, that is 60 % and 40 % in percentage terms correspondingly. The above-mentioned ratio was received for the CW with the biofilter height of 1,15m. In our opinion, when the new flat feed type with the height of 1,5-2m is used, the biofilter specific weight in the total purification efficiency may reach 70 %.

The analysis of these results enables to make the conclusion that specific conditions form in CW and the oxidizing capacity of the biocenosis

of the CW components is distributed and self-regulated. When assuming the design parameters for biofilters and aerotanks-settlers the biofilter sewage purification efficiency should be assumed 60-70% and that of the aerotank-settlers should be assumed 30-40%.
The biofilm and active sludge chemical composition is given in Table 7.8

Table 7.8

Components	Components Percentage in Biocenosis Total Mass, %	
	in Aerotank	in Biofilter
Carbon	31,38	15,14
Hydrogen	5,18	3,89
O_2+N_2+S+P	28,44	26,66
Mineral Substance	35,00	54,31

The operation of the CW two sections in 1985-1987 was tested together with the Krasnodar Regional Sanitary Epidemiological Station, the results are given in Tables 7.9 and 7.10 /41/.

Table 7.9

Sewage Purification Efficiency in v. Severino of Krasnodar Region

Sewage Type	BOD_5, mgO_2/dm^3	Suspended Substances, mg/dm^3	Clarity (Snellen), cm	Nitrogen, mg/dm^3		
				NH_4^+	NO_2^-	NO_3^-
From Settlement	296-324	251-294	1-2,9	8,8-13,8	0,008-0,13	0,53-0,82
From Fur Farm	1171-1680	22-63	–	17,4-19,5	0,019-0,025	0,24-0,29
After CW	4,5-10,2	3-4,5	18-21	2,2-4,7	0,11-0,27	4,1-8,4

Table 7.10

CW Active Sludge Parameters during Purification of Sewage in v. Severino of Krasnodar Region

Sewage Type	Sewage Amount (Design BOD_5 270 mg/dm^3), m^3/day	Temperature of Liquid in Aerotank, ^0C	Sludge Dose		Average Specific Resistance $r10^{10}$, cm/g	Ash Value, %
			Volume, %	Mass, g/dm^3		
Household	73-100	12,1 9,5 10,3	68-75 69 69	4,4 4,3 3,8	45,0 39,6 38,4	33,3 34,2-37,3 36,8
Mixture of Household Sewage and Industrial Wastewater	106-166	10,2 10,2 10,3	86	4,74 4,73-5,14 4,94	515,0 215,0-400,0 343,0	– 37,0-35,0 42,7

The data on other existing installations performance is given in Table 7.11.

Table 7.11

Existing CW Performance (without Aftertreatment Installations)

Parameters	v. Abrau-Dyurso, "Energetic" R/C (Krasnodar Region)	v. Kovalyovka, Psychoneurologic Dispensary (Rostov Region)	v. Kresty, Fur Animal Farm (Moscow Region)	Nazran, Cottage Settlement (Ingush Republic)
1	2	3	4	5
Sewage Composition	Household Sewage	Household Sewage	Household Sewage and Industrial Wastewater	Household Sewage

1	2	3	4	5
Sewage Flow, m^3/day	55,0	250,0	350,0	80,0
Installations Volume, m^3 - of Biofilters -of Aerotanks -of Settlers	 10,4 28,4 11,7	 29,2 119,0 42,0	 51,0 140,0 57,7	 10,1 36,0 12,0
Power Inputs, KWh	3,0	7,0	15,0	3,2
Operation Period, years	7,0	5,7	6,0	2,0
BOD_5, mgO_2/dm^3	320,0/4,8	390,0/15,0	2100/18,0	180,0/9,0
Suspended Substances, mg/dm^3	315,0/5,0	340,5/17,0	720,0/15,0	140,7/4,6
Total Nitrogen, mg/dm^3	32/9	32,5/14,3	147,5/22,8	31,0/12,4
$N\text{-}NH_4^+$, mg/dm^3	28,0/4,1	28,8/8,7	100/18,3	26,5/3,0
$N\text{-}NO_2^-$, mg/dm^3	Traces/0,15	0,08/0,9	–/–	–/–
$N\text{-}NO_3^-$, mg/dm^3	Traces/4,5	0,28/4,2	–/–	0,0/7,8
$P\text{-}PO_4^{3-}$, mg/dm^3	12,5/2,1	14,0/3,8	32,5/4, 2	4,0/1,5

Notes: Influent parameters are given in the numerator, effluent parameters are given in the denominator of “/”.

The general view of existing purification installations at “Fregat” recreation centre (v. Abrau-Dyurso) is given in Fig. 7.14, at “Baikonur” rehabilitation centre (Moscow Region) - in Fig. 7.15; at “Magas” airport (Ingush Republic) – in Fig. 7.16; at the recreation centre of the Ossetia National Bank – in Fig 7.17; at the Retirement Home of v. Belogornoye in the Saratov Region – in Fig. 7.18a, b.

Fig. 7.14

Fig. 7.15

Fig. 7.16

Fig. 7.17

a

b

Fig. 7.18. General Views of Existing Purification Installations.

During industrial research, the specific operation peculiarities of the CW aerotanks-settlers have been found out.

– When the sewage circulating ratio is increased to 9-13 the sludge index grows from 150 to 230. The deterioration of the active sludge sedimentating properties is explained with damage done to a part of bacterial cells due to mechanical effect of the circulation pump blades, striking against the reflectors of the biofilter sprinkling system, as well as due to hydrodynamic effect in the air-stripping towers. When the sewage circulating factor n equals 3-8, the sludge index value corresponds to its value for classic aerotanks (70 – 150).

– When the BOD_{comp} concentration of sewage organic pollutants is less than 120 mgO_2/dm^3 and the sewage flow is lower than the design parameter, a drastic decrease of the active sludge concentration (practically down to complete absence) is observed in the aeration zones of aerotanks-settlers, and in the zones of formation of higher active sludge concentrations its dose is 1,5 – 2 g/dm^3. In the similar conditions, active sludge is removed in classic aerotanks, as the sludge flakes form unstably when the sludge dose is less than 1,5 g/dm^3 . The CW sewage purification efficiency in these conditions remains high; the residual organic substances BOD_{comp} concentration is 4 mgO_2/dm^3. This phenomenon is connected with the stable operation of the biofilter where excessive biomass is generated stably, separated and then drawn into the aerotank; in the zones with higher active sludge concentrations it generates and supplies the suspended biomass layer, which sorbs and oxidizes the residual organic substances.

– When sewage is delivered into sewage purification installations in volleys (the day irregularity coefficient rises to 5), the suspended sludge layer rises to the level of 0,5-1m under the water surface. In the same time the sludge operating dose in the aeration zone remains high and is 5,1 – 5,5 g/dm^3; that testifies to the technological effectiveness of the given installation, stability of its biochemical processes during volley delivery of sewage and possibility to maintain the sludge operating dose within the limit of 6 g/dm^3.

– The CW lacks a drawback typical for existing aerotanks-mixers – the possibility of untreated sewage channeling. In this case, sewage first comes into the mixing chamber where it is mixed with the sludge liquid, then it comes into the biofilters where pollutants are biologically sorbed and transformed, then it is mixed with the total reaction volume of the aerotank-settler.

– Water-jet aeration assemblies are made in the form of radiating bunches (air-stripping towers), the lower edges of which are spread above the aerotank bottom and are at the distance of 0,2-0,4m from it; such placement ensures the impingement attack of gas-liquid jets on the bottom /31/. Such solution prevents sludge ingraining. The flows movement, vortexes formation and air bubbles emerging ensure the effective mixing of the aerotank content.

– Grouping of air-stripping towers in their upper parts facilitates the cleaning process and simplifies construction of installations. As the optimal bottom area per one d_y 37 – 70 mm air-stripping tower is 0,5 – 2 m^2, then the area of the flat bottom of the aerotank must be decreased when the sludge mixture circulating factor is limited (3-8) with the sludge index and energy parameters. To achieve this purpose, rollers with 45-60 degrees slopes are made.

The sludge dose in the aerotank may be increased due to the active sludge immobilization on the feed. Plastic sheets with bristles placed above rollers are suggested to be used as feed (Fig. 7.19.) /42, 43/.

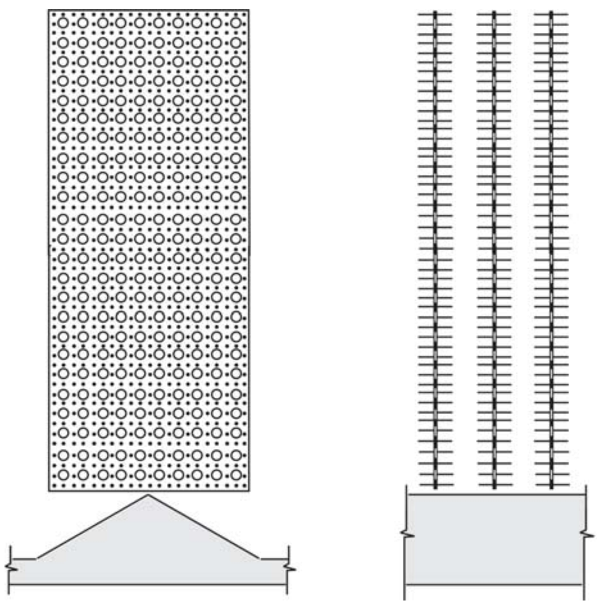


Fig. 7.19. View of Aerotank Feed Material for Biomass Immobilization.

Openings are provided in the sheets to ensure the liquid flow through the sheets raising consequentially the effectiveness of the fixed biocenosis formation and the contact between the liquid and the biomass. The uniform placement of bristles with a definite spacing prevents the microflora adhesion. The relatively lower turbulence and extinguishing of the flow energy in places where the sheets are installed promotes the development of nitrifying microflora.

Chapter 8. TERTIARY TREATMENT OF SEWAGE FROM ORGANIC POLLUTANTS

When the CW operates in the complete oxidation mode, white transparent flakes of mineralized biomass are sometimes formed in the settlement zones and removed from the installations with purified water. The suspended substances concentration, as well as BOD residual organic pollutants concentration, is decreased at the tertiary or aftertreatment installations.

In general, tertiary treatment installations are divided into two types according to the mechanism of pollutants removal.

1 – Tertiary treatment installations where mechanic entrapping of suspended substances in the feed interpore space is the dominating process (cohesion and adsorption forces act here to some extent). This process is accomplished in the filters with silica sand and (more seldom) with chalkstone-shell rock, activated carbon, etc. used as the feed material.

2 – Tertiary treatment installations where the processes of biosorption and biodegradation dominate. The feed in these installations is made of specific material (most often of pigs fulfilled from artificial rigid fibers or activated carbon), which is the carrier of the immobilized biomass developing in conditions where the air oxygen and nutritious substratum (the residual organic substances) are available. The processes of nitrification progress in the installations of the second type in certain conditions.

Lately the second type of installations has been preferred as this type of feed is less subject to sludging; its bioregeneration is possible, operating costs are less, including energy inputs.

The data on operation of the existing combined installations and works supplied with tertiary treatment bioreactors with pig feed is given in Table 8.1.

Table 8.1

Data on Operation of CW with Tertiary Treatment Block

Parameters	"Novorossmetal" Plant (Novorossiysk)			v. Beryozovka (Saratov Region)		
Sewage Composition	Household Sewage			Household Sewage		
Sewage Flow, m^3/day	50,0			1300,0		
Installations Parameters - Biofilters Feed Area, m^2 -Aeration Period of Settlers, h -Sludge Dose in Aerotank, g/l	 516 7,3 2,8 - 3			 10577 8,6 2,5 - 3		
Power Inputs, KWh	1,6			15		
Operation Period, years	2,5			3,5		
Sewage Parameters*	Primary Sewage	After CW	After Bioreactor	Primary Sewage	After CW	After Bioreactor
BOD_5, mgO_2/ dm^3	218,7	7,0	5,0	157	10	5
Suspended Substances, mg/dm^3	126	10	3,6	117,5	8	6
$N\text{-}NH_4^+$, mg/dm^3	41,5	3,15**	3,0	42	11**	7
$N\text{-}NO_2^-$, mg/dm^3	Not Found	1,1	0,8	0,19	0,021	0,021
$N\text{-}NO_3^-$, mg/dm^3	Not Found	12,1	12,1	0,98	10	10
$P\text{-}PO_4^{3-}$, mg/dm^3	3,12	2,6	2,6	3,5	1,3	1,1
Snellen Clarity	1,5	20	28	2,2	18	24

*Table 8.1 contains average parameters, the sampling volume n = 30.
**The ammonium nitrogen concentration in the purified water is 3,15 (11) mg/dm^3 at the initial nitrogen concentration of 41,5 (42) mg/dm^3 and BOD_5 concentration of 218 (157) mg/dm^3 in the primary sewage, testifying to the fact that the design of purification installations ensures favourable conditions for development of nitrification and denitrification processes.

The general view of the CW with the tertiary treatment block in v. Beryozovka in the Saratov Region is given in Fig. 8.1; the general view of the CW with the tertiary treatment block at the “Novorossmetal” Plant (Novorossiysk) is given in Fig. 8.2.

Fig. 8.1.

Fig. 8.2.

The tertiary treatment installations are to be operated according to the recommended instructions; in practice, they are far from being always followed. For example, at the sewage purification installations in v. Beryozovka in the Saratov Region the aeration in tertiary treatment blocks is insufficient, the condition decreasing the installations efficiency as anaerobic conditions form in them. Besides, the pig design has been established to influence the tertiary treatment process as well. Therefore, the analysis of biofouling has showed that the biomass accumulates in the pig centers, it adheres and rots. In order to regenerate the feed it is necessary to aerate it intensively or to wash it with water jets, the method leading in its turn to excessive washout of the active biomass from the feed bristles. In the following period of regeneration of the bristles coating the residual pollutants channel into the purified water. The pig feed service life is relatively short: 0,5–1 year in case of additional aeration by means of pneumatic equipment and 2-3 years in case of water-jet regeneration.

In order to eliminate the above-mentioned drawbacks it has become necessary to elaborate the more technologically effective design of the feed material, which operating parameters are considerably better, including economic parameters, due to the fact that less washing is required and consequently less power inputs are necessary.

The technological solution for the new type of the feed material is given in Fig. 8.3.

The suggested bioreactor feed is made of flat sheets with openings and bristles, the openings diameters and bristle spacings being decreased bottom up /43, 44/. This solution ensures the optimal hydrodynamic mode of the liquid movement and contact with immobilized microflora, trapping of emerging substances in the feed upper part, which operates as a biofilter, and free discharge of the separating mineralized biomass by means of the water level decrease in the reservoir and washing out with water jets. The feed design promotes development of high-age feed and enables not only to increase the BOD and suspended substances purification efficiency, but also to decrease the residual polluting nitrogen and phosphorus concentrations.

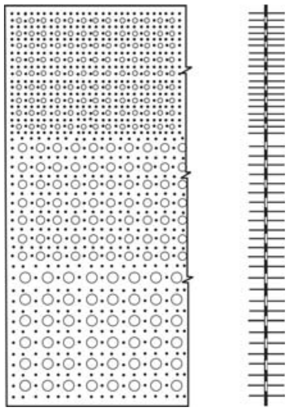


Fig. 8.3. Technological Solution for New Type of Feed Material

Chapter 9. SEWAGE PURIFICATION FROM NITROGEN AND PHOSPHORUS COMPOUNDS

9.1. Sewage Purification from Nitrogen Compounds

Nitrification

When the purified sewage is used for some industries or discharged into reservoirs threatened with eutrophication, biogenic elements – nitrogen and phosphorus – serve as limiting elements and in this case, CW process flow schemes must be designed based on the necessity of decrease of the biogenic elements concentration. In 1991-1993, the specialists of RSRI APS conducted the research of the processes of organic substances biodegradation, nitrification and denitrification in the CW /45/. The following order of calculation of the installations parameters was established based on the above-mentioned research results:

1. To determine the volume of the aeration zone of the aerotank-settler (V, m^3) based on the recommended CW dimension-types that are in their turn determined according to the sewage amount treated per day;

2. To determine the ash-free matter sludge dose in the aeration zone of the CW aerotank-settler based on the condition of complete nitrification; organic sludge load must not exceed 0,1g BOD_{comp}/g_{sludge} day, and 0,05 g BOD_{comp}/g_{sludge} day in the most favourable case. The corresponding inequation looks as follows: $L_{en}Q/a_iV < 0,1$. At high organic substances concentration in sewage, for example, when purifying wastewater from food industry, usually it is impossible to accomplish nitrification during one-stage biological purification. If the CW are used, it becomes possible as the first portions of organic substances are delivered to the CW biofilter where they are by 50-70 % removed. Thus, the aerotank sludge dose does not exceed, as a rule, the values necessary for nitrification. At the above-mentioned organic sludge loads not only complete nitrification is realized, but practically complete oxidation of organic substances is realized as well, the residual organic substances concentration in the purified sewage not exceeding 7 mg BOD_{comp}/dm^3, thus the so-called prolonged aeration mode is realized.
If the received value of the sludge dose turns out to exceed the one recommended for this type of installations (4-5 g/dm^3), then one should proceed to the next CW dimension-type and to recalculate the sludge dose;

3. To determine the growth rate of the nitrifying microorganisms taking into account the factors influencing the process – the treated water temperature, the system pH, the dissolved oxygen concentration. To determine the sludge age. The specific sludge age is demanded in the system with simultaneous nitrification and biodegradation of organic substances; such requirement is connected with the fact that the nitrifying sludge grows slowly. For example, the growth of Nitrosomonas is known to be 0,13 – 0,04 mg/dm^3 of sludge and the growth of Nitrobacter is 0,02-0,07 mg/dm^3 during oxidation of 1 mg/dm^3 of ammonium nitrogen. In order to prevent the removal of the nitrifying sludge from the system, its age must be

sufficiently high, not less than 5 days (sometimes the necessary sludge age is 15-30 days). It is natural that during simultaneous nitrification and biodegradation of organic substances in a one-sludge system it is impossible to separate the heterotrophic and autotrophic components of the sludge mixture and the sludge age is assumed equal to the necessary age of the autotrophic (nitrifying) component;

4. To determine the organic substances biodegradation rate (ρ) taking into consideration the sludge age and according to the following formula: $\rho = K_E + 0{,}0417 K_G/\Theta$, mg/(g.h), where K_E is the energy physiological coefficient, mg BOD_{comp}/(g.h) of sewage; K_G is the physiological growth coefficient of the active sludge microorganisms, $mgBOD_{comp}$/g; for city sewage and industrial wastewater of similar composition,
K_E = 3,7 $mgBOD_{comp}/(g \cdot h)$, K_G = 864 $mgBOD_{comp}$/g;

5. To determine the actual value of the aeration duration according to the following formula: $t_{aer} = V/Q$, h;

6. To determine the value of the residual organic pollutants concentration in the purified water according to the following formula: $L_{ex} = L_{en} - t_{aer}\, a_i \rho$, $mgBOD_{comp}/dm^3$,
where t_{aer} is the aeration duration, h; L_{en} and L_{ex} are the organic pollutants concentration in the influent and effluent water correspondingly, $mgBOD_{comp}/dm^3$;

7. To determine the residual concentration of ammonium nitrogen in the purified water corresponding to the known aeration duration:
$C^R_{N\text{-}NH4^+} = (C^I_{N\text{-}NH4^+} + C^E_{N\text{-}NH4^+}) - t_{aer} a_{iN} \rho_N$, where a_{iN} is the operating dose of nitrifying sludge determined according to its die-off rate $\beta_N = 0{,}12^{\ day\text{-}1}$ and the nitrifying sludge growth rate Y_N,
$a_i = Y_N/\beta_N\, ((C^I_{N\text{-}NH4^+} + C^E_{N\text{-}NH4^+}) - C^R_{N\text{-}NH4^+})$.

If we denote the expression in the parenthesis as $C^{tot}_{N\text{-}NH4^+}$, and take into account that $Y_N = 1/\Theta\rho$, then correspondingly the aeration time necessary to accomplish nitrification (t_{aerN}) is determined in the similar way:
$t_{aerN} = (N_{en} - N_{ex})\Theta Y_N / a_{iN}$, h,
where N_{en} and N_{ex} are the concentrations of ammonium nitrogen in the primary and purified sewage correspondingly, g/dm^3; Y_N is the sludge growth, $g_{sludge}/g_N h$; a_{iN} is the ash-free matter nitrifying sludge dose, g/dm^3;

8. To compare the received values of L_{ex} and $C^R_{N\text{-}NH4^+}$ with the maximum permissible concentration (MPC) value for discharge into the reservoir; if the residual nitrogen ammonium and BOD concentrations

exceed the established standards, the CW size must be enlarged or it must be provided with a tertiary treatment block;

9. To compare the nitrate nitrogen concentration in the purified water with the corresponding standard value. If the received value exceeds the MPC value, denitrification should be accomplished.

Denitrification

A denitrificator is not a CW component, it is erected as a separate installation.

The CW being installations of original design, some research was required to create the process flow scheme of purification including the denitrificator according to the actual flows of treated water inside the installation.

To calculate the parameters of denitrification it is convenient to use the equation associating the denitrifying sludge age, economy coefficient and specific denitrification rate:

$1/\Theta_d = Y^d \rho^d - K^d$,

where Θ_d is the denitrifying sludge age, day^{-1}; K^d is the half-saturation constant (determines the nitrate nitrogen concentration value at which the microorganisms' growth rate reduces twice). The Californian Davis University research established the half-saturation constant for suspended sludge systems, its minimum value being 0,08 mg/dm^3 $N\text{-}NO_3$; such a small value of the half-saturation constant testifies to practical absence of dependence of the denitrification process on the nitrate concentration. It is recommended to use the following value of the half-saturation constant in engineering calculations - 0,15 mg/dm^3 $N\text{-}NO_3$; Y^d is the specific biomass growth, g sludge/g $N\text{-}NO_3$; K^d is the biomass dying-off coefficient, day^{-1}, at 20^0C: $Y^d = 0{,}9\ g_{sludge}/g_{N\text{-}NO3}$; $K^d = 0{,}04\ day^{-1}$. To ensure the process reliability, the following coefficient is introduced into engineering calculations:

$SF = \Theta_c^d/\Theta_m^d$,

where Θ_c^d is the sludge age necessary for denitrification in current conditions,

$1/\Theta_c^d = Y^d\rho^d - K^d$;

$1/\Theta_m^d = Y^d\rho^d_{max} - K^d$.

In "Nitrogen Control…" it is recommended to assume the same SF values for calculation of the denitrification parameters as for nitrification. When the temperature of the treated sewage is within the range of 20 to 10^0C, SF = 2. The denitrification rate ρ^d has already been shown to depend on the utilized organic substratum type and the treated water temperature. The research made by the authors on the denitrification rate at sewage purification installations in v. Severino in the Krasnodar Region established the following: when the mixture of the primary sewage and circulating liquid was utilized as the carbonic substratum at the sewage temperature of 21^{0}C, the average denitrification rate was 7,5 mgN-NO_3/g_{sludge}h. To determine the specific denitrification rate for the clarified wastewater from a meat-packing factory as the organic substratum we conducted the laboratory research at the treated water temperature of 22^{0}C.

The research was fulfilled in the following way: a certain amount of denitrifying sludge (cultivated at the model denitrificator included into the process flow scheme of the pilot CW installation operating on the wastewater from the meat-packing factory) was put into the 500 cm^3 beaker. Aliquot fractions of the substrata – sewage after nitrification and clarified sewage – were introduced into the beaker as the organic substratum.

The beaker content was mixed by means of a blade mixer without access for air, thus ensuring the suspended state of the sludge. In definite periods of time the beaker contents was examined and the nitrates and the biomass concentrations were established. The specific rate of nitrates removal was determined according to the following formula:

$\rho^d = S_0 - S_1 / x_1 (t_1 - t_0)$, mgN-$NO_3$/(gh),

where S_0 and S_1 are the substratum (ammonium nitrogen) concentrations at the beginning (t_0, h) and at the end (t_1, h) of the observation; x_1 is the ash-free matter biomass concentration, g/dm^3. The research data is given in Table 9.1.

Table 9.1

Determination of Specific Rate of Nitrates Removal

Determined Parameters	Experiment Number (Based on Average Data of 3 Experiments)		
	I	II	III
1	2	3	4
N-NO_3 Concentration in Primary Sewage (S_0), mg/dm^3	15,0	15,0	14,3
N-NO_3 Concentration in Purified Sewage (S_1), mg/dm^3	14,1	12,5	11,1
Process Duration ($t_1 - t_0$) , h	0,25	0,25	0,25

1	2	3	4
Biomass Concentration (x_1), g/dm^3	2,2	3,2	4,3
Specific Denitrification rate (ρ^d), mgN-NO_3/(gh),	1,63	3,12	2,97
Denitrification Efficiency, %	6	16,6	22,3
Increase of Ammonium Nitrogen Concentration in Treated Sewage, mg/dm^3	Not Found	Not Found	Not Found

Notes; in all cases the dissolved oxygen concentration did not exceed 0,5 mg/dm^3; the sewage temperature was 23^{0}C. The research did not find out any increase of the ammonium nitrogen concentration throughout the experiment that testifies to absence of nitrite-nitrate respiration when nitrate nitrogen oxidizes to nitrite nitrogen and ammonium nitrogen.

When the wastewater from the meat-packing factory is used as the organic substratum for denitrification, the specific denitrification rate is 2,57 mgN-NO_3/(g_{sludge}h) on average. The received data analysis enables to make a conclusion that when the sewage with heavily oxidized organic substances is used as the carbonic substratum, the denitrification rate decreases. Evidently, it is expedient to utilize volatile organic acids received from sewage organic substances by means of anaerobic fermentation as the carbonic nutrition. It must be also noted that when the sewage with proteins is used, the sewage subjected to denitrification is saturated with ammonium nitrogen that requires its further removal or accomplishment of the nitrification process after the denitrification process is over in the general sewage purification scheme.

The order of the calculations for determination of the denitrificator's volume is as follows:

1. To determine the minimum sludge age at which denitrification progresses in optimal conditions, the denitrification rate being maximum: $1/\Theta_m{}^d = Y^d \rho_{max}{}^d - K^d$, day^{-1};
2. To determine the minimum sludge age $\Theta_m{}^d$ and the sludge design age $\Theta_d{}^d = SF\Theta_m{}^d$ day^{-1};
3. To calculate the specific denitrification rate:
   $\rho^d = (1/\Theta_m{}^d + K^d)/ Y^d$, mgN-$NO_3$/(gh);
4. To determine the residual nitrate nitrogen ($C_{N\text{-}NO3}$) concentration, which may be achieved in the present conditions according to the Michaelis-Menten

equation:

$\rho^d = \rho_{max}{}^d(C_{N\text{-}NO3}/(K^d + C_{N\text{-}NO3}))$, mgN-$NO_3$/(g.h), whence it follows that $C_{N\text{-}NO3} = (\rho^d K^d / \rho_{max}{}^d)/(1\text{-}(\rho^d / \rho_{max}{}^d))$, mg/$dm^3$;

5. To calculate the duration of denitrification (t, h) according to the following equation: $t = \Delta C_{N\text{-}NO3}/\rho^d a^d$, h, where $\Delta C_{N\text{-}NO3}$ is the difference of the nitrate nitrogen concentrations before and after denitrification; a^d is the ash-free matter denitrifying sludge dose, g/dm^3. The denitrifying sludge dose must be determined with consideration of the balance of rates of the sludge growth and dying-off. In compliance with recommendations in Reference Manual to Construction Norms and Specifications 2.04.03-85, the denitrifying sludge dose may be assumed equal to 1,5 –2,5 g/dm^3;

6. To determine the installation volume (V, m^3) according to the following formula:

$V = Qt$, m^3, where Q is the installations sewage capacity, m^3/h.

In 1992 at sewage purification installations of v. Severino in the Krasnodar Region the research was made aimed mainly at evaluation of conformity of the actual process parameters to the design ones. In order to achieve the above-mentioned purpose the process of transformation of nitrogen and phosphorus forms was controlled in the operating CW and the denitrificator. The purification installations included: a sand catcher, a combined works (2 sections), a biological lagoon. The purification installation capacity was 130 m^3/day, when the wastewater from the laundry was supplied, the capacity increased to 170 m^3/day; the purified sewage was discharged into biological lagoon ion this period; the sludge mixture circulating ratio equaled 7; the area of one biofilter was 15 m^2, asbestos-cement sheets with the effective area of 1,182 m^2 was used as the biofilter feed material. The aerotank reaction zone volume was 42,1 m^3. The sewage came from apartment houses, administrative and public buildings, the fur farm. The pilot denitrificator installation was included into the process flow scheme after the CW aerotank-settler. The denitrificator had two sections with volumes of 24 and 33 dm^3. The sections were not communicating, thus enabling to study different operation modes of the denitrificator simultaneously. It was designed to consist of a reservoir with a conical bottom and a bottom distribution system for delivery of biologically purified sewage and primary sewage from the aerotank-settler to the denitrificator. Water passed through the feed layer and was removed through chutes in the upper part of the installation.

Flat corrugated asbestos-cement sheets were used as feed. The biomass in the form of flocculi was fixed between the sheets. The microorganisms were immobilized on the feed in insufficient quantities. The initial parameters of primary sewage and purified water are given in Table 9.2.

Table 9.2

Results of Studies of Combined Operation of Industrial Purification Installations and Pilot Denitrificator Installation

Studied Parameters	Sampling Location						
	Primary Sewage	Sludge Mixture before and after Biofilter		Purified Water			
		Before Bio-filter	After Bio-filter	Aera-tion Zone	Clarifi-cation Zone	Denitri-ficator	Bio-logical Lagoon
COD, mgO/dm^3	500,0	178,0	145,0	88,0	42,0	33,0	140,0
BOD_5, mgO_2/dm^3	370,7	132,0	107,5	45,31	11,6	6,9	72
pH	7,0	6,8	6,8	6,8	6,8	7,0	6,8
Dissolved O_2, mg/dm^3	Not Found	0,64	6,3	5,5	3,0	1,6	2,6
Ammonium Nitrogen, mg/dm^3	21,0	5,0	3,88	3,37	2,36	2,04	2,0
Nitrite Nitrogen, mg/dm^3	0,15	0,33	0,33	0,27	0,33	0,2	–
Nitrate Nitrogen, mg/dm^3	0,51	–	4,06	3,66	4,96	3,2	0,85
Phosphates, mg/dm^3	5,3	3,8	3,66	3,00	2,98	2,2	1,5
Sludge Dose, g/dm^3	–	–	3,79	3,8	–	1,8	–
Biomass Ash Value, %	–	–	30,0	34,0	–	40,0	–

Notes: Table 9.2 contains average results of six observations; the primary sewage temperature was 23^0C.

The research results enabled to state the fact that nitrification might be accomplished successfully in the CW sections, in the aeration zone of the aerotank-settler especially. The denitrification rate was 7,5 mgN-NO_3^-/g of sludge per hour on average when a mixture of the primary sewage at the mentioned temperature was utilized as carbonic nutrition.

9.2. Dephosphorization of Biologically Purified Sewage

During biological purification the sewage phosphorus concentration decreases, however, as the water purification experience shows, the (PO_4^{3-}) phosphorus concentration in sewage after it has been purified biologically is 1,0 - 3,0 mg/dm^3, the figure 2-5 times exceeds the phosphorus MPC value for purified water discharge into reservoirs. Supplementary measures during the biological purification stage or as a separate technological process are taken in order to decrease the phosphorus concentration in the purified water. It is not possible to use the biological dephosphorization method in the CW without construction of supplementary anaerobic installations for volatile fatty acids generation. It is also difficult to distribute the sludge systems flows. Besides, as the water purification experience shows, the biological dephosphorization method is far from being always effective, as at low organic substances concentrations in primary sewage formation of volatile fatty acids in the amounts sufficient for development of Acinetobacter is impossible. At this stage of research, the efficiency of methods of physicochemical purification was evaluated. Physicochemical methods of phosphates removal from sewage are as a rule based on utilization of reagents – traditional mineral coagulants (aluminium or iron salts and lime), it is also possible to utilize the industrial waste containing iron or aluminium salts, non-toxic for the biological process. In Reference Manual to Construction Norms and Specifications 2.04.03-85 it is specified that when reagents are introduced at the mechanical purification stage of sewage treatment organic and other pollutants concentrations simultaneously decrease considerably, that is why it is expedient to use preliminary phosphates sedimentation for purification of industrial wastewater and mixture of industrial wastewater and household sewage with BOD_{comp} more than 400 mg/dm^3, as well as when sewage purification installations are overloaded. In this case, the reagent dose is determined according to the following formula: $C_{reag} = KCp_{tot}$, where K is the coefficient of the stoichiometric ratio increase calculated based on the total phosphorus (PO_4^{3-}) concentration and (metal oxide) reagent metals concentration determined with standard methods, the value of K may be determined according to Table 24 of Reference Manual to Construction Norms and Specifications 2.04.03-85; Cp_{tot} is the total phosphorus concentration in influent sewage, mg/dm^3. If there is no data about the total phosphorus concentration in the treated sewage the following may be assumed approximately:

$$Cp_{tot} = (2\text{-}3)C_{PO4}.$$

In order to use the reagent effectively and taking into consideration its influence on active sludge in traditional purification systems, it is recommended to introduce ferrous sulphate (II) at the beginning of the aerotank, of ferrous sulphate (III) before the final settler and of aluminium sulphate at the end of the aerotank. When aluminium sulphate is used, polyacrylamide should be added to decrease the suspended substances concentration in the purified water, its approximate dose being 0.2–1 mg/dm^3. Polyacrylamide is introduced into the sludge mixture before it enters the final settler. The introduction of the reagent at the biological purification stage enables to decrease the total phosphorus concentration in sewage to 85%, soluble phosphates concentration to 95%. It must be born in mind that introduction of reagents at the biological purification stage may either intensify the purification process or decelerate it. The influence degree depends on the reagent dose per 1 g of ash-free matter of sludge in the aerotank. The biological process is inhibited at the reagent load of more 5 – 9 mg Me_2O_3 per 1g of ash-free sludge. More integrated removal of total phosphorus (up to 90-95%) is achieved during tertiary treatment of sewage by means of filtration. Reagents may be introduced into the purified water as well; phosphates are accumulated (adsorbed) with flakes of forming products of coagulants hydrolysis. Chemosorption is possible in this case. The efficiency of phosphates removal in this case is determined practically with the introduced reagent dose only. Low reagent doses – less than 1 mg/dm^3 - do not lead to removal of phosphorus compounds. High concentrations of suspended substances have been observed to complicate phosphate adsorption.

The authors have analyzed the effectiveness of utilization of the reagent method of phosphorus sedimentation at different stages of sewage purification due to the following reasons – first, because this is a standard method, in other words, it is recommended in Construction Norms and Specifications 2.04.03-85, second, because it is convenient for operation and finally, because there are considerable amounts of different coagulants available. The last reason made the researchers to approbate the coagulants not envisaged in Reference Manual to Construction Norms and Specifications 2.04.03-85, but in the same time permitted for utilization for drinking water. Aluminium oxychloride is one of the most popular coagulants at present. This coagulant differs from the most well-known coagulant – aluminium sulphate – first of all with a hydroxide group in its composition determining its lower acidity. The coagulant with the commercial name of "Novoflock" is similar in its composition. Besides, the cationic flocculant VPK-402 was utilized as an independent reagent in this research.

The optimal pH value may be determined based on the phosphorus concentration in the purified sewage; this value presupposes the formation of the least soluble compound (Table 9.3). In calculations, the equation recommended by D.S. Orlov (1985) was used when using the expression of the phosphate potential /14/.

Table 9.3.

Optimal pH Values for Formation of Not Readily Soluble Phosphorus-Containing Aluminium and Iron Compounds

Coagulant Type	$pH_2PO_4^-$	pH Calculation Formula	Optimal pH Value
Aluminium-Containing Compounds	4,98	$pH = 10,7 - p\,H_2PO_4$	5,72
	4,50		6,2
	4,28		6,42
	4,00		6,70
	3,80		6,90
	3,68		7,07

Thus, the reagent water treatment requires maintenance of the pH value at the level not less than the one mentioned in Table 9.3.

The research was made on the basis of actual sewage already treated in the aerotank. The first series of research was aimed at determination of the reagent effective dosages based on their active part. The dosages were considered effective if the phosphate concentration in the settled water did not exceed the MPC value (0,6 mg/dm^3 based on PO_4^{3-}). The initial phosphate concentration was 4,5 mg/dm^3. The data for this part of the research is given in Table 9.4.

The reagent doses (based on their active part) corresponding to established considerable dephosphorization efficiency were established to exceed the theoretical ones – the design coagulant doses making 5 mg/dm^3 at the given initial phosphate concentration. Aluminium sulphate is the most effective one but optimal coagulant doses exceed the dose defined as the one inhibiting active sludge. Intensified silicic acid exerts practically no positive influence – the same as VPK-402.

Table 9.4

Results of Settled Water Coagulation with Different Reagents

Coagulant	Active Part Dose of Coagulant, mg/dm^3	Residual Phosphate Concentration, mg/dm^3 (Purification Efficiency, %)
Aluminium Sulphate (AS)	10 25 50 90	2,5 (44) 0,8 (82) 0,5 (89) 0,2 (95,6)
AS + ACA	50 + 2,5 25 + 2,5 50 + 5,0 25 + 5,0	0,6 (86,6) 0,8 (82) 0,4 (91) 0,7 (84)
ACA + CA	2,5 + 25	2,2 (44)
Aluminium Oxychloride	10 25 90	3,1 (31) 1,0 (78) 0,9 (80)
Novoflock	10 25 90	3,5 (22) 2,0 (55,5) 1,3 (71)
VPK-402	2,5	4,3 (4,4)

In the next part of the research, we deviated from the traditional coagulation method. Coagulating agents were introduced into the settled water and the received sample was being aerated for 15 minutes. In this case, rather high phosphorus removal efficiency was achieved. The research results testified to the fact that aeration with further settlement was more effective during dephosphorization; for example, when the initial phosphate concentration increased more than twice, the effective reagent dosage decreased twice. If in the first case (the standard coagulation method) the effective aluminium sulphate dosage (based on aluminium oxide) was 11,2 times as large as the theoretical dose, in the second case (preliminary aeration) it was 2,2 times as large (Table 9.5).

Table 9.5

Results of Reagent Dephosphorization with Aeration (Initial Concentration of Phosphate-Ions in Sewage after Aerotanks - 10,6 mg/dm³)

Coagulant	Al_2O_3 Coagulant Dose, mg/dm³	Phosphates Concentration in Purified Sewage, mg/l (Purification Efficiency, %)
Aluminium Oxychloride	15 25	1,8 (83%) 0,8 (92,5%)
Aluminium Sulphate	15 25	1,5 (86%) 0,5 (95,2%)

The present work contains the research on determination of possibility of phosphorus removal from biologically purified water with reagents being industrial wastes and evaluation of coagulating efficiency of the following coagulants: sodium hydroaluminate, which is a waste of industries with milling of aluminium surfaces, formula $Na_2A1_2O(OH)_6$, when diluted, aluminium hydroxides form in the solution that have different charges depending on the pH value; iron hydroxide solution received during dilution of steel scobs – a waste from metal-processing shops; defecation mud solution – a waste from sugar mills, which is produced during purification of sugar syrup with lime. The research results are given in Table 9.6.

The analysis of the research results enables to make the conclusion that dephosphorization of sewage after its biological purification with the reagent method and utilization of industrial wastes is a promising method. However, the process is stabilized when the pH value is corrected.

Filtration of settled sewage is necessary for achievement in the purified water of the MPC value based on coagulating metal ions.

The data of laboratory research testifies to the fact that during coagulation in the active sludge presence the reagent dose must be considerably higher than the one given in Reference Manual to Construction Norms and Specifications; it may be accounted for with sorption of the product of the coagulant hydrolysis on the sludge flakes.

Table 9.6

Research Results of Phosphorus Removal with Coagulation during Utilization of Different Industrial Wastes

Coagulant Dose, mg/dm^3	Phosphates Concentration, mg/dm^3		Note
	Initial	Residual	
1	2	3	4
Utilization of sodium hydroaluminate, the medium pH was corrected with sulphuric acid, Al_2O_3 coagulant dose, mg/dm^3:			
0,9 1,0 2,5 3,4 3,4 3,4 5,0 7,0 9,0	4,0 4,0 4,0 4,0 3,0 8,0 4,0 4,0 4,0	4,0 3,9 3,0 2,0 0,5 5,5 (acc. to reference 1,5 data) 0,8 0,6	Settled samples were transparent, coagulation was performed at optimal pH values. Aluminium residual concentration exceeded 0,6 mg/dm^3
Utilization of dissolved iron, the medium pH value - 6,5-7,2; Fe^{3+} coagulation dose, mg/dm^3			
1,0 2,0 4,0	3,9 3,9 3,9	3,8 2,8 1,0	Residual iron concentration: 0,5-0,7 mg/dm^3
The same in active sludge presence, sludge dose – 2 g/dm^3			
2,0	5,6	5,3	0,22 - 0,32 mg/dm^3
4,0	5,6	3,0	
6,0	5,6	2,8	

1	2	3	4
The same in the flocculant VPK-402 presence, reagents doses, mg/dm^3:			Residual iron concentration 0,4 - 0,5 mg/dm^3, in all samples the liquid above the sediment was pale yellow
Fe^{3+} VPK- 402			
4,0 1,0	4,6	4,0	
4,0 1,0	4,6	3,4	
4,0 3,0	4,6	4,4	
Utilization of defecation mud, Ca^{2+} reagent concentration, mg/dm^3:			The liquid above the sediment was opalescent
0,8	5,2	5,2	
1,7	5,2	5,0	
3,8	5,2	4,6	
7,6	5,2	4,0	

According to the reference data, during sewage purification the operating inputs for reagent dephosphorization may make up to 45% of the total operating costs for the total sewage purification scheme, as the reagent system is an additional component of the process flow scheme of sewage purification.

The authors approbated an alternative method of dephosphorization – phosphates sorption on the feed during filtration of water through a sorbent (ionite) compact layer. The $H_2PO_4^-$ ions prevail in the pH range (5-8) typical for sewage. Triple-substituted phosphates of bivalent and trivalent cations are not readily dissolved. That is why it seemed expedient to consider the possibility of phosphorus fixation due to formation of links with mineral substances. To achieve this purpose different filtrating materials were approbated: aragonite, clinoptillonium, monthmorillionite, shell limestone, etc. Shell limestone was established to be the most effective material – a natural, easy-to-obtain, cheap material which active part as regards phosphates is calcium, however, its specific sorption is low, and regeneration is impossible, as in this case it would be chemical sorption, not physical one. The chemosorption process is characterized with formation of amorphous calcium phosphates on the solid surface, which later transform into crystalline forms. 0,03 m^3 of filtrating material is necessary for adsorption of 1g of PO_4^{3-}.

Phosphates adsorption is distinct on iron oxides. Steel scobs are a waste at numerous industrial enterprises. It were scobs that were approbated as a filtrating material during tertiary treatment of water from phosphates. The optimal pH value at which poorly soluble compounds form was determined using the Lindsay and Moreno equation for $FePO_4 x 2H_2O$, $P_{H_2PO_4^-}$ =10,9-pH, depending on the initial (PO_4^{3-}) phosphates concentration of 1; 3; 5 and 10 mg/dm^3 the optimal pH value was 5,92; 6,4; 6,62; 6,9 correspondingly.

The results analysis enabled to discern an expressed tendency of increase of the phosphates concentration in the filtrate with increase of the filtration rate.

When a single-layer feed was used, the Fe^{3+} ions concentration in the filtrate exceeded the MPC of the Fe^{3+} ions in the purified water discharged into reservoirs. When a two-layer feed was used with shell limestone as the second (lower) layer, the Fe^{3+} ions concentration was 0,3 mg/dm^3.

In our opinion, aluminium oxide is the most perspective method of phosphate-ions removal; chemosorption is possible on its surface that progresses according to the ion-exchanging mechanism conditioned with exchange of phosphate-ions for water molecules: $[Al - H_2O]^+ + H_2PO_4^- \rightarrow [Al - H_2PO_4^-] + H_2O$, alternatively, for hydroxide groups: $[Al - OH] + H_2PO_4^- \rightarrow [Al - H_2PO_4] + OH^-$, $pK_{Al\ PO_4\ 2H_2O}$ = 30,5. The pH values optimal for formation of this compound may be calculated according to the Lindsay and Moreno equation: pH_2PO_4= 10,7 – pH. For the (PO_4^{3-}) phosphates concentration in the initial solution equal to 1; 3; 5 and 10 mg/dm^3 the pH value is 5,72; 6,2; 6,42; 6,7. The research results at the pilot installation with the filtration rate of 1 to 10 m/h have proved the possibility of application of aluminium oxide as a phosphate-ion sorbent and their complete removal from treated sewage. The filtration cycle duration depends on the initial phosphates concentration and the aluminium oxide adsorption capacity. As the filtration rate increases, it becomes the dominating factor that determines the duration of the sorbent protection. During the research there was established a relationship of the filtration cycle duration (t_{dur}) until the phosphate-ions begin to channel into the filtrate in concentrations exceeding the MPC, to the feed height (L) and the time of the feed protection (t); at the filtration rate of 5 m/h the N.A. Shilov equation looks as follows: t_{dur} =146 L – 18.

The dynamic exchange capacity depends on the initial phosphates concentration and the filtration rate. Its values (in eqiv/m^3) determined during different process conditions are given in Table 9.7.

Table 9.7

Initial Concentration, Co, g/dm^3	Filtration Rate, V, m/h	Sorption Capacity E_{dur}, equiv/m^3
2,0	2,0	110
2,2	10,0	34,2
2,9	5,0	50,9
5,3	5,0	96

The aluminium oxide that has exhausted its sorption capacity may be used as a concrete mixture component.

9.3. Laser Influence on Biochemical Processes

At high organic sludge loads, the maintenance of high quality of purified water is possible due to increase of fermentative activity of microorganisms.

The increase of sewage purification installations capacity enables to make the purification process more economic. Laser emission has been studied as a method of activation of bacteria activity. Helium-neon lasers (HNL) with the wavelength of 632,8 nm have been found lately to have highly biostimulating emission. This wavelength stimulates tissue regeneration, accelerates healing of wounds and trophic ulcers, promotes survival and development of fish embryos and larvae, intensifies growth and development of agricultural plants.

This HNL influence induced us to study the emission influence on the active sludge microflora of sewage purification installations, as well as some hydrochemical and hydrobiological characteristics of the water medium after the HNL impact. The results of this experiment were to confirm the possibility of utilizing laser emission in principle for stimulation of the active sludge microflora in sewage purification installations and raising their performance efficiency. We used helium-neon laser HNL-111 with the wavelength of 632,8 nm for radiation of an active sludge sample. The laser capacity was 25 maw. Different radiation dosages varied during these experiments by means of change of the exposition time from 3 seconds to 30 minutes. The experiment scheme was as follows:

One sample was defined as a check one; the others were exposed to radiation with HNL-111 with different expositions. The sludge mixture was mixed with a magnetic stirrer for aeration and more uniform radiation. The samples were subject to microbiological and hydrobiological examination after 1 hour and 3 hours of exposition. The total number of bacteria, heterotrophic and ammonifying microorganisms was defined. The results were treated statistically according to the standard method. Three series of experiments were made when laser emission influence on the sludge biological activity was studied at the aerotanks of sewage purification installations of Rostov-on-Don in three hours after the samples had been taken (Experiment 1) and in three days thereafter (Experiment 2), as well as at the pilot CW installation at the Rostov-on-Don meat-packing factory (Experiment 3). The experimental data showed that laser emission stimulated reproduction of various groups of microorganisms. The most clearly defined increase was observed in 1 hour after the radiation treatment – the microorganisms' number increased 5,9 times in Experiment 1 with newly taken samples after the 3-minute exposure. The bacteria concentrations remained high after 3 hours of exposure as well. In the other experiments (Experiments 2 and 3) the stimulating effect of laser impact was apparent at the exposition time from 3 seconds to 30 minutes, but it was less explicit; irradiation at the 1 minute exposition was more effective (the bacteria number grew 3,56 times). When the exposition was increased or decreased, the effect diminished. Thus, at the 3-minute exposition the bacteria number grew 3,52 times, at the 3-second exposition it grew 2,52 times. When the exposition time increased to 10 minutes, the bacteria growth was inhibited, their number reduced twice. During Experiments 2 and 3, unlike Experiment 1, the bacteria number decreased drastically after 3 hours of exposition and was 0,5-0,7 of the check sample number. Not only the bacteria number, but changes of the organic substances BOD_5 concentration as well was controlled. Thus, during Experiment 1 it was established that the largest decrease of the organic substances concentration (367 mgO_2/dm^3) was achieved during the 1-minute exposition. During Experiment 3 the change of the organic substances concentration observed in 1 hour after radiation was over was 569,6 mgO_2/dm^3 (the initial concentration was 1333,73 mgO_2/dm^3, after laser radiation it was 762,14 mgO_2/dm^3). This data was received while analyzing the sewage samples during 1 hour after radiation. In three hours the microorganisms' activity decreased.

Special attention was paid to determination of the laser impact on the vital capacity and growth of nitrifying microorganisms. The nitrification processes were established to intensify considerably during one hour after the 1-minute exposition to radiation.

Thus, it was established that laser emission exerted stimulating influence on the microorganisms' growth, however, the efficiency of laser impact depended on the radiation dose and on the observation time of the radiation effect. The most explicit effect was observed at the 1-minute exposition and it remained during one hour after exposition. Three hours later the microorganisms' activity decreased as compared to the check samples.

In order to accelerate the reproduction rate of nitrifying microorganisms and control nitrification during fluctuations in the sewage flow and composition, changes of temperature and pH, ingress of toxic components /46/, it is suggested to install helium-neon lasers in one or several distribution chutes of the CW sprinkling system (Fig. 9.1).

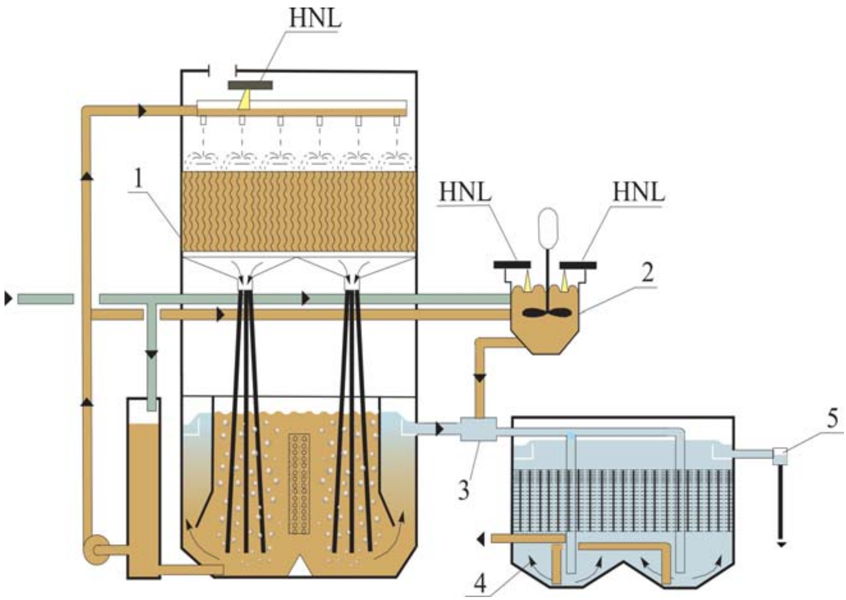


Fig. 9.1. CW with Helium-Neon Lasers Installations

The laser scans the circulating mixture of sewage and sludge in (1) the chute edgewise. When the laser installation with the output power of 25 mW and the wavelength of 0,63mm is erected at the height of not less than 300mm above the liquid surface, scanning of the zone not less than 100mm wide is ensured.

Another promising direction of utilization of helium-neon lasers is, in our opinion, preparation of the organic substratum for denitrifying microorganisms. At the next denitrification stage, the organic substances of primary sewage and excessive sludge are used as the source of organic carbon. As the “channeling” of a part of sewage through the denitrificator with the submerged feed layer increases the purified water BOD, the reactor for preparation of the organic substratum (2) is included into the purification process flow scheme. A part of sewage is drawn into the reactor together with active sludge. A mechanic aerator provides mixing of sewage and sludge and supply of the preparation process with oxygen.

The organic substratum preparation process presupposes three phases of the microorganisms’ growth: the lag-phase, the accelerated growth phase and the exponential phase. Only incomplete oxidation is allowed before CO_2, H_2O start to be produced. However, when the mass of the forming excessive sludge ratio to the mass of necessary sewage organic substances is 0,6:1, complete assimilation of organic substances with sludge flakes leads to oxidation of a considerable part of the organic substratum. That is why HNL are used during the substratum preparation process to accelerate the microorganisms’ reproduction, activation of reserve substances in cells and die-off of bacteria on fulfillment of their major function (sorption of pollutants).

The received organic substratum is drawn into mixer (3) where it is mixed with purified water. Then the liquid is drawn to the lower part of denitrificator reservoir (4). The liquid upflow passes through the layer of denitrifying sludge immobilized on the artificial feed bristles and leaves particles of a flake-like substratum on them.

Populations of elective anaerobes sorb the organic substratum that is bonded with cytoplasmic membranes of microbial cells and is a cell component, thus, the possibility of secondary contamination of purified sewage is eliminated. Emerging discharge and died-off products of biodegradation are entrapped in the feed upper part. As transparency of discharge water deteriorates, the feed is regenerated with jets of purified water. Then the water is drawn into receiving chamber of water-jet aerator (5). When water is discharged, molecular nitrogen is air-stripped and water is aerated.

Summarizing the above-mentioned, we may say that positive effects open a perspective of regulating the operation of microorganisms during purification of both household sewage and industrial wastewater, but additional research is necessary.

Chapter 10. AIR TREATMENT

Pathogenic microflora, viruses and helminth eggs get into household sewage together with man's vital activity products. During sewage purification an enormous amount of gas bubbles forms in the aerotanks, they burst forming drops that are driven into the atmosphere together with pathogenic microflora. Thus, the air is contaminated with causative agents of infectious and invasion diseases. For example, at the sewage purification installations of New York 21,800 live populations of microorganisms per 1 m^3 of the air were found /47/. 1,200 types of bacteria were found in the 0,03 m^3 sample of the air taken above the active sludge aerotank, 6% of this number were pathogenic bacteria /48/.

The research conducted by the specialists of the RSRI APS jointly with the researchers of the RPA "Biopreparat", the Medical Parasitology and Tropical Medicine Institute named after E.I. Martsinovsky and the Rostov-on-Don State University defined four ascarid eggs at the distance of 0,3m from the CW aerotank surface and one egg at the distance of 1-1,5m therefrom. The CO_2 flow rate per 1 cm^2 of the aerotank-settler surface was 0,14 – 0,35 mg/cm^2 per day and the nitrogen flow rate was 0,19 – 0,38 mg/cm^2 per day.

The world sewage purification practice has already had experience in protecting the atmospheric air, for example, the closed sewage purification installations have been built within the city boundaries in Antibes (France) in compliance with the techniques elaborated by the "OTU" company. Reeking gaseous substances are collected with the ventilation system and subject to the 3-stage scrubbing with oxidizing reagents; the air is disinfected and 99,95% H_2S, 99% mercaptans and 90% ammonia are removed. At the closed sewage purification installations in Monaco, situated in 100m from the Sali beach, all discharged gas flows (in the amount of up to 58 thousands m^3/day) are subject to the 4-stage scrubbing. Solving of the air purification problem has enabled to place the sewage purification installations in Nice not far from the residential areas (only an automobile road separates dwelling apartments from the sewage purification installations). The air from the closed sand catchers, primary and final settlers and aerotanks is subject to the 3-stage scrubbing, and the air from the sludge consolidation tanks and press-filters is subject to the 4-stage treatment (Fig. 10.1).

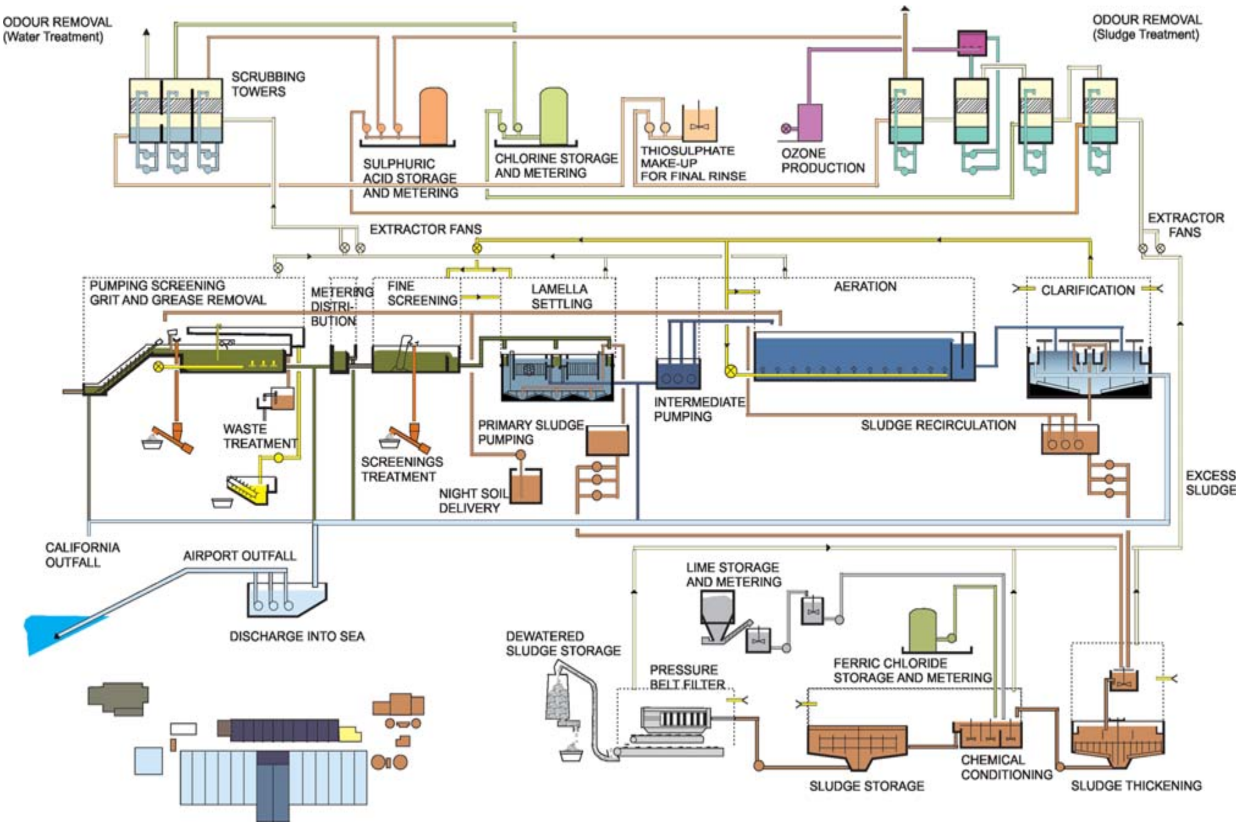


Fig. 10.1. Multi-Stage Air Treatment Schemes

The operation conditions of the sewage purification installations with the CW differ favourably from the existing installations performance: - odour nuisances enter the environment only from the receiving chamber and sand catchers, in other words, from the locations where sewage is received; - primary settling, mineralization and dewatering of the wet sediment are excluded from the process flow scheme of household sewage purification; these stages are the main sources of reeking volatile substances exhaust; - the aerotank-settler design prevents formation of stagnation zones that leads to the sludge ingraining and stagnation; - the oxygen utilization quotient in the CW achieves 15-20% of its total amount drawn into the system due to its multiple recirculation through the CW biofilters, air-stripping towers and aeration zones of the aerotank-settlers, in classic purification installations the quotient not exceeding 6%. Consequently, the amount of the air to be treated reduces 3-4 times.

The environmentally appropriate operation mode is determined with the purification installations capacity. When the installations capacity is from 50 to 5,000 m^3/day, the air from the CW and local suction pumps from the fine mechanical purification grids, sand catchers, sediments dewatering units, etc. is drawn with the combined extract-and-input ventilation first into the cellular pocket filters where the main mass of drops is entrapped (about 66%), then into the cellular folded filters, which entrap particles up to 0,3 mcm in size (99,97% efficiency).The filtration material is disinfected and dewatered regularly by means of a bactericidal irradiator. The air may be disinfected with UV-installations as well.

For the CW with the capacity of more than 5,000 m^3/day, it is recommended to use the single-stage and two-stage scrubbing schemes for purification of the air together with the installation in compliance with the patent /49/ (Fig. 10.2).

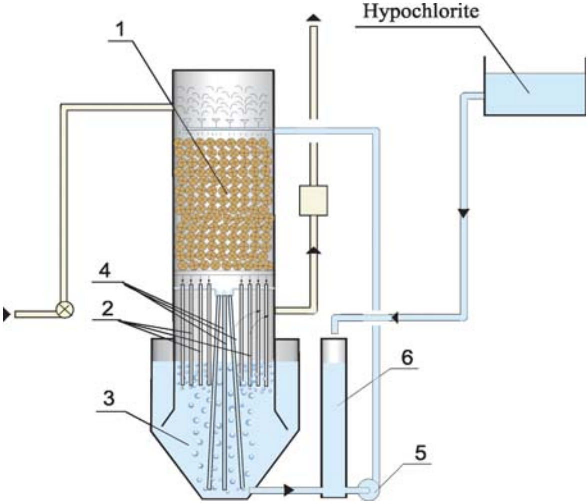


Fig. 10.2. Air Scrubbing Scheme

The air is driven with a fan to the installation checker 1 where it contacts the disinfecting, degassing and deodorizing solution.

Sodium hypochlorite may be used as a reagent. Then the air through direct pipes 2 is forced into the installation bubbling section 3 where the secondary contact of the air bubbles and the solution takes place. Then the air is ejected into the atmosphere through the spray separator. The solution is circulated with pump 5. When the liquid flows down the collecting tray into the air water-jet ejection pipes 4, some part of the air is sucked in. The following floating of the air bubbles ensures mixing of the bubbling section 3 content and renewal of the contacting surface of the gas-liquid phase. The fresh solution is replenished through mixing chamber 6.

Sodium hypochlorite used for degassing of nitrogenous heterocycles, hydrogen sulphide, methyl mercaptan transforms the above-mentioned compounds into non-toxic oxidized forms.

Hydrogen sulphide degassing methods.

$$NaOCl + H_2S \rightarrow NaCl + H_2O\downarrow + S$$

In the alkaline medium hydrogen sulphide may oxidize to sulphates:

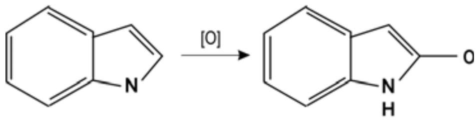
$$4NaOCl + 2NaOH + H_2S \rightarrow Na_2SO_4 + 4NaCl + 2H_2O$$

Methyl mercaptan – CH_3SH may oxidize to dimethyl disulfide:

$$2CH_3SH \xrightarrow[-H_2O]{+O_2} CH_3\text{-}S\text{-}S\text{-}CH_3$$

The latter may further transform into sulfoxides (>S → O).

Indole and skatole degassing with sodium hypochlorite as an oxidizer of medium capacity may be accompanied with formation of oxindole of the following type:



Indole Indoline

Chapter 11. RECOMMENDATIONS ON CW UTILIZATION FOR PURIFICATION OF DIFFERENT SEWAGE TYPES

11.1. Process Flow Schemes of Household Sewage Purification

The operation peculiarities of the installations and works intended for treatment of sewage from small and medium-sized settlements and towns have defined the CW design peculiarities and the purification process flow schemes. In accordance with the above-mentioned reasons, specific design solutions have been elaborated for each CW capacity range: 5 – 20; 25 – 100; 200 – 1,000; 1,200 – 100,000 m^3/day.

While preparing the present Chapter, the authors used the data from the projects of reapplication of the sewage biological treatment stations with the capacity of 50, 200, 400, 800 m^3/day and the 50 m^3/day purification installations for wastewater from mini-meatpacking factories and butter-dairies, the projects of biological purification stations for the Far North with the capacity of 200, 400, 800 m^3/day elaborated for the State Committee for Agricultural Produce of the Russian Federation (1982-1992) and "Recommendations for Designing and Utilization of Combined Installations and Works for Sewage Treatment" elaborated for the State Committee for Housing and Construction of the Russian Federation (1989-1990).

The CW operation principle may be used for purification of small amounts of sewage with the flow amount of less than 5 m^3/day as well. However, operation costs for both the existing aeration installations and CW are burdensome for the majority of the population in this case. Mainly well-to-do population can bear costs of energy inputs (10kW per day minimum) for small pneumomechanical devices and reserve mechanisms or pumps and qualified operating personnel services (switching of working and reserve mechanisms, removal of excessive sludge, disinfection, etc.). As the solution of the problem of prevention of open and closed water sources contamination lies in total sewage purification, we have elaborated the new principle of biological purification and 0,5 – 4 m^3/day installations have been designed (Appendix 1).

5 – 20 m^3/day Combined Installations and Works

The plan and section of the installation capable of treatment of household sewage in the amount of 5 – 7 m^3/day characterized with the BOD_5 100-1,000 mg/dm^3 concentration of organic pollutants and the suspended substances concentration of 100-400 mg/dm^3, are given in Fig 11.1.

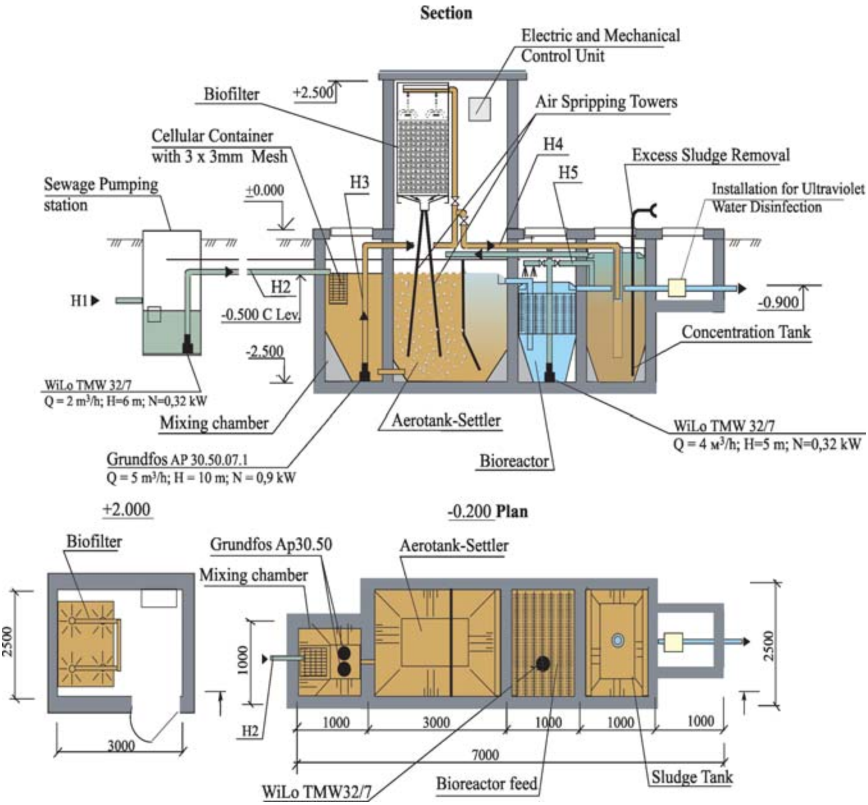


Fig. 11.1. 5 – 20 m^3/day CW Plan and Section

Sewage flows by gravity through header H1 into the Sewage Pumping Station (SPS) wherefrom it is pumped by pipeline H2 to the mixing chamber of the combined installations. In order to trap waste and sand a cellular container-sand catcher is installed in the mixing chamber. Entrapped wastes and sand are unloaded into the waste tank. In the mixing chamber sewage is mixed with the circulating sludge mixture from the aerotank-settler. Then the mixture is pumped with the circulation pump by pipeline H3 into the biofilter sprinkling system consisting of water spouting chutes with outlet pipes and reflecting disks. The falling liquid jets are broken upon the disks and sprinkle the biofilter feed. The biofilter feed is made of ceramic ball-shaped elements with recesses, the axes of which meet in the ball centre. The liquid passes through the biofilter and is driven with the collecting tray to the air-stripping tower, where the air is sucked in due to a vortex formation. During the gas-liquid flows movement the aerotank content is stirred efficiently. The sludge mixture displaced from the aeration zone is discharged into the settling zone where sludge settles. Some part of sludge is compacted and through the slot in the wall between the aeration zone and the settling zone is driven back to the aeration zone. The rest of sludge together with the transit flow rises and forms a suspended layer in the lower part of the settling zone. The purified water is then drawn to the tertiary treatment bioreactor with the artificial pig feed. The bioreactor feed ensures the decrease of the BOD_{comp} organic pollutants concentration to 3 – 5 mg/dm^3; the floating sludge flakes are also entrapped in the feed; the suspended substances concentration makes 3 – 7 mg/dm^3 when sewage leaves the bioreactor. The ammonium nitrogen concentration makes 1 – 1,5 mg/dm^3 when sewage leaves the reactor; the tribasic phosphates phosphorus concentration does not exceed 0,7 – 1,5 mg/dm^3. The clarified water is collected with the water discharge chute after it leaves the feed and is driven to the ultraviolet disinfection installation.

The feed is regenerated regularly in the following way: the pump is turned on, some part of the purified water is pumped out with pipeline H5 (to the bottom of the pig feed) and discharged, then the pipeline H5 valve is closed and the valve on the sprinkling pipeline is opened, the pig feed is being washed for 10 minutes, then the valve is closed, the valve on pipeline H5 is opened again and the water is fully pumped out into the sludge tank.

The excessive sludge is removed in the following way: the circulation pump is turned off for 15 minutes, the valve on pipeline H4 is opened to the sludge tank, then the pump is turned on and some part of the compacted sludge is discharged into the sludge tank. Then the above-mentioned valve is closed. The settled water from the sludge tank is discharged into the aerotank-settler. The excessive sludge from the sludge tank is regularly removed with specific vehicles to disposal sites approved by the SES or to the nearest sewage purification installations.

Power consumption is 1,5 – 2,5 kW.h per 1 m^3.

25 – 100 m³/day Installations

The design of the installation for treatment of sewage characterized with the BOD_{comp} 100 - 1,000 mg/dm³ concentration of organic pollutants and the suspended substances concentration of 50 - 400 mg/dm³, is given in Fig 11.2.

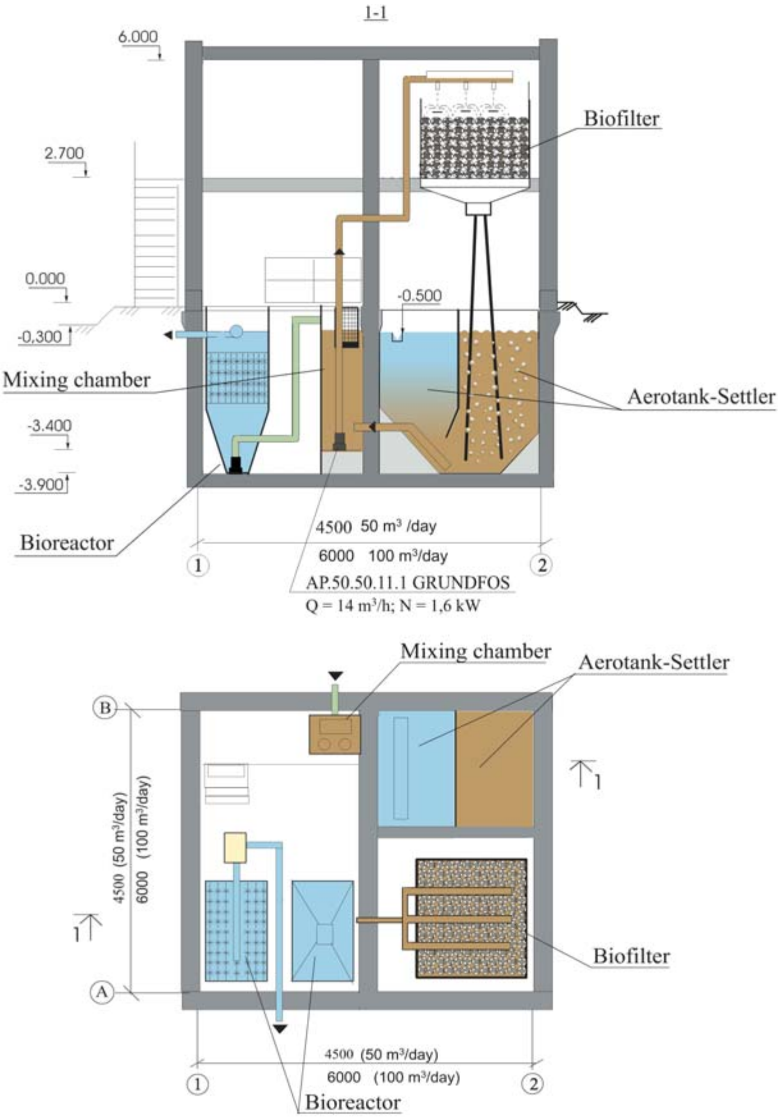


Fig. 11.2. 25 – 100 m³/day Installation Plan

These installations are accomplished of one or two sections united with a common mixing chamber with service pipelines and circulation pumps. Ceramic balls, asbestos-cement sheets or artificial flat feed may be utilized as the biofilter feed material.

An original process flow scheme for the installations with the given capacity was elaborated to enable to decrease by 30-50% the operation time of the circulation pump per day (Appendix 2).

The excessive sludge is dewatered at the sludge drying beds. When the installations are situated in the city residential area, the excessive sludge is drawn to the sludge tank wherefrom it is regularly removed to the nearest sewage purification installations. A new principle of the sediment impaction has been elaborated for thickening of small amounts of sludge that enables to automate the process of decrease of the excessive sludge humidity (Appendix 3).

Power consumption is 0,6 – 0,8 kW.h per 1 m^3.

200 – 1,000 m^3/day Purification Stations

For the installation capacity of 200 – 700 m^3/day the mechanical purification may be accomplished directly in the mixing chamber by means of in-built cellular containers with 2-4 mm mesh. The container bottom is made of two solid halves and a skirting (h = 100 – 150 mm). When the sewage passes through the container it entraps and accumulates biologically inoxidizable wastes and sand. The entrapped mass is regularly discharged into the accumulator tank through the opening halves and then removed to the disposal site. A design solution of the 200 m^3/day station is given in Fig. 11.3.

At the 800 – 1,000 m^3/day CW mechanical purification is accomplished by means of bow sieves and vertical sand catchers.

The stations are designed to consist of two or four CW sections assembled with the sewage tertiary treatment bioreactors, subsidiary and personnel rooms. The UV-disinfection installations for purified water are also placed in the building.

Organic pollutants are oxidized in the biofilters with immobilized microorganisms. The biofilter height may be 1,15 – 2,0m. Corrugated asbestos-cement sheets (All-Union State Standard 24986 – 81) sized 1750x1150mm may be used as the feed carrier.

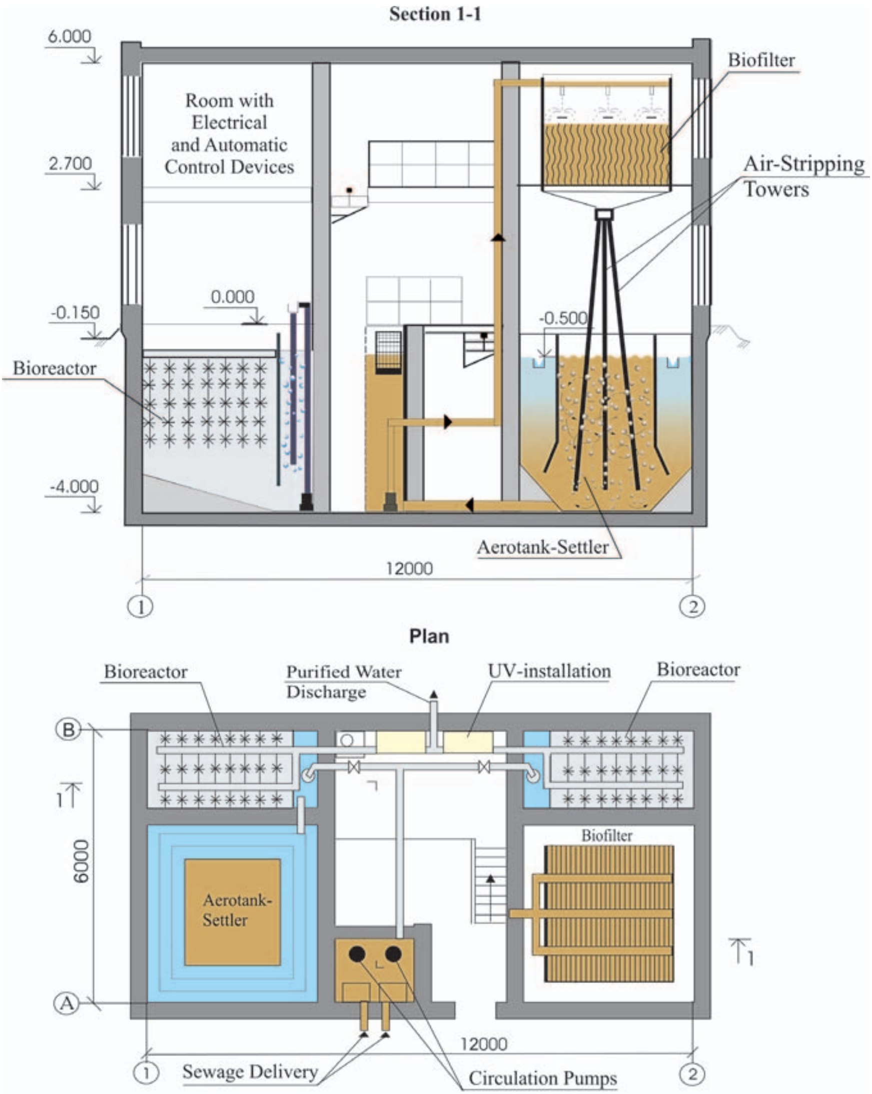


Fig. 11.3. 200 m^3/day Station Section and Plan

To optimize the hydrodynamic mode of the liquid movement on the feed surface and to fix the biomass, the asbestos-cement sheets should be erected upright, with the wave directions perpendicular to the flowing down liquid. The distance between the feed sheets should be not less than 20 mm. Flat feed made of artificial materials is planned to be used in future as the feed material in compliance with /33/.

Water-jet aeration systems in the CW are made in the form of one or several bunches of the air-stripping towers radiating top-down. The corresponding amount of the collecting trays is installed under the biofilter, their walls are inclined towards the sumps. Geometrically the sumps are placed above the centers of the sections served with every bunch of towers. As the length of the water-air jet leaving the lower edge of the air-stripping tower is 0,5-0,7 m, the impingement attack of gas-liquid jets on the bottom is necessary to prevent the sludge ingraining. Thereto the height of the air-stripping tower lower edges above the bottom should be assumed 0,2 – 0,3 m. The effective area of the 40-50 mm air-stripping tower is conditionally assumed in the plan to equal 1x1 – 1,2x1,2 m.

In order to lower the power consumption for maintenance of the optimal temperature, the air from the service and subsidiary rooms is used, except the air from the rooms with the receiving chamber, fine purification installations and sand catchers. The utilized air is partially removed from the CW through ventilation pipes to further treatment or to the atmosphere, it is partially discharged into the biofilters rooms as well. The air exchange is regulated by means of changing the ventilation pipe valve position and diameters of the discharging holes in the intersections between the biofilters and aerotank-settlers rooms. In order to organize the air flow, the holes in the intersections must be placed at regular intervals along the perimeter, near the room walls.

When the air-aerosol flows are distributed correctly, there is no condensation and air humidity in the room; in the foggy weather, the humidity inside the CW is lower than that in the atmosphere. The design amount of the outside air required for biochemical purification of municipal sewage with BODcomp 150 – 300 mg/dm^3 is 5 – 7 m^3 per 1 m^3 of water. At higher pollutants concentrations the design amount of the air is corrected with the ratio of the primary sewage BOD_{comp} to the BOD_{comp} value of 200 mg/dm^3.

If the average annual temperature in the settlement is below 12 ^{O}C, then the biofilters rooms should be provided with heaters. The design air temperature in the CW rooms should be not less than by 2 ^{O}C higher than the primary sewage temperature.

When these recommendations are followed, the treated water temperature will increase in a cold season by 0,5 – 2 ^{o}C. It should be noted that insufficient consideration of the temperature factor leads to 70% decrease of the purification efficiency of the sewage purification installations in the middle and northern parts of Russia in winter.

When the installations are constructed in residential areas, the combined extract-and-input system of ventilation with forced and natural drawing is provided in the CW building. The system of ventilation with forced drawing includes three stages of the air treatment: Stage I – cellular pocket filters with the bacteria entrapment efficiency of up to 60%; Stage II – cellular folded filters with the bacteria entrapment efficiency of up to 97-99,9%; Stage III – bactericidal irradiators. In order to disinfect the air, the UV-installations produced by RIA “ENT” Table. 11.1 may be used.

The UV-sections are made as canal modules with bactericidal lamps inside.

The air is disinfected with lamps producing or non-producing ozone when the air passes through the closed light chamber. During UV-irradiation bacteria, viruses, microflora (mold, yeast), spore forms of microorganisms are eliminated.

Table 11.1.

UV-Installations for Air Disinfection

Installation Type	Capacity m^3/hr	Room Volume m^3	Consumed Power, W	Dimensions mm
ADI-3m-15	40	50	25	d 110; 650
ADI-3m-30	40	70	35	d 110; 1150
ADI-3m-55	60	100	70	d 110; 1150
ADI-3m-60	60	150	80	d 110; 1150
ADI-2m-3	200	500	300	180x400x1050
ADI-2m-4	400	1000	400	180x500x1050

The purified water may be disinfected with the UV-installations produced by RIA “ENT” (Table 11.2), RIA “LIT” (Table 11.3) and the Kharkov Electrotechnical Company (Table 11.4).

Table 11.2.

UV-Installations for Water Disinfection

Installation Type	Capacity* m^3/hr	Consumed Power, W	Outlet Pipes Diameter mm	Weight, kg	Disinfection Block Dimensions (WxLxH), mm
WDI-0.5m-03	0,3	15	1/2”	2	75x100x300
WDI-0.5m-05	0,5	20	1/2”	3	80x110x390
WDI-0.5m-1	1	25	3/4”	5	95x170x530
WDI-0.5m-2	2	40	1”	7	125x176x980
WDI-3.0m-4	4	80	1 S”	11	155x205x1000
WDI-3.0m-6	6	90	1 S”	14	155x205x1350
WDI-3.0m-8	8	150	1 S”	25	380x560x1000
WDI-3.0m-10	10	200	2”	30	254x366x1025
WDI-3.0m-15	15	250	2”	35	254x366x1350
WDI-15m-20	20	350	70	45	310x450x1350
WDI-15m-30	30	510	70	60	337x580x1025
WDI-15m-50	50	680	100	85	390x540x1350
WDI-50m-100	100	1300	150	120	470x610x1350
WDI-50m-150	150	1800	150	160	500x640x1350
WDI-50m-500	500	8000	300; 400	380	600x2100x1700

Table 11.3

Disinfection Installations for Purified and Tertiary Treated Sewage

Equipment Type	Modal Capacity, m^3/h	Working Pressure, max kgc/cm^2	Consumed Power, kW	Camera Weight, kg	Outlet Pipes Diameter mm	Camera Volume, l	Head Loss, max, m	Camera Dimensions, m (LxWxH)	UV Lamp Type	Control Panel Type	UV Sensor Type	Washing Block Type
1	2	3	4	5	6	7	8	9	10	11	12	13
Series 4 (5-100 m^3/h)												
WDI-6/b	6	10	0,5	60	50	40	0,4	1,4x0,3 x1,6	DB-75-2	Panel 2	RS-2	WB-5
OS-5A	30	10	1,0	76	100	55	0,3	1,8x0,5 x0,6	DB-240	Panel 2	RS-2	WB-5

1	2	3	4	5	6	7	8	9	10	11	12	13
Series 5 (100-3,000 m^3/h)												
WDI-160/96	160	4	8,5	1300	250	870	0,5	3,5x1,6 x1,4	DB-75-2	Board-1	RS-20	WB-25
WDI-250/144	250	4	12,8	1600	300	1500	0,5	4,0x1,6 x1,5	DB-75-2	Case-1	RS-20	WB-25
WDI-500/288	500	4	26	3000	400	2800	0,5	6,0x1,6 x1,8	DB-75-2	Case-1	RS-20	WB-30
WDI-1000/288	1000	2	26	3600	500	3500	0,5	2,3x1,9 x4,0	DB-75-2	Case-1	RS-20	WB-30
WDI-1000/432	1000	4	38	5000	600	6000	0,5	6,0x1,6 x2,7	DB-75-2	Case-1	RS-20	WB-30
WDI-1000/576	1000	3	60	4500	600	6000	0,4	6,5x1,6 x2,1	DB-75-2	Case-1	RS-20	WB-30

The installations of Series 4 and 5 (Table 11.3) ensure the purified water quality that corresponds in its microbiological parameters to the requirements envisaged in Sanitary Norms and Regulations 4530-88 for purified sewage and to the process requirements for surface water. When the transmission factor for the UV-radiation is not less than 50% per 1 cm, the disinfection dosage is not less than 40 mJ/cm^2.
Power consumption for this range of the installation capacity is 0,4 – 0,7 kW h.

Table 11.4

Main Performance Parameters for "Vodogray-S" Installations for Sewage Disinfection

Parameter	Value						
1	2	3	4	5	6	7	8
UV Installation Type	V25C6	3V12 KS	8V12 KS	V250 TS	V600 TS	V650 TS	V3000 TS

1	2	3	4	5	6	7	8
Capacity (Nominal), m^3/hr	25	150	400	220	650	890	3200
Water UV Absorption Factor	0,45						
Effective UV-Dosage, mJ/cm^2	35						
Head Loss, m	0,2	0,2	0,5	0,5	1,0	2,4	1,8
Working Pressure, nominal, not more than, MPa	1,0	0,15	0,15	0,8	0,8	0,8	0,8
UV Lamp Type	TUV 115	TUV 115	TUV 115	NOK 20/100	NOK 20/100	NOK 20/100	NOK 105/120
UV Lamp Quantity, ps	6	36	96	6	18	24	18
UV Lamp Working Life, h	8000	8000	8000	5000	5000	5000	2500
Consumed Power, kW	0,8	4,8	12,8	12,6	37,6	50,4	175,0
Disinfection Module Dimensions, mm	1800x 365x 475	2250x 850x 1670	3200x 1800x 1670	800x 1250x 800	1600x 1250x 800	4500x 125x 800	1600x 2000x 800
Control Cabinet Dimensions, mm	800x 350x 600	800x 600x 2100	800x 1000x 2100	800x 600x 1600	950x 800x 1800	2400x 800x 1800	2400x 2400x 1800
Average Service Life of Installation, years	15						

1,200 – 100,000 m^3/day Installations.

The stations of this capacity are designed as blocks of industrial, subsidiary and administrative rooms. The design solution of the 12,000 m^3/day CW elaborated for the town of Volsk (The Saratov Region) is shown in Fig 11.4.

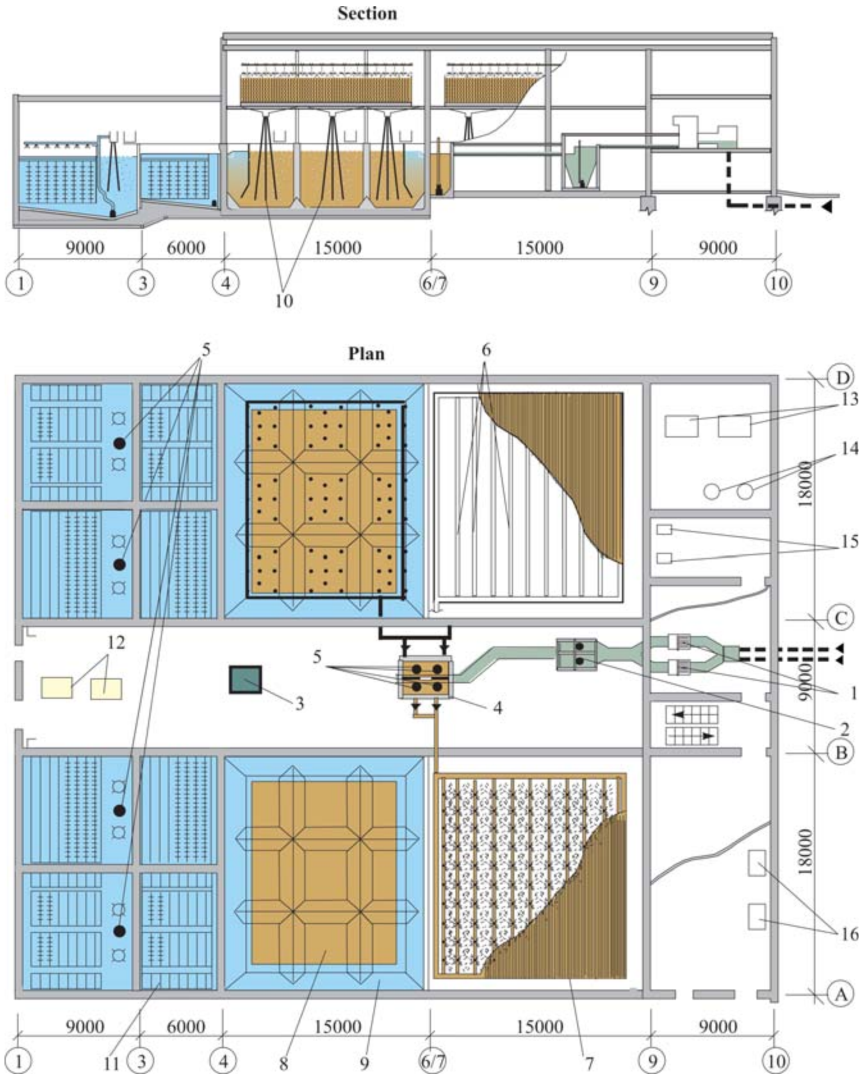


Fig. 11.4. 12,000 m³/day CW Section and Plan
1 – Fine Mechanical Purification Grid; *2* – Sand Catcher; *3* – Air Disinfection Installation; *4* – Mixing Chamber; *5* – Circulation Pump; 6 – Sprinkling System; *7* – Biofilters Feed; *8* – Aeration Zone; *9* – Settling Zone; *10* – Air-Stripping Towers; *11* – Denitrificator; *12* – Water Disinfection Installation; *13* – Filter Press; *14* – Bunkers for Sand and Sediment; *15* – Installations for Tempering and Dosing of Reagents; *16* – Transformers

The present capacity range has the following process characteristics:

– pipelines delivering the sewage and sludge mixture to the CW sprinkling systems are connected and the liquid is driven into the chutes from both sides;

– the sludge is removed from the aeration zones into the mixing chamber with perforated loop pipes placed along the zone perimeter. The sludge may also be removed through separate straight sections of the perforated pipes;

– the size of the flat parts of the aeration zones is decreased by means of rollers with 45-60 degree slopes;

– the air-stripping towers diameter may vary from 50 to 70mm, the effective area of the air-stripping towers is 1,2x1,2 – 1,4x1,m.

In order to remove large-sized impurities from sewage, it is recommended to utilize the fine mechanical purification grids with up to 2 mm mesh produced by the "RIOTEK" Company (St. Petersburg). The grids represent a set of mobile and fixed steplike plates joined into packages with the fixed distance between the plates of the mobile and fixed packages (Fig.11.5).

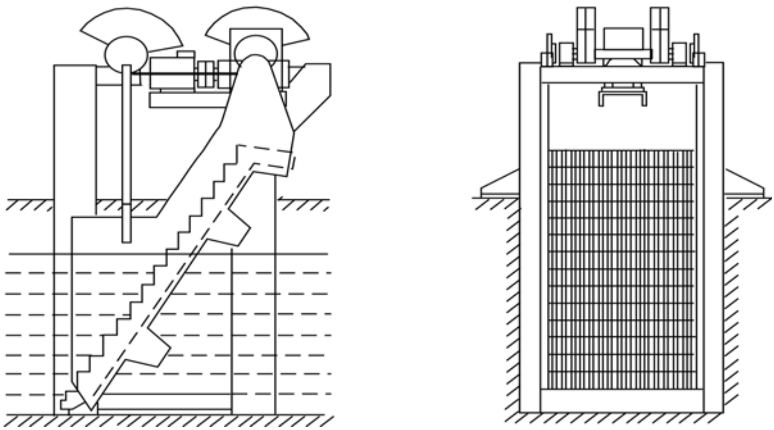


Fig. 11.5. Fine Mechanical Purification Grid

Wastes entrapped on the filtrating plates make up the additional filtrating layer promoting the best purification efficiency. Due to circular motion of the mobile steplike plates the impurities raise automatically up the steps and are gradually discharged and removed.

All drive moving details and components (bearings, tooth-wheels, chains) are assembled in such a way so as to prevent any contact of them with sewage; it raises the drive's reliability and durability. The filtrating plate, frame and other grid elements contacting the liquid are made of stainless steel. The grid operates in cycles as a rule, but it can also operate continuously. The beginning of the purification cycle coincides with achievement of the upper operating level in the canal before the grid, when the level sensor responds and sends the signal to turn on the grid drive. After the grid filtrating surface has been cleaned, the water level in the canal before the grid decreases and the level sensor signal turns the drive off. The wastes may be transported with the hydraulic press-conveyer HPC-200.
The performance parameters of the steplike grids produced by the "RIOTEK" company are given in table 11.5.

Table 11.5.

Performance Parameters of StepLike Grids Produced by "RIOTEK"

Item Index	Nominal Sewage Capacity, m^3/h	Nominal Wet Sediment Capacity, m^3/h	Grid Width–Canal Width, mm	Filtration Section Width, mm	Mesh Width, mm	Total Height, mm	Length, mm	Weight, kg
SG-240	30	20	240	125	1	1225	735	165
SG-500	210	150	500	350	2	1320	850	380
SG-630	280	200	630	440	2	1580	1160	790
SG-1000	970	750	1060	840	2	2530	1440	2380
SG-1000L	2000		953	807	5	2950	1730	1735
SG-1200L	2440		1160	1005	5	2950	1735	1950
SG-1560	2500		1560	1270	4	4420	2420	6640
SG-1900	5900		1903	1720	6	4850	2310	6300

Circulation sewage pumps with the head (H) of 7-9 m, number of revolutions n_N = 730 – 1,460 RPM are recommended as the main mechanical equipment for biological purification; for tertiary treatment bioreactors the circulation pumps with H = 5 m, n_N = 730 - 960 RPM are recommended.

The most preferable method of the sewage sediment treatment is its dewatering with band filter presses. The filter presses produced by "Ecofiltrvnedreniye" (Kazan) have proved well at sewage purification installations of Novorossiysk, Stavropol, Ulyanovsk, Glazov and other cities.

The band filter presses “SIR” with a thickener “SIR-S” accomplish mechanical dewatering of sediment of municipal and agricultural sewage and industrial wastewater. The main performance parameters of the band filter presses are given in Table 11.6.

Table 11.6

Name	Measurement Unit	SIR 0.7 SIR– 0,7+0,7S	SIR 1.6 SIR– 1,6+1,6S	SIR 2.1 SIR– 2,1+2,1S
1. Length	mm	2800	2800	2800
2. Width	mm	1100	2000	2400
3. Height Height with Thickener	mm mm	1320 1850	1320 1850	1320 1850
4. Weight	kg kg	800 1200	1600 2200	2200 3000
5. Band Effective Width	mm mm	650 650	1650 1650	2050 2050
6. Capacity	m^3/h m^3/h	6–7 10–15	14–16 20–30	20–25 30–50
7. Primary Sediment Humidity	% %	95–96 99,5	95–96 99,5	95–96 99,5
8. Dewatered Sediment Humidity	%	70–85	70–85	70–85
9. Consumed Power	kW	1,5	2,5	3
10. Materials		Stainless Steel		
No foundation, hydropower station, compressor, separate building is necessary				

The band filter presses (“SIR”) operate on both home-made and exported flocculants.

The UV-installations produced by RIA “LIT”, “ENT”, as well as “Vodogray” may be used for disinfection of purified sewage.

Below the process flow scheme (Fig. 11.6) is given for the sewage purification installations with the capacity of 12 thousands m^3/day with the BODcomp pollutants concentration in sewage of 141 mg/dm^3, the suspended substances concentration of 178 mg/dm^3, the NH_4^+ concentration of 19 mg/dm^3, and the P concentration of 3,3 mg/dm^3.

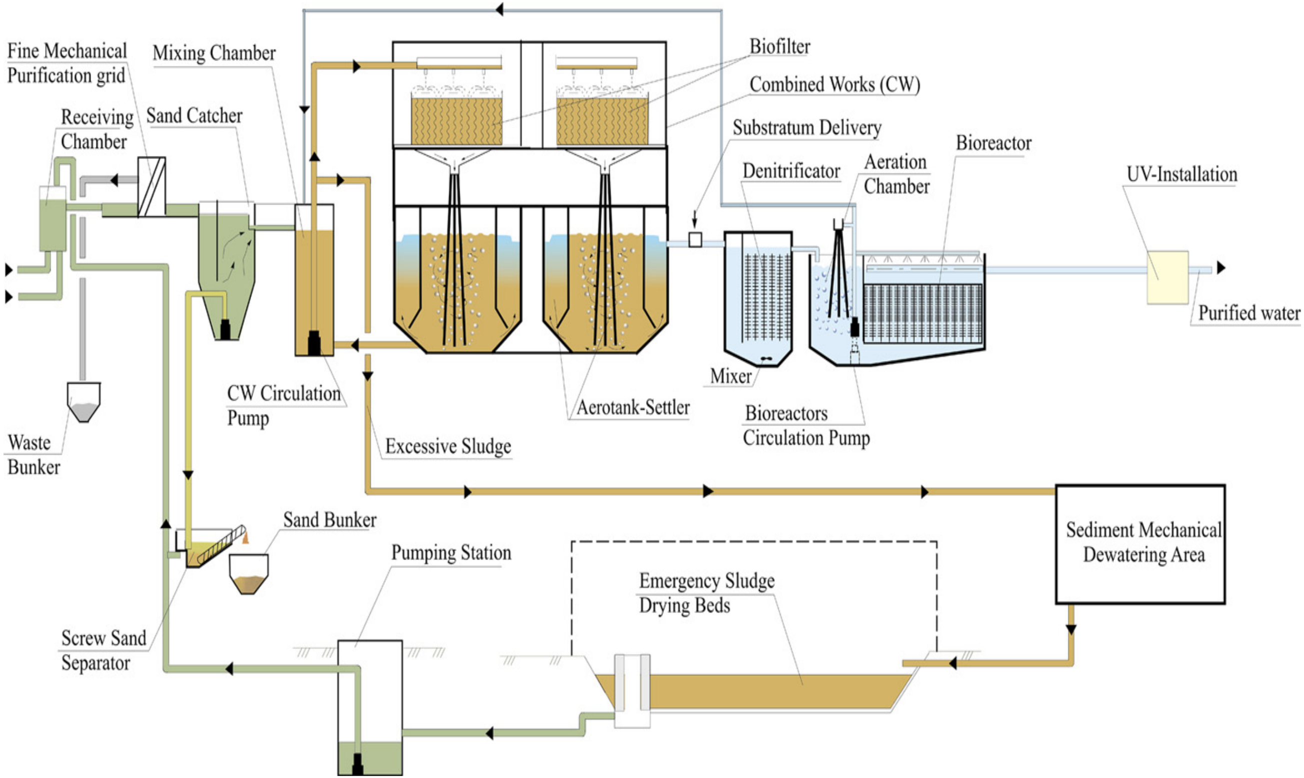


Fig. 11.6. Process Flow Scheme

According to Fig. 11.6 sewage is delivered into the receiving chamber of the sewage purification installations blocks wherefrom it is drawn to the fine mechanical purification grids SG-1000 N = 1,5 kW (with 2 mm mesh). The entrapped wastes are collected, dewatered and transported into the accumulating bunker with a hydraulic press-conveyer. The wastes are removed with automobiles to the disposal sites. The flows that have passed the grids are driven into the vertical sand catchers. The sand pulp is pumped to the screw sand separator wherefrom the sand is driven to the sand bunker. The dewatered sand is removed to the disposal pit. Then sewage is driven into the mixing chamber of the CW. The CW consist of four sections, each of them consisting of a flat feed biofilter, and an aerotank-settler. The CW sections are united into one technological facility with a common mixing chamber, circulation pumps and service pipelines.

In the mixing chamber sewage is mixed with the circulating sludge mixture delivered with the perforated pipeline from the aerotank-settlers. From the mixing chamber the mixture is taken with circulation pump and driven to the connected biofilter sprinkling systems consisting of spouting chutes with outlet pipes and reflecting disks. The falling jets split on the disks and sprinkle the biofilter feed (asbestos-cement or plastic corrugated sheets). Due to design reasons the design BOD_{comp} purification efficiency in the biofilters E_B is 69%.

On leaving the biofilters the liquid is driven with the collecting trays to the air-stripping towers where the air is sucked in (0,6 m^3/m^3) due to vortexes formation. The air-stripping towers distribute the water-air mixture inside the aerotanks. The water-air jets hitting on the bottom, bubbles floating and gas-liquid flows movement ensure efficient stirring of the aeration zones. In order to prevent the sludging zones formation the flat bottom area is reduced with rollers with 45-60 degrees slopes. The sludge mixture is drawn from the aeration zones to the settling zones where it is separated. The purified water gets into the collecting chutes and is delivered to further treatment, the sludge is compacted into flakes and recycled to the aeration zones.

In the lower parts of the settling zones a layer with enhanced sludge concentration forms (the suspended filter), which ensures integrated treatment of sewage and entrapment of small particles of pollutants and flakes of mineralized sludge.

The purified water in the settling zones gets into the collecting chutes and is delivered to further treatment, the sludge is compacted into flakes and recycled to the aeration zones.

The design BOD_{comp} purification efficiency E_A in the reaction volume of the aerotank-settler is 31 %. The circulating ratio necessary for provision of the active sludge with the air oxygen is 3,9. The circulation flow of 2,030 m^3/h with the head of H = 8 m is ensured with the pumps of the S3806M type by the "Grundfos" company (1 operating pump, 1 reserve pump), N = 80 kW.

The biomass (the biofilm and active sludge) operates in the complete oxidation mode in the CW (at the low oxidation rate and sludge load), thus ensuring the developed process of nitrification in the CW. Active sludge is highly mineralized (ash value 35 %) and has low specific resistance (33…45)x10^{-10} cm/g.

The excessive sludge is removed in the following way. A part of the circulating sludge mixture is drawn along the pipeline to the thickener where the sedimentation humidity is decreased with the cationic flocculant to 95%. Then the sediment is driven to the band filter press SIR-0,7 N = 2 kW where the final value of sludge humidity is achieved – 70-80 %. The formed cake is driven to the accumulating tank and then removed to the disposal site. In case of emergency, special emergency sludge drying beds are provided which constitute of underground reservoirs of reinforced concrete with the efficient drainage system (Inventor's certificate No. 729438), ventilation system and heating system (for the cold season). A solution of the cationic flocculant (VPK-402, AC-636, etc) is dosed into the excessive sludge delivered to the sludge drying beds to intensify the dewatering process.

After the CW water flows by gravity to the distribution systems of two nitrificators, each consisting of two sections. In the denitrificators the blocks with the artificial feed are installed. After it has passed the fine mechanical purification grids and sand catchers, the primary sewage is used as the organic substratum, as well as the sludge mixture from the CW. When the liquid passes through the layer of the suspended and immobilized denitrifying sludge nitrites and nitrates are reduced to molecular nitrogen.

Then the sewage is driven to aerobic bioreactors for tertiary treatment; the bioreactors consist of aeration chambers and reactors with artificial feed. In the aeration chambers water is freed from gaseous nitrogen and saturated with the air oxygen, which is necessary for tertiary treatment processes and observation of the requirements for water discharge into reservoirs. The water is aerated in the chamber with the circulation pump and air-stripping towers. The necessary circulating flow may be ensured with the pumps of the S1 044C type by the "Grundfos" company (4 operating pumps), N = 4,2 kW. These pumps also wash the bioreactor feed and pump the sediment out (the pumps are connected to pressure lines with flexible hoses and may lower to the chamber bottom).

From the aeration chambers the water comes to the artificial feed reactors. The biomass forming on the feed serves for tertiary treatment of sewage from organic, nitrogen and mechanical pollutants. In order to remove the residual phosphorus compounds (tribasic phosphates) the solution of aluminium sulphate may be dosed to the receiving chamber of the air-stripping towers and accomplish coagulation. When coagulant is used, the sediment is driven to the mechanical dewatering section.

Then the purified water flows by gravity to the ultraviolet disinfection installations. The installations produced by RIA "LIT" of the WDI-1000/288 type (1 operating installation, 1 reserve installation), N = 26 kW are used.

The air treatment is accomplished with the scrubbing installation (individually made), N = 3 kW.

The process flow chart may ensure the sewage purification efficiency corresponding to the MPC values of the fish industry reservoirs in Russia.

Power consumption is 0,28 kW.h per 1 m^3 of sewage taking into account the cost of lighting, ventilation and other needs. It should be noted that power consumption is 0,48 kW h per 1 m^3 at the 10 thousands m^3/day purification installations (without tertiary treatment installations) in Aspedia (Spain) built in the 1990s.

As there are no primary settlers in the CW process flow scheme and due to the CW design peculiarities that prevent formation of stagnation zones and sediment stagnation, reeking substances - the products of organic substances anaerobic biodegradation - do not form. When the sediment is treated, no reeking substances form either, as the excessive sludge is highly mineralized. That is why the air may be treated with the UV-installations produced with RIA "ENT" for the CW with the capacity of less than 5,000 m^3/day. In case of emergency, it is necessary to provide installations with ozone-producing lamps for temporary air deodorization.

When the installations of higher capacity operate, the gases CO_2, CO, CH_4, C_2H_6 may form with the concentrations that may affect the ecological situation in the city. That is why it is expedient to use the scrubbing installations with simultaneous disinfection, degassing and deodorization of the air.

11.2. Reconstruction of Existing Sewage Purification Installations

The cities growth and equipment with modern services and utilities lead to overloading of the existing sewage treatment installations. The installations are difficult to expand according to traditional schemes due to lack of additional areas. The necessity of reconstruction is determined with a great number of out-of-date water disposal systems that do not correspond to the contemporary sewage purification standards not only in Russia, but in Asia, Latin America, Eastern Europe as well. In Russia more than 80% of sewage purification installations do not operate or do not provide the sufficient purification efficiency due to the above-mentioned reason and severe climatic conditions, stops in power supplies, unsatisfactory servicing.

The installations capacity may be increased 2-4 times, the efficiency and reliability of purification technological modes may be enhanced while applying the reconstruction technology of the RSRI APS. The power consumption will decrease 2-3 times per 1 m^3 of sewage, the number of the operating personnel will decrease not less than by 30 %. The experience in the CW construction and operation has enabled to elaborate the design solutions for ineffective purification installations of different designs.

The reconstruction of the standard reinforced concrete aerotanks will increase the capacity of the treatment installations in Kineshma (The Ivanovo Region) from 7,000 to 20,000 m^3/day (Fig. 11.7.). The power consumed with main mechanical equipment (circulation pumps) is 102 kW per hour while the necessary capacity of blast blowers corresponding to the new installation capacity must be 320 kW.

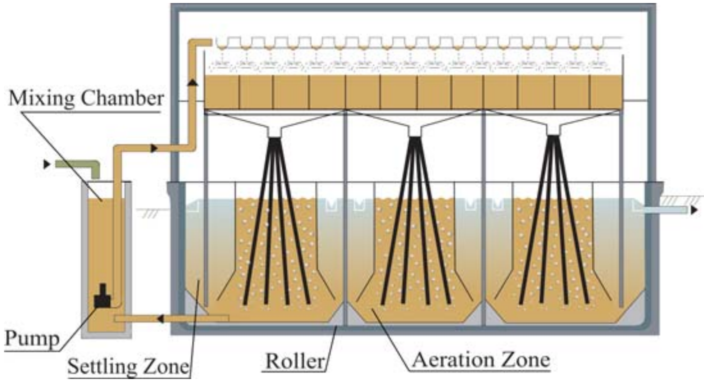


Fig. 11.7. Reconstruction of Standard Reinforced Concrete Aerotanks in CW with Increase in Capacity from 7,000 to 20,000 m^3/day.

The reconstruction of the high-rate biofilters of the purification installations in Starodub has enabled to increase the sewage treatment installations capacity from 1,500 to 6,000 m^3/day (Fig. 11.8., 11.9.).

Settlers, contact reservoirs, sewage pumping stations may be used for reconstruction of sewage purification installations.

The reconstruction plan of the 9 m pumping station in Barnaul envisages the construction of the relift station and biological purification of 200 m^3/day of sewage with integrated treatment.

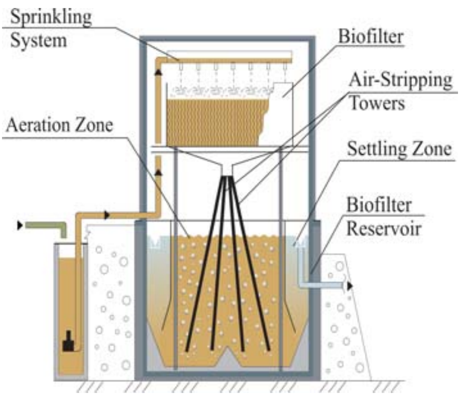


Fig. 11.8. Reconstruction of High-Rate Biofilters in CW with Increase of Capacity from 1,500 to 6,000 m^3/day

Fig. 11.9. Reconstruction of Sewage Treatment Installations in the city of Starodub

11.3. CW Utilization for Purification of Concentrated and Strong Sewage

The CW may ensure the 97 – 99 % purification efficiency, when the BOD_{comp} organic substances concentration is less than 1,000 mg/dm^3 and the suspended substances concentration is less than 400 mg/dm^3. It is economically feasible to use the CW for purification of concentrated and strong wastewater (1,000 to 50,000 mgO_2/dm^3) from food, chemical and pharmaceutical production in multi-stage purification schemes.

In order to diminish the size of biological purification installations it is expedient to use biocoagulation. That is why it has become necessary to determine experimentally the efficiency of the biocoagulation with aeration process while treating concentrated wastewater from sugar refineries. The laboratory research with actual wastewater has been made thereto /50/. The results analysis has established that the necessary period of aeration and sludge contact with sewage is 7-10 minutes, the optimal sludge dose being 400 mg/dm^3. When active sludge is available, aeration intensifies the decrease of the organic pollutants concentration considerably. For example, when COD_{prim} is 1,600 mg/dm^3, the purification efficiency is 36 %, when biocoagulation without aeration is applied – 49 %, when aeration is accomplished, active sludge being available, the purification efficiency increases to 60%. However, the efficiency of decrease of the organic pollutants concentration is to a considerable extent determined with the organic pollutants concentration in the primary sewage. Thus, when COD_{prim} is 4,000 mg/dm^3, the purification efficiency decreases to 25%, when the organic pollutants concentration is COD_{prim} 8,000 – 10,000 mg/dm^3, the purification efficiency is 4 – 11 % (Fig. 11.10). The results of experiments in intensifying the degree of purification from organic substances at the organic pollutants concentration of more than 4,000 mg/dm^3 (retreatment with sludge during sewage aeration, centrifugal purification, application of flocculants, treatment with high sludge doses of 4 – 10 g/l) have proved the purification efficiency to reach 35 %. The results analysis of the suspended substances removal has shown the removal efficiency not to exceed 70 %, 40-50 % mainly. Thus, biocoagulators have been included into the process flow scheme based on the laboratory research results.

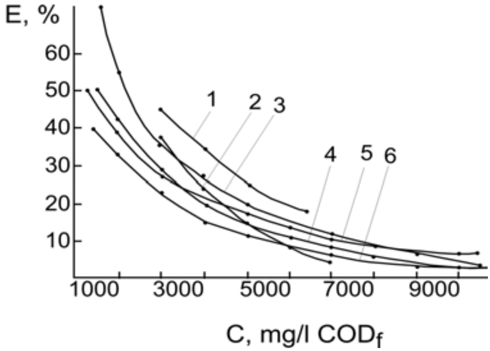


Fig. 11.10. Sewage Purification Efficiency Relationship (Influence of Different Methods of Sewage Preliminary Treatment on Efficiency of Organic Pollutants Concentration Decrease).

1 – Aeration with Active Sludge and Flocculant VPK-402; *2* – Aeration with VPK-402; *3* – 2-Stage Aeration with Active Sludge at Stage II; *4* – Biocoagulation; *5* – Aeration with Active Sludge; *6* – Aeration (with Active Sludge Dose of 400 mg/dm^3, VPK-402 Dose of 4 mg/dm^3).

For purification of concentrated sewage the process flow scheme is recommended that is accomplished at the following installations (Fig. 11.11).

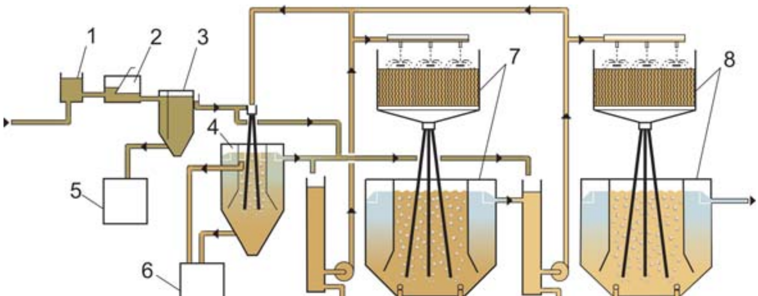


Fig. 11.11. Process Flow Scheme of Concentrated Sewage Treatment: Receiving Chamber (*1*); Fine Mechanical Purification Grids (*2*); Sand Catcher (*3*); Biocoagulator (*4*); Installation for Sand Dewatering (*5*); Installation for Sediment Treatment (*6*); Combined Works of Purification Stage I (*7*) Combined Works of Purification Stage II (*8*).

The primary sewage is driven to the fine mechanical purification grids with 2 mm mesh where suspended solids are entrapped. After the grids the sewage is purified from sand and other heavy fractions at the vertical sand catcher. The entrapped sand is pumped with the sand pump to be dewatered. In the biocoagulators superfine mineral and organic pollutants are removed from sewage, as well as some part of dissolved organic substances due to sorption and biocoagulation with excessive active sludge coming from the CW of the purification stage II. The BOD_{comp} purification efficiency of biocoagulators reaches 20 –30 %, the suspended substances concentration reaches 60 – 70 % /50/.

The present process flow scheme is realized at the sewage purification installations in v. Dolgiye Budy (The Kursk Region).

When the fats concentration in sewage is more than 100 mg/dm^3, it must be decreased. If the fats concentration does not exceed 200 mg/dm^3, they are removed directly in the biocoagulator. The fat is separated due to flotation, with the air delivered with the dispersants (pipes covered with artificial materials) and with the air from water-jet aerators. The reagents promote the flotation process. Aeration is envisaged in the flocculation chamber thereto; aeration intensifies the separation of the dispersion medium and dispersion phase; the fat particles adsorbed with the air bubbles float to the surface and form flotation foam. The waves from the water-jet ejector forming in the center of the chamber throw the flotation foam towards the collecting chute. In the collecting chute the foam is suppressed; the liquid containing fat is removed through the discharge pipe. When the fat concentration in sewage exceeds 200 mg/dm^3, it is removed in a separate fat catcher or flotator.

After the biocoagulator sewage is driven to the CW of the purification stage I where at high organic sludge loads (0,6 - 0,8 kg BOD_{comp} per 1 kg of ash-free sludge matter per day) incomplete biological purification is accomplished (the efficiency being BOD_{comp} 60-80%, suspended substances 70-90 %). Then the sewage is subject to complete biological purification at the CW of the purification stage II at low organic sludge loads (0,05-0,1 kg BOD_{comp} per 1 kg of ash-free sludge matter per day). At this CW stage the BOD_{comp} and the suspended substances concentration in purified sewage do not exceed 10 mg/dm^3. The excessive sludge with high sorption activity is drawn to the biocoagulators to raise the efficiency of the primary sewage clarification.

The process flow scheme presupposes the possibility of delivering some part of sewage after the biocoagulator to the CW of the purification stage II and delivery of excessive sludge from the CW of the purification stage I to the biocoagulators.

Power consumption for this process flow scheme makes 0,3 - 0,5 kW/kg BOD_{comp}.

When the CW is used for purification of strong sewage (BOD_{comp} is more than 5,000 mg/dm^3) it is expedient to include into the process flow scheme the anaerobic UASB-reactors after the fine mechanical purification grids (Fig. 11.12.).

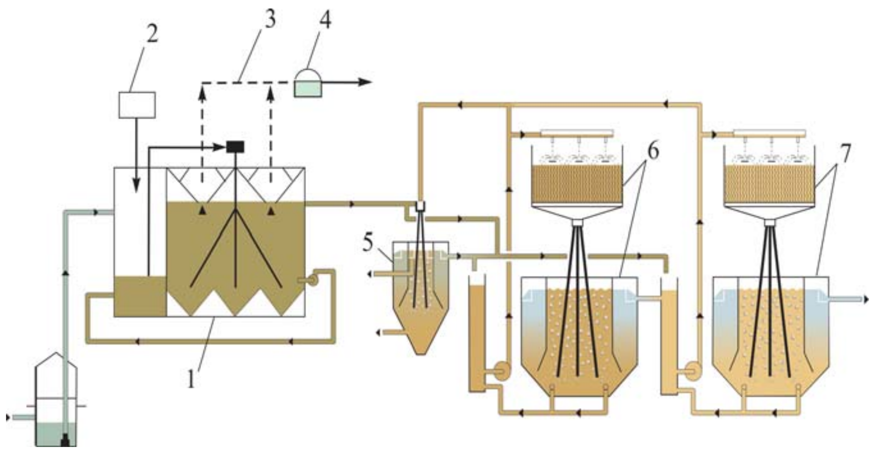


Fig. 11.12. Technology of Strong Sewage Purification at CW with UASB–Reactors

Then the sewage is driven to the biocoagulator and the CW of the purification stages I and II.

Power consumption for this process flow scheme make 0,15-0,2 kW/kg BOD_{comp}.

11.4. Automation of Sewage Treatment Process

The high possibility of the operating personnel contamination with pathogenic microflora while contacting sewage and air at sewage purification installations presupposes the necessity of the maximum degree of automation of the sewage purification installations operation.

The solution of this problem is inseparably connected with a wide range of theoretical and experimental works on the discrete law of the technological objects management and on its practical application on the modern element base.

For 5 to 100 m^3/day sewage purification installations it is expedient to utilize the small local control systems, their main advantages being low costs and high speed.

The local control systems have very good stability as regards the external disturbing factors, the application of optimal regulation laws received by means of the frequency synthesis enables to eliminate the static management errors completely, thus improving drastically the system's dynamic characteristics and decreases the power consumption. The local control system is represented in Fig. 11.13 at the following block diagram.

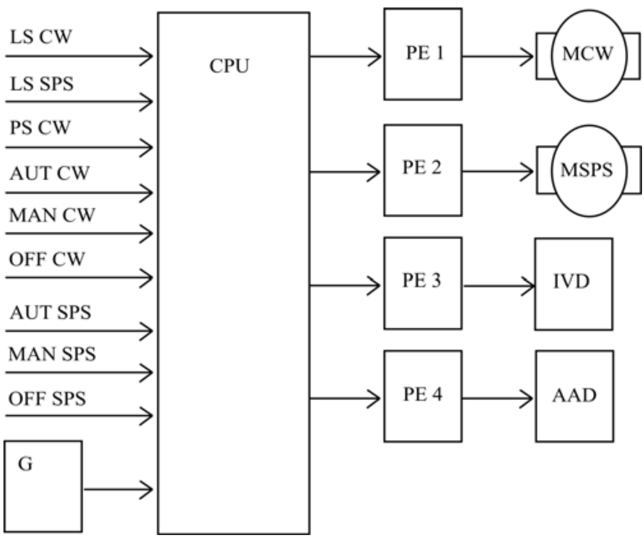


Fig. 11.13. Local Control System for Circulation Pumps of Mixing Chamber and Sewage Pumping Station:

LS CW – the level sensor of the CW mixing chamber; LS SPS – the level sensor of the sewage pumping station delivering sewage to the CW; PS – the pressure sensor of the mixing chamber; AUT, MAN, OFF – the junctions of the keyboard of operation modes connected with the CW and SPS actuated equipment; G – the clock oscillator; PE 1-4 – port expander; MCW, MSPS – pumps; IVD – the information viewing device; AAD – the acoustic alarm device; CPU – the controller.

The structure diagram of the local control system represented in Fig. 11.13 is a microprocessor-based system. The realized operation algorithm enables to control the actuated units on-line. The ultrasonic converters are used as the liquid level sensors – the sensors of the source information. They are chosen because of their high reliability. They are self-cleaning in their essence and do not require special maintenance. It is sufficient to install only one sensor per reservoir to control the liquid level. The local control panel is equipped with a convenient keyboard, a light-emitting diode display – the IVD, which does not only monitor the process flow but gives error messages as well. It permits switching of the actuated equipment depending on the established operation regulations and in case of deviations, a corresponding acoustic signal warns the operator about the emergency in the process flow.

The local control systems have been used at the sewage purification installations of the "Novorosmetal" plant, the recreation centre of the National Bank of Ossetia, the Rehabilitation, instruction and recreation centre for the RF citizens working on the "Baykonur" complex objects in the Istra

District of the Moscow region, etc.

The local system may be used at the purification stations with the capacity up to 500 m^3/day.

Into the process flow scheme of the 700 – 100,000 m^3/day sewage purification installations the fine purification devices are included – sand catchers; for tertiary treatment denitrificators and bioreactors are included; for sediment treatment the installations of mechanical dewatering are included.

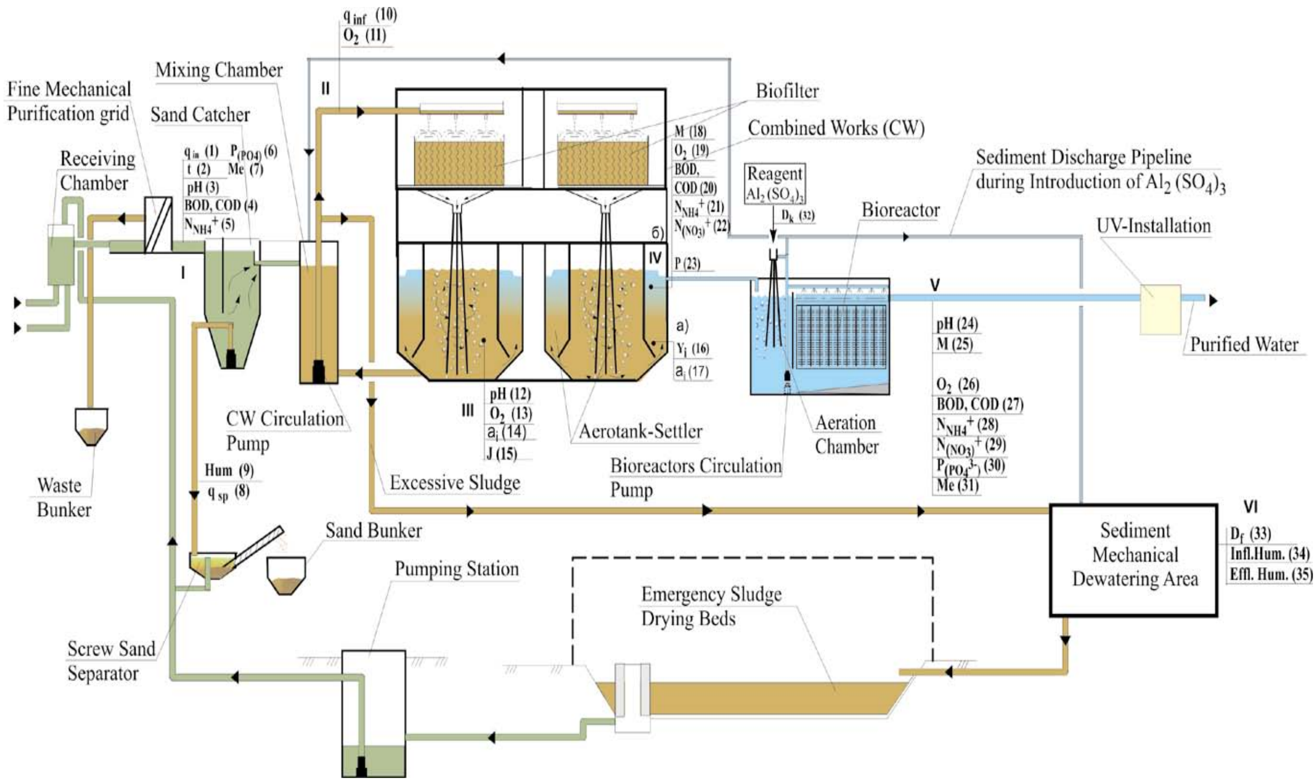
The CW design, the adopted engineering solutions and technologies for mechanical purification and integrated treatment enable complete automation of the operation process of the given elements. People may appear in the rooms where mechanical and biological purification progresses in connection with preventive inspection and repair only. As the process of the sediment dewatering is very difficult to automate, the rooms of the sediment mechanical treatment area and the reagent equipment must be separated hermetically from the above-mentioned rooms.

The operation principle of the sewage purification installations with the CW enables to create uniform diagnostics and operation process control systems. The ACS formation experience in Russia and other countries enables to make the conclusion about the necessity of stage-by-stage introduction of the following two subsystems of the operation process control for sewage purification installations corresponding to the first and second levels of automation and control.

The first level. The diagnostics and control subsystem is created for determination of quantitative characteristics of the unregulated parameters; for control and maintenance of the regulated parameters of the operation process within the set limits.

The second level. The follow-up control systems are created for control of the operation process parameters according to the set standard transfer characteristics of the observed output parameters.

The first level is based on application of the APCS of the separate areas of the operation process supporting the following single process parameters on the set level: the circulating flow of the sludge mixture, sediment discharge from the sand catchers, the removal of the excessive sludge mode, the bioreactors regeneration mode, the oxygen concentration in the sludge mixture, pH, the liquid temperatures, and other parameters. The ACS of separate areas are created thereto: of the fine mechanical purification grids, sand catchers, CW circulation pumps, denitrificators, bioreactors, the sediment mechanical dewatering area, etc. (Fig. 11.14).



Fine Mechanical Purification grid
Receiving Chamber
Mixing Chamber
Sand Catcher
q in (1) t (2) pH (3) BOD, COD (4) NNH4+ (5)
P(PO4) (6) Me (7)
I
II
q inf (10) O2 (11)
Biofilter
Combined Works (CW)
M (18) O2 (19) BOD, COD (20) NNH4+ (21) N(NO3)+ (22)
P (23)
IV
б)
а)
Yi (16) ai (17)
III
pH (12) O2 (13) ai (14) J (15)
Aerotank-Settler
Reagent Al2 (SO4)3
Dk (32)
Bioreactor
Sediment Discharge Pipeline during Introduction of Al2 (SO4)3
UV-Installation
V
Purified Water
pH (24) M (25)
O2 (26) BOD, COD (27) NNH4+ (28) N(NO3)+ (29) P(PO43-) (30) Me (31)
Aeration Chamber
Bioreactors Circulation Pump
CW Circulation Pump
Hum (9) q sp (8)
Excessive Sludge
Waste Bunker
Sand Bunker
Pumping Station
Screw Sand Separator
Emergency Sludge Drying Beds
Sediment Mechanical Dewatering Area
VI
Df (33) Infl.Hum. (34) Effl. Hum. (35)

Fig. 11.14

This ACS level is thus intended for control of operation of several operation process objects (pumps, valves). On the first level the on-off law of objects management and source information acquisition is used.

The ACS second level comprises the follow-up control systems intended for stabilization and control of all operation processes, in other words, for control of all ACS of the separate areas of the operation process. Thereto the operator and the WKS (the automated working station) are introduced into the controls; they are connected with the operator stations and corresponding computer programmes. The above-mentioned subsystems constitute a man-and-machine system, in which the operator first preprocesses with a computer the technological information of the first level (the data on the controlled parameters of the separate areas of the operation process), then based on the computer recommendations on the optimal parameters of the sewage purification process the operator controls the process with different hardware of the first level.

An example of the first and second automation level operation: determination of the dissolved oxygen concentration in the aeration zone of the CW aerotank-settler (and its comparison to the design parameter) enables to regulate the circulating ratio of the sludge mixture by means of controlling the rotation frequency of the electric motor or the rate of the gate opening, which is in its turn automated. The rate of the gate opening for the discharge pipe for excessive sludge removal from the system is regulated according to the determined humidity of the sludge mixture in the settling zone compared to the design parameter.

The general functional organization of the APCS for sewage purification is given in Fig. 11.15.

The first subsystem of the CW biological purification process is the most interesting one as regards the process technology automation. Its possible option is represented in Fig. 11.16.

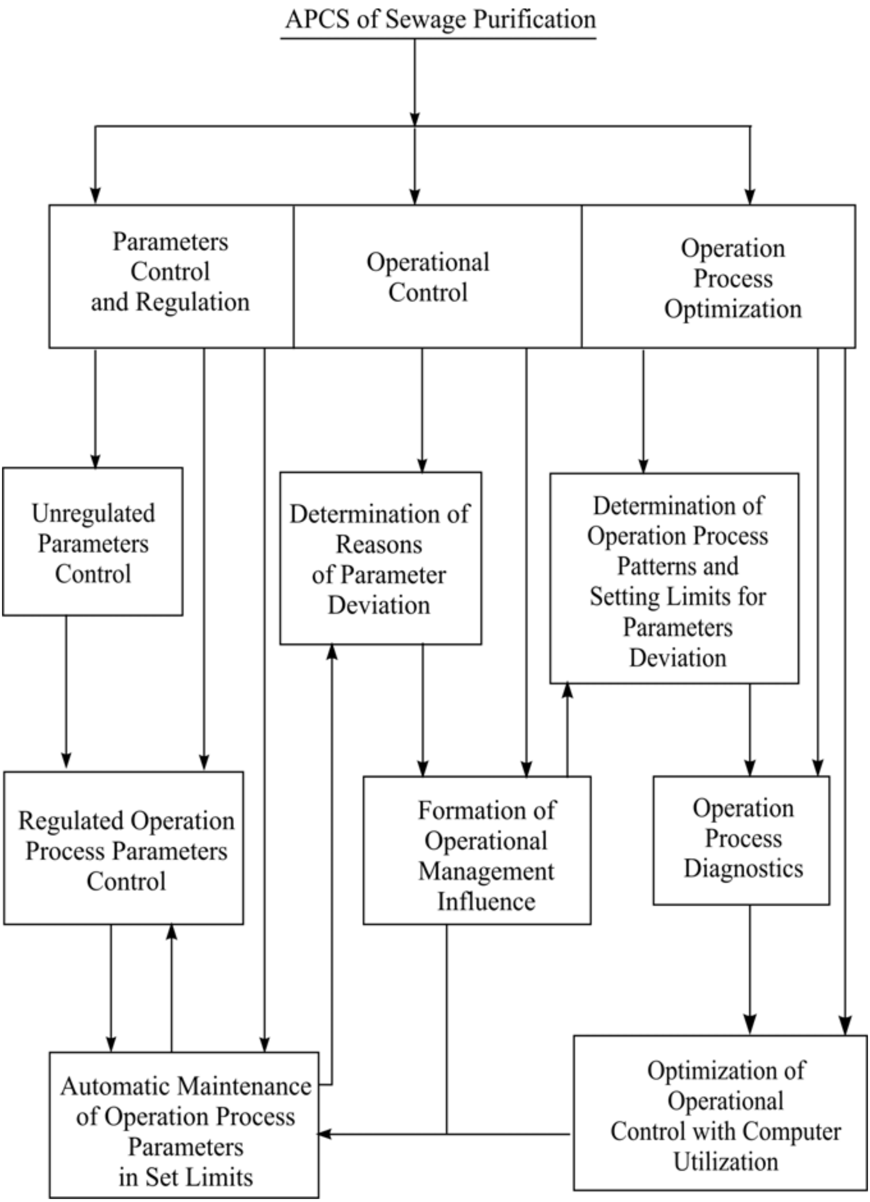


Fig.11.15 – Flow Diagram of Automated Process Control System of Sewage Purification

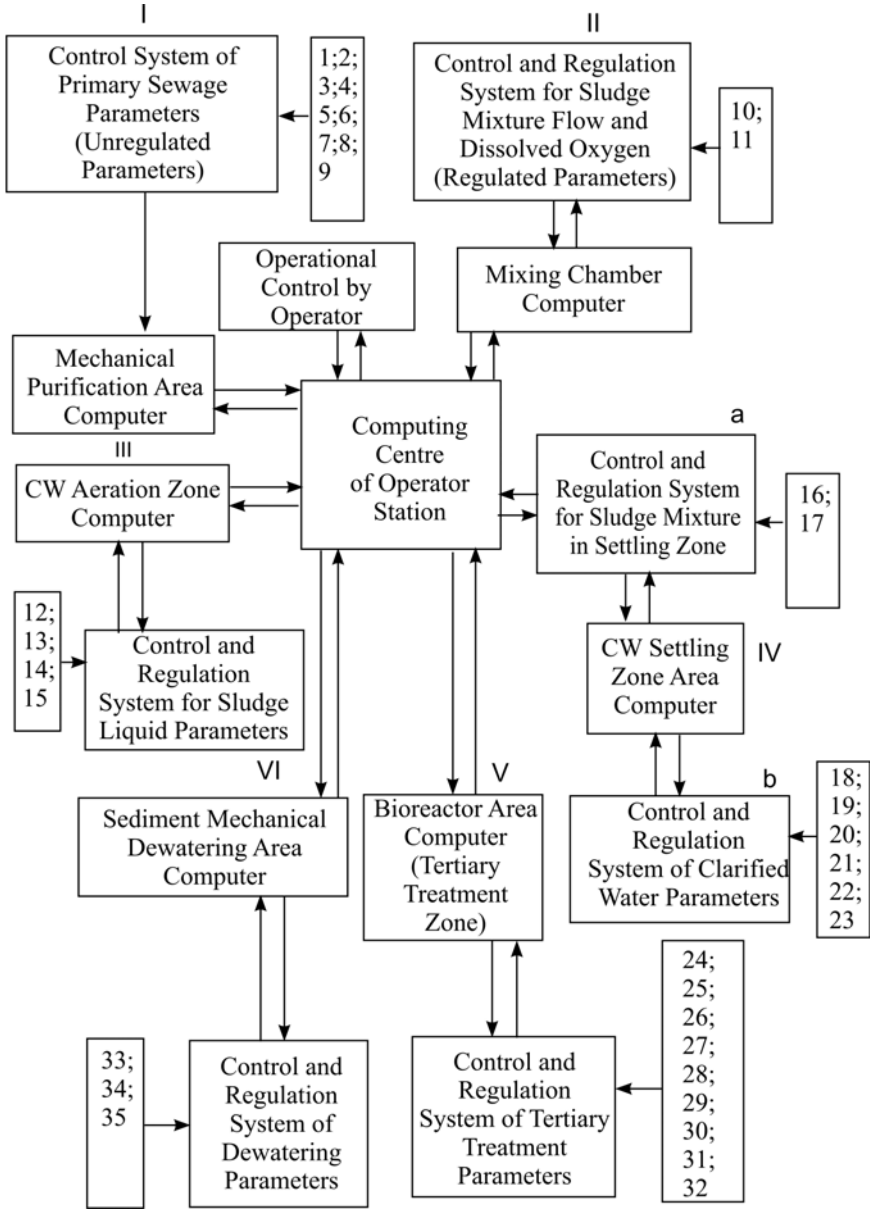


Fig. 11.16 – Flow Diagram of Automated Control System of First Subsystem of CW Biological Purification:

1, 8, 10 – rate-of-flow meters for the primary sewage; sand pulp; and circulating sludge mixture correspondingly;

2 – temperature gauge;

3, 12, 24 – pH gauge for the primary sewage; sludge mixture in the CW aeration zone; sewage after the tertiary treatment bioreactor;

4, 20, 27 – sensors for the oxygen consumption rate in the primary sewage; clarified sewage; sewage after tertiary treatment correspondingly;

5, 2, 28 – sensors for the ammonium nitrogen concentration: in the primary sewage; clarified sewage; sewage after tertiary treatment correspondingly;

6, 23, 30 – sensors for the phosphorus (phosphates) concentration in the primary sewage; clarified sewage; sewage after tertiary treatment correspondingly;

7, 31 – sensors for the metals concentration in the primary sewage and sewage after tertiary treatment correspondingly;

9, 34, 35 – sensors for determination of humidity of: the sediment after the sand catcher; the sediment drawn to dewatering; the cake correspondingly;

11, 13, 19, 26 – sensors for the dissolved oxygen concentration in: the circulating sludge mixture; sludge mixture in the CW aeration zone; clarified sewage; sewage after tertiary treatment;

14, 17 – sensors for the active sludge concentration in: the aeration zone and the active sludge settling zone;

15 – sensor for the sludge index in the aeration zone;

16 – sensor for the level of the settled sludge;

18, 25 – sensors for turbidity of the clarified sewage; sewage after tertiary treatment;

22, 29 – sensors for the nitrate nitrogen concentration in: the clarified sewage; sewage after tertiary treatment correspondingly;

32, 33 – dispensers for the phosphates removal coagulant and for the flocculant for intensification of the sediment dewatering correspondingly.

Analyzing the above-mentioned variants of automation of the sewage purification process we come to the following conclusions: a global expert control system can help to improve drastically the main output quality parameters of the automated regulation system, to which we can refer the system transient time, the value of the first dynamic override or overcorrection due to introduction of multiloop feedback into the system.

Visualization of the sewage purification process will enable the operating personnel to choose and adopt solutions offered with the expert system. It will enable to eliminate unqualified intervention into the sewage purification operation process. Only high costs may be considered to be the system drawback.

The third level of control is the expert system of evaluation and analysis of the condition of the sewage purification operation process and actuated equipment. The expert system enables to accomplish diagnostics of the condition of the local automation levels and variants of correction of the actuated equipment operation by means of formation of master controls for local control systems. The present system presupposes the realization of the principle of the open dialogue of the operator and the global control system. The expert system is based on the principle of application of synthesized laws of discrete systems management.

The qualitative leap in the area of household sewage purification can be ensured exclusively with modern highly efficient microprocessor-based systems that may enable to increase drastically the system efficiency and reliability, to reduce the number of the operating personnel. One of the important advantages of the microprocessor-based systems is their flexibility, as their operation logic is determined with the programme stored in ROM or RAM.

Chapter 12. START-UP AND ADJUSTMENT OF SEWAGE PURIFICATION INSTALLATIONS

12.1. Start-Up and Adjustment of Biological Purification Installations

The start-up and adjustment periods determine to a great extent the efficiency of the further operation of the purification installations, as it is at these two stages that the active sludge forms, optimal purification process modes are determined, the operating personnel develops the professional skills of the operation process management.

The start-up works require the comprehensive preparation. By the moment the purification installation is put into operation and by the moment of the test start accomplished with clean water, it is necessary to train the operating personnel during the probation period at the existing purification installations, of the similar type preferably. It is also necessary to conduct the specific preliminary instruction of the personnel of the chemical and microbiological laboratories that should master the set of the analytic methods of the installations operation control. The personnel must also be trained in safety rules and industrial sanitation rules.

The most critical and labour-intensive part of the start-up period is accumulation of the active sludge and, which is more important, its adaptation to the specific pollutants typical for the wastewater of the given enterprise.

The active sludge may be accumulated in the following conditions:

a) the purification installations operate nearby treating wastewater similar in its composition;

b) the sewage contains the specific microflora;

c) there are no purification installations nearby treating similar industrial wastewater that contains no specific microflora.

In the first case, the excessive active sludge is delivered to the CW from the final settlers of the existing purification installations. The active sludge is transported with the corresponding vehicles, with tank-trucks, for example. First of all, nearly all amount of the transported active sludge forms the immobilized microflora in the biofilters and only later the sludge flakes appear in the aerotanks. The initial sludge concentration is assumed to be within the limits of 0,2—0,3 g/dm^3. Then the CW starts to operate on the sewage flow with the 10-15% of the design load. When the active sludge concentration reaches 2,5—3,5 g/dm^3, the CW load is increased to the design parameters and the stability of all parameters on the level envisaged with the technological regulations for this type of installations is ensured.

If the industrial wastewater contains the specific microflora, the mixed flow is prepared according to the parameters envisaged with the technological regulations for the CW operation with the design load.

Household sewage may also be used for active sludge formation. In this case, the sewage is circulated in the CW that operates under the load of not more than 50 % of the design one. Then, after the sewage flow has been stopped, the circulation goes on; the ammonium nitrogen removal and the nitrates formation (if the CW operates with nitrification), as well as dissolved oxygen concentration is observed continuously. Simultaneously, during settling the appearance of the typical flakes of quickly sedimentating sludge is observed. Then the sewage flow is resumed and the load is increased until it reaches the design values.

If the CW ensures the incomplete purification, the active sludge is received by the above-mentioned method, but the load is increased not based on the nitrates amount that are not available in the purified sewage during incomplete purification, but based on the BOD_5 value of the water discharged from the given CW settling zone.

During the start-up period, it is possible to start the CW with the small load. After the steady results of the flow purification have been achieved, the load is increased gradually until it reaches the design value.

It is also possible to utilize the thermally dried active sludge to intensify its accumulation.

The important stage of the start-up period is the active sludge microflora adaptation to the specific pollutants of all types of sewage that are to be treated at the given purification installations. The microflora must be adapted preliminarily, before the industrial wastewater is delivered to the purification installations. The preliminary adaptation of the active sludge microflora to the specific sewage components enables to reduce the development period and to create conditions for the CW non-failure operation under the full load since the industrial wastewater has been received.

In these conditions, the quick achievement of the design capacity and stability of the purified sewage quality is ensured. The adaptation may be realized with several methods, with modal flow delivery mainly. Thereto the specific pollutants (subquality chemical products, concentrated wastewater from similar enterprises transported in tank-trucks or tank-wagons, etc. may be used) are added into the household sewage that has been mechanically purified. The specific pollutants are dosed from the special reservoirs and their amount is corrected depending on the received load. The load is determined according to the biochemical properties of the pollutants and their assimilability with the saprophytic microflora, but it must make not less than 50 % of the allowable load.

The industrial wastewater is dosed in the same way, if it is used for the active sludge adaptation. The lower loads have proved during observations to be unpractical, as the active sludge microflora assimilates the specific pollutants in insignificant quantities, if they are delivered in the minimum amounts (in other words, together with household sewage). The competing role of the organic pollutant components of household sewage is enhanced, they serve as the main nutritious substratum, and consequently, there is no directed transformation of the bacteria biochemical properties.

In these conditions the specific microflora of the active sludge cannot form, as it is grown by means of the directed variability method with the final result of the set biochemical properties formation, and, which is more important, in the artificial living conditions there forms the bacterial population capable to increase the specific rates of the biochemical oxidation of the specific substratum. According to the laws of the fermentative catalysis, the oxidation rate of the substratum depends on its initial concentration originally. The initial active sludge adaptation to the specific sewage components must be based on this very principle. It may be adapted consecutively or comprehensively, depending on the chemical production requirements. In most cases, the consecutive adaptation to every sewage category is determined with the production needs and is envisaged with the start-up schedule for the main technological production types of the chemical enterprise.

The main parameters of formation of the specific microflora of the active sludge during the start-up period are the optimal loads criterion and the criterion of the complete stability of all technological and analytical parameters of the biochemical oxidation.

The CW start-up operation mode with minimum loads, not exceeding the 50 % of the design parameters in other words, leads to low purification efficiency, as in these conditions there forms the active sludge ecosystem with eventual microbial populations; they preserve the main metabolism type peculiar to them in natural conditions. Such adjustment of the purification installations operation results in instability of hydrochemical parameters of the purified sewage, in channeling of enhanced pollutants concentrations in the purified water, which is difficult to explain on the face of it.

The well-established process of adaptation of the active sludge, described above, is the basis for the active sludge microflora formation, which governs the high biochemical oxidation rates for specific substrata.

Continuous receiving of the industrial wastewater at the start-up moment is the important final stage of the start-up period of the purification installations operation. It is important to maintain the achieved level of the active sludge loads in this period. The possibility of forced starvation of sludge, which is possible in the start-up period, must be prevented.

If such situations are allowed, it may cancel all efforts on the active sludge adaptation and its specific microflora formation. The forced starvation of the active sludge has been observed not only to decrease the bacteria oxidizing capacity, but to change its physical properties as well. Large amounts of active sludge are withdrawn with the purified sewage, as the starving sludge floats in the settling zone.

It is also important to prevent sudden fluctuations in the pollutants concentrations in the treated sewage and volley discharges of sewage with enhanced pollutants concentrations. If such situations occur regularly enough, the active sludge may degenerate and masses of the bacteria filamentous forms will develop.

During the start-up and adjustment period, the composition and amount of the forming sewage may be subject to sudden fluctuations. The operating personnel task consists in correct receiving, mixing and neutralizing of the sewage, as well as in the sewage flow correction before it is delivered to the CW, if necessary. The regular analytical control is necessary, which determines the dichromate oxidability, pH, the nitrogen compounds and specific components concentration.

Thus, the comprehensive technological measures aimed at the purification installations start-up and the active sludge adaptation to the industrial wastewater components enable to form the specific microflora of the active sludge with high oxidizing capacity, as regards the sewage ingredients of the given enterprise. It will serve the basis for the effective operation of the purification installations and achievement of their design capacity.

12.2. Process Inspection during Start-up and Adjustment Period of Purification Installations Operation

The process control in the start-up and adjustment period enables to provide the operating personnel with timely and reliable information, sufficient for taking necessary decisions on the purification installations control.

The purification installations control is based on determination of such operation process parameters as the flows, temperature of all types of sewage, pollutants concentrations, physicochemical and sanitary characteristics of purified sewage, aeration period, active sludge concentration and amount of oxygen in the aeration zones.

The values of technological parameters (flows, temperature, pH, concentrations, etc.) may be determined with the corresponding devices and appliances, as well as a result of calculations (determination of the aeration duration, active sludge load, installation oxidizing capacity, etc.).

The time of the treated liquid passing through the purification installation must be taken into account during the process control.

In order to ensure the sewage purification process control, in the definite points the samples of water, sludge mixture and purified sewage are taken regularly. The location of the sampling points depends on the purification installations scheme and their design.

However, in any case the sampling points are defined in such a way so as the operating personnel may receive the information about the type, composition and quantity of the primary sewage, the quality characteristics of the purified sewage, the conditions of the biochemical oxidation of pollutants in the CW and bioreactors.

When the samples are analyzed, the physical, chemical and bacteriological parameters are determined that will enable the technologist to take the necessary decisions on the biological purification operation process. The parameters lists are determined first of all with the sample characteristics and the operation conditions of the purification installations. During the start-up and adjustment works separate elements of the APCS are approbated and regulated in different operation modes of the purification installations.

REFERENCES

1. Water Supply and Water Disposal. External Networks and Installations. Reference Manual ed. by B. Repin. Moscow, Vysshaya Shkola, 1995. p. 431.
2. E. Golubovskaya. Microorganisms of Purification Installations. Leningrad, LUACE, 1985. p.74.
3. M. Gladchenko. Elaboration of Biotechnological Methods of Utilization of Viniculture Waste. Cand. Sc. Thesis. Moscow, 2001. p.146.
4. G. Zavarzin. Trophic Bonds in a Methanogenic Population.//Proceedings of the USSR Academy of Sciences, Biology Series, 1986. No. 3. pp. 341 – 360.
5. Ya. Karelin, D. Zhukov, V. Zhurov, B.Repin. Purification of Industrial Wastewater in Aerotanks. Moscow, Stroyizdat, 1978. p.222.
6. Intensification of Thermophilic Methane Fermentation in Production of B12 Fodder Concentrate//A. Babayants at al. Applied Biochemistry and Microbiology, 1976. No. 12, pp. 259 – 264.
7. T. Karyukhina, I. Churbanova. Water Quality Control. – 2nd Ed. Moscow, Stroyizdat, 1986. – p.158.
8. S. Kalyuzhnyi, D. Danilovich, A. Nozhevnikova. Anaerobic Biological Purification of Sewage//Science and Technology Results. Biotechnology Ser. Moscow, VINITI, 1991. Vol. 29. p.155.
9. S. Kalyuzhnyi, A. Puzankov, S. Varfolomeev. Biogas. Problems and Solutions//Science and Technology Results. Biotechnology Ser. Moscow, VINITI, 1988. Vol.21, p.176.
10. G. Lutsenko, A. Tsvetkova, I. Sverdlov. Physicochemical Purification of City Sewage. Moscow, Stroyizdat, 1984. p. 88.
11. Microbiology/M. Gussev, L. Mineeva. Moscow, the Publishing House of the Moscow University, 1985. p.376.
12. Microbiology of Water Purification/M. Rotmistrov, P. Gvozdik, S. Stavskaya. Kiev, Naukova Dumka, 1978. p.298.
13. M. Mcinerny, M. Briant. Main Principles of Anaerobic Methanogenic Fermentation//Biomass as Energy Source. Moscow, Mir, 1985. pp. 247 – 265.
14. D. Orlov. Soils Chemistry. Moscow, the Publishing House of the Moscow University, 1985. p.376.
15. A. Nozhevnikova. Anaerobic Bacteria Growth in Methanogenic Associations and Mixed Cultures// Science and Technology Results.

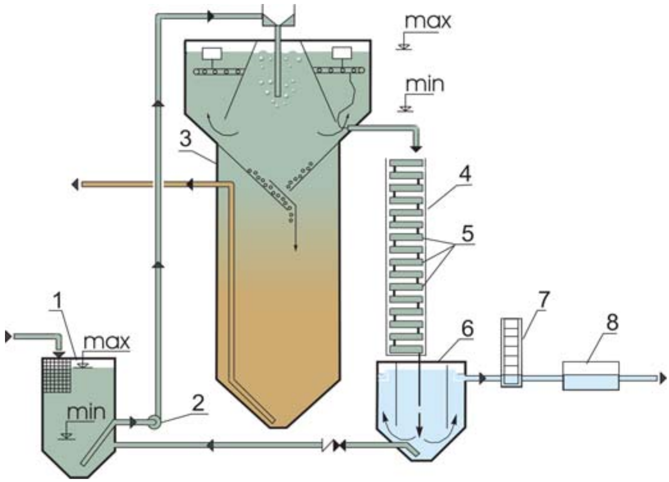
Microbiology Ser., Moscow, VINITI, 1991. p.56.
16. Handbook on Modern Purification Techniques and Equipment for Natural Water and Sewage. Danish Cooperation for Environment in Eastern Europe in Cooperation with Ministry of Natural Reserves of RF and Federal Ecological Fund of RF, 2001. p.254.
17. Construction Norms and Regulations 2.04.03-85 Construction Norms and Regulations. Sewage. External Networks and Installations, Moscow CPTP, 1986. p. 72.
18. G. Shlegel. General Microbiology, Moscow, Mir, 1972. p. 476.
19. S. Shifrin, B. Mishukov, Yu. Feofanov. Calculation of Parameters for Biochemical Purification Installations for Municipal and Industrial Sewage/ /Manual for Students of Speciality 1217 – "Purification Technology for Natural Water and Sewage" and Speciality 1209 – "Water Supply and Sewage", Leningrad, LUACE, 1977. p.71.
20. Chan Din Toay, M. Khludova et al. Methane Biogenesis// Science and Technology Results. Biotechnology Ser., 1983. Vol. 1. pp. 151 – 194.
21. S. Yakovlev, T. Karyukhina. Biological Processes in Sewage Purification, Moscow, Stroyizdat, 1981, p. 200.
22. V. Proskuryakov, L. Schmidt. Sewage Purification in Chemical Industry, Leningrad, Khimiya, 1977, p. 464.
23. S.Yakovlev, Yu. Voronov. Water Disposal and Sewage Purification/ Manual for Higher Educational Establishments: Moscow, ASV, 2002. p.704.
24. S. Yakovlev, Yu. Voronov. Biological Filters. Moscow, Stroyizdat, 1982.
25. V. Kolesnikov. Patent SU 1020379 (Installation for Sewage Biochemical Purification) C02 F3/02 30.05.83. Bull. No. 20.
26. V. Kolesnikov, V. Gordeev-Gavrikov. Patent SU 1533239. Installation for Sewage Biochemical Purification. C02 F3/02 06.10.87. Bull. No. 22.
27. V. Kolesnikov Patent SU 1761688. Installation for Sewage Biochemical Purification. C02 F3/02 15.09.92. Bull. No. 34.
28. V. Kolesnikov, E. Vilson, L. Chernikova, V. Vavilin. Paper title: A Novel Combined Reactor (biofilter up and aeration/sedimentation chambers down) for Treatment of Sewage and Agricultural Association. Paper Reference No. Np004b.
29. V. Kolesnikov, E. Vilson, V. Vavilin, N. Kolesnikova. Paper title: Effective Sewage Treatment In Combined Reactor. Berlin World Water Congress. Paper Reference No. P 2117.
30. D. Tsiklauri. Hydraulic Compressors. Moscow, Stroyizdat.

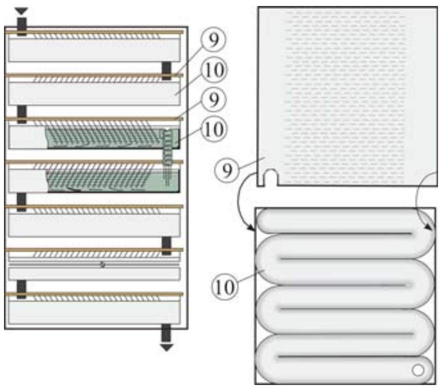
31. M. Alexeev. Theoretical Research on Amount of Air in Free-Flow Liquid Vertical Pipelines. Inter-College Subject Digest of Works, Leningrad, 1980.
32. Yagusch Leonhardt, Puschel Siegfried. Jauchstrahlheluftung – ein neicarfiges im V B Kombinat “Schwarze Pumpe” erprobtes Beluftungssystem zur biologischen Reinigung hocnhelasfeter Abwasser.
33. N. Kolesnikova. Patent RU 2220915. Installation for Sewage Biochemical Purification. C02 F3/00, 3/02, 10.01.2004. Bull. No.1.
34. Subject Report. Biological Purification Techniques at Combined Works with Biofilters and Aerotanks for Rural and Small Settlements. Ministry of Housing and Public Services of the Russian Federation, State Reg. No. 0182.8.042290.
35. V. Kolesnikov. On Utilization of Combined Works with Biofilters and Aerotanks for Sewage Purification. Proceedings of North Caucasian Research Center of Higher School. Technical Sciences. 3. 1984.
36. V. Kolesnikov. Patent SU 1761690. Biofilter Feed. C02 F3/04 15.09.92. Bull. No. 34.
37. V. Kolesnikov, V. Klimukhin. Patent RU 2116262. Biofilter Feed. C02 F3/04 27.07.98. Bull. No. 21.
38. V. Kolesnikov. Patent SU 1214608. Installation for Sewage Biochemical Purification. C02 F3/02 14.06.84. Bull. No. 22.
39. Subject Report 1.4.3.87/88. Creation and Application of Sewage Biological Purification Techniques at Combined Works in Experimental-Industrial Conditions. Ministry of Housing and Public Services of the Russian Federation, State Reg. No 0187.0085852.
40. Subject Report 1.4.1.84/86-0.64.06. Sewage Biological Purification Techniques at Combined Works with Biofilters and Aerotanks for Rural Settlements. Ministry of Housing and Public Services of the Russian Federation, State Reg. No. 0182.8.042920.
41. V. Kolesnikov, T. Koltsova, N. Nikolaenko, I. Kovarskaya, G. Rudnev. E. Stasenko. Combined Works for Sewage Biological Purification. M-ne Water Supply and Sanitary Equipment. 12.1990.
42. V. Kolesnikov, V. Klimukhin, V. Gordeev-Gavrikov. Patent RU 2139257. Purification Installation for Strong Sewage. 10.10.99. Bull. No. 28.
43. V. Kolesnikov, N. Kolesnikova, V. Klimukhin, V. Gordeev-Gavrikov. United States Patent No. US 6,217,759 B1 Apr. 17, 2001.
44. V. Kolesnikov, V. Klimukhin. Patent RU 2139257. Purification Installation for Strong Sewage. C02 F3/02 10.10.99. Bull. No. 28.

45. Subject Report 6.4.-10-160/93. Elaboration of Installation for Nitrogen and Phosphorus Compounds Removal from Purified Sewage. State Committee for Housing of the Russian Federation. All-Union Scientific and Technical Centre. Reg. No. 02.9.40 0 03204.
46. V. Kolesnikov. Patent RU 2114070. Installation for Biochemical Purification of Sewage from Organic and Nitrogen-Containing Compounds. C02 F3/02, 27.06.98. Bull. 18.
47. Woodcoc KA.H. – Sewage and industr. Wastes – 1955-V.27-No.10.
48. Blanchard D.C. – Nature, – 1955 – V.175-pp.334-336.
49. V.Kolesnikov, V. Motovilov. Patent SU 1583148. Installation for Gases Purification and Absorption. B 01 047/00. 29.02.88 (22).
50. N. Serpokrylov, E. Vilson, V. Kolesnikov, V. Seleznev, L. Kulichkova. Sewage Combined Purification Techniques. M-ne Water Supply and Sanitary Equipment.
51. V. Kolesnikov. Patent SU 1118620. Installation for Sewage Biochemical Purification. C02 F3/04. 15.10.84. Bull. No. 38.
52. V. Kolesnikov. Patent SU 1761691. Installation for Sewage Biochemical Purification. C02 F3/04. 15.09.92. Bull. No. 34.
53. V. Kolesnikov., V. Seleznev, V. Gordeev-Gavrikov, I.Ivanova, E. Vilson. Patent RU 2051131. Tower Biotank for Sewage Biochemical Purification. C02 F3/30 27.12.95. Bull. No. 36.
54. V. Utyakov, V. Kolesnikov, E. Vilson. Patent RU 2085515. Installation for Biological Purification and Nitrogen and Phosphorus Compounds Removal from Sewage. C02 F3/02 27.07.97. Bull. No. 21.
55 V. Kolesnikov, A.Mirzoyan. Patent SU 1376503. Installation for Sediment Dewatering. C02 F11/12 23.04.86 (22).

0,5 - 4 m^3/day BIOINSTALLATIONS

The installations /51, 52, 53/ are intended for biochemical purification of sewage coming from separate dwelling apartments, public buildings, farms and small enterprises with BOD concentrations lower than 300 mg/dm^3, the suspended substances concentration lower than 400 mg/dm^3.





The primary sewage and liquid with sediment from final settler *6* come to accumulator *1*, wherefrom they are regularly pumped with pump *2* to clarificator-digester-neutralizer of the flow *3*. The clarified water is uniformly discharged to tower biotank *4* with basket feed *5*. When the liquid overflows from the upper baskets to the lower ones, the organic pollutants are oxidized. The upper and lower baskets parts *9, 10* design ensures solution of the following tasks: creation of the optimal hydrodynamic mode of the liquid movement; formation of the developed surface of the flow contact with the immobilized microflora; prolongation of the flow contact with the biocenosis; dilution of the air oxygen in the liquid; removal of the mineralized biomass. From the tower biotank the water gets into *6*, wherefrom it is driven to device *7*, where it contacts the dissolving calcium hypochlorite tablets and then it is moved through catalyst case *8* to be discharged. A part of sewage and sediment from *6* flows to *1*, thus ensuring the double or triple liquid circulation and correspondingly the increase of the purification efficiency. The installation design ensures decrease of the BOD pollutants concentration to 20 – 30 mg/dm^3, the suspended substances concentration - to 15 – 20 mg/dm^3, the natural formation of the biomass in 7-10 days, maintenance of the microflora vital activities during breaks in operation up to 3 days long; reduction of the pump operation time to 3 hours per day; power consumption lower than 1 kW.hr per 1 m^3.

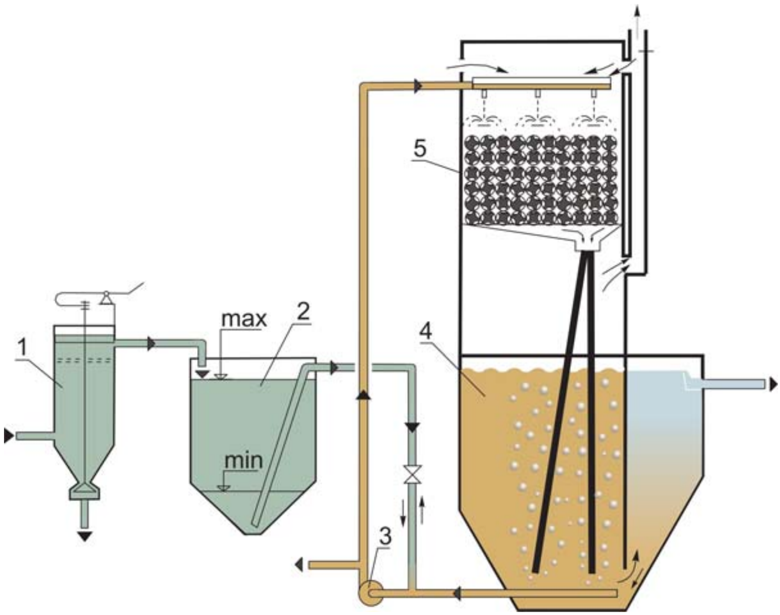
Maintenance - maintenance inspection, discharge of the fermented sediment, filling with tablets is done once in 5-10 days.

Experimental research has been made to the orders of the State Committee of Housing and Construction and Ministry of Agriculture of the RF and the 3 m^3/day biological installation has been elaborated.

We propose to those organizations that show interest and potential customers to complete the refinement (finalizing) of the installations in working conditions and to organize their wide implementation.

25-100 m^3/day INSTALLATIONS

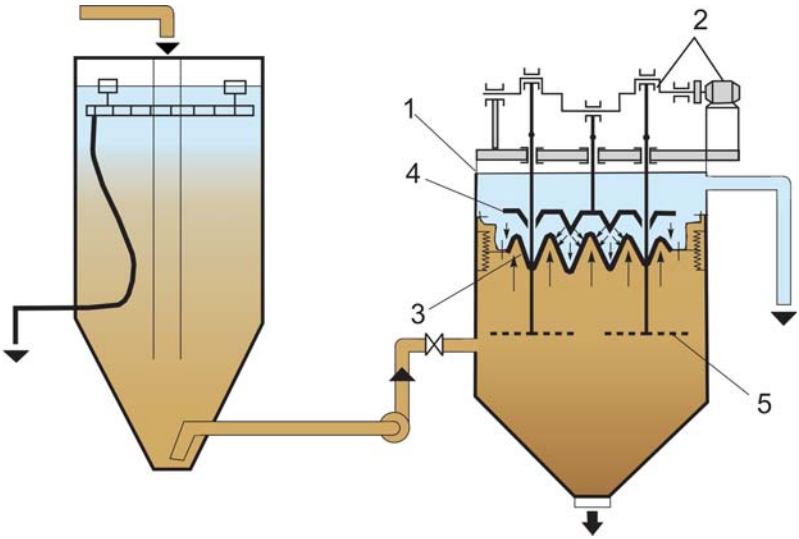
The combined works /25, 26, 53, 54/ are intended for biochemical purification of sewage from small settlements and small enterprises with the BOD pollutants concentration lower than 1,000 mg/dm^3 and the suspended substances concentration lower than 400 mg/dm^3.



The primary sewage is first discharged into the tangential sand catcher with dirt catching gauze *1* and then to mixing chamber *2*. As the water level in *2* reaches the (max) mark, pump *3* engages automatically and pumps the sewage through the siphon piping from *2* and the sludge mixture through the suction pipeline from aerotank-settler *4* simultaneously. Then the sewage and sludge mixture is discharged to biofilter *5* to be treated. The biofilter feed is made of ceramic ball-shaped elements having evenly placed recesses, which axes meet in the ball center. Irrespective of the manner the elements are laid, some part of the recesses will be filled with the sludge mixture. A longer contact between the sewage and the immobilized microflora and availability of active sludge in the feed ensure the 80-85% purification efficiency in the aerotank-settler. Oxygen is driven into the aerotank due to the air oxygen dilution during the feed sprinkling and as a result of the air entrainment (formation of vortexes) during the liquid discharge into the air-stripping towers. Oxygen is dissolved in the towers during the air bubbles floating, too. The aerotank content is mixed due to definite placement of the air-stripping towers inside the reservoir. As the sewage flow stops and the water level in *2* gets down to the (min) mark, the pump is turned off. However, the sludge mixture from aerotank-settler *4* begins to flow backwards to chamber *2* through the siphon pipeline. At night time in prearranged periods (40-60 minutes) the chamber is periodically filled with the sludge mixture and the pump engages again. The pump shutdown periods are regulated with gate *6*. When the pump does not operate during long emergency shutdown, the humidity level inside the biofilter feed is maintained due to a large number of vessels filled with liquid, thus enabling to preserve the microflora vital activity during operation shutdowns up to 2 days long. The installations provide the decrease of the BOD organic pollutants concentration from 100 – 1,000 to 7 – 20 mg/dm^3, the suspended substances concentration - from 100 – 400 to 3 – 15 mg/dm^3. The total pump working time is 16-20 hours per day, the power consumption is 0,4 – 0,6 kW.hr per 1 m^3, the labour expenditure is 2 – 3 man-hours/day.

SEDIMENT THICKENING INSTALLATIONS

The installations /55/ are intended to treat the sewage sediment produced with the 50 to 1,000 m^3/day sewage purification installations.



The sediment (excessive sludge) is pressure driven to case *1*, where the liquid from the separating sediment suspension is separated through the filtering fabric. As the filtration resistance grows, vibrodrive with a crankshaft *2* engages. The regeneration process of filtering element *3* comprises vibro-shaking of filter *3* and generation of hydraulic shocks in the liquid (filtrate) that are caused with screening plate *4* in the direction of the filtering fabric. The filtrate vibration is excited with periodical coming together and moving away of filtering element *3* and screening plate *4*; it happens during the crankshaft rotation. The screening plate valves open and close as they come close and move away from the filtering element, thus enhancing the impingement attack of the filtrate. Perforated plates *5* promote sediment thickening and discharging. The installation may be produced provided with the dehelminting equipment.

Research-and-Production Edition

Vladimir Kolesnikov
Elena Vilson

MODERN DEVELOPMENT OF OPERATION PROCESSES OF SEWAGE PURIFICATION AT COMBINED PURIFICATION INSTALLATIONS

Editor O. Zholobova
Art and Technical Editor R. Kim
Composition and Make-up O. Zholobova
Proof-Reader O. Zholobova

UYG Publishing House Ltd., Mechnikova St. 75, 344018,
Rostov-on-Don, Russia. Tel: 232-15-80, 232-16-27.
Published in ViV Ltd. Printing House, Mechnikova St. 75.