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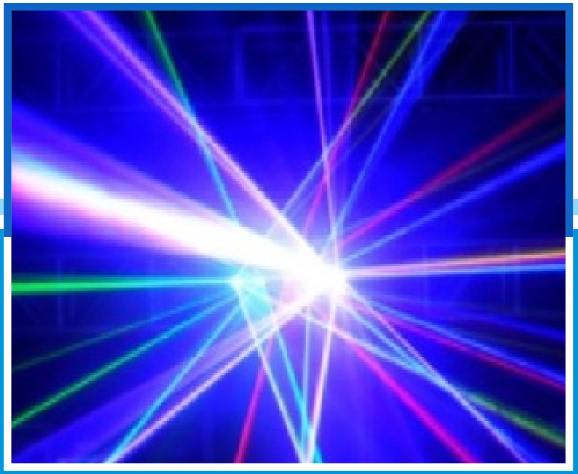

Kyzylorda-Poltava
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The monograph extensively explores ultraviolet (UV) radiation and its impact on substances and living organisms, as well as discusses sources of this type of radiation and methods of its measurement. The monograph investigates physical and chemical methods of water disinfection, particularly methods that utilize ultraviolet radiation in combination with chlorine or ozone. It also considers technological approaches to using ultraviolet radiation in water disinfection, including applications in water purification systems for drinking, in bottling drinking water, in swimming pools, and in fish cultivation in closed recirculating systems. The monograph focuses on technological solutions for the development and use of ultraviolet disinfection units for water systems.

Recommended for scientific researchers, engineering and technical personnel involved in bactericidal disinfection issues, bacterial inactivation under ultraviolet radiation, using ultraviolet sources of different spectral ranges; higher education students in the fields of «Electrical Engineering» and «Chemical Engineering and Bioengineering».

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INTRODUCTION

Optical radiation is a fundamental factor in the human habitat, akin in significance to air and water. Understanding its state and ecological parameters is paramount for sustaining life. UV radiation has emerged as a potent tool in addressing various challenges across industries such as medicine, utilities, energy, and agriculture, where traditional chemical methods often fall short. Its utilization has led to groundbreaking solutions within the agro-industrial complex and deepened our comprehension of chemical, physical, and biological processes at the atomic-molecular level.

The development and industrial production of modern, highly efficient UV radiation sources alongside associated electrical devices have paved the way for widespread adoption in systems for bactericidal disinfection of air, water, and surfaces. This transformative shift has significantly contributed to enhancing public health and environmental safety measures.

This comprehensive monograph delves into the intricacies of electrotechnical systems related to the production of drinking water, water used in bottling processes, swimming pools, and closed recirculation systems for fish farming. A thorough analysis of both physical and chemical methods of water disinfection is conducted, providing an insightful examination of their respective advantages and disadvantages.

The study establishes precise parameters and criteria for identifying non-compliance with microbiological indicators in products. This understanding has led to the development of sophisticated electrotechnical complexes for disinfection and ultraviolet irradiation, coupled with optimized parameters and operational modes that significantly enhance the efficacy of UV action in disinfection processes.

Critical factors affecting the effectiveness of bactericidal disinfection in water irradiation systems are meticulously identified and scrutinized. These factors encompass UV radiation flow stability, variations in transmission parameters, water layer thickness, and UV transparency within the spectrum, all of which play pivotal roles in optimizing disinfection outcomes.

An innovative approach to water disinfection in swimming pools, eliminating reliance on chlorine-containing substances by leveraging ozone generated through short-wave ultraviolet radiation from UV sources, is elucidated. Furthermore, the monograph highlights the development of cutting-edge devices tailored for optimal disinfection modes in UV complexes, alongside specialized equipment designed for drinking water disinfection and complex water disinfection in swimming pools using ozone. These advancements underscore the ongoing evolution toward sustainable and efficient disinfection practices in various domains.

CHAPTER 1 MODERN IDEAS ABOUT THE NATURE OF UV RADIATION

1.1 Nature and characteristics of electromagnetic radiation

The field of optical radiation covers ultraviolet, visible and infrared radiation that is very similar in their physical properties. X-rays and radio waves, which are also electromagnetic vibrations, do not belong to the optical domain. In terms of the method of obtaining and application, these types of radiant energy differ significantly from optical radiation [1].

Ultraviolet radiation entering the optical region, for a number of reasons, occupies a special position in it. First of all, a person does not have a perceptual organ that can directly respond to ultraviolet radiation, just as the eye perceives visible radiation. Therefore, ultraviolet radiation was discovered relatively late (1801). Further, unlike other regions of the optical spectrum, ultraviolet radiation can affect the atoms and molecules of a substance and change its physical and chemical properties [2,3].

The nature of ultraviolet radiation is electromagnetic radiation, which represents the process of transferring electromagnetic vibrations of energy from the radiation source to the environment and occupies the range between visible and X – ray radiation (from 10 to 400 nm). According to modern physical concepts, radiation has both wave and corpuscular properties.

UV radiation is part of the optical radiation range (from 10 nm to 1 mm), which includes visible (from 380 (400) to 760 (780) nm) and infrared (from 760 (780) nm to 1 mm). The range is divided into near UV (400-200 nm) and far or vacuum (200-10 nm) Ultraviolet, which is intensively absorbed by air and studied only by vacuum devices.

According to the recommendations of the International Lighting commission [4], the optical range with wavelengths from 100 to 400 nm includes the following regions of ultraviolet radiation (A, B, C), which have different nature and, accordingly, different biological effects:

UV-A (soft) from 315 to 400 nm;

UV – B (average) from 280 to 315 nm;

UV-C (hard) from 100 to 280 nm.

The boundaries between these regions were chosen conditionally in accordance with the predominant effect of interaction between radiation and a biological object.

The UV-A range is considered a soft UV radiation that penetrates well into the human skin and, when interacting with it, leads to the formation of a tanning effect. The UV-B range causes sunburn and can lead to various skin diseases with prolonged and systematic exposure. The UV-C range is considered hard UV radiation, which is well absorbed by protein molecules, causing the death of bacteria and viruses or their irreversible mutations, loss of the possibility of reproduction, etc. this range is called bactericidal because of its effectiveness against bacteria and viruses. UV-C-band does not penetrate well into human skin, but due to its high absorption capacity, it can lead to Burns, and with systematic exposure - to skin damage and even to skin cancer [1, 3].

UV radiation Quanta have more energy ε thanks to a higher frequency ν electromagnetic vibrations than visible radiation Quanta ($\varepsilon = h\nu$, where $h = 6{,}63 \cdot 10^{-34}$ J·s – became Planck), UV radiation is better than visible, manifests itself in those phenomena that have a quantum character – photoelectric effect (external and internal), photochemical and photobiological processes, and in the latter, the effect of UV radiation on human and animal organisms can be both useful and harmful [1, 2].

On the other hand, UV radiation manifests itself better than X-ray radiation (due to the relatively small wavelength of the latter) in those phenomena that have a purely wave character – dispersion (dependence of the radiation propagation velocity on the optical density of the medium, that is, on its refractive index) and diffraction (strengthening or weakening of the intensity of electromagnetic vibrations (interference) after passing holes or skirting small obstacles, or passing through a system of alternating interference holes (diffraction grating)), which allows you to decompose UV radiation into spectra at wavelengths, and thus measure the intensity (spectral) at each individual length determine the so-called spectra of UV radiation and their spectral efficiency in certain phenomena (processes).

When studying the effect of UV radiation on various biological objects, their selectivity and selectivity to different wavelengths were noted [1, 3].

1.2. Energy values of radiation

One of the main characteristics of radiation is its spectral composition [3,5]. The spectral distribution expresses the dependence of the spectral energy quantity in absolute or relative units, for example, the spectral density of the radiation flux $F_{\mathrm{e},\lambda}$, W/nm, which is defined as the ratio of the radiation flux F_e, W in a narrow wavelength range up to this interval $\delta\lambda$, nm. Presence of the spectral density distribution of the radiation flux $F_{\mathrm{e},\lambda}$ the source allows you to determine its integral radiation flux F_e in any part of the wavelength range by the formula [3]:

$$F_\mathrm{e} = \delta\lambda \sum_{i=1}^{n} F_{\mathrm{e},\lambda,\mathrm{i}}, \text{ W}, \tag{1.1}$$

where i - serial number of the spectral interval.

If the values of the spectral flux density are given in relative units $F_{\lambda,\mathrm{i(в)}}$, then they can be written down:

$$F_{\mathrm{e},\lambda,\mathrm{i}} = F_{\lambda,\mathrm{i(в)}} K_a, \text{ Wt/nm} \tag{1.2}$$

In this expression, the multiplier is K_a in the spectral range of wavelengths $\lambda_1 - \lambda_n$ calculated using the formula:

$$K_a = \frac{F_\mathrm{e}}{\Delta\lambda \sum_{\mathrm{i}=1}^{\mathrm{T}} F_{\lambda,\mathrm{i(в)}}}, \text{ Wt/nm} \tag{1.3}$$

An important characteristic of the source є distribution of its radiation flux in space. The spatial density of the radiation flux in this direction is understood as the radiation force equal to the ratio of the radiation flux F_e, which extends inside the solid angle to that angle. The Solid Angle is equal to the ratio of the surface area ΔS, which is cut into a sphere of unit size that surrounds the radiation source by a cone with a vertex in the center of the sphere to the square of its radius R. Connection to the flat angle of a circular cone γ (in degrees) and a solid angle is expressed by the formula:

$$\Delta\Omega = 2\pi(1 - \cos\gamma) \tag{1.4}$$

The Solid Angle is measured in steradians (sr). One Steradian is equal to the ratio $\Delta S = 1\text{m}^2$ to the square of the radius $R = 1\text{м}$, that is $\Delta\Omega = \Delta S/R^2 = 1$ sr. The radiation strength has a unit of measurement W/sr.

$$\mathrm{I_e} = \frac{\Delta F_\mathrm{e}}{\Delta\Omega}, \text{ W/sr.} \tag{1.5}$$

For a point source, which can be conventionally called a spherical isotropic source (equally radiating in all directions), located in the center of a sphere with a radius of R, radiation flux F_e spreads in the body corner:

$$\Omega = \frac{S}{R^2} = \frac{4\pi R^2}{R^2} = 4\pi, \text{ sr,} \tag{1.6}$$

and the value of the radiation force in any direction is equal to

$$\mathrm{I}_{\mathrm{e},k} = \frac{F_\mathrm{e}}{\Omega} = \frac{F_\mathrm{e}}{(4\pi)}, \text{ W/sr.} \tag{1.7}$$

The surface radiation flux density or irradiation at any point on the bullet surface is defined as

$$\mathrm{E_e} = \frac{F_\mathrm{e}}{S_k} = \frac{F_\mathrm{e}}{(4\pi R^2)}, \text{ W/m}^2 \tag{1.8}$$

If we take into account the expression (1.5), we obtain the formula:

$$\mathrm{E_e} = \frac{\mathrm{I_e}}{R^2}, \text{ W/m}^2 \tag{1.9}$$

which will reflect one of the fundamental laws of physics – the law of squares of distances, according to which the irradiation at a point is inversely proportional to the square of the distance to this point from the source and directly proportional to the strength of radiation in this direction.

It should be noted that this law is valid if the dimensions of the radiation source are significantly smaller than the distances to the measurement point (they are no more than a tenth of the distance from it to the measurement point of irradiation).

The main radiometric values used in estimating UV radiation parameters are shown in Table 1.1.

Table 1.1.

Basic UV values and their units of measurement

Value	**Definition**	**Formula**	**Unit of measurement**
Radiation energy	Energy carried by radiation	W_e	J (Joule)
Radiation flux	Ratio of radiation energy to exposure time	$F_e = \frac{W_e}{t}$	W (Wat)
Irradiation (surface radiation flux density)	Ratio of the radiation flux to the irradiated area	$E_e = \frac{F_e}{S}$	W/m^2
Surface dose (Fluence)[1]	Ratio of radiation energy to the irradiated surface	$H_S = \frac{W_e}{S}$	J/m^2
Volume dose	Ratio of radiation energy to irradiated volume	$H_V = \frac{W_e}{V}$	J/m^3

The propagation of radiation in space is associated with the transfer of energy from the source to another material body that meets in its path. Radiation energy W_e equal to the product of the radiation flux F_e (W) for the duration of the action t (c), that is

$$W_e = F_{\mathrm{e}} t, \mathrm{J} \tag{1.10}$$

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[1] The amount of radiation energy according to table.1.1 per unit area is measured J/m^2 and it's called "Fluence". However, the term "Fluence" is used in the United States and Canada, and in Europe, Ukraine, according to the decision of the International Committee of phytobiology, the use of the term "dose"is allowed.

Value, what characterizes the energy density of incident radiation on a surface with an area of S, m^2, it is called the surface energy exposure and is determined by the ratio:

$$H_{e,S} = \frac{W_e}{S} = \frac{F_{\mathrm{e}} t}{S} = E_e t, \text{ J/m}^3 \qquad (1.11)$$

If Radiation energy fills the volume V, m^3, then used Value «volumetric energy exposure», which characterizes the volumetric energy density. The volume energy exposure is determined by the ratio:

$$H_{e,V} = \frac{W_e}{V} = \frac{F_{\mathrm{e}} t}{V}, \text{ J/m}^3 \qquad (1.12)$$

The vast majority of artificial radiation sources are based on the conversion of electrical energy into radiation energy [6, 7, 8]. Evaluation efficiency of conversion of spent electrical energy into radiation energy in a given spectral range of wavelengths $\lambda_1 - \lambda_n$ it is determined by the value of the so-called energy efficiency (efficiency factor), taking into account (1.1), calculating:

$$K_{\mathrm{E}} = \frac{\Delta\lambda \sum_{\mathrm{i}=1}^{\mathrm{i}=n} F_{\mathrm{e},\lambda,\mathrm{i}}}{\mathrm{P}} = F_{\mathrm{e},(\lambda_1-\lambda_n)} P < 1, \qquad (1.13)$$

where P – electrical power of the radiation source, W.

Energy efficiency of the source K_{E} is a dimensionless quantity.

The contribution of individual spectral lines to total radiation is sometimes estimated using spectral efficiency $K_{\lambda,f}$ or radiation forces $K_{\lambda,\mathrm{I}}$, which have the following units of measurement [6]:

$$K_{\lambda,f} = \frac{F_{\mathrm{e},\lambda}}{\mathrm{P}}, \text{ нм}^{-1} \qquad (1.14)$$

$$K_{\lambda,\mathrm{I}} = \frac{\Delta F_{\mathrm{e},\lambda}}{\Delta\Omega \cdot \mathrm{P}} = \frac{I_{e,\lambda}}{P}, \text{ нм}^{-1}\text{sr}^{-1}. \qquad (1.15)$$

When a stream of radiation passes through an object, it is either partially or completely absorbed, depending on its optical properties. For objects with non-selective absorption (which does not affect the spectral composition of radiation), an experimental relationship was found, and then theoretically confirmed, between the values of the incident radiation F_{e} and completed F_{τ} radiation fluxes for a flat object with a thickness of X (m) - Booger-Lambert Law [7]:

$$F_{\mathrm{e},\tau} = F_{\mathrm{e}} \exp(-k\mathrm{x}), \tag{1.16}$$

where k – weakening rate, m^{-1}, from where

$$\tau = \frac{F_{\mathrm{e},\tau}}{F_{\mathrm{e}}} = \exp(-k\mathrm{x}) \tag{1.17}$$

Value k for this type of object, it is determined experimentally. it depends on the absorption capacity of the object: the greater the transparency of the object, the lower the value k. When $k = 0$ об'єкт it has maximum transparency, i.e. the transmittance of such an object is equal to one, since $\exp(0) = 1$.

If the object affects the spectral composition of radiation, i.e. it is selective, then the value of the spectral absorption coefficient is determined $k(\lambda)$ and, accordingly, the spectral transmittance $\tau(\lambda)$. The value of the absorbed radiation flux can be determined from the equation:

$$F_{e,\alpha} = F_e - F_{e,\tau} = F_e - F_e \exp(-kx) = F_e(1 - \exp(-kx)) \tag{1.18}$$

Thus, the energy radiometric values of radiation and their units of measurement are considered, which make it possible to estimate their own physical parameters of radiation without taking into account its effect on a particular body.

Bodies that convert radiation energy into other types of energy, such as thermal, chemical, or electrical energy, are commonly referred to as receivers [10].

When studying the effect of radiation on different receivers, it was found that the vast majority of receivers, especially biological ones, have selectivity or selectivity for different wavelengths. The selectivity of the radiation receiver means that at the same values of absorbed radiation fluxes with different spectral composition, they cause an unequal degree of response of the receiver [3].

Therefore, when evaluating the effectiveness of radiation interaction with a selective receiver, the use of energy values can lead to significant errors. Effective values allow us to identify optimal radiation parameters and assess the degree of interaction between radiation and the selective receiver. This is based on the fact that not all of the radiation energy absorbed can cause one effect or another: a significant part of it is converted to heat. The proportion of useful absorbed energy is determined by the spectral sensitivity of the receiver. As a rule, the sensitivity of the receiver is shown on the graph as a curve, which is a functional dependence of the relative spectral sensitivity S_{λ}, what is deposited on the ordinate axis, depending on the radiation wavelength λ, what is deposited on the abscissa axis. Usually the wavelength is λ_{max} corresponds to the maximum spectral sensitivity of the receiver $S_{\lambda,max}$.

The presence of an experimental spectral sensitivity curve of the receiver makes it possible to determine the radiation efficiency of both individual spectral lines and their total effect.

So, if the spectral density of any radiometric quantity in energy units is known, for example, the flux $F_{\mathrm{e},\lambda}$, then for the effective value of the spectral density of the radiation flux $F_{\mathrm{e}F,\lambda}$ you can write:

$$F_{ef,\lambda} = F_{e,\lambda} S_{\lambda},\ \mathrm{W/nm} \tag{1.19}$$

and for complex radiation in the wavelength range $\lambda_1 - \lambda_n$, consisting of individual spectral lines or a continuous spectrum divided into narrow wavelength intervals $\Delta\lambda$ (nm), effective radiation flux is determined by:

$$F_{\mathrm{e}F(\lambda_1-\lambda_{\mathrm{т}})} = \Delta\lambda F_{\mathrm{e}F,\lambda_{\mathrm{i}}} = \Delta\lambda \sum_{\mathrm{i}=1}^{\mathrm{i}=n} F_{\mathrm{e},\lambda_{\mathrm{i}}} \cdot S_{\lambda},\ \mathrm{W} \tag{1.20}$$

Formulas (1.19) and (1.20) are valid for receivers that have a linear dependence of the reaction level on the value of the incident radiation flux, regardless of its spectral composition, if the additivity condition [8] is met, that is, the sum of the receiver reaction levels from two or more separate spectral fluxes is equal to the reaction level from their total effect. In this case, it is possible to build a system of effective radiometric quantities [3].

In the Table 1.2 there are no erythema values and units of measurement [9-11], but in Table 1.3 bactericidal values and Units [3, 13].

Table 1.2.

Erythema values and units

Value	Designation	Definition	Unit	Definition
Erythema flow	F_{ep}	Erythema radiation power-effective Value, what characterizes UV radiation by its beneficial (in small doses) effect on humans and animals	Er	Erythema flux corresponding to a radiation flux with a wavelength of 297 nm and a power of 1 W
Erythema energy	Q_{ep}	Product of erythema flux and radiation duration	Er·г	Erythema energy, which corresponds to the erythema flow of 1 ER emitted or perceived for 1 hour
Erythema radiation efficiency	К_{ep}	Ratio of erythema flux to the corresponding radiation flux	Er/W	Erythema radiation efficiency, at which an erythema flux of 1 ER is created by a radiation flux of 1 W

Erythema luminosity at a surface point	M_{ep}	The ratio of the erythema flow emitted by an element of the surface containing a given point to the area of this element	ep/m^2	Erythema luminosity of a 1m^2 surface emitting an erythema flux of 1 ER
Erythema illumination (erythema irradiation) at a surface point	E_{ep}	The ratio of the erythema flow falling on a surface element that contains a given point to the area of that element	ep/m^2	Erythema illumination of a surface area of 1m^2 with an erythema flow of radiation incident on it 1 ER
Erythema dose (erythema exposure)	H_{ep}	The ratio of the erythema energy of radiation incident on a surface element to the area of this element	ep·г/m^2	Erythema dose, which receives a surface area of 1 m^2, on which Radiation Falls with an erythema energy of 1 ER·G
Erythema brightness	L_{ep}	The ratio of the erythema luminous intensity of a surface element (volume) in	ep/(sr·m^2)	Erythema brightness of a uniformly radiating flat surface with an area of 1 m2 in the direction

		the considered direction of the area of its projection on a plane perpendicular to this direction		perpendicular to it with an erythema light intensity of the surface in the same direction of 1 ER/CP
Erythema lamp recoil	η_{ep}	The ratio of the erythema flow of the lamp to the power consumed by it	ep/W	Erythema return of a lamp emitting an erythema flux of 1 ER at a power consumption of 1W
Erythema transmittance	τ_{ep}	-	%	-
Erythema reflection coefficient	ρ_{ep}	-	%	-
Erythema absorption coefficient	α_{ep}	-	%	-

Table 1.3.

Bactericidal values and units

Value	**Designation**	**Definition**	**Unit**	**Definition**
Bactericidal flow	F_{bk}	The power of bactericidal radiation is an effective Value that characterizes	bk	Bactericidal flux corresponding to the radiation flux with a

		UV radiation by its ability to kill bacteria		wavelength of 254 nm and a power of 1 W
Bactericidal energy	Q_{bk}	Product of bactericidal flow and irradiation duration	bk ·h	Bactericidal energy that corresponds to the bactericidal flow of 1 BK emitted or perceived for 1 h
Bactericidal radiation efficiency	$К_{bk}$	Ratio of the bactericidal flux to the corresponding4 radiation flux	bk/W	Bactericidal efficiency of radiation, at which a bactericidal flux of 1 Bq is created by a radiation flux with a power of 1 W
Bactericidal luminosity at a surface point	$М_{bk}$	The ratio of the bactericidal flow emitted by an element of the surface containing a given point to the area of this element	bk/m^2	Bactericidal luminosity of a surface area of 1 m2 emitting a bactericidal stream of 1 BK
Bactericidal illumination (bactericidal irradiation)	$Е_{bk}$	The ratio of the bactericidal flow falling on a surface	bk/m^2	Bactericidal illumination of a surface area of 1 m2

at a surface point		element containing a given point to the area of this element		with a bactericidal flow of radiation incident on it of 1 BK
Bactericidal dose (bactericidal exposureя)	H$_{bk}$	The ratio of the bactericidal energy of radiation incident on a surface element to the area of this element	bk·g/m^2	A bactericidal dose that receives a surface area of 1 m2, on which Radiation Falls with a bactericidal energy of 1 BK·G
Bactericidal light intensity (bactericidal radiation strength) of the source in where what direction	I$_{bk}$	The ratio of the germicidal flow radiating by the source propagating in where what direction inside an elementary solid angle to this solid angle	bk·g/sr	Bactericidal luminous intensity of a uniform point source emitting an erythema flux of 1 BC in a solid angle of 1 CP
Bactericidal brightness	L_{bk}	The ratio of the bactericidal luminous intensity of a surface element (volume) in the considered direction of the	bk/(sr·m^2)	Bactericidal brightness of a uniformly radiating flat surface with an area of 1 m^2 in the direction

		area of its projection on a plane perpendicular to this direction		perpendicular to it with a bactericidal luminous intensity of the surface in the same direction of 1 BK / CP
Bactericidal return of the lamp	η_{bk}	Ratio of lamp germicidal flow to power consumption	bk/W	Bactericidal return of a lamp that emits a bactericidal flow of 1 BK at a power consumption of 1 W
Bactericidal transmittance	τ_{6k}	-	%	-
Bactericidal reflection coefficient	ρ_{bk}	-	%	-
Bactericidal absorption coefficient	α_{bk}	-	%	-

For some specific biological receivers, in which deviations from nonlinearity and additivity are not so significant that they can actually be ignored. Microorganisms can also be attributed to this type of biological receivers.

This is consistent with A. Khinchin's theorem, which refers to the theory of large numbers. In one of the consequences of this theorem (nonlinearity-additivity), it is stated that with an increase in the number of elements of the system, including cells, it is simplified. In this case, the system can be considered as linear and additive [12].

CHAPTER 2 EFFECT OF UV RADIATION ON SUBSTANCES AND LIVING ORGANISMS

When radiation hits the interface of two media, penetrates into another medium and passes through it, the radiation undergoes certain changes – a decrease in intensity, a change in the direction of propagation, and the speed of propagation. All these phenomena show the wave nature of optical radiation, and these phenomena are well explained by wave and electromagnetic radiation theories.

At the same time, when a substance absorbs or passes through radiation under certain conditions, physical, chemical or biological changes can occur that are caused by the action of optical radiation [13].

According to [], such phenomena are collectively called the «photoelectric effect», they show the quantum nature of optical radiation and are well explained by quantum theory. These effects include photophysical, photochemical, and photobiological effects.

2.1. Photophysical effect of UV radiation

The photophysical effect of radiation should be understood as any change in physical parameters or the course of any processes under the influence of radiation. Among the most well-known and widely used in science and technology are the photoelectric effect and photoluminescence [1,5]. There is a distinction between external and internal photovoltaic effects (photoelectric effects).

In the external photoelectric effect, radiant energy falling on the metal surface causes the release of the smallest carriers of negative electric charge – electrons. A necessary condition for the output of each electron is the absorption of one light quantum. If the radiation composition remains unchanged, the number of electrons per unit time is proportional to the irradiation. Therefore, the external photoelectric effect is often used in special devices – photocells – for various types of measurements related to radiation [9]. The external photoelectric effect has a well-defined dependence on the radiation wavelength. Processes related to the external photoelectric effect occur mainly.

When radiation is absorbed, another process can occur that is not associated with a change in the irradiated substance – fluorescence [1]. Materials with fluorescent properties absorb radiation and, after a short period of time, emit it again in the form of fluorescent radiation. The spectrum of this radiation in most cases does not depend on the spectral composition of the excited radiation and is characteristic of this substance, but for the occurrence of fluorescence, it is necessary that the excited radiation has a shorter wavelength than the fluorescence radiation (Stokes ' law). Where what substances do not immediately emit absorbed energy, but store it. After a certain time after the start of excitation, these substances slowly release stored energy in the form of radiation with a gradually decreasing intensity. Such substances are called phosphors, and the phenomenon itself is phosphorescence. Fluorescence and phosphorescence are combined under the general concept of luminescence [4].

In the most favorable case, one quantum of luminescence radiation is emitted for each absorbed light quantum. Observation of the luminescence inherent in this substance is best done when it is excited by invisible ultraviolet rays, since in this case the excited radiation does not interfere with the visual observation of the usually weak glow of the luminescence. The analytical lamp works on this principle. The phenomenon of fluorescence is used in measurement technology, since the brightness of fluorescence, a luminous substance, can serve as a measure of the irradiation of the surface with ultraviolet rays. Currently, luminescence has received great practical application, since it is possible to convert ultraviolet radiation into visible light and thereby increase the luminous efficiency of mercury lamps used for lighting (fluorescent lamps). In addition, using different phosphors, you can change the color of the fluorescent lamp radiation.

Along with these phenomena, when radiation interacts with matter, another process is possible, which also does not cause changes in the irradiated substance. We are talking about the heating of bodies under irradiation [1]. In most cases, heating is so insignificant that it can be ignored, but it is undesirable if the process under study depends on temperature.

2.2. Photochemical effects

The most important property of ultraviolet rays, on which their use in biology and engineering is mainly based, is the ability to cause photochemical transformations in the irradiated substance [1, 2].

The essence of photochemical processes (reactions) is the activation of a system (molecules, atom) by an absorbed quantum of radiation. Therefore, according to [3], the property of optical radiation that allows them to cause chemical changes in certain living and inanimate materials is called actinicity, and radiation that has this property and photochemical effects is called actinicity.

A direct (indirect) actinic effect is an effect that occurs in a place (out of place) where the energy that causes the effect is absorbed [2]. The difference between direct and indirect actinic effects is usually observed in the case of biological changes.

For example, photostimulation of the endocrine glands is an indirect effect.

It is easy to understand that actinic radiation (including light) can cause such transformations of substances that would normally require high temperatures.

Indeed, the room temperature of 290 K corresponds to the energy of translational motion of molecules:

$$\frac{3}{2}kT \approx 0{,}04\text{eB} = 6{,}4 - 10^{-21}J, \tag{2.1}$$

while the photon energy of green light $(\nu = 6 * 10^{14}Hz)$

$$\varepsilon = h\nu \approx 2{,}5\text{eB} = 4 \cdot 10^{-19}J \tag{2.2}$$

Thus, the absorption of a photon of visible radiation is equivalent to an increase in temperature by a factor of 100, that is, heating up to a fraction of a thousand degrees. It is also clear that the shorter the wavelength of radiation, the more chemically active it can be [1,2].

The process of photochemical action of radiation can be divided into three stages [2,14]:

1) the act of absorption, during which electrically excited states occur;

2) primary photochemical processes in which systems in electron-excited states participate;

3) secondary or dark (thermal) reactions involving products of primary processes.

Features of photochemical activation in comparison with thermal activation are its selectivity (selectivity). The absorbed radiation quantum excites or activates only a single bond or group of bonds in a particular molecule. Using the frequencies of excitatory radiation characteristic of substance molecules, it is possible to activate them without sinking other molecules (for example, a solvent) or other bonds in the same molecule, while thermal activation of the same molecules and bonds can only be achieved by increasing the total energy of the surrounding molecules.

All photochemical effects occur through electron-excited states. To understand the essence of the photochemical process, it is necessary to have information about the energy, lifetime, and structure of electron-excited states. To describe this process, a complex mathematical apparatus of quantum theory is used, which is not necessary for the practical use of optical radiation. To do this, it is enough to consider photochemical processes at the next level [2].

Therefore, the excitation energy can be consumed in one of the following ways::

$A*$ → radiation (fluorescence): $A^{o} + h\nu$;

$A*$ → radiation-free process: $A_{o} +$ heat;

$A*$ → chemical reaction: reaction products, where $A*$ – a molecule in an electron-excited state; A_{o} – the molecule is in an undisturbed state.

Molecules live long enough only at the lowest vibrational levels of the lowest electron-excited states. However, the rate of where (loss) of energy and these states is extremely high compared to the rates of conventional «thermal» chemical reactions. Therefore, the chemical reactions of the excited state must occur quickly enough to successfully compete with where occlusion processes.

Molecules in one of the excited states can then undergo one of the following photochemical transformations [15]:

a) photoresponse

$$AB + h\nu \rightarrow AB * \rightarrow A + B; \tag{2.3}$$

b) photo Connection:

$$A + A + h\nu \rightarrow A * + A \rightarrow A_2 \text{ або } A + BC + h\nu \rightarrow A * + BC \rightarrow ABC; \tag{2.4}$$

c) electron photo transfer:

$$A + B + h\nu \rightarrow A * + B^- \rightarrow AB; \tag{2.5}$$

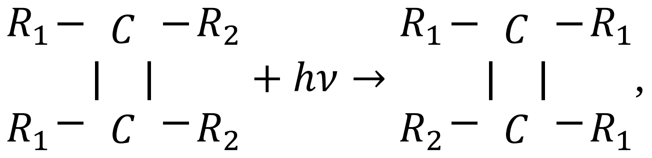
d) photopolymerization:

$$A_n + A_n + h\nu \rightarrow A_n * + A_n \rightarrow 2A_n; \tag{2.6}$$

e) photo grouping:

$$A + BC + h\nu \rightarrow A * + BC \rightarrow AC + B; \tag{2.7}$$

or



$$\begin{array}{c} R_1- \; C \; -R_2 \\ | \quad\; | \\ R_1- \; C \; -R_2 \end{array} + h\nu \rightarrow \begin{array}{c} R_1- \; C \; -R_1 \\ | \quad\; | \\ R_2- \; C \; -R_1 \end{array}, \tag{2.8}$$

where A, B, C – atoms or molecules of simple chemical compounds; AB, BC, ABC – molecules, A^+, B^- - ions; R_1, R_2 – radicals; A^* – molecules or atoms in the excited state.

The quantitative dependence of photochemical action on irradiation conditions is determined by the Bunsen-Roscoe law, which relates the number N molecules that have reacted with the absorbed radiation flux F_α:

$$N = \alpha \cdot F_\alpha t \tag{2.9}$$

where α – became the speed of the photochemical reaction.

It should be noted that most real processes in cases of small and large industrial flow densities are characterized by a deviation from this law.

The second law of photochemistry is the Stark – Einstein law (the law of quantum equivalence), according to which [8], each molecule participates in a chemical reaction that occurs under the influence of radiation, absorbs one of its Quanta, which causes the reaction.

At the same time:

$$\eta_k = \frac{N}{n_\alpha} \leq 1 \tag{2.10}$$

where η_k - quantum yield of the reaction; N – number of molecules that react; n_α – the number of photons absorbed.

Later it was found that this law can be applied only to primary processes, since secondary reactions accompanied by the release of heat (for example, chain reactions) can lead to the fact that the total quantum yield determined by the above formula is greater than one [8].

An important quantitative characteristic of any chemical transformation є process speed, measured by the amount of substance formed per unit volume V per unit of time, i.e.:

$$\vartheta = \frac{1}{V} \cdot \frac{\Delta M}{\Delta t} \tag{2.11}$$

If the process proceeds at a stable volume, then

$$\vartheta = \frac{\Delta c}{\Delta t} \tag{2.12}$$

where $c = \frac{M}{V}$ – mass concentration of the substance.

Chemical reaction rate є function of the concentration of reactants:

$$\vartheta = [\mathrm{A}_1]^{n_1}[A_2]^{n_2}\ldots[A_i]^{n_i},$$

where $[A_i]$ – substance concentration A_i; n_i – reaction order by substance A_i.

The number of excited molecules formed is determined by the Bunsen-Roscoe law formula:

$$A *= aF_\alpha t \tag{2.13}$$

where A* – the molecule is in an electron-excited state.

Applying the Booger-Lambert Law [5], we obtain

$$\mathrm{A} * = \mathrm{a}(1 - \mathrm{e}^{-\mu l})F_{\alpha}t \tag{2.14}$$

where μ – radiation attenuation coefficient, l – thickness of the absorbing layer.

For a unit of volume:

$$[A *] = a(1 - e^{-\mu})Et, \tag{2.15}$$

Because for a unit of volume $l = 1$, i in the expression $F_{\alpha} = ES$, also $S = 1$.

where E – irradiation, or

$$[A *] = a(1 - e^{-\mu_c \mathrm{C}_A})Et \tag{2.16}$$

where $\mu_c = \frac{\mu}{c}$ – molecular coefficient of radiation flux attenuation; C_A – concentration of absorbing substance molecules.

Change in the concentration of excited molecules per unit time

$$\frac{\Delta c_{\mathrm{A}*}}{\Delta t} = \frac{[A*]}{t} = aE(1 - e^{\mu_c \mathrm{C}_A}) \tag{2.17}$$

If the concentration of molecules and attenuation of radiation є small, $(\mu_c c_A \leq 0{,}1)$, then

$$(1 - e^{-\mu_c \mathrm{C}_A}) \approx \mu_c \mathrm{C}_A \tag{2.18}$$

then

$$\frac{\Delta c_{A*}}{\Delta t} = a\mu_c c_A E \tag{2.19}$$

Denote by K_2 constant speed of various kinds where activation transformations of excited molecules, and through K_1 - constant rate of emergence of a new product of a chemical reaction, for example, a photodetector reaction:

$$A * + B \rightarrow AB \tag{2.20}$$

Then the rate of disappearance (Where of objectification) of excited molecules $A*$

$$\frac{\Delta c_{A*}}{\Delta t} = k_2 c_{A*}, \tag{2.21}$$

and according to the law of active masses, (the rate of an elementary reaction, that is, a reaction in a homogeneous system, is directly proportional to the product of the concentration of reactants) the rate of appearance of product molecules AB:

$$\frac{\Delta c_{AB}}{\Delta t} = k_1 c_{A*} c_B \tag{2.22}$$

In the equilibrium state, the number of forming excited molecules is equal to the number of vanishing(where objectified and reacted), i.e.

$$a\mu_c c_A E = k_2 c_{A*} + k_1 c_{A*} c_B \tag{2.23}$$

Solving the last two equations together (getting rid of c_{A*}) we determine the rates of formation of molecules AB:

$$\frac{\Delta c_{AB}}{\Delta t} = k_1 \frac{a\mu_c c_A E}{k_2 + k_1 c_B} c_B \tag{2.24}$$

The simplest case of a photochemical reaction, where the initial substance, is considered above A it is consumed only as a result of transformations of excited particles $A*$. However, more complex reactions are known, during which the initial substance is consumed due to interaction with the products of primary chemical transformation.

A classic example is the use of photochemical transformations in photography.

Note that vision and color perception are also explained by special photochemical reactions that occur in the light – sensitive shell of the eye- the retina. The retina consists of light-sensitive elements that contain pigments that respond to light, transmit excitation to the optic nerves and provide the corresponding processes of where and night vision.

2.3. Photobiological effect of UV radiation

Photobiological action is the action of actinic radiation on everywhere, animals, microorganisms and plants [2]. Common to all processes of photobiological action of radiation are photo transferences that occur in the substance of a living cell due to its absorption of radiation. A huge number of photobiological processes are divided into physiological and structural-modifying (destructive-modifying) processes [5, 7].

The most common photobiological reaction in nature and the most important for all life on Earth is photosynthesis [16,17]. During photosynthesis, the energy of actinic radiation is transformed into the chemical energy of the forming molecules of plants and microorganisms by converting carbon dioxide into carbohydrates, and in most cases the source of hydrogen is water:

$$6CO_2(\uparrow\downarrow) + 6H_2O(\uparrow\downarrow) + h\nu \xrightarrow{chlorophyll} C_6H_{12}O_6(\uparrow\downarrow) + 6O_2(\uparrow\uparrow)$$

$$C_6H_{12}O_6(\uparrow\downarrow) + 6O_2(\uparrow\uparrow) \xrightarrow{enzyme} 6CO_2(\uparrow\downarrow) + 6H_2O(\uparrow\downarrow) + \text{energy} \quad (2.25)$$

The release of oxygen due to photolysis of water is the main, if not the only factor in the formation of the Earth's atmosphere and maintaining its oxygen balance.

Photosynthesis begins with the absorption of a quantum of actinic radiation by Specialized Micro – formations-chromophores, which can be divided into three main groups: chlorophylls, carotenoids and phycobilin's. Combinations of pigments in different plants and protozoa are very diverse. However, in all cases, the presence of chlorophyll (or bacteriophile) is mandatory – the main (green) pigment of the photosynthetic organism, through which the primary photochemical effect of radiation is realized.

Actinic radiation that is absorbed by plant photoreceptors and used in their vital activity is called physiological radiation, which is usually limited to the range of 300-800 nm. The range of radiation involved in energy exchange (photosynthesis) is limited to the region of 400-700 nm (according to other sources, 380-710) called photosynthetic active radiation (far) [18].

The main processes that occur in plants (with plants) under the influence of actinic radiation are listed below [19].

Photomorphogenesis is a change in the size and shape of plants under the influence of radiation of various intensity and quality, which begins with the absorption of radiation by phytochrome, which exists in two forms: one of them absorbs red light λ=660 нм, the second is far red light with λ=730 nm. Under the action of excited phytochrome, seed germination, stem stretching, leaf formation, and root system formation are stimulated.

Phototronism-uneven growth due to the orientation of the plant to the radiation source, with the participation of pigments such as flavins and carotenides.

The following types of phototronism differ:

- phototaxis-Fixed movement both towards and away from the source (which leads to bending of the stems);
- photonasty-nondirectional short-term movements.

Photoperiodism is a plant's response to a light-dark rhythm (i.e., to periodic alternations of light and darkness), which is insufficiently studied from the point of view of the Everywhere ntification of defining pigments. According to modern concepts, the basis of Photoperiodism is the phytochromic system.

Chlorophyll biosynthesis, more precisely, is one of its last stages of phototransformation [2], which is independent of radiation and plays a crucial role in plant life not only at the stage of leaf Greening.

According to approximate estimates, certain ranges of optical radiation cause the following physiological processes relative to plants:

- more than 1000 nm-favorable thermal effect;
- 700-1000 nm – stem pulling effect;
- 610-710 nm – photosynthesis (maximum effect), chlorophyll biosynthesis, Photoperiodism;
- 510-610 nm – photosynthesis;
- 400-510 nm – carotenoid uptake, second peak of chlorophyll adsorption, and photosynthesis, growth and formative effects;
- 315-400 nm – photosynthesis, regulatory effect;
- 280-315 nm – harmful effect for most plants;
- less than 280 nm – harmful effect on plants.

As can be seen from this list, only the UV-a region (315-400 nm) is useful for physiological processes, while photosynthetically active radiation covers a wider range of the spectrum.

Recent studies have shown that, in addition to the visible part of the optical radiation spectrum, the intensity of many physiological processes, the internal structure of the plant cell and, finally, the formation of the entire plant is largely determined by long-wave ultraviolet (315-400 nm) radiation. Long-wave (315-400 nm) in moderate doses stimulates metabolic processes and promotes plant growth. Therefore, with additional irradiation, plants should be given small doses of long-wave UV radiation (315-400 nm).

The second most important biological photo process (after photosynthesis) can be confidently considered photoreception and, in particular, one of its types – vision. Vision plays a huge role in the life of animals: information at a distance, correct orientation in space, and so on. Vision is even more important in human life: about 90% of all information a person acquires through visual receptors.

Without dwelling on the functioning of the visual receptors themselves and emphasizing the above-mentioned circumstances that the lighting technique is based on the functioning of these radiation receivers, we note that it is necessary to carefully take into account the harmful nature of UV radiation on the retina and other components of the visual organ [20].

The situation is complicated by the fact that UV radiation is not perceived by the retina of the eye in the sense that it occurs with visible radiation (light) due to the absorption of UV radiation by the rest of the eye-the cornea, the watery environment of the eye, the crystal and vitreous body. Therefore, the eye cannot carry out its natural preventive responses (reducing the pupil diameter, etc.) to UV radiation, as it happens, for example, in the case of bright light, and UV radiation (even soft UVA) can lead to serious damage to the visual apparatus, since the visual receptors do not sense its presence.

Due to the fact that UV radiation can negatively affect the health of people, we will consider two reactions that cause UV radiation to vision-photokeratitis and photo conjunctivitis, as well as photobiological safety requirements for radiation sources and irradiation installations.

Photokeratitis is an inflammation of the cornea as a result of UV radiation. The irradiation time before the onset of pain is from 30 minutes to 24 hours. Maximum dose for λ=288 nm it is equal to 100 J/m^2 [2].

Photoconjunctivitis is an inflammation of the conjunctiva caused by UV radiation. The threshold dose is considered to be Value 50 J/m^2 at λ=260 nm. Relative spectral sensitivity of photokeratitis and photoconjunctivitis in Figure 2.1.

A large number of modern studies are devoted to the photobiological influence of light on human health [21-35].

Standardized methods for assessing and classifying the risks of ultraviolet blue and infrared radiation were developed by the MKO and jointly with IEC nave where in the MKO s009 standard, and then adopted by IEC in the IEC 62471 safety of lamps and lamp systems photobiological.

In the development of the IEC 62471 standard, the IEC/TR 62471standards were developed. The safety of lamps and lamp systems is photobiological. Part 2. Guidelines on design requirements for the safety of non-laser optical radiation and IEC TR 62778 application of IEC 62471 provisions to light sources and luminaires for blue light hazard assessments. Based on these standards, everywhere standards have been developed in Ukraine [36,37].

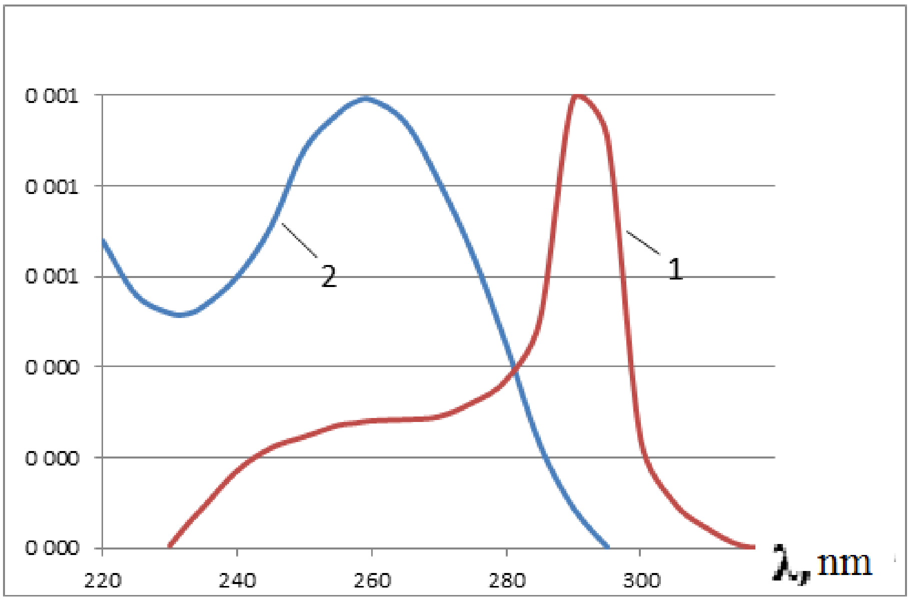


Figure 2.1 Relative spectral sensitivity for photokeratitis (1) and photo conjunctivitis (2).

In [38], the limit values of radiation exposures (RE) are set, which should not be exceeded when using lamps and lamp Systems (Luminaires). GSE is taken from various ICNIRP recommendations (International Commission on Non-Ionizing Radiation Protection – International Commission for protection against non-ionizing radiation), which in turn are based on information about experimental studies (set of publications in Appendix A of IEC 62471).

HSE is a condition in which it is believed that almost everyone can be repeatedly exposed to radiation without irreversible health consequences.

To prevent damage to the eyes and skin by UV radiation, the total radiation exposure is effective E the source must not exceed the level determined by the formula:

$$E \cdot t = \sum_{200}^{400} \cdot \sum_t E_\lambda(\lambda, t) \cdot S_{UV}(\lambda) \cdot \Delta t \cdot \Delta\lambda \leq 30 \quad \text{J}\cdot\text{m}^{-2}, \tag{2.26}$$

where: $E_\lambda(\lambda, t)$ – spectral irradiation in $\text{W}\cdot\text{m}^{-2}\cdot\text{nm}^{-1}$; $S_{UV}(\lambda)$ – function of spectral efficiency of actinic UV radiation hazard; $\Delta\lambda$ – wavelength range in nanometers; Δt – duration of exposure in seconds.

Spectral efficiency function $S_{UV}(\lambda)$ graphically shown in Figure 2.2. since the function covers many orders of magnitude, the values of the value $S_{UV}(\lambda)$ provide logarithmically. In addition, the spectral values $S_{UV}(\lambda)$ specified in Table 2.1.

The permissible exposure time to UV radiation that gets on unprotected skin and in the eye should be calculated by the formula

$$t_{max} = \frac{30}{E} \tag{2.27}$$

where: t_{max} – acceptable exposure time in seconds; E – effective UV irradiation in $\text{W}*\text{m}^{-2}$.

The total irradiation exposure in the spectrum range from 315 nm to 400 nm (UV-A) for the eye should not exceed 104 $\text{J}\cdot\text{m}^{-2}$ for exposures less than 1000 s. for exposures greater than 1000 s (approximately 16 min), the irradiation of the unprotected eye in the area (UV-A) should not exceed 10 $\text{W}\cdot\text{m}^{-2.}$

These conditions can be expressed as follows:

$$E_{UVA} \cdot t = \sum_{315}^{400} \sum_{t} E_{\lambda}(\lambda, t) \cdot \Delta t \cdot \Delta\lambda \leq 10^{4} \text{ J·m}^{-2} \ (t<1000 \text{ c}) \quad (2.28a)$$

$$E_{UVA} \leq 10 \quad \text{W·m}^{-2} \quad (t>1000 \text{ c}) \quad (2.28b)$$

where: $E_{\lambda}(\lambda, t)$ – spectral irradiation in W·m^{-2}, nm^{-1}; $\Delta\lambda$ – wavelength range in nanometers; t– duration of exposure in seconds.

Table 2.1

Spectral efficiency function for UV Hazard Assessment for skin and eyes

Wave length1$^{1)}$ λ, nm	Function UV dangers $S_{UV}(\lambda)$	Wavelength λ, nm	Function UV dangers $S_{UV}(\lambda)$
200	0,030	313$^{*)}$	0,006
205	0,051	315	0,003
210	0,075	316	0,0024
215	0,095	317	0,0020
220	0,120	318	0,0016
225	0,150	319	0,0012
230	0,190	320	0,0010
235	0,240	322	0,00067
240	0,300	323	0,00054
245	0,360	325	0,00050
250	0,430	328	0,00044
254$^{*)}$	0,500	330	0,00041
255	0,520	333$^{*)}$	0,00037
260	0,650	335	0,00034
265	0,810	340	0,00028
270	1,000	345	0,00024
275	0,960	350	0,00020
280$^{*)}$	0,880	355	0,00016
285	0,770	360	0,00013
290	0,640	365$^{*)}$	0,00011
295	0,540	370	0,000093
297$^{*)}$	0,460	375	0,000077
300	0,300	380	0,000064

303*)	0,120	385	0,000053
305	0,060	390	0,000044
308	0,026	395	0,000036
310	0,015	400	0,000030

1) The selected wavelengths are represented: the remaining values must be drawn by logarithmic interpolation on intermediate values of longer waves.
*) Radiation lines in the mercury discharge spectrum.

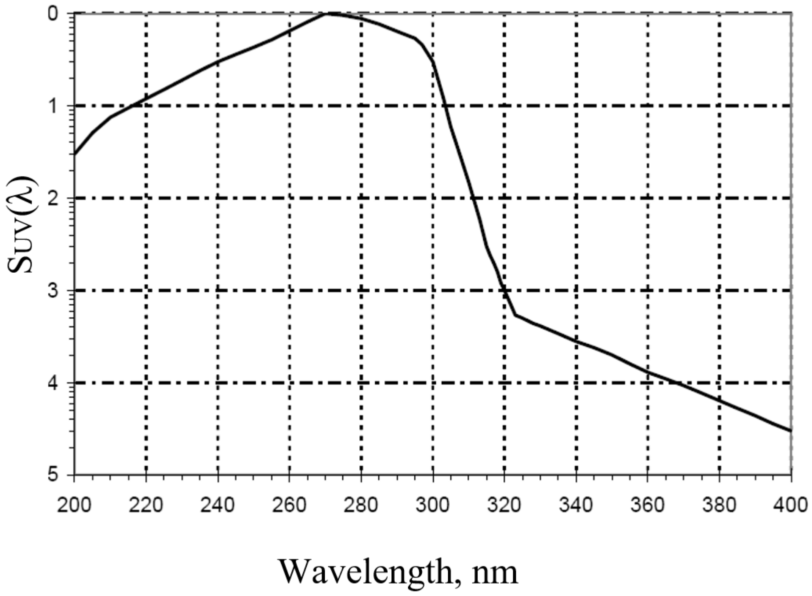


Figure 2.2. Spectral efficiency function $S_{UV}(\lambda)$ dangers of actinic UV radiation for the skin and eyes

Acceptable exposure time to UV radiation entering the unprotected eye for longer periods of time 10^3 c, it is necessary to calculate by the formula:

$$t_{max} \leq \frac{10^4}{E_{UVA}} s \tag{2.29}$$

Another photoreceptor is the skin, the surface layer of which transmits radiation to varying degrees. One of the signs of UV radiation on the skin is erythema actinic-redness of the skin (with or without a burn) caused by the actinic effect of solar or artificial optical radiation in 1 cm^3. Accordingly, radiation can cause erythema-erythema [2].

The quantitative characteristic of radiation exposure is the actinic dose – Value, which is determined by spectral evaluation of the dose in accordance with the values of the effective intensity of monochromatic radiation of the actinic action spectrum [3].

The actinic dose, which gives slightly noticeable erythema on normal «white» (previously unaffected skin), is called the minimum erythema dose (honey). According to international standards, Value corresponds to a radiation exposure of about 100 J/m^{-2} with the maximum erythema efficiency of monochromatic radiation λ=295 nm.

Following the formation of erythema, pigmentation of the skin develops, its darkening (sunburn) occurs. Darkening of the skin during and as a result of actinic action is a more important natural mechanism for protecting it from further damage by UV rays.

Radiation in the range from 320 to 400 nm causes minor erythema in people with normal skin, while radiation in the wavelength range from 290 to 320 nm or less causes burns and subsequent pigmentation [2].

Overdose, as well as systematic UV exposure to the skin, can lead to undesirable consequences [1].

Living organisms on Earth and humans that developed under solar radiation have developed a whole complex of photobiological reactions that have a beneficial effect on their vital activity [7].

Optical, and in particular UV radiation, increase the tone of the sympathetic-adrenaline system, activate defense mechanisms, increase the activity of mitochondrial and microsomal enzymes and the level of non-specific (general) immunity, significantly increases the secretion (release) of a number of hormones, promotes the formation of vitamin D. Under the influence of UV radiation, histamine and similar substances are formed, which have a vasodilating effect, increase the permeability of skin vessels.

Systolic and diastolic blood pressure decreases even in the case of doses that do not cause erythema. Blood pressure gradually drops and can remain low for several days. In addition, there are changes in blood composition due to radiation – in particular, hemoglobin, white blood cells, neutrophils, as well as sugar, cholesterol, tyrizine, calcium, etc.

Under the influence of UV radiation, hydrocarbon and protein metabolism in the body change. Exposure to radiation changes pulmonary ventilation-the frequency and rhythm of breathing. Increases gas exchange and oxygen consumption. The activity of the endocrine system is activated, the content of adrenaline increases, which indicates the participation of the hormonal link in the body's response to radiation.

Irradiation with suberythemic doses of 0.5-0.7 honey is used to prevent hypovitaminosis conditions in people who have been in conditions of «solar starvation» for a long time. As a result of repeated exposures in doses that increase from suberythemic to those exceeding honey, the body's adaptive mechanisms develop to the surrounding conditions – the hardening effect. Preventive UV radiation prior to immunization reduces the risk of allergic consequences of vaccination and helps to increase the effectiveness of immunization.

In countries where large populations live in Arctic conditions, it is generally recognized that prolonged lack of UV radiation can have adverse consequences for the human body. Numerous studies show that a lack of sun exposure can lead to the development of a pathological condition known as «UV radiation deficiency» or «light starvation.» The same applies to workers who regularly stay in industrial premises during daylight hours, which are provided only with artificial lighting and are deprived of Natural (Solar) Lighting, as well as miners, Metro workers, etc.

The most common manifestation of this disease is a violation of mineral metabolism and the development of vitamin D deficiency (as well as rickets in children), which is accompanied by a sharp decrease in the body's resistance and makes it susceptible to diseases.

Despite extensive studies of the effect of UV radiation as a powerful hygienic and therapeutic factor, systematic studies of the beneficial effects of monochromatic radiation of different wavelengths have not yet been carried out. Currently, there are only attempts to link the variety of favorable effects of UV radiation with one fairly well-studied function and attribute it to the cause of Integral favorable effects [39]. Sometimes the function of selecting UV radiation doses is taken as an objectively and sufficiently defined function of the spectral sensitivity of vitamin D formation, the graph of which, together with the graph of the spectral sensitivity function of erythema formation, is shown in Figure 2.3.

Taking into account the fact that the spectral curve of photo-formation of vitamin D is located in the same spectrum zone as the long-wave branch of the erythema curve, usually the spectral effectiveness of the tonic and therapeutic effect of radiation is estimated by the values of the erythema efficiency of UV radiation from the wavelength λ ≥ 280 nm (sometimes ≥ 300 nm). For radiations with λ < 280 nm the effectiveness of a beneficial general biological action is assumed to be zero. Taking into account the fact that long-wave UV radiation up to 400 nm certainly plays a significant role in the development and normal existence of a living organism, the erythema curve has been extended to 400 nm [2].

Together with the preventive (hygienic) effect of UV radiation, it can be used as a powerful therapeutic agent [1, 3, 34]. Numerous studies confirm the protective capabilities of suberythemic radiation in the case of carcinogenic substances, the possibility of treatment (and Prevention) of chronic nasopharyngeal diseases, bronchopulmonary diseases, prolonged and chronic pneumonia, various skin diseases (eczema, psoriasis, seborrhea, etc.), coronary heart disease, glaucoma, rheumatic diseases of childhood, etc.

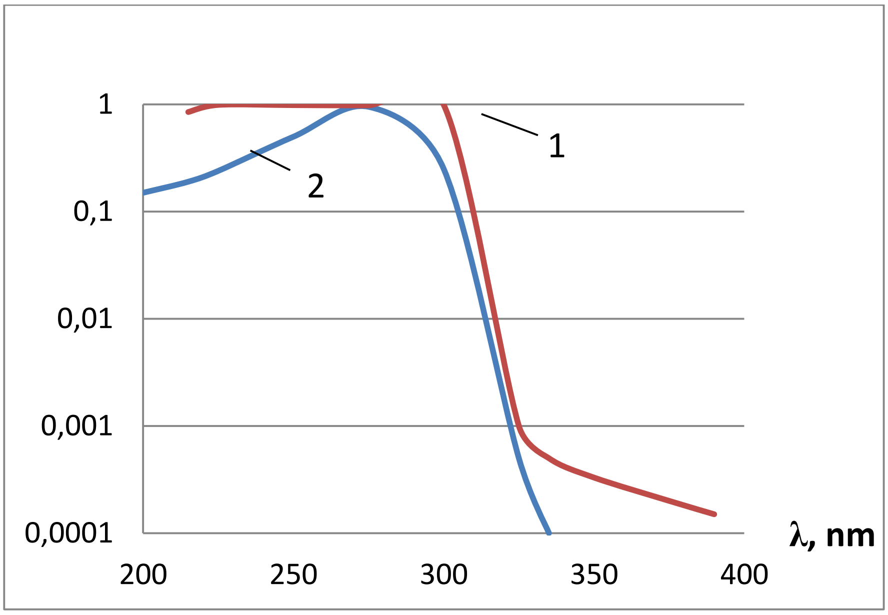


Figure 2.3. spectral sensitivity of photobiological reactions

Unfortunately, despite the extensive factual material, neither general nor specific recommendations regarding the spectra of action and doses of therapeutic radiation have yet been provided.

In the effect of short – wave radiation on a living organism, the effect of ultraviolet rays on biopolymers-proteins and nucleic acids-is of the greatest interest. Biopolymer molecules contain ring groups of carbon and nitrogen molecules that intensively absorb radiation with a wavelength of 260 ... 280 nm. The absorbed energy can migrate along the chain of atoms within the molecule without significant loss, until it reaches weak bonds between the atoms and breaks the bond. During this process, called photolysis, fragments of molecules are formed that have a strong effect on the body.

For example, the amino acid histidine forms histamine, a substance that dilates blood capillaries and increases their permeability. In addition to photolysis under the influence of ultraviolet rays, where naturalization occurs in biopolymers. When exposed to light of a certain wavelength, the electric charge of molecules decreases, they stick together and lose their activity – enzyme, hormonal, antigenic, etc. They are caused by different radiation ranges: Rays 280...302 nm causes mainly photolysis, and 250... 265 nm-preferably where the nature is. The combination of these processes determines the picture of the effect of ultraviolet rays on the cell.

The most sensitive function of the cell to UV rays is division. Irradiation at a dose of 10(-19) J/m^2 causes the division of about 90% of bacterial cells to stop. But the growth and vital activity of cells does not stop. Over time, their separation is restored. To cause the death of 90% of cells, inhibition of the synthesis of nucleic acids and proteins, and the formation of mutations, it is necessary to increase the radiation dose to 10(-18) J/m^2. Ultraviolet rays cause changes in nucleic acids that affect the growth, division, and heredity of cells, that is, the main manifestations of vital activity.

The significance of the mechanism of action on nucleic acid is explained by the fact that each DNA molecule is unique. DNA is the inherited memory of a cell. Its structure contains encrypted information about the structure and properties of all cellular proteins. If any protein is present in a living cell in the form of where knots and hundreds of identical molecules, then DNA stores information about the structure of the cell as a whole, about the nature and direction of metabolic processes in it. Therefore, violations in the structure of DNA can be irreparable or lead to a serious violation of vital functions.

Short-wave UV radiation causes a structural lethal effect on plant and living microorganisms, in particular, on bacteria, viruses, microbes, etc [1, 2, 6, 34].

According to international terminology, radiation capable of destroying any worm-like microorganisms is called germicidal radiation, and radiation capable of neutralizing only bacteria is called bactericidal radiation. In where countries, including Ukraine, the first term is not used, and in all cases, the adjective «bactericidal» is used to neutralize worm microorganisms. The effect of neutralization of worm microorganisms is called an inactivating effect.

The lethal effect in highly organized multicellular creatures at real dose values is practically not observed. In viruses, the lethal effect is manifested in the loss of the ability to intracellular reproduction, and in other microorganisms – in cell death before the first division or most often in the first or subsequent generations (generations) [34].

As early as 1929, it was shown that the spectrum of action of microbial lethality (Figure 2.4) coincides not with the absorption spectrum of the cell as a whole, but with the absorption spectrum of nucleic acids. Later, this fact was confirmed by numerous experiments.

Usually, the lethal effect Spectra have a pronounced maximum of 260-265 nm [1]. However, for individual organisms, «protein» Spectra with a maximum of 280 nm and mixed lethal effect Spectra with Maxima of 260 and 280 nm are indicated [2].

Weak inactivating effect on cells is also inherent in close (soft) UV radiation (λ>320 nm). To achieve a lethal effect in the case of exposure to such radiation, doses hundreds of thousands of times higher than in the case of using average ultraviolet light are required [2].

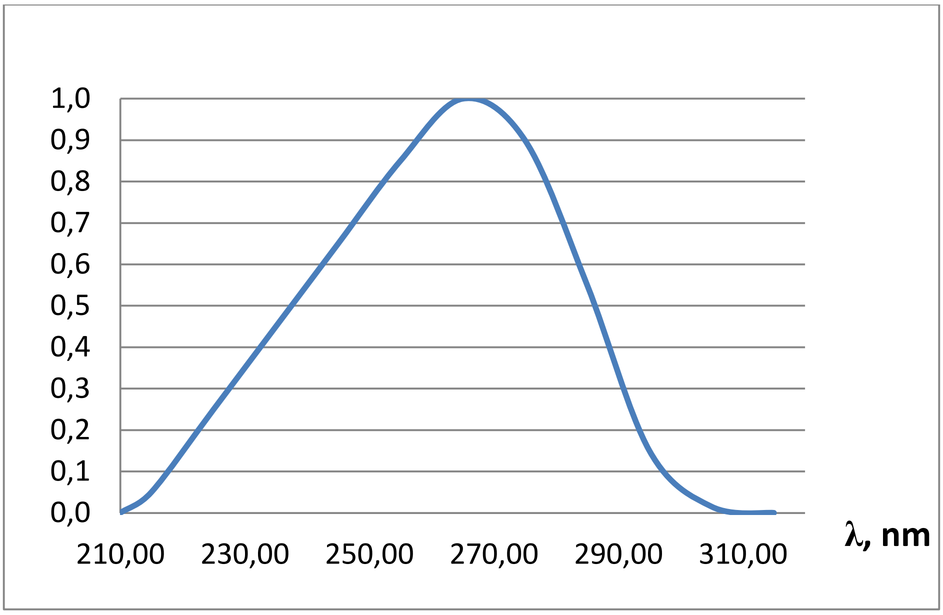


Figure 2.4. Efficiency curve of the bactericidal action of UV radiation

The mechanism of action of near ultraviolet light is insufficiently studied. There is only evidence that it is associated with indirect damage to DNA molecules [6, 34].

Far (hard) UV radiation (λ < 200 nm), on the contrary, it is very effective, which may be due to its ionizing effect.

The unit of the bactericidal flow F_b (that is, the radiant flux estimated using the above function) is bact, which is numerically equal to the radiant flux with λ=254 nm with a power of 1 W.

Information on other parameters that are used to evaluate bactericidal radiation is provided in Table 2.2.

It is established that the course of the relative spectral bactericidal efficiency curve for different types of microorganisms is almost the same. Viruses and bacteria (rods, cocci) in Vegetative form are more sensitive to the effects of ultraviolet radiation.

Fungi and protozoan microorganisms are less sensitive. Bacterial spores are most resistant.

When microorganisms are exposed to radiation, there is an exponential relationship between the number of surviving microorganisms N_B from entry level N_0 and the dose value N_S or N_V.

Table 2.2.

Parameters of bactericidal radiation

Value (parameter)	Formula Definition	Unit
Bactericidal energy luminosity (radiation)	$\mathrm{M}_b = \frac{dF_{\text{б}}}{dS}$	$bk\cdot m^{-2}$
Bactericidal power of radiation	$\mathrm{I}_b = \frac{dF_{\text{б}}}{d\Omega}$	$bk\cdot sr^{-1}$
Bactericidal brightness	$L_b = \frac{dI_{\text{б}}}{dS \cdot cos\,\alpha}$	$bk\cdot m^{-2}\cdot sr^{-1}$
Bactericidal irradiation	$\mathrm{E}_b = \frac{dF_{\text{б}}}{dS}$	$bk\cdot m^{-2}$
Bactericidal energy	$Q_b = \int_0^t F_{\text{б}} dt$	$bk\cdot s$
Bactericidal radiation efficiency	$H_b = \int_0^t E_{\text{б}} dt$	$bk\cdot s^{-1}\cdot m^{-2}$
Bactericidal efficiency of radiation	$\eta_b = \frac{F_{\text{б}}}{F_{\mathrm{e}}}$	$bk\cdot W^{-1}$

Such a process under surface irradiation is approximated by the expression:

$$N_{\mathrm{B}} = N_0\, exp(- \sigma_s H_s) \tag{2.30}$$

and when irradiating volumes:

$$N_{\mathrm{B}} = N_0\, exp(- \sigma_v H_v) \tag{2.31}$$

where: σ_s, σ_v – constants that characterize the photosensitivity values of this type of microorganism, respectively, under surface or volumetric ultraviolet irradiation.

If you indicate the bactericidal effectiveness J_{bk} as the ratio of the number of dead microorganisms N_z to their original value N_0, expressed as a percentage, and take into account that $N_z = N_0 - N_B$, then, using formulas (2.30) and (2.31), we obtain an expression for the bactericidal efficiency under surface irradiation:

$$J_{bk} = (N_z/N_0) \cdot 100 = (1 - \exp(-\sigma_s H_s)) \cdot 100\% \qquad (2.32)$$

and with volume irradiation:

$$J_{bk} = (N_z/N_0) \cdot 100 = (1 - \exp(-\sigma_v H_v)) \cdot 100\% \qquad (2.33)$$

From these expressions, it follows that in extreme cases, in the absence of dead microorganisms after irradiation, the bactericidal efficiency is zero, and if they are completely destroyed, the bactericidal efficiency is 100 %. It is obvious that σ as a constant of photosensitivity of this type of microorganism (UVB biosimilar), it is the main characteristic of the process of radiation exposure.

In the Table 2.3 there are no values of constants for where microorganisms when they are irradiated on the surface or in air with ultraviolet radiation with a wavelength of 253,7 nm.

Table 2.3

Photosensitivity constants for where microorganisms under surface irradiation (σ_V, m^3/J) and air volumes (σ_V, m^3/J)

Bacteria	σ_S	σ_V	Fungal yeast	σ_S	σ_V
Bacillus anthracis	0,051	0,0195	Baking yeast	0,060	
Bacillus megatherium (veg)	0,084	0,034	Brewer's yeast	0,070	-
Bacillus megatherium (spores)	0,178	0,0743	Yeast-like fungi	0,038	-
Bacillus paratyphosus	0,072	0,0274	Saccharomyces cerevisiae	0,038	-
Bacillus subtilis (veg)	0,032	0,0123	Saccharomyces ellipsoideus	0,038	-
Bacillus subtilis (spores)	0,019	0,0073	Saccharomyces sp.	0,029	-
Campylobacter jejuni	0,209	0,0768	Mold spores		
Clostridium tetani	0,019	0,0073			
Corynebacterium	0,069	0,026			

diphtheriae					
Dysentery bacilli	0,105	0,040	Aspergillus flavus	0,003	-
Eberthella typhosa	0,108	0,041	Aspergillus glaucus	0,004	-
Escherichia coli	0,077	0,029	Aspergillus niger	0,0014	-
Klebsiella terrifani	0,089	0,034	Mucor racemosus	0,013	-
Micrococcus Candidus	0,038	0,015	Oospora lactis	0,046	-
Phytomonas tumefaciens	0,023	0,0088	Penicillium expansum	0,018	-
Mycobacterium tuberculosis	0,038	0,015	Penicillium roqueforti	0,018	-
Nesseria catarrhalis	0,053	0,020	Rhizopus nigricans	0,002	-
Micrococcus sphaeroidcs	0.053	0,020	Viruses		
Pseudomonas aeruginosa	0,042	0,014			
Pseudomonas lluorcscens	0,065	0,025			
Proteus vulgaris	0,086	0,035	Hepatitis A	0,032	0,011
Salmonella enteritidis	0.058	0,022	Flu virus	0,064	0,024
Salmonella paratyphi	0,072	0,068	MS-2 Coliphage	0,012	0,0043
Salmonella lyphimurium	0,029	0,011	Poliovirus	0,040	0,015
Sarcina lutea	0,012	0,0045	Rotavirus	0,028	0,0107
Scratia marcescens	0,095	0,037	The simplest ones		
Shigella paradysentcriae	0,141	0,051			
Shigella sonnei	0,077	0,029			
Staphylococcus aureus	0,047	0,0179	Cryptosporidium parvum	0,092	0,033
Staphylococcus faecalis	0,053	0,020	Giardia lamblia	0,209	0,0768
Staphylococcus hemolylicus	0,106	0,042	Seaweed		
Streptococcus lactus	0,037	0,014			
Streptcoccus viridans	0,043	0,115			

Vibrio cholerae (V.comma)	0,066	0,025	Common cholera	0,019	-

The data is not shown in the Table 2.3, are reference books, as they are obtained by different authors and do not always coincide. In addition, it should be taken into account that no functional relationship between σ_s and σ_v a was detected due to different conditions of the disinfection process.

Converting formulas (2.32) and (2.33) and using those taken from Table 2.3 values of constants, it is possible to determine the required dose value for a microorganism at a given bactericidal efficiency of 90, 95, 99 or 99.9% under surface or volumetric irradiation:

$$H_s = -Ln(1 - J_{bk}10^{-2})/\sigma_s, J/m^2 \tag{2.34}$$

$$H_v = -Ln(1 - J_{bk}10^{-2})/\sigma_v, J/m^3 \tag{2.35}$$

Dry and non-dusty air is transparent, despite the presence of microorganisms in it, and practically does not absorb bactericidal UVB in the wavelength range of 205-315 nm. Even a thin layer of air does not allow radiation with a wavelength of less than 200 nm to pass through. This is due to the fact that such radiation interacts with diatomic oxygen molecules O_2, resulting in the formation of ozone – triatomic oxygen molecules O_3. Ozone is an effective bactericidal decontaminator of water and air.

The concentration of ozone in the indoor air of 0.015 mg/m^3 causes a characteristic smell that is felt by humans. Due to its physical and chemical properties, ozone is an extremely toxic gas. Ozone belongs to the first hazard class.

When the ozone concentration in the indoor air is 2 mg/m^3, it causes a person to have a strong cough, nausea, nosebleeds and even poisoning, which leads to death. When exposed to ozone, toxic substances can form on where products. The use of ozone in water disinfection is successfully used to this day [40,41], but its amount is limited due to the appearance of toxic substances [42-44].

Humidity and dustiness of the air affect its ability to pass UVB, while reducing the effectiveness of disinfection. This is due to the fact that water droplets settle on dust particles, which have a shielding effect, as a result of which the transmittance decreases [34].

CHAPTER 3. UV RADIATION SOURCES

3.1. Methods of generating UV radiation

Ultraviolet radiation (radiation) covers the range between visible and X-ray radiation, i.e. between 1 and 400 nm. UV radiation is part of the range of so-called optical radiation [45], which together includes visible radiation from 380 (400) to 760 (780) nm and infrared radiation from 760 (780) nm to 1 mm.

UV radiation Quanta have more energy due to the higher frequency of electromagnetic vibrations than visible radiation Quanta ($\varepsilon = h\nu,$ where $h = 6{,}63 \cdot 10^{-34}$ J·s – UV radiation is better than visible, manifests itself in those phenomena that have a quantum character – photoelectric effect (external and internal), photochemical and photobiological processes [46], and in the latter, the effect of UV radiation on organisms everywhere and animals can be both useful and harmful [47].

On the other hand, UV radiation manifests itself better than X-ray radiation (due to the relatively small wavelength of the latter) in those phenomena that have a purely wave character – dispersion (dependence of the radiation propagation velocity on the optical density of the medium, that is, on its refractive index) and diffraction (strengthening or weakening of the intensity of electromagnetic vibrations (interference) after passing holes or skirting small obstacles, or passing through a system of alternating interference holes (diffraction grating), which allows you to decompose UV radiation into spectra at wavelengths, and due to this, measure the intensity (spectral) at each individual wavelength, determine the so – called spectra of UV radiation and their spectral efficiency in certain phenomena (processes).

Due to the wave properties of UV radiation, there is (and is being realized) the possibility of creating special devices-UV – spectroradiometers, in which the radiation is decomposed into spectra using prisms made of quartz glass (which passes UV radiation well enough) or artificial diffraction gratings, while X-ray diffraction can only be observed on natural «diffraction gratings», namely on crystal lattices of certain solids [48].

By their nature, that is, according to the method (principle) of radiation generation, UV radiation sources, as well as visible radiation sources (light), are divided into [2,49] according to the chronology of development and implementation: thermal; fluorescent; laser; semiconductor (emitting diodes).

Let's consider the principles of generating UV radiation, as well as aspects related to the creation and use of sources of these radiation.

3.1.1. Heat sources

According to the conclusions of classical thermodynamics, any physical body whose temperature differs from Absolute Zero (that is, zero on the Kelvin scale) emits in the optical range. Thermal radiation is generated inside the atoms of substances spontaneously (regardless of the thermal motion of atoms and molecules, the intensity of which also depends on temperature), but the excitation of atoms occurs due to the exchange of atomic energies in the case of interaction during thermal motion. According to the Stefan-Boltzmann Law, the intensity of such radiation is proportional to the fourth power of absolute temperature T [2].

The intensity of radiation in this law is characterized by the total emissivity $\mathrm{E_T}$ a body that is measured by the energy emitted per unit time from a unit of the body's surface over the entire optical wavelength range. Tom Value $\mathrm{E_T}$ it is called «Full» in contrast to the spectral density of the emissivity $\mathrm{E}_{\lambda_1 \mathrm{T}}$, which characterizes the radiation intensity over a separate interval $d\lambda$ length waves.

Formula the Stefan-Boltzmann Law [50]:

$$\mathrm{E_T} = \alpha\sigma T^4, \tag{3.1}$$

where $\sigma = 5{,}67 \cdot 10^{-8}$ $\mathrm{W \cdot м^{-2} \cdot K^{-4}}$; α – body grayness coefficient, which shows how different the body in question is from a completely black body (IRT).

Spectral distributions of IRT radiation at different temperature values in Figure 3.1.

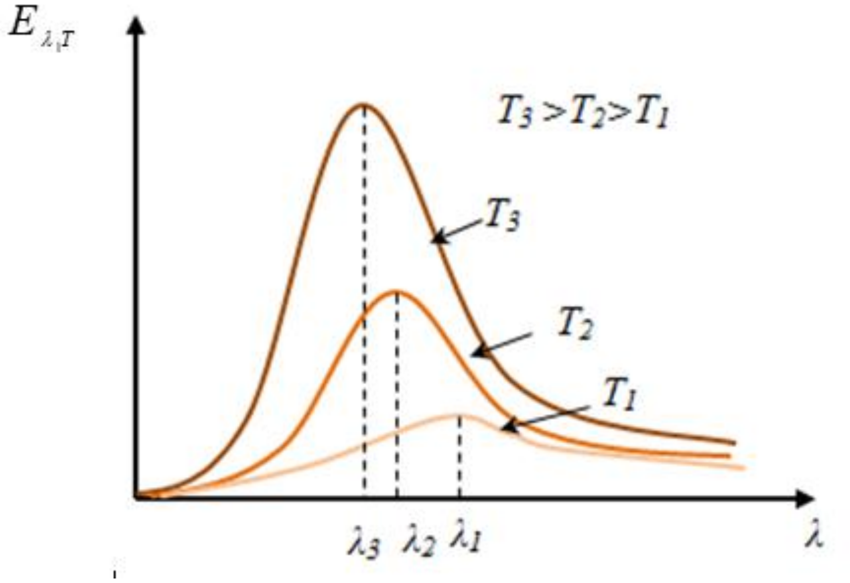


Figure 3.1. Spectral distributions of IRT radiation
($T_3 > 6000K$, $T_2 = 4000K$, $T_1 = 1000K$)

As can be seen from Figure 3.1, as the temperature increases, the area under the spectral distribution curve increases (which indicates an increase in the total emissivity of the IRT), and the position of the wavelength increases λ_{max}, which corresponds to the maximum radiation in the IRT spectrum shifts towards lower values, that is, towards the ultraviolet Region [3].

According to the law (displacement) of wine [6]:

$$\lambda\frac{b}{T_{max}} \text{ або } \lambda_{max} \qquad (3.2)$$

where $b = 2{,}9 \cdot 10^{-3} m$·K - became.

Unfortunately, within the framework of classical thermodynamics, it was not possible to theoretically establish the numerical values of either The Wien constant or the Stefan-Boltzmann constant; they were determined experimentally. Moreover, classical thermodynamics, as well as Maxwell's electromagnetic radiation theory, were not able to explain the distribution of energy in the IRT spectrum. This was done in 1900 by Planck for assuming that the atoms of substances do not emit continuously, but in leaps and bounds, due to the fact that this is how the atoms move from the excited state to the main one, that is, the electrons in them «jump» from a higher energy level to a lower one, and during this a quantum of energy is emitted

$$\varepsilon = h\nu.$$

Formula Planck for spectral emissivity density:

$$\mathrm{E}_{\lambda_1 \mathrm{T}} = \frac{2\pi \cdot h \cdot c^2}{\lambda^5} \cdot \frac{1}{e^{\frac{hc}{\lambda kT}}}, \tag{3.3}$$

where c $=3\cdot10^8$ m·c^{-1} – the speed of light in a vacuum;
k=1.38·10^{-23} J·K^{-1} – Boltzmann; h =6,63·10^{-34} J·s – steel bar.

According to the graphs (functions) of Planck distributions, you can determine the UV efficiency (efficiency factor) of heat sources. It is easy to understand that the efficiency of UV radiation is measured by the ratio of the area bounded by the distribution curve, the abscissa axis, and the short-wave area (Figure 3.1 - left) boundary of the visible radiation region to the area under the entire distribution curve at a given body temperature of the heat source glow.

As can be seen in Figure 3.1, the ratio of these areas under the second curve from below, i.e. at a temperature of 3500 K (close to the melting point of tungsten – the most refractory metal in the world in general and in particular among those from which the incandescent bodies of thermal sources are made), the efficiency of the heat source under UV radiation is insignificant. In Figure 3.1 it can also be seen that even at such temperatures, the main share of Radiation Falls on the infrared (IR) region of the spectral range, not to mention the real values of the temperatures of incandescent bodies, which for conventional tungsten incandescent lamps range from 2400 to 2600 K, and for the brightest tungsten-halogen ones – from 3000 to 3200 K.

For the consumer of UV radiation sources, this means high energy costs for everywhere the desired UV radiation fluxes are emitted.

Therefore, any incandescent lamps are not such that they should be used as sources of UV radiation [5].

3.1.2. Lasers

The main features of these devices are that, firstly, the transition of atoms in the substances of the working bodies of these devices from the excited state to the main one (and at the same time radiation generation) does not occur spontaneously, as in the case of thermal radiation, but is forcibly initiated [51], and, secondly, radiation passing through the substance is not only not weakened, but on the contrary increases [52]. The principle of operation of the laser is as follows [53]: induced radiation is introduced into the working gap of the substance (resonator), at the edges (ends) of which reflectors (mirrors) are located. This process is called «laser pumping». Each part of the radiation (photon), due to successive reflections passes the gap several times, interacting on its way with the atoms of matter, initiates radiation, that is, the appearance of new photons, which in turn are involved in the process described above. Thus, at the first stage of the process, a rapid (avalanche-like) increase in radiation occurs until equilibrium occurs between the number of excited and non-excited atoms. One of the mirrors is Semi-Transparent, which allows photons to partially escape through it, and have a radiation source [51].

The word «laser» comes from the English abbreviation «laser», what does it mean: light amplification by stimulated emission of radiation, that is, «amplification of light by induction radiation». But with the help of such devices, it is possible to amplify other types of electromagnetic radiation from short-wave (microwave) radio radiation to gamma radiation. Then such devices are called «Maser» and «gazer», respectively. And since UV and IR radiation belong to the same region as visible radiation – optical radiation [51], the corresponding devices are called «UV laser» and «IR laser», respectively.

The positive qualities of lasers are that with the help of conventional lenses, the intensity of concentrated beams (10^{-3} cm in diameter) almost everywhere of parallel beams can reach 10^{15} W/cm^2, and the amplitude of vibrations of the electromagnetic field of the wave is 10^9 V/cm. The pressure of radiation (light) in such a stream can reach one million atmospheres, which makes it possible to sew calibrated holes in Superhard Materials [52].

Lasers have many more positive qualities, but their low (about 1 %) efficiency and high cost of these devices (together with their power supply systems) make the use of UV lasers impractical in widely used technological processes that can be implemented by more efficient and simpler means.

3.1.3 Semiconductor sources

One of the manifestations of the quantum nature of radiation (light) is the internal photoelectric effect – the appearance of an electromotive force (EMF) at the boundary of the hole-Electric P–n junction between semiconductors or at the boundary of metal contact with a semiconductor during their irradiation with a stream of photons. Since 1907, researchers from different countries have observed a glow at the interface between a metal and a semiconductor (silicon carbide SiC) during the flow of current through them, that is, the phenomenon is the inverse of the internal photoelectric effect [54]. The glow was bluish-green in color with very low brightness, the practical use of which at that time was out of the question.

But before considering what success has been achieved in this direction over 100 years, it is worth mentioning where is the information from the electronic theory of semiconductors [55].

So, semiconductors are substances with electrical resistivity values (10^{-2}–10^{6} Ω*m), intermediate between metals (10^{-8}–10^{-6} Ω*m) and dielectric values (10^{8}–10^{13} Ω*m).

We consider the mechanisms of formation of electrical conductivity of semiconductors [56].

a) Intrinsic conductivity

The most important semiconductor materials are GE germanium and Si Silicon. The atoms of these chemical elements have 4 electrons on the outer electron shell, which (in pairs with the electrons of neighboring atoms) form valence bonds between the atoms. In the case where additional energy (thermal, light, etc.) is generated, interatomic bonds lose electrons, and positive charges are formed in these places. Such places in the crystal lattice are called holes.

Under the action of an electric field, free electrons move (drift) to the positive pole, and holes to the negative pole (in fact, their places are occupied by valence electrons of neighboring atoms).

Therefore, in a pure semiconductor, there is an intrinsic electrical conductivity due to the thermal excitation of atoms. Carriers of electric charge are electrons and holes (in equal amounts) that move in the electric field in opposite directions. The conductivity increases with increasing temperature.

Electrons that lose their energy are captured by holes; electron-hole pairs recombine. Under constant temperature conditions, the number of electron-hole pairs in a pure single superconductor is constant, since the rate of pair formation and the rate of their recombination are the same (there is a so-called thermodynamic equilibrium).

b) electronic conductivity

The conductivity of a semiconductor can be increased by adding atoms of other elements (doping). In this case, the so-called impurity conductivity occurs. For example, when tetravalent germanium is doped with pentavalent arsenic or antimony or phosphorus, an extra free electron appears at the location of the impurity atom (Figure 3.2).

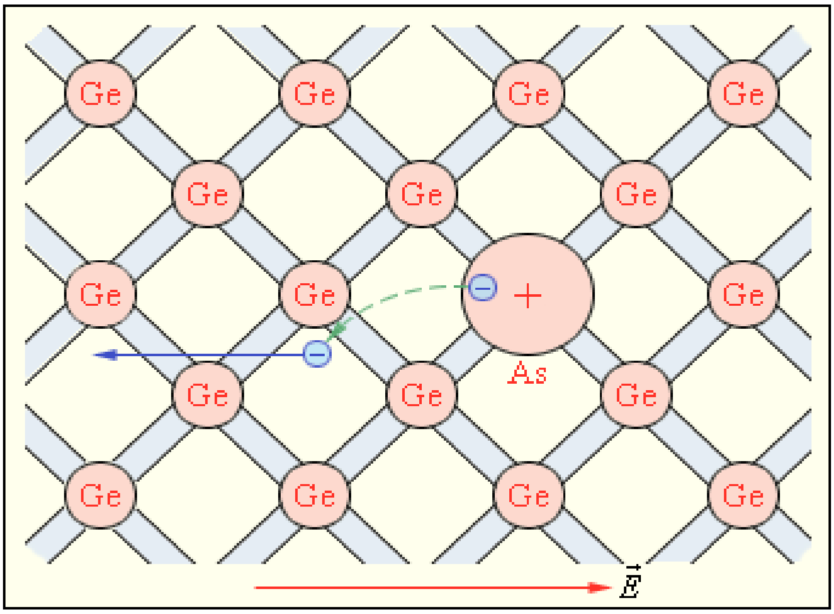


Figure 3.2. Arsenic Atom in the germanium lattice. N-type semiconductor

One impurity atom usually falls on 10^5–10^6 atoms of the semiconductor lattice. Impurities that cause the appearance of free electrons are called donors (i.e., those that give up electrons). In this case, the concentration of n-electrons increases by 10^3, and the concentration of n+ holes remains the same number of times lower. Hence, n- ≈10^6 n+.

Since n - > > n+, electrons are the main charge carriers, and holes are non – basic; germanium in this case is called an electron–conducting semiconductor or an n-type semiconductor.

c) hole conductivity

The conductivity of a semiconductor can be increased by doping it with an element with a lower valence. If, for example, germanium is doped with trivalent indium (or boron or gallium), an extra hole will appear in the location of the impurity atom (Figure 3.3). Impurities that increase the number of holes are called acceptor (i.e., those that «take» electrons). Since now n + « n -, holes are called main charge carriers, and electrons are called non – main ones. Such a semiconductor is called a hole or p-type semiconductor. The main Free charge carriers in r-type semiconductors are holes.

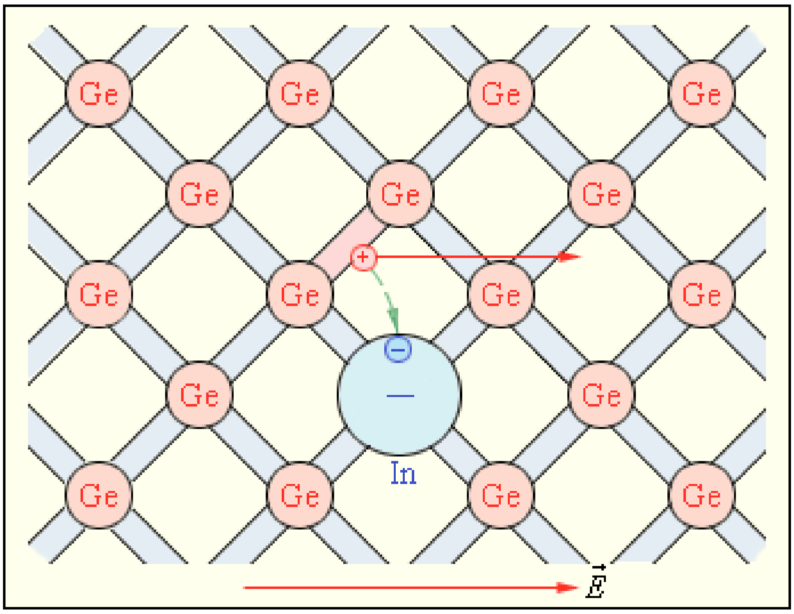


Figure 3.3. Indium Atom in the germanium lattice. r-type semiconductor

d) formation of energy bands in a crystal from discrete atomic levels.

Electrons in an atom have different energy values. Internal electrons that are strongly bound to the nucleus experience only minor disturbances from other atoms, causing their energy levels in the crystal to remain almost as narrow as in isolated atoms. In Figure 3.4 schematically shows a picture of the formation of energy zones in a crystal from discrete atomic levels.

Each energy level of an isolated atom in a crystal corresponds to a zone of permitted levels: 1s – zone 1s, level 2r – zone 2r, etc.

Zones of permitted energies are separated by areas of prohibited energies - forbidden zones.

The degree to which electrons fill the energy levels in the zone is determined by filling the corresponding atomic level. If, for example, a certain level of an atom is completely filled with electrons according to the Pauli principle, then the energy zone formed from such levels is also completely filled. At each Sublevel, according to the Pauli principle, there can be no more than two electrons with antiparallel spins.

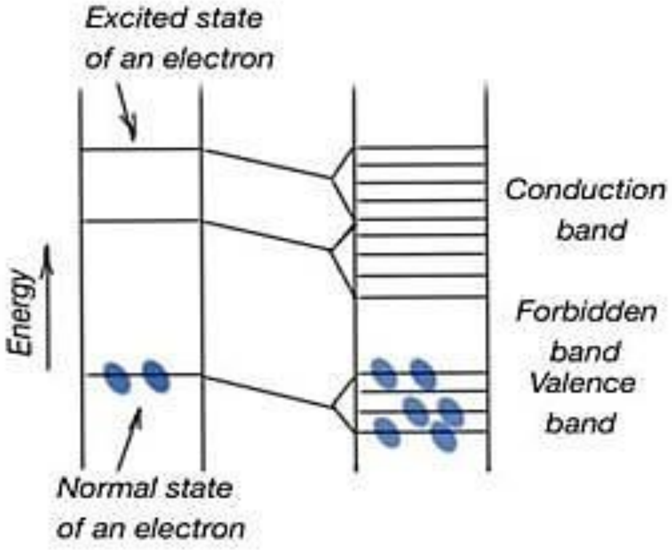


Figure 3.4. Formation of energy zones in the Crystal

Electrons in solids can move from one allowed zone to another. To move an electron from the Lower Zone to the neighboring Upper Zone, it is necessary to spend energy equal to the width ΔW a restricted area that is located between them.

For internal transitions, electrons in the zone need very little energy because the distance between adjacent energy levels in the zone is approximately 10^{-22} eV. For example, an energy of 10^{-4}-10^{-8} eV is sufficient for this, which receives an electron in the metal under the action of an electric field at the free path length at normal potential differences. Under the action of excitation, electrons can be given energy sufficient for both intra-band and inter-band transitions.

The band theory of solids made it possible to explain from a single point of view the physical properties of not only semiconductors, but also metals and dielectrics, explaining the differences in their electrical properties by the unequal filling of allowed zones with electrons and different widths of forbidden energy zones.

To form an electron-hole pair, you need to spend a quantum of radiation, so their recombination can give rise to such a quantum. It also becomes clear that the energy of such a quantum depends on the width of the ΔW band gap [11].

Let's estimate what the band gap should be for the rust-free UV radiation Quanta, for the limit value (between Ultraviolet and visible radiation) λ=400 nm. So,

$$\Delta W = h\nu = \frac{hc}{\lambda} = \frac{6{,}63 \cdot 10^{-34} \cdot 3 \cdot 10^{8}}{4 \cdot 10^{-7}} = 5 \cdot 10^{-9}\ \mathrm{J} = 3{,}1\ \mathrm{eV} \qquad (3.4)$$

Since the p-n junction is a diode (two-pole device), therefore, the developers of diodes that generate UV radiation face the task of selecting semiconductor materials for the formation of the P–N junction, in which the band gap is significantly larger than 3.1 eV.

It should be noted that the need to transfer electrons to more distant energy levels for everywhere radiation at the p–n junction became clear in the 50s of the last century. But for several years, it was possible to create only single-color (red, orange, yellow and green) light-emitting diodes (SVDS) based on Arsenides and phosphates of gallium, arsenic and indium with a luminous flux of no more than 0,02 lm (light output of 0.1-0.2 lm/W), which were suitable for use only as indicator devices.

A real revolution in SVD production occurred in the early 90's with the Everywhere rusting of multi-junction double heterostructures (BPGS) such as GaAlAs, AlInCaAs, AlInCaP [57]. The light output of red and green SVDS increased 100 times and amounted to 10-20 lm/W, and in 2004 reached values of 30-50 lm/W.

In 1994, Japanese physicists of the company «Nichia Chemical Industries» created on the basis of gallium nitride GaN and its solid solutions InGaN and AlGaN SVD with blue radiation color [58], the light output of which can reach more than 200 lm/w.

The appearance of SVDS with radiation in the short-wave part of the visible spectrum opened the way for the creation of UV radiation devices.

Regarding diodes that generate UV radiation, there are reports of creating such diodes [59-62].

The rapid development of SVD in recent years allows us to hope for the near future creation and use of efficient UV radiation diodes. Therefore, it is worth noting the undoubted positive qualities of emitting diodes [57, 59, 60]:

- exceptionally high reliability;
- long service life;
- small overall dimensions;
- no need for external optical elements (lenses, diffusers, reflectors) for most use cases;
- high (up to 100%) radiation flux utilization rate;
- high resistance to mechanical loads;
- ability to operate over a wide temperature range;
- environmental friendliness associated with the absence of mercury and other harmful substances;
- electrical hazard;
- simple power and control circuit diagrams.

Perhaps the only drawback of emitting diodes is the low single Power [62]. But to overcome this, SVD panels are made, which are also called «LED lamps», on which many individual diodes are mounted, connected in series-in parallel, which together form a «surface» that glows evenly. In addition, they produce structural «assemblies» of several SVDS on a single board – the so-called SVD modules.

3.1.4 Fluorescent sources of UV radiation

Of the four known artificial methods of generating UV radiation specified in subsection 3.1, only one remains unexplored - luminescence it is worth noting that luminescent sources of UV radiation are currently the only widely available and effective sources with all their advantages and disadvantages [59].

The main factors determining the efficiency of UV radiation sources are [54,63]: the spectrum of the source, which affects the possibility of using the source in various technologies, lamp power, efficiency, working (useful) and full life, the drop in the UV radiation flux to the end of the lamp life, the compactness and cost of the lamp and the Electronic start-up and power supply unit (EPRA), the safety and manufacturability of using the source, as well as its cost.

In the case of using a source for disinfection, the main characteristic is bactericidal efficiency [54, 5]. Radiation from a rather narrow spectral range of 205-315 nm has the greatest bactericidal effect, so the bactericidal efficiency of a UV radiation source is determined by how close the spectrum of its radiation is to the maximum bactericidal sensitivity (about 265 nm).

The efficiency or efficiency of a source for UV disinfection is the ratio of the radiation power in the bactericidal region to the electrical power of the lamp. In this case, the spectral characteristic of the lamp is given or the power or efficiency is indicated, taking into account the dependence of the bactericidal efficiency on the radiation wavelength [2].

As a rule, when determining the efficiency of the source, losses in the power source are not taken into account, which must be taken into account when calculating the total electrical power of the equipment. Similarly, the effectiveness of a UV source can be determined for other technological processes. Additional requirements may include the possibility of operating the lamp in the air flow or when the ambient temperature changes. In where what technologies it is necessary to ensure fast switching on of the lamp with the appropriate output to the mode. When using UV radiation for the treatment of media or disinfection on an industrial scale, one of the urgent tasks is the speed of processing, so the dose of UV radiation should be provided in a fairly short period of time while the object of treatment is in the irradiation area. To solve this problem, we need powerful, efficient and environmentally friendly sources of UV radiation.

Gas-discharge sources of UV radiation are used most often, since they make it possible to obtain high specific powers of UV radiation with a high efficiency of converting electrical energy. They are characterized by a long service life and are quite easy to operate.

Depending on the discharge conditions and the working substance, the plasma of the gas-discharge lamp emits both a continuous and linear spectrum. The most effective source of UVB with a continuous spectrum is the arc plasma of a gas discharge, the gas in which can be heated to temperatures of 10000 K and above. A high-pressure arc discharge, an example of which is an electric welding arc, is close to a thermal source with a high temperature and a continuous spectrum. However, most applications require UVB of a certain spectral range, so UV radiation sources usually have a selective spectrum designed to achieve the maximum possible effect for a particular process.

To increase the efficiency of converting electrical energy into UVB energy up to 40-80%, a low-pressure electric discharge is used, which gives a linear spectrum. Naturally, the question arises why the conversion efficiency of a low-pressure electric discharge is much higher than that of thermal sources, for example, the same electric discharge in the form of a high-pressure arc. A low-pressure discharge, unlike discharges at pressures above 40-50 kPa, is not isothermal, the gas and Ion temperatures are close to the wall temperature of 40-100°C, and the electron energy is large. Electrons receive energy from an electric field and are heated to temperatures of 1-5eV (1 eV = 11600 K), effectively excite the atoms and molecules of the gas, and only a small fraction of the energy is transferred to the heating of the gas.

For example, to generate bactericidal UV radiation as an emitting Atom, a Mercury atom with a resonant wavelength of 254 nm is well suited, for the excitation of which an electron must have an energy of about 5 eV. With optimal discharge parameters, the theoretical efficiency of converting electrical energy into resonant UV radiation can reach 70% or higher [64]. Part of the Pi where energy is used to heat the gas when electrons collide with mercury atoms and buffer gas, since not every electron collision leads to the excitation of the mercury atom, part – to ionization and excitation of other Mercury lines, so the efficiency of converting electrical energy into UV radiation in high-power low-pressure sources is 25-50 %, and the higher the specific power, the lower the efficiency [65].

For various areas of UVB use, mercury, xenon, excimer, metal vapor and other gas-discharge lamps are currently produced, the flasks of which are made of transparent materials for UV radiation, most often from special glass or quartz. According to the method of summing up electrical energy, lamps are available with electrodes and without electrodes, with continuous and pulsed modes of operation.

Sources based on the discharge in mercury vapor are divided into low-pressure mercury lamps and high-pressure lamps [5, 9].

Only low-pressure mercury lamps will be considered in this paper. We plan to consider high-pressure discharge lamps (Mercury and metal halide), as well as excimer UV lamps in the next research project «Ultraviolet irradiating installations of photobiological action: research and development of technologies for irradiation of bulk food products and seeds of agricultural crops».

3.2 Low pressure Mercury discharge lamps and their classification

Low-pressure discharge lamps include lamps in which the operating pressure of gas (or Steam) 0,1-10^4 Pa.

Mercury vapor-based lamps are most widely used, since it is known that the structure of mercury energy levels is extremely favorable for highly economical generation of resonant radiation in the UV region [9,66]. The optimal mercury vapor pressure is 0.7-1.5 PA, and the pressure of inert gases (most often neon or argon, or a mixture of them) is 10-500 Pa.

Low-pressure mercury lamps are the most effective sources of ultraviolet bactericidal radiation due to the fact that with the optimal selection of parameters (tube diameter, current density, mixture vapor pressure, cooling conditions), more than 60% of the radiation in the ultraviolet region falls on the resonant line of 254 nm, which lies in the range of maximum bactericidal action (Figure 2.4). It is for this reason that they are called bactericidal lamps [66].

Conventionally, low-pressure mercury lamps can be divided into three classes: soft Glass lamps, standard quartz glass lamps, and high-power low-pressure mercury lamps. Where which companies also allocate compact-reduced size due to the U-shaped flask. This is how Philips Lighting distinguishes Philips TUV PL-s class lamps with an electric power of 5.5 to 13 Watts.

The advantages of soft glass lamps are well known, and with relatively low transmission losses, such where lamps are larger than their pure quartz counterparts, easier to manufacture and more durable to store. The most popular lamps are 15, 30, 55 and 75 watts. Philips Lighting and LighTech, which own their own production of uviol glass, are the world's leading manufacturers of this type of source. Major manufacturers can also be attributed in Germany – Osram, and the countries of the Eastern alliance. Low - pressure mercury lamps have relatively low power-in the range from 4 to 300 Watts. The radiation spectrum of a low-pressure mercury lamp is shown in Figure 3.5.

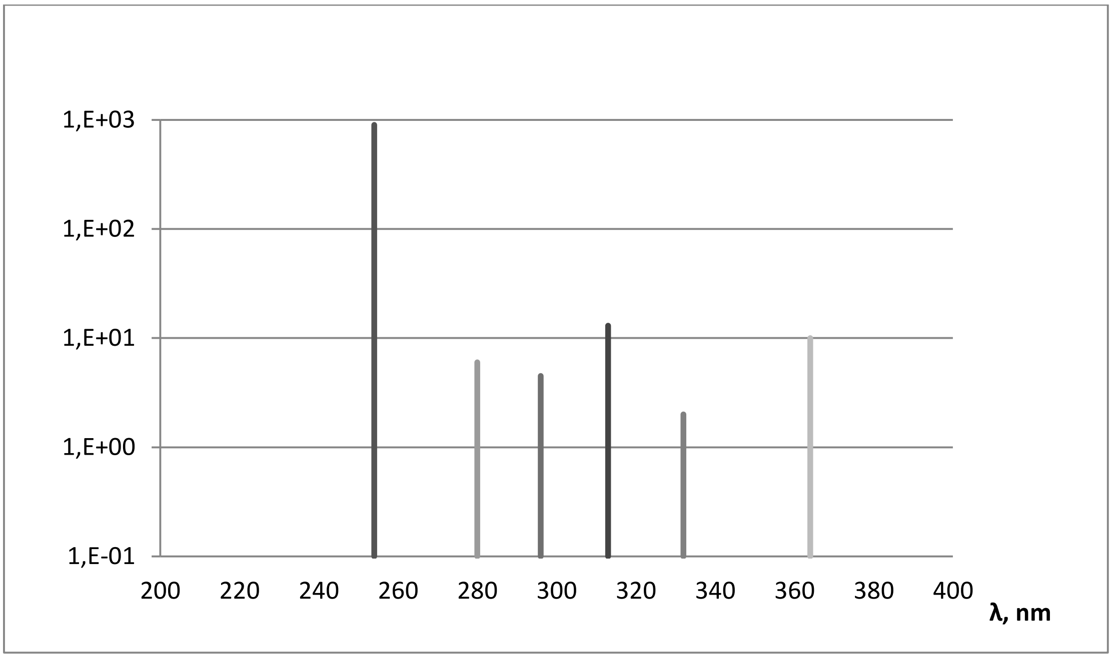


Figure 4.5. Radiation spectrum of a low-pressure mercury lamp

In appearance, low-pressure mercury lamps differ from the known fluorescent lamps only in that no phosphor is applied to the inner part of the tube.

Structurally, such lamps are a cylindrical tube, the length of which is significantly larger than the diameter, made of pure quartz glass (Stanford Quartz), which passes both lines: 185 nm and 254 nm, or from uviol glass (Soft Glass), which practically does not pass the radiation of the 185 nm Line [5].

Taking into account the economic possibilities of obtaining short-wave UV radiation based on a low-pressure Mercury discharge, bactericidal lamps of the DB type were created (Table 3.1) [2]. The bulb of such lamps is made of uviol glass, which transmits UV radiation in the C range.

It is known [67] that attempts were made to create more powerful sources of resonant radiation of a Mercury discharge by increasing the current density and maintaining a low mercury pressure. It is shown that the radiation density of the Mercury line $\lambda = 253{,}7$ nm you can raise it by almost an order of magnitude, but the discharge efficiency in this line drops by almost 10 %. In the Table. 4.1 there are no parameters of the prototype of such a lamp with a power of 1 kW (UV-lamp).

There are lamps made of alloyed quartz glass or with a special coating that also filter the 185 nm line. According to this feature, discharge lamps are divided [2, 5] into ozone and non-ozone.

Table 3.1 shows the technical parameters of where low-pressure Mercury germicidal lamps [2].

Table 3.1

Main technical parameters of where low pressure mercury lamps

Lamp type	P, W	I, A	Nominal bactericidal flow, W	Service life, H	Geometric dimensions, mm	Flask material
ozone						
DB-15	15	0,33	2,5	5000	451x30	uviol glass
DB-30-1	30	0,36	6	5000	909x30	also
DB-60	60	0,7	8	3000	909x30	also
DRB-8-1	8	0,17	1,6	5000	302x16	also
DB-15-E*	15	0,31	2,5	3000	451x30	also
DB-30-E	30	0,36	6	5000	909x30	also
DB-60-Э	60	0,7	8	3000	909x30	also
DRB-8	8	0,17	3	5000	315x17	quartz glass
DRB-40-1	40	0,45	10	3000	540x20	also
DRB-60	60	0,75	15,8	3000	715x28	also

DB-75-1	75	0,67	29	5000	1200x26	also
ozone-free						
DRB-15	15	0,35	4,5	3000	452x25	coated quartz glass
DRB-20	20	0,37	5,6	3000	414x25	also
DRB-40	40	0,45	9	3000	634x25	also
DRB-60	60	0,75	14	3000	715x28	also
DB-18	18	0,35	5	8000	480x16,5	also
DB-36-1	36	0,38	10,5	8000	860x16,5	also
DRBE-8**	8	0,17	2,5	2000	140x16	also

* - *lamps with a lower mercury content;*
** - *U-shaped lamps;*
*** - *prototype*

Leading manufacturers, such as Philips, Osram and LightTech, also specialize in the production of low-pressure uviol glass lamps, which are similar in appearance and technical characteristics to DB lamps. For example, Philips produces TUV series lamps [68], Osram HNS series [69] and LightTech LTC series [70].

TUV, HNS and LTC series lamps are low – pressure discharge lamps that produce short-wave UV radiation with a maximum at 253.7 nm (UV-C) and have a bactericidal effect. The glass filters out the 185 nm spectral line, which causes ozone formation. TUV, HNS and LTC series lamps are used in various fields of activity [68, 69, 70]:

- sterilization of water (drinking water, swimming pool water, sewage);
- sterilization and sterilization of air in air conditioners, hospitals, warehouses;
- surface sterilization in the pharmaceutical and packaging industries;
- erasing information from modern microelectronic memory units.

In Figure 3.6 shows the appearance of a 30 W Philips TUV series uviol glass germicidal lamp with a G13 base.

Figure 3.6. Appearance of the Philips TUV 30W/G13 T8 germicidal lamp.

The characteristics of Philips TUV (Special Fluorescent lamps Disinfection) series UV lamps are not shown in Table 3.2 [68].

Table 3.2

Characteristics of Philips TUV series UV lamps, power from 4 to 115 W

Lamp type	P, W	U, B	UV-C radiation, W	Service life, H	Base type	Geometric dimensions, mm
TUV 4	4	29	0.9	8000	G5	150,1x16
TUV 6	5	42	1.5		G5	226,3x16
TUV 8	8	56	2.1		G5	302,5x16
TUV 10	10	46	2.2		G13	345,7x28
TUV 11	11	37	2.2		G5	226,3x16
TUV 15	15	51	4.7		G13	451,6x28
TUV 16	16	46	3.2		G5	302,5x16
TUV 25	25	46	7.0		G13	451,6x28
TUV 30	30	100	11.2		G13	908,8x28
TUV 36	36	103	15.3		G13	1213,6x28
TUV 55 HO	55	83	18.0		G13	908,8x28
TUV 75 HO	75	108	26.0		G13	1213,6x28
TUV 115 R VHO	115	92	33.5	5000	G13	1213,6x28

TUV 115 VHO	115	92	38.8		G13	1213,6x40
TUV 9 PL-S	9	60	2.4	8000	G23	145x28
TUV 11 PL-S	11	89	3.6		G23	214x28
TUV 18 PL-L	18	60	5.5		2G11	225x38
TUV 36 PL-L	36	105	12.0		2G11	415x38
TUV 55 PL-L	55	103	17.0		2G11	535x38

The characteristics of OSRAM HNS series UV lamps are not shown in Table 3.3 [69].

Table 3.3

Characteristics of OSRAM HNS series UV lamps [69], power from 5 to 55 W

Lamp type	**P, W**	**I, A**	**Energy illuminance, µW/cm^2**	**UV-C power, W**	**Base type**	**Geometric dimensions, mm**
7 W OFR*	7	0,17	-	1,9	G23	137x13
9 W OFR*	9	0,17	-	2,5	G23	167x13
11 W OFR*	11	0,15	-	3,6	G23	237x13
15 W OFR	15	0,33	40	3,5	G13	438x26
30 W OFR	30	0,37	90	8	G13	895x26
55 W OFR	55	0,93	170	15	G13	895x26
G5 W OFR*	5	0,15	18	1,5	G23	122x10
10 W OZ	10	0,17	50	4	E27	221x10
10 W/U OFR	10	0,17	50	4	E27	221x10
20 W/U OZ	20	0,5	80	7	E27	221x10

Note: OZ - irradiators for sterilization and ozonation;
OFR - irradiators for sterilization without ozone formation.

The characteristics of lighttech LTC series UV lamps are not shown in Table 3.4 [70].

Table 3.4

Characteristics of lighttech LTC series UV lamps, power from 4 to 76 Watts

Lamp type	P, W	I, mA	U*, B	Energy illuminance, µW/cm^2	UV-C power, W	Geometric dimensions, mm
LTC4T5	4	180	23	9	0,9	77x15,7
LTC6T5	6	180	34	16	1,6	154x15,7
LTC8T5	8	180	45	21	2,1	231x15,7
LTC11T5	11	280	40	22	2,2	154x15,7
LTC11T5SE	12	280	43	24	2,4	170x15,7
LTC16T5	16	280	44	40	4	231x15,7
LTC16T5SE	17	370	46	42	4,2	245x15,7
LTC40T5	41	370	98	141	15,6	767x15,7
LTC64T5	76	425	180	225	31	1481x15,7
LTC40T5SE	41	425	98	141	15,6	767x15,7
LTC64T5SE	76	425	180	225	31	1481x15,7
LTC10T8	10	280	36	23	2,3	330,3x25,7
LTC15T8	15	350	44	47	4,8	436,2x25,7
LTC30T8	30	380	80	100	11,3	893,4x25,7

** - electrical parameters were measured using an electronic launcher (EPRA).*

The industry has developed so-called Compact bactericidal lamps with a U-shape (Figure 3.7). For these lamps, at the same power as straight tube lamps, the overall length is reduced by almost half (Table 3.2 - TUV PL series lamps, Table 3.3 -HNS series lamps with G23* base, Table 3.4 - LTC series lamps).

Figure 3.7. Lamp Osram HNS 9 W with a G23 base.

In Figure 3.8 shows the emission spectrum of the HNS lamp [69].

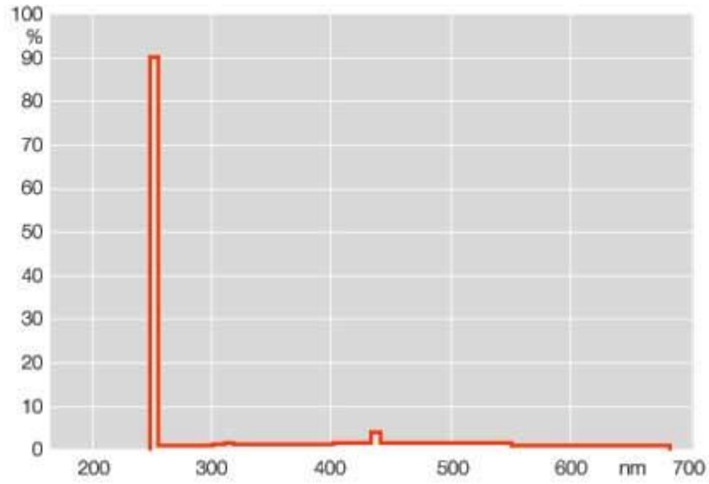


Figure 3.8. Lamp radiation spectrum HNS 9 W OFR.

Characteristics of UV lamps made of uviol and quartz glass LightTech LTC series U-shaped with plinths G23 i 2G11 shown in the Table 3.5 [70].

Standard lamps (Standard quartz) are made of pure quartz, which allows everywhere to emit a higher ultraviolet output and, accordingly, an efficiency of higher transmission at a wavelength of 254 nm (90 %). Depending on the application, quartz can be coated with titanium oxide to absorb short-wave UV Radiation with a wavelength of 185 nm (such lamps are called Band-free). In addition, it is necessary to note other advantages of quartz mercury lamps – this is the absence of solarization effect and significantly higher mechanical strength. The service life of such lamps reaches 16,000 hours, with an efficiency of up to 40 %.

Table 3.5

Characteristics of lighttech LTC Light Tech series U-shaped UV lamps with power from 5 to 13 w and from 18 to 95 w

Lamp type	P, W	I, mA	U, B	Energy illumination at a distance of 1 m, μW/cm^2	UV-C power, W	Geometric dimensions, mm
Made of uviol glass						
LTC5W/G23	5	180	34	9	1,0	83x12.5
LTC7W/G23	7	175	47	16	1,8	115x12,5
LTC9W/G23	9	170	60	22	2,4	145x12,5
LTC11W/G23	11	160	89	33	3,6	214x12,5
LTC13W/G23	13	290	59	31	3,4	155.2x12,5
Made of high-power uviol glass						
LTC18W/2G11	18	370	60	51	5.5	225x17,5
LTC24W/2G11	28	350	87	65	7	320x17,5
LTC35WHO/2G11	35	850	40*	105	11	225x17,5
LTC36W/2G11	36	440	105	110	12	415x17,5
LTC55W/2G11	55	540	103*	156	17	535x17,5
LTC60WHO/2G11	60	670	120	169	18	415x17,5
LTC95WHO/2G11	95	950	100*	304	32	535x17,5

* - *electrical parameters were measured using an electronic launcher (EPRA)*

Table 3.6 shows the characteristics of lighttech quartz glass ultraviolet lamps (Hungary) in the power range from 10 to 79 W [70].

Table 3.7 shows the characteristics of lighttech U-shaped quartz glass

UV lamps with a 2g11 base in the power range from 36 to 95 W [70].

The Eastern Alliance countries also specialize in the production of UV lamps made of quartz and uviol glass of various capacities. Recently, products manufactured in China are widely represented on the market of Ukraine and other countries under the brands of leading manufacturers, as well as under their own trademarks.

Table 3.6

Characteristics of lighttech quartz glass UV lamps, power from 10 to 79 Watts

Lamp type	P, W	I, mA	Energy illumination, $\mu W/cm^2$	UV-C power, W	Geometric dimensions, mm	Service life, H
Cathode preheating lamps «ozon-free»						
GPH212T5L	10	425	27	2.7	212x15	16000
GPH287T5L	14		40	4	287x15	
GPH303T5L	15		43	4.3	303x15	
GPH357T5L	17		57	5.7	357x15	
GPH436T5L	21		72	7.3	436x15	
GPH793T5L	38		125	13.5	793x15	
GPH843T5L	41		150	16	843x15	
GPH1148T5L	55		180	22	1148x15	
GPH1554T5L	75		240	33	1554x15	
GPH1630T5L	79		252	34.5	1630x15	
Lamps with preheating of the cathode»ozone»						
GPH212T5VH	10	425	27	2.7	212x15	16000
GPH287T5VH	14		40	4	287x15	
GPH303T5VH	15		43	4.3	303x15	
GPH357T5VH	17		57	5.7	357x15	
GPH436T5VH	21		72	7.3	436x15	
GPH793T5VH	38		125	13.5	793x15	
GPH843T5VH	41		150	16	843x15	
GPH1148T5VH	55		180	22	1148x15	
GPH1554T5VH	75		240	33	1554x15	

GPH1630T5VH	79		252	34.5	1630x15	
Lamps without preheating the cathode «ozon-free «						
G10T5L	17	425	57	5.7	357x15	16000
G24T5L	32		95	11	692x15	
G36T5L	41		150	16	843x15	
G48T5L	55		180	22	1148x15	
G64T5L	75		240	33	1554x15	
G67T5L	79		252	34.5	1630x15	
Lamps without preheating the cathode «ozone»						
G10T5VH	17	425	57	5.7	357x15	16000
G24T5VH	32		95	11	692x15	
G36T5VH	41		150	16	843x15	
G48T5VH	55		180	22	1148x15	
G64T5VH	75		240	33	1554x15	
G67T5VH	79		252	34.5	1630x15	

Table 3.7

Characteristics of lighttech LTC series U-shaped UV lamps with power from 36 to 95 W

Lamp type	**P, W**	**I, mA**	**U, B**	**Energy illuminetion at a distance of 1 m, μW/cm^2**	**UV-C power, W**	**Geometer. dimensions, mm**	**Service life, H**
LTC35WHO/2G11	36	800	45*	110	11	225x15	9000
LTC36W/2G11	36	440	105	119	13	415x15	
LTC55W/2G11	55	540	103*	168	18	535x15	
LTC60WHO/2G11	60	670	118	179	19	415x15	
LTC95WHO/2G11	95	950	100*	328	34	535x15	

** - electrical parameters were measured using an electronic launcher (EPRA)*

Table 3.8 shows the characteristics of Jiangyin Feiyang Instrument Co. Quartz UV lamps., Ltd (China) in the power range from 15 to 40 W with cathode preheating, Base type G13 [71].

Table 3.8

Characteristics of Jiangyin Feiyang Instrument Co.quartz glass lamps, Ltd power from 15 to 40 W with G 13 type base

Lamp type	P, W	I, mA	U, B	Energy illumination at a distance of 1 m, W/cm^2	Geometric dimensions, mm	Service life, H
ZW15S19W	15	310	40	45	437x19	8000
ZW15S19Y	15	310	40	45	437x19	
ZW20S19W	20	320	70	75	589,8x19	
ZW20S19Y	20	320	70	75	589,8x19	
ZW30S19W	30	360	100	107	894,6x19	
ZW30S19Y	30	360	100	107	894,6x19	
ZW40S19W	40	410	110	117	1199,4x23	
ZW40S19Y	40	410	110	117	1199,4x23	

Table 3.9 shows the characteristics of Jiangyin Feiyang Instrument Co. Quartz UV lamps., Ltd (China) in the power range from 4 to 240 W [71] with an unbalanced 4-pin 4pe base (Figure 3.9).

Figure 3.9. Ultraviolet lamps made of quartz glass Jiangyin Feiyang Instrument Co., Ltd with a base type 4 pe.

Table 3.9

Characteristics of quartz lamps Jiangyin Feiyang Instrument Co., Ltd 4 up to 240 W with 4pe base

Lamp type	**P, W**	**I, mA**	**U, B**	**Energy illumination at a distance of 1 m, W/cm^2**	**Service life, H**
ZW4D15W(Y)	4	133	30	26	8000
ZW8D15W(Y)	8	265	30	26	
ZW10D15W(Y)	10	250	22-39	21-24	
ZW14D15W(Y)	14	350	28-39	31-35	
ZW15D15W(Y)	15	370	30-40	33-37	
ZW17D15W(Y)	17	275	62	72	
ZW18D15W(Y)	18	340	34-46	48-54	
ZW23D15W(Y)	23	420	40-55	62-69	
ZW28D15W(Y)	28	370	51-69	85	
ZW37D15W(Y)	37	350	78-101	110	
ZW40D15W(Y)	40	380	81-99	120-130	
ZW55D15W(Y)	55	320	122-149	150-180	
ZW75D15W(Y)	75	330	173-210	180-210	
ZW80D19W(Y)	80	800-1200	120	240-270	
ZW120D19W(Y)	120	800-1200	170	330-380	
ZW150D19W(Y)	150	800-1200	220	400-450	
ZW250D19W(Y)	250	1600-1800	190	3000	

Table 3.10 shows the characteristics of compact U-shaped germicidal lamps of Jiangyin Feiyang Instrument Co., Ltd with power from 5 to 55 W [71].

Table 3.10

Characteristics of Jiangyin Feiyang Instrument Co.lamps, Ltd 5 to 55W U-shaped power supply

Lamp type	P, W	I, mA	U, B	Energy illumination at a distance of 1 m, W/cm^2	UV-C power, W	Service life, H
ZW5D12WG5PL/L	5	180	34	18	1,2	8000
ZW7D12WG7PL/L	7	180	47	22	1,9	
ZW9D12WG9PL/L	6	170	60	41	2,4	
ZW11D12WG11PL/L	11	160	89	50	3,2	
ZW18D12WG18PL/L	18	370	60	66	5,5	
ZW24D12WG18PL/L	24	340	87	85	8,5	
ZW36D12WG36PL/L	36	430	105	114	12	
ZW55D12WG55PL/L	55	540	103	145	17	

The «High Output Quartz» series lamps are a version of the more powerful Quartz standard lamps. Such lamps operate with a higher current of 0.6-0.8 A instead of 0.3-0.45 a compared to standard lamps, have a more powerful electrode and, of course, a higher UV Radiation power [71]. Philips Lighting (Holland), LightTech (Hungary), Heraeus Noblelight (Germany), Osram (Germany), and Ushio (Japan) are the world's leading manufacturers of lamps of the classes mentioned in this section.

Table 3.11 shows the characteristics of lighttech «high Output Quartz» series UV lamps in the range from 48 to 155 W [70].

The highly economical generation of low-pressure Mercury discharge Radiation makes it possible to take advantage of photoluminescent transformations of short-wave Radiation to longer-wave Radiation. On this principle, erythema lamps of the LE and leer types with a wavelength of 280-315 nm for UV-in the region were developed [2]. The radiation spectrum of an erythema lamp is shown in Figure 3.10.

Table 3.11

Characteristics of lighttech quartz glass UV lamps, power from 48 to 155 Watts

Lamp type	P, W	I, mA	Energy illumination, W/cm^2	UV-C power, W	Geometric dimensions, mm	Service life, H
lamp «ozonne»						
GHO436T5L	48	800	120	13	436x15	16000
GHO36T5L	87		260	28	842x15	
GHO846T5L	90		265	29	846x15	
GHO893T5L	95		270	30	893x15	
GHO64T5L	155		395	54	1554x15	
lamp «ozone-free»						
GHO436T5VH	48	800	120	13	436x15	16000
GHO36T5VH	87		260	28	842x15	
GHO846T5VH	90		265	29	846x15	
GHO893T5VH	95		270	30	893x15	
GHO64T5VH	155		395	54	1554x15	

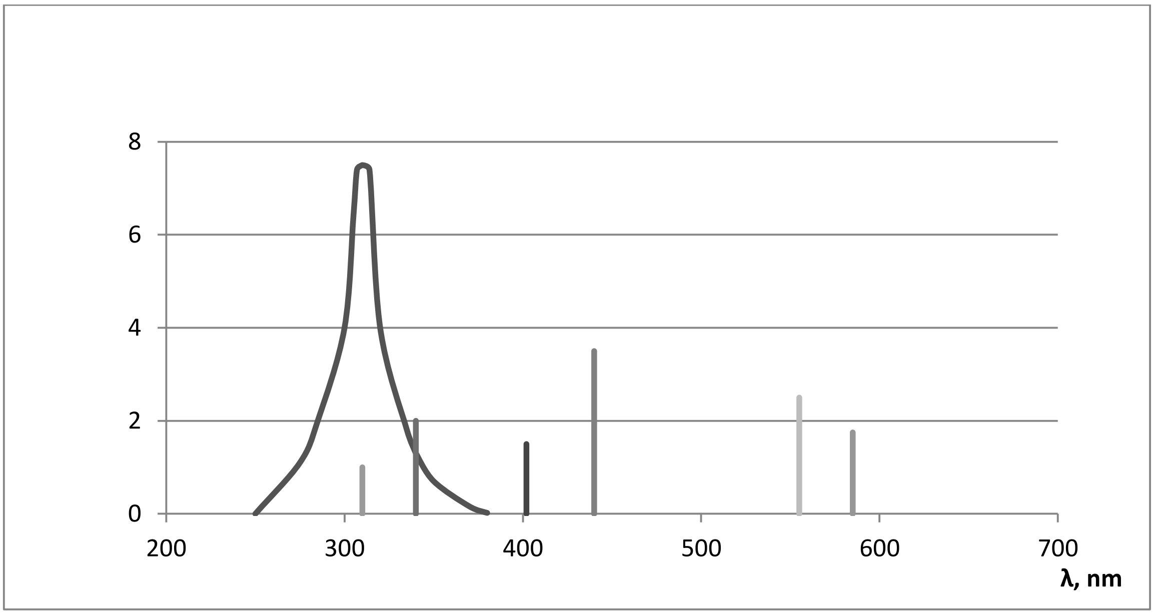


Figure 3.10. radiation spectrum of low-pressure erythema lamp

For the longer-wave region of the UV-C range of 315-400 nm, ultraviolet lamps of the LUF type are used [2], which are used to compensate for ultraviolet insufficiency in devices for creating artificial tanning of the skin, tanning salons, photochemical processes, phototherapy, for skin treatment, in photobiology. The Radiation spectrum of a LUF 40 lamp is shown in Figure 3.11.

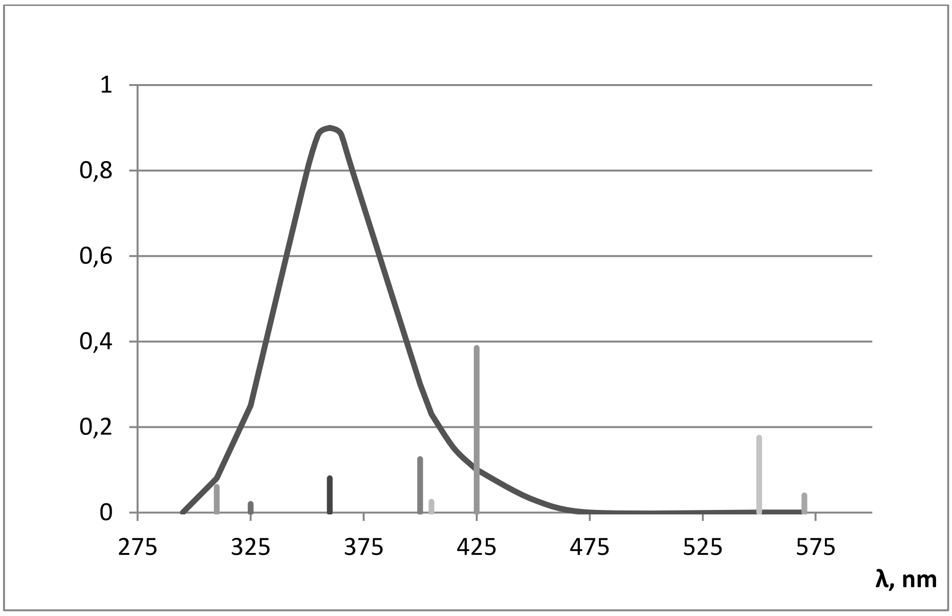


Figure 3.11. radiation spectrum of low-pressure lamps of the LUF type 40.

Table 3.12 shows the parameters of erythema lamps and LUF lamps for tanning [2].

Table 3.12

Parameters of erythema lamps and LUF lamps

Lamp type	P, W	U, B	Spectral range Radiation, nm	Radiation flux in the spectral range, W	Service life, H.	Geometer. dimensions, mm
LE 30	30	104	280-315	9,5	5000	908x30
LER 40	40	103	280-315	14,0	3000	1213x40
LUF 80	80	102	300-400	9,2	4000	1213x40
LUF 80-2	80	102	300-400	10,0	7500	1213x40

The world's leading manufacturers also produce erythema lamps of the UV-A range, for example, Osram calls the Eversun series of tanning lamps [69], a Philips – CLEO (CLEO Professional, CLEO Performance, CLEO EFFECT, CLEO Compact) [68]. The characteristics of these lamps are presented in Tables 3.13 and 3.14-3.16, respectively.

Table 3.13

Characteristics of lamps with radiation in Area A for tanning salons and beauty salons Osram series EVERSUN

Lamp type	P, W	UV-A radiation, W	UV-B radiation, W	Safety factor**	Geometric dimensions, mm
L 100W/78 R*	100	26	0,02	>50	1760x38
L 40/79 R	40	8	0,05	4	590x38
L 80/79	80	21	0,15	4	1500x38
L 80/79 R	80	18	0,13	4	1500x38
L 100/79	100	27	0,19	4	1760x38
L 100/79 R	100	23	0,16	4	1760x38
L 100/79 Super	100	27	0,38	0,8	1760x38

Note: R - is a reflex lamp. Safety factor ** - the ratio of erythema threshold times to direct pigmentation. The higher this value, the lower the risk of sunburn.*

EVERSUN 78 R lamps with virtually Pure Type A ultraviolet radiation (wavelength above 350 nm). When exposed to radiation in this range, there is practically no risk of getting burned for normal skin. With a sufficiently long exposure due to skin pigmentation, the tanning effect appears shortly after the first irradiation session.

EVERSUN 79 and 79 R lamps with high-power ultraviolet Radiation Type A for direct pigmentation and with a small component of ultraviolet Radiation Type B for new pigment formation. Due to the minimum value of the type B ultraviolet component, the risk of sunburn is minimal. The Radiation spectrum of the EVERSUN l 40/79 lamp is shown in Figure 3.12.

EVERSUN SUPER lamps with a similar effect to sunlight, due to a significant component of ultraviolet Radiation Type A and a harmonic component of Type B. After regular use of irradiation procedures, a stable natural tan is formed as a result of prolonged pigmentation of the skin with a high degree of protection of the skin from radiation.

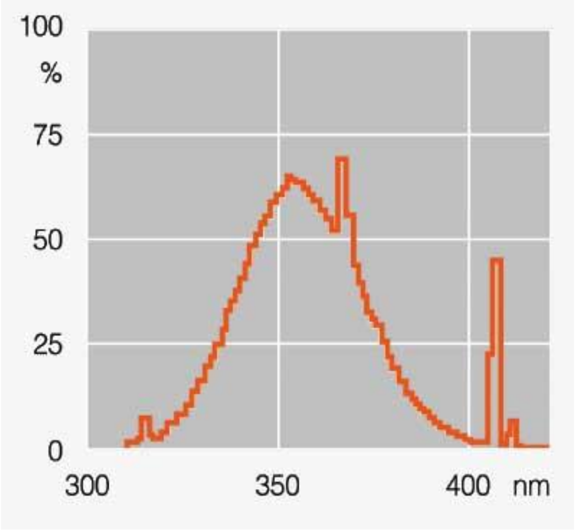


Figure 3.12. Radiation spectrum of the EVERSUN l 40/79 lamp

Philips-CLEO Effect lamps are the first representatives of the generation of tanning lamps. Unlike CLEO lamps, CLEO effect lamps are made in T8 tubes (diameter 26 mm). The lamps provide long-wave UV Radiation in the range of 300-400 nm. The radiation ratio in the UV-B/UV-A ranges is 1 % (UV-B range 280...315 nm) or 2 % (UV-B range 280.320 nm). The advantage of these lamps is the equality of Radiation powers in the ranges up to 320 nm and above 320 nm.

Scope of use – indoor tanning units.

Table 3.14 shows the main characteristics of the Philips CLEO Effect series tanning lamps.

Philips CLEO Performance low-pressure Mercury fluorescent lamps provide long-wave UV Radiation in the range of 310-400 nm, designed for tanning and other applications. The Radiation ratio in the UV-B/UV-A ranges is 0.7% (UV-B range 280...315 nm) or 1.4% (UV-B range 280. 320 nm).

Table 3.14

Characteristics of lamps with radiation in Area A for tanning Philips CLEO Effect series

Lamp type	**U, B**	**I, A**	**Radiation UV-A, W**	**Erythema Radiation, mW with wavelength**		**Geometer. dimensions, mm**
				less than 320 nm	**more than 320 nm**	
Long-wave UV Radiation in the range of 300-400 nm						
Effect 70 W	105	0,85	18	14	14	1514,2x26
Effect 70 W-R*	105	0,85	16	12	12	1514,2x26
Effect 90 W	114	1,0	23	17	17	1778,0x26
Effect 90 W-R*	114	1,0	21	15	15	1778,0x26

** R - lamps with reflector*

Scope of use of such lamps: cosmetic tanning, photochemical processes.

Reflectors (- R) have an internal reflector with a transverse coverage angle of 200°. Lamps with the P symbol in the marking have Radiation with a pink hue.

Table 3.15 shows the main characteristics of Philips CLEO performance tanning lamps.

Philips CLEO Professional low-pressure Mercury fluorescent lamps provide long-wave UV Radiation in the range of 300-400 nm, designed for tanning and other applications.

The Radiation ratio in the UV-B/UV-A ranges is 1.4 % (UV-B range 280...315 nm) or 2.6 % (UV-B range 280.320 nm). CLEO Professional-R lamps have an internal reflector with a transverse coverage angle of 200°. CLEO Professional-S-R lamps have a UV-B/UV-A ratio of 1.6 %.

For lighting tanning lamps with a power of 80 W and 100 W, it is recommended to use a starter type S11. for lamps with a power of 140 W or 160 W, it is recommended to use a starter S12.

Table 3.15.

Characteristics of Philips CLEO performance series radiation lamps in Area A for tanning

Lamp type	**U, B**	**I, A**	**Radiation UV-A, W**	**Erythema Radiation, mW with wavelength**		**Geometer. dimensions, mm**
				less than 320 nm	**more than 320 nm**	
Long-wave radiation UV-A in the range of 310-400 nm						
Performance 40W	49	0,86	7,4	4,04	5,58	604,0x26
Performance 40W-R	49	0,86	6,5	3,55	4,90	604,0x26
Performance 80W	110	0,83	21,0	11,47	15,83	1514,2x26
Performance 80W-R	110	0,83	18,5	10,10	13,95	1514,2x26
Performance P 80W	110	0,83	20,0	10,92	15,08	1514,2x26
Performance	110	0,83	18,0	9,83	13,57	1778,0x26
Performance 100W	122	0,97	27,0	14,74	20,36	1778,0x26
Performance 100W-R	122	0,97	25,0	13,65	18,85	1778,0x26
Performance P 100W	122	0,97	26,0	14,20	19,60	1778,0x26

Performance P 100W-R	122	0,97	23,0	12,56	17,34	1778,0x26
Performance 140W-R	118	1,46	30,0	19,00	21,47	1514,2x26
Performance P 160W-R	116	1,61	35,0	22,20	25,00	1778,0x26

Scope of use – professional installations for cosmetic tanning.

Table 3.16 shows the main characteristics of Philips CLEO Professional tanning lamps.

In addition, fluorescent lamps (LL) with flasks made of «black» glass are also known [68, 69]. The inner surface of the bulb is coated with a phosphor that emits long-wave UV Radiation (UV-A range, wavelengths from 300 to 400 nm), which excites the glow of fluorescent materials. A black or dark blue glass flask lets in UV Radiation. Radiation in the visible range is kept to a minimum so that it does not interfere with ultraviolet radiation.

Areas of use:

- control and analysis in the textile and chemical industries;
- archeology, banking, criminalistics, food industry, medicine, mineralogy, philately; special effects in nightclubs, discos, and theaters;
- sign lighting.

Table 3.16.

Characteristics of lamps with radiation in Area A for tanning Philips CLEO Professional Series

Lamp type	**U, B**	**I, A**	**UV-A radiation, W**	**Erythemne Radiation, mW with wavelength**		**Geometer. Dimensions, mm**
				<320nm	**>320nm**	
Long-wave radiation UV-A in the range of 300-400 nm						
Professional 80W	110	0,83	18	32,76	14,04	1514,2x26
Professional 80W-R	110	0,83	16	29,12	12,48	1514,2x26
Professional 100W	122	0.97	25	45,50	19,50	1778,0x26

Professional 100W-R	122	0.97	21	38,22	16,38	1778,0x26
Professional 140W	118	1,46	30	54,60	23,40	1514,2x26
Professional 140W-R	118	1,46	28	50,96	21,84	1514,2x26
Professional 140W-S-R	118	1,46	33	51,61	24,28	1514,2x26
Professional 160W	116	1,61	34	61,88	26,52	1778,0x26
Professional 160W-R	116	1,61	31	56,42	24,18	1778,0x26
Professional 160W-S-R	116	1,61	37	57,87	27,23	1778,0x26

The main characteristics of Osram LL with a «black» (dark blue) flask are not shown in Table 3.17, but Philips LL is shown in Table 3.18.

Table 3.17.

Characteristics of OSRAM LL with «black» flask

Lamp type	Power, W	Lamp current, A	Overall dimensions, mm	Plinth
L 18W/73	18	0.37	590x26	G13
L 36W/73	36	0.43	1200x26	G13

The Radiation intensity measured at a distance of 1 m from the center of the lamp is L18W/73 ~ 0.5 W/m^2 for the lamp, and L36W/73 ~ 1 W/m^2 for the lamp. TL(- D)/08 black light lamps are designed in linear tubular flasks and operate in an AC Network with a PRA and a starter. In addition to the lamps described above, the PL-S 9W/08 lamp consists of two fluorescent tubes soldered together; the PL-S 9W 2P lamp additionally contains a starter built into the base, which ensures fast ignition of the lamp.

To facilitate ignition, low-pressure mercury lamps are equipped with electrodes in the form of spirals located at the ends of the tube, through which current is passed before applying a high-voltage pulse to preheat them to the appropriate temperature. Preheating the electrodes significantly increases the service life of the lamps. With «hot» ignition, each switch-on reduces the service life by about 2 hours, and with «cold» ignition by several times more.

Table 4.18.

Characteristics of Philips Blacking Blue LL with «black» flask

Lamp type	Power, W	Lamp current, A	Radiation UV-A, W	Overall dimensions, mm	Plinth
TL 4W/08	4	0,17	0,5	1501,0x16	G5
TL 6W/08	6	0,16	0,9	226,3x16	G5
TL 8W/08	8	0,15	1,2	302,5x16	G5
TL-D 15W/08	15	0,34	3,1	451,6x16	G13
TL-D 18W/08	18	0,36	3,5	604,0x16	G13
TL-D 30W/08	30	0,36	6,0	908,8x16	G13
TL-D 36W/08	36	0,44	8,0	1213,6x16	G13

During the operation of low-pressure mercury lamps, the Radiation flow decreases [2, 3, 5]. Its particularly rapid drop is noted during the first where spots of burning hours and can reach more than 10% of the initial value. In the future, the decrease in the Radiation flux slows down. This process is illustrated by the graph shown in Figure 4.13 for a germicidal lamp DB 40 and DB 30 [2].

The radiation flux value of low-pressure mercury lamps depends on the ambient temperature. The optimal value of the ambient temperature is 20°C. a decrease or increase in this temperature leads to a change in the lamp parameters, which is shown in the graph shown in Figure 3.14. a decrease in temperature also leads to a decrease in the service life and deterioration of ignition [2, 5].

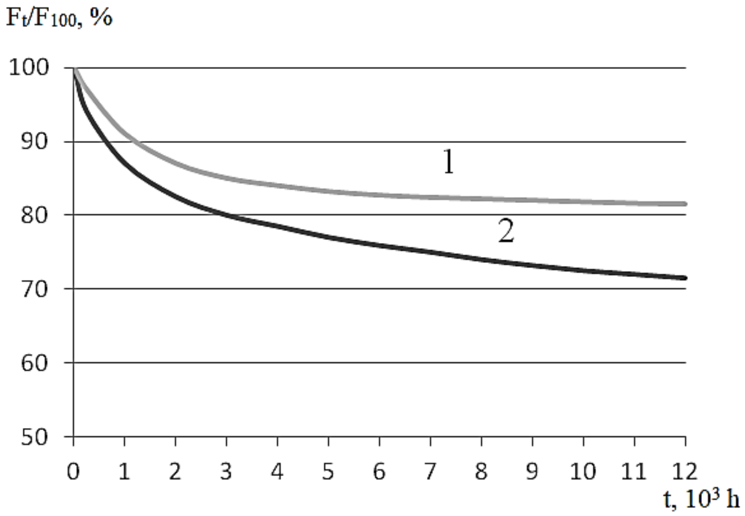


Figure 3.13. Dependence of radiation flux attenuation low-pressure mercury lamps from the burning time (1 – DB-40; 2 – DB-30)

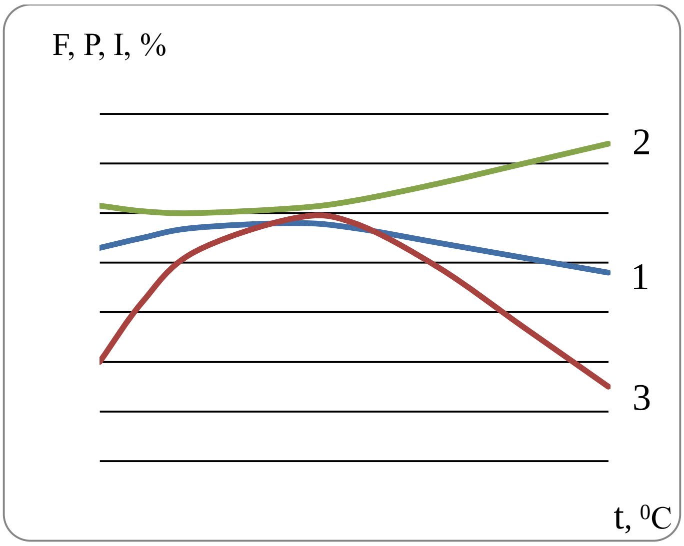


Figure 3.14. Dependence of low-pressure mercury lamp parameters on ambient temperature: 1 - lamp power P; 2 - Current I; 3 - Radiation flux

At temperatures below 10°C, a significant number of lamps may not light up. This effect increases when the network voltage decreases [2, 5]. The electrical and radiating characteristics of low-pressure mercury lamps depend on voltage fluctuations. In Figure 3.15 shows the graph of the dependence of lamp power and radiation flux on voltage fluctuations.

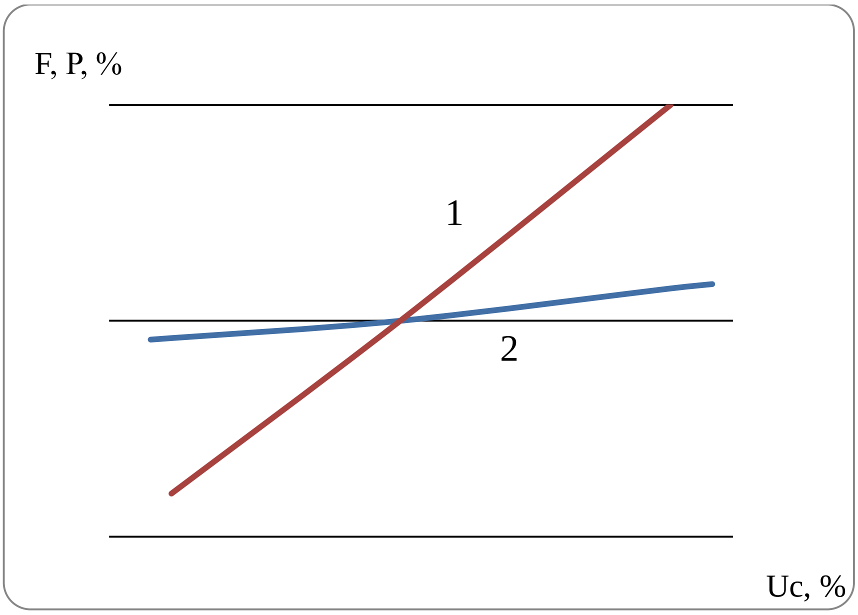


Figure 3.15. Change in the power of a low-pressure mercury lamp (1) and radiation flow (2) from mains voltage fluctuations

Depending on the type of Lamp, The Current varies from 1.8 to 0.1 A, and the service life of low-pressure lamps depends on the type of ballast used. Traditionally, when using a throttle-type launcher, the service life does not exceed 5-9 thousand hours, with the use of electronic launchers of so-called HF (high frequency) ballasts, the service life reaches 16-18 thousand hours and above [21].

One of the varieties of low-pressure lamps is amalgam lamps [2], which are widely used for bactericidal disinfection, the source of UV Radiation is an arc discharge in mercury vapor and inert gases, as in conventional low-pressure lamps. The difference between them lies in the source of mercury vapor: a drop of metallic mercury is placed in the bulb of mercury lamps, and amalgam lamps use amalgam – a hard alloy of Mercury with metals. In Figure 3.16 the appearance of the SPA «LIT» DB 300 amalgam lamp is presented.

Figure 3.16. Amalgam lamp SPA «LIT» DB 300

The use of amalgam makes it possible to maintain the optimal pressure of mercury vapors in a low-pressure discharge at significantly higher currents and, accordingly, capacities than in traditional low-pressure lamps using liquid mercury (the pressure of saturated mercury vapors over liquid mercury is significantly higher than over amalgam at the same temperature). In this way, it is possible to increase the electrical power of the discharge to 2-3 W/cm and maintain a high efficiency of converting electrical power into UV Radiation, which is characteristic of low-pressure mercury lamps.

In addition, the use of amalgam makes it possible to raise both the operating temperature of the bulb and increase the range of external temperatures at which high light output of the lamp is maintained. Using a different composition of amalgams, it is possible to obtain areas of stabilization of mercury vapor pressure in different temperature ranges. The width of the temperature range with stable mercury vapor pressure is also determined by the composition of the amalgam.

In Figure 3.17 it is shown that using a 4-component amalgam, it is possible to provide a mercury vapor pressure of 0.7-1.5 PA in a wide temperature range from 60 to 150 °C. Thus, for the required lamp power, you can choose your optimal amalgam composition (Figure 3.17-3.19).

In the simplest version of an amalgam lamp containing mercury, the alloy is placed directly on the inner wall of the discharge tube. In this case, the wall temperature coincides with the operating temperature of the amalgam. For where what amalgam composition, the pressure characteristics are so stable that the lamp can operate effectively over a wide temperature range of the bulb wall, for example, from 80 to 130 °C (see Figure 3.17-3.19).

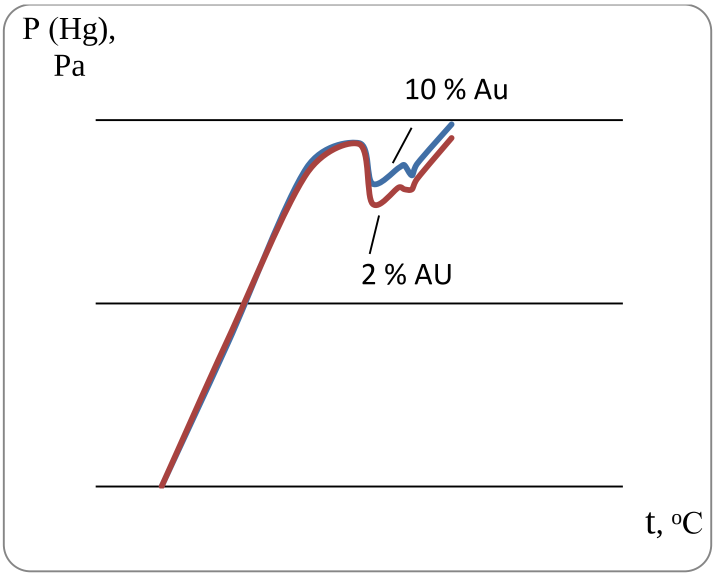


Figure 3.17. dependence of mercury vapor pressure on temperature above $Bi_{0,55}Pb_{0,43}Au_{0,02}Hg_{0,01}$ *i* $Bi_{0,5}Pb_{0,4}Au_{0,1}Hg_{0,01}$ *amalgams*

In Figure 3.18 indicates the dependence of the relative radiation power on the wall temperature of the amalgam lamp. In Figure 3.19 here is the dependence of UV Radiation power on Wall temperature for mercury and amalgam lamps. Since amalgam lamps operate at high wall temperatures, therefore, the power is not as sensitive to changes in ambient temperature as that of low-pressure mercury lamps.

Currently, the world's largest sources in the production of amalgam lamps offer UV Radiation sources with a power of 50 to 1000 W with an efficiency of 25 to 42 %, at discharge currents from 1 to 7 A, a decrease in UV Radiation to the end of the service life of 5-30% and a useful service life of 8000 to 18,000 hours.

The main sources of light in the production of such specific light sources as a powerful amalgam lamp include the following companies: Heraeus Nobelight (Germany), Philips Lighting (nowhere), LSI/Lighttech (USA/Hungary), First Light (USA) and Ushio (Japan).

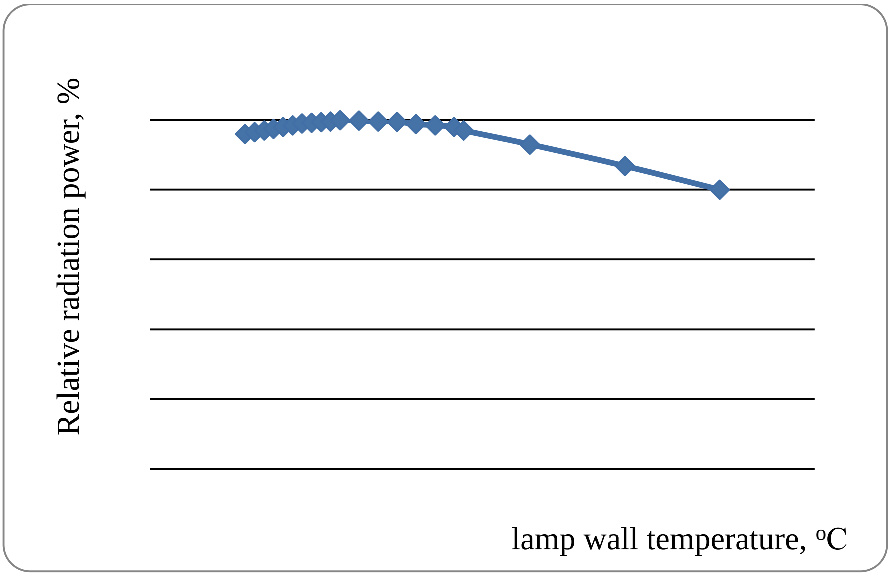


Figure 3.18 Dependence of the UV Radiation power of a low-pressure amalgam lamp on the bulb wall temperature

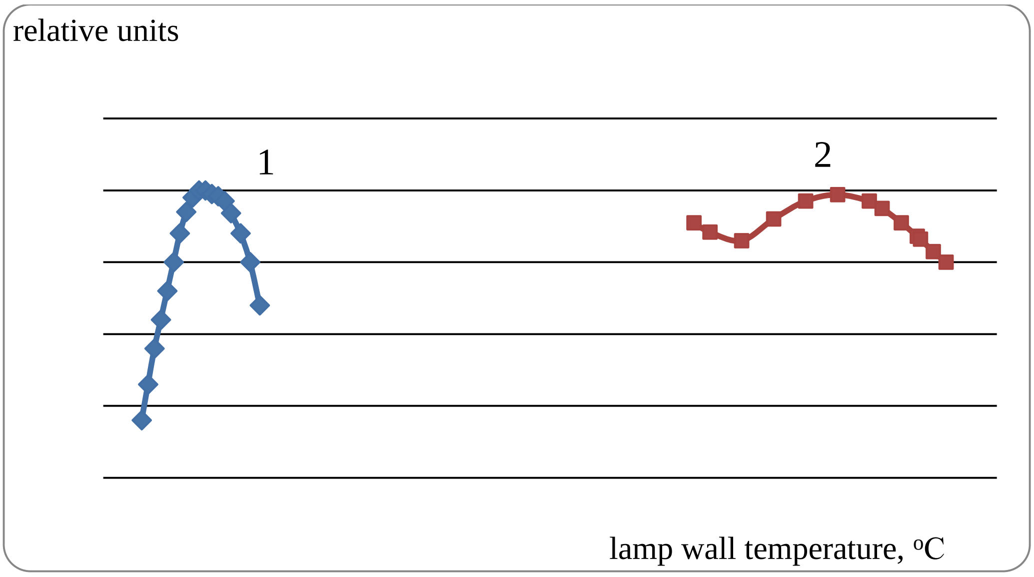


Figure 3.19. Dependence of UV Radiation power on bulb wall temperature for Mercury (1) and amalgam (2) lamps

The wide variety of amalgam sources is due to the fact that such lamps are becoming more and more widespread in various fields of use, the main of which are water, air and surface disinfection. We can say that over the past 15 years, the equipment market, as well as the market for amalgam bactericidal lamps themselves, has been increasing. In many cases, a low-pressure amalgam lamp is not only the optimal solution for water and air disinfection tasks, but often the only possible one, because in terms of the combination of key indicators it is the only alternative: efficiency (bactericidal, as well as energy efficiency), environmental friendliness (mercury content and other harmful materials), lamp and EPRA service life [72], UV Radiation decline [73], lamp and EPRA cost, unit power.

Despite its simplicity, the amalgam lamp is a complex electric vacuum device. In addition to high efficiency, it should have a high service life and work for 1-2 years without a noticeable decrease in the power of UV Radiation when the ambient temperature changes 5-70 °C. The size of the lamps and their power depend on the specific areas of use. To prevent the formation of ozone in the air, the lamp bulb is made of quartz doped with titanium oxide (approximately 200 ppm), which absorbs ozone Radiation with a wavelength of 185 nm. Such lamps are called zone-free, and the spectrum of UV Radiation bactericidal action consists of a single line of 254 nm.

One of the main goals of manufacturers is to increase the power of bactericidal amalgam lamps while maintaining the efficiency of generating UV Radiation 254 nm of about 35-40% and a useful service life of at least 12000-16000 hours for use in water and air disinfection installations.

Recently, and taking into account significant progress in the technology of using amalgam lamps, especially SPA «LIT» DB500, DB700HO, DB900HO (Table 3.19) together with the corresponding electronic ballast controlled by the controller, make it possible to carry out deep regulation of UV power (as well as electrical power) of the system in the range from 100 to 30%, while the use of multicomponent amalgams and special algorithms for the operation of lamp electrodes allow not only to regulate, but also significantly increase the efficiency of the entire system. Thus, UV equipment based on such powerful amalgam lamps with special properties provides an economical mode of operation with reduced (for example, at night) water consumption.

Table 3.19

Amalgam lamps SPA «LIT» series no power from 115 to 610 W

Lamp type	Lamp power, W	Warranty service life, H	Overall size, mm
DB 125 HO	115	10000	412
DB 250 HO	228		682

DB 500 HO	460		1227
DB 700 HO	610		1660

An important characteristic is the number of lamp on and off switches [29], which depends on the design of the lamp electrode assembly, the EPRA operation algorithm, and their mutual matching. The correct choice of the EPRA start algorithm in the starting period, the optimal design of the electrode, the ability to work with the lamp current set by the EPRA, allow you to achieve a lamp life of up to 25000 hours, while the number of ON/OFF switches can reach 50-100 thousand cycles, which is quite comparable to the electrodeless versions of amalgam lamps. However, it can be noted that in most cases, the Value of 2000-5000 inclusions during the entire lamp life is quite sufficient. Where the companies mentioned above, in addition to the possibility of manufacturing UV-Radiation amalgam sources, can also offer ready-made solutions, that is, the «lamp + EPRA» kit with optimally selected parameters. This is a company Philips Lighting.

In general, it should be noted that modern technologies for the development of amalgam lamps are determined by the corresponding tasks, so, for example, the task of reducing the cost of UV installations and reducing operating costs when replacing lamps leads to the task of creating an amalgam lamp with a high unit power, which allows you to reduce the number of lamp units, make the installation more compact and where it is at the same consumption and water quality. On the other hand, increasing the power of the lamp leads to a decrease in its efficiency, as well as to an even greater decrease in the total efficiency of the lamp-EPRA system due to a decrease in the efficiency of the EPRA. Therefore, the task of choosing a source is complex, taking into account the initial capital investment in equipment, the cost of replacing lamps and EPRA, and operating costs.

The use of multicomponent amalgam lamps makes it possible to obtain Radiation sources with several maximum Radiation power over temperature. Due to the complexity of calculating the thermodynamic functions of multicomponent amalgams, the choice of amalgam is carried out experimentally, which is not always an easy problem to solve. This limits the widespread use of amalgam lamps in the spheres of human activity for the purpose of bactericidal disinfection.

CHAPTER 4. MEASUREMENT OF UV RADIATION PARAMETERS

4.1. Method of measuring Energy illumination and dose UV Radiation

Measurement of the parameters of UV Radiation sources is carried out by measuring the Energy illumination in regions A, B, C and, if necessary, calculating the energy strength of Radiation sources in regions A, B, C based on the obtained data, or the energy dose of Radiation in regions A, B, C [2,74].

When making everywhere measurements, the measuring equipment specified in Table 4.1 [1] is used.

Table 4.1

Measuring equipment

№	Name of measuring equipment	Metrological characteristics	
		Measuring range	Basic error limit
1	Ultraviolet Energy illumination radiometer (Tensor -31)	(10^{-4} – $2 \cdot 10^2$) W/m^2 from 200 nm to 400 nm	$\delta = \pm 10\%$
2	Roulette	5 м	1 mm
3	Stopwatch	From 0 s to 30 min	$\Delta = \pm$ 0,1 c

When carrying out measurements, it is possible to use any radiometers of Energy illumination, the Metrological characteristics of which are not worse than those indicated in the Table. Also, this measuring equipment must be an attorney or pass the state Metrological certification.

When performing measurements, the necessary conditions (environmental requirements) must be observed:

* ambient temperature from 10 ^{0}C to 35 ^{0}C;

* atmospheric pressure from 84.0 KPa to 106.7 KPa (from 630 mm Hg up to 800 mm Hg art..);

* air humidity from 40% to 80%.

Safety requirements must be observed when performing measurements:

If the total surface of the unprotected skin areas of the meter is not more than 0.2 m^2, the duration of the irradiation period is up to 5 minutes. if the duration of pauses between them is not less than 60 minutes, then the Energy illumination at the place where the measurements are made should not exceed [1]:

- for region a (400 nm-315 nm) - 50 W/m^2;
- for Region B (315 nm – 280 nm) – 0.05 W/m^2;
- for the C region (280 nm – 200 nm) – 0.001 W/m^2.

Otherwise, the measurement should be discontinued and additional protection of personnel from UV Radiation should be provided.

Preparing for everywhere measurements:

1. Before making measurements, make sure that the UV Radiation source is working properly. Use the operational documents to determine the type and full name of the source. It is necessary to check the operability of the radiometer in accordance with its operational documents.
2. Ensure reliable reproducible installation of the Radiometer, which allows you not to change its position when installing filters and measuring the distance from it to the source. The radiometer must be focused on the UV Radiation source. Prepare the radiometer for operation in the range in which maximum illumination is expected.
3. Stabilize the parameters of the UV Radiation source (if this is provided for in their technical documentation) and the measuring equipment used during the time specified in the operational documents.
4. Measure the illumination in the range in which maximum illumination is expected, using a shortened method (without using filters and everywhere corrections).
5. Check the illumination using a shortened method (without using filters and making corrections), make sure that the indicators are stable. Observation time – at least 5 minutes.
6. Check the possibility of using the radiometer to work with the measured UV Radiation source in accordance with RMG 69 [75], RMG 70 [76] and RMG 71 [77]. To do this, in each of the regions a, B, and C, you should measure the signal from the source without additional filters, then measure the signal from the radiometer with additional filters. If the first signal is more than 5% of the second signal, the radiometer is not suitable

for working with this source. Colored glass filters according to RMG 69, RMG 70 and RMG 71 can be replaced with filters from the radiometer kit. Monitoring the operation of the radiometer with the measured source can be replaced by monitoring the operation of the radiometer with a household incandescent lamp, which significantly improves the quality of checking the characteristics of the radiometer.

Method for measuring Energy illumination and UV radiation dose in [78]:

1. Measurement of Energy illumination is carried out in order to determine the effect of UV Radiation on the object located in the place of irradiation. When measuring Energy illumination, follow these steps:

Record radiometer readings in regions A, B, and C without additional filters and with additional filters;

If necessary (for example, for tanning salons), repeat the previously specified steps at several points. Fix the location of the measurement points, indicating them relative to the characteristic points of the equipment.

2. Measurement of the Energy illumination dose is carried out in order to determine the effect of UV Radiation on an object located at the irradiation site and exposed to UV Radiation for a limited time. There is a distinction between measuring the UV Radiation dose from sources with a constant Radiation level and from sources with a variable Radiation level.

2.1 The dose anywhere from sources with a constant level of Radiation depends on the time of stay of the object in the irradiation zone, so the time of stay is not measured, but only indicated. PR Record radiometer readings in regions A, B, and C without additional filters, and then with additional filters.

2.2 The dose generated from sources with a variable Radiation level depends on the time of stay of the object in the irradiation zone and the operating mode of the source. When measuring the dose of Energy illumination from sources with a changing Radiation level, perform the following steps:

Find out the time period during which the dose should be determined. The beginning of the time interval should be determined in relation to characteristic events, for example, in relation to switching on the source or in relation to placing an object in the irradiation zone;

Record the readings of the radiometer without a nozzle in Area A at regular intervals during the time during which the dose must be determined. The recommended number of measurements is from 10 to 20 in the specified time.

The minimum interval between measurements should be longer than the time required to set the instrument readings. Record the measurement time relative to the characteristic action (specified in the previous paragraph);

Record the radiometer readings with the nozzle in Area A at the same time points;

Repeat the specified steps for areas B, C;

Exclude the source and radiometer in accordance with the rules that are not stated anywhere in the operating documents.

3. Measurement of the energy strength of the radiation source is made in order to rust the characteristics of the UV Radiation source.

3.1 To measure the maximum energy force of the radiation source, install the radiometer in the plane of symmetry of the source at a distance not less than twice the maximum size of the source. The recommended distance is 5 maximum source sizes. Measure the distance from the center of the source to the radiometer, and record the result in the measurement protocol.

3.2 Record radiometer readings in regions A, B, and C without additional filters and with additional filters.

3.3 To measure the spatial distribution of the Radiation energy force of the source, find out the directions in which the measurement should be performed. Record radiometer readings in regions A, B, and C without additional filters and with additional filters for each direction.

Processing and processing of measurement results: enter corrections in the measurement results due to differences in the conditions during radiometer calibration and measurements. Calculate for each source the amount of energy illumination according to the obtained measurement results, in accordance with the rules of this technique, or in the operating documents of the radiometer;

If necessary, calculate the dose of Energy illumination and the energy strength of the Radiation source for each source.

To correctly measure Energy illumination, it is necessary to have a receiver with constant spectral sensitivity inside one of the regions A, B or C and zero sensitivity outside this region. Technically, this requirement is very difficult to implement, so there are specific spectral problems that lead to significant errors. In everywhere, spectral corrections are made in order to take into account the difference between the actual spectral sensitivity of the radiometer channels and in everywhere and the difference between the measurement conditions and the conditions under which the radiometer was graded. Below are the main formulas used when making amendments.

The signal of each of the radiometer channels with A, B, and C channels can be recorded:

$$I_{A,B,C} = \int_0^\infty \mathrm{E}(\lambda) S_{A,B,C}(\lambda) d\lambda \tag{4.1}$$

where: $I_{A,B,C}$ – signals of each of the A, B, and C channels of the radiometer; $S_{A,B,C}(\lambda)$ – sensitivity of radiometer channels; $E(\lambda)$ – spectral illumination in the radiometer plane.

The result of measuring energy illuminations in the corresponding intervals $E_{A,B,C}$ can be recorded:

$$E_{A,B,C} = \int_{A,B,C} E(\lambda) d\lambda = \frac{I_{A,B,C} \int_{A,B,C} E(\lambda) d\lambda}{S_{A,B,C} \int_0^\infty E(\lambda) S_{A,B,C}(\lambda) d\lambda} \tag{4.2}$$

where: $E(\lambda)$ – relative spectral illumination in the radiometer plane; $S_{A,B,C}(\lambda)$– relative spectral sensitivity of receivers A, B, and C channels, i.e. each of them is normalized at any wavelength within the A, B, and C ranges; $S_{A,B,C}(\lambda)$ – the experimentally measured absolute sensitivity of receivers A, B, and C channels, its Definition and accounting are the task of the radiometer manufacturer.

Equation 5.2 contains the actinicity coefficient-expression

$$F_{A,B,C} = \frac{\int_{A,B,C} E(\lambda) d\lambda}{\int_0^\infty E(\lambda) S_{A,B,C}(\lambda) d\lambda} = \frac{\int_0^\infty E(\lambda) P_{A,B,C}(\lambda) d\lambda}{\int_0^\infty E(\lambda) S_{A,B,C}(\lambda) d\lambda} \tag{4.3}$$

For an inaccurate source, the illumination generated by it $E_{A,B,C}$, related to the energy power of the Radiation source $I_{A,B,C}$ and the distance from the source to the radiometer L the equation

$$I_{A,B,C} = E_{A,B,C} L^2 K_g \qquad (4.4)$$

Value K_g [79] it is determined from Table 4.2 as a function of the distance between the source and the radiometer, expressed in fractions of the maximum lamp size.

For example, if the distance from the radiometer to the lamp is 2 meters, the maximum lamp size is 1 meter, then the distance in fractions of the lamp size is glass anywhere 2, the coefficient is 1.17.

Table 4.2

Definition Value K_g

Distance in fractions of size lamps	**Multiplier**	**Distance in fractions of size lamps**	**Multiplier**	**Distance in fractions of lamp size**	**Multiplier**
1	1,60	4	1,05	7	1,01
1,1	1,51	4,1	1,04	7,1	1,01
1,2	1,44	4,2	1,04	7,2	1,01
1,3	1,38	4,3	1,04	7,3	1,01
1,4	1,33	4,4	1,04	7,4	1,01
1,5	1,30	4,5	1,04	7,5	1,01
1,6	1,26	4,6	1,03	7,6	1,01
1,7	1,23	4,7	1,03	7,7	1,01
1,8	1,21	4,8	1,03	7,8	1,01
1,9	1,19	4,9	1,03	7,9	1,01
2	1,17	5	1,03	8	1,01
2,1	1,16	5,1	1,03	8,1	1,01
2,2	1,14	5,2	1,03	8,2	1,01
2,3	1,13	5,3	1,03	8,3	1,01
2,4	1,12	5,4	1,02	8,4	1,01

2,5	1,11	5,5	1,02	8,5	1,01
2,6	1,10	5,6	1,02	8,6	1,01
2,7	1,10	5,7	1,02	8,7	1,01
2,8	1,09	5,8	1,02	8,8	1,01
2,9	1,08	5,9	1,02	8,9	1,01
3	1,08	6	1,02	9,0	1,01
3,1	1,07	6,1	1,02	9,1	1,01
3,2	1,07	6,2	1,02	9,2	1,01
3,3	1,07	6,3	1,02	9,3	1,01
3,4	1,06	6,4	1,02	9,4	1,01
3,5	1,06	6,5	1,02	9,5	1,01
3,6	1,06	6,6	1,02	9,6	1,01
3,7	1,05	6,7	1,02	9,7	1,01
3,8	1,05	6,8	1,02	9,8	1,01
3,9	1,05	6,9	1,02	9,9	1,01

There are many methods for accounting for the finite size of the source, reflecting different degrees of approximation to reality. For any location or calculation, the error of the final source size becomes insignificant when measuring at a distance of more than 4 maximum lamp sizes. It is allowed to use other methods within the scope of amendments, for example, in accordance with RMG 69, RMG 70 and RMG 71. In this case, you should specify the formula by which the amendment was calculated.

For calculating the dose of Energy illumination in regions A, B, and C of the UV range $D_{A,B,C}$ from sources with a constant level of Radiation, it is necessary to multiply the Energy illumination $E_{A,B,C}$ [W] in the relevant area for the time t [s] of the object's stay in that area

$$D_{A,B,C} = E_{A,B,C}t \tag{4.5}$$

For calculating the dose of Energy illumination in regions A, B, and C of the UV range $D_{A,B,C}$ from sources with variable Radiation levels, it is necessary to multiply the Energy illumination when measuring at each time point $\mathrm{E}^{i}_{A,B,C}$ [W] in the appropriate area for the time t_i [c] between measurements and add results.

$$D_{A,B,C} = \sum_{i=0}^{n} E_{A,B,C}^{i} t_i \tag{4.6}$$

4.2 Method of measuring bactericidal flow

Radiation measurements of germicidal lamps are carried out in the following order [2]:

Irradiation proportional to the radiation flux is measured with an Argus-06 radiometer, Tensor-31 or any other certified radiometer in the rank of a working measuring instrument, provided that its main relative error is not more than 10 %. The dynamic range of measured irradiation with an error of 10% for Argus-06 is equal to 1.10-3-2,00 W/m^2, for Tensor-31 – 1.10-3-2.102 W/m^2. The vast majority of irradiators in medical institutions use lamps of the DRB-8, dB-15 and DB-30 types with a nominal bactericidal flow of 1.6, 2.5 and 6 W, respectively. If you use the formulas (5.7 and 5.8), you can calculate, taking into account the size of the lamps, the irradiation from the lamps at the installation site of the radiometer receiving head: 0.57 W/m^2 (at a distance of 0.5 m), 0.22 and 0.5 W/m^2 (at a distance of 1.0 m), respectively. Therefore, these irradiation values are within the dynamic range of the radiometer.

To estimate the error in measuring the Radiation flow, «working standards» (PE) are used. Radiation flux PE at the rated mains voltage must differ by no more than + 5% from the nominal value specified in the technical specification for lamps used in the irradiator. There must be at least two PE's for each lamp type. Radiation flux lamps are determined by the formula when selecting PE:

$$F_{\mathrm{P}} = \Omega_c \mathrm{I} = \Omega_c \mathrm{E}'_{\mathrm{p}} \lambda^2 \tag{4.7}$$

where Ω_c – equivalent solid angle equal to 11.3 sr for a gas-discharge cylinder emitter, according to [80,81]; I – Radiation lamp power, W/sr; E'_{p} – irradiation, W/m^2, measured by a radiometer; λ – distance between the lamp and the radiometer in meters. When the ratio of the length of the emitting part of the lamp, L to λ no more than 0.2 relative error due to deviation from the square law of distance of no more than 1 % [82].

According to [83] at $L/\lambda < 0.2$:

$$\mathrm{E}''_P = I\frac{(f + 0.5\,sin\,2f)}{L\lambda},\ \mathrm{W/m^2} \tag{4.8}$$

where: $f = arctg(L/2\lambda)$, Rad-the angle at which half of the radiating part of the lamp is visible from the point directly below the lamp, where the radiometer is located;E''_P – the total irradiation from two symmetrical (left and right) emitting parts of the lamp, measured by a radiometer at this point, W/m^2.

Using formula (4.8) and performing the corresponding transformations, we obtain the formula for defining the Radiation flow:

$$F_P = \frac{\mathrm{E}''_\mathrm{P} L\lambda\Omega_C}{(f + 0.5\,sin\,2f)},\ \mathrm{W} \tag{4.9}$$

Relative error of deviation from the square law of distance depending on the ratio L/λ you can calculate it using the formula:

$\sigma = (1 - \mathrm{E}'_\mathrm{P}/\mathrm{E}''_\mathrm{P}) \cdot 100$, % або

$$\sigma = \left\{1 - \frac{L}{\lambda}\left(arctg\,\frac{L}{2\lambda}\right) + 0.5\,sin\,2\,arctg\left(\frac{L}{2\lambda}\right)\right\} \cdot 100,\ \% \tag{4.10}$$

The value of the relative error of deviation from the square law of distance, calculated by the formula (4.10), for a lamp with the length of the part that shines $L = 0{,}8$ m when λ =1, 2, 3 і 4 m makes up σ = 10, 3, 2, 6 і 1 % accordingly.

When determining the Radiation flow PE, it is necessary to estimate the main relative measurement error Δ, using mathematical statistics methods. To do this, you must conduct $n \geq 6$ measurements of the irradiation value E_1 from each lamp and calculate the radiation flux value $F_{P(1)}$ by the formula (4.9). Next:- determine the arithmetic mean of the Radiation flow:

$$\bar{F}_P = \frac{\sum_{l=1}^{l=n} F_{\text{P}(l)}}{n} \tag{4.11}$$

- the relative mean square deviation of the measurement results is determined by the formula:

$$\sigma_{\text{в}} = \frac{\left[\frac{\sum_{l=1}^{l=n}\left(F_{\text{P}(l)} - \bar{F}_{\text{P}}\right)}{n(n-1)}\right]^{0,5}}{\bar{F}_{\text{P}}} \times 100, \% \tag{4.12}$$

- the value of the coefficient for a confidence probability of 0.95 is determined by the formula:

$$t_{0,95} = 2\left[\frac{n-1}{n-3}\right]^{0,5} \tag{4.13}$$

- confidence limits (excluding the sign) of random error of the measurement result are determined by the formula:

$$\varepsilon = t_{0,95} \cdot \sigma_{\text{в}} \tag{4.14}$$

- if $\theta/\sigma_{\text{в}} \leq 0{,}8$, then the non-exclusive systematic error in comparison with the random one is ignored and taken as the error of the measurement result $\varDelta = \varepsilon$;

- if $\theta/\sigma_{\text{відн}} > 8$, then the random error in comparison with the systematic one is ignored and assume that the error limit of the measurement result is assumed $\varDelta = \theta$;

- if $\theta/\sigma_{\text{відн}} < 8$, then the error of the measurement result $\varDelta = \theta + \varepsilon$.

The measurement results are considered satisfactory if $\varDelta \leq 15$ %. Here is a practical example of the definition of the bactericidal flow of the DB-30 lamp.

The measurements were carried out at a mains voltage of 220 V with a ballast resistance in the form of an approximate measuring choke. Irradiation measurements were carried out 10 minutes after the lamp was warmed up, then the lamp power was turned off for 10 minutes. This cycle was repeated 6 times. The results of nave where irradiation measurements are not shown in Table 4.3.

Table 4.3

Results of irradiation measurements

n_1	**1**	**2**	**3**	**4**	**5**	**6**
E''_P, W/m^2	0,473	0,497	0,489	0,493	0,478	0,48
$F_{P(1)}$, W	5,9	6,2	6,1	6,15	5,96	6,0

In the same Table, there are no values of the lamp Radiation flux for each measurement, calculated by formula (4.9) based on the fact that the part of the lamp that glows $L = 0{,}8$ м, a $f = arctg(L/2\lambda)$=21,8^0 = 0,38 rad.

Using the data in Table 4.3, according to the formulas (4.11), (4.12), (4.13) and (5.14) calculate the values respectively F_P, $t_{0,95}$ i ε, which names are not shown in Table 4.4.

Table 4.4

Value F_P, $t_{0,95}$ i ε

F_P, W	$\sigma_в$, %	$t_{0,95}$	ε, %
6,05	1,93	2,58	4,98

Because $\theta/\sigma_в = 10/1{,}93 \approx 5,$ then $\Delta = \theta + \varepsilon = 10 + 4{,}98 = 14{,}98 < 5$ %.

So, the results of Definition of the bactericidal flow of the DB-30 lamp $F_P = 6{,}05$ W with a confidence probability of 0.95 are satisfactory.

CHAPTER 5 PHYSICAL AND CHEMICAL METHODS OF WATER DISINFECTION

5.1 Indicators of epidemic safety of drinking water

Water is the most important component of the life of all living organisms. it is an integral indicator for the plant and animal worlds, as well as for the person himself. water quality is determined by the complex of its chemical, biological components and physical properties, which determine the suitability of water for water use [45].

The main requirements for the quality of drinking water as a whole were determined in the middle of the 20th century. These include the following criteria: drinking water must be safe from an epidemic point of view, drinking water must be chemically harmless, drinking water must have satisfactory organoleptic properties.

These criteria are accepted today all over the world. When assessing the risk of drinking water for public health, microbiological contamination is of greatest importance. It is believed that the danger of diseases from microbiological water pollution is several thousand times higher than when water is polluted with chemical compounds of various nature. Reliable disinfection is one of the main tasks in the production of drinking water. In the documents of the World Health Organization (WHO), it is stated: «The potential consequences of microbial contamination are such that they must be monitored at all times.»

Considering the special importance of the quality of drinking water for the health of the population, the World Health Organization (WHO) is developing basic water quality standards, which are issued in the form of «Guidelines for the control of the quality of drinking water». These documents include the following WHO standards for drinking water [84]: microbiological indicators; inorganic components; radioactivity; organic indicators; pesticides and components used or produced during water disinfection.

In addition to WHO international standards, there is a European Union Drinking Water Directive, which lists water pollutants that are a priority for control.

Achieving guaranteed quality based on microbiological indicators is possible only if the water disinfection system meets a number of requirements. Requirements for the drinking water disinfection system [2]: efficiency, continuity, reliability, human safety, environmental safety.

Since drinking water is the most important substance for every person's consumption, it should be the object of state legislation in every country.

In particular, the Law of Ukraine [48], is in force in our country, which includes the legal, economic and organizational principles of the functioning of the drinking water supply system, which is aimed at the guaranteed supply of the population with high-quality and safe drinking water for human health.

This law establishes in the field of drinking water and water supply:

- subjects of relations (authorities, water supply enterprises, consumers) and objects of legal regulation (public relations);
- guarantees of consumer rights;
- principles of state policy and powers of authorities;
- regulations regarding economic activity;
- rights and obligations of drinking water consumers;
- rights and obligations of drinking water supply enterprises;
- measures to provide drinking water in case of emergencies;
- provisions regarding standardization and rationing;
- economic mechanisms;
- regulations on sanitary protection;
- regulations on monitoring, accounting and control;
- responsibility for violation of legislation;
- directions of international relations.

Among the urgent measures in the implementation of this legislative provision is the improvement of the regulatory framework that determines the quality of drinking water, in accordance with the development of science [49]. The basis of the hygienic requirements for the quality of drinking water is the principle that directly determines the characteristics of water quality, on which human health and living conditions depend. Based on this principle in the middle of the 20th century. a triad of hygienic requirements for drinking water was formulated: drinking water should be safe in epidemiological and radiation terms, harmless in chemical composition and have favorable organoleptic properties. This triad is now recognized all over the world and on its basis, national normative documents in the field of drinking water quality control are created.

As a result of improving the sanitary and microbiological control of water, in order to increase the reliability of ensuring the epidemic safety of water use by the population, in addition to the E.coli indicator, various countries also use such indicator indicators as enterococci, total microbial count (TCM), total coliform bacteria (TCB), thermotolerant coliform bacteria (TCB). In our country, until 2010, as the main microbiological indicators of drinking water, TCM (CFU colony-forming units (microorganisms) no more than 100 in 1 cm^3) and coli index (CFU <3 in 100 cm^3) were standardized, an indicator that ensured a high degree of epidemic safety of water use, as it made it possible to determine a wide range of bacteria of the Enterobacteriaceae family, which includes a group of indicator coliforms, a large group of opportunistic and pathogenic bacteria [50].

However, studies conducted both in our country and abroad have shown that sanitary indicator bacteria do not guarantee the safety of drinking water use in relation to infections [51], caused by pathogens that are more resistant to the action of traditional modes of water treatment and disinfection by pathogenic intestinal protozoa [52,53]: giardia cysts, dysentery amoebas, cryptosporidium oocysts and others.

One of the main regulatory documents in force in Ukraine, which systematizes and sets out the main hygienic requirements for the quality of water of centralized domestic and drinking water supply, is the State Sanitary Norms and Rules [54]. This document includes, in addition to the sanitary indicator groups of bacteria (TCM, total coliform bacteria), also coliphages – indicators of viral contamination and giardia cysts, cryptosporidium oocysts, as representatives of parasitic protozoa, etc.

Safety indicators in relation to the epidemic are given in Tables 5.1 and 5.2 (according to Tables No. 1 and No. 2 in [2]).

Table 5.1

Microbiological indicators of drinking water safety

№ з/п	**Name of indicators**	**Units of measurement**	**Norms for drinking water**
1	Total microbial count at t 37° C - 24 h*	CFU/cm^3	≤ 100 (≤ 50)**
2	Total coliforms***	CFU/100 cm^3	absence
3	E.coli***	CFU/100 cm^3	absence
4	Enterococci***	CFU/100 cm^3	absence
5	Pathogenic enterobacteria	available in 1 dm^3	absence
6	coliphages****	BOO/dm^3	absence
7	Enteroviruses, adenoviruses, antigens of rotaviruses, reoviruses, hepatitis A virus and others	availability in 10 dm^3	absence

** For 95% of water samples taken from the water supply network that were examined during the year.*

*** After 10 years from the entry into force of the Sanitary Regulations.*

**** For 98% of water samples taken from the water supply network that were examined during the year.*

***** They are additionally determined in drinking water from surface water sources at the places of its entry from treatment facilities into the distribution network, as well as in groundwater.*

Drinking water (by definition [4]) is water that meets state standards and sanitary legislation in terms of organoleptic (taste) properties, chemical and microbiological composition, and radioactive indicators. Therefore, in [2, 10], hygienic requirements are established that determine the suitability of water for vital purposes and cover:

- radiation safety and epidemic safety;
- harmlessness of the chemical composition;
- favorable organoleptic properties.

Table 5.2

Parasitological indicators of drinking water safety

№ з/п	Name of indicators	Units of measurement	Norms for drinking water
1	Pathogenic intestinal protozoa: oocysts, cryptosporidium, isospores, giardia cysts, dysentery amoebae, intestinal balantidia, and others.	Cells, cysts in 50 dm^3	absence
2	Intestinal helminths	Cells, eggs, larvae in 50 dm^3	absence

The most important component of water, as a natural system, from the point of view of the impact on human health are biological living objects, which are represented by bacteria, viruses and protozoa, the fight against which is a complex task, the solution of which is paid attention to scientists from different countries.

Chemical and physical methods are used for water disinfection, in particular, such as chlorination, ozonation, membrane technologies, ultrasound, heat treatment, ultraviolet and ionizing radiation, etc.

5.2 Research of chemical methods of water disinfection

One of the most important stages of drinking water purification is its disinfection [6,56]. Among the technological processes of water treatment, disinfection is the most important from the point of view of prevention of epidemic diseases.

Today, there are many alternative methods of disinfection in the world (UV irradiation, ozonation, water ammonization with chlorination, the use of chlorine dioxide, the use of sodium hypochlorite, combined methods, etc.). Each of them has both advantages and disadvantages.

In the practice of water treatment, methods of water disinfection are conventionally divided into two main groups [7]: reagent, chemical (the use of chlorine and its compounds, ozone, silver preparations, copper, iodine and other reagents) and non-reagent, physical (the use of ultraviolet and ionizing radiation, ultrasonic vibrations, heat treatment and others). In addition, there is a combination (combination) of various chemical and physical methods that make up a separate group, combined.

Of these methods, the methods of the first group are most widely used. Chlorine, chlorine dioxide, ozone, iodine, potassium permanganate, sodium hypochlorite, calcium and hydrogen peroxide are used as oxidizing agents. In turn, among the listed oxidizing agents, in practice, preference is given to chlorine, ozone, and sodium hypochlorite.

To date, the method of disinfection of water with chlorine in our country is the most common method of combating bactericidal pollution [58,85]. However, it turned out that chlorination of water carries a danger to human health людей [62]. It is possible to eliminate this dangerous effect for human health and achieve a reduction in carcinogenic substances in drinking water by replacing primary chlorination with ozonation [59,60], as well as using non-reactive methods, ultraviolet radiation, etc.

Chlorine and ozone, chlorine preparations with hydrogen peroxide, silver and copper ions, as well as a number of other combinations are used as combined chemical methods. These technologies make it possible to reduce the concentrations of reagents used, reduce the time of water treatment with a constant, and sometimes with a more pronounced antimicrobial effect.

Disinfection of drinking water is important in the overall water treatment cycle and is used almost everywhere, as it is the last barrier to transmission of bacterial and viral diseases. Water disinfection is the last stage of drinking water treatment [63,64].

The chlorination method is the most well-known method of water disinfection both in our country and abroad. Chlorination of water is carried out with chlorine gas or substances containing active chlorine: bleach lime, hypochlorides, chloramines, chlorine dioxide, and others.

Chlorination is characterized by a wide spectrum of antimicrobial action in relation to vegetative forms of microorganisms, cost-effectiveness, simplicity of technological design, and the presence of a method of operational control over the disinfection process. According to modern concepts, active chlorine is characterized by the complex nature of its effect on various molecular structures of the microorganism: the membrane, cytoplasmic proteins, and the cell nucleus. It was found that chlorine destroys enzymes of the respiratory chain of bacteria.

The bactericidal effect of chlorine largely depends on its initial dose and the duration of contact with water. Most often, only a small part of chlorine is spent on cell destruction. Most of the chlorine reacts with various organic and mineral impurities that are contained in water [18].

Chlorine also acts on organic substances by oxidizing them, so chlorination is also a good way to prevent the multiplication of microorganisms in water. For the chlorination effect, good mixing is necessary, and then at least 30 minutes (with joint chlorination and ammonization, 60 Minutes) contact of chlorine with water before the water reaches the consumer. Contact can occur in a clean water tank or in a pipeline through which water is supplied to consumers, if the latter is of sufficient length.

The dose of chlorine is set by test chlorination based on the calculation that in 1 liter of water supplied to the consumer, there is still at least 0.3 and no more than 0.5 mg of chlorine that has not reacted (residual), which is an indicator of the sufficiency of the Taken dose of chlorine [61]. Under this condition, the dose of chlorine during chlorination of filtered water is 0.5 ... 2.0 mg/l depending on the so-called value of water chlorination, and when chlorinating unfiltered river water, it can reach even more.

When chlorine is introduced into water, substances that make up the protoplasm of bacterial cells are oxidized, which causes their death. Chlorination of water is a reliable means of preventing the spread of epidemics, since most pathogenic bacteria (typhoid and dysentery bacilli, cholera Vibrios) are very unstable in relation to chlorine. Chlorine does not destroy spore-forming bacteria, which is one of the disadvantages of this method of disinfection [47].

The effect of chlorination depends on the dose of chlorine administered and the duration of its contact with water. A relatively small proportion of chlorine introduced into the water is spent on the oxidation of microorganisms; most of it is spent on reactions with organic and some mineral impurities contained in the water. The rate of these reactions depends on a number of factors, so chlorine absorption is equal to the total consumption of chlorine for the oxidation of microorganisms, organic and inorganic impurities, is a variable value that depends on the dose of chlorine, the duration of contact, pH, water temperature, etc.

The dose of chlorine should be greater than the amount of chlorine absorption by the amount of residual chlorine, the presence of which is a guarantee that the oxidation of bacteria and organic substances in water is almost complete.

According to [2], the residual chlorine content in tap water should be within 0.3...0.5 mg/l.

Since there may be cases of a sharp decrease in the concentration of residual chlorine in water, the choice of the required dose of chlorine should be approached with caution, determining it experimentally.

When water is chlorinated with bleach , the latter decomposes into calcium hypochlorite and calcium chloride . As a result of the reaction of calcium hypochlorite with carbon dioxide or bicarbonates in water, as in the case of chlorination with chlorine gas , perchloric acid is formed, which dissociates to form a hypochlorite ion . Perchloric acid and hypochlorite ion have a bactericidal effect.

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When chlorinating water with bleach $CaOCl_2$, the latter decomposes into calcium hypochlorite $Ca(OCL)_2$ and calcium chloride $CaCl_2$.

As a result of the reaction of calcium hypochlorite with carbon dioxide or bicarbonates in water, as in the case of chlorination with chlorine gas, perchloric acid is formed $HOCl$, what dissociates with the formation of a hypochlorite ion OCl^-. Perchloric acid and hypochlorite ion have a bactericidal effect.

Since chlorine is a toxic gas, when designing chlorination plants, it is necessary to provide for the necessary measures of service personnel.

Despite the fact that chlorination is still the most common method of water disinfection, currently its use for water treatment is constantly being reduced. This is caused by the following reasons:

* as a result of chlorination, halogen – containing compounds (HCC)

are formed in the treated water, while the use of water containing HCC leads to suppression of the immune system, diseases of the liver, kidneys, pancreas, thyroid gland, central nervous system, but most importantly-a number of HCC are carcinogens [65];

* traditional chlorination schemes in many cases are not a barrier to the penetration of certain bacteria and viruses into drinking water;

* chlorine is a highly toxic substance, and when transporting, storing and using it, special measures must be taken to ensure the safety of service personnel, the public and the environment;

* working solutions of chlorine-containing reagents are corrosive and cause rapid wear of equipment and pipelines.

In recent years, data have been obtained that have proved the insufficient effectiveness of existing chlorination schemes (even two-stage) in relation to enteroviruses and protozoa [64]. Studies have shown that even if water treatment with chlorine leads to a decrease in the content of indicator bacteria of the Escherichia coli group to a regulated level, resistant forms of microorganisms, and primarily viruses, can enter the distribution water supply network.

The hepatitis A virus (HVA) is highly resistant and is practically not inactivated during chlorination with bound residual chlorine of 0.8-1.2 mg/l, which is used at water treatment plants [66]. For inactivation of HVA in water by 99%, the concentration of residual bound chlorine should be at least 4.2 mg/L. for disinfection of water from enteroviruses, a contact duration of 30 minutes to 4 hours and a concentration of residual free chlorine of 1-2.7 mg/l is required. For disinfection of water from giardia cysts for 30-60 minutes, a concentration of residual free chlorine of 2-5 mg/l or 1-3 hours with residual chlorine of 5-20 mg/l, which significantly exceeds the permissible norms of current regulations regulatory documents.

Many countries have introduced state regulations that limit the content of hot water in drinking water. In Ukraine, the standards (MPC) of several dozen GIS are presented. In recent years, the standards of a number of GIS have been revised to take into account new scientific data on their carcinogenic activity and correspond to the recommendations of the World Health Organization.

The trend towards a decrease in MPC is also indicated by the fact that in the regulatory documents of many developed countries, the complete absence of HCC is defined as long - term goals, and the permissible total HCC content in many countries is much lower than in Ukraine (Germany - 10 mg/l, Switzerland - 25 mg/l, Sweden - 50 mg/l, USA - 80 mg/l, etc.).

Currently, two main methods of preventing the formation of hot water are proposed: correction of the chlorination scheme and refusal to use chlorine as the main method of water disinfection. Correction of the chlorination scheme involves refusing to supply high doses of chlorine to untreated water and moving the input point of its main part to the end of the technological scheme. However, this leads to a decrease in the efficiency of water disinfection and a decrease in the barrier role of cleaning devices (which requires the introduction of an additional disinfection procedure: ozonation, UV irradiation, filtration, etc.).

The use of ozone as an alternative disinfectant for the disinfection of drinking water encourages the continuous development of basic research in this area. To date, significant experimental material has been accumulated on ozone inactivation of opportunistic microorganisms [67,68] and the influence of various physical and chemical factors on this process [86].

Ozonation of water is one of the effective methods of disinfection of water with oxygen, it not only has a bactericidal effect on pathogenic microflora, but is also able to destroy many chemicals present in water: there is a destruction of high-molecular organic compounds, elimination of taste and odors.

The ozonation method can be used both at all and at individual stages of preliminary, intermediate and finishing water treatment, but only if other, simpler and cheaper technologies cannot solve the problem. This is a rather expensive and complex technology. Especially expensive is the item of electricity. For example, electricity costs are 60-200 kWh/m^3.

A special feature of ozone is the ease of its decomposition with the formation of atomic oxygen – one of the most powerful oxidizing agents. Atomic oxygen destroys bacteria, spores, viruses, and destroys organic substances dissolved in water. This makes it possible to use Ozone not only for disinfection, but also for removing toxic organic substances, that is, for deodorizing drinking water. During ozonation, the mineral composition, pH, and alkalinity of water remain unchanged [71].

The decontaminating effect of ozone is 15-20 times more effective than that of chlorine, and about 300-600 times more effective on bacterial spore forms [13]. The required time for the manifestation of the bactericidal effect of ozone in water is about 10 minutes. A high virucidal effect of ozone is observed at concentrations of 0.5-0.8 mg/L and exposure for about 10 minutes. Recent studies have shown a high efficiency of ozone in destroying protozoan cysts present in water [72]. The mechanism of bactericidal action of ozone consists in inactivation of bacterial enzymes, irreversible disruption of the structure of cell DNA by exposure to these structures of atomic oxygen formed during the breakdown of ozone. The advantages of ozone over chlorine in water disinfection are that ozone improves the organoleptic properties of water and provides a bactericidal effect with a shorter contact time, however, unlike chlorine, it has no aftereffect.

Ozonation is common in many industrialized countries-the United States, France, Japan, Finland, and Germany. Most often, primary ozonation is used in small doses (1.5-2.0 mg/l), which allows combining with other technologies, including UV disinfection, to achieve high results in water treatment.

Ozonation in wastewater treatment has been used in the United States since the 1970s, but its popularity has declined dramatically with the development of much more cost-effective UV disinfection systems. Currently, ozonation of water is used only when additional intensification of purification processes or removal of specific ingredients is required. In the case of wastewater treatment, ozone is used when it is necessary to remove petroleum products, phenols, organic solvents and dyes.

The main hygienic advantages of ozone in comparison with other oxidizing agents in water treatment are as follows: a stronger oxidative potential than that of chlorine preparations; a high spectrum of bactericidal activity, including against protozoan cysts [28].

The conducted studies have shown that in comparison with chlorination, ozone disinfection of water has a number of advantages:

- do not form THMs (trihalogenmethanes);
- improves the organoleptic properties of water;
- there is no need to store large volumes of harmful substances at water treatment plants. Ozone is generated directly at the station.

Ozonation of water is also characterized by disadvantages, namely::

- no aftereffect, formation of biodegradable organic compounds in water, what are the carbon sources for bacteria that create the potential for secondary microbial growth in networks ;

- during ozonation, harmful by-products (formaldehyde and other aldehydes) are formed, ozone causes active corrosion of equipment and materials.

Ozonation, as well as chlorination, is not without drawbacks. Ozone is an explosive and toxic reagent that requires strict compliance with safety regulations and technologically reliable equipment at drinking water treatment plants. The rapid decomposition of ozone in treated water (within 25-30 minutes) limits its use as the final means of disinfection [73]. Some sources of information note that even ozone doses of more than 20 mg/L and an exposure time of up to 2 hours do not provide the full effect of ozone disinfection in relation to spore forms of bacteria. The effectiveness of ozone disinfection depends on the water quality and process parameters процесу [87].

When water is treated with ozone, by-products are formed in the form of carbonyl compounds (aldehydes, low-molecular carboxylic acids, Brom); among which formaldehyde is the most toxic. Deeper changes in the chemical composition of water are observed if water chlorination is used in the ozonation scheme. In this case, ozonolysis products are formed – trihalogenmethanes (THM), which have mutagenic and carcinogenic properties, which often requires the use of subsequent sorption purification.

Interest in ozone remains due to its high efficiency as an oxidizer of a number of organic compounds, which is the basis of redox-sorption water purification technology, which combines ozonation with subsequent filtration on Activated Carbon. This method ensures that water matches both chemical and microbiological parameters.

Water ozonation technology is widely used all over the world, and is an integral part of the technological process of water treatment [88].

Practical experience of using silver and its preparations for the purpose of disinfection and preservation of drinking water has accumulated by mankind for many centuries. The spectrum of antimicrobial action of silver covers many types of bacteria and viruses, but the virucidal effect is manifested only at high concentrations above 0.5 mg/l [22].

In modern conditions, electrolytic or anode-soluble silver is most widely used. Electrolytic introduction of the reagent makes it possible to automate the process of water disinfection, and the ions formed at the anode, hypochlorites and peroxide compounds enhance the bactericidal effect of anode-soluble silver. The advantages of this method include the ability to automate the process and accurately dose the reagent. Silver has a pronounced aftereffect, which allows you to preserve water for up to several months [89].

The mechanism of bactericidal action of silver is to block the functional groups of the enzyme systems of the bacterial cell, primarily sulfhydryl groups located in the cytoplasmic membrane or in the periplasmic space [90].

The use of silver for disinfection of drinking water is constrained by its high cost, as well as the fact that the maximum permissible concentration in water is 0.05 mg/L, which is an order of magnitude lower than the effective concentrations. Silver has no sporicidal effect, but spore germination in the presence of silver ions is delayed. The microbial effect of silver is significantly affected by the physicochemical properties of the treated water [33].

The necessary bactericidal effect at a silver concentration of 0.06-0.1 mg/L is achieved after exposure for 2-6 hours, and in some cases – after 24 hours [33]. There is also a development of resistance in pathogenic microorganisms. Effective working concentrations of silver in the practice of water disinfection in autonomous life support systems are 0.2-0.4 mg/L and above, which exceeds the toxicological sign of harmfulness – 0.05 mg/L, which is accepted in most countries of the world. The WHO Drinking Water Quality Control Manual (1994) emphasizes that such silver content affects human health. Therefore, silver is used for disinfection and preservation of small volumes of drinking water in autonomous water supply systems [32].

Attempts continue to use the oligodynamic effect of other metals, such as copper ions, to disinfect drinking water. The antimicrobial spectra of silver and copper coincide, the current copper concentrations are lower than the maximum permissible (the current copper concentration is 0.7 mg/l, the maximum permissible concentration is 1 mg/l), but the bactericidal effect develops more slowly than when using silver. It is established that under the action of copper ions, the electrokinetic potential of a microbial cell changes extremely. Copper ions disrupt the barrier functions of bacterial membranes, which in turn leads to changes in their permeability. Inactivation of microorganisms with copper is slower than with free chlorine or chloramine. The efficiency of water disinfection with copper is affected by physical and chemical indicators of water quality [91].

Practical use of copper as a means for disinfection of significant volumes of drinking water has not been found; it is successfully used for electrolytic coating of sand in some models of household filters, preventing the growth of saprophytic microflora on the grains of the filter load.

For disinfection of individual small amounts of water, iodine preparations can be used, which, unlike chlorine, act faster and at the same time do not worsen the organoleptic properties of water. The bactericidal effect is provided at concentrations of 0.3-1.0 mg/L and exposure for up to 30 minutes. Due to its high bactericidal properties, the presence of virucidal and parasitocidal effects, iodine preparations are considered as one of the promising means of disinfection of drinking water [92].

The search for new oxidative methods (preparations based on peracetic acid, peroxides, etc.) continues, but the sun.

5.3 Research of physical methods of water disinfection

Insufficient efficiency of chlorination in relation to certain biological agents (viruses, protozoan cysts, spores, etc.), the negative impact on human health of by-products formed as a result of irrational use of reagent methods of water disinfection (chlorination, ozonation), technological limitations on the use of bactericidal properties of other reagents for disinfection of large volumes of water initiated the use of physical methods of water purification and disinfection.

Physical methods of disinfection of drinking water include the use of ultraviolet and ionizing radiation, ultrasonic vibrations, heat treatment, and membrane technologies. They are often combined with chemical technologies and with each other in the disinfection of natural, wastewater and industrial water

In the last decade, including in the municipal sector, research and development of membrane filtration methods have been carried out [93].

These technologies are mainly designed to solve the problems of natural, wastewater and industrial water treatment in general water treatment complexes. The use of membrane installations often allows you to abandon primary chlorination, which reduces the danger of the formation of organochlorine compounds. Ultrafiltration can also be considered as an effective means of water disinfection. Membranes with a pore size of 0.01-0.005 microns serve as a barrier for pathogenic microorganisms [94], since the size of giardia cysts and Cryptosporidium oocysts is 5-15 microns, Escherichia coli bacteria - 0.5 microns, viruses - 0.01 - 0.03 microns. If we consider only the aspects of disinfection, Ultra and nano filtration remain expensive and energy – intensive technologies today. In general, the absence of an aftereffect requires the use of chlorination, but ultrafiltration is not always effective for destroying viruses [95], like ionizing gamma radiation.

Ionizing gamma radiation forms free radicals in the process of radiolysis of water, which have a harmful effect on microorganisms [96]. The bulk of bacteria up to 90% die at radiation doses of 10-15 thousand rad. and doses of 25-50 thousand rad cause the death of almost all bacterial forms. During radiolysis, a large range of by-products is formed.

A crucial role in the damage of bacterial cells and viruses under the influence of ionizing radiation belongs to free radical products resulting from radiolysis of water [97]. The advantages of this method of disinfection are: high penetrating power of gamma rays, independence of bactericidal action from the chemical composition and physical properties of water, no effect on organoleptic parameters, relative cheapness.

The disadvantages of the method include: at high doses, using gamma radiation, it is necessary to create special radiation protection systems, strict safety requirements for the operation of installations, a limited number of such radiation sources, the absence of an aftereffect and a method of operational control over the effectiveness of disinfection, the equipment poses a potential danger in the event of depressurization.

All of the above disadvantages limit the use of the gamma radiation method.

To increase the efficiency of disinfection, domestic and foreign scientists suggest using ultrasound water treatment. A special feature of this physical factor is the high intensity of vibrations, which determines its physico-chemical and biological effect.

When ultrasound is applied to a liquid, specific physical, chemical and biological effects occur, such as cavitation, capillary effect, dispersion, emulsification, degassing, disinfection, local heating, and many others [98]. The biological effect of ultrasound has been known for a long time [99]. The effect of ultrasound exposure on microorganisms depends on the intensity: at low intensities and low exposure, ultrasound can stimulate the activity and growth of microorganisms [42, 100,101]. At high intensity, ultrasound suppresses and destroys microorganisms. Prolonged treatment of water with high-power ultrasound leads to its disinfection to the required extent. The bactericidal effect of ultrasound is associated with cavitation, which creates shock waves with a pulsed pressure of up to several thousand atmospheres and a temperature of up to 5000 K. if a shock wave meets an obstacle in its path, it destroys its surface. In addition, during the cavitation process, active radicals of the OH group appear, which are the strongest oxidizing agents. The cavitation process occurs at sound field intensities above the peak value of 0.3-1 W/cm^2.

An increase in frequency leads to an increase in the peak intensity value corresponding to the beginning of cavitation. As the frequency increases, the size of cavitation bubbles decreases, and their number increases. At a frequency of 30 kHz, the characteristic size of cavitation bubbles is 100 microns. The lower the frequency, the easier it is to obtain cavitation, and the more aggressive the effect of cavitation on the processed object, so many devices use ultrasound with a frequency of 20-22 kHz [42].

Ultrasonic vibrations have a harmful effect on a wide variety of microorganisms – pathogenic and non-pathogenic, anaerobic and aerobic, vegetative and Spore, as well as destroy the products of their vital activity. The effectiveness of the bactericidal action of ultrasonic depends on a number of factors: physical parameters (intensity, frequency of vibrations, exposure); physical features of the voiced medium (temperature, viscosity); morphological features of the pathogen (size and shape of the bacterial cell, chemical composition of the membrane) [29]. The bactericidal effect of ultrasonic vibrations does not depend on the turbidity (up to 50 mg/l) and color of water, which is voiced, extending equally to both vegetative and Spore forms of microorganisms [22].

The advantages of using ultrasonic vibrations include the following: a wide spectrum of antimicrobial action, no negative impact on the organoleptic properties of water, independence of bactericidal action from the main physical and chemical parameters of water, the ability to automate the process. However, many theoretical, scientific and technological foundations for the use of ultrasonic vibrations have not yet been developed. As a result, it is difficult to determine the optimal intensity of vibrations and their frequency, the time of voicing, and other process parameters. The disadvantage of ultrasonic vibrations is also the lack of an aftereffect and a method of operational control over the effectiveness of disinfection. The process of water disinfection using ultrasonic vibrations remains expensive, with an energy consumption of 2-2.5 kW. Difficulties in designing high-performance installations remain a deterrent to the widespread implementation of this physical method.

All these factors make the ultrasonic disinfection method not yet competitive for industrial use.

High-voltage (20-100 kV) or low-voltage (1-10 kV) pulsed discharge in water is accompanied by powerful hydraulic processes with the formation of shock waves, cavitation phenomena in the water column, with the appearance of ultraviolet and ultrasonic pulses, magnetic and electric fields [40], which is the basis for Radicals of the OH group, etc., which affect microorganisms. It should be noted that the material of metal electrodes during discharge passes into water in the form of ions involved in the processes of disinfection and preservation, and the maximum permissible concentration of these ions in water may be exceeded.

The efficiency of disinfection does not depend much on the physical and chemical composition of the treated water and is determined by the technical parameters of the process (the value of the operating voltage, the total energy density of the discharge).

The disadvantages of water disinfection with high-voltage IERS include: relatively high energy intensity of 0.3-1 $(kW{\cdot}h)/m^3$ and the complexity of using the equipment, the imperfection of the method of operational control over the effectiveness of disinfection, the insufficient degree of study of the mechanism of action of the discharge on microorganisms, and therefore the role of each component of this combined method. The scope of application is limited to use only for special tasks.

Hot air, superheated steam, and an open flame (high-temperature plasma) are used for thermal disinfection of drinking water [22]. Among the types of heat treatment of water, its boiling is the most common. Boiling for several minutes frees water from vegetative forms of microorganisms, inactivates viruses [102]. The death of microorganisms after boiling is irreversible, which, combined with the possibility of automation, allows you to abandon operational control over the effectiveness of disinfection.

The advantages of boiling are: reliability and speed of decontaminating action, independence of the effect from the physical and chemical parameters of the decontaminated water, ease of monitoring the efficiency of processing, the possibility of automation. The disadvantages of the boiling method include high energy consumption due to significant electricity or fuel consumption, low productivity. Boiled water is easily exposed to secondary microbial contamination, since there is no aftereffect. Due to economic and technological difficulties, boiling is considered as a method of decontamination of individual drinking water supplies at home, at Autonomous facilities, in a difficult epidemic situation [40].

In addition to the above physical methods, it is also possible to use some others: electromagnetic fields, laser radiation, vacuuming, transmission of shock waves and powerful acoustic waves. However, the study of these methods is in the stage of laboratory studies.

5.4 Methods of wastewater disinfection

Until recently, technologies using chlorine were most widely used, but chlorine-containing reagents have a number of significant disadvantages [103]. The interaction of chlorine with organic substances contained in wastewater leads to the formation of chloroform, carbon tetrachloride, bromidichloromethane, dibromochloromethane, which have mutagenic and carcinogenic properties. Data from the national literature indicate that hygienic criteria for the effectiveness of the process (doses of active chlorine 3 - 5 mg/dm^3, exposure 30 minutes and residual active chlorine 1.5 mg/dm^3) in some cases are not sufficient for reliable disinfection of wastewater. The use of increased doses of active chlorine for this purpose is undesirable. In addition, this method is associated with the need to comply with safety rules when storing, transporting and using chlorine. A forced increase in the doses of chlorine-containing reagents (during floods) leads to a slowdown in the processes of self-purification of water in water bodies.

Studies conducted back in the twentieth century established that it is possible to completely remove bacterial and viral microflora from wastewater only with a dose of active chlorine of 15-20 mg/dm^3 and an exposure of at least 2 hours [46]. Two-hour exposure to a dose of active chlorine of 3-5 mg/dm^3 made it possible to disinfect wastewater from Escherichia coli bacteria by 99.99 %. Complete release of wastewater from bacteria was achieved by decontaminating it within 24 hours. It was found that the maximum virucidal activity is shown by chlorine gas and bleach lime, the lowest – by chloramine. The use of active chlorine for disinfection of wastewater in such significant concentrations will contribute to its entry into water bodies, where it will enter into oxidation reactions with humic substances and organic compounds of anthropogenic origin, forming organochlorine compounds that are dangerous to public health.

In particular, if complete inactivation of viruses was observed during chlorination at doses of 10 mg/dm^3 in 1 hour., then when decontaminated with chlorine dioxide, the same effect was observed at a dose of 5 mg/dm^3 with a contact time of up to 0.5 hours.

In [104], it was found that for disinfection of wastewater from infectious diseases hospitals, in order to achieve the desired effect, the dose of active chlorine after 30 minutes of contact should be increased to 5-10 mg/dm^3. It is impossible to completely free wastewater from pathogenic Enterobacteria and viruses under such decontamination conditions.

The advantages of chlorine dioxide as a disinfectant compared to chlorine are as follows:

- the oxidizing capacity of chlorine dioxide is higher than that of chlorine;
- the biocidal effect of chlorine dioxin is higher than that of chlorine at the same doses of reagents and disinfection exposure;
- the properties of chlorine dioxide do not depend on the pH of water;
- chlorine dioxide when interacting with ammonia and amines does not form chloramines and toxic by-products of chlorination (trihalomethanes);
- organic oxidation products are biochemically oxidized and do not pose a danger when entering natural water bodies compared to trihalomethanes, which do not oxidize and accumulate in environmental objects;

- by-products (chlorates and chlorites) are not dangerous to the environment, because chlorites are quickly reduced to chlorides, and chlorates are stable in the aquatic environment.

The authors of the article [105] suggest using chlorine dioxide for disinfection of domestic wastewater from small settlements, local facilities, including transport facilities, as well as wastewater that is an epidemiological hazard (for example, in infectious diseases hospitals).

Since the formation of toxic organochlorine compounds harmful to the human body is possible during chlorination of wastewater, it was proposed to disinfect urban wastewater by other methods, in particular by ultraviolet irradiation, ozonation, treatment with chlorine dioxide, etc.

In addition to chlorine compounds, bromine and iodine compounds with oxidative activity can be used in the practice of wastewater disposal. Despite the large amount of literature, there is conflicting information about the bactericidal activity of these halogens. The chemical effect of bromine chloride in water is similar to that of chlorine. $BrCl$ it reacts rapidly with water to form hypobromic acid, which quickly combines with ammonia to form bromamines. They are superior to chloramines in bactericidal and antiviral activity. Bromine preparations are used to disinfect the water of swimming pools, and iodine is used to disinfect water in closed systems, in particular, in the life support system of space stations. Due to the high cost and the possibility of forming iodine bromine derivatives, which have a toxic effect and are characterized by long-term effects, bromine and iodine compounds are not widely used.

Ozonation is a promising method of disinfection. The source of ozone production is air or oxygen, it easily decomposes to form atomic oxygen, which destroys bacteria, spores, viruses, oxidizes organic substances, and improves the organoleptic properties of water. The use of ozone eliminates time-consuming processes and greatly simplifies wastewater treatment technology.

Ozone is a much stronger oxidizer than chlorine. The decontaminating effect of ozone on vegetative forms of bacteria is 15-20 times, on Spore forms of bacteria is 300-600 times stronger than the effect of chlorine. In addition, ozone has an antiviral effect. The mineral composition, alkalinity, and pH of water remain unchanged [106]. Ozonation is an effective and promising method of wastewater treatment also from impurities of aromatic compounds, surfactants and can be recommended as a local treatment method before final biochemical post-treatment [107].

With the combined use of ozonation, UV radiation, ultrasound and microwave, the quality of wastewater disinfection increases significantly [108].

Fundamental difficulties in ozone disinfection are associated with the formation of toxic by-products, low solubility of ozone in water, its own high toxicity and explosion hazard. Ozonation of wastewater can promote secondary microbial growth due to the formation of organic compounds in the water, which are available carbon sources for bacteria.

Deeper changes in the chemical composition of water are observed if chlorination is used in the scheme after ozonation of water. In this case, chlorination of by-products of water ozonation leads to the formation of trihalomethanes [109].

Ozonation increases the possibility of residual ozone entering water bodies and their impact on hydrobionts. In [110], it was found that at an ozone concentration of 1.5 mg/dm^3, protozoa die within 0.5 hours. When the ozone concentration in water is 0.5 mg/dm^2, protozoa die in 5 hours. The ozone concentration of 0.0001 mg/dm^3 is not very toxic for Protozoa, they remain alive for more than 120 hours.

Ozone also has a virucidal effect [111]. Inactivation of enteroviruses depends on the dose of ozone and the time of contact with it. The rate of inactivation of the polio virus at an ozone dose of 5 mg/dm^3 was significantly higher than at a dose of 3 mg/dm^3.

At the end of the XX century, an active search for new methods of wastewater disinfection began, which would not be based on the oxidative action of reagents. The main disadvantage of these reagents is their high corrosion activity.

Disinfection methods based on the action of organic reagents on the membrane and/or internal structure of the Microbial Cell do not have this disadvantage.

Currently, biocidal polymers based on polyhexamethylene-guanidine (PHMG) compounds are most widely used [112]. The developed biocidal polymers are highly soluble in water. Their solutions are odorless and colorless, non-volatile, stable and safe for use, storage and transportation, not aggressive to a variety of materials. The advantages of using reagents based on PHMG are not high corrosion activity of solutions, but a fairly wide spectrum of action against pathogenic microorganisms [113]. However, the widespread use of biocidal polymer reagents for disinfection of drinking and wastewater is hindered by insufficient study of the effect of residual concentrations of polymer reagents on humans and warm-blooded mammals, as well as the lack of reliable methods for extracting excess reagent from water води [114].

5.5 Ultraviolet methods of water disinfection

The analysis shows that the most promising method of disinfection of natural, as well as wastewater and industrial water is the technology using ultraviolet radiation, which has been dynamically developing in recent decades in comparison with other methods of water purification [14, 17].

The trend towards widespread use of the UV disinfection method of water instead of traditional chlorination and other chemical methods is due to the introduction of increased requirements for water quality [2] and the identification of negative effects of by-products [15] formed during chemical disinfection methods, which made the UV treatment method competitive.

Ultraviolet radiation (UVB) with a wavelength of 250-260 nm has the greatest antimicrobial effect on bacteria, viruses and spores. The sensitivity of microorganisms to UVB in this range is well studied and is determined by the radiation dose measured in mJ/cm^2. The antimicrobial effect of UV radiation against various types of microorganisms is in the dose range from 2.5 to 440 mJ/cm^2 [11]. In the practice of water treatment, it is generally assumed that for effective disinfection of water, UV technology must provide a radiation dose of at least 16 mJ/cm^2 [39].

UV radiation is an effective remedy against all micro-organisms, including bacteria, viruses, fungi, mold, yeast and algae present in water. Although all bacteria can be neutralized by UV radiation, some of them are more resistant than others [115].

Under the influence of UV radiation, irreversible processes occur in the cells of microorganisms that cause violations of Molecular and intermolecular bonds. This leads to denaturation (destruction) of protoplasmic cell proteins, in particular, to damage to DNA, cell membranes, and, as a result, to the death of microorganisms. Ozone molecules, atomic oxygen, free radicals, and hydroxyl groups formed under the influence of UV radiation additionally affect the inactivation of microorganisms in water.

In addition, data obtained in recent decades show that not only short-wave, but also UVB in the region of 280-400 nm is able to create photodestructive reactions in DNA [58].

The method of disinfection of water with UV radiation has a number of advantages over other methods of disinfection:

* UV radiation effectively inactivates not only most bacteria, viruses, but also parasitic protozoa, including those resistant to chlorine and other oxidizing agents. It destroys pathogens of infectious diseases such as typhoid, cholera, dysentery, viral hepatitis, polio, etc.

* UV disinfection of water does not lead to the formation of harmful by-products in it, unlike oxide technologies, even if the dose required for disinfection is repeatedly exceeded. UV radiation does not impair the organoleptic properties of water (smell, taste);

* UV radiation does not change the properties of the treated water, namely, there are no changes in the content of total organic carbon, pH, corrosion activity.

* The UV disinfection process is not affected by the pH and temperature of the water, unlike oxidative disinfection technologies.

* The UV disinfection time is 1-10 seconds in the flow mode, so there is no need to create contact tanks.

* The UV disinfection method is safer and more environmentally friendly compared to chemical technologies (there is no need to create and operate compositions of toxic chlorine-containing reagents that require compliance with special technical and environmental safety measures.

* When using UV technology, there are no problems associated with Corrosion of process equipment.

* UV equipment is compact, requires minimal space and is usually easily integrated into existing water treatment facilities; its introduction into existing technological processes of purification is possible without stopping them, with minimal volumes of construction and installation work.

* Modern UV complexes based on low-pressure arc electrical devices operate on industrial power supply with a voltage of 110, 220, 380 V, while ozone-based complexes use a voltage of up to 8-30 kV, which leads to higher requirements for electrical safety and qualification of service personnel.

* Modern bactericidal electrical systems and start-up equipment have a high operational life, provide a high degree of technological reliability of UV disinfection complexes, and automation of large systems, which requires regulation of only electrical parameters, is much easier and more reliable than during chlorination and ozonation.

* UV disinfection is characterized by lower operating costs than during chlorination and even more so ozonation. This is due to relatively low electricity costs (10-30 W per 1 m^3 of treated water).

The negative aspects of UVB water disinfection are:

- dependence of the bactericidal effect on the turbidity and color of the treated water, the type of microorganisms, their number, radiation dose;
- among the negative features of the UV method is the possibility of precipitation of humic acids, iron and manganese salts in water on the Quartz cover of the source, which reduces the intensity of radiation;
- this technology has no aftereffect, which can cause secondary bacterial growth in the treated water. Reactivation [116] of microflora occurs when the UVB intensity is lower than the required level, the treated water is subjected to secondary contamination or subsequent irradiation with visible light – photoreactivation [117].

However, these shortcomings do not reduce the effectiveness of using UV technologies for water disinfection, but only serve as a reason for further research and search for alternative use of UV methods in combination with ozonation, ultrasonic dispersion, chlorination and other physical and chemical methods.

5.6 Research of methods of water disinfection by UV radiation in combination with chlorine or ozone

UV irradiation in combination with chlorination is widely used in the purification and disinfection of natural and industrial waters [7, 52]. The combination of UV treatment with chlorination in various combinations can significantly reduce the concentration of organochlorine compounds, ensure (including viruses and protozoa) disinfection of water and preserve the prolonged effect of the disinfectant during its further transportation or use in a closed cycle, as well as significantly reduce the consumption of the disinfectant. By the way, when evaluating the effect of the combined action of chlorine and UV radiation at different doses, the absence of mutual reinforcement of the decontaminating ability is shown [7].

In some cases, an interesting area of UV water treatment is the removal of residual chlorine from it. The use of UV radiation for dechlorination of water is a relatively new field of application of UV technology, although the destruction of free chlorine in water requires quite high doses of radiation, several times higher than for disinfection, and for the destruction of chloramines even more. The use of UV radiation for dechlorination of water instead of treating it with sorbents has certain advantages: first of all, simultaneous disinfection of water, and, in addition, no consumables are required, etc.

Treatment of chlorinated water with ultraviolet radiation leads to a decrease in the concentration of chlorine compounds due to photolysis. The decrease in the concentration of these compounds depends on the UV spectrum and radiation dose. The process of photolysis of residual chlorine depends on the type of compounds that are present in the water. Residual chlorine in water can be in the form of hypochlorite ion, perchloric acid, mono-, Di-, tri - chloramines, organochlorine compounds. The ratio of these chlorine compounds depends on the type of chlorine reagent, the pH of the water, and the concentration of nitrogen-containing compounds. Each of these types of chlorine compounds has its own peak UV absorption [51].

The peak energy absorption of chlorine compounds is: monochloramine – 245 nm; dichloramine – 297 nm; trichloramine – 340 nm; chloroform and trihalomethane – 400 nm. Treatment of chlorinated water with high doses of UV radiation can lead to a decrease in the content of free chlorine by 10-45 %, bound chlorine-up to 10-15 %, by – products of chlorination – up to 10-20 %.

Typical photolysis products are ions: Cl^-, H^+, NO^-_3 ; i NH_3. As a result of photolysis of chlorine compounds, the formation of toxic by-products is not recorded. In general, medium-pressure electrical devices with a wide radiation spectrum cause a more pronounced decrease in final chlorine than low-pressure sources. For photolysis, radiation doses are used several times higher than those used for water disinfection, so in the dose range of 25-40 mJ/cm^2, the effect of photolysis on reducing the concentration of chlorine-containing substances will be insignificant. When exposed to UV radiation with a wavelength of 254 nm on chlorine compounds, the research results showed that:

* residual active chlorine, which is formed when hypochlorite is introduced into pre-ammonized water, is fully represented as chloramines;

* under the influence of UV irradiation with doses from 58 to 105 mJ/cm^2, the total active chlorine content decreases by an average of 8%, the maximum decrease reaches 12%; thus, at the stage of UV irradiation, the total residual chlorine decreases by 0.1 mg/l on average;

* simultaneously with a decrease in the content of total residual chlorine, a decrease in harmful organochlorine compounds was noted by 4-8 %.

Thus, the doses of UV radiation for a noticeable reduction in chlorine-containing substances are several times higher than the UV doses required for disinfection. When chlorinated water is treated with high doses of UV radiation of 150-500 mJ/cm^2, the concentration of residual chlorine decreases to 10-45 %. Bound chlorine compounds (chloramines) are generally more resistant to UV radiation than free chlorine compounds. Photolysis of chlorine compounds is not accompanied by the formation of undesirable by-products. Moreover, along with a decrease in residual chlorine, there is a decrease in harmful organochlorine compounds.

These patterns do not solve the problem of using chlorine as a dangerous substance, so ozonation is preferred in some cases.

Ozonation of water can significantly improve water quality and solve many problems that are characteristic, for example, for chlorination [7]. Ozonation is used as an integral part of the overall technological process.

The use of ozone as an alternative disinfectant for the disinfection of drinking water encourages the continuous development of basic research in this area. To date, significant experimental material has been accumulated on ozone inactivation of opportunistic microorganisms and the influence of various physico-chemical factors on this process [69,70].

The ozonation method can be used both at all and at individual stages of preliminary, intermediate and finishing water treatment, but only if other, simpler and cheaper technologies cannot solve the problem. This is a rather expensive and complex technology. Especially expensive is the item of electricity. For example, electricity costs are 60-200 kWh/m^3.

Ozonation in wastewater treatment has been used in the United States since the 1970s.most often, primary ozonation is used in small doses (1.5-2.0 mg/l), which allows combining with other technologies, including UV disinfection, to achieve high results in water treatment. Currently, ozonation of water is used only when additional intensification of purification processes or removal of specific ingredients is required. Ozone treatment of water is usually used in cases where petroleum products, surfactants, cyanides, phenols, organic solvents and dyes, heavy metal ions, etc. must be removed from the water simultaneously with disinfection.

The raw material for producing ozone is air or oxygen. From 50 - 60 m^3 (70-80 m^3 depending on the type of ozonator) of Air, 1 kg of ozone is obtained. As a rule, the ozone yield is 10-20% of the oxygen content in the air. There are two types of ozonators: lamellar and tubular (vertical and horizontal), recently ozonators of the fourth (last) generation have appeared.

Ozone is an explosive and toxic reagent that requires strict compliance with safety regulations and technologically reliable equipment at drinking water treatment plants. The rapid decomposition of ozone in treated water (within 25-30 minutes) limits its use as the final means of disinfection [73]. Some sources of information note that even ozone doses of more than 20 mg/L and an exposure time of up to 2 hours do not provide the full effect of ozone disinfection in relation to spore forms of bacteria. The efficiency of ozone disinfection depends on the water quality and process parameters [30].

When water is treated with ozone, by-products are formed in the form of carbonyl compounds (aldehydes, low-molecular carboxylic acids, Brom); among which formaldehyde is the most toxic. Deeper changes in the chemical composition of water are observed if water chlorination is used in the ozonation scheme. In this case, ozonolysis products are formed – trihalogenmethanes (THM), which have mutagenic and carcinogenic properties, which often requires the use of subsequent sorption purification.

Interest in ozone remains due to its high efficiency as an oxidizer of a number of organic compounds, which is the basis of redox-sorption water purification technology, which combines ozonation with subsequent filtration on Activated Carbon. This method ensures that water matches both chemical and microbiological parameters.

Ozone acts in a complex way, leading to an improvement in the physico-chemical and bacteriological parameters of water. It can also be used in conjunction with UV technology. This treatment scheme allows for reliable disinfection [31].

CHAPTER 6 USE OF UV RADIATION IN WATER DISINFECTION

6.1 Disinfection of drinking water

Drinking water, as a rule, contains a whole set of pollutants of different nature: mechanical particles, heavy metal salts, organic molecules of different sizes, bacteria, viruses, etc. Therefore, the fundamental criteria for creating a hardware and technological scheme for water disinfection at the stages of water treatment are the composition of incoming water and water quality requirements due to the technological process.

Requirements for drinking water have recently become more stringent [3, 10], and it is not always possible to achieve these parameters in terms of microbiological parameters without changing the chemical composition of water.

Figure 6.1 shows a water treatment scheme that includes in a logical sequence water treatment techniques used depending on the scope of water use and the required parameters of its purity. The main technological techniques are: water purification from suspended particles; purification from manganese and iron; removal of organic pollutants; water softening; desalination; removal of biological pollutants; adjustment of water composition.

Tables 6.1 and 6.2 show microbiological indicators of drinking water safety of various agricultural enterprises before the introduction of electrical disinfection systems using UV radiation.

According to the data (Table 6.1) the non-compliance of drinking water with Clause 1 (total microbial number) is 28 %, but according to 2-7 no more than 7 %, and according to the data in Table 6.2 in terms of the content of pathogenic intestinal protozoa, drinking water does not match – 2 %.

To solve the problem of microbiological contamination of drinking water, we use the electrical scheme of ultraviolet radiation for disinfection of drinking water at the final stage of water preparation (Figure 6.2).

Table 6.1

Microbiological indicators of drinking water safety

№ з/п	**Name of indicators, unit of measurement**	**Standards for drinking water**	**Actual data**
1	Total microbial number when t 37° C - 24 H, CFU/cm^3	≤ 100 (≤ 50)	5-280
2	Common coliforms, CFU/100 cm^3	absence	0-17
3	E.coli, CFU/100 cm^3	absence	0-42
4	Enterococci, CFU/100 cm^3	absence	0-21
5	Pathogenic Enterobacteria (available in 1 dm^3)	absence	0-19
6	Coliphages, CFU/dm^3	absence	0-24
7	Enteroviruses, adenoviruses, antigens of rotaviruses, reoviruses, hepatitis A virus and others (presence in 10 dm^3)	absence	missing

The method of ultraviolet disinfection has a number of significant advantages over chemical reagent methods [7,63, 118], the main one of which is the absence of changes in the composition and organoleptic properties (smell, taste). In cases of overdose, there are also no negative effects.

The advantages of UV technology are as follows: no undesirable side substances are formed and the chemical composition of useful (mineral and other) impurities does not change and the organoleptic properties of water do not change; the method and process are characterized by reliability, simplicity, low energy intensity and cost. Ultraviolet radiation makes it possible to destroy viruses and fungi that are not affected by traditional chemical methods, in particular chlorination [22,119].

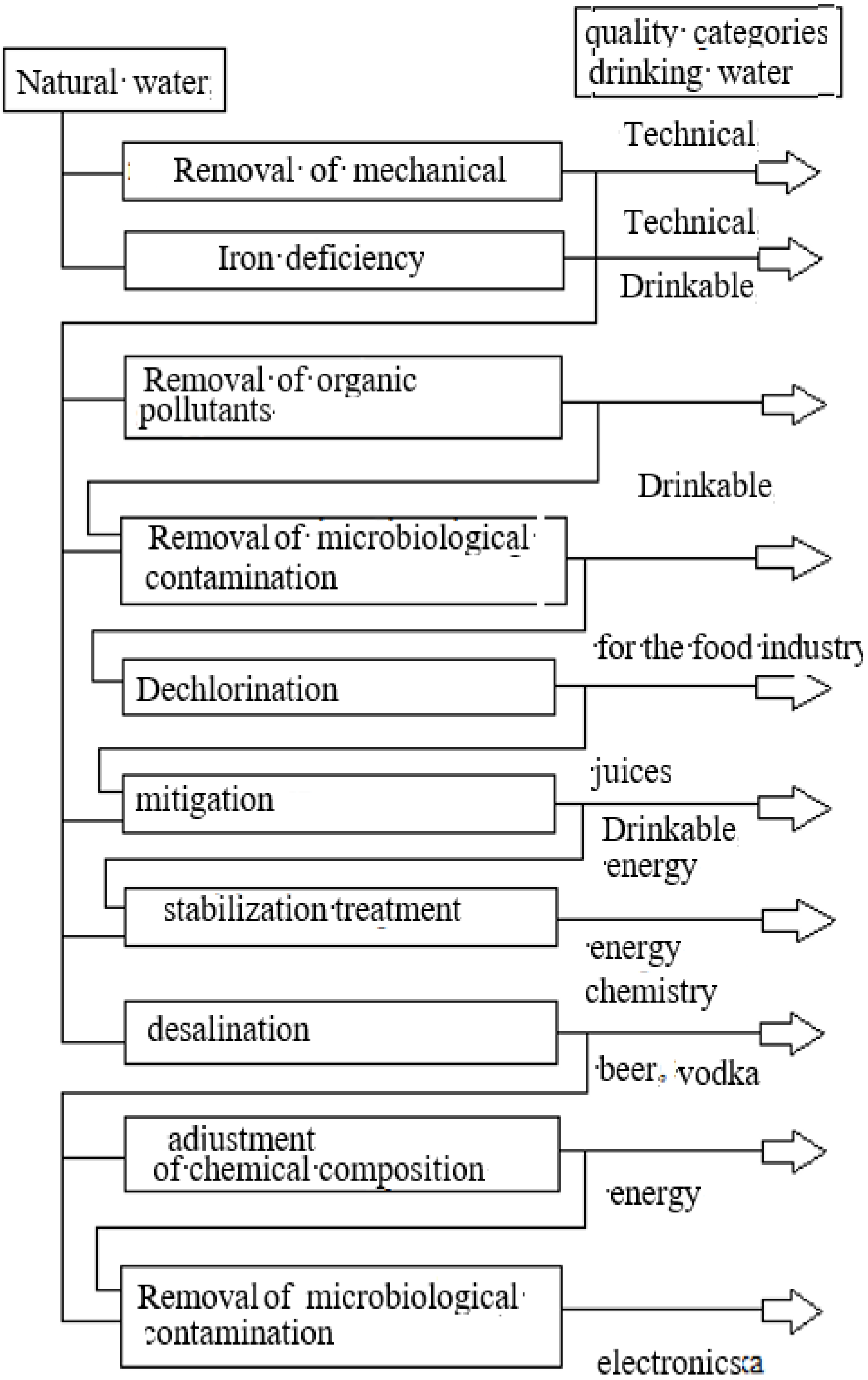

Figure 6.1 Standard scheme of an electrical water treatment complex using various methods.

Table 6.2

Parasitological indicators of drinking water safety

№	Name of indicators (units of measurement)	Standards for drinking water	Actual data
1	Pathogenic intestinal protozoa: oocysts, cryptosporidium, isospores, giardia cysts, dysentery amoebae, intestinal balantidia, and others. (cells, cysts in 50 dm^3)	absence	0-6
2	Intestinal helminths (cells, eggs, larvae in 50 dm^3)	absence	missing

The bactericidal effect of ultraviolet radiation during water disinfection is carried out due to the direct action of ultraviolet rays on the cell and molecular structure of microorganisms, causing modifying photochemical damage to DNA [65]. Changes in the DNA of microorganisms accumulate and lead to a slowdown in the rate of their reproduction and subsequent extinction in the first and subsequent generations [120].

In Figure 6.2 a typical scheme of the developed electrical system for disinfection of drinking water [121] using the developed electrical devices of UV irradiation is given.

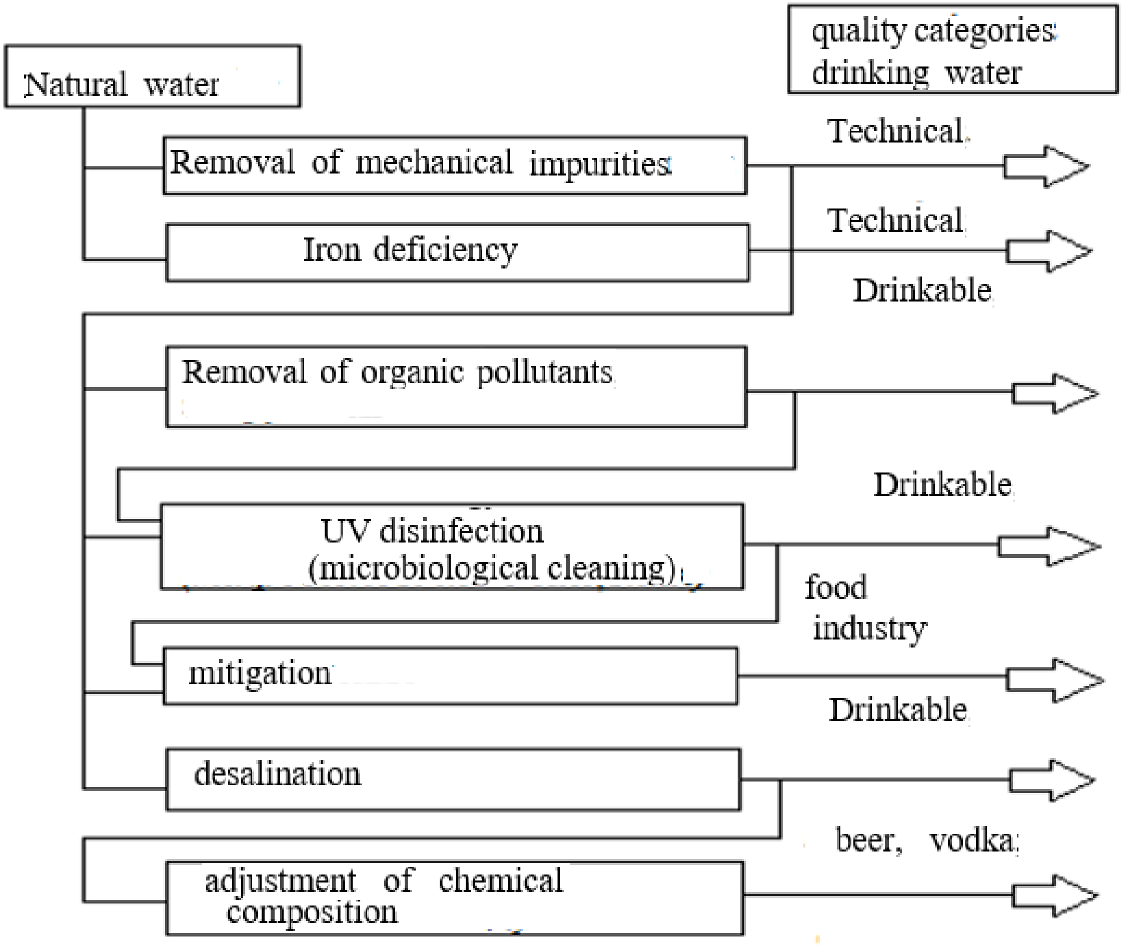

Figure 6.2 diagram of the developed electrical water disinfection system using ultraviolet radiation

When implementing electrical systems for disinfection of drinking water in complexes for disinfection of water under the influence of UV radiation, it was possible to achieve standard indicators for microbiological indicators (Table 6.3 and 6.4).

Table 6.3

Microbiological indicators of drinking water safety

№	**Name of indicators, unit of measurement**	**Standards for drinking water**	**Actual data**
1	Total microbial number at t 37° C-24 h, CFU / cm^3	≤ 100 (≤ 50)	0-13
2	Common coliforms, CFU / 100 cm^3	absence	missing
3	E.coli, CFU/100 cm^3	absence	missing

4	Enterococci, CFU/100 cm^3	absence	missing
5	Pathogenic Enterobacteria (available in 1 dm^3)	absence	missing
6	Coliphages, CFU/dm^3	absence	missing
7	Enteroviruses, adenoviruses, antigens of rotaviruses, reoviruses, hepatitis A virus and others (presence in 10 dm^3)	absence	missing

Table 6.4

Parasitological indicators of drinking water safety

№	Name of indicators (units of measurement)	Standards for drinking water	Actual data
1	Pathogenic intestinal protozoa: oocysts, cryptosporidium, isospores, giardia cysts, dysentery amoebae, intestinal balantidia, and others. (cells, cysts in 50 dm^3)	absence	missing
2	Intestinal helminths (cells, eggs, larvae in 50 dm^3)	absence	missing

According to the obtained data, drinking water meets all the requirements of regulatory documentation for the content of microbiological and parasitological indicators of drinking water safety [2].

Based on the analysis and experience in designing drinking water disinfection plants using UV radiation, the most efficient design of a flow-type installation is proposed, in which the lamp is placed along the axis of a cylindrical irradiation chamber.

In the case of such a design solution, almost the entire UV radiation stream passes through the water layer and disinfection (neutralization of 99.9% of microbiological objects in the water) is provided with minimal energy consumption.

The calculation of the irradiation unit is reduced to determining such a zone of the irradiation space that is exposed to minimal bactericidal irradiation E_{min} [122]. Therefore, all other active volume zones V_a installations will be exposed to excessive exposure. Required exposure H_S (W·cm^2) achieved by variation E_{min} (W·m^2) or time t(c):

$$H_S = E_{\min} \cdot t \tag{6.1}$$

Effective time t (c) the stay of water in the installation is determined by the formula:

$$t = \frac{V_a}{3600 \cdot Q} = \frac{V - V_1 - V_2}{3600 \cdot Q} \tag{6.2}$$

where V – volume of the irradiation cavity of the installation, m^3; V_1 – volume of the submerged part of the outer bulb of the lamp, m^3; V_2 – the volume of stagnant zones of the chamber, which reaches up to 10% of the volume of the irradiation cavity and depends on the design of the installation, m^3; Q – installation performance, m$^{3}\cdot$ H $^{-1}$.

The calculation of parameters of an electrotechnical water disinfection system of a flowing type is carried out taking into account the recommendations [69,123]. The starting point is that the installation provides the necessary surface exposure H_S irradiation for inactivation of various types of microorganisms in the most remote places that are least irradiated in the active volume chamber. Surface exposure to inactivation H_S, not bulky H_V selected because for inactivation of microorganisms, data on the values of H_S they are determined by a simpler method and are known (Table 6.2).

Energy brightness L_0 external surface of the lamp with a radius of R_1 it was determined experimentally using a Tensor-31 UV radiometer. To take into account the natural decrease in the luminous flux of the lamp during the service life (~35% to 8000 hours of combustion), we apply a margin factor of 0.65:

$$L_1 = 0{,}65 L_0 \tag{6.3}$$

The chamber diameter is chosen taking into account the data [70], where it is recommended that in the case of using low-pressure Mercury discharge lamps, the diameter of the irradiating cavity should not exceed 100 mm.

The length of the irradiation cavity was determined by the length of the immersion part of the outer bulb of the lamp. The diagram of the irradiating part of the unit is shown in Figure 6.3.

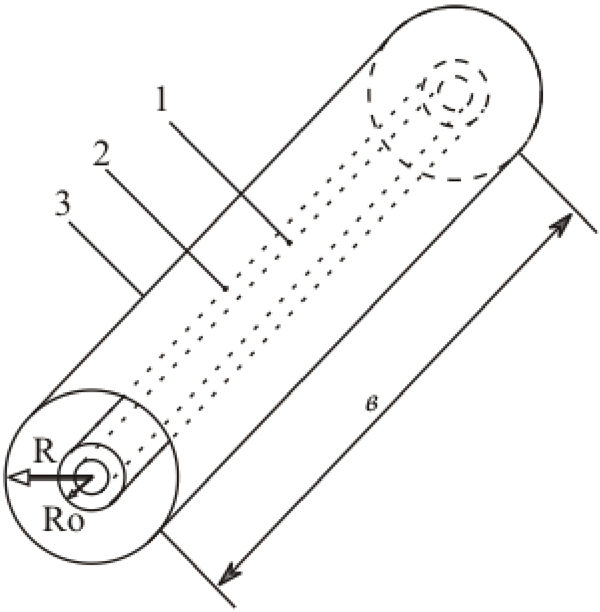

Figure 6.3. Scheme of the irradiation Unit: 1 - germicidal lamp; 2 - Quartz case; 3 - camera Wall

Since, according to the second law of irradiation, it is inversely proportional to the square of the distance from the source, i.e.

$$E \sim \frac{1}{R^2} \qquad (6.4)$$

and according to the Booger-Lambert Law, the radiation flux (and in proportion to it, the irradiation) during passage through the water layer along the X-axis changes according to the formula:

$$F(x)=F_0\, e^{-kx}, \qquad (6.5)$$

where k – indicator of attenuation of the radiation flux, then the formula for determining the minimum value of bactericidal irradiation $E_{b,min}$ on the inner surface of the chamber Wall 3 (Figure 2.4) the installation has the form:

$$E\,\frac{E_{b,o}\cdot R_0^2}{R^2}^{-k(R-R_0)}{}_{b,min}, \tag{6.6}$$

where $E_{b,o}$ – irradiation on the outer surface of the Quartz Cover 2 (Figure 6.4); R_0 та R – respectively, the outer radius of the Quartz Cover 2 and the inner radius of the camera 3.

The indicator k attenuation of the radiation flux indicates how much of the initial bactericidal flux is lost during passage through a unit thickness of the water layer. However, since the absorption decreases along with a decrease in the intensity of the bactericidal flow, the value of the indicator *k* of the weakening of the bactericidal flow by a 1 cm thick layer of water is taken for calculations.

The value of the absorption coefficient at this thickness varies within:

natural water from surface sources - from 0.2 to 0.6;

drinking water from artesian water supply sources - from 0.05 to 0.2;

drinking water from surface sources – from 0.15 to 0.3.

If this option is available, the indicator k_1 it is determined in the laboratory in each specific case.

Then the minimum value of the irradiation time interval in hours is required for the formation of a bactericidal (surface) dose H_b on the inner surface of the chamber wall (when the water in it is stationary), we determine by the formula:

$$t_{mim} = \frac{H_b\cdot R^2}{E_{b,0}\cdot R_0^2\cdot 3600}\cdot e^{k(R-R_0)} \tag{6.7}$$

If the water moves (flows) evenly (laminarno, that is, without mixing) along the chamber, then according to the formula:

$$\vartheta = \frac{b}{t}, \tag{6.8}$$

where b – the length of the emitting part of the lamp, you can determine the minimum value of the speed (in meters per hour) of water flow. So,

$$\vartheta\,\frac{3600\cdot E_{b,0}\cdot R_0^2}{H_b\cdot R^2}^{-k(R-R_0)}\qquad {}_{min} \tag{6.9}$$

Performance Q installations (in cubic meters per hour) can be determined by the formula:

$$Q=\frac{V}{t_0} \tag{6.10}$$

where V – irradiated volume of water.

In our case $V=\pi\cdot b\cdot(R^2-R_0^2)$, tom

$$Q=\frac{3600\pi\cdot b\cdot E_{b,0}\cdot R_0^2(R^2-R_0^2)}{H_b\cdot R^2}\cdot e^{-k(R_2-R_1)} \tag{6.11}$$

Under such conditions, even in the case of laminar flow (when the water layers are not mixed), the water layers removed from the UV source will receive the necessary dose for inactivation.

Use in formulas (6.7) – (6.11) irradiation $E_{b,o}$ together with the exponential multiplier, it has an advantage over methods where the irradiation value averaged over the thickness of the water layer is taken as a basis, since the indicator $k(R-R_0)$ it matters more than it actually does. Due to this, the value of irradiation $E_{b,min}$ on the inner surface of the chamber wall, it is always taken with a certain margin. The same applies to other disinfection parameters, namely t_{min}, ϑ_{min} та Q, while methods with average irradiation can lead to under-irradiation of water layers close to the chamber wall.

In some cases, it is proposed to mix water in the installation chamber to increase the efficiency of disinfection, and there are even attempts to build mathematical models of such processes [29]. But no mechanical «stirrers» can be mounted inside the chamber, and magnetic» stirrers « are also unsuitable, since water is a diamagnet.

We can talk about a set of plates of a certain shape (blades) attached in a certain way to the inner wall of the chamber, which would direct water from the wall to the lamp by squeezing it from the lamp to the periphery of the chamber. But the water outside such plates will be in a stagnant state and will be shielded from radiation by them, and in such places of the chamber, on the contrary, microorganisms will multiply. And in general, the possibility of mixing seems illusory, since, for example, the mass (and volume) of a 10 mm thick layer of water that is adjacent to the inner wall of a 100 mm diameter chamber will be larger than a layer of water of the same thickness that is adjacent to a 30 mm diameter tube cover $\frac{100^2-90^2}{40^2-30^2} = 2.7$.

It should be noted that any calculations of the parameters of UV disinfection installations should be considered approximate. There are several reasons, namely:

- the Booger-Lambert Law is strictly valid only for a narrow beam of rays, while calculations consider beams that fall per unit area(irradiation);

- the Booger-Lambert Law is valid only for monochromatic radiation, and the spectra of germicidal lamps of both low and high pressure are not;

- not along the entire length of the chamber, water moves (flows) evenly, in the end zones near the transitions from the diameter of the inlet pipe, stagnant zones are formed, where water almost does not move; in addition, these zones are irradiated on one side, while in the middle section of the chamber – on both sides along the length of the lamp.

In this regard, in all civilized countries, the effectiveness of UV water disinfection systems is evaluated (certified) by biodosimetry [21]. The essence of this method is that the value of the radiation dose required to achieve the desired degree of inactivation of microorganisms is determined (controlled) experimentally. In practice, this is done by directly counting the number of living and dead microorganisms per unit volume of a water sample (luminescence microscopy). This approach is not only justified, but also necessary because due to natural evolution, the resistance of pathogenic microorganisms has increased: to chlorine by 5 times; to ozone by 2 – 3 times; to ultraviolet light by 4 times.

In this regard, if earlier the minimum value of the UV disinfection dose was considered: 160-200 J/m^2 (16 – 20 mJ/cm^2) for drinking water; 280-300 J/m^2 (28-30 mJ/cm^2) for domestic and industrial wastewater, now in industrialized countries these values are 400 J/m^2 and 700 – 1000 J/m^2, respectively.

6.2. Disinfection of drinking water during bottling

Providing the population with high-quality water is one of the most pressing problems that requires an effective solution. Today, consumers prefer bottled water. Thus, the process of obtaining and supplying the population with high-quality drinking water depends on a number of factors, the main ones being: the state of water sources, the sanitary and technical level of water supply systems at enterprises, and the bottling process itself.

Industrial production of drinking water is a multi-stage process. It includes, first of all, the process of monitoring the quality of drinking water at the preparatory stage. This stage is necessary for selecting and evaluating the adequacy of certain water treatment methods. First of all, the parameters that characterize the purity and safety of water – topological, radiological, microbiological, organoleptic-are analyzed. In addition, it is necessary to establish how much this water meets the criteria of «physiological usefulness», that is, it contains vital macro – and microelements in concentrations that meet the needs of the body.

In the production of bottled water, various types of water are used, extracted from various sources, including streams, wells and municipal water supply sources. Regardless of the source of origin or purpose of use, the water must be prepared before further use. Therefore, the production of drinking water in most cases begins with water treatment using various methods.

Figure 6.4 shows a diagram of the Electrical Complex for the production of bottled water with a capacity from 1.8 m^3/h to 6 m^3/h, which is successfully used at a number of enterprises, as well as at PJSC Mirgorod Food Products plant Kalinka. There is no fundamental difference between more powerful electrical complexes for the production of drinking water.

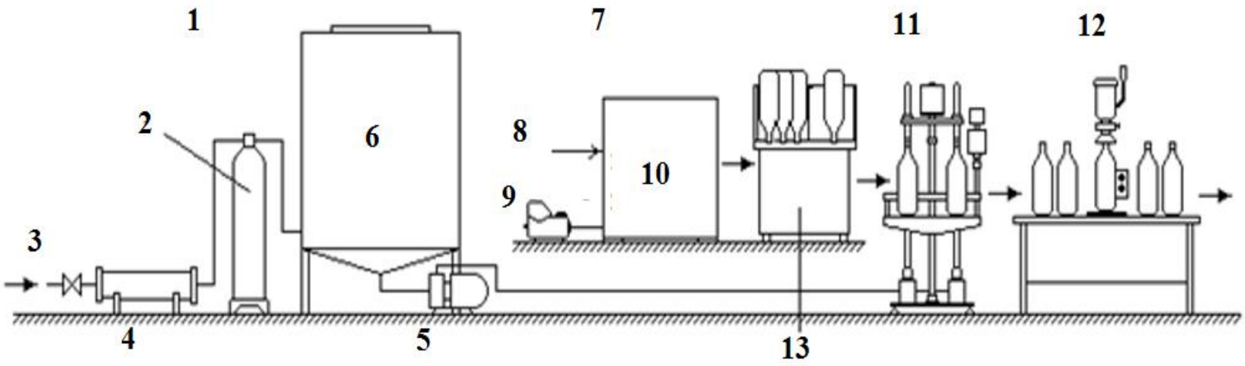

Figure 6.4 Standard scheme of an electrical complex for drinking water production.

Water preparation (1); carbon filter (2); water(3atm)(3); mechanical filter (4); water supply pump (5); container with water (6); production of bottles (7); water (8); compressor (9); blowing machine (10); bottling (11); clogging (12); bottle rinsing (13).

At the water treatment site, water is treated using a mechanical filter (figure 6.4), where solid mechanical inclusions and particles are deposited, and then using a carbon filter, where chemical compounds are removed from the water due to absorption. The purified water enters a container (storage tank), where it is stored until it is spilled.

The process of microbiological contamination of water, as experimental studies show, occurs at all stages of the technological process, namely, when stored in a storage tank, when bottled, etc.so, after bottling, the number of viable microorganisms increases rapidly, reaching $10^4 – 10^5$ CFU/ml in 3-7 days. The number of bacteria and their metabolic activity are directly proportional to the ratio of the surface area to the volume of the container in which water is stored. This is due to the fact that the nutrients present in low concentrations are absorbed and concentrated on the surface, thus becoming more accessible to bacteria.

The number of viable microorganisms on the surface of pet butyls and on HDPE lids varies from 11 to 632 CFU/cm^2 [124,125]. Washing containers before bottling is not always an effective measure, especially if they are used repeatedly. The disinfectants that are used in this case partially remain on the walls of butyl and affect the organoleptic properties of water.

To control microorganisms, various methods of control are used, the analysis of which is carried out in Section 5. thus, with chemical methods of water treatment, in order to achieve a stable disinfection effect, it is necessary to correctly determine the dose of the injected reagent and ensure a sufficient duration of its contact with water. The reagent dose is determined by trial disinfection or calculation methods. It is known that exceeding the reagent dose gives water a specific smell and changes organoleptic parameters.

Of the physical methods of drinking water treatment, the most widespread is disinfection with ultraviolet rays, the bactericidal properties of which have a detrimental effect on microorganisms. Ultraviolet rays destroy not only vegetative, but also spore forms of bacteria and do not change the organoleptic properties of water.

Data on the advantages and disadvantages of the methods described above are presented in Table 6.5. It Follows that the use of ultraviolet radiation in electrical complexes of water disinfection at the main and final stage of the technological process (Figure 6.1.) is a solution to the problem of disinfection in the preparation of drinking water from various water supply sources [126].

The technological process is based on the method of disinfection by UV radiation using the developed installations. The developed technology makes it possible to decontaminate containers and water simultaneously during the bottling process.

Table 6.5

Advantages and disadvantages of drinking water disinfection methods

Name of the method and its characteristics	Advantages	Disadvantages
Ozonation is used to disinfect and improve color, taste and eliminate odors	- strong oxidizer and disinfectant; - effective against pathogenic microflora viruses;	- forms by - products, namely: organic acids, ketones, peroxides; - the need to use biologically active

Name of the method and its characteristics	Advantages	Disadvantages
	- helps to remove turbidity from the water; - removes foreign tastes and odors	filters to remove the formed by-products; - does not provide a residual decontaminating effect; - requires high initial equipment costs; - ozone, reacting with complex compounds, breaks them down into fragments that are a nutrient medium for microorganisms in water distribution systems
Chlorination is used in gaseous form, so the strictest safety measures should be observed	- effective oxidizer and disinfectant; - characteristic aftereffect; - prevents algae growth; - destroys organic compounds; - characteristic for removing unpleasant tastes and odors	- increased requirements for transportation and storage; - potential health risk in case of leakage; - formation of disinfection by-products; - worsens organoleptic parameters
Ultraviolet radiation - the process technologically	- does not require storage and	- disinfection activity depends on

Name of the method and its characteristics	Advantages	Disadvantages
consists in irradiating water with ultraviolet light, which is able to kill various types of microorganisms	transportation of chemicals; - does not form by-products; -does not change the organoleptic parameters of water	the turbidity of the water, its hardness

In Figure 6.5 the diagram of the developed Electrical Complex for disinfection of drinking water in the process of bottling using UV radiation is given.

The Electrical Complex of disinfection of drinking water in the process of bottling consists of two technological processes: disinfection of drinking water and disinfection of the inner surface of packaging containers and lids.

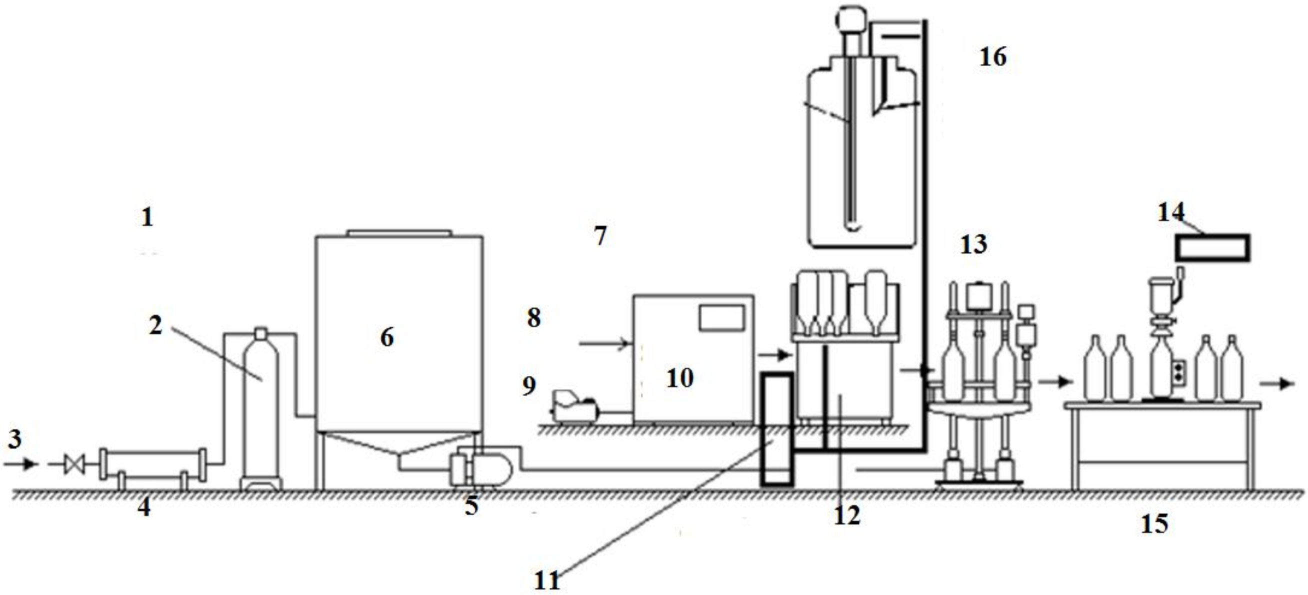

Figure 6.5. Scheme of the developed Electrical Complex for disinfection of drinking water during bottling: Water preparation (1); carbon filter (2); water(3atm)(3); mechanical filter (4); water supply pump (5); container with water (6); production of bottles (7); water (8); compressor (9); blowing machine (10); installation of UV water disinfection (11); rinsing bottles with disinfected water (12); bottling (13); UV irradiation of covers

(14); clogging (15); UV-irradiation of the surface of the bottle before pouring water and during filling of the bottle (16).

The sequence of decontamination of water, plastic bottles and lids for sealing bottles includes the following steps: the water that is poured into the bottle is passed through the UV decontamination unit; the inner surface of the bottle is UV-irradiated, before bottling water; when pouring water into the bottle, the water and its surface are additionally UV-irradiated; the surface of the lids for sealing bottles is decontaminated.

6.3 Disinfection of water in swimming pools by UV radiation and ozonation

Today, the construction of swimming pools is an integral part of social programs for the development of infrastructure in cities and settlements, as they are provided for in the projects of modern medical centers, hospitals, sanatoriums, preschool institutions, schools and other facilities. For a significant part of the population, the use of swimming pools is becoming the norm and an indicator of a healthy lifestyle.

Pool water directly affects the health of visitors. But along with the health-improving effects, there is a possibility of harmful effects of pool water on the human body, in particular, the irritating effect of chemical impurities in the water on the skin and mucous membranes, intoxication when harmful substances enter the respiratory tract and when water accidentally enters the gastrointestinal tract. there is also a possibility of infection with infectious diseases that can be transmitted through the water of swimming pools and bathing.

The operation of swimming pools requires a set of measures for filtration and disinfection of water. The water quality requirements for swimming and swimming pools are set in [127-131]. An extremely urgent task in water disinfection is the use of technologies that do not lead to the formation of toxic compounds during disinfection, while completely destroying pathogenic microflora and do not affect human health. Microbiological indicators of water should ensure the impossibility of transmission through water of dangerous intestinal diseases, as well as adenovirus infections, scabies, conjunctivitis, otitis media, viral hepatitis, dysentery.

To ensure compliance of the main water indicators with the requirements of sanitary standards, it is necessary either to ensure a constant replacement of water in the pool bath, that is, to create a system of flowing water supply to the pool with drinking-quality water [2], or to create a system of circulating water supply with water purification and disinfection. From the point of view of sanitary safety, a running water supply system is more acceptable, but it requires a large consumption of water and energy resources. From an economic point of view, a circulation system that constantly cleans the water in the pool is more acceptable.

In accordance with the requirements of regulatory documents and practical experience to ensure the required level of water purification and disinfection, it is necessary to ensure at least four times the circulation of the entire volume of water in the pool through the cleaning and disinfection system during the day [132]. In [133], full water exchange is recommended for sports pools no more than 8 hours, for health pools – no more than 6 hours, for children over 7 years - 2 hours, and for children under 7 years – 0.5 hours.

Even when the pool is filled with drinking water that fully meets the requirements in the absence of appropriate preparation, the surface of the water in the pool is covered with a film after 2-3 days, and mucus appears on the walls. Then the water gets a green hue, which is given to it by the presence of algae, and an unpleasant smell appears. One person, even after a preliminary shower, brings up to 50 thousand microorganisms into the pool [134]. The pool can get harmful and dangerous inorganic and organic substances that not only pollute the water but can lead to disease. In order for the water that is in the pool to meet the necessary parameters, it must be prepared, which must necessarily contain: water heating, recirculation, mechanical cleaning and disinfection (disinfection).

Disinfection is the destruction of pollutants and waste products of microorganisms, algae, bacteria, viruses, and fat secretions. For this purpose, various technologies and methods are used, which are divided according to the mode of action on microorganisms [80, 135-137]:

- reagent methods-disinfection is achieved by adding biologically active chemical compounds to the water (chlorination, bromination, ozonation, use of oxygen-containing reagents, combined preparations such as chlorine+oxygen, etc.);

- non-reactive methods - treatment of water by physical exposure (high temperature, ultraviolet light, etc.);
- combined methods-a combination of reagent and non-reagent methods.

Today, combined methods are most widely used [41] UV irradiation in combination with chlorination and UV irradiation in combination with ozonation [2, 138, 139,140]. The use of combined methods of disinfection of water in swimming pools is caused by the need to reduce the use of reagents, primarily chlorine, which forms products with organic and inorganic impurities introduced into the water by visitors to swimming pools, and which are part of the water. The formation of by-products is associated with the high reactivity of halogens (chlorine and bromine), actively reacting with impurities in water, they form secondary organometallic compounds. .This also applies to ozone, which is also able to form secondary reaction products. In the pool, water has a constant supply of organic substances that are introduced by bathers and are a source of disinfection by-products, which complicates the process of disinfection and ensuring the toxicological safety of pool water. Today, more than a hundred different disinfection products are known in swimming pools [141].

Let's consider more common schemes of Electrical Water Treatment complexes in swimming pools.

In Figure 6.6 presents a diagram of an electrical complex for water treatment in a swimming pool with periodic treatment with sodium hypochloride, which is periodically supplied to the pool for disinfection (disinfection).

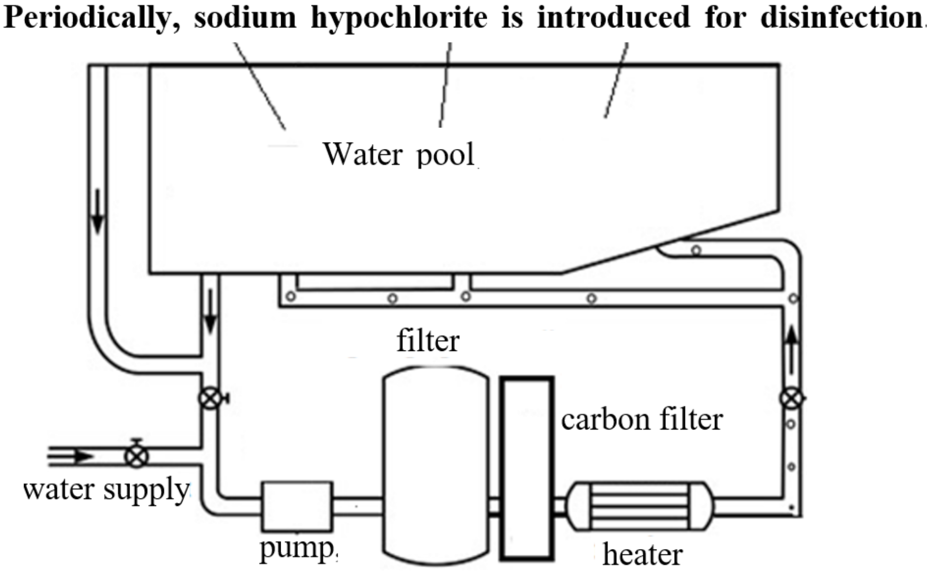

Figure 6.6. Standard scheme of an Electrical Water Treatment Complex for swimming pools using sodium hypochloride

At the water treatment site, water is treated using a flushing filter (figure 2.6), where solid mechanical inclusions and particles are deposited, and then using a carbon filter, where chemical compounds are removed from the water due to absorption. After that, the purified water enters the pool, where sodium hypochloride is periodically introduced to disinfect the pool water. The use of chemical methods, namely Sodium hypogloride, leads to negative consequences. In addition, chlorination of water with a high content of bromine and iodine compounds leads to a high content of bromine - and iodine-containing by-products, which are usually more cytotoxic and mutagenic than chlorine-containing ones. Since many of the by-products are volatile and easily evaporate from water, they enter the human body through the skin and lungs. Individual compounds can cause mutagenic and carcinogenic effects [88].

An assessment of the danger of some compounds formed during chlorination of water in swimming pools and a calculated forecast of their toxicity is given in [88]. Among the problems associated with the potential danger to human health of disinfection byproducts is their removal. From a technological point of view, it is possible to reduce the concentration and remove already formed toxic by-products by oxidation, followed by complete or partial destruction of toxic molecules. Effective oxidation technologies are based on the use of OH radicals. The technology used in oxidative processes differs in the methods of obtaining OH radicals in water. The most common methods of obtaining OH radicals for water disinfection are:

- using the reaction of interaction of ozone and UV radiation (ozone/UV);
- use of hydrogen peroxide (H_2O_2) and ozone reactions;
- use of reactions of interaction of hydrogen peroxide and UV radiation (H_2O_2/UV).

Despite the fact that chlorination is still the most common method of water disinfection, its use is constantly reduced due to the insufficient effectiveness of existing chlorination schemes in relation to enteroviruses and protozoa, the formation of health-threatening by-products, in particular chloramines, halogen-containing compounds and nitrosamines, as well as the deterioration of organoleptic parameters of water and the negative impact of chlorine on the mucous membranes and respiratory tract.

An alternative to chlorine as a disinfectant can be ozone. Ozonation of water is one of the effective methods of disinfection of water with oxygen, it not only has a bactericidal effect on pathogenic microflora, but is also able to destroy many chemicals present in water: there is a destruction of high-molecular organic compounds, elimination of taste and odors.

In Figure 6.7 presents a diagram of an electrical complex for water treatment in a swimming pool using ozone for disinfection (disinfection).

Such a scheme using the ozonation method can be applied both at all and at individual stages of preliminary, intermediate and finishing water treatment, but only if other, simpler and cheaper technologies cannot solve the problem. This is a rather expensive and complex technology. Especially expensive is the item of electricity.

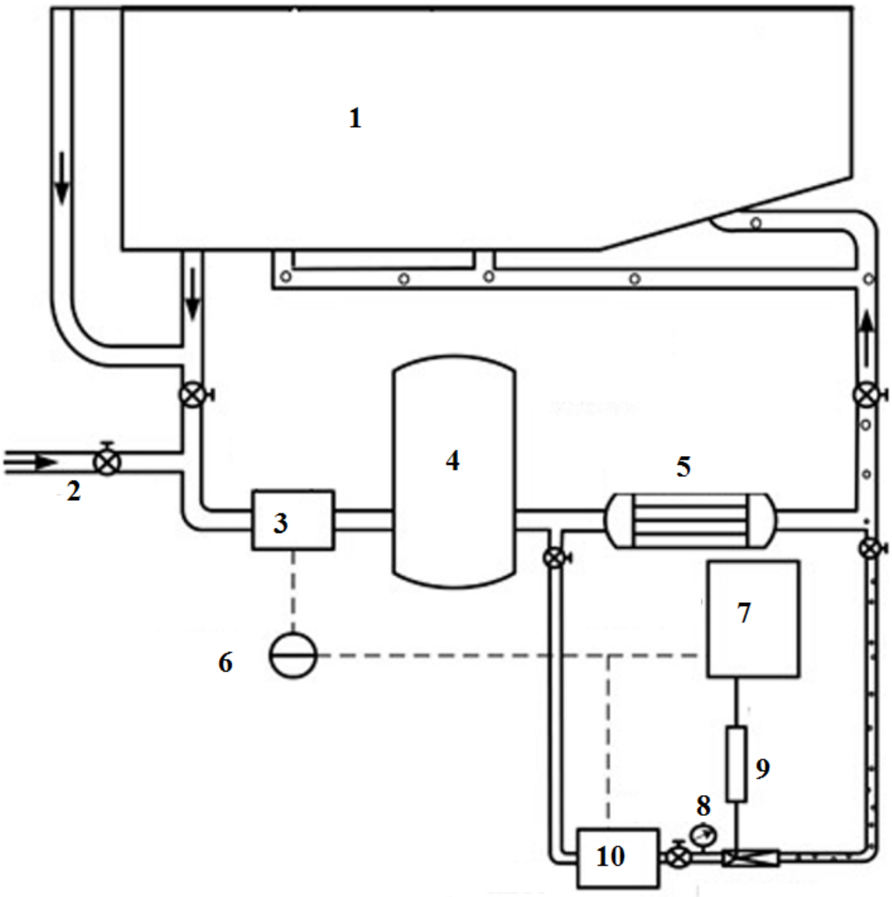

Figure 6.7. Standard scheme of an Electrical Water Treatment Complex for swimming pools using ozonation: Pool with water (1); Water supply (2); Pump (3); Washable filter (4); Heater (5); Timer (6); Ozonator (7); Manometer (8); Valve (9); Injection pump (10).

A special feature of ozone is the ease of its decomposition with the formation of atomic oxygen – one of the most powerful oxidizing agents. Atomic oxygen destroys bacteria, spores, viruses, and destroys organic substances dissolved in water. This makes it possible to use Ozone not only for disinfection, but also for removing toxic organic substances, that is, for deodorizing water. During ozonation, the mineral composition, ph, and alkalinity of water remain unchanged [71].

The decontaminating effect of ozone is 15-20 times more effective than that of chlorine, and about 300-600 times more effective on Spore forms of bacteria [142]. The advantages of ozone over chlorine in water disinfection are that ozone improves the organoleptic properties of water and provides a bactericidal effect with a shorter contact time, however, unlike chlorine, it does not have a long aftereffect.

Ozonation is common in many industrialized countries-the United States, France, Japan, Finland, and Germany. Most often, primary ozonation is used in small doses (1.5-2.0 mg/l), which makes it possible to combine it with other technologies, including UV disinfection, to achieve high results in water treatment [143,144].

Ultraviolet light does not create disinfection by-products, and its dose can be increased to values that ensure epidemiological safety for both bacteria and viruses. The effect of UV on viruses is much stronger than in the case of using chlorine. Economically, this type of disinfection is quite effective, but one of the disadvantages that does not allow effective use for disinfection of pool water is the lack of radiation after effect.

When ozone is exposed to the cell wall of Giardia cysts, the cytoplasmic membrane and ultrastructural elements of organisms change. When comparing the decontaminating effect of ozone and chlorine at 0.1 mg/dm^3 each, it was found that for the complete destruction of 60 thousand Escherichia coli in 1 liter of water, it takes 5 seconds for ozone and 15 thousand seconds for chlorine [95]. The required time for the manifestation of the bactericidal effect of ozone in water is about 10 minutes. A high virucidal effect of ozone is observed at concentrations of 0.5-0.8 mg/L and exposure for about 10 minutes. Recent studies have shown a high efficiency of ozone in destroying protozoan cysts present in water [96]. The mechanism of bactericidal action of ozone consists in inactivation of bacterial enzymes, irreversible disruption of the structure of cell DNA by exposure to these structures of atomic oxygen formed during the breakdown of ozone. The advantages of ozone over chlorine in water disinfection are that ozone improves the organoleptic properties of water and provides a bactericidal effect with a shorter contact time, however, unlike chlorine, it has no aftereffect.

Ozone can be produced by an electric discharge. This method has found the greatest application in industry, but its cost is high.

Therefore, when developing an electrical complex for disinfection of water treatment for swimming pools, the advantages and disadvantages of the above methods are taken into account and a technically new approach is proposed - to use a combined ozonation method with UV exposure. In this case, ozone is obtained as a result of ultraviolet radiation from an electrical device.

In Figure 6.8 presents a diagram of an electrical complex for water treatment of swimming pools using a combined method - the complex effect of ozone and ultraviolet light.

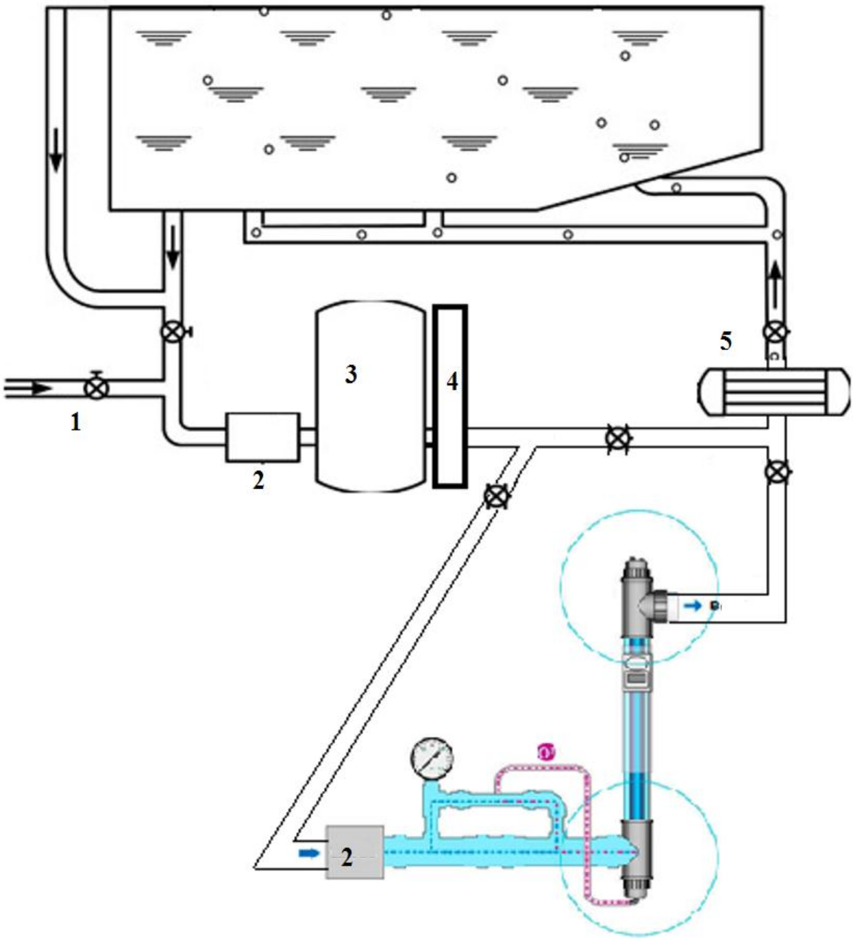

Figure 6.8. Scheme of the developed Electrical Complex for disinfection of water in swimming pools by the complex action of ozone and ultraviolet light: Water supply (1); Pump (2); The filter is washable (3); Carbon filter (4); Heater (5).

Thus, according to the developed electrical complex of water treatment in the pool, water disinfection occurs under the influence of ozone, and then under the influence of UV radiation. Ozone is produced by a source of UV exposure without the use of additional devices. Due to the breakdown of ozone, water is enriched with oxygen.

Ozone acts in a complex way, leading to an improvement in the physico-chemical and bacteriological parameters of water. This treatment scheme allows for reliable disinfection [31].

UV irradiation of ozone molecules dissolved in water leads to its partial decomposition with the formation of atomic oxygen and OH radicals. Their reactivity (oxidation) is many times higher than that of ozone. The extinction coefficient of O_3 at a wavelength of 254 nm is 3300 L/(mol·cm), and it is much higher than that of H_2O_2 [18.6 L/(mol·cm)]. Approximately, the rate of ozone decay is 1000 times higher than that of H_2O_2.

Currently, it is proved that there are three UV/O_3 reaction pathways leading to the formation of hydroxyl radicals OH through the formation of excited oxygen atoms, hydrogen peroxide, and perhydroxyl ions. In fact, there are many more ways to generate free radicals, but the complexity of the chemical process does not allow us to study in detail all chemical reactions, their kinetics and the process of producing hydroxyl ions.

The process of water disinfection by the combined method of UV radiation in combination with ozone can also be used in the purification of certain types of water to decompose complex organic impurities. These processes are effective at very high UV doses of 500-600 mJ/cm^2, which is much more than is necessary for deep disinfection.

During experimental studies during the introduction of the electrotechnical complex of water disinfection in swimming pools, it was found that pre-ozonation of water, followed by its purification, significantly improves the transparency of water for UV radiation (naturally, the process of ozone disinfection is also underway), which makes the use of ultraviolet disinfection more economical.

A diagram of the electrical water disinfection complex is given (Figure 2.8) has successfully passed tests for disinfection of water in swimming pools with a volume of up to 100 m^3.

Ozonation of water primarily solves the problems of physical and chemical purification, reduces the consumption of reagents, and provides a primary barrier against microbial contamination. It is known that if aqueous solutions contain organic compounds that absorb UV light, then UV radiation usually does not give any effect due to the shielding of ozone with optically active compounds. Using UV/O_3 technology, it is possible to achieve complete mineralization of organic compounds with a short molecular chain.

6.4 Disinfection of water when growing fish in closed recirculating systems

In recent years, in Ukraine, as in a number of other countries, industrial methods of breeding aquaculture facilities have become increasingly important, including growing fish in swimming pools using warm water from power facilities in reversible water supply systems and installations with a closed water supply cycle – closed water supply installations [145,146].

In Ukraine, aquaculture is part of Agriculture, estimated at approximately in 3.5 million (0.35% of all agriculture). Historically, production in the field of aquaculture in Ukraine was one of the most developed among the CIS countries СНГ [147].

When growing fish, partial or complete reuse of natural and artificial reservoirs is used, as well as artesian water [148] through recirculating systems. This approach is economically beneficial for industrialists of this market due to the reduction in the amount of water resources when they are reused using preventive disinfection measures [149].

The choice of the method and means of implementing recycled water treatment, especially in conditions of intensive use of USV, is crucial for the technological cycle of fish rearing. In this regard, scientists are constantly looking for alternative non-reactive methods, the use of which will ensure the inactivation of microorganisms, without the formation of by-products harmful to fish cultivation. A number of scientific papers are devoted to this problem [150, 151], which reveal the advantages and disadvantages of existing technologies.

In Ukraine, ozonation is most often used to disinfect water in recirculating systems when growing fish, less often ultraviolet UV radiation. The effectiveness of these methods, as well as their combination [86], depends on the presence of dissolved and suspended organic compounds in water.

In world practice, the method of ozonation in fish farming has been criticized, since the effect of excessive dosing can cause serious damage to fish and can be harmful [152].

Most scientific papers [104, 153] are devoted to the problem of using UV radiation in recirculating fish rearing systems.

When developing a water disinfection system for growing fish in closed water supply systems, UV technology was used, the effectiveness of which depends on many factors, primarily on the irradiation and degree of inactivation of microorganisms.

As a rule, when using ultraviolet installations in fisheries, the following two types are used: type 1 - installations that reduce the number of microorganisms, without accurately determining the productivity and intensity of radiation; Type 2 - installations that reduce the number of bacteria and viruses by at least 10^4, with a radiation intensity of 400 mJ/m^2.

Installations of the first type are used for general water improvement in relation to the reduction of pathogens, installations of the second type are particularly important, and sometimes necessary components in the work of incubation shops and installation of closed water supply (ICWS) systems.

Among the considered types of UV disinfection installations, UV sterilizers are distinguished: surface and submersible. The surface one consists of a battery of UV lamps with reflectors fixed at a certain height from the treated water. However, the use of such systems is unproductive due to the limited penetration of UV rays into the water column [121]. Sterilizers in which water disinfection takes place in the irradiation chamber [94] are more productive and reliable, they can be installed anywhere in the water purification system [154, 155].

To obtain satisfactory results in terms of water safety in recirculation systems, it is necessary to continuously process water using filters, disinfection to remove fish waste products, providing the necessary favorable conditions for its existence, adjusting the composition of water by pH and oxygen in the recycled system [156].

For cleaning and disinfecting water when growing fish, an electrical disinfection system using UV radiation is proposed, which is shown in Figure 6.9, using the following stages of disinfection [157, 158]: installation for removing large contaminants (coarse cleaning); installation for removing highly dispersed impurities (fine cleaning) that cause turbidity and color of water; installation for ultraviolet disinfection of water (inactivation of microorganisms), as well as equipment for PH correction, oxygen saturation of water, water heating and electronic control systems

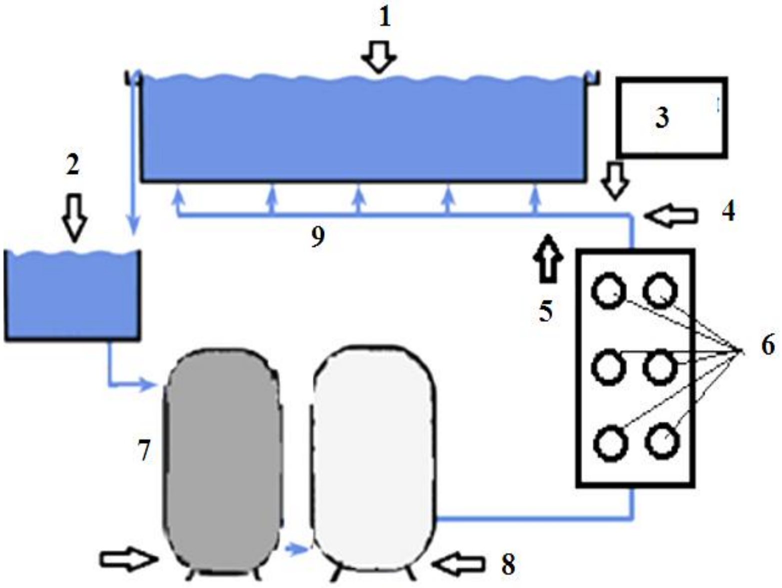

Figure 6.9. Scheme of water purification and disinfection in the ICWS system when growing fish: Pool for growing fish (1); Water drain tank (2); Setting water saturation with oxygen (3); pH adjustment (4); Water heating (5); UV lamps (6); Coarse cleaning filter (7); Fine filter (8); Purified water (9)

Installations for removing large contaminants and highly dispersed particles cope with water purification from foreign inclusions, but do not solve the issue of inactivation of microorganisms. Therefore, for the inactivation of microorganisms, a UV unit with a power of 480 W has been developed, which ensures the inactivation of microorganisms when water flows through a channel that ensures not only its disinfection, but also filtration.

Thus, an electrical scheme for water disinfection in closed recirculating systems when growing fish by UV irradiation without the use of ozone has been developed.

CHAPTER 7 TECHNOLOGICAL APPROACHES TO USING UV-IRRADIATING WATER DISINFECTION PLANTS

7.1. Calculations of electrical systems for disinfection of drinking water

In practice, electrical systems with «non-submerged» and «submerged» sources of bactericidal radiation are used for disinfection of drinking water [159]. Electrical systems with non-submerged sources have some advantages (placing sources above the water surface, without Quartz covers and their relatively simple design), but they are not without disadvantages (a lower coefficient of utilization of the germicidal radiation flow, since the reflector they have partially absorbs it).

In systems for disinfection of water by ultraviolet radiation with submerged electrical devices, a higher use of bactericidal radiation is achieved. Electrotechnical UV-acting devices in such systems are placed in special Quartz covers that are transparent to bactericidal Rays [160]. In Figure 7.1 an image of an electrical device in a quartz case is presented.

Figure 7.1. Electrical device with a power of 20 W in a quartz case

The analysis showed that the main goal of the new technical solutions being created is to increase the efficiency of water disinfection. However, achieving this efficiency is usually accompanied by a complication of the design of the electrical system, an increase in operating costs [161].

To develop an effective electrical water disinfection system, we will use the well-known designs of UV water disinfection installations [111, 112, 113, 162].

Thus, in [112], a device for decontamination of aqueous media by treatment with ultraviolet radiation is described. The installation for implementing the proposed method contains a source of ultraviolet radiation, a power supply device. The radiation source is a vacuum ultraviolet device on a barrier discharge filled with xenon, which emits a monochromatic beam with a wavelength of 172 nm, located inside the reactor, containing internal and external electrodes connected to the control source. The treated water medium is placed in the gap between the inner wall of the reactor and the UV source, into which air is supplied under pressure. The described method can be used to purify water from organic compounds. We note the disadvantages of this method of water disinfection: when using a vacuum ultraviolet device on a barrier discharge in a water disinfection unit that emits a monochromatic beam with a wavelength of 172 nm, the bactericidal effect is very small, since the spectra of action have a pronounced maximum at wavelengths of 260÷265 nm.

In [113], the efficiency of water disinfection is achieved by simultaneously exposing the treated water to ozone and ultrasonic waves. However, the use of ozone leads to a more complex design of the installation and additional costs during its maintenance. In addition, this design of the system does not allow you to create significant overpressure, which significantly limits its performance.

In the works [163,164] a water disinfection unit is proposed, containing a housing with pipes for the supply of source water and the discharge of treated water, a source of ultraviolet radiation with a protective Quartz cover [111]. In order to increase the efficiency of irradiation, the UV unit is equipped with an additional device for creating a turbulent mode of water flow during irradiation, as well as a device for cleaning the Quartz cover, which significantly complicates it. However, as practice shows, such a complication of the installation does not make a corresponding contribution to improving the efficiency of disinfection.

Based on the analysis of known designs of water disinfection plants, we will develop an electrotechnical UV-acting system [165] for UV-acting water disinfection complexes. The developed electrical system provides for simplifying the design and reducing maintenance costs while maintaining the efficiency of water disinfection.

It is known that the range of UV installations and disinfection systems for various technological processes, tasks and, accordingly, water characteristics is quite diverse and wide. UV installations are designed and developed using different element bases (device type, start-up equipment, etc.), which significantly changes the technical parameters of the electrical system depending on the task to be solved.

The main condition for applying the method of ultraviolet disinfection is the correctly selected dose of inactivation of microorganisms, that is, the amount of ultraviolet radiation energy that is necessary for the destruction of microorganisms in water [166]. To ensure the effectiveness of disinfection, the UV radiation dose is selected taking into account not only the water transparency coefficient [115], but also calculations are performed using experimental methods or modeling [167]. The value that characterizes the disinfection dose – UV irradiation-must not be lower than the specified value for the type of bacteria at any remote point of the disinfection chamber from the UV radiation source.

When designing electrical water disinfection systems, it is necessary to solve a number of problems related to the study of hydrodynamic flow, reducing pressure loss, achieving maximum mixing of the hydrogen medium in the irradiation zone, etc.

The physical process of light propagation in an aqueous medium (absorbing medium) is described by the Booger-Lambert-Baer law [142], according to which, for a parallel beam of light with a wavelength and intensity, the distance traveled in the absorbing medium, the intensity is determined by the formula:

$$I = I_0 e^{-k_\lambda \cdot l} \tag{7.1}$$

where k_λ – the absorption coefficient of the medium, which depends on the wavelength.

For convenience, when calculating electrical disinfection systems, the penetration coefficient is used k , which is always less than 1, which characterizes the decline in the intensity of UV radiation with a wavelength of 253.7 nm, when passing a certain distance in an aqueous medium, for example, 50 mm, which determines the permissible decline in the intensity [169]. In this case, the intensity I in a medium with k a penetration coefficient over the distance traveled I:

$$I = I_0 k^{\frac{l}{50}} \tag{7.2}$$

where l – it has dimension [mm]. The penetration coefficient for each medium is determined experimentally.

To perform calculations when designing electrical systems of UV exposure, it is necessary to know the spatial distribution of the radiation intensity of the UV lamp, or in the case of water disinfection, the «UV lamp+Quartz cover» system $I(k, x, y)$, where k – penetration rate; x, y – coordinates in the plane perpendicular to the longitudinal axis of the lamp.

The intensity distribution is calculated using numerical methods. A UV emitter, i.e. a lamp, is divided into a large number of point radiation sources: the larger their number, the more reliable the calculation result. In this case, for each fixed distance from the axis of the radiation source, the contribution from each radiating point is calculated. This takes into account the dependence of the refractive index and reflection on the wavelength. If we consider a multi-lamp system, the calculation of the average irradiation takes into account the overlap of one lamp with others. The result of the calculation is the dependence of the intensity on the distance to the axis of the radiation source and on the coordinate along the axis of the radiation source.

The intensity of radiation exposure is a function of the dose H, the calculation of which is a complex task. In general, the calculation requires the following data: distribution of UV radiation intensity in the disinfection chamber and calculation of the flow of water flows. To simplify the solution of this problem, various models are used [119, 170,171].

Let's use the generally accepted calculation model, the complete mixing model, which allows us to calculate the average dose required for inactivation of microorganisms.

The principle of the complete mixing model is that each elementary particle of liquid passes through all points of UV irradiation and stays in each of them at equal intervals. In the complete mixing model, the average dose is determined by the following formula:

$$\langle H \rangle = \langle I \rangle \cdot \langle t \rangle \tag{7.3}$$

where $\langle I \rangle$ – average intensity in the decontamination chamber; $\langle t \rangle$ - average time of liquid stay in the disinfection chamber.

The average intensity is calculated as follows:

$$\langle I \rangle = \frac{L}{V} I(k, x, y) dxdy \tag{7.4}$$

where V – volume of the disinfection zone; L - lamp arc length (interelectrode distance); $I(k, x, y)$ – intensity in the cross-section of the irradiation chamber at a point with coordinates for the penetration coefficient of UV radiation k. The average residence time of liquid in the disinfection chamber is determined by the following ratio:

$$\langle t \rangle = \frac{V}{Q} \tag{7.5}$$

where Q – installation performance. Thus, in the complete mixing model, the average decontamination dose, taking into account formulas (3.4) and (3.5), is determined by:

$$\langle H \rangle = \frac{\nu \cdot L}{Q} I(k, x, y) dxdy \tag{7.6}$$

where ν – margin factor for accounting for stagnant zones (usually $\nu \cong 0.8$). Accounting for stagnant doses is mandatory, since the design of the installation is unable to ensure uniform flow for all areas in the disinfection chamber.

The advantage of the proposed complete mixing model is the relative simplicity of the calculation and the absence of dependence on the sensitivity of microorganisms to UV radiation. For electrical disinfection systems used for water disinfection, this is not enough, since the complete mixing model does not allow taking into account the influence of various structural elements (mixing devices, grates, etc.). To solve this disadvantage, we suggest using hydrodynamic modeling or an experimental method that allows measuring the residence time distribution function, which can be used to judge the effectiveness of the disinfection unit.

Modeling of the movement of water flows in UV disinfection installations is performed by numerically solving a system of equations consisting of the Navier-Stokes equation.

The calculation of the bactericidal dose of disinfection is carried out as follows: the volume of water entering the irradiation chamber and filling it is divided into elementary volumes (jets), for each point of such a jet, the velocity components and coordinates are known. If the number of jets is equal , and each jet is divided into elementary segments, then, by definition, the radiation dose is i - th segment n - th jet is defined by:

$$H_i^n = I_i(k) \cdot t_i \qquad (7.7)$$

where t_i – elemental volume travel time i - th segment; I_i – UV intensity on the segment, which depends on the water transmission coefficient . The UV intensity at any point can be calculated by summing the intensities of all lamps.

Dose received n - m jet, will be equal to:

$$H^n = \sum_i H_i^n \qquad (7.8)$$

Decontamination of microorganisms by UV radiation obeys an exponential law, that is, if each elementary volume of water at the inlet contains N_0 (we assume that the number of bacteria at the input is evenly distributed), then at the output we get the number of bacteria for n-th jet:

$$N_n = N_0^n \cdot e^{-qH^n} \qquad (7.9)$$

where q – coefficient that characterizes the sensitivity of bacteria to ultraviolet light and individual for each type of bacteria, viruses, etc. then the total number of bacteria at the output of the installation N:

$$N = \sum_n N_i \qquad (7.10)$$

and at the installation input:

$$N_0 = \sum_n N_0^n \qquad (7.11)$$

The total number of bacteria at the outlet of the unit allows you to get an effective dose of disinfection H_{ef}:

$$H_{ef} = \frac{ln\, N/N_0}{-q} \tag{7.12}$$

where N_0 – total number of bacteria at the entrance to the unit.

The bactericidal dose obtained in the above way takes into account the sensitivity of microorganisms to UV radiation, as well as the influence of structural elements on the ultraviolet flow and, as a result, on the effectiveness of bactericidal disinfection. The proposed model of hydrodynamic water flow makes it possible to identify areas of inefficient disinfection at the design and development stages of the UV irradiation Chamber of an electrical system.

In addition, in other cases, to solve the problem of water disinfection, it is necessary to take into account the indicator of the decline in the bactericidal flow due to water permeability, that is, the permeability coefficient or absorption coefficient, which affect the effectiveness of disinfection.

To characterize the water permeability for ultraviolet rays, we use the indicator discussed above (formula 7.2) – the permeability coefficient, the decline of which is taken into account when calculating the minimum bactericidal efficiency of water irradiation. In Figure 7.2 a scheme for measuring the water permeability coefficient is shown.

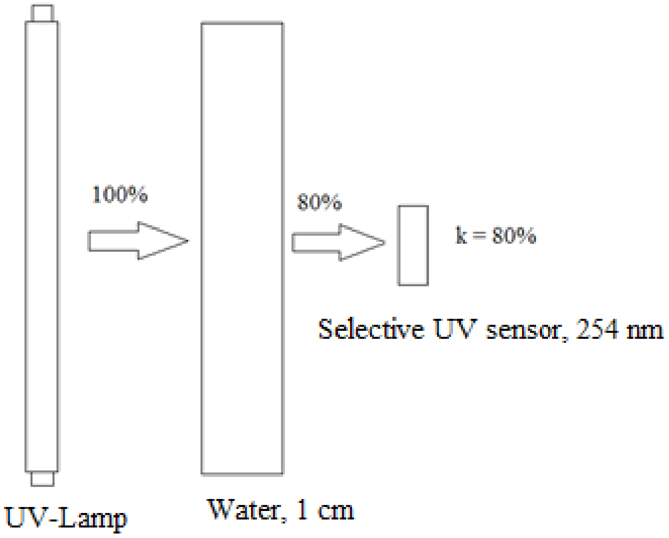

Figure 7.2. scheme for measuring the water permeability coefficient by a selective UV sensor

It has been experimentally established that at wavelengths less than 230 nm, the water absorption coefficient begins to increase sharply and increases by 5-7 times at a wavelength of 280 nm, and in comparison with absorption at a wavelength of 254 nm, it increases by an order of magnitude or more (Table 7.1). Since the law of radiation absorption is exponential, UV radiation in the spectrum region of 200-300 nm will be almost completely absorbed at a distance ten times less than radiation with wavelengths greater than 240 nm. Due to the strong absorption of water, the contribution of short-wave radiation of 200-230 nm to the disinfection process is small, despite the increase in the absorption of short-wave radiation by DNA molecules. Therefore, disinfection in water is mainly carried out by UV radiation in the range of 240-280 nm with a maximum in the region of 260 nm, which is close to the wavelength of 254 nm of low-pressure Mercury quartz lamps.

Table 7.1

Results of UV absorption by drinking water and DNA molecules as a function of wavelength

Wavelength, nm	Drinking water absorption coefficient	Absorption coefficient by DNA molecules
200	0,65	-
210	0,5	1,2
220	0,2	0,65
230	0,06	0,43
240	0,03	0,7
260	0,02	1,0
280	0,01	0,5
300	0	0

The range of physical and chemical indicators of water quality, at which it is possible to use the UV disinfection method, is quite significant. However, the presence of a number of organic and inorganic substances in the water that absorb UV radiation leads to a decrease in the actual dose of UV radiation acting on microorganisms. The influence of water quality on the radiation transmittance should be taken into account when choosing electrical systems with UV exposure.

The transmission coefficient depends on the thickness of the water layer, as well as on the content of dissolved organic and inorganic compounds in it and the presence of hanging particles.

So, in Figure 7.3 the experimentally obtained dependence of the UV radiation absorption coefficient is shown α from the presence of hanging particles in the water. Measurements were carried out in the ultraviolet region of radiation C (200-280 nm) using a Tensor-31 radiometer, according to the method [172].

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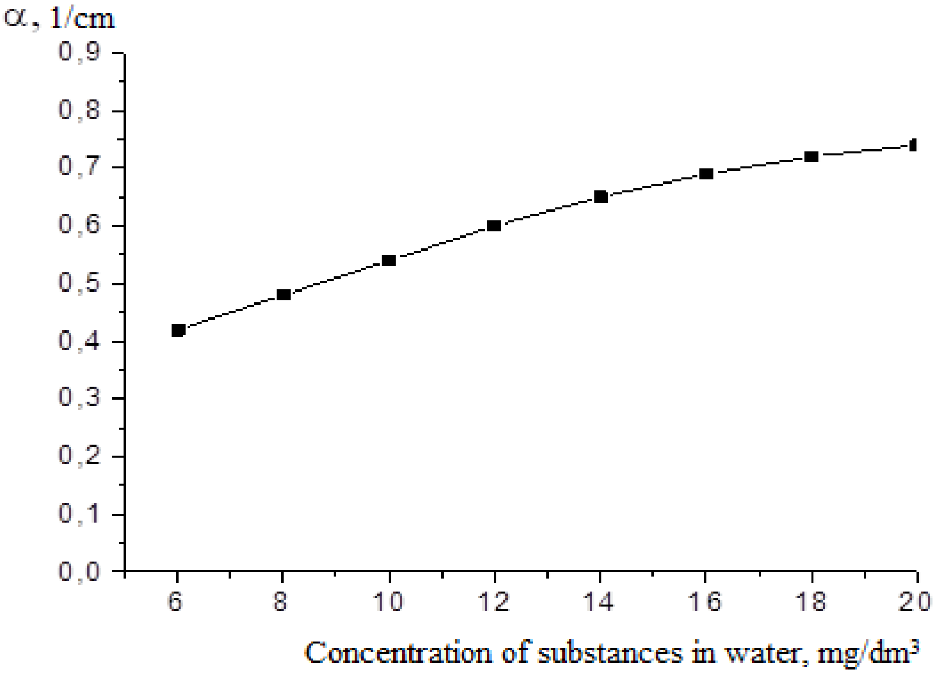


Figure 7.3. Dependence of the UV radiation absorption coefficient B depending on the presence of hanging substances in the water.

The absorption coefficient c characterizes the proportion of ultraviolet energy [173] that was absorbed by water during the passage of UV rays through the water layer and is calculated by the formula:

$$\alpha = -\frac{1}{x} ln \frac{E}{E_0}, \tag{7.13}$$

where α - UV absorption coefficient, см$^{-1}$; x – the thickness of the water layer, cm; E_0 – UV irradiation on the water surface, mW/cm^2; E – UV irradiation after passing a layer of water with a thickness of *x.*

In the course of experimental work, it was found that the lower the transmittance, the greater the number of electrical UV-acting devices that need to be used, and the greater the cost of electricity. The dependence of the effective radiation dose on the transmission coefficient is stepwise, so the difference in the transmission coefficient of 10 % (for example, between 60% and 70%) leads to a change in the number of electrical devices (lamps) and electricity by 1.5-2 times. Therefore, the calculation of electrical systems of UV exposure is carried out taking into account the minimum value of the water transmission coefficient, so that disinfection is provided in all cases.

Of course, UV transmission at a wavelength of 254 nm is used as the main water parameter in the design of UV disinfection systems. The UV transmission spectrum is also important for UV reactors that use polychromatic light sources (such as medium-pressure mercury lamps), because wavelengths other than 254 nm affect the quality of disinfection.

In Figure 7.4 p UV transmission coefficients for different types of water are shown.

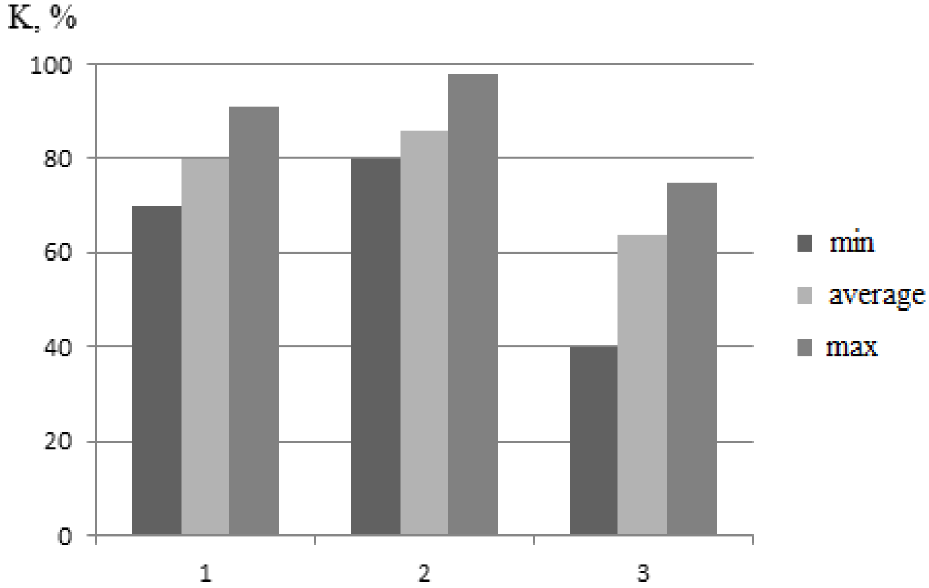


Figure 7.4. Transmittance for different types of water at a wavelength of 254 nm.: 1-Tap Water; 2-underground water; 3-water drains

In Figure 3.5 shows the dependence of ultraviolet radiation absorption on the thickness of the distilled water layer.

As can be seen from the presented dependence, the intensity of UV rays decreases with increasing thickness of the water layer through which they pass, so the decrease in UV dose caused by water absorption should always be taken into account when designing installations.

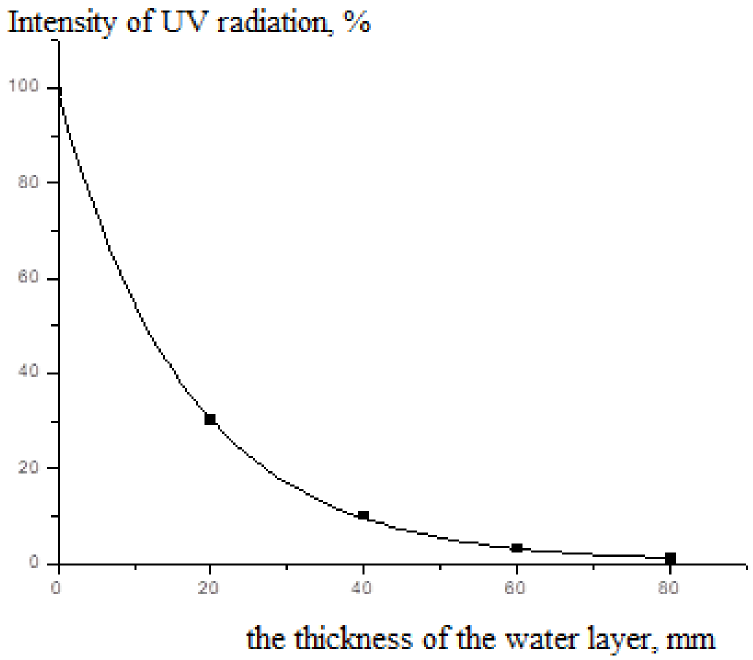


Figure 7.5. Dependence of UV radiation on the thickness of the water layer

It is proposed to choose the level of Final intensity of UV rays in the range of 15-20 %. This level of final UV radiation intensity guarantees reliable disinfection indicators. This level, as our experimental measurements and studies show, corresponds to the thickness of the water layer of approximately 35 mm. With such indicators, it becomes quite possible to effectively use the entire internal volume, that is, the volume between the UV source and the walls of the irradiation chamber through which water passes. At a higher level of final UV intensity (more than 20%), a significant proportion of UV Energy may not be used. Accordingly, at a lower level of the final intensity of UV radiation, the amount of water that does not receive the amount of UV energy necessary for disinfection increases.

When calculating electrical disinfection systems, the minimum exposure value was used, which is more than 5 times higher than the above standards [70], i.e. 70÷100 MJ·cm^{-2}. Energy brightnessL_0 the radius of the outer surface of the source was determined experimentally using a Tensor-31 UV radiometer according to the method [123].

A drinking water disinfection unit is proposed [174] (Figure 7.6) is equipped with an electrical device – an irradiator [175], which has a detrimental effect on bacteria, viruses and other microorganisms.

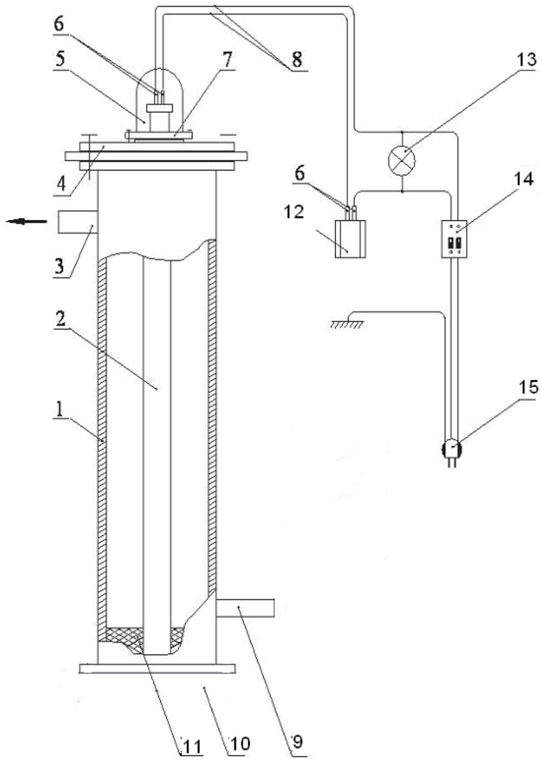


Figure 7.6. Scheme of drinking water disinfection installation: 1-chamber; 2-UV source; 3 – Upper pipe; 4 – Upper flange for the source; 5 – Hood; 6 – pads; 7 – flange with O – Ring; 8 – wires; 9 – lower pipe; 10 – lower solid flange; 11 – rubber stop; 12 – electromagnetic ballast; 13 – indicator lamp; 14-circuit breaker; 15-plug with connecting wires and ground wire.

The developed installation consists of a cylindrical chamber 1, in the cavity of which a bactericidal source of UV-action 2 is placed. water is supplied to the chamber through the inlet pipe 9, which is located in the lower part of the chamber, and the discharge of decontaminated water is carried out through the pipe 3. with the power supply network, the source of UV-Action 2 is connected by means of a plug 15 with connecting wires and a ground wire through a circuit breaker 14, electromagnetic ballast 12, wires 8 with pads 6. the circuit breaker, electromagnetic start-up device and indicator lamp 13 are located in plastic boxes attached to the frame. The sensor for applying voltage to the UV source is an indicator lamp, and the fact that the source is working should show a flickering glow of its part protruding beyond the flange 7.

The inner diameter of the irradiation chamber is 100 mm. The length of the irradiation cavity is determined by the length of the submerged part of the outer bulb of the UV source. The initial data for the calculation and the results of calculating water disinfection plants with a capacity of 1 and 3 m3 are shown in Table 7.2.

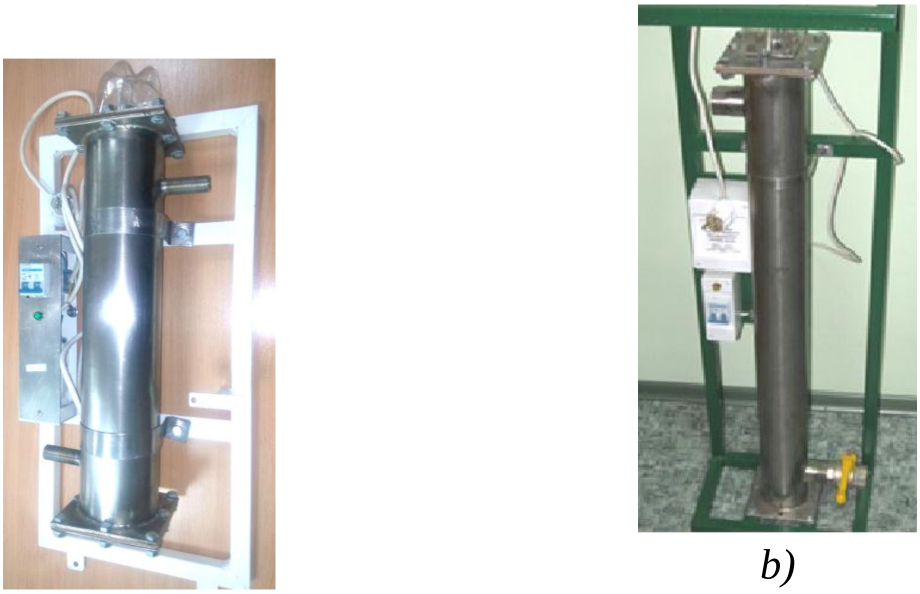
Table 7.2

Initial data for calculation and results of calculation of electrical water disinfection systems with a capacity of 1 and 3 m^3

Parameter name	Parameter value
Radiation dose, mJ/cm^{-2}, not less than	100
Energy brightness of the outer surface on the R_1 mW·cm^{-2}	975
Radius of the outer surface of the source R_1, mm	23,5
Irradiation radius R_2, mm	50
Camera length l, mm	400; 800
Performance Q, m$^{3\cdot}$ year $^{-1}$, not less than	1; 3

In Figure 7.7 experimental samples of electrical complexes for disinfection of drinking water with a capacity of 1 and 5 m^3/h are presented.

Disinfection of water is carried out during its flow through the chamber due to ultraviolet radiation. The control panel consists of start-up equipment for the source of UV exposure and alarm in case of deviation from the set mode. Sampling of decontaminated water can be carried out 2 minutes after starting the electrical system (the time required to reach the specified source mode and decontaminate the primary volume of water in the irradiation chamber).



a) *b)*

Figure 7.7. experimental electrical systems for disinfection of drinking water, with a capacity of: a) 1 m^3/h.; b) 5 m^3/h.

The lowest irradiation of the inner surface of the Chamber of an electrical system is calculated from the conditions for ensuring the surface dose at a given volume of water passage through the chamber $H_S \geq 100\,\frac{mJ}{cm^2}$ [125,176].

As can be seen from the description of the electrical system, in comparison with well-known electrical devices, their design is significantly simplified, does not require additional maintenance costs and is safer.

In Figure 3.8 an electrical water disinfection system with a capacity of up to 20 m^3/h is schematically presented [125]. The system consists of 4 identical irradiation chambers, in each of which there is an electrical device DRBO 60, and is equipped with a control unit, which contains electronic starting equipment, electronics for monitoring the operation of bactericidal sources of UV action-led indication.

The design features of this electrical system [177] make it possible to use it in the technological process of water purification continuously. The closed ball valve of the water supply in the lower part and the non-return valve in the upper part of the irradiation Chamber make it possible to perform work on replacing a failed bactericidal source. The internal diameter of the disinfection chamber is 92 mm with a source diameter of 23 mm, which creates a water layer thickness of less than 35 mm and provides the required dose of UV radiation near the walls of the chamber.

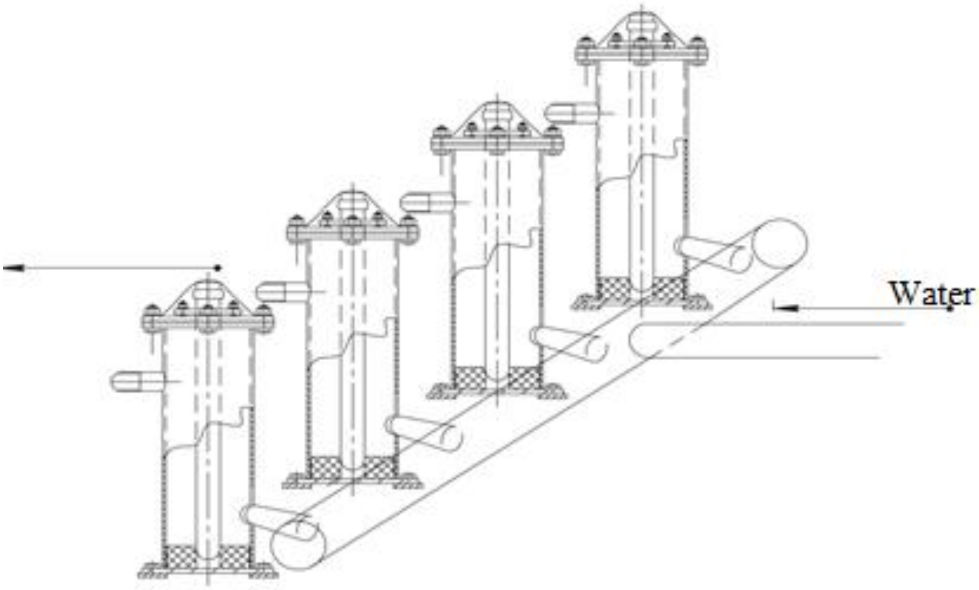


Figure 7.8. Diagram of the electrical system for disinfection of drinking water,with a capacity of up to 20 m^3/h.

In Figure 7.9 an experimental sample of an electrical complex for disinfection of drinking water with a capacity of up to 20 m^3/h is presented.

Figure 7.9. Experimental sample of an electrical drinking water disinfection system with a capacity of up to 20 m^3/h.

The capacity of the developed electrical systems is from 0.2 to 20 m^3/h in an hour. The actual performance of disinfection depends on the concentration and type of harmful microorganisms, the desired degree of disinfection and the speed of water passage and can be determined experimentally based on the results of microbiological analysis of water.

Based on the proposed technical solution, a series of electrical systems for disinfection of drinking water of various capacities and designs has been developed, which are successfully used by a number of Ukrainian enterprises.

7.2. Water disinfection technology in the bottling process

In [178], a technology for water disinfection in the bottling process is proposed. The technology of water bottling and packaging without the use of chemical disinfectants, which can change the structure of water and its physical and chemical properties, has been developed and studied.

As the basis of the technological process, we have chosen a method of disinfection by UV radiation using the developed electrical systems for disinfection of water and surfaces. The technology developed by us makes it possible to decontaminate containers and water simultaneously during the bottling process.

The sequence of disinfection of water, plastic bottles and lids for sealing bottles is as follows:

1. Bottled water is passed through a disinfection unit of the UBZV-60 type (installation of bactericidal disinfection of drinking water – water capacity up to 5000 L/H; the irradiation of the UV source in the wavelength range of 220-280 nm at a distance of 40 mm is 70 W/m^2; the nominal value of the bactericidal flow of the source is 13.5 W).

2. After preliminary disinfection using the UBZV-60 electrical system, water is supplied through plastic tubes to fill bottles, into which OBIS-15 irradiators are introduced before filling to disinfect the surface of bottles. (Bactericidal irradiator with individual ballast and built – in starter: source power – 15 W; bactericidal flow-3.80 W). Several bottles can be filled at the same time.

3. After short-term irradiation (~5÷10 s), water is supplied to the inner surface of the bottle to fill it. During the filling process, the irradiators function and additional irradiation of water and the inner surface of the

bottle occurs. The UV radiation dose received by the bottle surface is not less than 150 J/m^2, and the water in the bottle is not less than 400 J/m3.

4. Simultaneously with filling the bottle, the surface of the lids is decontaminated to seal the bottles on a special conveyor equipped with a surface and air irradiator of the UBZP-2 Type (Power 15 W) developed by us.

5. After disinfection, the water and bottle caps are sealed and sent to the next technological operation.

A diagram of an electrical system for decontaminating the inner surface of bottles and water during bottling is shown in Figure 7.10.

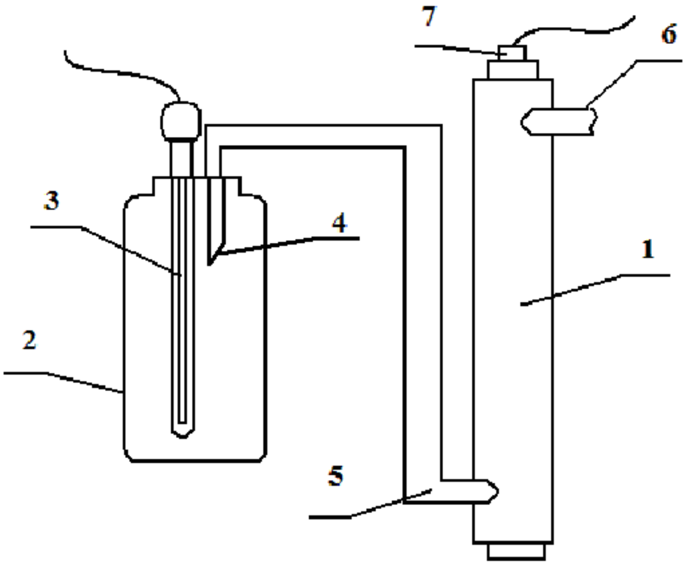


Figure 7.10. installation diagram for disinfection of water and containers in the process of bottling: 1 – housing of the UBZV-60 installation; 2 – bottle; 3 – OBIS-15 irradiator; 4 – water supply tube; 5 – outlet pipe; 6 – inlet pipe; 7 – source-drbo-60 irradiator.

Our microbiological studies of treated water using this technology and untreated water (base sample) prove that CFU/cm^2 decreases by 80-90% depending on the available types of microorganisms present in the water and their percentage. These results are confirmed by a sanitary report. The considered technology of disinfection of drinking water with UV rays during its bottling allows preserving the natural organoleptic properties of water, ensuring bacteriological safety and extending the shelf life of water in accordance with the requirements [177].

In Figure 7.11 the developed electrical device (OBIS-15 irradiator) is presented, which is used to irradiate the surface of a bottle and water [179, 180, 181].

Figure 7.11 Developed electrical device with a power of 15 W (OBIS-15 irradiator)

Based on the conducted studies and the obtained results, a method for decontamination of drinking water in the bottling process is proposed [129].

Based on the proposed technical approach, a technology has been developed that has been successfully implemented at PJSC Mirgorod Food Products plant Kalinka, which specializes in the production of bottled drinking water.

7.3. Technology of water disinfection in swimming pools by the complex action of UV radiation and ozonation

Public pools are usually disinfected with traditional filtration methods, chlorine gas or sodium hypochlorite, while indoor pools are usually chlorinated.

When filtering water in a pool, sand, diatomaceous earth or membrane filters are used to remove physical contaminants, while some filter materials can create BPD [182] and their correct functioning must be directed to minimize contamination. Unfortunately, membrane filtration methods (ultrafiltration [183]), due to the large amount of organic matter inflow, are characterized by low productivity and low membrane service life, which makes the method technologically and economically competitive.

According to the WHO [184], the use of chlorine-containing substances is insufficiently effective against enteroviruses and protozoa. In addition, methods of water purification using chlorine gas and sodium hypochlorite are capable of producing various BPD [185]: Trihalomethanes (THM), which are manifested in the blood and respiratory tract of swimmers; halogenated acetic acid and haloketones, which are irritating to the eyes, skin and mucous membranes; trichloramines which causes asthma, respiratory tract infection [186] and other harmful compounds that impair the organoleptic characteristics of water.

In the of work [187] data about the presence of nitrosamines in water, the formation of which is associated with the interaction of chlorine derivatives of products and nitrogenous impurities are represented. Nitrosamines are toxic substances that cause mutagenic and carcinogenic effects even at low concentrations. Disinfection of water with a high content of bromide or iodine compounds leads to the presence in the treated water of a large amount of bromine and iodine-containing BPDs, which are usually more cytotoxic and mutagenic than chlorine-containing compounds [188].

In addition to traditional water purification processes, ultrafiltration and UV-irradiation [189] or a combination of various reagent and reagent-free methods [190] have recently been used.

In a number of works [191, 192] it is reported that ultraviolet irradiation in combination with various methods is used to reduce the concentration of BPD and to inactivate chlorine-resistant bacteria Cryptosporidium. It has been reported that UV-irradiation is capable of mineralizing organic matter and, thus, reducing the concentration of RPE in the pool water [193].

Note that in pools that are re-treated with ozone or ultraviolet in addition to chlorine or bromine, the number of reported negative impacts on visitors is reduced [194].

It is possible to reduce the concentration of BPD, as well as to remove already formed compounds, by using oxidative technologies with the subsequent complete destruction of toxic substances. Ozonation, as an alternative to chlorination, has an advantage in all investigated methods, since the disinfecting effect of ozone is 15-20 times more effective than that of chlorine [195].

Effective technologies for the oxidation of organic compounds are based on the use of hydroxyl radicals, among which the most effective methods are:

- using the reaction of ultraviolet radiation (UVC) and ozone [196];
- use of reactions of hydrogen peroxide and ozone [197];
- hydrogen peroxide and ultraviolet radiation (UVC).

In the works [198,199] a technology for disinfection of water in swimming pools is proposed. The effectiveness of bactericidal water treatment systems for small-volume swimming pools using ozone and UV irradiation of water (without the use of chlorine-containing reagents) is studied.

One of the tasks was to study the possibility of disinfection of water in swimming pools by the complex action of UV radiation and ozone [132] without the use of an additional ozonator, but using ozone generated by short-wave UV radiation from the source.

Designs of low-pressure discharge electrical devices, the flasks of which are made of transparent quartz glass for a wavelength of 185 nm, create an ultraviolet flux, which is approximately 15-20% of the UV flux of the line with a wavelength of 253.7 nm.

According to [200], a UV source with a power of 80 W per hour emits enough energy to form ozone in the air in an amount of approximately 0.8 g/h. This ozone is a» byproduct « in the generation of UV radiation and can be used for ozonation of water in electrical UV disinfection systems at no additional cost.

To test the hypothesis about the possibility of implementing the technology of UV disinfection of water in pools of small volumes (up to 100 m^3) using ozone generated by short-wave radiation from the source, we have developed the design of the electrical system shown in Figure 7.12.

The developed electrical system is a cylindrical chamber with an internal diameter of 90 mm and a length of 950 mm, in which the UV source in a quartz case is located along the axis of the chamber. The source flask diameter is 19 mm, the cover diameter is 30 mm, and the wall thickness is 1.2 mm. With this design, almost the entire UV stream passes through the water layer circulating through the chamber. Ozone generated in the air space between the source and the walls of the Quartz cover is fed into the water using an ejector. The volume of air passing through the chamber is 240 liters/hour. The UV-C radiation dose was calculated using the recommendations [124].

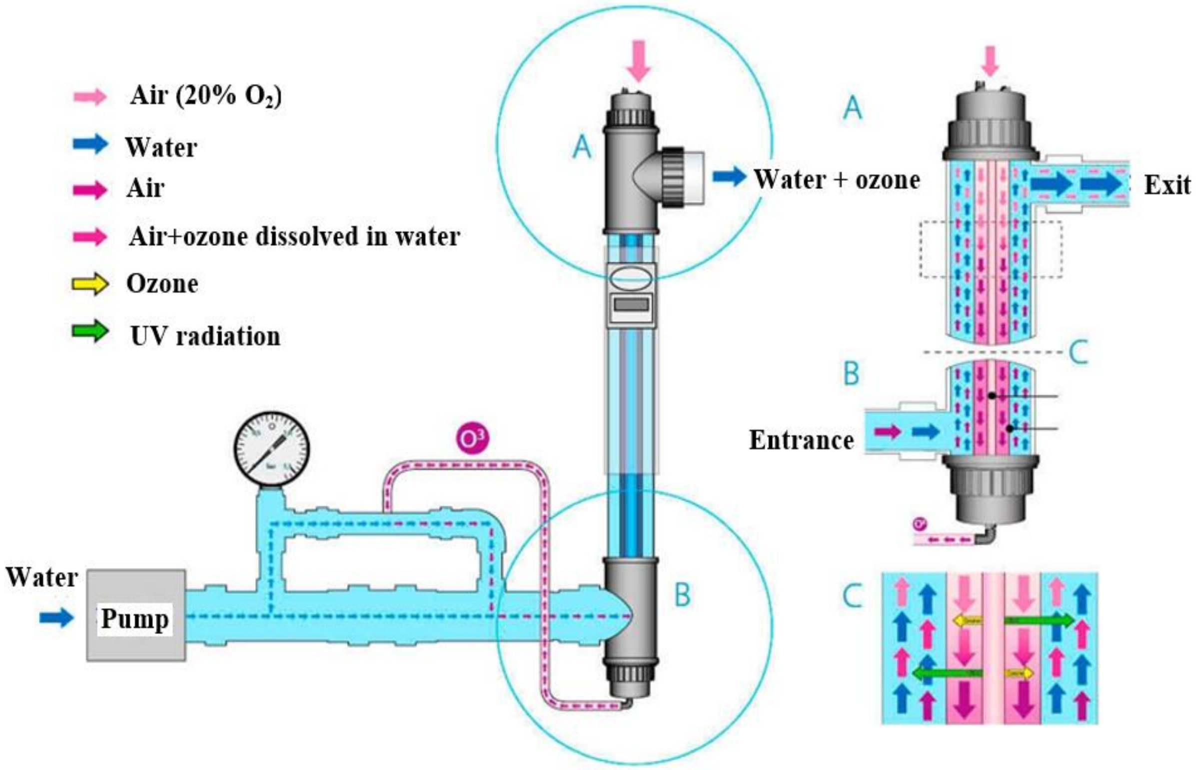


Figure 7.12. Design of an electrical system for UV disinfection of water in swimming pools using ozone

The calculations took into account the absorption of UV-C in a quartz cover, a decrease in radiation output when the source is heated, the transparency of water in the UV range, a margin factor of 1.5 to compensate for the decrease in UV radiation output during the service life and when the supply voltage decreases (within tolerances). This electrical system provides a water irradiation dose of at least 250 J/m^2 and additional ozonation with an amount of ozone of approximately 0.1 g/m^3 of water. The residual concentration of ozone entering the pool with water after UV irradiation does not exceed 0.015 mg/L (with a norm of no more than 0.02 mg/l).

The study of the effectiveness of water disinfection using an electrical system of this design was carried out in a pool with a volume of 75 m^3.

To ensure water circulation of at least 4-fold exchange per day, two electrical systems with a capacity of 8 m^3/h were installed. To ensure a capacity of 8 m^3/h, UV sources of the ZW80D19Y type were used in the electrical system, the parameters of which are given in Table 7.3.

Table 7.3

Characteristics of water disinfection sources, production facilities Jiangyin Feiyang Instrument Co.

Electrical device (source type)	**P, W**	**I, mA**	**U, B**	**Energy illumination of UV-C at a distance 1 m, W/cm^2**	**Geometric shapes dimensions, mm**
ZW80D19Y	80	800-1200	120	240-270	846x19

Measurement of microbiological parameters of water for compliance with the requirements [2, 74, 81] was carried out in a certified microbiological laboratory. The values of the obtained results of bacteriological studies of pool water under various operating modes of electrical systems are summarized in Table 7.4.

Table 7.4

Results of bacteriological studies of pool water

The name of the indicator	**Requirements**	**Results of the research**				
		Initial water data	**UV irradiation without ozonation (after 2 and 4 days)**		**UV irradiation with ozonation (after 2 and 4 days)**	
Total microbial count CFU/cm^3 when 37^{0}C	Not more than 100 CFU in 1 cm^3	3	47	115 does not match	19	24
General coliforms CFU/100cm^3	Missing	Not found	220 does not match	1100 does not match	Not found	Not found
Enterococci	Missing	Not	Not	Not	Not	Not

CFU/100cm^3		found	found	found	found	found
E.coli CFU/100cm^3	Missing	Not found	Not found	Not found	Not found	Not found

Bacteriological studies of the water in the pool have established that ultraviolet disinfection without ozonation does not meet the requirements for the total microbiological number CFU/cm^3. With additional ozonization, CFU does not exceed 24 CFU/cm^3. Additional ozonation (with a dose of 0.1 g/m^3) when using UV technology for water disinfection provides the necessary bacteriological purity of water in small pools. With the proposed combined technology, disinfection by-products were not found in water. In addition, the concentration of ozone in the pool water does not exceed 0.015 mg/l, while the norm is not more than 0.02 g/l.

7.4. Technology of ultraviolet water disinfection when growing fish in closed recirculating systems

The object of research is sturgeon fish, namely Sturgeon raised for caviar. All experimental work was carried out in a USV system with a volume of 300 M3 under the following optimal conditions (Table 7.5). Water purification was carried out continuously through a channel with a width of 200 mm and a height of 1000 mm, where the water flow was constantly at a height of 830-860 mm.

Table 7.5

Conditions for conducting the experiment

Temperature, ^{0}C	pH level	Dissolved oxygen content, mg/l
21-22 ^{0}C (when normal 20-22 ^{0}C)	7,4-7,8 (when normal 7,2-7,8)	5,6-5,8 (when normal 5,5-6)

Measurement of microbiological parameters of water for compliance with the requirements [201] was carried out in a certified microbiological laboratory. The values of the obtained results of bacteriological studies of pool water during fish farming are summarized in Table. 7.6.

Table 7.6

Results of bacteriological studies of pool water when growing fish

Name of the indicator	**Requirements**	**Results of the study (after an hour, days)***				
		Initial data	**24 hour**	**7 day**	**30 day**	**60 day**
TMC CFU/cm^3 at 37 °C	No more than 100 CFU in 1 cm^3	17	57	40	79	64
Common coliforms CFU/100 cm^3	Missing	-	-	-	-	-
E.coli CFU/100 cm^3	Missing	-	-	-	-	-
* Note: change the water if the parameters do not meet the requirements of Table. 2.						

Bacteriological studies of pool water have established that ultraviolet disinfection in combination with filtration provides the necessary bacteriological purity of water in swimming pools when growing fish in pools with a volume of up to 300 m^3.

According to the authors of [105], different levels of irradiation are required for different types of organisms: for inactivation of bacteria and fungi from 100 mJ/cm^2, and for inactivation of viruses from 250 mJ/cm^2. These are relatively large doses that compensate for changes in water turbidity and changes in the permeability of ultraviolet radiation energy to water due to water absorption and low turbulence around the UV lamp.

For USV systems with a water volume of 300 m^3, bacteriological purity of water is provided by a 480 W unit with an irradiation of 80 J/m^2. At the same time, water quality is within acceptable limits for 2 controlled months, and bacterial diseases and Mycoses are not detected.

Conclusions

The monograph further develops the scientific and technical foundations of the use of ultraviolet radiation in water disinfection on the basis of theoretical and practical generalization of developments and implementation of disinfection complexes.

1. Nature and Effects of UV Radiation: The exploration of modern ideas about UV radiation's nature and characteristics, including its energy values, lays a foundation for understanding its diverse effects on substances and living organisms. This includes the photophysical, photochemical, and photobiological impacts, highlighting the complexity of interactions at molecular and biological levels.

2. UV Radiation Sources: The text thoroughly investigates various methods of generating UV radiation, ranging from traditional heat sources to advanced technologies like lasers, semiconductor sources, and fluorescent sources. The classification of low-pressure Mercury discharge lamps adds depth to understanding these sources' characteristics and applications.

3. Measurement and Disinfection Techniques: Detailed discussions on measuring UV radiation parameters, such as energy illumination, dose measurement, and bactericidal flow assessment, provide insights into monitoring and controlling UV exposure. Moreover, the research on physical and chemical methods of water disinfection, including indicators of drinking water safety, contributes to developing effective disinfection strategies.

4. Experimentally established quantitative values of factors affecting the efficiency in electrical complexes of bactericidal disinfection of water during the operation of irradiation systems: the stability of the UV radiation flow-a decrease of no more than 40% of the initial value; the thickness of the water layer should not exceed 40 mm.

5. Developed irradiation devices for bactericidal disinfection of drinking water during bottling. Disinfection efficiency is achieved through the use of ultraviolet devices with an energy brightness of at least 25 W/m^2, under the influence of which the internal surfaces of the bottle are disinfected with a surface dose of 150 J/m^2.

6. The technology of bactericidal disinfection of water in swimming pools without the use of chlorine-containing substances, by UV irradiation

and using ozone has been developed. The effectiveness of the complex water bactericidal disinfection system has been tested in swimming pools with a volume of up to 100 m^3. The plant's ozone capacity is 0.8 g/h., which provides an ozonation dose of 0.1 g/m^3 at an irradiation of 25 J/m^2, and the ozone concentration in the water supplied to the pool after irradiation does not exceed 0.015 mg/l.

7. A technology for disinfection of water in swimming pools using low-pressure ultraviolet lamps has been developed. The proposed UV water disinfection unit provides a bactericidal flow of 160 W/m^2. For a pool with a water volume of 300 m^3, bacteriological purity of water is provided by one unit with a power of 480 W, with an irradiation of at least 80 J/m^2.

LIST OF ABBREVIATIONS

WHO – World Health Organization
VUV – vacuum ultraviolet
HHC – halogen-containing compounds
MAC – maximum allowable concentration
MPE – maximum permissible exposure
DNA – deoxyribonucleic acid
ESA – electronic starter-adjustable device
TCC – total coliform bacteria
TMC – total microbial count
IEC – International Electrotechnical Commission
IR – infrared radiation
UVD – ultraviolet lamps
UVA – ultraviolet radiation in the range of 315-400 nm
UVB – ultraviolet radiation in the range of 280-315 nm
UVC – ultraviolet radiation in the range of 280-100 nm
MED – Minimal Erythema Dose
IEC – International Electrotechnical Commission
UHF – ultra high frequency
ESA – electronic starter-adjustable device
LED – light-emitting diodes
THMs – trihalomethanes
TCB – thermotolerant coliform bacteria
UV – ultraviolet
PAR – photosynthetically active radiation

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CONTENT

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THE SCIENTIFIC FOUNDATIONS OF ULTRAVIOLET RADIATION USAGE: EFFECTS, SOURCES, AND APPLICATIONS IN WATER DISINFECTION

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