Biological Hindrances in Power Stations Exploitation, Their Typization and Main Hydrobiological Principles of Control[†]

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Paper deals with conceptual principles of technical hydrobiology, related to research of techno-ecosystems. The basic hydrobiological principles related to the problem of biological hindrances of the water-supply are discussed, in particular in the water systems of HPS and NPS and their control by different methods.

KEYWORDS: *techno-ecosystem, cooling pond, biological hindrances, zooperiphyton, fouling control methods, water supply systems.*

Numerous and various impacts of the technical objects on the environment, in part on hydroecosystems are well known [21, 27, 30, 32, 45]. However technical objects, in particular their water supply systems, are not isolated from the hydrobionts' vital activity effect, which can considerably influence their functioning. So, hydrobionts' communities of the power stations cooling ponds have considerable impact on the water quality forming processes, and cause different hindrances in the facilities' functioning. Study of the direct effect of the technical objects, in particular power stations (HPS, NPS) on hydroecosystems, as well as inverse effect on the technical systems' operation enabled to formulate concept of the techno-ecological system. According to this concept ecological and technical elements are considered in their interrelation [25, 28]. *Techno-ecological system* is a set of natural and anthropogenic biotopes and their population, integrated by a system of direct and inverse connections, temporary and spatially varying.

The most part of biocenosis of the aquatic ecosystems', which are directly or indirectly connected with the water supply systems, to some extent influence forming of the biological hindrances in the technical systems operation. *Biological hindrances* are an effect of interrelation between technical and biological elements of the techno-ecosystem. As a result just occurrence of the organisms, their vital products or residues cause negative effect on the normal exploitation of the technical systems.

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Biological hindrances should be distinguished from the *biological deteriorations*. These are "any not-desirable changes in materials' and products' properties caused by the organisms' vital activity" [12]. Problems associated both with biohindrances and biodeteriorations in the hydrosphere, lie within the interest of technical hydrobiology. Various facilities and systems of water supply are, as a rule, designed without taking into account probability of biological hindrances arising. Even if these last are supposed, they are considered as external mechanical factor.

The aim of this work was comprehension of the conceptual principles, associated with development of strategy and concrete measures in water supply systems exploitation, under technical and ecological factors interrelation, causing biological hindrances. The main attention was paid to the biological hindrances in HPS and NPS operation.

Structure of the techno-ecological systems. Techno-ecological system is a set of interconnected and interrelated biological and technical elements. In the power stations it comprises: ecosystem of the cooling pond (or other water object used for circulation water and technical water supply source) including all organisms related with each other and environment; ecosystem of the intake channel (with cooling water) and tail-race (with heated water) as hydraulic objects, as well as technical water supply systems of the station itself (Fig. 1).

For example, the water supply system of the Khmelnitsky NPS, situated in the north-west part of Ukraine, comprises some interrelated water objects – cooling pond, intake channel, technical bulks and pipelines filled with water, tail-race, as well as system of water delivery for chemical treatment. About 97.4% of all water volume fall on cooling pond, 1.3% – intake channel, 1,2% – tail-race, 0,1% – water supply systems of NPS. In summer period circulation pumps of two pumping plants transport up to 400 000 m^3/hour, or 9.6 million m^3/day, that is about 8% of all water of the system.

Derivation and sources of biological hindrances. In the water supply systems operation biological hindrances arise as a result of vital activity of different organisms, first of all hydrobionts occurring in the water source or in the water supply systems. Biological hindrances can be caused by bacteria, algae, protists, invertebrates and vertebrate animals and vascular plants [2, 4, 39, 41, 54, etc.]. Among zooperifiton of the cooling ponds of the temperate zone potential threat, besides well known mollusks of the genus *Dreissena*, can cause sponges *Spongilla lacustris* L., *Ephydatia mulleri* Liberkiihn, pearlworts (Bryozoa) *Plumatella emarginata* Alm. and *P. fungosa* Pallas, polyp *Cordilophora caspia* Pallas, as well as filamentous algae and some vascular aquatic plants.

Problem of biological hindrances sharply appears at mass development of zebra mussels (*Dreissena polymorpha* Pall., *D. bugensis* (Andr.)), because their settlements, as a rule, have high density and biomass [37, 38, 47, 50, 52]. Biological hindrances caused by settlements of these hydrobionts are associated with their mass development and have two aspects. The first is associated with settlements development close to water-intake facilities and drifting of shells after the mollusks death into the systems. Separate sections of the water-supply systems can serve as analogous "reservoirs" of biological material, transported by water. The second aspect is associated with the properly fouling of different surfaces, increase of hydraulic roughness, pipelines and filters choking etc.

Preconditions of the biological hindrances arising in the water supply can be divided into natural and anthropogenic. The first include: natural processes of the organisms settling in the water

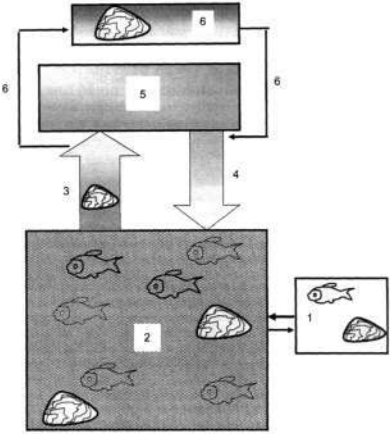

Fig. 1. Scheme of the techno-ecosystem of the power station. 1 – external water sources; 2 – cooling pond (or other cooling system); 3 – intake channel; 4 – tail-race; 5 – heat exchangers; 6 – technical water supply systems.

bodies, reproduction processes, active and passive selection of the most favorable habitats, organisms concentration in the mono-species settlements, activation of biological processes at the phases boundaries. Design of the cooling pond, water-intake facilities, and headrace should be considered among anthropogenic (technical) preconditions. They are usually designed without taking into account biological hindrances. In some cases design of hydraulic constructions even favors development of the hydrobionts. Pumping stations operation causes slow but constant water circulation within the cooling pond, and so promotes hydrobionts spreading in the water body, as well as their income into the water-supply systems. Availability of hydraulic constructions, various coverings provide many favorable hard substrates for the periphyton organisms' settlement.

Typification of the biological hindrances. Biological hindrances can be typified according to their character and localization [3, 5], as well as according their origin, duration, periodicity etc.

Typification of the biological hindrances is needed, because every type demands special approach to the monitoring, preventing and elimination methods selection [7, 43].

6 types of the bio-hindrances can be assigned according to their localization in the techoecosystem, which includes HPS or NPS.

Bio-hindrances, arising at exploitation of the cooling pond itself, which appear as deviations from its design characteristics.

Bio-hindrances, arising in the systems of circulated cooling water intake and off-take ways, additional cooling facilities (headrace, tail-race, spray ponds, cooling towers).

Bio-hindrances, arising in the systems of circulation water supply and heat exchangers.

Bio-hindrances, arising in the system of technical water supply lines.

Bio-hindrances, arising in the water-supply systems from external relative to the cooling pond sources.

Bio-hindrances, arising in the system of chemical water treatment.

Biological hindrances can arise as a result of vital activity of various organisms. Bio-hindrances can be assigned according to their origin and genesis:

A – Bio-hindrances, caused by Bacteria;

B – Bio-hindrances, caused by vegetative organisms (planktonic microalgae, filamentous algae, vascular aquatic plants etc.);

C – Bio-hindrances, caused by animals (attached and active animals);

D – Bio-hindrances of mixed character.

Also it is important to distinguish hindrances caused by immediate occurrence of the organisms in the certain section of the system, and hindrances caused by infusion of the organisms or their remains from other sections of the system:

a) Bio-hindrances, caused by occurrence and vital activity of hydrobionts in the water supply systems (fouling, over-growth by vascular aquatic plants);

b) Bio-hindrances, arising as a result of drift and accumulation of the dragged alluvia.

In some cases it is useful to know whether bio-hindrance is a result of aboriginal organisms' vital activity, or of adventive, invasive. Therefore it is important to distinguish:

Bio-hindrances caused by aboriginal species;

Bio-hindrances caused by invasive species (alien species).

All living organisms to a greater or lesser extent are associated with periodical, seasonal natural events. Therefore, according to periodicity of their development bio-hindrances can be divided into:

A – all-the-year-round;

P – periodically appearing, seasonal;

E – associated with extreme phenomena (hot weather, strong storm).

So, in every concrete case formula of bio-hindrances can be compiled, which is of special importance, particularly, for monitoring. For example, formula (I-B-a-1-P) indicates that in this case periodical hindrances, which are located in the cooling pond, are caused by aboriginal plants, vegetating directly in the water body.

Bio-hindrances of the I type, arising at exploitation of the cooling pond can be associated with the following processes:

- Overgrowing of the cooling pond by vascular aquatic plants, which cause decreasing of the active heat-exchanging surface and changes of hydrodynamic regime [41];
- Accumulation of planktonic algae during the water bloom, floating filamentous algae on the surface, vegetation of plants with floating leaves, which causes deterioration of heat transfer into the atmosphere;
- Accumulation of biogenic sediments on the bottom, such as mollusks' shells, vascular plants remains, which causes water body's depth decreasing, preconditions to mass influx of the dragged biogenic sediments into the water supply systems;
- Mass development of zooplankton (some Crustaceans, for instance, *Cercopagis*), which causes their influx into the water supply systems and deterioration of the filtering capability of the block pumping stations (BPS) revolving nets;
- Mass death of hydrobionts under considerable growth of temperature, oxygen regime worsening etc., which causes growth of the organic matters concentration in water, intensive forming of biofilms on the heat-exchanging surfaces.

Biological hindrances of the II type. Bio-hindrances arising in the intake channels are of special hazard, because they affect directly operation of the BPS. It is necessary to take into account that in the headrace favorable conditions for many hydrobionts, particularly for zebra mussel, are formed due to constant flow, favorable oxygen regime, bringing of food from the water body. Biological hindrances here are associated with some factors, which are possible to typify in the following way:

- Accumulation and drift of biogenic material, first of all mollusks' shells, vascular plants' remains;
- Increase of hydraulic roughness of the channels' slopes;
- Concentration of zebra mussel larvae, which can be spread by water flow in the technological channels and form fouling;

- Settlement of some bio-hindrances-causing organisms in the channel can form conditions for settlement of other. For instance, accumulation of zebra mussels' druses on the concrete substrate form conditions for vegetation of rooting vascular plants.

Biological processes occurring in the tailrace can be related to hindrances forming in the following aspects:

- During the period of high temperature in the channels – mass development of the thermophilic filamentous algae, their further evacuation into the cooling pond and probable drift to the headrace;

- Mass death of hydrobionts in the tailrace under considerable growth of temperature, which causes growth of the organic matters concentration in water of cooling pond, which increase hazard of biofilms forming on the heat-exchanging surfaces.

Bio-hindrances of the III type, arising in the systems of circulation water supply, can be caused by biogenic material drift into the water supply systems (Bacteria, mollusks' shells, filamentous algae, vascular aquatic plants, fishes), as well as by fouling in the system itself. In the latter case zebra mussel's, sponges or pearlwort settlements are of special hazard. They can form considerable fouling, up to some kilograms per square meter, on the chambers walls of circulation pumps'. In the HPS and NPS slight fouling was registered on the tube plates in the cool chambers of condensers. No macro-fouling is formed on the internal surfaces of the condenser tubes because of high velocity of flow and temperature. Biological fouling here can be caused by bacterial films on the heat-exchanging surfaces.

Bio-hindrances of the IV type, arising in the system of technical water supply lines, can be conditioned by entrance of living organisms and biogenic material from outside or other sections of the system, or by development of organisms in the water supply system.

It should be kept in mind that the first group of biofoulings is associated with peculiarities of the technical water supply systems, namely occurring of the unidirectional water flow and gradual decreasing of the pipeline cross-section. Biogenic material, like zebra mussels shells, sponges and pearlworts colonies, is able to pass some sections, but choke up empty space in other with less diameter. Organisms, settling in the cooling systems, even under favorable conditions exist in the systems only during limited period. After their death biogenic material is formed, which can cause bio-hindrances. Filtering element of the system, intended for limiting of the foreign particles entrance into the water supply systems, can be overgrown itself and does not operate appropriately.

Bio-hindrances caused by bacteria can be of essential significance in the heat exchangers. Bacterial films development directly depends on organic matters content, thermal and hydrochemical regime.

Bio-hindrances caused by plant are very diverse. Vascular aquatic plants are able to develop in the cooling pond and channels. Their direct effect is associated with the ponds' overgrown and decreasing of their cooling abilities, and their drift with flow to the BPS, especially of the submerged plants. Macroalgae causing biological hindrances are presented by filamentous Chlorophyta, Cyanophyta and Bacillariophyta, which to a greater or lesser extent are able to vegetate all the year. They need solar irradiation for their development, so in the techno-ecosystem they are able to develop almost everywhere, except darkened sections. Algae distribution within the techno-ecosystem is considerably affected by thermal regime. For instance, mass development of the filamentous Cyanophyta is dated to the zone of the heated waters discharge

Animals causing biological hindrances are very diverse. Among them the most damage can cause attached forms, which have high density and biomass, such as zebra mussel, some pearlworts (Bryozoa), and sponges. Observations on zebra mussel development in different water bodies shows, that the most abundance was reached in different reservoirs, technical water bodies, cooling ponds, channels [37, 38].

Hydrobiological and technical principles and strategies of the biological hindrances control. Revelation of regularities of the techno-ecological system organization for substantiating and development of their different characteristics control principles is primarily based on the *systemic hierarchic principle* [1, 22]. The cooling pond as the techno-ecosystem's element is a part of bigger landscape-hydrological system, at the same time it comprises some separate biotic and abiotic systems. This principle assumes existence of both direct relations and feedbacks. In techno-ecological system this appears as two interrelated aspects: technological systems' operation effect on biotic communities, and inverse effect of the hydrobionts on the equipment operation.

Ecological system is peculiar with considerable complexity, therefore it is essential to observe *principle* of sufficiently *complete description* for description and search of the management means [21, 22]. It should be taken into account that correct preliminary answers regarding essential points finally are more crucial than exact knowing of insignificant details [21]. Sufficiency principle supposes implementation of *completeness principle*, which demands description of the most significant interrelations.

Biological hindrances as a rule is a local phenomenon, significant only within certain sections of the water supply systems, but regarding its origin it is related to all techno-ecological system (to a greater or lesser extent). So it should be recognized that monitoring of the whole ecosystem, including the cooling pond of the power station, is a precondition to bio-hindrances limitation.

Many biological hindrances arise as a result of mass death of the hydrobionts in the water supply systems, including cooling pond. In order to avoid this phenomenon it essential to take into account *principle* of ecological *conditions stabilization*, which demands to prevent sharp fluctuations of ecological factors, first of all temperature. Alterations should be similar to seasonal fluctuations in the natural water bodies. At the cooling ponds design and exploitation it is essential to keep in mind that their size, volume and area are not only the factors important from the technical point of view regarding heat-exchanging, but also from the ecological point of view, as precondition for *buffer capacity*, that is mitigation of consequences of the sharp fluctuations of the ecological factors.

Synergism of factors should be also taken into account, because sharp fluctuations of one factor can cause changing of other, which effect on the organisms is more aloud. For instance, temperature and oxygen regime are closely interrelated.

Ecological and economical effectiveness of the certain bio-hindrances control methods is in many respects connected with observation of the *locality* principle. It supposes, on the one hand, sufficient study of the biological hindrances' sources, on the other hand – realization of some measures for their as much as possible local elimination. Correct choice of the application point will determine effectiveness and costs of the measures.

Principle of locality of the control measures application is directly connected with the principle of the environmental *safety*. Some reagents intended to cause suppressive effect on the undesirable organisms, are also harmful or hazardous for human or hydrobionts, which are not a bio-hindrances source. Therefore local application of different methods makes them more effective and less expensive, as well as more safe for human and environment.

Any method of the bio-hindrances control can be effective only if hydrobionts' biological peculiarities are taken into account. One of the essential is the principle of *disruption of the vital cycles* of the undesirable organisms. It is based on the provision that all organisms, including those causing bio-hindrances, have certain ontogenetic cycles, and elimination of any of them causes impossibility of the population's further existence. For instance, zebra mussel has a floating larvae stage, settling larvae stage, stage of young mobile specimens and adult attached stage. Every stage of the life cycle has different tolerance to the external effects. For instance, larval stages withstand considerably less concentrations of the chemical compounds than adult specimens.

Principle of limiting management and control optimization also is of essential importance. It should be recognized that under high complexity of the processes, their low predictability, and high expenses absolute management of the whole techno-ecosystem regarding elimination of bio-hindrances and their causes is practically impossible. In most cases considerable costs are associated not with bio-hindrances level or character, but with their unexpectedness. Therefore constant observations and monitoring of the main processes is of essential importance.

Priority principle also should be taken into account. Two main interrelated priorities are evident – providing of safety and reliability of the facilities operation and observation of the environmental protection, in particular hydroecosystems, against undesirable technogeneous impacts.

Main methodic techniques and methods of control of the biological hindrances caused by hydrobionts. One of the tasks of the hydrobiological monitoring in the techno-ecological systems is data collection for the bio-hindrances forecasting. Such forecast enables application of different preventing measures. Just application of hydrobiological and ecological studies enables to forecast probable bio-hindrances' behavior. Measures of the bio-hindrances-causing organisms control should be preventive and active [41]. The first should be prospected already at the design stage. It is essential that preventive methods should be based on the monitoring of the key ecological parameters, such as temperature, velocity of flow and hydrodynamics character, surfaces' properties [3].

The next strategy can be named *germs' interception* strategy. It is based on the peculiarities of the periphyton communities' organization: they mainly consist of the attached forms, but expansion occurs by plankton larvae or other floating forms. So, this strategy can be realized in two directions: 1) extermination (considerable disturbance of all functions) of the floating larvae or 2) larvae's interception by substrates, on which fouling would not have negative consequences.

Just fouling is the most hazardous for the different technical water supply systems [8, 15, 17, 24, 31, 46]. It is a collection of living organisms occurring in stationary or mobile state on the surface of different substrates in the direct contact with aquatic environment.

General scheme of the biological hindrances (fouling) control methods application foresees use of some their types [31, 44, 49, 50]. Suggested and applied principles and methods can be classified (Table 1). Every method has its own advantages and shortcomings. Mechanical methods are effective, but labor-consuming [14, 16, 19, 33]. Application of electrical current is too energy-consuming [13, 20, 39, 40, 48]. Application of the heated water and draining is effective only in the cases when long break in the facilities operation and total drainage of the system is acceptable [17, 36].

One of the effective fouling control methods is chlorination or application of the so called oxidants, but it is hazardous for the staff and environment [53]. As molluckocides of the not-oxidizing effect a series of preparations were suggested: BULAB 6002, BULAB 6009, Calgon H-130M, Clam-Trol™ , MACROTROL 9210, VeliGON, MEXEL-432 and other. They possess molluckocide properties, that is have selective effect on the mollusks, but they have no special "zebra-mussel-cide" properties, though zebra mussel is a main bio-hindrances source. Sure, after ingress into the water bodies they can cause harmful effect on the mollusks out of the water supply systems [53].

Antifouling paints are often used for the fouling control [35, 52]. They have complex composition and are harmful for human, because contain some toxic components. Biocide properties of the anti-corrosive coverings VMX-Bazalt [10] with different anti-fouling additives were studied [9, 24]. Furan concrete was suggested for application [38]. Additives to the concrete solutions limiting their fouling were developed [29]. Silicon-based covering is used; its anti-fouling effect is based on the surfaces unfavorable for the larvae attaching [48].

Since the cause of the biological hindrances lies in the development of the certain organisms, it seems rational to search for their control methods based on factors, which limits number of this organisms in the natural habitats [23, 37, 39]. Thus, veligers of zebra mussel were registered in the food ration of 15 fish species of 4 families; in the European water bodies juvenile and adult specimens were noted as food object of 27 fish species of 5 families and of 21 bird species [50]. In zebra mussel bacteria and intra-cellular prokaryotic pathogen organisms were found [18, 42, 49]. Considerable pathogenic effect was observed at parasitizing of Trematoda *Phyllodistomum spp.* (localization in gonads and gills of the mollusks) [11]. For zebra mussel development control rhizobacterium *Pseudomonas fluorescens* was used [8].

Principles of the biological hindrances and their causing process monitoring management. The aim of hydrobiological monitoring is preventing of the biological hindrances and control of the measures effectiveness. Its tasks can be grouped into four directions:

Control of the bio-hindrances-causing organisms development in the water supply systems, for the well timed measures for their extermination;

Control of biological factors of the undesirable species density regulation (predators, parasites);

Control of appearance of new bio-hindrances-causing agents and development of the organisms which might directly or indirectly effect on them – in the whole techno-ecosystem;

Ecological state of the water source control, first of all processes, stipulating bio-hindrances.

Table 1

Principles and methods of the biological hindrances control (according to [6, 44, 46, 50, 51], with additions)

Preventive methods		Active methods			
design	operation	mechanical	physical	chemical	biological
Selection of the cooling ponds' and courses' morphometric parameters Selection of natural and anthropogenic substrates' surfaces ratio Consideration of possible biopositiveness of constructions Selection of hydrodynamic regime Consideration of level regime Construction of the water-inlet facilities Selection of not-fouling materials and coverings Use of closed water-supply systems	Thermal regime regulation Hydrodynamic regime regulation Limitation of the nutrients and organic pollution influx	Filtration of planktonic larvae stages Mechanical retraction, cleaning Washing by high-velocity flow Vegetation cutting Drift prevention Interception of mobile sediments	Suppression of the planktonic larvae stages Water treatment by UV radiation, ultrasound, magnetic field Cathodic protection Destruction of periphyton Thermal treatment Draining Immobilization (covering) Pressure Radio waves with frequency > 500 Hz Microwaves Destruction by hydro blow combined with high temperature	Oxidants (chlorine, bromine, ozone etc) Not-oxidants (heavy-metals compounds, tetraamines etc.) Specific biocides (bacteriocides, algicides, molluskocides)	Predatory hydrobionts Plant-eating hydrobionts Water birds Parasites

Reasoning from the techno-ecosystem conception, populations can be quite neutral, but become the bio-hindrances cause after settling in the water supply systems. Therefore, appropriate location of the monitoring measures application should be chosen. In the very general case, minimum three monitoring points are needed: the cooling pond, water-supplying channel and one of the crucial sections of the water supply system. One of the essential methodic issues, first of all for zebra mussel larvae landing and development, is design and construction of the desks for the substrates' exposure and samples taking.

Data obtained in the course of monitoring should be significant and reliable, because they serve as a base for the crucial decisions' making. For the various potential bio-hindrances formation control in the technical water supply systems creation of the model systems for the constant monitoring is of considerable importance.

Conclusion

Problem of the biological hindrances in operation of the different technical systems connected with water objects is one of the essential tasks of the technical hydrobiology. But it should not be reduced to the development of elimination methods, for instance elimination of the fouling. Technical hydrobiology should consider integral techno-ecological system. It should be recognized, that technical and biotic elements of this system are closely connected with direct relations and feedback. Therefore decreasing of the biological hindrances in the water supply is a factor to improve reliability of the technical systems' operation and to decrease their negative impact on the environment.

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