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PERFORMANCES OF OXYGENATION DEVICES ON TROUT FARMS IN REPUBLIC OF SERBIA, REPUBLIC OF NORTH MACEDONIA, AND BOSNIA AND HERZEGOVINA

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Abstract: Dissolved oxygen is universally recognized as the most decisive limiting factor in intensive trout aquaculture, exerting profound effects not only on production efficiency but also on fish welfare, physiological stability, immune competence, and the capacity to resist disease. When oxygen levels fall below optimal thresholds, trout are exposed to chronic stress, impaired metabolic processes, reduced feed intake, and a heightened susceptibility to pathogens, all of which compromise both productivity and sustainability. To counter these risks, water oxygenation—defined as the technological process of enriching aquaculture water with pure oxygen—has become an indispensable intervention for modern trout farming. In Republic of Serbia and Republic of North Macedonia, oxygenation systems have been continuously applied for more than two decades, while in Bosnia and Herzegovina their use has been established for over ten years, collectively enabling production intensification, seasonal stability, and improved economic outcomes.

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This study explores the diversity of oxygenation technologies currently employed, ranging from diffuser systems and low-head oxygenators to pressurized tanks and devices with rotating mechanical components.

Particular emphasis is placed on their operational principles, efficiency parameters, and exploitation characteristics, with attention to how these technologies are adapted to the specific environmental conditions and management practices of rainbow trout farms in the region.

Keywords: *trout farms, water oxygenation, operational characteristics*

INTRODUCTION

The first oxygenation devices in trout farms in the Republic of Serbia were introduced in 2004. In the Republic of North Macedonia, the adoption of these devices started several years later, driven mainly by individual farm owners' investments and partly supported by state subsidies. Over time, oxygenation has become a critical technology for maintaining production stability, particularly during summer months and under conditions of elevated stocking densities. Initial steps toward the implementation of water oxygenation systems in trout farms in Bosnia and Herzegovina were recorded in 2008, planned as a pilot system for recirculating aquaculture (RAS) at a salmonid hatchery in the Krušnica River valley, Bosanska Krupa [1]. More intensive work on water oxygenation in Bosnian trout farms has been evident over the past six years, during which modern equipment for improving and maintaining optimal oxygen regimes in rearing ponds has been successfully implemented. A leading role in this development is held by Tropic Ribarstvo ("Ribnjak Janj"), located in the Republika Srpska, Bosnia and Herzegovina. The company operates extensive production areas with several large trout farms at different locations, including a hatchery, production of consumable rainbow trout, and trout for processing. The necessity for implementing oxygenation systems is also driven by climate change, which affects the availability of water required to maintain production intensity based on high stocking densities. Simultaneously, Tropic Ribarstvo has become the largest producer of rainbow trout in Bosnia and Herzegovina. Thanks to the implementation of modern technical and technological solutions, the company has experienced continuous growth in rainbow trout production. Dissolved oxygen in water represents the primary limiting factor in trout production. For this reason, oxygen enrichment of water constitutes the most direct means of increasing the carrying capacity of production ponds at a given time, which consequently leads to an increase in production over a specific period. It is important to note that proper planning and organization of production play a crucial role both under traditional production conditions and in intensified systems utilizing oxygenation.

Figure 1. Mortality of rainbow trout fry caused by hypoxia (Photo: S. Čanak, 2007).

Insufficient dissolved oxygen in water represents a production risk [2], the probability of which can be estimated from natural conditions, the production plan, and the evaluated competence of farm personnel.

For water oxygenation to be feasible, it is essential to design and construct a system in accordance with legal, technical, and safety requirements. Such a system comprises a source of "pure" oxygen (technical or medical), which may be an O_2 generator or an oxygen tank, evaporators, pressure regulators, oxygen distribution lines from the source to the manifold, manifolds with rotameters for dosing O_2, and devices for oxygen enrichment of water [2]. In Serbia, North Macedonia, and Bosnia and Herzegovina, liquid oxygen tanks serve as the oxygen source, while the distribution lines are aboveground and made of stainless steel. Oxygen is stored in the tank in liquid form and, after passing through the evaporators and pressure regulators, is delivered to the distribution network in gaseous form.

Devices and equipment for water oxygenation can be operated in different modes:

- Regular oxygenation
- Intermittent oxygenation
- Emergency oxygenation

Regular oxygenation involves continuous use of the equipment, either constantly or over an extended period, such as during the summer months. Intermittent oxygenation is applied in specific situations, for example during medicinal baths without water flow or during fish grading. Emergency oxygenation is aimed at rescuing fish in the event of a sudden drop in dissolved oxygen levels. Devices and equipment for water oxygenation can be classified according to their operating principles: passive oxygenators without overpressure (low-head oxygenators), passive oxygenators with low overpressure (jet platforms), downflow bubble contactors, devices with active components (e.g., FAS Turboxygen, Loxy, Force 7), and perforated hoses or ceramic diffusers.

MATHERIALS AND METHODS

This study is based on data obtained from multiple trout farms located in the Republic of Serbia, Republic of North Macedonia, and Bosnia and Herzegovina. In Serbia, data were collected from six trout farms over an extended observation period. Data acquisition employed two complementary approaches: (i) oral and telephone interviews and (ii) experimental measurements on farms conducted under varying water temperatures, stocking densities, and flow conditions. In a limited number of cases, where direct measurement of dissolved oxygen concentrations was not feasible, estimates of oxygenation effectiveness were derived from published sources. The analysis was primarily directed toward assessing the operational performance of oxygenation devices under field conditions.

The dataset encompassed information on: the modes and locations of oxygenation device and equipment operation, dissolved oxygen concentrations across different water temperatures, the efficiency of diverse technical oxygenation systems, and the cost of oxygen. The study offers an analysis of the working principles, applications, and operational characteristics of oxygenation devices across the three countries examined.

RESULTS AND DISCUSSION

In Serbia, the following oxygenation devices are in use: boxes for passive oxygen enrichment (low-head oxygenators and oxy-jet), devices with pressurized chambers (oxy-trans), devices with active working elements (FAS Turboxygen), perforated hoses, and ceramic diffusers. In North Macedonia, on larger trout farms, FAS Turboxygen and FORCE7 aerators/oxygenators are commonly used, in combination with pure oxygen. In Bosnia and Herzegovina, the following devices are employed: oxygen boxes with nozzles (Oxygen-box with lifting pump), devices with active working elements (FAS Turboxygen, Loxy), perforated hoses, and ceramic diffusers.

Operational principles and performance of oxygenation devices on the investigated trout farms

To evaluate the performance of water oxygenation devices under operational conditions, it is necessary to have various pieces of information. Among all of the needed information for the exploitation of oxygenation devices the most important are amount of oxygen supplied to the water ($kg \times day^{-1}$) and oxygenation efficiency rate (%). Other information can help calculate the cost of the injected oxygen ($€ \times kgO2^{-1}$; $€ \times kg^{-1}$ fish), etc.

Low-head oxygenators may have either a single chamber or multiple parallel chambers. Single-chamber devices are simple systems for water oxygen enrichment. Water can be supplied to these devices by gravity or pumps, and they may have circular or rectangular cross-sections, often constructed in-house based on literature designs.

Typically, these devices consist of three horizontally divided working spaces, separated by perforated plates: (i) the water distribution chamber, (ii) the oxygen–water mixing chamber, and (iii) the chamber of oxygen-enriched water from which water exits into the pond. Water enters the distribution chamber via overflow or piping, while oxygen is supplied directly into the mixing chamber through a hose. In the distribution chamber, water passes through a perforated plate (hole diameter 8–15 mm) before entering the mixing chamber. The oxygen–water mixing chamber can be filled with various plastic media (e.g., BioBlock®, EXPO-NET Danmark A/S) to further disperse water in the pure oxygen atmosphere.

In Serbia, low-head oxygenators are used on several trout farms, primarily in hatcheries, and are generally supplied with water by gravity. An exception is a system with partial water recirculation for the production of fry from 1 g to 20 g, where water is supplied using a pump. These devices may be equipped with various plastic media or operate without any media. In some hatcheries, they are constructed from plastic PVC pipes and filled with plastic media. Multi-stage low-head oxygenators represent an advanced version of the previously described devices. They feature a larger number of parallel chambers (7–10), with the same internal arrangement as single-chamber devices. These systems are based on a patented design [3]. In Serbia, they are used at a single trout farm in the first series of ponds for the production of fry up to 50 g. The efficiency of oxygen utilization in these devices depends on several factors, including the water level difference, device dimensions, oxygen-to-water ratio, and perforation size, typically ranging between 65 % and 91 % [5], [6], [7].

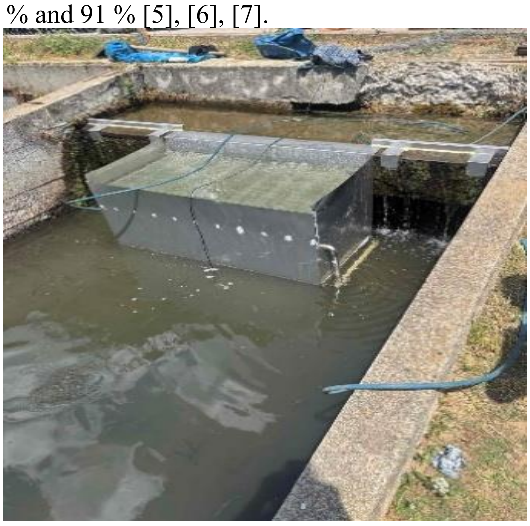

Figure 2. Low-head oxygenator on trout farm in Serbia (foto: S. Canak, 2025)

Based on testing of this device at a trout farm in Serbia under operational conditions during the summer of 2025, the following results were recorded: water temperature ranged from 15 °C to 18 °C, water flow rate from 8 $l \times s^{-1}$ to 12 $l \times s^{-1}$, and the difference in dissolved oxygen concentration in the water ranged between 5 $mg \times l^{-1}$ and 6 $mg \times l^{-1}$. The amount of oxygen dissolved in the water ranged from 4,1 $kgO2 \times day^{-1}$ to 6,2 $kgO2 \times day^{-1}$.

Devices with low overpressure and nozzles (Jet box) are similar in construction to the previously described devices, with the following differences: the water distribution chamber is significantly deeper with a higher water level, while the oxygenation chamber is of lower height. This design creates a small overpressure in the oxygenation chamber, enabling higher dissolved oxygen levels in the water. Instead of a large number of perforated openings, water passes through a few specially designed nozzles into an atmosphere of pure O_2, penetrating the water layer and forming numerous bubbles.

Figure 3. Oxygen-box with lifting pump at the trout farm of Tropic Fishery in Bosnia and Herzegovina (foto N. Savić, 2020)

The oxygen box with a lifting pump is used for water oxygenation integrated into existing channels or ponds. The lifting pump is incorporated into the oxygen box. This system is characterized by high oxygen dissolution efficiency, requiring only 0.7 m of water lift for optimal oxygen transfer. Nozzles with a diameter of 51 mm result in low energy costs for oxygenation and minimal maintenance, approximately 1 kW per 1.5 kg of dissolved oxygen. The devices are manufactured according to customer specifications (water flow, target DO values, etc.; source: https://frea-solutions.dk/en/produkt/oxygen-box-with-lifting-pump/).

Such devices have been widely used worldwide in intensive trout production systems, particularly over the past decade. One device operating on this principle was acquired in 2007 at a trout farm in Serbia. The device was intensively tested at the outlet of a pond used for rearing larger fingerlings (100–200 g), with a water column height above the nozzles of 60 cm, water flow rates between 10 $l \times s^{-1}$ and 25 $l \times s^{-1}$, and water temperatures ranging from 14 °C to 17.5 °C. Under these conditions, the device was able to increase dissolved oxygen levels from 5–6 $mg \times l^{-1}$ to 8–10 $mg \times l^{-1}$ before significant oxygen losses occurred in the form of O_2 bubbles exiting the device with the water.

These results were comparable to those obtained when testing low-head oxygenators of similar dimensions under the same conditions. Observations indicated that the device was likely still in a developmental stage.

Down-flow bubble contactors: devices of this type, also known as Speece cones [8] or oxygenation cones, are most commonly conical, although cylindrical versions also exist. Both types have similar working principle with a difference in oxygen bubbles size and distribution within the device. Water is supplied by a pump, creating elevated pressure in the oxygen–water mixing chamber, which results in high dissolved oxygen concentrations ranging from 25 $mg \times l^{-1}$ to 50 $mg \times l^{-1}$. The most common configuration of these devices is conical, although cylindrical versions were produced in Europe for a certain period. Several cylindrical Oxy-trans devices were imported into Serbia during 2004–2005, including one larger unit and several smaller ones. The larger Oxy-trans device was configured to operate at an overpressure of 0.5–0.6 bar and supplied with 100 $l \times s^{-1}$ of water via a pump. The smaller units operated at 0.7–0.8 bar with a water flow of 8 $l \times s^{-1}$. A key characteristic of these devices is their ability to deliver smaller volumes of water with high dissolved oxygen content.

Figure 4. Downflow bubble contactor at a trout farm in Serbia (Photo: S. Čanak, 2007).

Devices with active working elements: devices with different working principle fall in this group of oxygenating equipment and some of them are used in analized countries: FAS® turboxygen, (F.A.S. srl. Italia), Loxy® (LINN Gerätebau GmbH, Germany), Force7® (Acqua&Co S.R.L, Italy).

Figure 5: FAS KR94/L devices in operation at a trout farm in Republic of Serbia
(Photo: S. Čanak, 2007)

FAS Turboxygen KR94/L devices consist of a pontoon or float that allows the unit to float on the water surface, a hood submerged from below, and a drum with blades. Oxygen is supplied to the hood via a hose. Beneath the hood, a pocket of pure oxygen is trapped between the hood above and the water below. The drum with blades disperses water into the oxygen atmosphere under the hood. Due to the shape of the hood, the oxygen-enriched water is directed forward and downward. These devices process large volumes of water, but the dissolved oxygen content at the outlet typically reaches only 110 % - 120 % of saturation. The amount of oxygen dissolved in the water can be adjusted to fish needs and ranges usually from 12 $kgO2\times day^{-1}$ to 20 $kgO2\times day^{-1}$ under farming conditions. Higher scores are also possible but lower oxygen transfer efficiency will be the consequence.

In Serbia and Bosnia and Herzegovina, devices of this type are used on several trout farms. They are also employed in the Republic of North Macedonia, applied on two larger trout farms, particularly during the summer months and under conditions of increased biomass.Perforated hoses and ceramic diffusers are positioned at a distance of between ¼ and ½ of the pond length from the water inlet, based on measurements of dissolved oxygen in the water under conditions of high fish biomass. The aim of this positioning is to further enrich the water with oxygen after partial consumption by the fish, thereby ensuring survival and optimal growth in the downstream section of the pond. Experimental measurements of dissolved oxygen have shown that stable oxygen levels are highest at approximately 2 m from the device, near the pond bottom at a depth of about 1 m. Maximum measured oxygen concentrations in the water reached approximately 120 % saturation. For this type of device, it is not straightforward to accurately measure either the dissolved oxygen content immediately after passage through the device or the device's operational efficiency.

Figure 6. FAS KR94/L devices at a trout farm in North Macedonia (Photo: A. Trajchovski, 2020)

Figure 7. FAS KR94/L device, Tropic Ribarstvo, Bosnia and Herzegovina, Republic of Srpska (Photo: Lj. Todorović, 2025.)

The LOXY® oxygenation system features an innovative rotating mixing mechanism within a plastic housing. It is driven by an electric motor located above the water surface. Due to rotation, the mixer pushes water outward within the closed system. The resulting high-velocity water flow creates a vacuum, drawing pure oxygen through a pipe into the mixer, where it is dispersed in the water as very fine bubbles. LOXY® achieves a very high level of oxygen enrichment with low energy consumption. Its main advantage is that, thanks to the rotating mixer, only a very small portion of the water needs to be accelerated, and no water pressure is required. A fluidized layer forms on the surface of the innovative rotating mixer, reducing energy consumption and enabling excellent oxygenation.

Figure 8. LOXY25220, Tropic Ribarstvo, Bosnia and Herzegovina, Republic of Srpska (Photo: N. Savić, 2024)

Additionally, on two large trout farms in North Macedonia, the Force7 system is used. It belongs to the group of aspiration aerators, with the option of adding pure O_2. This device independently injects large volumes of air or pure oxygen, creating microbubbles that dissolve in the water, ensuring optimal oxygen transfer. Thanks to its high-speed propeller, a strong water current is generated, enabling circulation and homogenization of the entire water body, preventing thermal stratification, and improving ecosystem stability. A key advantage of this device is its ability to directly inject pure oxygen or ozone, achieving high dissolution efficiency even under intensive farming conditions. The Force7 system can be installed in multiple configurations—floating, static, or dock-mounted—making it suitable for ponds with high stocking densities, lakes, or tanks of varying depths. On the trout farms analyzed in North Macedonia, Force7 devices are employed as oxygenators. Practical advantages include adjustable operating depth and angle, the option to select different propellers depending on the purpose (circulation, pure oxygen injection, or conventional aeration), corrosion protection via anodes, and ease of maintenance. These features also make the device suitable for use in systems with floating cages.

Figure 9. Force7 device at a trout farm in North Macedonia (Photo: A. Trajčovski, 2020)

Perforated hoses and ceramic diffusers: perforated hoses and ceramic diffusers are primarily used to maintain dissolved oxygen levels in the water during fish transport. Additionally, they can be employed during therapeutic baths, ceramic diffusers in small tanks for fry and perforated hoses for market-size fish. Perforated hoses play a particularly important role in emergency oxygenation, when a fish crisis has already occurred due to depleted dissolved oxygen levels and mortality has begun. In such cases, it is essential to rapidly increase dissolved oxygen concentrations to provide conditions for fish survival.

Ceramic micro-bubble diffusers for pure oxygen release operate on the principle of generating fine oxygen bubbles that rise slowly through the water column, ensuring maximum O_2 solubility. This makes oxygenation both efficient and cost-effective. Certain characteristics of perforated hoses are particularly important for their operation and maintenance. Perforated hoses must be weighted to ensure proper placement on the pond bottom. Maintenance of perforated hoses includes removing algae from their surface at least once per year.

The oxygen utilization efficiency of perforated hoses typically ranges from 3 % – 7 % per meter of water depth, while for ceramic diffusers usually ranges from 10–20 % and in some applications even more. Oxygen transfer efficiency for ceramic diffusers had increase over the years, from below 15 % [9] to above mentioned.

Figure 10. Use of pure oxygen for rearing trout fry, injected into the water via ceramic micro-bubble diffusers – Tropic Ribarstvo, Bosnia and Herzegovina, Republika Srpska (Photo: N. Savić, 2024)

In Republic of Serbia, on several trout farms that rely heavily on oxygen supplementation, perforated hoses are installed in every rearing pond for potential emergency oxygenation. Sometimes, two hoses are placed in a single pond: one along the length of the pond, covering 2/3 to the entire pond length, and another in the first 3–5 m from the pond inlet. The purpose of the hose near the inlet is to save fish that instinctively gather at the inflow of fresh water. Experience has shown that a significant portion of the fish (several tons) instinctively congregates near the fresh water inlet during sharp drops in dissolved oxygen levels.

CONCLUSIONS

The use of water oxygenation devices in trout farms has a long history in all three analyzed countries. The method of use and placement depends on the type of oxygenator. Ceramic diffusers are suitable for smaller tanks for rearing fry. Perforated hoses are primarily used in tanks for transporting live fish and play an important role as an emergency oxygenation system.

Downflow bubble contactor devices are currently used on only one trout farm in Serbia. Globally, devices operating on this principle are widely employed in intensive and super-intensive (RAS) systems for producing rainbow trout, and their use can be expected to increase in the observed countries in the near future.

Overall, devices with active working elements, specifically the FAS KR94/L model, are the most commonly used oxygenators in all three countries.

This is primarily because they allow significant production intensification without the need for additional equipment or technology.

Box-type oxygenation devices (Oxy-box) with nozzles are used in Bosnia and Herzegovina, Republika Srpska, and their further adoption can be expected in all three countries. Similarly, low-head oxygenators are among the devices whose usage is expected to increase in the near future.

BIBLOGRAPHY

[1] Ajanovic, N., Moth–Poulsen, T., Peteri, A., Wurzbacher, S., Bollerup, L. 2010. FISH hatchery in the municipality of Bosanska Krupa in northwestern Bosnia and Herzegovina: A sustainable development pilot project. Ribarstvo, 68, 2010, (2), pp.79-92.

[2] Čanak, M., Stevan, M., Savić, M., Trajčovski, B. A., Cvetkovikj, S. A. 2023. Risks in trout aquaculture in Serbia, Bosnia and Herzegovina and North Macedonia. Proceedings of the 6th International Symposium on Agricultural Engineering (ISAE-2023), Belgrade–Zemun, Serbia.

[3] Colt, J.; Watten, B. Applications of pure oxygen in fish culture. Aq. Eng. 1988, 7, pp. 397–441.

[4] Watten, B.J., 1989. Multiple Stage Gas Absorber. United States Patent #4880445.

[5] Wagner, J. Erick, Bosakowski, T., Miller, A. Scoth. 1995. Evaluation of the absorption efficiency of the Low Head Oxygenation System, Aquacultural Engineering, Volume 14, Issue 1, pp. 49-57.

[6] Davenport, M., Timmons, M., Vinci, B., Crum, M. 2001. Experimental evaluation of low head oxygenators. Aquacultural Engineering - AQUACULT ENG. 24. pp. 245-256.

[7] Vinci, B. J., Davidson, J., Naveh, E., & Engler, O. (2016). Low head oxygenator performance characterization for marine recirculating aquaculture systems. Aquacultural Engineering, 75, 22–28. https://doi.org/10.1016/j.aquaeng.2016.07.00

[8] Speece, R.E., 1972. Downflow bubble contact aeration apparatus and method. United States Patent #3643403.

[9] Carmichael, J. Gary, R. M. Jones, J. C. Morrow, Comparative Efficacy of Oxygen Diffusers in a Fish-Hauling Tank, The Progressive Fish-Culturist, Volume 54, Issue 1, January 1992, pp. 35–40.

PERFORMANSE UREĐAJA ZA OKSIGENACIJU NA PASTRMSKIM RIBNJACIMA U REPUBLICI SRBIJI, REPUBLICI SEVERNOJ MAKEDONIJI I BOSNI I HERCEGOVINI

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Sažetak: Rastvoreni kiseonik se univerzalno prepoznaje kao najznačajniji ograničavajući faktor u intenzivnoj akvakulturi pastrmke, jer ima dubok uticaj ne samo na proizvodnu efikasnost, već i na dobrobit riba, fiziološku stabilnost, imunološku kompetentnost i sposobnost odolevanja bolestima. Kada nivo kiseonika padne ispod optimalnih vrednosti, pastrmke su izložene hroničnom stresu, poremećajima metaboličkih procesa, smanjenom unosu hrane i povećanoj osetljivosti na patogene, što sve zajedno negativno utiče na produktivnost i održivost proizvodnje. U cilju ublažavanja ovih rizika, oksigenacija vode, definisana kao tehnološki proces obogaćivanja vode čistim kiseonikom, postala je nezamenjiva mera u savremenoj pastrmskoj akvakulturi. U Srbiji i Severnoj Makedoniji sistemi za oksigenaciju se kontinuirano primenjuju više od dve decenije, dok su u Bosni i Hercegovini u upotrebi duže od deset godina, čime su omogućeni intenziviranje proizvodnje, sezonska stabilnost i poboljšani ekonomski rezultati. Ova studija razmatra raznovrsnost tehnologija za oksigenaciju koje se trenutno koriste, uključujući difuzorske sisteme, niskonaponske oksigenatore, rezervoare pod pritiskom i uređaje sa rotirajućim mehaničkim komponentama. Poseban akcenat stavljen je na njihove principe rada, parametre efikasnosti i eksploatacione karakteristike, uz razmatranje načina na koji su ove tehnologije prilagođene specifičnim ekološkim uslovima i upravljačkim praksama na ribnjacima sa kalifornijskom pastrmkom u regionu.

Ključne reči: *Pastrmski ribnjaci, oksigenacija vode, eksploatacione karakteristike*

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