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Research and improvement of the design of a sedimentation tank for hydropower and irrigation

Abstract. The study is devoted to the analysis and optimisation of the design of the sedimentation tank to increase the efficiency of settling solid particles in hydropower and irrigation systems. Both experimental and numerical methods were used to analyse and optimise the design of sedimentation tanks to increase their efficiency in hydropower and irrigation systems. The study examined and analysed various types of sedimentation tanks according to design schemes, flow regime, deposition dynamics and sediment flushing methods, and also considered recommended improvements for hydropower and irrigation of various types of sedimentation tanks. During the study, it was revealed that optimising the geometry of the sedimentation tank significantly increases the efficiency of solid particle deposition. Experimental data have shown that changing the angle of inclination of the walls and increasing the area of the bottom of the sedimentation tank contribute to improving the deposition of silt and sand. It has also been found that the use of special turbulent inserts reduces the particle deposition time and improves the quality of treated water. Hydraulic flow modelling has confirmed that a more uniform velocity distribution in the sedimentation tank reduces turbulence and promotes more efficient particle deposition. The introduction of automated systems for monitoring and controlling the cleaning process has made it possible to increase the reliability and stability of the sedimentation tank. As a result, it was proved that the proposed design and technological changes can significantly increase the efficiency and durability of sedimentation tanks in hydropower and irrigation. The study provides practical recommendations for improving the design of sedimentation tanks, which helps to increase their efficiency and reliability in hydropower and irrigation, thereby improving water management

Keywords: suspended particles; infrastructure elements; pumps and filters; sedimentation; hydraulic flows

INTRODUCTION

Effective water management is a critical aspect for hydropower and irrigation, as both the economic and environmental sustainability of systems depend on it. Sedimentation tanks play a key role in this process, which ensure the removal of solid particles from the water, preventing clogging of equipment and improving water quality for future use. The analysis will identify the most effective approaches to the design and optimisation of sedimentation tanks, which becomes the basis for the development of recommendations to improve their efficiency and increase durability in hydropower and irrigation systems, contributing to more efficient use of water resources and reducing the ecological footprint of industrial processes.

This study was necessary due to the critical importance of improving the efficiency of sedimentation tanks in hydropower and irrigation. Traditional structures often face problems with insufficient deposition of solid particles, which leads to increased wear of equipment, reduced water quality, and increased operating costs. Modern requirements for sustainable management of water resources and improvement of environmental safety emphasise the need to optimise the designs of sedimentation tanks.

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By analysing and improving design schemes, flow regimes, deposition dynamics, and precipitation flushing methods, the efficiency of these systems can be significantly improved, which will better meet the growing needs for clean water and reliable hydraulic structures.

The problem of insufficient efficiency of sedimentation tanks in hydropower and irrigation has long attracted the attention of researchers. K. Hirom & T.T. Devi (2022) investigated the influence of the sedimentation tank shape on the efficiency of solid particle deposition, suggesting optimal geometric parameters for various operating conditions. G.J. Hoffmans (2022) focused on the analysis of hydraulic regimes and found that changing the flow rate can significantly improve the deposition process. Important observations on deposition dynamics and particle behaviour in sedimentation tanks were made by D.A. Yaseen *et al.* (2024), who emphasised the role of turbulence in these processes. H. Feng *et al.* (2023) proposed new methods for washing sediments to reduce cleaning time and improve the overall efficiency of the system. In turn, A.K. Dudhpachare *et al.* (2022) focused on automating the process of managing sedimentation tanks, which significantly increased the reliability of their operation.

The results of the study by R. Singh *et al.* (2021) have shown that the use of composite materials can increase the durability of structures and reduce operating costs. S. Juraev *et al.* (2022) conducted an extensive study of the impact of environmental factors on the operation of sedimentation tanks, suggesting methods to minimise the negative impact on the environment. K. Czernek *et al.* (2021) demonstrated the importance of integrating sedimentation tanks with other elements of drainage systems, ensuring a more coordinated and efficient operation of the entire system. Ultimately, the research conducted by M. Ajith *et al.* (2021) confirmed that the introduction of innovative technologies such as nanomaterials can significantly improve the water purification process and increase the overall performance of sedimentation tanks.

J.C. Iyer & E.J. James (2022) focused on model studies aimed at designing the inlet transition of sedimentation tanks for hydropower projects in regions with high alluvial runoff. Despite extensive research, there are still many gaps that require additional investigation. It is necessary to conduct a more detailed analysis of the influence of various hydraulic modes on settling efficiency, to investigate the long-term effects of using new materials, and to develop more advanced automation and control methods to ensure reliable and stable operation of sedimentation tanks in various operating conditions.

The purpose of the study was to develop and improve the design of a sedimentation tank to significantly improve the efficiency of solid particle deposition in hydropower and irrigation systems. The objectives of the study included:

1. Analysis of existing design schemes of sedimentation tanks to identify their main advantages and disadvantages in the context of the efficiency of precipitation of solid particles.

2. Investigation of hydraulic flows in sedimentation tanks to determine optimal conditions conducive to improving the particle deposition process.

MATERIALS AND METHODS

A study on curved sedimentation tanks at hydroelectric power plants was conducted in Azerbaijan, in 2023, at the National Academy of Sciences of Azerbaijan. During the analysis, a detailed optimisation of both the shape and size of the sedimentation tank was carried out to maximise the process of capturing suspended particles from the water. A study considered various methods of solid particle deposition aimed at improving the efficiency of the process with minimal loss of water and energy. Direct and reverse gradient sedimentation tanks, curved sedimentation tanks, and the use of chemical reagents and innovative technologies in the field of water purification were analysed. The main emphasis was placed on the development of design solutions that contribute to the optimal use of hydraulic flows and the most efficient deposition of particles, which significantly increases the performance of the sedimentation tank in hydropower and irrigation systems.

In the course of the research, modern materials were developed for the construction of sedimentation tanks. This process involved careful research and testing of various materials for strength, corrosion resistance, and durability. The purpose was to determine the best material options, considering the specific operating conditions of the sedimentation tanks, which ensures their efficient operation in various climatic and operational conditions necessary for hydropower and irrigation systems. During the study, a hydraulic analysis was carried out aimed at optimising the flow profile in the sedimentation tank. The main purpose of this analysis was to minimise pressure losses and maximise the efficiency of the particle deposition process. The analysis included an assessment of hydraulic losses, the distribution of flow rates and the influence of geometric parameters of the sedimentation tank on its performance in conditions of hydropower and irrigation.

During the study, the technical parameters of the sedimentation tank design were coordinated with other key elements of the wastewater disposal and water treatment system, such as pumps and filters. The purpose of this process was to ensure trouble-free operation of the sedimentation tank within the framework of an integrated water supply and treatment infrastructure, which contributes to improving the overall efficiency of the system. During the study, environmentally sustainable solutions were developed and implemented aimed at reducing energy and water consumption, minimising emissions and waste into the environment. This is achieved through the use of advanced cleaning technologies and improvement of internal processes in sedimentation tanks, which reduces the environmental footprint of hydropower and irrigation systems.

During the analysis, advanced technologies such as automation of purification processes, the use of nanomaterials, and sensor systems were actively implemented. These measures are aimed at significantly improving the efficiency of sedimentation tanks and improving control over water purification processes in the conditions of hydropower and irrigation. To assess the effectiveness of new designs of sedimentation tanks, comprehensive testing was carried out both in laboratory conditions and in practice using computer modelling. This approach helps to pre-evaluate and verify the operability of the structure by simulating various operating conditions and loads, which reduces risks when introducing new technologies and ensures a high degree of reliability and efficiency of sedimentation tanks in hydropower and irrigation.

The tests were carried out using a large-scale model of the washing gallery with a length of 3.8 m, an initial diameter of 6 cm, and a final diameter of 18 cm. During the experiments, a constant height of the longitudinal slit was maintained to determine the flow coefficient of the slit μ at flow rates from 36 to 41 litres per second at the outlet.

Equations (1-7) were used in the study:

$$u_{avg} = u_k \left(\frac{x}{L}\right)^{1/3}, \quad (1)$$

where: u_{avg} – average flow velocity at point x; u_k – flow velocity on the axis of symmetry; x – distance from the axis of symmetry; L – characteristic size of the flow.

$$Q = \mu \Delta L \sqrt{2gh_{p.avg}}, \quad (2)$$

where: Q – volumetric flow rate of liquid through the pipe; μ – dynamic viscosity of the liquid; Δ – height of the slit; L – length of the slit; $h_{p.avg}$ – average value of the effective pressure.

$$z = (1 + \Sigma\xi)\frac{\upsilon_n^2}{2g}, \quad (3)$$

where: Σξ – sum of the resistance coefficients.

$$\mu = \varepsilon\varphi, \quad (4)$$

where: μ –cavity flow coefficient; ε – compression coefficient; φ – velocity coefficient.

$$\frac{1}{\varphi^2} - \Sigma\xi, \quad (5)$$

where: ε – compression ratio; φ – velocity coefficient.

$$\varphi = \frac{\mu}{\varepsilon}, \Sigma\xi = \frac{1}{\varphi^2}, \quad (6)$$

$$h_{w_m} = \Sigma\xi \frac{\upsilon_n^2}{2g}, \quad (7)$$

where: h_{w_m} – average height of the piezometric pressure in the section with coordinates w; Σξ – sum of the coefficients characterising the velocity distribution over the section; υ_n^2 – flow velocity at the point n of the section; 2g – gravity acceleration.

All these aspects together contributed to the development and improvement of the design of sedimentation tanks, which, in turn, contributed to improving the efficiency and sustainability of hydropower and irrigation systems.

RESULTS

The research and improvement of the design of a sedimentation tank for hydropower and irrigation is a significant task aimed at improving the efficiency of water resources use and reducing the negative impact on the environment. This process is aimed at creating more efficient and environmentally sustainable solutions that can optimise sedimentation tanks to save water, improve the quality of treatment and minimise the environmental footprint during their operation. Sedimentation tanks play a key role in water purification from solid particles such as sand and silt, which significantly affects water quality in hydropower and irrigation systems (Zamanikherad *et al.*, 2022). The research is aimed at optimising the shape and size of sedimentation tanks to achieve maximum particle deposition efficiency and minimise water and energy losses. This includes the development of structures capable of efficiently trapping suspended particles under various hydraulic conditions, which is the main aspect of the study. Laboratory studies and numerical modelling help to determine the optimal operating conditions of the sedimentation tanks necessary to improve water treatment technologies and sustainable use of water resources.

The choice of materials for sedimentation tanks is a difficult task, requiring consideration of chemical resistance to water and chemicals in the treated environment. The strength of the materials is important to ensure the durability of the structure under high hydraulic loads and mechanical influences. The cost and the possibility of recycling materials also play a significant role in the overall economic efficiency of the project. The development of new composite materials with improved resistance characteristics and mechanical properties opens up prospects for improving sedimentation tanks and their application in various climatic conditions. Sedimentation tanks play a key role in the operation of hydroelectric power plants (HPPs) by removing solid particles from the water. This process has several important positive effects. Removing solid particles from the water reduces wear and damage to turbines, extending their service life. Particles such as sand, silt, and other suspended solids can seriously damage the turbines of a hydroelectric power plant if they enter the system. These particles cause abrasive wear of turbine blades and other components, which leads to more frequent repairs and replacement of parts. By removing solid particles, sedimentation tanks reduce the likelihood of damage and reduce the need for maintenance, which ultimately extends the service life of the equipment.

Cleaner water has less resistance to movement through turbines, which increases their efficiency and the overall performance of hydroelectric power plants. The presence of solid particles in the water increases its viscosity and resistance to flow through the turbines. Cleaner water moves more freely through turbines, which contributes to a more efficient conversion of hydraulic energy into mechanical and, eventually, into electrical energy. This leads to an increase in the overall productivity of hydroelectric power plants and more efficient use of water resources. Optimisation of the hydraulic parameters of the sedimentation tank is aimed at improving the efficiency and reliability of hydropower and irrigation systems. Research in this area includes the analysis of pressure losses and the distribution of flow velocities inside the sedimentation tank to minimise hydraulic losses and optimise the deposition of solid particles. This is important to ensure stable operation of systems in conditions of variable water flow and variability of hydrogeological conditions. Important aspects of optimising the hydraulic parameters of sedimentation tanks include pressure loss analysis, uniform distribution of flow rates, minimisation of hydraulic losses, and optimisation of the solid deposition process.

Pressure losses in the sedimentation tanks should be minimal to ensure maximum efficiency of the entire system. This is achieved by designing and optimising the shape of the sedimentation tanks and the path of water movement. It is important to ensure an even distribution of flow rates inside the sedimentation tank so that solid particles can settle efficiently. This contributes to a more complete removal of suspended solids from the water. The optimisation of sedimentation tanks includes measures to reduce hydraulic losses, such as improving the design of sedimentation tanks and using modern technologies to control and manage water flows. The process of precipitation of solid particles should be as efficient as possible, which requires an accurate analysis of hydrogeological conditions and variable water flow. This includes choosing the right size and shape of the sedimentation tanks, and the optimal placement of internal partitions and deflectors. These measures ensure more stable and efficient operation of hydropower and irrigation systems, which is especially important in conditions of variable hydrogeological conditions and changing water volumes.

The integration of the sedimentation tank into the overall drainage and water treatment system is an important aspect in improving water treatment technologies. Interaction with other infrastructure elements, such as pumps and filters, requires an integrated approach to the design and management of the sedimentation tank (Saeed *et al.*, 2021). This includes adapting the design to technological processes and considering environmental aspects to minimise the impact on the environment. The development of environmentally sustainable sedimentation tanks includes reducing energy consumption, minimising emissions, and consideration of the impact on aquatic ecosystems. The use of advanced technologies and materials helps to reduce the environmental impact and ensure the sustainable development of water treatment systems. The introduction of new technologies, such as automation of purification processes and the use of nanomaterials, plays an important role in improving the functionality of sedimentation tanks and improving the quality of treated water (Borysov & Gevod, 2023). This line of research helps to reduce operating costs and ensure the environmental safety of water treatment systems. Water sedimentation is used in hydraulic structures, centralised water supply and sewerage systems (Dev *et al.*, 2021). Sedimentation tanks are water storage tanks or open containers in which mechanical impurities are removed from the water by settling. During settling, the particles of the dispersed phase either rise to the surface of the water or settle to the bottom of the tank, forming a precipitate, depending on their density. In some cases, settling is accompanied by particle enlargement. This method is widely used to remove large mechanical impurities from water in hydraulic structures, centralised water supply and sewerage systems, hydroelectric power plants, irrigation systems, and for urban wastewater treatment and after biological wastewater treatment.

In pumping and hydroelectric power plants, water from open reservoirs is settled to prevent wear of impellers and pump components due to solid particles larger than 0.25 mm. In irrigation systems, the use of sedimentation tanks is justified to prevent clogging of channels with silt. In centralised water supply systems, sedimentation tanks are used at water treatment plants for pretreatment of water with a turbidity of more than 2 g/l. Only contamination particles larger than 10-5 cm are subject to deposition. Particles ranging in size from 10-7 to 10-5 cm form a colloidal microheterogenic system and do not settle due to the balance between gravity and the kinetic energy of Brownian motion, which is typical for low-mass particles. As a rule, flocculants are used to remove colloidal impurities from water, and the resulting flakes are removed in sedimentation tanks or other equipment (Noor *et al.*, 2021). For complete precipitation, the water flow rate should be 0.25...0.5 m/s. The second important factor affecting the completeness of deposition is the settling time, which is usually 1.5...2 hours. Sedimentation tanks can be classified according to various criteria, however, the researcher suggests that the most accurate classification is according to the main flow direction of the treated water. According to this feature, sedimentation tanks are divided into horizontal, vertical, and radial. The most common type is horizontal sedimentation tanks used in water treatment plants with a capacity of 15 to 50,000 m^3/day. They usually remove up to 60% of suspended impurities. Horizontal sedimentation tanks are rectangular reinforced concrete tanks divided into several sections. Their length can reach 48 m, while the width is usually three to five times less than the length. The depth does not exceed 4 m, and the thickness of the water layer is 2-2.5 m. The water enters through a series of holes in the end walls of the horizontal sedimentation tank, is evenly distributed throughout the tank and flows along its entire length. The purified water is discharged through a spillway on the opposite side.

There are several sediment collection pits at the bottom of the sedimentation tank. Sediment that does not enter the pits is removed from the bottom by a special scraper device (Zapico *et al.*, 2021). The scrapers are moved along the sedimentation tank using a gear and chain drive system. The scraper collects sediment as it moves along the bottom and collects suspended impurities as it moves along the surface of the water, directing them into a special chute. Sediment can be discharged through pipes at the bottom, lifted through pipes using water pressure, or removed from the pits using submersible pumps. The disadvantages of horizontal sedimentation tanks are high installation costs, unreliability of the scraper mechanism and the presence of stagnant areas where sediment is not removed. Horizontal sedimentation tanks play a key role in hydropower systems, providing water purification from solid particles before they enter the turbines. They prevent wear and damage to turbines by removing sand, gravel, and other suspended materials, which significantly improves the quality of water supplied to the equipment. This not only increases the efficiency of hydraulic turbines, but also increases their service life, thereby reducing maintenance and repair costs. The protection of sedimentation tanks from clogging and their proper functioning also reduce the risk of accidents at a hydroelectric power plant, which makes operation more reliable and safe. The effective operation of sedimentation tanks is also important from an environmental standpoint, since it prevents pollution of natural reservoirs with solid waste, which contributes to the conservation of biodiversity and ecosystems. Thus, horizontal sedimentation tanks are necessary for the optimal functioning of hydropower systems, ensuring high efficiency of the electricity generation process and minimising the negative impact on the environment.

Vertical sedimentation tanks, which are cylindrical tanks with a conical bottom, are another common type. They are commonly used in wastewater treatment plants for primary water sedimentation and removal of suspended particles after coagulation. In vertical sedimentation tanks, water flows through pipes from above to the lower part of the device, where it is evenly distributed over the entire section. The sediment settles in the lower conical part, and the purified water rises and pours through a circular drain into a collecting tray. A special chamber is located in front of the drain to remove suspended impurities. During settling, sediment accumulates at the bottom of the device and is discharged through a special pit. Scraper mechanisms are installed only in those tanks where a large amount of sediment accumulates. Vertical sedimentation tanks usually remove up to 40% of suspended impurities. Vertical sedimentation tanks have a simpler design and operating conditions compared to horizontal sedimentation tanks (Raeesh *et al.*, 2022). Their main advantage is the presence of an annular spillway in the upper part, which reduces the flow rate and reduces the likelihood of sediment removal. However, the disadvantage of this type of equipment is the lack of a scraper mechanism, which complicates the removal of sediment from the drain lid. Vertical sedimentation tanks are an important device in hydropower systems, which has a significant impact on their operation. The main function of vertical sedimentation tanks is to purify water from solid particles such as sand, gravel and other suspended materials before it enters the hydraulic turbines (Litynska *et al.*, 2023). This water purification plays a key role in preventing wear and damage to turbines, which ensures their longer service life and reduces the need for repairs.

The efficient operation of vertical sedimentation tanks also contributes to improving the efficiency of the hydropower plant as a whole. Clean water supplied to hydraulic turbines reduces friction and wear of internal mechanisms, which ultimately increases electricity generation. This also helps to reduce the risk of accidents related to possible blockages and damage to equipment. In addition, vertical sedimentation tanks play an important role in the environmental aspect of energy production. By removing solid particles from the water before its return to natural reservoirs, the negative impact on the environment is minimised and biodiversity in aquatic ecosystems is preserved. In conclusion, vertical sedimentation tanks are an integral part of the infrastructure of hydropower systems, ensuring their efficient and stable operation while maintaining high standards of environmental safety and cost-effectiveness of operation. Radial sedimentation tanks are a type of vertical devices (Ganjare & Patwardhan, 2023). They usually have a height of less than 0.1-0.15 m and a diameter of 16 to 60 m, sometimes reaching 100 m. These tanks are used to treat very turbid water and purify water in industrial water supply systems. Water enters such a device through a central pipe, and purified water exits through a circular spillway at the top of the device. The sediment settling to the bottom is collected using a rotating scraper. Radial sedimentation tanks are used in wastewater treatment plants with a capacity of more than 20,000 m^3/day, ensuring the removal of up to 50% of suspended solids.

Radial sedimentation tanks are key elements in hydropower systems that play a crucial role in ensuring their efficient operation and durability. The main function of radial sedimentation tanks is to purify water from various solid particles such as sand, gravel, debris, and other suspended materials before they enter the hydraulic turbines. This water purification prevents wear and damage to the hydraulic turbines, which can be caused by abrasive particles. The efficient operation of radial sedimentation tanks helps to increase the service life of hydraulic equipment and reduce the need for its repair and replacement. Clean water supplied to hydraulic turbines also helps to increase their efficiency by reducing friction and wear of mechanical elements, which, in turn, increases productivity and electricity generation. In addition, the proper operation of radial sedimentation tanks reduces the likelihood of accidents at a hydroelectric power plant associated with possible blockages and damage to equipment. This ensures a more stable and safe operation of the hydropower complex, which is especially important given the environmental impact.

Thus, radial sedimentation tanks not only protect hydraulic turbines from the negative effects of solid particles, but also contribute to improving the overall efficiency and reliability of hydropower systems, reduce operating costs, and minimise the impact on natural ecosystems. The operation of the sedimentation tanks is considered from the standpoint of using only one type of periodic flushing, also known as energy sedimentation tanks, which are also suitable for irrigation conditions. This type of sedimentation tanks is designed for the deposition of relatively large fractions of suspended particles with a size of 0.2-0.25 mm or more. Since such particles usually do not move in open surface watercourses, the sedimentation tanks are located either within the limits of the hydropower complex or at some distance from it. Regularly flushed sedimentation tanks operate in two cycles (Fig. 1). In the first cycle, which takes most of the time, some of the suspended particles are deposited from the river stream, and the purified water is supplied to consumers. In the second cycle, the sediment is removed from the sedimentation tank, and the water supply from the treatment chamber to the watercourse stops.

Figure 1. Rectangular sedimentation tank with 2 chambers
Source: compiled by the author

Forward and reverse gradient sedimentation tanks play a significant role in the hydropower systems of Azerbaijan, affecting the efficiency of hydroelectric power plants and providing optimal conditions for electricity production (Fig. 2). Direct gradient sedimentation tanks located at various hydroelectric power plants in the country, such as the Mingachevir HPP, play an important role in the process of cleaning water from solid particles before it is supplied to hydraulic turbines. They provide more efficient filtration and removal of suspended sediments, which reduces pollution of turbines and other equipment, extending their service life and increasing the overall performance of hydroelectric power plants. In addition, direct gradient sedimentation tanks help to save water, which is especially important in conditions of limited water resources. Reverse gradient sedimentation tanks provide more efficient removal of fine suspended particles from the water. They minimise the risk of siltation of reservoirs and reduce the environmental impact, improving the quality of the environment in the reservoir areas. Saving reagents used in the water purification process is also an important advantage of reverse gradient sedimentation tanks. The choice between direct and reverse gradient sedimentation tanks depends on the specific conditions of each HPP, such as the size and type of suspended particles, water quality requirements, and economic considerations. The decision should be reasonable and focused on achieving optimal system performance, considering all factors affecting the efficiency and environmental sustainability of electricity production.

Figure 2. Rectangular sedimentation tank with 1 chamber
Source: compiled by the author

Direct slope sedimentation tanks are often used because of their simplicity of design (Xu *et al.*, 2021). Backslope sedimentation tanks are more complex in design, however, they are preferable when the sediment contains a large number of coarse particles (Fig. 3). In such sedimentation tanks, more intensive deposition occurs in the initial part of the tank, and the depth here is greater, which allows retaining more sediment compared to direct sedimentation tanks with a slope.

Figure 3. Rectangular sedimentation tank with 3 chambers
Source: compiled by the author

Curved sedimentation tanks in hydroelectric power plants represent an innovative solution that, although not widespread, demonstrates significant advantages over traditional rectangular sedimentation tanks (Fig. 4). They are usually used in small and medium-sized hydroelectric power plants, where compactness and efficiency are of particular importance. Curved sedimentation tanks significantly increase the efficiency of water purification due to their shape, which ensures a more uniform distribution of water flow (Griborio *et al.*, 2021). This contributes to more efficient deposition of fine suspended particles, which minimises pollution of turbines and other equipment, as well as reduces the risk of siltation of reservoirs. In addition, such sedimentation tanks can reduce the consumption of chemicals used for water purification, which helps to save resources and improve environmental sustainability. The main features of the operation of curved sedimentation tanks include the use of washing pipes with a circular cross-section, which create an upward flow of water that lifts suspended particles to the surface, where they separate from the water. This contributes to more efficient sludge removal, which further increases the efficiency of the system. Among the advantages of curved sedimentation tanks, their high efficiency in water purification, compactness and relative ease of operation should be highlighted. However, it should be borne in mind that such sedimentation tanks can be more complex in design and more expensive to build compared to conventional settling tanks. They also have limited applicability at large hydroelectric power plants with large volumes of water, which makes them less preferable for such facilities. It is important to emphasise that the efficiency of a curved sedimentation tank depends on many factors, including the flow rate of water and the properties of suspended particles. Regular monitoring and maintenance of the sedimentation tank is necessary to ensure its efficient operation and durability.

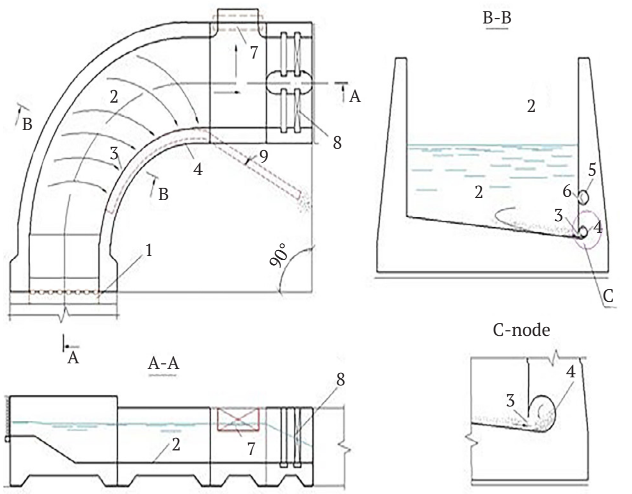

Figure 4. Curved sedimentation tank: plans and sections
Note: 1 – steel grate; 2 – rectangular tray; 3 – flushing slots; 4 – collector; 5 – forming pipe; 6 – gaps of the forming pipe; 7 – valve of the intake device; 8 – flushing valves at the end of the chamber; 9 – valve for regulating the flushing pipe
Source: compiled by the author

The principle of operation of the sedimentation tank is based on the creation of artificially favourable conditions for settling, in which sediments are moved by a circulating stream to the inlet of a round-section washing pipe under a convex wall. It was found that the curved sedimentation tank prevents the deposition of up to 20% of suspended sediments of large fractions with a size of d > 0.25 mm, in addition to sediment at the bottom. The sedimentation tanks are made of rectangular reinforced concrete and equipped with a siphon device for draining the flushing water (Lu *et al.*, 2023). A special feature is the presence of a washing gallery designed to move sediments of sand, gravel, and silt into the lower pool. The prefabricated pipes have a circular cross-section and are located inside the walls of the spillway. At the end of the lower rectangular reinforced concrete drain there is a vertical basin designed to trap sediments of sand, gravel, and silt and vertically connected to a collection pipe. Dampers are installed on the side walls of the drain for periodic cleaning of the sedimentation tank (Fig. 5).

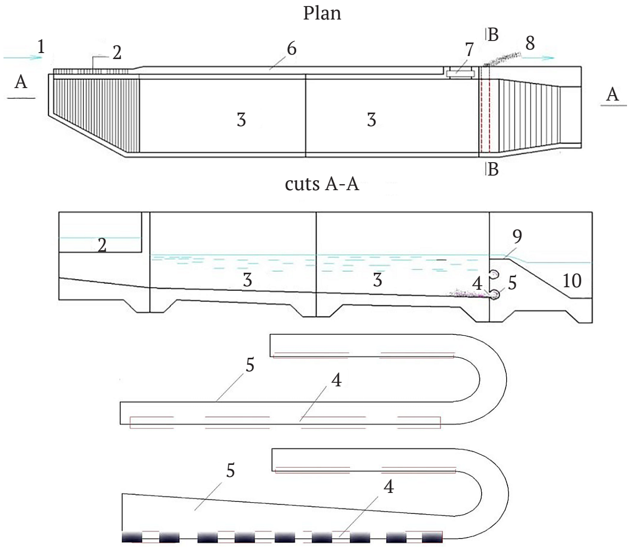

Figure 5. Sedimentation tank: plans and sections
Note: 1 – upper pool; 2 – intake device; 3 – chamber; 4 – gravel catching slots; 5 – collector; 6 – side walls; 7 – gates; 8 – lower pool; 9 – spillway walls; 10 – outlet channel
Source: compiled by the author

The new sedimentation tanks have an advantage over conventional designs by directing the sediments of sand, gravel and silt entering the reservoir into the cracks located at the bottom near the lower wall of the discharge channel. These sediments are mixed with water and transported by a high-speed flow into collecting pipes inside the spillway wall. This efficient transport mechanism easily directs the sediments of sand, gravel, and silt into the lower basin. Closures are installed on the side walls of the tank to facilitate regular cleaning. This configuration turns the sedimentation tank into a barrier that prevents deposits of sand, gravel, and silt from entering the outlet pipes of the hydroelectric power plant. This type of sedimentation tank is designed for the deposition of relatively large suspended sediment particles, usually 0.2-0.25 mm or more. The conditions of its application are similar to those mentioned earlier for sedimentation tanks using periodic flushing. These sedimentation tanks can consist of one or two chambers and be installed either as part of a water intake system or at some distance from it. Screw-flow flushing galleries initially demonstrate a reliable ability to transport sediment and have recently gained popularity for removing bottom sediments at water management facilities. The helical movement inside the gallery is created by the tangential entry of water through its cross-section. To maintain continuous circulation, water must be supplied along the entire length of the gallery, usually through a longitudinal slit inlet. The dimensions of this inlet slot are critically related to the set flow and velocity parameters inside the flushing gallery.

Usually, the height of the longitudinal slit does not facilitate the unobstructed penetration of bottom sediment into the tunnel. Therefore, it is common practice to create intermittent slits and include separate windows of sufficient height to ensure a constant distance between the continuous slit and the window. Laboratory studies of flow hydraulics in treatment rows and practical experience in sedimentation tanks have concluded that for ease of manufacture, the shape of the row should be conical, and the change in the average flow velocity in the row should correspond to the dependence set out in equation (1), which satisfies the initial condition: at x = 0, $u_{avg} = 0$, where: u_k – average longitudinal velocity in the final section of the gallery. The results of laboratory studies of the hydrodynamics of flushing galleries and the practical knowledge gained during the design and operation of sedimentation tank galleries show that the adoption of a conical shape for the gallery is beneficial for the rationalisation of production. It is recommended to adjust the change in the average flow velocity in the gallery in accordance with equation (1), which satisfies the initial condition: at x = 0, $u_{avg} = 0$, where u_k – average longitudinal velocity in the final section of the gallery. The coefficients μ were calculated using equation (2). In the course of eight experiments, the calculated values of the gap flow coefficient μ ranged from 0.609 to 0.687, with an average value of 0.648.

To ensure adequate consideration of throughput in the design of the flushing gallery, it is recommended to use the cavity flow coefficient μ = 0.64. The pressure difference between the gallery and the level of the free surface is affected by the velocity of the water as it moves through the cavity, overcoming various resistances in its path (3). These resistances include coefficients for entry (ξin), friction (ξfr), exit (ξout) and curvature (ξzak). In hydraulic principles, it is usually assumed that ξin ⩽ 0.5, ξout ≈ 1, and ξfr varies from 0.06 to 0.1. In practice, the combined value of these coefficients at the output often exceeds 1.5. According to equation (5), when the sum of the coefficients Σξ is 1.5, and assuming that the compression ratio ε is 0.8, the ratio can be derived from equation (4):

$$\varepsilon = \frac{\mu}{\varphi} = \frac{0.64}{0.8} = 0.8\,.$$

Thus, the value of ε cannot be less than 0.8. Therefore, the coefficient ε ranges from 0.8 to 1. Taking the average value according to equation 6, ε = 0.9, obtain:

$$\varphi = \frac{\mu}{\varepsilon} = \frac{0.64}{0.9} = 0.71,$$

$$\Sigma\xi = \frac{1}{\varphi^2} = \frac{1}{0.71^2} = 2.$$

The calculated value Σξ=2 is approximate. To achieve greater accuracy, an exact value of ε will be required, which cannot be determined experimentally. However, since the pressure loss due to local resistance is only a small part of the total pressure loss in the gallery, it is sufficient to use an approximate value Σξ for calculations. Therefore, the following equation (7) is used to calculate the pressure loss associated with local resistance:

$$h_{w_м} = \Sigma\xi \frac{\upsilon_n^2}{2g} = 2\frac{\upsilon_n^2}{2g}. \qquad (7)$$

A distinctive feature of continuously flushing sedimentation tanks is their ability to simultaneously deposit and remove suspended sediments, supplying purified water to consumers. These tanks maintain a constant water depth, but when the sections are disconnected for flushing, this changes the flow dynamics inside the tank, causing uneven flow conditions. As a rule, the improvement and improvement of the design of sedimentation tanks requires an integrated approach combining engineering, environmental and technical aspects. This holistic approach aims to optimise results in both hydropower and irrigation applications.

DISCUSSION

Research and improvement of the design of sedimentation tanks play an important role in the field of hydropower and irrigation, aimed at ensuring effective management of water resources and reducing negative environmental impacts. This aspect was also considered by S. Dairi *et al.* (2023), and they concluded that one of the key aspects of the research is the optimisation of the hydraulic parameters of the sedimentation tanks. This includes analysis of the water flow profile, calculations of hydraulic losses and the development of design solutions aimed at minimising pressure losses and maximising the efficiency of particle deposition. This approach allows increasing the productivity of hydropower systems and improving the efficiency of irrigation systems, ensuring reliable removal of solid particles from water and preventing clogging of equipment. N. Gemza & M. Kuśnierz (2022) noted that the development of corrosion-resistant materials and composites contributes to increasing the durability of structures and reducing the cost of their operation. In an aggressive environment, for example, with a high concentration of salts or chemically active substances in water, such materials ensure reliable operation of sedimentation tanks and minimise the need for frequent maintenance, which is consistent with the results of this study.

One of the key aspects of the study is the optimisation of the hydraulic parameters of the sedimentation tanks. This includes analysis of the water flow profile, calculations of hydraulic losses, and the development of design solutions aimed at minimising pressure losses and maximising the efficiency of particle deposition. This approach allows increasing the productivity of hydropower systems and improving the efficiency of irrigation systems. This has also been found in the study by A. Ferdowsi *et al.* (2022), where the results confirmed that effective control of the water flow in the sedimentation tanks is crucial to increase their productivity and ensure reliable operation of the entire system. Optimisation begins with an analysis of the water flow profile, which allows identifying areas of uneven distribution of velocity and pressure. With the help of modern modelling methods, accurate calculations of hydraulic losses can be carried out and turbulence zones can be determined where the efficiency of particle deposition decreases. Based on these data, design solutions are being developed to improve flow distribution and minimise pressure losses, which helps maximise particle deposition. As a result of such measures, hydropower and irrigation systems become more reliable and efficient, ensuring stable water quality and preventing clogging of equipment.

S. Yao *et al*. (2022) also found that traditional materials such as concrete and steel, although they have sufficient strength, are often susceptible to corrosion and destruction under the influence of aggressive media. The development and application of new composite materials and corrosion-resistant metals significantly increase the durability of sedimentation tanks and reduce the cost of their maintenance and repair. Modern materials have not only high chemical resistance, but also improved mechanical properties, which makes it possible to create lighter and more durable structures (Ismayilov *et al*., 2021). In conditions of high loads and variable temperatures typical for hydropower and irrigation systems, such materials ensure stable operation of sedimentation tanks. It is worth noting that the introduction of new technologies and methods into the design of sedimentation tanks requires careful testing and modelling to assess their effectiveness and reliability.

An important aspect of improving the design of sedimentation tanks is the choice and use of modern materials. The development of corrosion-resistant materials and composites helps to increase the durability of structures and reduce the cost of their operation (Serikuly *et al*., 2015). This is especially important for sedimentation tanks operated in aggressive climatic conditions and in conditions of high concentrations of salts or chemically active substances in water. This aspect has attracted the attention of many researchers, in particular, M. Amar *et al.* (2021) emphasise that traditional materials such as concrete and steel are often susceptible to corrosion and wear, especially in aggressive climatic conditions or at high concentrations of salts and chemically active substances in water. Modern composite materials and corrosion-resistant metals can significantly increase the durability and reliability of sedimentation tanks. The use of such materials not only reduces the frequency of repairs and replacements, but also reduces the cost of operation and maintenance. The use of innovative materials allows creating lighter and more durable structures that can withstand extreme operating conditions, which is especially important for hydropower and irrigation systems operating in difficult natural conditions.

W. He *et al.* (2021) concluded that the development of new composite materials and corrosion-resistant alloys opens up opportunities for the introduction of advanced technologies in the design of sedimentation tanks. Such materials have high chemical resistance, excellent mechanical properties and durability, which makes them ideal for use in conditions of high load and exposure to aggressive environments. This is especially true for regions with extreme climatic conditions, where traditional materials quickly fail. These results confirm the above study, since the introduction of modern materials into the design of sedimentation tanks is a key factor for increasing their efficiency, durability and economic feasibility, which contributes to the overall improvement of water resources management in hydropower and irrigation.

Environmental aspects also play an important role in the research and improvement of sedimentation tank designs. The development of environmentally sustainable solutions aimed at reducing energy consumption, minimising emissions and waste into the environment, contributes to improving the environmental situation and preserving water resources (Hulevskyi & Postol, 2022). N.N.C. Obiuto *et al.* (2024) investigated this phenomenon, noting that modern technologies such as process automation and the use of renewable energy sources can significantly reduce the carbon footprint of water treatment and water treatment systems. For example, using solar energy to power pumps and other sedimentation tank mechanisms can significantly reduce emissions of carbon dioxide and other greenhouse gases.

A. Ahmad *et al.* (2022) investigated that the use of sediments as fertilisers or raw materials for the production of building materials can significantly reduce the amount of waste to be disposed of. Such solutions contribute not only to reducing the load on landfills for waste disposal, but also to the reuse of resources, which corresponds to the principles of a closed-cycle economy. These data are consistent with the theses given in the previous section, demonstrating the importance of environmentally sustainable solutions in the design and operation of sedimentation tanks. Modern technologies aimed at reducing energy consumption and minimising emissions confirm their effectiveness not only in laboratory conditions, but also in practice. This is confirmed by the findings, where the introduction of such technologies has led to a significant improvement in environmental performance.

Research into new technologies, such as automation of cleaning processes and the use of innovative materials, opens up new opportunities to improve the operation of sedimentation tanks. The introduction of sensor systems and the use of nanomaterials contribute to improving the efficiency of water purification and reducing environmental impact (Kulikova, 2022). The study by L.K. Wang & M.H.S. Wang (2021) revealed that automation of cleaning processes includes the introduction of advanced sensor systems and control algorithms that allow real-time monitoring and adjustment of the parameters of the sedimentation tanks. This leads to a significant increase in the efficiency of the cleaning process, as the system automatically adapts to changing conditions, such as fluctuations in pollution levels or changes in hydraulic flow.

E.F. Latif (2022) also showed that nanomaterials have unique properties such as high adsorption capacity and resistance to aggressive chemical media, which makes them ideal for use in water purification systems. The introduction of such materials allows improving the quality of precipitation of solid particles and significantly reducing water pollution. Moreover, the use of nanomaterials can reduce the environmental impact, as they require fewer reagents for processing and are able to operate in a wider range of conditions. Comparing the data obtained during the research, the use of innovative technologies and materials is a key factor in improving the design and operation of sedimentation tanks, which contributes to more sustainable and efficient management of water resources.

Thus, the research and improvement of the design of sedimentation tanks for hydropower and irrigation are aimed at improving their efficiency, sustainability, and environmental safety. This contributes to improving water resource management and ensuring the sustainable development of agricultural and energy systems.

CONCLUSIONS

As a result of the conducted research, significant progress has been achieved in the development and optimisation of sedimentation tank designs for hydropower and irrigation systems. The main conclusions can be formulated as follows. Optimisation of the shape and size of the sedimentation tanks helped to develop and test various geometric configurations, which ensured maximum water retention time and contributed to the most efficient deposition of solid particles. This significantly increased the performance of the sedimentation tanks and reduced operating costs.

Research and testing of various materials, including modern composite materials and corrosion-resistan alloys, allowed selecting the most suitable options for use in sedimentation tank designs. This provided increased durability and resistance to aggressive operating conditions, which increased the service life and reliability of the sedimentation tanks. Hydraulic analysis helped to optimise the flow profile in the sedimentation tanks, minimise pressure losses, and maximise the efficiency of particle deposition. Solutions have been developed that consider both stationary and dynamic operating conditions of the system, which has improved the overall efficiency of hydropower and irrigation systems.

The introduction of environmentally sustainable technologies has significantly reduced energy and water consumption, and minimised emissions and waste. These measures have reduced the environmental footprint and ensured more sustainable and safe use of water resources. The active introduction of advanced technologies, such as automation of cleaning processes, the use of nanomaterials and sensor systems, has significantly increased the control and efficiency of the sedimentation tanks. These technologies have provided more precise process control and improved the quality of water treatment.

Comprehensive testing and modelling of new designs of sedimentation tanks, carried out both in laboratory conditions and in practice, allowed the authors to pre-evaluate their effectiveness and reliability. The results of these tests confirmed the high degree of readiness of the developed solutions for practical implementation, minimising risks and ensuring reliable operation of the systems. In general, the conducted research has made a significant contribution to the improvement of sedimentation tank designs, which ultimately led to an increase in the efficiency, reliability, and environmental sustainability of hydropower and irrigation systems.

The main limitation of the study is the need for further testing of the developed designs of sedimentation tanks in various climatic and operational conditions to confirm their versatility and adaptability. It is necessary to further investigate the effect of various chemical compositions of precipitating particles on the efficiency of sedimentation tanks and develop methods for their optimal removal.

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CONFLICT OF INTEREST

None.

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Дослідження та вдосконалення конструкції відстійника для гідроенергетики та іригації

Анотація. Роботу присвячено дослідженню та оптимізації конструкції відстійника для підвищення ефективності осадження твердих частинок у гідроенергетичних та іригаційних системах. У даному дослідженні були використані як експериментальні, так і чисельні методи для аналізу та оптимізації конструкції відстійників з метою підвищення їхньої ефективності в системах гідроенергетики та іригації. У дослідженні розглянуто та проаналізовано різні типи відстійників за конструктивними схемами, режимом потоку, динамікою осадження і методами промивання осаду, а також вивчено рекомендовані поліпшення для гідроенергетики та іригації різних типів відстійників. Під час дослідження було виявлено, що оптимізація геометрії відстійника істотно підвищує ефективність осадження твердих частинок. Експериментальні дані засвідчили, що зміна кута нахилу стінок і збільшення площі дна відстійника сприяють поліпшенню осадження мулу і піску. Також було встановлено, що використання спеціальних турбулентних вставок знижує час осадження частинок і покращує якість очищеної води. Моделювання гідравлічних потоків підтвердило, що більш рівномірний розподіл швидкостей у відстійнику зменшує турбулентність і сприяє більш ефективному осадженню частинок. Впровадження автоматизованих систем контролю та управління процесом очищення дало змогу підвищити надійність і стабільність роботи відстійника. У результаті було доведено, що запропоновані конструктивні та технологічні зміни можуть значно підвищити ефективність і довговічність відстійників у гідроенергетиці та іригації. Дослідження надає практичні рекомендації щодо поліпшення конструкції відстійників, що сприяє підвищенню їхньої ефективності та надійності в гідроенергетиці та іригації, тим самим покращуючи управління водними ресурсами

Ключові слова: зважені частинки; елементи інфраструктури; насоси та фільтри; осадження; гідравлічні потоки