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IMPROVING THE DESIGN OF WATER INTAKE STRUCTURES FOR COMBINED WATER ABSTRACTION USING VEE-WIRE® JOHNSON SCREENS FILTERS

Kovalenko R. Yu. *– PhD in Technical Sciences, Associate Professor*
at the Department of Hydraulic Construction, Water and Electrical Engineering
Kherson State Agrarian and Economic University
ORCID ID: 0000-0002-6185-577X
Scopus-Author ID: 57202211226

The article addresses the urgent issue of enhancing the reliability and energy efficiency of water intake facilities under conditions of variable hydrological regimes and increasing anthropogenic pressure on water resources. The study examines the formation of water quality in open water bodies and the under-channel horizon, identifying key factors that lead to increased concentrations of suspended solids, biogenic components, and organic impurities. The shortcomings of traditional intake structures–prone to silting, clogging, and seasonal water-level fluctuations–are highlighted, as these factors destabilize water treatment systems and require the application of costly purification technologies.

Special attention is given to next-generation infiltration–filtration systems that enable combined abstraction of surface and under-channel waters, while simultaneously providing natural pre-treatment. The article analyzes global experience with high-precision Vee-Wire® Johnson Screens, which are characterized by low hydraulic resistance, resistance to mechanical and biological fouling, high slot accuracy, and long maintenance-free operation. The prospects for integrating such filters into radial drainage systems, as well as into bank and riverbed intakes, are outlined.

The study presents the results of an experimental investigation of a model water intake facility equipped with a radial drainage system and Vee-Wire® filters. Hydraulic calculations of total discharge, filtration velocities, head losses, and pre-filter zone resistance were performed, taking into account the filtration characteristics of alluvial sediments. It is established that the use of Vee-Wire® filters significantly reduces local hydraulic resistance, ensures uniform water abstraction even under partial clogging conditions, and increases the operational lifespan of the drainage system compared to traditional perforated or mesh elements.

The findings confirm the feasibility of implementing innovative filtration technologies in the design of combined water intake structures, enabling improved reliability, energy efficiency, and stability of water supply systems. The proposed technical solutions may be integrated into the engineering practice of water management facilities and contribute to improving raw water quality at the initial intake stage, reducing the load on treatment plants, and ensuring the long-term sustainability of water supply systems in Ukraine.

Key words: *water intake structures, radial drains, infiltration systems, Vee-Wire® filters, Johnson Screens, filtration processes, hydraulic calculations, riverbed flow, clogging, water supply.*

Коваленко Р. Ю. Удосконалення конструкцій водозабірних споруд для комбінованого забору води з використанням фільтрів Vee-Wire® Johnson Screens

У статті висвітлено актуальну проблему підвищення надійності та енергоефективності водозабірних споруд в умовах змінного гідрологічного режиму та зростання техногенного навантаження на водні ресурси. Розглянуто особливості формування якості води у відкритих водоймах і підрусловому горизонті, визначено чинники зростання вмісту завислих речовин, біогенних компонентів та органічних домішок. Показано недоліки традиційних водоприймальних конструкцій, схильних до замулення, кольматації та сезонних коливань рівнів води, що знижує стабільність роботи систем водопідготовки та підвищує потребу в дорогих технологіях очищення.

Особливу увагу приділено інфільтраційно-фільтрувальним системам нового покоління, які забезпечують комбінований забір поверхневих і підруслових вод та виконують функції природного попереднього очищення. Проаналізовано світовий досвід застосування спірально-навитих фільтрів Vee-Wire® Johnson Screens, що вирізняються низьким гідравлічним опором, стійкістю до обростання, високою точністю каліброваної щілини та тривалим ресурсом. Окреслено перспективи їх інтеграції у променеві дрени та берегові й руслові водозабори.

Наведено результати експериментального дослідження моделі водозабірної споруди з променевою дренуючою системою та фільтрами Vee-Wire®, виконано гідравлічні розрахунки дебіту, швидкостей фільтрації, втрат напору та опору прифільтраційної зони. Встановлено, що застосування фільтрів Vee-Wire® істотно знижує локальні опори, підтримує рівномірний забір води за умов часткового замулення та збільшує ресурс дренажної системи порівняно з традиційними фільтрами.

Отримані результати підтверджують перспективність впровадження інноваційних фільтраційних технологій у комбіновані водозабірні споруди, що підвищує надійність, енергоефективність і стабільність водопостачання. Запропоновані рішення можуть бути застосовані у проєктуванні водогосподарських комплексів та сприяти покращенню якості води на етапі первинного відбору, зменшенню навантаження на очисні споруди та забезпеченню довгострокової стійкості систем водопостачання України.

Ключові слова: *водозабірні споруди, променеві дрени, інфільтраційні системи, Vee-Wire®, Johnson Screens, фільтрація, гідравлічні розрахунки, підруслoвий потік, кольматація, водопостачання.*

Introduction. Ensuring reliable and energy-efficient water intake is a key task of modern water supply systems [1]. The deterioration of the hydrological state of river basins in Ukraine, seasonal fluctuations in water levels and quality, as well as increasing anthropogenic pressure, necessitate the implementation of structural solutions capable of operating under complex natural conditions [2]. Traditional water-intake structures used on rivers and canals often exhibit a number of drawbacks, including clogging of intake screens, increased concentrations of suspended solids, clogging (colmatation) of filtration elements, and significant operational costs [3].

One of the promising directions for improving the efficiency of water-intake systems is the use of infiltration-filtration technologies that combine water abstraction with its initial natural purification [4]. International practice shows a growing interest in high-precision filtration elements such as Vee-Wire® Johnson Screens, which are characterized by low hydraulic resistance, high resistance to colmatation, and long service life [5]. Integrating such filters into the design of water-intake structures creates opportunities for combined abstraction of surface and riverbed-filtrated water, ensuring stable water supply even during seasonal drying or freezing of the riverbed [6].

In the context of developing modern water-management systems in Ukraine, research and improvement of water-intake structures capable of operating under variable hydrogeological conditions remain highly relevant. Particular attention is given to designs with radial drains and infiltration elements, which help reduce the load on water treatment facilities and improve water quality at the initial stage of its abstraction [7].

Analysis of Recent Research and Publications. The issue of improving the efficiency of water abstraction from natural surface and groundwater sources has been actively investigated by both domestic and international researchers. Studies devoted to the classification of water-intake structures examine their performance under unstable hydrological conditions of rivers, freezing and drying of channels, as well as the influence of suspended solids and biological contaminants on the operation of intake systems [1]. Considerable attention is given to infiltration and infiltration-filtration technologies, which provide preliminary water purification through natural filtration in alluvial riverbed deposits [4, 6].

The literature emphasizes that infiltration and bank filtration systems can compensate for adverse effects of hydrological fluctuations and flood events, as they rely on the natural filtering capacity of alluvial sediments. Their efficiency depends on grain-size distribution, filtration coefficient, and the presence of fine silt particles that may cause colmatation of the near-filter zone. Research in the field of artificial groundwater recharge indicates that long-term operation of infiltration systems may reduce the filtration capacity of sediments, thereby decreasing the productivity of water-intake structures [8, 9].

Experimental studies demonstrate that bank filtration and riverbed infiltration systems significantly reduce concentrations of suspended solids and phytoplankton while lowering the risk of colmatation in traditional intake devices [4, 6]. Scientific publications present various designs of filtering water intakes – radial drains, riverbed galleries, trench-type and island-type water intakes – as well as recommendations for selecting filtration media according to local hydrogeological conditions [4]. Several studies highlight that the application of radial drains ensures uniform flow distribution and enhances the operational efficiency of water-intake structures [7].

A separate direction of development concerns the improvement of filtration elements. High-precision spiral-wound filters of the Vee-Wire® type are increasingly used in global practice, demonstrating low hydraulic resistance, high resistance to colmatation, and long operational lifespan [5, 10]. Compared with traditional slotted or perforated filters, Vee-Wire® elements provide highly accurate slot geometry and an optimized hydraulic profile. Research conducted by manufacturers and independent scientific groups confirms their effectiveness in well, bank-filtration, and riverbed-filtration systems [5, 10].

International experience also demonstrates the high efficiency of Vee-Wire® screens in complex geological environments – gravel-pebble deposits, water-saturated sediments with elevated turbidity, and zones with high hydraulic gradients. Particularly valuable are studies on their use in radial collector systems, where long drains require high mechanical strength and stable slot geometry [7].

Despite numerous publications, the integration of Vee-Wire® elements into combined water-intake systems with radial drains remains insufficiently explored. Hydraulics of such systems under varying hydrogeological conditions, as well as their techno-economic performance compared with traditional bank and river-intake structures, require further investigation. These gaps determine the relevance of ongoing research and the need for scientific justification of combined infiltration-filtration water-intake designs.

The aim of the study is to evaluate the effectiveness of innovative Vee-Wire® Johnson Screens filtration elements as part of combined-type water intake structures and to determine their impact on the reliability and hydraulic performance of infiltration–filtration systems. An additional objective is to substantiate design solutions that enhance the productivity and operational stability of water intake facilities under varying hydrological conditions.

Materials and Methods. The materials of the study included the structural elements of the infiltration–filtration water-intake system, in particular spiral-wound Vee-Wire® Johnson Screens filters [5, 10], the intake well, and the radial drain of the experimental installation. The filters are manufactured from trapezoidal profile wire with a calibrated slot of 0.2 mm, ensuring selective retention of fine particles and minimal hydraulic resistance [5]. To evaluate their performance, the geometry of the filters, the conditions of contact with alluvial sediments, and the degree of clogging of the near-filter zone were also considered.

The study used the technical specifications of the pumping unit, the passport data of the ultrasonic flowmeter, as well as natural hydrological parameters of the riverbed section composed of alluvial deposits: filtration coefficient, grain-size distribution, thickness of the aquifer, and the velocity of the sub-channel flow. Data on soil hydraulic conductivity were obtained by sampling sediment cores and determining permeability in the laboratory under constant and variable head conditions [11].

The methodological basis consisted of analytical, comparative, and hydraulic methods. The analytical method was applied to process technical parameters of the filtration elements and assess the relationship between their structural characteristics and the hydraulic regime of the system. The comparative method made it possible to evaluate the performance of Vee-Wire® filters against traditional perforated and mesh elements using criteria such as hydraulic resistance, resistance to colmatation, uniformity of water inflow, and service life.

Hydraulic calculations were carried out in accordance with current standards and methodological guidelines [11, 12] and included the determination of:

- filtration velocities in the near-filter zone and within the drain;
- head losses at the filter entrance;
- total discharge of the radial drain;
- variation of the hydraulic gradient under conditions of partial clogging;
- influence of filter geometry on the distribution of velocities along the drain.

The calculations were performed under steady and quasi-steady conditions for different water levels in the river, which made it possible to assess system stability during seasonal fluctuations.

Water sampling during experimental tests was carried out in accordance with the requirements of the standard [13]. Samples were taken at several points: inside the intake well, at the outlet of the drain, and in the river channel upstream of the installation. The analyses included turbidity, suspended solids concentration, oxidizability, content of mechanical impurities, and corrosion-active components.

The experimental installation operated in a pressurized mode with the possibility of smooth flow-rate regulation by the pumping unit. The ultrasonic flowmeter provided non-contact measurement with an accuracy of ±1%. The technological scheme of the installation is shown in Fig. 1.

Additional monitoring of system performance was carried out using water-level sensors, pressure gauges, and visual inspection of clogging in the near-filter zone. The experiment included several stages: system start-up under clean conditions; simulation of increased turbidity; assessment of discharge reduction under partial clogging; comparison of Vee-Wire® filters with a traditional filter analogue. This comprehensive methodology enabled an in-depth evaluation of the infiltration–filtration system and the identification of patterns in its performance under varying hydrogeological conditions.

Results of the Study. One of the promising directions for improving the efficiency of water-intake facilities is the use of infiltration–filtration systems that combine the extraction of surface and sub-channel water [4]. Under natural conditions, alluvial deposits of riverbed sections act as a natural filter, reducing the concentrations of suspended solids, biogenic substances, and organic inclusions [6]. This significantly decreases the load on treatment facilities and enhances the operational stability of water-supply systems during periods of seasonal siltation or riverbed freezing.

In traditional designs of sub-channel water-intake structures, perforated or mesh filtering elements are used; however, they often lack sufficient slot precision, exhibit high hydraulic resistance, and are prone to clogging with fine mechanical particles.

Vee-Wire® Johnson Screens filters provide a calibrated 0.2-mm slot and reduced clogging risk [5]. The V-shaped wire profile creates a self-cleaning effect, while the rigid structure ensures resistance to deformation within the soil environment.

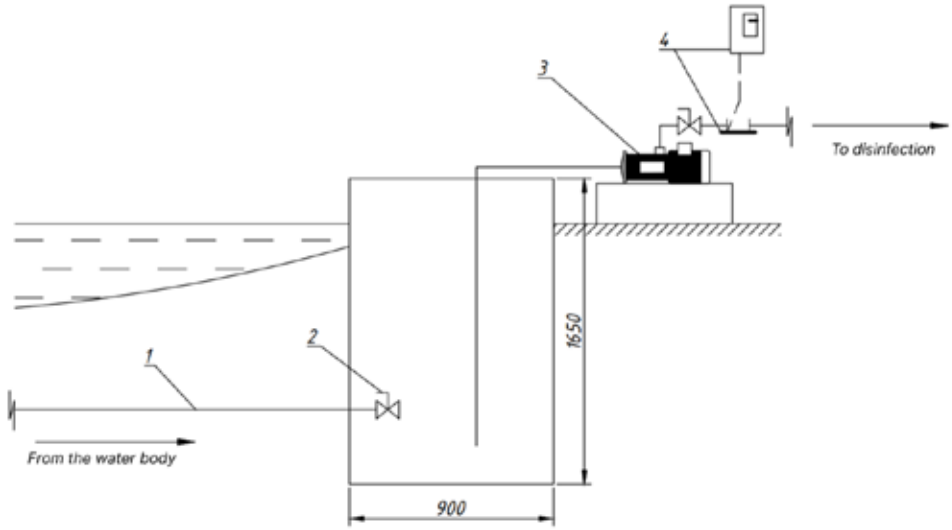

Fig. 1. Technological scheme of the experimental water-intake installation: 1 – ultrasonic flowmeter; 2 – shut-off valve; 3 – pumping unit; 4 – intake well

The experimental installation developed for evaluating the performance of the combined water-intake system includes an intake well, a radial drain equipped with Vee-Wire® filters, a pumping unit, and measuring equipment. The design of the radial drain is consistent with modern principles of radial collector systems [7]. The intake well serves as a reservoir for water accumulation, damping of flow pulsations, and stabilization of pumping-unit operation.

Hydraulic calculations of the system's performance were carried out considering the filtration properties of alluvial deposits, the length and diameter of the drain, filter parameters, and the pump head characteristics [11]. The results demonstrated that the use of Vee-Wire® filters reduces local hydraulic resistance within the radial drain and ensures stable discharge values across a wide range of river water levels.

Further analysis showed that the inflow velocity along the entire length of the radial drain remains uniform, confirming the effectiveness of the calibrated slot and optimized geometry of the Vee-Wire® filter [5]. Comparison with a traditional analogue filter revealed that the specific discharge increased by 12–18%, which corresponds with contemporary findings in the field of water-intake structure improvement [7, 11].

Experimental data showed that the infiltration–filtration water-intake system equipped with Vee-Wire® filters reduces the concentration of suspended solids in the extracted water by 35–60%, confirming the efficiency of the natural filtration layer of alluvial deposits [4]. Increased turbidity of river water did not cause substantial discharge reduction: the flow rate decreased by no more than 5–7%, whereas traditional filters typically exhibit significantly greater losses [3].

The combined water-intake approach compensates for seasonal variations in river discharge and water levels, ensuring stable and energy-efficient operation of the water-supply system [1]. During low-water periods, the proportion of the infiltration component increased, maintaining productivity without additional load on the pumping unit. During flood periods, the surface-water component increased, yet due to the filtration properties of alluvial sediments, water quality remained more stable [6].

The results obtained confirm the feasibility of using Johnson Screens filters in radial drains and infiltration water-intake systems. These findings form the basis for further research aimed at optimizing drain length, selecting the appropriate filter diameter, and predicting colmatation processes during long-term system operation [5].

Conclusions. The conducted study confirmed the effectiveness of innovative Vee-Wire® Johnson Screens filtration elements in the design of combined water-intake structures. The use of profiled spiral-wound filters ensures a reduction in hydraulic resistance, improved uniformity of water extraction, and a significant decrease in the risk of colmatation in the near-filter zone compared to traditional filtering elements.

Experimental evaluation of the test installation demonstrated that a radial drain equipped with Vee-Wire® filters is capable of maintaining stable discharge rates and providing high-quality filtration even under conditions of alluvial sediment clogging. The combined intake of surface and sub-channel water enhances the reliability of water supply during periods of seasonal hydrological fluctuations, reduces the load on treatment facilities, and improves water quality at the initial stage of extraction.

The results obtained indicate the feasibility of implementing Vee-Wire® Johnson Screens in the design of infiltration and infiltration-filtration water-intake structures. The use of such filtration systems increases the energy efficiency, operational reliability, and durability of water-intake facilities operating in diverse hydrogeological conditions of Ukraine.

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