

## Assessing the efficiency of water reuse at Khorostkiv sugar factory

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**Abstract.** The Ukrainian sugar industry applies large amounts of water for production needs but is not sufficiently focused on the optimal use of water resources. The aim of this study was to evaluate the effectiveness of reusing condensate and cooling water to optimise water resource use and reduce the volume of water intake from surface water bodies. Based on the data from official reports of the Khorostkiv Sugar Factory in 2017-2024 years an analysis of the water use changes after improvement of the circulating-water system was conducted. In particular, a statistical method was used to calculate changes in water intake and the water recycling coefficient, as well as to conduct an environmental and economic assessment. It has been found that the total water intake since 2019 has decreased by approximately 8.1-21.3 times (2019-2024) compared to the value calculated for 2017. It has been shown that the water use process has been optimised through the functioning of a modern recycling system with the effective use of condensate and cooling water. It was emphasised that such optimisation led to the termination of discharge of heat-exchange wastewater into surface water bodies. It was estimated that the economic effect of reusing cooling and condensate water only for a rental fee led to a reduction in the company's annual financial costs of approximately 350-400 thousand hryvnias. The practice of reusing cooling water and condensate water can be recommended for use at other Ukrainian sugar enterprises

**Keywords:** hydric resources; sugar industry; effluents; water optimisation; condensate; cooling water

### INTRODUCTION

The sugar industry is a water-intensive sectors of the economy, using large amounts of water resources for various stages of production and producing significant volumes of wastewater of various categories. The latter can be successfully reused, but it is necessary to treat such water and control its quality. Category I water – condensate and heat exchange water – does not undergo significant changes in chemical parameters but

is characterised by higher temperatures and requires cooling for further return to the water cycle.

Previous studies have shown that the discharge of untreated or inadequately treated wastewater causes changes aquatic ecosystems. For example, researchers M.A. Rahim & M.G. Mostafa (2021) published the results of a two-year monitoring of samples of wastewater, surface and underground water. A significant decrease

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in dissolved oxygen content and a steady increase in BOD<sub>5</sub> levels in water were detected, which led to a deterioration in the existence of aquatic organisms in the studied water bodies. In particular, according to the survey data, there was a decrease in the numbers of fish in surface water bodies in the range of 50-95%. Elevated concentrations of metals (Fe<sup>3+</sup>, Mn<sup>2+</sup> and Pb<sup>2+</sup>) were found in soil samples, which may lead to bioaccumulation of these elements in plants. Even the discharge of treated wastewater requires monitoring of the content of various components in it. Given the need to treat wastewater from sugar factories, a large number of review and experimental studies have been devoted to this issue. The latest achievements in the use of physical, chemical, and biological methods to eliminate or minimise pollutants generated at various stages of sugar production were presented, in particular, in K.B. Shivaram *et al.* (2024). It was noted that, along with traditional physical, chemical, and biological methods (adsorption, chemical and electrocoagulation, anaerobic and/or aerobic biological treatment, membrane treatment, etc.), the implementation of new promising methods was being investigated.

J. Malinauskaite *et al.* (2024) described the practices for treated wastewaters of different origin and the possibilities for its further application. The researcher indicated that primary treatment is provided for wastewater after washing sugar beets. Effective sedimentation of such loaded wastewater is achieved by their mechanical treatment in settling tanks. The possibility of using wastewater from the sugar industry, obtained after primary treatment, for irrigation of agricultural land and partial overcoming of water shortages in European countries was investigated. J. Hristov *et al.* (2021) noted that sugar beets are agricultural crops that are mainly grown using irrigated farming methods. Accordingly, the use of re-treated water is considered an economically appropriate approach. The most difficult to treat is wastewater from the direct processing of raw materials, as it is saturated with large amounts of organic and inorganic substances. The use of membrane technologies allows for more thorough treatment of wastewater, which can then be reused. The possibility of using such water for irrigation, as well as for reuse in a closed-loop water supply system, was being considered by A.W. Nouhou Moussa *et al.* (2023). The reuse of treated water to overcome water shortages in various sectors of the economy is regulated by various legislative initiatives, including the European Union (2019). These documents are primarily aimed at addressing issues related to the optimisation of water resources, which are rapidly declining due to global climatic changes. The study presented by European Environmental Agency (2018)

demonstrated increasing water shortage in European countries. K. Hryhorieva (2024) analysed the wastewater treatment process in terms of its benefits to society and noted the steps taken in some countries to regulate the reuse of treated wastewater. It should be mentioned that this publication focuses on the use of such water for irrigation as one of the alternatives to overcoming water shortages due to climate change.

It should be noted that Ukrainian researchers mainly assessed the pollution of wastewater from sugar factories and studied methods for its treatment. Thus, N.O. Bubliko (2021) presented a classification of wastewater from the sugar industry into three categories and analysed the use of wastewater of category III for biomethane production. It was noted that wastewater of this category is the most difficult to treat. Methane fermentation was proposed as a highly effective method of treating highly concentrated wastewater, during which large volumes of biogas are produced that can be used as a renewable energy source. The author analysed in detail the use of inactivated anaerobic activated sludge to start fermentation processes and noted that this reduces the start-up time of the methane tank. In this publication, the researcher did not detail the possibilities of using category I and II wastewater, although the researchers emphasised the need to optimise the use of water resources, which are used in huge volumes in the operation of a sugar factory. A. Rohovyk *et al.* (2021) provided a detailed diagram of the formation of different wastewater categories at sugar enterprises and noted that, in terms of percentage distribution, the largest amount of wastewater fell into the categories II and I. The main focus of this study was on improving wastewater treatment systems at sugar production facilities using developed control systems, where the key component was the use of a chemical oxygen consumption monitor.

O. Salavor *et al.* (2024) emphasised that the volumes of water required for the operation of a sugar factory are enormous, and the wastewater produced varies in terms of treatment and reuse. In their work, the authors focused on the treatment of category II wastewaters, which are identified as transporter and washing waters. The scientists developed a method for purifying these waters using basic aluminium salts. It was noted that this physicochemical purification method improved the quality of category II wastewater, which can be reused in recirculation systems. It was noted that this improvement led to a reduction in water consumption and a positive impact on the hydrosphere as a whole, but the optimisation of water resource use through category I wastewater was not considered. The aim of the study was to determine the economic and environmental

benefits of improving water use processes at sugar industry enterprises in Ukraine, in particular using the example of a specific sugar factory, given the lack of data on the reuse of Category I wastewater and analysis of the effectiveness of such measures.

## MATERIALS AND METHODS

The object of the study was the water use at the Khorostkiv sugar factory. This enterprise is a structural subdivision of the Radehiv Sugar LLC which is part of the

German group of companies Pfeifer & Langen. It was the first factory among the group's six to introduce a modernised water use system. For production needs, water intake is mainly carried out from surface water bodies (the Taina River in the Dniester basin, located in Ternopil Region). Small amounts of water for utility purposes and certain technological processes are taken from the artesian well located in the territory of the sugar factory. The approximate distribution of water supply during the operation of the sugar factory is shown in Table 1.

**Table 1.** Approximate water use structure at the Khorostkiv sugar factory

Category	Type of source	Share of the total, %*
Production needs (transportation and washing of sugar beet, diffusion, filtration, evaporation, etc.)	Water intake from Taina River + underground water	~93.7
Service-utility needs (drinking water, showers, dining room, laboratories)	Underground water	~6.3

**Note:** \* as a percentage of the total volume of water intake from natural sources

**Source:** compiled by the authors based on data from official reports provided by the Khorostkiv Sugar Factory

Information on the total volume of water used during the year, obtained from various water intake sources (groundwater and surface water), was taken from the official reports prepared by of the Khorostkiv Sugar Factory. The sources were compiled in accordance with the Procedure for State Accounting of Water Use (Order of the Ministry of Ecology and Natural Resources of Ukraine No. 78, 2015), and the data was entered into official forms entitled Form No. ZTP-vodgosp (annual) (State accounting of water use, 2015). These reports are submitted annually to the territorial divisions of the State Water Agency and are stored as internal documents (not available for public access) at the enterprise responsible for completing the forms. In addition, data on annual water limits from both water sources were also provided. Data from the explanatory note on maximum permissible discharges for the Khorostkiv sugar factory was used, as well as materials from the technical and economic substantiation of the reconstruction of the vacuum condenser unit at this enterprise. All the information provided corresponds to the actual state of water management activities at the Khorostkiv sugar factory during 2017-2024 and was confirmed by documentary evidence.

The main equipment involved in returning used water to the water management system includes two cooling ponds located on the sugar factory territory, a cooling tower, and a vacuum condenser unit. The latter was reconstructed, in particular, new efficient water distributors were installed on condensers, automatic water supply and non-condensed gas bypass lines were introduced in condensers. These measures made it possible to increase the efficiency of heat exchange in condensers,

reduce the amount of circulating water for condensers, and adjust the temperature of circulating water to the temperature of vapor. All calculations were performed using appropriate formulas and statistical method of comparative analysis – the method of relative values (coefficients), which is implemented in the Microsoft Office package using the Microsoft Excel spreadsheet program. The statistical method used is a classic example of relative dynamics, in which the ratio of two water intake values is calculated: the base value (maximum, 2017) and the current value (after modernisation of the recycling system with efficient use of condensate and cooling water). Thus, the comparative coefficient of water use by year ( $k_{comp}$ ) was calculated using the formula:

$$k_{comp} = V_{max} / V_{year}, \quad (1)$$

where  $k_{comp}$  – comparative coefficient of water use by year;  $V_{max}$  – volume of maximal water intake;  $V_{year}$  – volume of water intake in appropriate year.

The economic effect was assessed by calculating the rental pay for each production season. The formula for calculating the rental pay ( $RP$ ) for special water use is as follows:

$$RP = V_o \cdot V_f \cdot R \cdot k_c, \quad (2)$$

where  $V_f$  – actual volume of water used,  $m^3$ ;  $V_o$  – volume of water for which the rate is set ( $100 m^3$ );  $R$  – rent rate for  $V_o$ ;  $k_c$  – correlation coefficient (Law of Ukraine No. 3817-IX, 2024).

The water use balance of a sugar industry enterprise can be represented in the following general form:

$$V_{pr} + V_s = V_{swb} + V_{aw} + V_{sb} + V_r - V_l, \quad (3)$$

where  $V_{pr}$  – the volume of water for production use;  $V_s$  – the volume of water for service-utility use;  $V_{swb}$  – the volume of water intake from a surface water body;  $V_{aw}$  – the volume of water intake from an underground source (artesian well);  $V_{sb}$  – the volume of water released from sugar beet;  $V_r$  – the volume of water that was reused;  $V_l$  – the volume of water losses (evaporation, leakage, etc.).

## RESULTS

Water use at the Khorostkiv sugar factory can be divided into several main categories: production (technological needs for water directly involved in the sugar production process), utility purposes (drinking water, sanitary and hygiene needs of the personnel), cooling needs (feeding there cycling cooling water system), losses (water that leaves the cycle due to evaporation or leaks), and reuse (water that circulates and is reused). Until 2018, water supply to the Khorostkiv sugar factory had been carried out using a classic open system with partial reuse. The pumping station was intaking huge volumes of water from the Taina River. Various stages of the technological process led to the formation of wastewater of varying composition, for which the enterprise has implemented a separate discharge system. The treatment and further management of wastewater is determined by the technological process that produced such water. Water circulating through the heat exchange equipment of sugar factories (evaporator condensers, diffusion juice coolers, heat exchangers of thermal power plants, etc) was characterised by an actual change in temperature range, since the water does not come into direct contact with products or reagents but rather removes excess heat from heated equipment. In terms of chemical composition, it is close to the original

river water, and some of its parameters only slightly exceed natural background and sanitary standards.

However, discharging water heated by heat exchangers into water bodies leads to a decrease in the concentration of dissolved oxygen, which affects the state of aquatic ecosystems. In previous years (until 2018), heated water from the Khorostkiv sugar factory was discharged into the Taina River, and industrial wastewater of categories II and III was diverted to filtration fields. Thus, most of the water, after passing through the technological process, did not return to the enterprise. Small volumes of water after cooling down the equipment could be directed to washing sugar beets. To meet the constant demand for water, the pumps operated almost 24 hours a day throughout the season (120 days a year). The pumping equipment was designed for huge volumes: the installed units delivered hundreds of cubic meters per hour. Approximately, prior to modernisation, the total water intake was ~0.5-1.5million m<sup>3</sup> per season. In 2018, the modernisation of the water supply system began: two artificial reservoirs connected by a pipeline were built in the territory of the factory. The construction of the ponds took five months, and the reservoirs were put into operation at the end of 2018. Heated water from heat exchangers flows into the artificial reservoirs, where it cools down, and then is pumped back to the heat exchange equipment. This cycle repeats without any external discharges. Due to evaporation, some of the water is lost, so fresh water from the river was constantly added to the ponds to maintain the level. Replenishment was carried out within the established limit, which is approximately 314.4 thousand m<sup>3</sup>/year from the Taina River and 16.9 thousand m<sup>3</sup>/year from the well (special water use permit No. Ek-000000037). The actual replenishment was significantly lower than these limits (Table 2).

**Table 2.** The volumes of water intake at the Khorostkiv sugar factory in 2017-2024

Year	Water intake from Taina River, thousand m <sup>3</sup> /year	Water intake from underground source, thousand m <sup>3</sup> /year	Total for the year, thousand m <sup>3</sup> /year	$k_{comp}$
2017	~1,200	~17	~1,217	-
2018	~850	~16	~866	1.4
2019	64.7	13.3	78.0	15.2
2020	41.5	14.0	55.5	21.3
2021	63.1	14.7	77.8	15.2
2022	129.5	17.1	146.6	8.1
2023	99.2	15.3	114.5	10.3
2024	55.5	7.6	63.1	18.8

**Note:**  $k_{comp}$  – comparative coefficient of water use by year

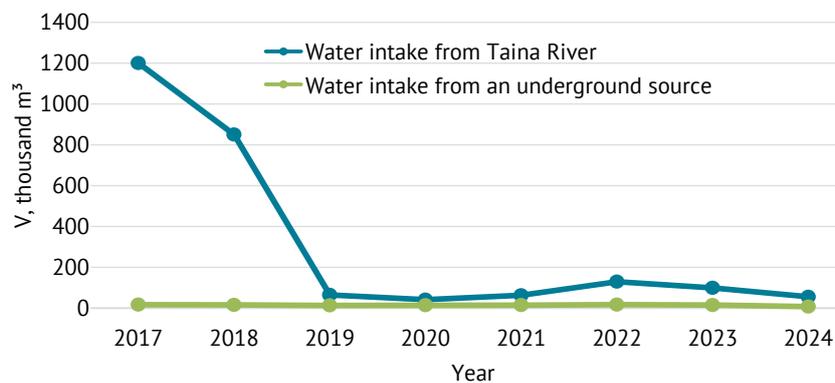
**Source:** compiled by the authors based on data from official reports provided by the Khorostkiv Sugar Factory

Due to the lower need for fresh water supply, it was possible to modernise the pumping equipment, which

was converted to a flexible operating mode: modern pumps of lower capacity are automatically switched on

as needed, maintaining the water level in the ponds. Previously, the pumps operated for about 2,880 hours per season (120 days of 24 hours), but after modernisation they operated for only a part of this time (for example, in 2020, the total operating time of the pumps was approximately 600 hours, which is ~79% less than previously), the rest of the time the system operated on recirculation. Water intake volume has also decreased: from several hundreds of m<sup>3</sup>/hour to several dozens of m<sup>3</sup>/hour, since fresh water intake is only necessary to compensate for losses due to evaporation and certain technological deviations. In addition to the closed cooling system, the factory has implemented the use of water for other needs as well. For example, purified condensate water from the evaporation station is used to prepare diffusion juice; warm water can be partially used for washing beets, etc. All these activities minimise the need for fresh water. The main water losses from the system are evaporation (from the surface of

cooling ponds and cooling towers of thermal power plants) and moisture removed with products and waste (pressed pulp, molasses, water, etc.). These losses are compensated by the fresh water from both water sources. As a result, the balance is closed: the intake water either circulates repeatedly or eventually returns to the environment in the form of vapor or recycled waste, but is not discharged as wastewater into the river. Due to the implementation of a closed cycle of the use of water heated by heat exchangers, there is no discharge into the river, and it only occurs in exceptional situations when there is a need for discharge of excessive water from the ponds due to heavy rains or when cleaning the reservoirs, but this was not observed in 2022-2024. Figure 1 shows the dynamics of surface and groundwater intake in 2017-2024, which indicates a sharp decline in water intake since 2018, following the introduction of reuse of a significant portion of water resources that were previously used for the needs of the enterprise.



**Figure 1.** Dynamics of surface and underground water intake by the Khorostkiv Sugar Factory in the period 2015-2024  
**Source:** compiled by the authors based on data from official reports provided by the Khorostkiv Sugar Factory

Fluctuations in water consumption during the period 2019-2024 were attributed to changes in the volume of sugar beet processing. Thus, in the period from 2020 to 2021, minimal water intake was observed due to a decrease in the raw material base and the Covid-19 pandemic. Starting in 2022, increased production volumes led to higher water consumption, but the level of water intake remained significantly lower than in 2018. These results were achieved at the Khorostkiv sugar factory due to the installation of the circulating water supply systems. It should be noted that certain volumes of water involved in technological processing are covered by the large moisture content in the raw material itself. Sugar beets are an extremely moist material: approximately 75-80% of their mass consists of water (Muir, 2022). That is, each ton of root crops contains an average of 0.7-0.8 m<sup>3</sup> of water, which is released during processing. At the factory, this internal moisture plays a

significant role in the water balance, actually becoming the source of technological water.

The remaining water is distributed between products and waste: it remains in molasses, pulp and condensates. According to regulatory data of the Khorostkiv sugar factory, processing 1,000 tonnes of beet per day yields approximately 700 m<sup>3</sup> of internal water. This is approximately 84,000 m<sup>3</sup> of moisture entering the system together with raw materials during the 120 days of the production season. In fact, the internal water of beets replaces the fresh water that would otherwise have to be taken from the river. The high moisture content of the raw material has a positive effect on the water balance. The factory can maintain an almost continuous water cycle with minimal external replenishment. The water that evaporates from the diffusion juice is condensed and reused – it is used to extract sugar again or to heat the diffusion device. The moisture from the beets also

reduces the need for fresh water for washing: the roots arrive at the wash already wet, and part of the water after washing is returned to the fields along with the soil residues. As a result, almost all of the internal water of the sugar beets that evaporates is further condensed and returned to the closed cycle, or is pressed out of the solid waste. The remaining water needs were covered by

the internal moisture of the raw materials and recycled water. Due to the modernisation, the annual volume of saved water was very significant, which indicates a positive environmental and economic effect. In monetary terms, the saving was also noticeable. As an example, the rental pay of water was calculated and the financial savings were evaluated considering this value (Table 3).

**Table 3.** Calculation of rent payments at the Khorostkiv sugar factory

Year	Rent rate, in hryvnias	Number of volume units (100 m <sup>3</sup> )	Rental pay in hryvnias	Cost savings compared to 2017 in hryvnias
2017	35.66	12,000	427,920.0	0
2018	38.47	8,500	326,995.0	100,925.0
2019	39.47	647	25,537.09	402,382.9
2020	39.9	415	16,558.5	411,361.5
2021	39.9	631	25,176.9	402,743.1
2022	39.9	1,295	51,670.5	376,249.5
2023	39.9	992	39,580.8	388,339.2
2024	39.9	555	22,144.5	405,775.5
Cost savings from 2018 to 2024				2,487,777.7

**Source:** compiled by the authors based on data from official reports provided by the Khorostkiv Sugar Factory and values of rent rate from 2017 to 2024 based on Law of Ukraine No. 3817-IX (2024)

In addition, less water intake means less pumping and potential treatment costs, which gives an additional financial benefit. After transition to a recirculating system, the operating time of the pumps was reduced several times, and their capacity was reduced. At the same time, reducing the load on the equipment extends its service life and reduces repair costs. Saving electricity on pumps has an impact on reducing CO<sub>2</sub> emissions at the power plant. The saved ~300 thousand kWh is equivalent to ~150 tons of CO<sub>2</sub> (at a rate of ~0.5 kg CO<sub>2</sub> per 1 kWh), which were not emitted as a greenhouse gas into the atmosphere, and that has a positive impact on the company's contribution to the implementation of decarbonisation measures and is consistent with the practice of achieving a reduction in greenhouse gas emissions produced during wastewater treatment (European Commission, 2022). This contribution can be enhanced by equipping a biogas plant for waste, which would allow the waste recycling (pulp, molasses) to produce biogas for the enterprise's own boiler house, as well as to return part of the water. The operation of an anaerobic reactor leads to the production of biogas and the accumulation of fermentation products. The latter can be separated into a solid fraction, which is subsequently used as organic fertiliser, and a liquid fraction, which after minimal purification can be returned for the enterprise's needs. Thus, the factory will receive an additional source of energy and further close its water cycle reducing the moisture content of the waste.

Optimising the use of water resources at the Khorostkiv sugar factory not only resulted in significant cost

saving for the enterprise, but also had a positive effect on the environment. The absence of discharges into the Taina River since 2022 has eliminated problems that previously arose when warm heat-exchange waters entered the river, which led to a decrease in dissolved oxygen content, siltation of the riverbed, etc. Currently, these impacts are absent – the river actually receives only natural runoff from the territory (rain and drainage water), but not industrial discharges. The absence of large intakes and discharges not only improved the quality of the river water, but also led to the stabilisation of the river's hydrological regime. Previously, the intake of 1-2 million m<sup>3</sup> of water per season could significantly reduce the level of the Taina River during low water in the middle of summer. Now, the intake of ≤0.15 million m<sup>3</sup> has almost no effect on the river level, that is, the Taina River retains more natural inflow, which is important for fish, especially in the summer low-water period. In addition, eliminating heat stress helps to preserve fish populations, as previously, excessively warm water sharply reduced the concentration of dissolved oxygen and could cause fish mortality.

Having achieved significant success in water saving, the enterprise is developing a number of promising measures that can increase the efficiency of water use and the environmental friendliness of production. These include the expansion of cooling ponds or the construction of an additional pool, provided that production capacity is increased, or to meet the needs in case of abnormally warm seasons with higher evaporation. This will increase cooling capacity and provide a

water reserve. It is also advisable to carry out dredging and sealing of the existing reservoirs (for example, lining the bottom with a geomembrane to reduce filtration into the soil) and equipping them with aeration fountains for better cooling. Modernisation of the pumping equipment (installation of frequency drives) allows for more precise regulation of the fresh water supply and a reduction in energy consumption. Other measures include the use of rainwater, as such water currently flows from roofing and asphalt surfaces into the river or onto filtration fields. A promising solution is to arrange a rainwater collection system by installing gutters on roofs, drainage of yard runoff, and using a storage tank. The collected rainwater after settling can be used for non-potable purposes, for example, for washing beets, moistening pulp, and watering green spaces in the territory. This will reduce water intake from the river and lead to efficient use of natural precipitation.

The study found a significant reduction in water intake from surface and underground sources following the modernisation of the water supply system in 2018 and the introduction of a closed-loop water cycle at the Khorostkiv Sugar Factory. The creation of two artificial reservoirs has enabled a closed loop for cooling water from heat exchangers. The water is cooled in ponds and returned to production, eliminating the need for constant fresh water intake and stopping the discharge of heat exchange wastewater into the Taina River. Purified condensate water from the evaporation station is used for the preparation of diffusion juice and other technological needs. In addition, the internal moisture of sugar beets plays a significant role, condensing and returning to a closed cycle, minimising the need for external replenishment. The reduction in water intake, in particular savings on water rental fees and reduced pump operating time, had resulted in significant financial savings. Modernisation and investment in improving the water recirculation system not only proved to be economically beneficial for the enterprise, but also had a direct social and environmental benefits for the entire local community. On the one hand, a significant reduction in water abstraction ensured a more stable water level in the Taina River, and the absence of direct discharges contributed to the preservation of the stability of the aquatic ecosystem. On the other hand, it is worth noting the positive social effect, as reduced water consumption means that more water remains for other consumers – the local water supply company, farmers and local residents.

## DISCUSSION

The problem of rational use of water resources, considering the water shortage caused by climate change,

according to S. Snizhko *et al.* (2024), remains relevant for various sectors of the Ukrainian economy, in particular the sugar industry. The authors analysed how other factors, such as war, occupation of part of Ukraine's territory, and the destruction of the Kakhovka a reservoir, affected the supply of water for different needs, including water resources used for irrigation of agricultural land. The destruction of a significant number of water infrastructure facilities not only created a threatening environmental situation but also affected food security in Ukraine and worldwide. L. Parkhomenko (2024) pointed out in her work that the Ukrainian sugar industry has undergone significant changes during 2019-2022 years due to a reduction in the area under sugar beet cultivation, a decrease in the number of sugar factories, and a drop in production volumes. The author analysed that in 2023-2024 years, despite the challenges caused by military actions in the territory of Ukraine, it has been possible to significantly increase the rate of raw sugar production and increase the volume of its exports to the world market. In 2023-2024, Radekhiv Sugar LLC was the largest sugar producer in Ukraine, so modernising production, including optimising water use, is an important condition for the company's successful development.

Sh.V. Wadodkar *et al.* (2020) noted that one of the water management problems of the sugar industry is the consumption of large volumes of water and the generation of large amounts of wastewater. Statistical data presented in the United Nations Environment Programme (2023) indicated that a significant proportion of untreated wastewater (more than 50%) in the world in was returned to water bodies, while only approximately 11% was recycled. It should be noted that for European countries this value was even lower (Interreg North-West Europe, 2020). Modern world practices are oriented towards such water resource management at sugar industry enterprises, in which the optimal use of water taken from external sources involves maximum purification of the generated wastewater with its subsequent return to production processes. Researchers S. Fida *et al.* (2025) noted that the implementation of new promising methods is being investigated. This paper analysed the possibilities of optimising the use of water resources at the Khorostiv sugar factory (Ukraine). As a result of the analysis, it was found that the main volume of water consumed at this enterprise is for production needs – more than 80%, therefore, optimisation measures were focused on the development of measures for such water. The efficiency of returning cooling heat-exchange water to production processes, reducing the consumption of fresh water during water intake were assessed, and approaches to the possibility of implementing a closed water use cycle were considered.

Similar practices are already being used at sugar factories around the world. For example, the article by P. Ranjan *et al.* (2023) analysed water reuse at sugar factories in India, where the raw material for processing was sugarcane. The possibilities of using heat exchange and condensate water, which is necessary to ensure the operation of sugar refinery equipment, were analysed. It was noted that water reuse has made it possible to reduce the need for water from underground sources and partially cover the need for irrigation water for watering nearby fields. Similar technologies were described in the article by G.K. Deshmukh & N.P. Sonaje (2017), where the specific case of a sugar factory emphasised the importance of using condensate water, which was generated as a result of cooling the turbine cooling towers. In particular, the volumes required to ensure both direct sugar production and for auxiliary operations, which include water for boiler operation, washing, and cooling of equipment, were analysed. The use of condensate water and its recirculation were described in detail, and the results of a water balance study were presented. The results of the latter indicated the elimination of the need for constant replenishment of fresh water for certain technological operations. The modernisation measures carried out at the Khorostkiv sugar factory, including the commissioning of settling ponds and the operation of a cooling tower and vacuum condenser unit, have resulted in the reduction in water intake since 2018. Since 2019, significant volumes of water have been used in a virtually closed cycle, due to which only a minor replenishment of fresh water from an external source was required to compensate for losses. As a result, in 2019, for the first time, there were no direct discharges of wastewater into the river.

The transition to a virtually continuous water supply closed-loop recirculation system can be achieved using different systems. Thus, W.H. Balla *et al.* (2017) pointed out the advantages of using an open recirculating cooling system compared to one-time cooling. Such cooling can be achieved using cooling towers, spray ponds, and evaporative condensers. Two cooling ponds have been put into operation at the Khorostkiv sugar factory, the main function of which is to provide recirculation cooling of technological equipment. The ponds act as open cooling towers (coolers), into which water heated during the production process is directed, where it is cooled and fed back into the technological cycle. Since the cooling water is not contaminated with production impurities, after cooling it can be re-used for technological needs without additional purification. It should be noted that in cooling ponds, a process of natural self-purification of water occurs: mechanical impurities settle to the bottom, organic pollutants are

partially oxidised biologically. Thus, even with long-term circulation, the water quality remains acceptable for reuse. Cooling ponds have become a key element of the water supply cycle, which has made it possible to abandon the constant discharge of coolant into the river and thereby improve its ecological state. Due to the commissioning of two artificial cooling ponds, it was possible to loop the heat exchange flows, so the pumping station for intaking river water began to be used much less frequently – only to replenish losses.

Saving water resources is achieved by various methods, including the use of water condensed from raw materials in technological processes. Thus, this practice of using moisture from sugarcane was presented in the article by P. Ranjan *et al.* (2023). At the Khorostkiv sugar factory, where sugar beet was processed and which had a higher moisture content than sugar cane, the water released from the raw material was recovered and fully returned to the system through condensates and recycles. Due to this, the need for external water was significantly lower than it would be without taking into account the moisture of the sugar beets. The technological process of processing raw materials can be optimised, in terms of reducing evaporation by modernising the evaporation station. Evaporation of juices is one of the key stages where significant flows of water vapor circulate. A promising direction is the introduction of thermocompression vapor technology (TVR/MVR), when the secondary vapor from the evaporators is compressed by a compressor and reused to heat the next body of the evaporation unit. This reduces the need for fresh vapor and, accordingly, reduces the load on the condensers and the cooling system. Thus, reducing the volume of vapor will lead to reduced heat input into the water and, accordingly, less evaporation from the ponds. This technology requires investment in vapor compressors, but in the long term it will have an impact on saving water and energy resources. Therefore, at the Khorostkiv sugar factory it is necessary to take into account such recommendations as maintaining the proper condition of the existing facilities, in particular, regular cleaning of cooling ponds from excess sediment, monitoring the tightness of dams, and calibrating measuring instruments. It is important to implement new measures that help save the water usage, in particular, to establish a full-fledged online monitoring system for water supply and drainage, which will allow real-time monitoring of all parameters (in particular, water consumption at each site, water levels in tanks, pressure, temperature, quality indicators). Based on this data, automatic control of pumps and valves will be carried out, and the operation modes of the equipment will be optimised. In this way, the supply of make-up water from the river will be

switched on in a timely manner, based on the weather forecast. Automation eliminates the influence of the subjective human factor regarding possible overruns or negligence, and also promptly signals about leaks (sudden drop in water level), the need to clean filters, etc.

Improving water use efficiency will also be facilitated by conducting a water balance analysis using the water pinch-analysis technique to identify even minor points of loss. This technique is widely tested at foreign enterprises of food industry. For example, K. Nemati-Amirkolaii *et al.* (2019) analysed the features of applying water pinch analysis as a technology aimed at reducing water consumption and water discharge in the food industry, particularly in the sugar industry. It has been shown that the key point of the methodology is the identification of water flows that can be reused in other processes with lower quality requirements. The authors noted that this method should be more actively implemented to save water resources in industries that are water-intensive and energy-consuming. J.R. Vidal *et al.* (2024) noted that the use of pinch-analysis at sugar factories not only contributed to water conservation, but also had a positive impact on the energy efficiency of such enterprises. The authors analysed that specialised software made it possible to control energy flows in sugar production, which reduced cold and hot water consumption and optimised the operation of heat exchange systems. The energy efficiency of sugar factories can be ensured through biogas obtained from raw material residues and highly concentrated wastewater. The article presented by M. Dębowski & M. Zieliński (2022) described the successful implementation of such practices around the world. The authors analysed modern technologies for managing wastewater with a high concentration of organic pollutants, including an analysis of their potential use for biogas production as an alternative energy source. The proposed innovative method using fluidised active filling increased the efficiency of the anaerobic bioreactor in treating sugar industry wastewater and improved the quality of the biogas obtained due to its high methane concentration.

It is also worth emphasizing that the introduction of a water recycling system allows the enterprise to avoid penalties from regulatory authorities. Previously, fines and claims for damages could be imposed for exceeding limits or polluting a water body. Now there are no such risks, which saves money and reduces the negative impact on the environment. Rational water use has increased the environmental reputation of the enterprise, which indirectly contributes to investment attractiveness and trust of partners. In addition, improving environmental performance can provide preferences when obtaining environmental certifications, it also increases

the chances of receiving international and Ukrainian grants. The Khorostkiv sugar factory is an example of the successful implementation of certain practices for the maximum use of water resources and the successful reduction of their intake from external sources. An analysis of the volume of intake/used water at this enterprise indicates the effectiveness of the reuse of water involved in production cycles, this also indicates the prospects for the implementation of recycled water use, which can be applied at other Ukrainian sugar factories. Effective water resource management and organisation of a closed water-use cycle is a promising direction that the Ukrainian sugar industry should focus on in order to be resource-saving, energy-efficient, and environmentally friendly, that is, to function and develop in accordance with the principles of sustainable development.

## CONCLUSIONS

The analysis of data obtained during the 2017-2024 period included information on the volumes of water intake from surface and underground sources, which was carried out at the Khorostkiv sugar factory; also highlighted was the impact of measures to optimise the use of water resources on the ratio of reused and freshly collected water. It was shown that the Khorostkiv sugar factory is currently one of the leaders in the sugar industry in the field of economical water use. The plant has implemented a circulating-water system that allows for transferring heat-exchange heated wastewater into constructed cooling ponds with subsequent return of this water to production processes. Optimising the use of water resources, in addition to implementing a closed cooling cycle, also included recycling and reusing condensates. In fact, each liter of water was used by the factory dozens of times before it was lost to evaporation. The important role of using the internal moisture of beets is shown – practically all water from the raw material was involved in the process and is recycled many times. Such an optimal result from the point of view of resource conservation made it possible to reduce water intake from approximately 1 million m<sup>3</sup> per year to 0.1 million m<sup>3</sup>, to eliminate direct discharges into the Taina River and significantly reduce anthropogenic pressure on the environment. As a result, savings of hundreds of thousands of hryvnias per year were obtained, the risks of environmental fines were eliminated, the company's image was improved, and the impact on the surface water body was minimised, which had a positive social effect for the objects of the territorial community that also use the river's water resources. The implementation of long-term investment projects, such as the construction of a biogas plant, the improvement of evaporation technologies, and the construction

of local treatment systems will contribute to improving water resources management and ensure long-term environmental safety and economic profitability of production. Focusing on a sustainable development strategy and implementing new technologies will allow the Khorostkiv sugar factory to reach a new level of environmental efficiency, approaching the concept of “zero fresh water use” due to a fully closed water use cycle.

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## Оцінювання ефективності повторного використання води на Хоростківському цукровому заводі

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**Анотація.** Українська цукропереробна промисловість використовує великі обсяги води для виробничих потреб, але не приділяє достатньої уваги оптимальному використанню водних ресурсів. Метою даного дослідження було оцінити ефективність повторного використання конденсату та охолоджувальної води для оптимізації використання водних ресурсів та зменшення обсягів водозабору з поверхневих водойм. На основі даних офіційних звітів Хоростківського цукрового заводу за 2017-2024 роки було проведено аналіз змін у використанні води після вдосконалення системи циркуляції води. Зокрема, було використано статистичний метод для розрахунку змін у водозаборі та коефіцієнті рециркуляції води, а також для проведення екологічної та економічної оцінки. Встановлено, що загальний обсяг водозабору з 2019 року зменшився приблизно в 8,1-21,3 раза (2019-2024 роки) порівняно з показником, розрахованим для 2017 року. Доведено, що процес водокористування було оптимізовано завдяки функціонуванню сучасної системи рециркуляції з ефективним використанням конденсату та охолоджувальної води. Було підкреслено, що така оптимізація призвела до припинення скидання теплообмінних стічних вод у поверхневі водойми. За підрахунками, економічний ефект від повторного використання охолоджувальної та конденсатної води лише за орендну плату призвів до скорочення річних фінансових витрат підприємства приблизно на 350-400 тисяч гривень. Практику повторного використання охолоджувальної та конденсатної води можна рекомендувати для застосування на інших цукрових підприємствах України

**Ключові слова:** водні ресурси; цукровий завод; стічні води; оптимізація використання води; конденсат; охолоджувальна вода