

When it comes to sustainable water infrastructure development, the investment cost is not the most important factor

Life-cycle cost-based arsenic removal

Reducing the arsenic content of drinking water remains a water quality challenge in many regions today. However, the solution is not merely about meeting regulatory limits: operability, cost-effectiveness and long-term sustainability are at least as important. The regenerable adsorbent-based arsenic removal project at the Cociuba Mare (Romania) waterworks is a good example of how the right technological choice not only ensures safe drinking water quality but also reduces waste generation, supports circular operations and offers a more favourable solution in terms of life-cycle costs. The project also validates the engineering approach that one should strive not for the lowest capital cost, but for the most favourable solution over the entire life cycle.

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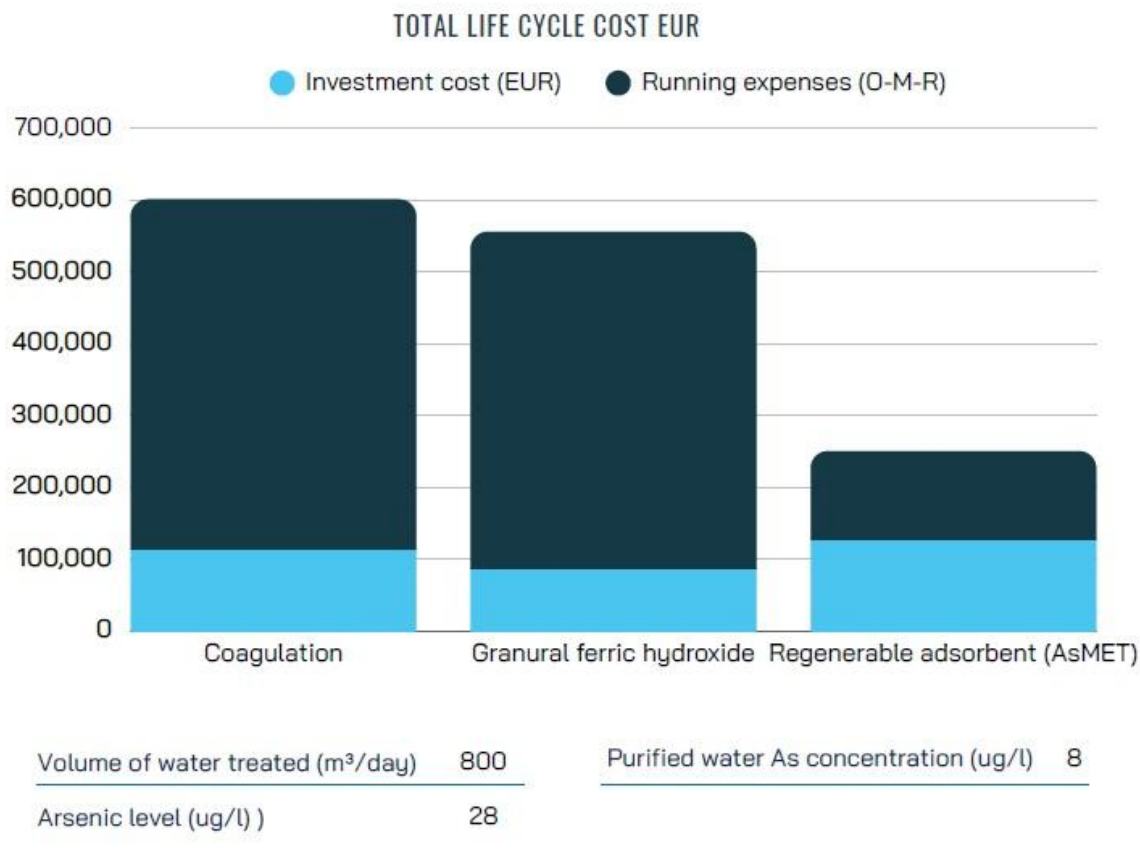
Why is arsenic removal still relevant today?

Reducing the arsenic content of drinking water remains a water quality challenge in many regions today. However, the solution is not

merely about meeting regulatory limits: operability, cost-effectiveness and long-term sustainability are at least as important. The regenerable adsorbent-based arsenic removal project at the Cociuba Mare waterworks (Romania, Bihor County) is a good example of how the right technological choice not only ensures safe drinking water quality but also reduces waste generation, supports circular economy principles, and offers a more favourable solution in terms of life-cycle costs. The project also validates the engineering principle that the most favourable solution should be selected not based on the capital cost, but because of the total life-cycle cost.

In most cases, the arsenic content of drinking water is of natural, geological origin, but human activity can also increase its concentration. European Union and national regulations stipulate a limit of 10 µg/l for the arsenic content of drinking water intended for human consumption; consistently meeting this limit remains a significant technological challenge for many water sources even today. Drinking water quality improvement programmes over the past two decades have significantly reduced the number of settlements affected by arsenic; however, the unfavourable geochemical conditions of the Carpathian Basin have not changed. In many regions, continuous operation, monitoring, maintenance and periodic technological upgrades are still required to maintain a safe drinking water supply.

Arsenic removal is therefore no longer merely a matter of meeting regulatory limits. It is at least as important that the chosen technology can be operated reliably in the long term, and that it is cost-effective and sustainable.



A comparison of arsenic removal technologies based on total life-cycle costs, over a 30-year period

When selecting a technology, it is not sufficient to examine total arsenic concentration alone. The chemical form of the arsenic is also of crucial importance. In groundwater, arsenic may be present in both the As(III) and As(V) forms, and the ratio between them fundamentally influences the water treatment technology that can be applied. As(V) can generally be removed effectively using adsorption or coagulation processes, whilst As(III) is much more difficult to precipitate within a neutral pH range and therefore often requires pre-oxidation. For the same total arsenic concentration, the As(III)/As(V) ratio significantly influences the efficiency of the technology, the utilisation of the adsorbent, the regeneration cycles, the operating costs and, ultimately, the sustainability of the system.

The challenge, therefore, is not merely to meet the 10 µg/l limit, but to maintain compliance with it in the long term and reliably, whilst

ensuring that arsenic removal is achieved with the lowest possible energy, chemical and waste management requirements. This is particularly important in the case of waterworks in small settlements, where, due to limited operational capacity, technologies that are simple to operate and sustainable in terms of both life-cycle costs and a circular economy are of paramount importance.

Technological options for arsenic removal
Technologies applicable to the removal of arsenic from drinking water can be classified into three main groups:

- precipitation and coagulation processes (iron and aluminium

coagulation, iron–manganese oxidation, lime softening);

- adsorption technologies (activated aluminium oxide, iron oxide-based adsorbents, ion exchange, etc.);
- membrane processes (membrane filtration, electrodialysis).

The selection of the appropriate technology is determined not only by the arsenic concentration, but also by a combined assessment of its chemical form, the water's pH, and its iron, manganese, phosphate, silicate and organic matter content, as well as the operating conditions, the treatment of by-products and the total life-cycle cost.

In small-town waterworks, arsenic removal is a particularly complex engineering challenge. Capital and operating costs are spread across a smaller volume of water and a smaller consumer base, whilst operational staff, laboratory facilities and technical reserves are also more limited. For this reason, it is particularly important to select a technology that simultaneously ensures reliable water quality, low operating costs and long-term sustainability.

Regenerable adsorbent technology

Among arsenic removal technologies, the regenerable adsorbent-based solution stands out due to its long-term operational and economic benefits. In contrast to conventional, chemical-intensive processes, specially developed filter resins ensure stable water quality, low operating costs and sustainable operation. The technology can be integrated into existing water treatment lines and removes arsenic as the water flows through. Its cost-effectiveness is underpinned by the long service life of the adsorbent and low-cost chemical regeneration. As a result, operating costs can be significantly reduced.

Unlike single-use adsorbents, there is no need to regularly purchase new media or dispose of the spent filter material as hazardous waste.

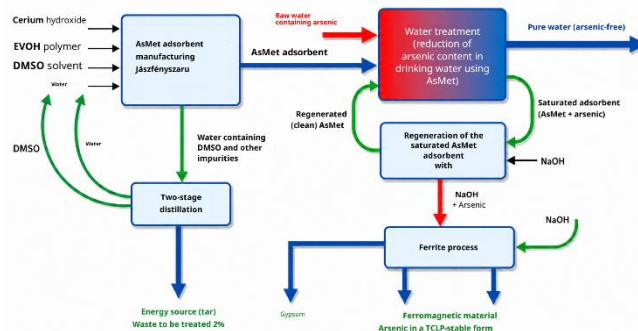
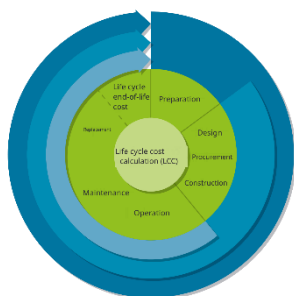
The regenerable technology thus reduces both waste generation and operating costs, whilst offering better economic and environmental performance than processes requiring large quantities of chemicals.

The mechanism of arsenic adsorption

Arsenic adsorption takes place via the formation of internal spherical complexes (ligand exchange) on the surface of cerium hydroxide. The most important advantage of this is that the adsorbent is capable of directly adsorbing not only pentavalent As(V) but also trivalent As(III), without the need for prior oxidation. This is particularly important because a significant proportion of the arsenic in groundwater occurs in the form of As(III), which conventional technologies are generally only able to remove after pre-oxidation. In contrast, the regenerable adsorbent is capable of consistently ensuring arsenic concentrations below 10 µg/l even in cases where processes based on oxidation and iron chelation have not proved sufficiently effective.

Why isn't the cheapest technology the best?

When comparing arsenic removal technologies, the capital cost alone is misleading. A water treatment plant is built to last not just a few years, but several decades; therefore, in addition to the capital investment, the costs of operation, maintenance, chemical and energy consumption, media replacement, waste management and operating staff must also be taken into account. The most technically and economically favourable solution can therefore be determined on the basis of the total life-cycle cost. This is particularly important in the case of water utility developments funded by EU grants. The grant typically finances the capital expenditure, but the operating costs are borne in the long term by the service provider and, ultimately, by consumers. Therefore, decisions based solely on the capital cost may result in significant additional costs later on.



AsMET regenerable adsorbent: production and distribution of arsenic-removing products from an economic perspective

In the case of arsenic removal, this risk is particularly acute. The role of the technology is not merely to reduce the arsenic content of the treated water to below the 10 µg/l limit, but to ensure this on a sustained basis, even in the face of fluctuations in raw water quality, As(III)/As(V) ratios, bed depletion, regeneration cycles and operating conditions. A solution that appears cheap may prove costly in the long term if it requires frequent bed replacement, produces large quantities of arsenic-containing waste, involves significant chemical consumption, or demands operational interventions that are difficult to ensure at a smaller waterworks.

The selection of a technology that is sustainable in the long term is supported by dynamic cost analysis (DCC) and life-cycle cost analysis (LCC). Both methods take into account not only the capital cost but also the expenditure incurred throughout the entire operational period. Life-cycle cost analysis evaluates all significant cost elements, from construction through operation and maintenance right up to replacement or decommissioning. This enables the selection of technical solutions that are both cost-effective and sustainable in the long term.

Arsenic removal using regenerable adsorbents is precisely in this context that it becomes a viable alternative from both an engineering and economic perspective. Simply selecting the cheapest technology is not an adequate approach. The correct objective is to select the solution that is most favourable overall, has the

lowest cost on a life-cycle basis, and is technically sustainable.

This is particularly important for waterworks in small settlements in the region affected by arsenic, where unit costs are sensitive, operational capacities are limited, and waste management tasks can represent a disproportionate burden. The question ‘Are we rich enough to buy cheaply?’ is not a rhetorical device in this context, but a direct engineering and economic warning: a poorly prepared decision, optimised for the initial investment cost, can embed high operating costs and sustainability risks into the water supply system for decades.

Arsenic removal at the Cociuba Mare Waterworks

The raw water to be treated at the Cociuba Mare Waterworks comes from an existing deep borehole located on the works’ premises. The plant’s nominal capacity is 792 m³/day, which corresponds to a net output of 741.5 m³/day. The nominal raw water flow rate is 36 m³/h; the plant is designed for continuous operation for 22 hours a day, utilising a process line comprising parallel tanks. The quality of the raw water, based on the components that are critical from a technical perspective, is summarised in Table 2. The iron and manganese content is already below the relevant limit values in the raw water; therefore, their removal is not specified as a separate process objective. With regard to these components, the treatment line primarily functions as a safety barrier. The actual target

parameters for water treatment are arsenic and ammonium.



The design challenge and objective

The design objective was to reduce arsenic from 28 µg/l to below 10 µg/l and ammonium from 2.29 mg/l to below 0.5 mg/l, whilst maintaining stable water quality even under varying load conditions, with low chemical and energy consumption, and minimal waste generation.

Arsenic removal at this site is a more complex task than usual. Iron-based processes (coagulation and iron oxyhydroxide adsorption) bind arsenic in the As(V) form to an iron surface; however, to achieve this, trivalent arsenic must first be oxidised to pentavalent arsenic.

The raw water's own iron content is too low to ensure effective arsenic binding, and preliminary experiments involving the addition of external iron did not result in compliance with the limit value: the arsenite resisted oxidation, meaning that the arsenic level in the treated water could not be reliably reduced below 20 µg/l. Conventional arsenic removal

Waterworks, Coicuba Mare

In the case of arsenic, two factors were decisive when designing the technology. On the one hand, the arsenic concentration in the raw water varies over time; consequently, the system must respond reliably not to a constant, easily predictable load, but to fluctuating raw water quality. Secondly, arsenic is predominantly present in the trivalent arsenite (As(III)) form. This is particularly unfavourable from a technological perspective, as As(III) is more difficult to remove under standard drinking water treatment conditions, and its effective removal requires pre-oxidation in many processes.

based on oxidation and iron chelation was therefore not a viable option for this water – this realisation led to the development of a solution based on a regenerable adsorbent.

Implementation

The waterworks was built around the existing well and the existing 200 m³ reservoir, supplemented by a new 300 m³ treated water reservoir. The design of the parallel tanks was determined by the manufacturer's (standard) dimensions: the nominal capacity is covered by parallel sand filters, activated carbon filters and arsenic removal tanks. The arsenic adsorber tanks are made of corrosion-resistant PA-6 polyamide; the plant's other pressure vessels are made of epoxy-coated steel.

A key operational feature is that, within the waterworks premises, the adsorbent bed is only backwashed; regeneration to restore capacity takes place off-site. This means that no regenerating chemicals need to be stored or handled on site, and no arsenic-contaminated wastewater is generated on site.

COMPARISON OF THE TWO TECHNOLOGY'S OPERATING COSTS

Operating costs of the regenerable adsorbent (AsMET) based arsenic removal technology as a percentage of arsenic removal coagulation technology costs (Tiszagyenda project, Q_{max}. 16 m³/h, avg. 80 µg/l arsenic concentration)



Comparison of operating costs associated with arsenic removal

If iron content is also a challenge

A chemical-dosing coagulation system had been installed at Tiszagyenda, Hungary; however, the arsenic concentration in the treated water did not consistently remain below the prescribed limit of 10 µg/l. This was mostly due to the high concentration of As(III) in the raw water. To address this, it became necessary to add further oxidising agents and iron during the treatment process, which led to complaints and problems among consumers.

Arsenic removal is carried out using four filter tanks. After the sand filter, the water is divided into two parallel branches. In each branch, the water is passed through two filter tanks connected in series; after recombining, it is reconnected to the existing system's pipework, which directs the water to the existing activated carbon filter. The system contains a total of 800 litres of filter media across four beds. Each bed has a capacity of 200 litres. The beds are arranged in two parallel branches, with two beds in each branch. The system is capable of performing its arsenic removal function at any flow rate between 1 and 16 m³/h.

Currently, as part of a lease arrangement, a regenerable adsorbent-based arsenic removal (AsMET) unit has been installed in Tiszagyenda, integrated into the existing technology, which is designed to reduce the erratic and high (average 80 µg/l) arsenic content of the water

production well. With the use of this system, the iron ions previously dosed under the current (old) technology are no longer required. Thanks to the long-term contract, regeneration is guaranteed, ensuring predictable costs and operational reliability for the parties involved.

Operational experience shows that the introduction of this technology has led to a significant reduction in costs and workload. Chemical costs have fallen by around 52 per cent, maintenance tasks by approximately 20 per cent, and laboratory costs by 50–80 per cent, whilst ancillary tasks arising from exceedances of limit values, rejected samples, additional backwashing and the handling of consumer complaints have virtually ceased. Overall, the operational costs associated with arsenic removal have fallen by more than 50 per cent, whilst cost savings of around 25 per cent have been realised across the entire waterworks.

Summary

A life-cycle cost approach is not a new concept for the Hungarian engineering profession. As early as 2014, in connection with the new European Public Procurement Directive, the professional view emerged that, in the evaluation of public procurement tenders, greater weight should be given to life-cycle costs, quality and long-term sustainability

rather than the exclusive focus on the lowest price. The question raised by Etelka Barsiné Pataky, then President of the Hungarian Chamber of Engineers – “Is the reign of the lowest price over?” – clearly signalled this shift in professional thinking. In line with this same idea, we demonstrated as early as 2014 that the DCC methodology could serve as a suitable tool for laying the practical foundations of the new approach to public procurement and investment preparation. The Cociuba Mare arsenic remediation project, carried out under a main contract by KEVIÉP, is therefore not an isolated technological case, but rather confirms the professional direction represented jointly by the Hungarian Chamber of Engineers, the Hungarian Water and Wastewater Technology Association (MaSzeSz) and other professional bodies: rather than the lowest capital cost, the solution sought must be the one that is most favourable overall, operable in the long term and sustainable.

IN THE TEXT BOX IN THE ORIGINAL ARTICLE INTERNATIONAL WATERS

Arsenic removal using regenerable adsorbents can be successfully applied not only in Central Europe but also in other regions.

In Vietnam in 2024, during a six-month trial of a pilot plant with a daily capacity of 10 m³, the system achieved an arsenic removal efficiency of over 90 per cent, and the arsenic content of the treated water remained consistently below the 10 µg/l limit. Based on these results, preparations have also begun for two systems with significantly higher capacity.

In the Indian state of Uttar Pradesh, an AsMET system with a daily capacity of 6 m³ was commissioned in 2024. In addition to installing the equipment, the project also included training for local operators. The technology’s arsenic removal efficiency exceeded 80 per cent, confirming its suitability for use in smaller rural water supply systems as well.