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MINISTRY OF AGRICULTURE AND FORESTRY
GENERAL DIRECTORATE OF WATER MANAGEMENT

Water Efficiency Campaign

Water Efficiency Guidance Document Series

MANUFACTURE OF CENTRAL HEATING RADIATORS (EXCLUDING ELECTRIC RADIATORS) AND HOT WATER BOILERS

NACE CODE: 25.21

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Abbreviations

WTP	Wastewater Treatment Plant
EU	European Union
SSM	Suspended Solid Matter
BREF	Best Available Techniques Reference Document
EMS	Environmental Management System
MoEUCC	Republic of Turkey Ministry of Environment, Urbanization and Climate Change
NOM	Natural Organic Matter
EMAS	Eco Management and Audit Program Directive
EPA	United States Environmental Protection Agency
IPPC	Industrial Pollution Prevention and Control
ISO	International Organization for Standardization
BAT	Best Available Techniques
NACE	Statistical Classification of Economic Activities
GSWM	General Directorate of Water Management
RO	Reverse Osmosis
MAF	Ministry of Agriculture and Forestry of the Republic of Turkey
TurkStat	Turkish Statistical Institute
NF	Nanofiltration
MF	Microfiltration
UF	Ultrafiltration
GW	Groundwater
SW	Surface Water

Su Verimliliği Rehber Dokümanı

1 Introduction

Our country, located in the Mediterranean basin where the effects of global climate change are intensely felt, is recognized as one of the regions that will be most impacted by its adverse effects. Projections regarding the future impact of climate change on the water resources in our basins indicate that our water resources could decrease by up to 25% over the next century.

As of 2022, the per capita annual available water in our country is 1,313 m³, but due to human pressures and the effects of climate change, it is expected to fall below 1,000 m³ per capita after 2030. Without taking necessary precautions, Türkiye is at risk of becoming a water-scarce country in the near future, which would bring about numerous social and economic challenges. As demonstrated by future projections, the drought and water scarcity risks that lie ahead make it imperative to use our existing water resources efficiently and sustainably.

The concept of water efficiency can be defined as "the use of the minimum amount of water needed for the production of a product or service." The approach to water efficiency emphasizes the rational, cooperative, fair, efficient, and effective use of water across all sectors—including drinking water, agriculture, industry, and households—while preserving water in terms of both quantity and quality and considering not only human needs but also the ecosystem’s requirements.

With the increasing demand on water resources, changes in precipitation and temperature patterns due to climate change, and rising population, urbanization, and pollution, it has become even more critical to distribute available water resources among users in a fair and balanced manner. Therefore, a roadmap that prioritizes efficiency and optimization has become necessary to ensure that limited water resources are preserved and used under sustainable management practices.

In the sustainable development vision set forth by the United Nations, the Millennium Development Goal 7 on Ensuring Environmental Sustainability and Sustainable Development Goals, specifically Goal 9 on Industry, Innovation, and Infrastructure and Goal 12 on Responsible Production and Consumption, emphasize the efficient, fair, and sustainable use of resources—particularly water—as well as environmentally friendly production and consumption practices mindful of future generations.

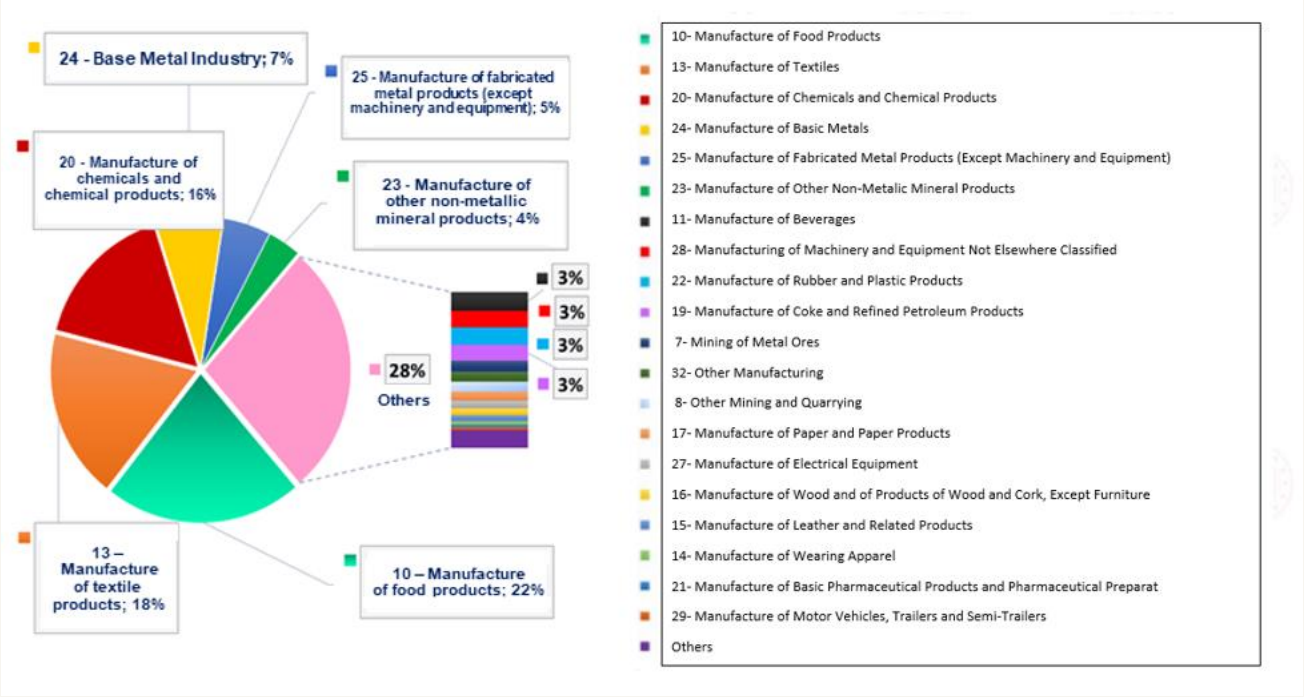
The European Green Deal, which member countries have agreed upon to realize a carbon-neutral, circular economy model, aims to expand the efficient use of resources and reduce environmental impacts. In alignment with these goals, Türkiye has established a European Green Deal Action Plan that outlines actions to promote water and resource efficiency in various fields, particularly in industry, as part of production and consumption.

The "Industrial Emissions Directive (IED)," one of the most significant components of European Union environmental legislation for industry, encompasses measures to control, prevent, or reduce discharges/emissions into receiving environments, including air, water, and soil, from industrial activities using an integrated approach. In the Directive, Best Available Techniques (BAT) are introduced to systematically implement cleaner production processes and address practical difficulties encountered in application. BAT represents the most effective application techniques aimed at high-level environmental protection, considering both costs and benefits. Under the Directive, sector-specific Reference Documents (BAT-BREF) have been prepared, detailing BAT for each sector. These BREF documents provide a general framework for BAT, including good management practices, general preventive techniques, chemical use and management, techniques for various production processes, wastewater management, emission management, and waste management.

The Ministry of Agriculture and Forestry, through the General Directorate of Water Management, is conducting activities aimed at promoting efficient practices and raising public awareness in urban, agricultural, industrial, and individual water use. Within the framework of the "Water Efficiency Strategy Document and Action Plan (2023-2033) in Adapting to Changing Climate," which came into force with Presidential Circular No. 2023/9, water efficiency action plans targeting all sectors and stakeholders have been prepared. The Industrial Water Efficiency Action Plan specifies 12 actions for the 2023-2033 period, with responsible and relevant institutions designated for each action. The responsibilities of the General Directorate of Water Management within this Action Plan include conducting studies to identify specific water usage ranges and quality requirements for subsectors in industry, organizing sector-specific technical training programs and workshops, and preparing water efficiency guidance documents.

Meanwhile, within the "Project on Industrial Water Use Efficiency According to NACE Codes," conducted by the General Directorate of Water Management under the Ministry of Agriculture and Forestry, sector-specific best practices for water efficiency in industry tailored to Türkiye have been identified. As a result, sector-specific guidance documents and action plans classified according to NACE codes have been developed, outlining recommended measures to improve water use efficiency in high water-consuming sectors operating in Türkiye.

As in the rest of the world, the sectors with the highest water consumption in Türkiye are the food, textile, chemical, and primary metal sectors. Under these studies, field visits were carried out in 35 main sectors and 152 sub-sectors, including facilities that represent a variety of capacities and production types with high water consumption under NACE codes in Türkiye, especially in the food, textile, chemical, and primary metal industries. Data were collected on water supply, sectoral water use, wastewater generation, and recovery practices, and information was provided on topics such as BAT and sectoral reference documents (BREF) published by the European Union, water efficiency, clean production, and water footprint.



The distribution of water usage by sector in industry in Türkiye

As a result of the studies, specific water consumption and potential savings rates were identified for 152 different four-digit NACE codes with high water consumption. Water efficiency guideline documents were prepared by considering the EU Best Available Techniques (BAT) and other clean production techniques. Within these guidelines, 500 techniques (BAT) for water efficiency were examined under four main groups: (i) Good Management Practices, (ii) General Preventive Measures, (iii) Auxiliary Process Measures, and (iv) Sector-Specific Measures.

During the determination of BATs for each sector within the scope of the project, environmental benefits, operational data, technical specifications-requirements, and applicability criteria were considered. The determination of BATs was not limited to BREF documents alone; global literature data, real case analyses, innovative practices, and sector representatives' reports were also thoroughly examined, and sectoral BAT lists were created. In order to evaluate the suitability of the prepared BAT lists for the local industrial infrastructure and capacity of our country, BAT lists specific to each NACE code were scored by enterprises based on criteria such as water savings, economic savings, environmental benefits, applicability, and cross-media effects. The final BAT lists were determined using the scoring results. Sectoral water efficiency guidelines based on NACE codes were created using water and wastewater data from the visited facilities and the final BAT lists identified by considering local dynamics specific to our country, as highlighted by sectoral stakeholders.

2 Scope of the Study

The guide documents prepared within the framework of water efficiency measures in industry include the following main sectors:

- Plant and animal production, hunting, and related service activities (including 6 sub-production areas represented by four-digit NACE codes)
- Fishing and aquaculture (including 1 sub-production area represented by a four-digit NACE code)
- Extraction of coal and lignite (including 2 sub-production areas represented by four-digit NACE codes)
- Support activities for mining (including 1 sub-production area represented by a four-digit NACE code)
- Mining of metal ores (including 2 sub-production areas represented by four-digit NACE codes)
- Other mining and quarrying (including 2 sub-production areas represented by four-digit NACE codes)
- Manufacturing of food products (including 22 sub-production areas represented by four-digit NACE codes)
- Manufacturing of beverages (including 4 sub-production areas represented by four-digit NACE codes)
- Manufacturing of tobacco products (including 1 sub-production area represented by a four-digit NACE code)
- Manufacturing of textile products (including 9 sub-production areas represented by four-digit NACE codes)
- Manufacturing of clothing (including 1 sub-production area represented by a four-digit NACE code)
- Manufacturing of leather and related products (including 3 sub-production areas represented by four-digit NACE codes)
- Manufacturing of wood, wood products, and cork (excluding furniture); manufacturing of woven goods made from straw, hay, and similar materials (including 5 sub-production areas represented by four-digit NACE codes)
- Manufacturing of paper and paper products (including 3 sub-production areas represented by four-digit NACE codes)
- Manufacturing of coke and refined petroleum products (including 1 sub-production area represented by a four-digit NACE code)
- Manufacturing of chemicals and chemical products (including 13 sub-production areas represented by four-digit NACE codes)
- Manufacturing of basic pharmaceutical products and pharmaceutical preparations (including 1 sub-production area represented by a four-digit NACE code)
- Manufacturing of rubber and plastic products (including 6 sub-production areas represented by four-digit NACE codes)
- Manufacturing of other non-metallic mineral products (including 12 sub-production areas represented by four-digit NACE codes)
- Basic metals industry (including 11 sub-production areas represented by four-digit NACE codes)
- Manufacturing of fabricated metal products (excluding machinery and equipment) (including 12 sub-production areas represented by four-digit NACE codes)
- Manufacturing of computers, electronic, and optical products (including 2 sub-production areas represented by four-digit NACE codes)
- Manufacturing of electrical equipment (including 7 sub-production areas represented by four-digit NACE codes)

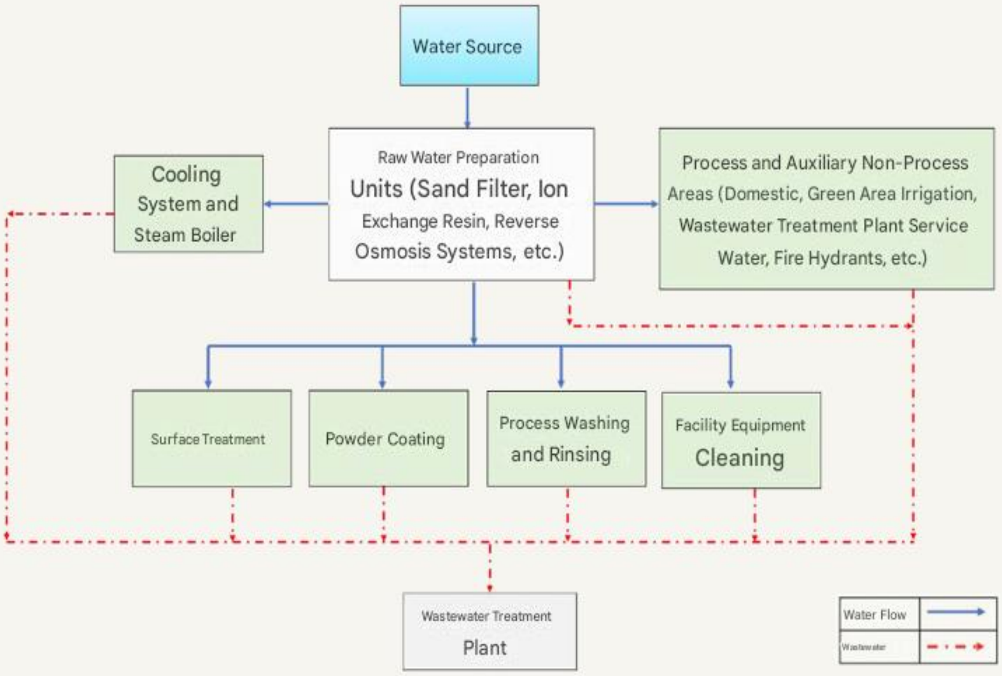
- Manufacturing of machinery and equipment not classified elsewhere (including 8 sub-production areas represented by four-digit NACE codes)
- Manufacturing of motor vehicles, trailers, and semi-trailers (including 3 sub-production areas represented by four-digit NACE codes)
- Manufacturing of other transportation equipment (including 2 sub-production areas represented by four-digit NACE codes)
- Other manufacturing (including 2 sub-production areas represented by four-digit NACE codes)
- Installation and repair of machinery and equipment (including 2 sub-production areas represented by four-digit NACE codes)
- Production and distribution of electricity, gas, steam, and air conditioning systems (including 2 sub-production areas represented by four-digit NACE codes)
- Waste collection, treatment, and disposal activities; recovery of materials (including 1 sub-production area represented by a four-digit NACE code)
- Construction of buildings outside structures (including 1 sub-production area represented by a four-digit NACE code)
- Storage and supporting activities for transportation (including 1 sub-production area represented by a four-digit NACE code)
- Accommodation (including 1 sub-production area represented by a four-digit NACE code)
- Education (including 1 sub-production area represented by a four-digit NACE code)
- Sports activities, entertainment, and recreation activities (including 1 sub-production area represented by a four-digit NACE code)

“Primary Metal Industry" and "Manufacturing of Fabricated Metal Products (excluding machinery and equipment)" sectors include the following sub-production branches for which guidance documents have been prepared:

24.10	Manufacturing of Basic Iron and Steel Products and Ferroalloys
24.20	Manufacturing of Steel Tubes, Pipes, Hollow Profiles, and Similar Connection Parts
24.31	Cold Drawing of Bars
24.32	Cold Rolling of Narrow Strips
24.34	Cold Drawing of Wires
24.41	Production of Precious Metals
24.42	Production of Aluminum
24.51	Iron Casting
24.52	Steel Casting
24.53	Casting of Light Metals
24.54	Casting of Other Non-Ferrous Metals
25.12	Manufacturing of Metal Doors and Windows
25.21	Manufacturing of Central Heating Radiators (Excluding Electric Radiators) and Hot Water Boilers
25.30	Manufacturing of Steam Generators, Excluding Central Heating Hot Water Boilers
25.50	Forging, Pressing, Stamping, and Rolling of Metals; Powder Metallurgy
25.61	Processing and Coating of Metals
25.62	Machining and Shaping of Metals
25.71	Manufacturing of Cutlery Sets and Other Cutting Tools
25.73	Manufacturing of Hand Tools, Tool Machine Tips, Saw Blades, etc.
25.92	Manufacturing of Light Packaging Materials from Metal
25.93	Manufacturing of Wire Products, Chains, and Springs
25.94	Manufacturing of Fasteners and Products for Screw Machines
25.99	Manufacturing of Other Fabricated Metal Products Not Classified Elsewhere

2.1 Manufacture of Central Heating Radiators (Excluding Electric Radiators) and Hot Water Boilers (NACE 25.21)

Central Heating Radiators (Except Electric Radiators) and Hot Water Boilers (Boilers) Manufacturing Sector Water Flow Diagram



	Minimum	Maximum
Specific Water Consumption of Facilities Visited within the Scope of the Project (L/product)	44.6	319.6
Reference Specific Water Consumption (L/kg product)	6	42

* A comparison could not be made since the reference specific water consumption value and the specific water consumption units of the facilities visited within the scope of the project were different.

Percentage Distribution of Water Efficiency Practices

The sector involves various process stages such as metal processing, surface treatment, drying, painting, baking, assembly, testing, and packaging. During the metal processing stage, raw materials are shaped. Following this, metals undergo degreasing and rinsing in baths within the surface treatment stage. In the drying stage, moisture is removed from the metal surfaces, after which they are painted in the painting stage. The painted metals are then baked to prepare them for assembly. In the assembly stage, physically combined final products are subjected to performance tests. Approved products are then packaged and made ready for shipment or sale.

In the manufacture of central heating radiators (excluding electric radiators) and hot water boilers (calorifiers), water consumption occurs primarily in surface treatment and powder coating processes. Additionally, water is consumed in raw water preparation units, such as ion-exchange resin and reverse osmosis systems, to produce soft water for production processes. These systems require water for resin regeneration and membrane cleaning. Furthermore, water consumption also takes place in auxiliary units such as cooling towers and steam boilers.

The reference specific water consumption for the sector is in the range of 6–42 L/kg. For the production line analyzed in this study, specific water consumption is between 44.6–319.6 L/unit. Through the implementation of sector-specific techniques, good management practices, general preventive measures, and measures related to auxiliary processes, it is possible to achieve a water saving rate of 30–82% within the sector.

25.21 The following table presents the priority water efficiency implementation techniques recommended within the scope of NACE code 21 for the manufacture of central heating radiators (excluding electric radiators) and hot water boilers.

NACE Code	Description		Prioritized Sectoral Water Efficiency Techniques
25.21	Manufacture of Central Heating Radiators (Excluding Electric Radiators) and Hot Water Boilers		**Sector-Specific Measures**
		1.	To enhance the efficiency of the rinsing process, techniques such as immersing multiple parts in the rinsing tank at once, using the smallest possible rinsing tanks, positioning water inlets and outlets oppositely, installing screens, distributors, or diffusers at water inlets, and rinsing using a counter-current principle can be applied to reduce water usage
		2.	To reduce effluent water in baths, compatible chemicals can be used in sequential tanks
		3.	Surfactants can be employed to decrease effluent water in baths
		4.	Baths can be operated at the lowest possible concentration, and increasing bath temperatures can lower the viscosity of solutions, thereby reducing material carryover
		5.	Materials should be extracted from tanks at low speeds to minimize effluent water
			Good Management Practices
		1.	An integrated wastewater management and treatment strategy should be implemented to reduce wastewater volume and pollutant load
		2.	An environmental management system should be established
		3.	Water flow diagrams and mass balances for water should be prepared
		4.	A water efficiency action plan should be developed to reduce water usage and prevent water pollution
		5.	Technical training should be provided to staff for reducing and optimizing water usage
		6.	Effective production planning should be conducted to optimize water consumption
		7.	Water efficiency targets should be set
		8.	The quantity and quality of water used in production and auxiliary processes should be monitored, and this information should be integrated into the environmental management system

NACE Code	Description		Prioritized Sectoral Water Efficiency Techniques
25.21	Manufacture of Central Heating Radiators (Excluding Electric Radiators) and Hot Water Boilers		**General Measures**
		1.	Minimizing spills and leaks
		2.	Recovering water from rinsing solutions and reusing the reclaimed water in suitable processes
		3.	Using automatic equipment and devices (sensors, smart handwashing systems, etc.) that promote water conservation at water usage points such as showers and toilets
		4.	Utilizing pressure washing systems for equipment cleaning, general cleaning, etc.
		5.	Reusing filter wash waters in filtration processes, reusing relatively clean cleaning waters in production processes, and reducing water consumption by employing on-site cleaning systems (CIP)
		6.	Avoiding the use of drinking water in production lines
		7.	Using cooling water as process water in other processes
		8.	Detecting and reducing water losses
		9.	Employing automatic control and shut-off valves to optimize water use
		10.	Maintaining documented production procedures to prevent water and energy waste, and ensuring these procedures are used by employees
		11.	Reusing backwash water from pressure filtration before water softening at suitable points
		12.	Optimizing the frequency and duration (including rinses) of regeneration in water softening systems
		13.	Implementing closed storage and impermeable waste/scrap areas to prevent the transportation of toxic or hazardous chemicals in aquatic environments
		14.	Preventing the storage, handling, and post-use wastewater mixing of substances that pose risks in aquatic environments (such as oils, emulsions, binders, etc.)
		15.	Preventing clean water flows from mixing with dirty water flows
		16.	Characterizing the quantities and qualities of wastewater at all generation points to identify wastewater streams that can be reused either treated or untreated
		17.	Utilizing closed-loop water cycles in suitable processes
		18.	Employing computer-aided control systems in production processes

NACE Code	Description		Prioritized Sectoral Water Efficiency Techniques
25.21	Manufacture of Central Heating Radiators (Excluding Electric Radiators) and Hot Water Boilers	19.	Reusing relatively clean wastewater generated from washing, rinsing, and equipment cleaning without treatment
		20.	Separately collecting and treating greywater on-site for use in areas that do not require high water quality (e.g., irrigation of green areas, floor washing, etc.)
		21.	Implementing time optimization in production and organizing all processes to be completed in the shortest time possible
		22.	Collecting rainwater and utilizing it as an alternative water source for facility cleaning or in suitable areas
		23.	Characterizing nanofiltration (NF) or reverse osmosis (RO) concentrates for potential reuse, either treated or untreated
		Measures Related to Auxiliary Processes	
		1.	Replacing old equipment in the ventilation system with ion exchange resins based on reverse osmosis principles (systems producing demineralized water) and reusing the water
		2.	Reusing the liquid formed by condensation from the ventilation system
		3.	Identifying processes that require wet cooling to avoid unnecessary cooling operations
		4.	Increasing the number of cycles in closed-loop cooling systems and improving the quality of make-up water to reduce water consumption
		5.	Reducing evaporation losses in closed-loop cooling water
		6.	Utilizing corrosion and scale prevention inhibitors in systems with a closed water cycle to increase the number of cycles
		7.	Employing air cooling systems instead of water cooling systems in cooling applications
		8.	Establishing water softening systems to ensure the effective operation of cooling water recovery systems
		9.	Using closed-loop cooling systems to reduce water usage
		10.	Implementing localized dry air cooling during periods of low cooling demand throughout the year
		11.	Collecting surface runoff with a separate collection system for use as cooling water, process water, etc
		A total of 47 technical recommendations have been proposed for this sector.	

For the manufacturing of central heating radiators (excluding electric radiators) and hot water boilers, the NACE code outlines the following measures under separate headings: (i) Sector-Specific Measures, (ii) Good Management Practices, (iii) General Measures, and (iv) Measures for Auxiliary Processes.

2.1.1 Sector Specific Measures

- ***To reduce the leachate waters transported in baths, the use of compatible chemicals in consecutive tanks is recommended***

  It is important to keep the leachate waters at the lowest possible levels. If adequate rinsing cannot be achieved between processes, the chemicals carried over on the parts can contaminate the process solutions. By using compatible chemicals in consecutive tanks, the transport of chemicals can be reduced (MoEUC, 2013).

- ***To reduce the leachate waters transported in baths, the material should be extracted from the tanks at a low speed***

  Performing the extraction of materials placed in tanks slowly prevents chemicals and rinse waters from backflowing into the tanks and helps avoid unwanted leachate outside the tank (MoEUC, 2013).

- ***To reduce the leachate waters transported in baths, the baths should be operated at the lowest possible concentration, and by increasing the bath temperatures, the viscosities of the solutions can be lowered, thereby reducing their transport over the materials***

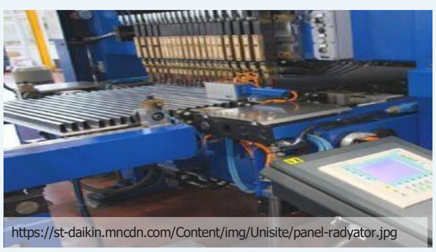
  To lower the viscosities of the solutions, keeping the concentrations of fresh solutions at the lowest levels and increasing them over time if necessary can reduce the transport of solutions over the materials (MoEUC, 2013).

- ***To reduce the leachate waters transported in baths, the use of surfactants is recommended***

  Surfactants help reduce surface tension, thus decreasing the transport of chemicals and leachate waters (MoEUC, 2013).

- ***To improve the efficiency of rinsing, multiple pieces should be submerged in the rinse tank at once, the smallest possible rinse tanks should be used, water inlets and outlets should be placed oppositely, curtains, distributors, or diffusers should be installed at the water inlets, and rinsing should be done using the counterflow principle to reduce water usage***

  Submerging parts in the rinse tank multiple times is a more effective method than simply immersing and agitating them inside the tank. Immersing coated materials twice in the rinse tank is six times more effective in preventing leachate than doing it once (ÇŞİDB, 2013). In counterflow rinsing, the rinsing water flows in the opposite direction to the coated piece. The material first contacts the dirtiest rinse water instead of the cleanest, and as it progresses, it enters cleaner baths. This way, the clean water does not contact the dirtiest state of the material in the first tank, resulting in less contamination compared to parallel flow. It has been reported that this method can achieve water savings of over 90% (MoEUC, 2013).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Radiator Production Line


https://bit.ly/3TqxI29

Rinsing Bath

2.1.2 Good Management Practices

- ***Use of integrated wastewater management and treatment strategies to reduce wastewater quantity and pollutant load***

Wastewater management should adopt a holistic approach from the production of wastewater to its final disposal, encompassing functional elements such as composition, collection, treatment including sludge disposal, and reuse. The selection of appropriate treatment technology for industrial wastewater depends on integrated factors such as land availability, desired quality of treated water, and compliance with national and local regulations (Abbassi & Al Baz, 2008).

The reuse of treated wastewater on-site not only improves the quality of water bodies but also reduces the demand for freshwater. Therefore, identifying suitable treatment strategies for different reuse targets is very important.

In integrated industrial wastewater treatment, various aspects such as wastewater collection systems, treatment processes, and reuse targets are evaluated together (Naghedi et al., 2020). Methods such as SWOT (Strengths, Weaknesses, Opportunities, and Threats), PESTEL (Political, Economic, Social, Technological, Environmental, and Legal factors), and decision trees can be combined with expert opinions to establish an integrated wastewater management framework (Naghedi et al., 2020). The integration of Analytical Hierarchy Process (AHP) and Combined Compromise Solution (CoCoSo) techniques can be used to determine priorities based on multiple criteria for industrial wastewater management processes (Adar et al., 2021).

The implementation of integrated wastewater management strategies can lead to an average reduction of up to 25% in water consumption, wastewater quantities, and pollution loads in wastewater. The potential payback period for the implementation ranges from 1 to 10 years (MoAF, 2021).

http://www.asw-eg.com/en/images/products/116567Water-Sewage-Treatment-System-With-Plant-And-Facility.jpg

Industrial Wastewater Treatment Plant

- ***Providing Technical Training to Personnel for Water Use Reduction and Optimization***

  his measure enhances the education and awareness of personnel, enabling water conservation and recovery, thereby reducing water consumption and costs while improving water efficiency. In industrial facilities, high water usage and wastewater generation issues can arise due to personnel lacking the necessary technical knowledge. For instance, it is crucial that cooling tower operators, who represent a significant proportion of water consumption in industrial operations, are properly trained and possess technical knowledge. Relevant personnel must also have sufficient technical expertise in applications such as determining water quality requirements in production processes and measuring water and wastewater quantities (MoAF, 2021). Therefore, providing training to personnel on water use reduction, optimization, and conservation policies is essential. Involving personnel in water conservation initiatives, regularly generating reports on water consumption before and after such initiatives, and sharing these reports with staff support participation and motivation in the process. The technical, economic, and environmental benefits gained through personnel training will yield results in the medium to long term (TUBİTAK MAM, 2016; MoAF, 2021).

- ***Monitoring the Quantity and Quality of Water Used and Wastewater Generated in Production and Auxiliary Processes, and Integrating This Information into the Environmental Management System***

  Industrial facilities have resource uses, and inefficiencies and environmental problems arising from resource utilization can stem from input-output flows. Therefore, it is necessary to monitor the quantity and quality of water used and wastewater generated in production and auxiliary processes (TUBİTAK MAM, 2016; TOB, 2021). Process-based quantity and quality monitoring, combined with other good management practices (such as personnel training and establishing an environmental management system), can achieve reductions of 6-10% in energy consumption and up to 25% in water consumption and wastewater quantities (Öztürk, 2014).

  The main steps for monitoring the quantity and quality of water and wastewater are as follows:

  - Using monitoring equipment (such as meters) to track water, energy, etc., on a process basis,
  - Establishing monitoring procedures,
  - Identifying and documenting all input and output points (raw materials, chemicals, water, products, wastewater, sludge, solid waste, hazardous waste, and by-products) related to the production process, monitoring them in terms of quantity and quality, evaluating them comparatively, and reporting,
  - Monitoring raw material losses in production processes where raw materials are converted to products and taking measures against these losses (MoEUC, 2020e).

- ***Preparation of a Water Efficiency Action Plan to Reduce Water Use and Prevent Water Pollution***

  Developing an action plan that includes short, medium, and long-term measures to reduce water and wastewater quantities and prevent water pollution is crucial for water efficiency in industrial facilities. In this context, it is essential to determine water needs throughout the facility and within production processes, establish quality requirements at water usage points, identify points of wastewater generation, and characterize the wastewater (TOB, 2021). Additionally, it is necessary to specify the measures to be implemented to reduce water consumption, wastewater generation, and pollution loads, assess their feasibility, and prepare action plans for the short, medium, and long term. This approach promotes water efficiency and sustainable water use within the facilities (TOB, 2021).

- ***Setting Water Efficiency Targets***

  The first step in achieving water efficiency in industrial facilities is to define specific targets (TOB, 2021). To do this, a detailed water efficiency analysis must first be conducted on a process basis. This analysis helps identify unnecessary water uses, water losses, inappropriate practices affecting water efficiency, process losses, and reusable water/wastewater sources that can be treated or untreated. It is also vital to determine the water-saving potential and water efficiency targets for each production process and for the facility as a whole (TOB, 2021).

- ***Preparation of Water Flow Diagrams and Mass Balances for Water***

  Identifying water use and wastewater generation points in industrial facilities and establishing water-wastewater balances in production processes and auxiliary processes forms the basis for many good management practices. Creating process profiles on a facility-wide and production process basis facilitates the identification of unnecessary water use points and high water consumption areas, evaluates water recovery opportunities, assesses process modifications, and identifies water losses (TOB, 2021).

- ***Effective Production Planning for Optimizing Water Consumption***

  Planning industrial production processes with minimal process use until a raw material is converted into a product is an effective practice for reducing labor costs, resource usage costs, and environmental impacts while enhancing efficiency (TUBİTAK MAM, 2016; TOB, 2021). When production planning in industrial facilities takes water efficiency into account, it leads to reductions in water consumption and wastewater generation. Modifying production processes or combining certain processes can provide significant benefits in terms of water efficiency and time management (TOB, 2021).

- ***Establishment of an Environmental Management System (EMS)***

Environmental Management Systems (EMS) provide the necessary organizational structure, responsibilities, procedures, and resources for industrial organizations to develop, implement, and monitor their environmental policies. Establishing an EMS enhances decision-making processes related to raw materials, water-wastewater infrastructure, planned production processes, and various treatment techniques. Environmental management organizes how to manage resource procurement and waste discharge requirements with the highest economic efficiency, without compromising product quality, while minimizing environmental impact.

The most widely used Environmental Management Standard is ISO 14001. Alternatives include the Eco-Management and Audit Scheme (EMAS) Directive (761/2001), which is developed for assessing, improving, and reporting on the environmental performance of businesses. It is a leading practice in EU legislation under eco-efficiency (clean production) and is voluntarily participated in (TUBİTAK MAM, 2016; TOB, 2021). The benefits of establishing and implementing an EMS include:

- Economic benefits can be obtained by enhancing operational performance (Christopher, 1998).
- Adopting International Organization for Standardization (ISO) standards leads to greater compliance with global legal and regulatory requirements (Christopher, 1998)
- Environmental liability risks are minimized, resulting in decreased waste volumes, resource consumption, and operational costs (Delmas, 2009).
- Utilizing internationally recognized environmental standards eliminates the need for multiple registrations and certifications for businesses operating in different locations worldwide (Hutchens Jr., 2017).
- In recent years, the improvement of companies' internal control processes has been valued by consumers. The implementation of EMS provides a competitive advantage over companies that do not adopt these standards, contributing to a better position for organizations in international markets (Potoski & Prakash, 2005).

The benefits listed above depend on various factors such as production processes, management practices, resource use, and potential environmental impacts (TOB, 2021). Through practices such as preparing annual inventory reports with similar content to the EMS and monitoring the quantity and quality of inputs and outputs in production processes, water consumption can be reduced by approximately 3-5% (Öztürk, 2014). The overall duration for developing and implementing an EMS is estimated to be 8-12 months (ISO 14001 User Manual, 2015).

Industrial organizations are also working under the ISO 14046 Water Footprint Standard, which defines requirements and guidelines for assessing and reporting water footprints. The implementation of this standard aims to reduce the use of freshwater necessary for production and its environmental impacts. Additionally, the ISO 46001 Water Efficiency Management Systems Standard helps industrial organizations save water and reduce operational costs by developing water efficiency policies through monitoring, benchmarking, and review activities.

2.1.3 General Measures

• ***Detection and Reduction of Water Losses***

Water losses occur in industrial production processes through equipment, pumps, and pipelines. It is crucial first to detect water losses and then prevent leaks by maintaining equipment, pumps, and pipelines in good condition through regular maintenance (IPPC BREF, 2003). Regular maintenance procedures should pay particular attention to the following aspects:

- Including pumps, valves, level switches, pressure and flow regulators in maintenance checklists,
- Conducting inspections not only of water systems but also of heat transfer and chemical distribution systems, as well as broken and leaking pipes, barrels, pumps, and valves,
- Ensuring that filters and pipelines are cleaned regularly,
- Calibrating and routinely monitoring measurement equipment such as chemical dosing and distribution devices, thermometers, etc. (IPPC BREF, 2003).

Effective maintenance, cleaning, and leak control practices can achieve water savings ranging from 1% to 6% in consumption (Öztürk, 2014).

• ***Minimizing Spills and Leaks***

Spills and leaks in operations can lead to losses of both raw materials and water. Moreover, using wet cleaning methods to clean areas where spills have occurred can increase water consumption, wastewater amounts, and the pollution load of the wastewater (TOB, 2021). To reduce raw material and product losses, measures such as splash guards, catch pans, drip trays, and screens are employed to minimize spills and splashes (IPPC BREF, 2019).

• ***Reuse of Relatively Clean Wastewater from Washing, Rinsing, and Equipment Cleaning Processes***

In industrial facilities, relatively clean wastewater, such as wash and final rinse wastewater and filter backwash water, can be reused without treatment for processes like floor washing and garden irrigation, which do not require high water quality. This practice can save between 1% to 5% in raw water consumption. The initial investment costs for this application involve the installation of new pipelines and the creation of storage tanks (Öztürk, 2014).

- ***Prevention of Mixing Clean and Dirty Water Flow***

In industrial facilities, identifying points of wastewater generation and characterizing the wastewater enables the separation of highly polluted wastewater from relatively clean wastewater into different collection systems (TUBİTAK MAM, 2016; TOB, 2021). This separation allows for the appropriate treatment or reuse of wastewater streams based on their quality. By segregating wastewater flows, water pollution is reduced, treatment performances are enhanced, energy consumption related to treatment needs is decreased, and emissions are minimized through the recovery of valuable materials and wastewater. Additionally, it is possible to recover heat from the separated hot wastewater streams (TUBİTAK MAM, 2016; TOB, 2021). Although the separation of wastewater flows generally requires high investment costs, the potential recovery of significant amounts of wastewater and energy can lead to a reduction in costs in suitable scenarios (IPPC BREF, 2006).

- ***Characterization of Wastewater Quantities and Qualities for Reuse***

Characterizing the quantities and qualities of wastewater generated at all points allows for identifying wastewater streams that can be reused either after treatment or without treatment. This characterization facilitates the reuse of various wastewater streams in industrial facilities (Öztürk, 2014; TUBİTAK MAM, 2016; TOB, 2021). Examples of such streams include filter backwash water, total organic (TO) concentrates, blowdown water, condensate, and relatively clean washing and rinsing water, which can be reused without treatment in processes or areas that do not require high water quality (e.g., cleaning of facilities and equipment). Additionally, wastewater streams that cannot be reused directly can be treated using appropriate treatment technologies and subsequently reused in production processes.

Membrane filtration processes are an integral part of many wastewater reuse systems. Nanofiltration (NF) and reverse osmosis (RO) filtration systems are employed for industrial wastewater recovery. Microfiltration (MF) and ultrafiltration (UF) are typically used for the pre-treatment of water before NF or RO processes (Singh et al., 2014).

- ***Rainwater Harvesting as an Alternative Water Source***

In times of dwindling water resources, rainwater harvesting is particularly favored in regions with low rainfall. Various technologies and systems are available for rainwater collection and distribution. These include cistern systems, ground infiltration, surface collection, and filtration systems. Collected rainwater can be utilized for production processes, garden irrigation, tank and equipment cleaning, surface cleaning, and other purposes, provided it meets the required quality standards (Tanık et al., 2015).

In several instances, rainwater collected from industrial rooftops has been stored and used within the building and landscape areas, resulting in a 50% water saving for landscape irrigation (Yaman, 2009). To enhance soil permeability and facilitate the absorption of rainwater into the ground, perforated stones and green spaces may be utilized (Yaman, 2009). Collected rainwater can be used for vehicle washing and garden irrigation. After use, the water can be biologically treated, allowing for a recovery rate of up to 95% for reuse (Şahin, 2010).

- ***Use of Air-Cooling Systems Instead of Water-Cooling Systems***
- Industrial cooling systems are employed to cool heated products, processes, and equipment. These systems can operate as closed or open circuit cooling systems, using either a fluid (gas or liquid) or dry air (IPPC BREF, 2001b; TOB, 2021). Air-cooling systems consist of finned tube components, condensers, and air fans (IPPC BREF, 2001b; TOB, 2021). Various operating principles can be found in industrial air-cooling systems, where heated water is cooled by air in closed circuit cooling condensers and heat exchangers (IPPC BREF, 2001b; TOB, 2021). In water-cooled systems, heated water is transferred to a cooling tower, where cooling is achieved through evaporation in wet cooling systems. However, despite operating in a closed circuit, water-cooled systems experience significant evaporation losses. Additionally, cooling systems often incur water losses due to blowdown, where a certain amount of water is discharged (IPPC BREF, 2001b; TOB, 2021). The adoption of air-cooling systems over water-cooled systems effectively reduces evaporation losses and minimizes the risk of cooling water contamination (IPPC BREF, 2001b; TOB, 2021).

- ***Optimization of Regeneration Frequency and Duration in Water Softening Systems***

  One of the most commonly used methods for softening raw water in industrial facilities is the use of cation exchange resins, which are routinely regenerated. The regeneration process typically involves pre-washing the resin with raw water, regenerating it with brine, and then rinsing it afterward. The regeneration periods are determined based on the hardness of the water; higher hardness levels necessitate more frequent regeneration in the water softening systems. In regeneration operations, washing, regeneration, and rinsing wastewater is typically discharged directly. However, if the washing and final rinse water are of raw water quality, they can be redirected to the raw water tank or reused in processes that do not require high water quality, such as facility cleaning or irrigation of green areas (TOB, 2021). Determining the optimal regeneration frequency in regeneration systems is crucial. Although the frequency of regeneration in water softening systems can be adjusted based on supplier recommendations or the flow and duration entering the softening system, it can also vary depending on the calcium concentration in the raw water. Therefore, online hardness measurements are employed when determining regeneration frequency. This approach not only optimizes regeneration intervals but also prevents excessive washing, rinsing, or brine backwashing by utilizing online hardness sensors.

Water Softening Systems

- ***Reusing Pressurized Filtration Backwash Water Before Water Softening in Appropriate Locations***

  Many industrial processes require softened water with low calcium and magnesium concentrations. Water softening systems remove calcium, magnesium, and other metal cations from hard water to obtain soft water.

  By reusing pressurized filtration backwash water before water softening in appropriate locations, savings can be achieved. This measure is similar in content to practices such as "reusing backwash water in filtration processes, reusing relatively clean water in production processes, and reducing water consumption by using on-site cleaning systems."

- ***Reuse of Nanofiltration (NF) or Reverse Osmosis (RO) Concentrates Based on Characterization, Either Treated or Untreated***

  Based on the characterization of wastewater and suitable usage points, the reuse potentials of other wastewater generated from membrane processes (backwashing without chemicals or with chemicals, CIP cleaning, module cleaning, cleaning chemical tanks, etc.) should be assessed.

  Nanofiltration is a membrane-based liquid separation technique suitable for treating well water and surface water, characterized by low energy consumption and low operating pressures. Reverse osmosis is also a membrane-based liquid separation technique that can separate smaller particles than nanofiltration (Akgül, 2016).

  Savings can be achieved by reusing nanofiltration or reverse osmosis concentrates based on their characterization, either treated or untreated. Measures should be taken to reuse clean water in production processes and reduce water consumption through cleaning systems in filtration operations (TOB, 2021).

- ***Preventing the Storage, Retention, and Post-Use Contamination of Aquatic Environments with Hazardous Substances (such as oils, emulsions, binders)***

  In industrial facilities, dry cleaning techniques can be employed to prevent the mixing of hazardous chemicals, such as oils, emulsions, and binders, with wastewater flows. This helps protect water resources (TUBİTAK MAM, 2016).

Reverse Osmosis System

- ***The use of closed-loop water cycles in appropriate processes***

  Refrigerants are chemical compounds that absorb heat from the materials to be cooled, cooling them down, and possess specific thermodynamic properties that affect the performance of the cooling process (Kuprasertwong et al., 2021).

  In many industrial processes, particularly in product cooling operations, water is used as the refrigerant. During this cooling process, the water can be reused through cooling towers or central cooling systems. If undesirable microbial growth occurs in the cooling water, chemicals can be added to the recirculated water to control it (TUBİTAK MAM, 2016). By reusing cooling water in processes such as cleaning, both water consumption and the amount of wastewater generated can be reduced. However, the need for energy for cooling and recirculating cooling waters presents a side effect. Heat recovery is also achieved through the use of heat exchangers in cooling waters. Generally, closed-loop systems are used in facilities that utilize water cooling systems. However, cooling system blow-offs are directly discharged into the wastewater treatment facility channel for removal. These blow-off waters can be reused in appropriate production processes.

- ***The construction of closed storage and impermeable waste/scrap areas to prevent the transport of toxic or hazardous chemicals in aquatic environments***

  In industrial facilities, closed and impermeable waste/scrap storage areas can be constructed to prevent the transport of toxic or hazardous chemicals to receiving environments. This practice is already being implemented under existing environmental regulations in our country. Through field studies conducted, separate collection channels can be made for storage areas of toxic or hazardous materials in industrial facilities, allowing the separate collection of any leakage waters and preventing them from mixing with natural water environments.

- ***The use of automatic devices and equipment (sensors, smart handwashing systems, etc.) to save water at water usage points such as showers/toilets***

  Water is extremely important in many sectors of the manufacturing industry, both for production processes and for personnel to meet necessary hygiene standards. Water consumption in industrial facilities can be managed in various ways, including the use of equipment such as sensor-operated taps and smart handwashing systems in water usage areas for personnel, leading to savings in water consumption. Smart handwashing systems adjust the mixture of water, soap, and air in the correct proportions, providing not only water savings but also resource efficiency.

- ***The separate collection and treatment of gray water in the facility and its use in areas that do not require high water quality (such as irrigation of green areas, cleaning of floors, etc.)***

  The wastewater generated in industrial facilities includes not only industrial wastewater originating from production processes but also wastewater from showers, sinks, kitchens, etc. Wastewater from areas such as showers, sinks, and kitchens is referred to as gray water. By treating these gray waters through various treatment processes, water savings can be achieved by using them in areas that do not require high water quality.

- ***Recovery of water from rinsing solutions and reuse of recovered water in suitable processes***
  In industrial facilities, rinsing wastewater is relatively clean and can be reused without treatment in processes such as floor cleaning and garden irrigation that do not require high water quality (Öztürk, 2014). The recovery of rinsing water can lead to savings of 1-5% in raw water consumption.

- ***The use of computer-assisted control systems in production processes***
  In industrial facilities, inefficient resource use and environmental problems are directly linked to input-output flows, making it essential to define the input-output of production processes as accurately as possible (TUBİTAK MAM, 2016). This enables the development of measures to enhance resource efficiency and improve economic and environmental performance. Organizing input-output inventories is considered a prerequisite for continuous improvement. Such management practices require the involvement of technical personnel and upper management, while their implementation can quickly pay off through the work of various experts (IPPC BREF, 2003). The use of measurement equipment based on application processes and conducting routine analyses/measurements specific to those processes is necessary. To maximize the benefits from the application, utilizing computerized monitoring systems as much as possible will increase the technical, economic, and environmental benefits obtained (TUBİTAK MAM, 2016).

Computer-Aided Control System

- ***Reuse of filter washing waters in filtration processes, reuse of relatively clean cleaning waters in production processes, and reduction of water consumption by using on-site cleaning systems (CIP)***

  Wastewater generated from backwashing activated carbon filters and softening devices predominantly contains high levels of suspended solids (SS). Backwash waters, one of the easiest types of wastewater to recover, can be filtered and recovered using ultrafiltration plants. This method can lead to water savings of up to 15% (URL - 1, 2021).

  Regeneration wastewater generated after the regeneration process consists of soft waters with high salt content and accounts for approximately 5-10% of total water consumption. The regeneration wastewater can be collected in a separate tank and utilized in processes that require high salt, for facility cleaning, and for domestic uses. This requires a reserve tank, water piping, and a pump. The reuse of regeneration wastewater results in a reduction of about 5-10% in water consumption, energy consumption, the amount of wastewater, and the salt content of the wastewater (Öztürk, 2014). The payback period varies depending on whether the regeneration waters are consumed in production processes, facility cleaning, or domestic uses. In production processes that require high salt, the reuse of regeneration waters (which would result in both water and salt recovery) is expected to have a potential payback period of less than one year. For facility and equipment cleaning and domestic uses, the payback period is estimated to be over one year (TOB, 2021).

  In our country, reverse osmosis (RO) concentrates are combined with other wastewater streams and sent to the wastewater treatment plant channel. Concentrates generated in RO systems, which are used for additional hardness removal, can be utilized for garden irrigation and for internal facility and tank-equipment cleaning (TUBİTAK MAM, 2016; TOB, 2021). Additionally, with the structuring of monitoring for raw water quality, it is also possible to return RO concentrates to the raw water reservoirs and mix them for reuse (TOB, 2021).

- ***Use of pressurized washing systems in equipment cleaning, general cleaning, etc.***

  Water nozzles are commonly used for cleaning equipment facilities. Effective results can be achieved in reducing water consumption and wastewater pollution loads through the use of properly placed and suitable nozzles. The use of active sensors and nozzles at high water consumption points is very important for efficient water use. Significant water savings can be achieved by replacing mechanical equipment with pressurized nozzles (TUBİTAK MAM, 2016). In technically suitable processes, the use of optimized nozzles can lead to reductions in water consumption, wastewater generation, and wastewater pollution load, providing primary environmental benefits in practice.

- ***Avoiding the use of drinking water in production lines***

In different sub-sectors of the manufacturing industry, waters with varying qualities suitable for production purposes can be used. In industrial facilities, raw waters sourced from groundwater are typically treated before being used in production processes. However, in some cases, despite the high cost, drinking waters may be directly used in production processes, or raw waters may be disinfected with chlorine compounds and then utilized in production processes. These waters, which contain residual chlorine, can react with organic compounds present in the water (dissolved organic matter (DOM)), leading to harmful disinfectant by-products for living organisms (Özdemir & Toröz, 2010; Oğur et al.; TOB, 2021). The use of drinking waters containing residual chlorine compounds or raw waters disinfected with chlorine compounds should be avoided as much as possible. Instead of chlorine disinfection, disinfection methods with high oxidation capabilities, such as ultraviolet (UV), ultrasound (US), or ozone, can be used for the disinfection of raw waters. By identifying and using the necessary water quality parameters for each production process, the technical, economic, and environmental benefits of the application can be enhanced, which helps to reduce unnecessary water procurement and treatment costs. This application makes it possible to reduce water, energy, and chemical costs (TUBİTAK MAM, 2016).

Using cooling water as process water in other processes

Cooling systems using water are commonly employed in processes that require significant thermal energy and cooling. The use of heat exchangers in the return of cooling water allows for heat recovery, preventing the contamination of cooling water and increasing cooling water return rates, thus achieving water and energy savings (TUBİTAK MAM, 2016; TOB, 2021). Additionally, if cooling waters are collected separately, it is often possible to use the collected waters for cooling purposes or to reevaluate them in suitable processes (EC, 2009). The reuse of cooling waters can lead to a savings of 2-9% in total water consumption (Greer et al., 2013). Energy consumption savings can also reach up to 10% (Öztürk, 2014; TOB, 2021).

- ***Using automatic control-shutoff valves to optimize water use***

Monitoring and controlling water consumption using flow control devices, meters, and computer-aided monitoring systems provide significant technical, environmental, and economic advantages (Öztürk, 2014). Monitoring the amount of water consumed within the facility and various processes helps to prevent water losses (TUBİTAK MAM, 2016). The use of flow meters and meters throughout the facility and in specific production processes, the use of automatic shutoff valves and valves in continuously operating machines, and the development of monitoring-control mechanisms based on water consumption and certain quality parameters using computer-aided systems are required (TUBİTAK MAM, 2016). This application can achieve water savings of 20-30% on a process basis (DEPA, 2002; LCPC, 2010; IPPC BREF, 2003). By monitoring and controlling water consumption on a process basis, savings of 3-5% in process water consumption can be achieved (Öztürk, 2014).

- ***Documenting production procedures to prevent water and energy waste and ensuring their use by employees***

  To achieve efficient production in an enterprise, effective procedures must be implemented to identify, assess, and control potential problems and resources during the production stages (Ayan, 2010). The establishment and application of appropriate procedures in production processes ensure the more efficient use of resources (such as raw materials, water, energy, chemicals, personnel, and time) and guarantee reliability and quality in production processes (Ayan, 2010). Having documented production procedures contributes to the ability to evaluate business performance and develop rapid reflexes for problem-solving (TUBİTAK MAM, 2016; TOB, 2021). The effective application and monitoring of procedures created for specific production processes are among the most effective ways to ensure product quality, receive feedback, and develop solutions (Ayan, 2010). Documenting, effectively implementing, and monitoring production procedures is a good management practice and an effective tool in structuring and maintaining the clean production approach and environmental management system. While potential benefits exist, the costs of implementation and economic gains may vary depending on the sector or the structure of the facility (TUBİTAK MAM, 2016; TOB, 2021). Although the creation and monitoring of production procedures may not be costly, when considering the savings and benefits it provides, the payback period can be short (TUBİTAK MAM, 2016; TOB, 2021).

- ***Implementing time optimization in production and organizing all processes to be completed in the shortest time possible***

  In industrial production processes, planning the transformation of raw materials into products with the least amount of processes is an effective practice for reducing labor costs, resource utilization costs, environmental impacts, and ensuring efficiency. In this context, it may be necessary to revise production processes to use the minimum number of process steps (TUBİTAK MAM, 2016). In cases where certain deficiencies in basic production processes, inefficiencies, and design flaws prevent the desired product quality from being achieved, the renewal of production processes may be required. Consequently, in such cases, the resource utilization required for the production of a unit quantity of product and the resulting waste, emissions, and solid waste amounts increase. Time optimization in production processes is an effective application (TUBİTAK MAM, 2016).

2.1.4 Measures Related to Auxiliary Processes

METs Related to Cooling Systems

- ***Use of Closed-Loop Cooling Systems to Reduce Water Consumption***

  Closed-loop cooling systems significantly reduce water consumption compared to open-loop systems, which use water more intensively. In closed-loop systems, the same water is recirculated, while usually, an amount of cooling water equal to the evaporated water must be added. By optimizing cooling systems, evaporation losses can also be minimized.

- ***Using Local Dry Air for Cooling During Certain Periods of the Year***

  In periods when the cooling demand is low, water savings can be achieved by using local dry air for cooling.

- ***Reducing Evaporation Losses in Closed-Loop Cooling Water***

  During the cooling process of heated water in cooling systems, a certain amount of water evaporates. Therefore, in closed-loop cooling systems, cooling water is added equivalent to the amount of evaporated water. Evaporation losses can be prevented by optimizing cooling systems. Additionally, practices such as treating the makeup water added to the cooling systems and preventing biological growth in cooling systems can also reduce blowdown amounts. In field studies conducted, blowdown water generated in cooling systems is typically discharged directly into wastewater channels. By reusing cooling system blowdown water, savings of up to 50% in water consumption can be achieved in cooling systems. Implementing this measure may require the establishment of new piping and reserve tanks. (TOB, 2021).

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Cooling Systems (Chiller)

• ***Increasing Cycle Count in Closed-Loop Water Systems by Using Corrosion and Scale Inhibitors***

Refrigerants are chemical compounds that absorb heat from the materials to be cooled, cooling them down, and possess specific thermodynamic properties that affect the performance of the cooling process (Kuprasertwong et al., 2021). In many industrial processes, particularly in product cooling operations, water is used as the refrigerant. During this cooling process, the water can be reused through cooling towers or central cooling systems. If undesirable microbial growth occurs in the cooling water, chemicals can be added to the recirculated water to control it (TUBİTAK MAM, 2016). By reusing cooling water in processes such as cleaning, both water consumption and the amount of wastewater generated can be reduced. However, the need for energy for cooling and recirculating cooling waters presents a side effect. Heat recovery is also achieved through the use of heat exchangers in cooling waters. Generally, closed-loop systems are used in facilities that utilize water cooling systems. However, cooling system blow-offs are directly discharged into the wastewater treatment facility channel for removal. These blow-off waters can be reused in appropriate production processes. Cooling towers and evaporative condensers are efficient and low-cost systems used to remove heat from HVAC and industrial process cooling systems (IPPC BREF, 2001b; TOB, 2021). Over 95% of the water circulating in these systems can be recovered (TUBITAK MAM, 2016). However, because cooling systems operate on the principle of evaporating a portion of the recirculated water, impurities remain within the recirculated water, with their concentration increasing in each cycle. Impurities that can enter the cooling system with air may cause contamination in the recirculation water (TUBITAK MAM, 2016). If impurities and pollutants are not effectively controlled, they may lead to scale and corrosion, unwanted biological growth, and sludge accumulation. This may become a chronic issue, reducing the efficiency of heat transfer surfaces and increasing operating costs. In such cases, it is necessary to implement a water conditioning program tailored to the feedwater quality, cooling water system materials, and operating conditions. This may include controlling blowdown, managing biological growth, preventing corrosion, avoiding hard water use, applying sludge control chemicals, and utilizing filtration and screening systems (TUBITAK MAM, 2016). Additionally, establishing and periodically implementing an effective cleaning procedure and schedule is a best management practice for maintaining cooling systems. Corrosion is a primary concern in cooling systems. As the hardness in the tower recirculation water increases, dissolved solids (such as sulfates, chlorides, carbonates, etc.) that cause scale and deposits will eventually lead to surface degradation. Accumulated deposits also negatively affect heat transfer, reducing energy efficiency. To prevent these issues, a chemical conditioning program for scale and corrosion prevention, disinfection with a biocide to control biological activity, and the chemical and mechanical cleaning of cooling towers at least twice a year are recommended. Additionally, the hardness and conductivity values of makeup water should be kept as low as possible (IPPC BREF, 2001; Kayabek et al., 2005). Proper treatment (conditioning) of makeup water using a suitable treatment system may be necessary to improve its quality, and controlling unwanted microbial growth is also essential (IPPC BREF, 2001b; TOB, 2021). Similar to boilers, blowdown occurs in cooling systems due to micro-deposits and residues in cooling water. Controlled drainage of the cooling system to balance the increasing concentration of solids is known as cooling blowdown. By pre-treating cooling water with appropriate methods and continuously monitoring its quality, biocide usage and blowdown amounts can be reduced (TUBITAK MAM, 2016). Although the investment cost depends on the scale of the application, the expected payback period for investment expenses ranges from 3 to 4 years (IPPC BREF, 2001).

- ***Avoiding Unnecessary Cooling by Identifying Processes that Require Wet Cooling***

  Design parameters such as facility site boundaries and cooling tower height are impacted by this consideration. In cases where reducing the height of the cooling tower is necessary, a hybrid cooling system can be implemented. Hybrid cooling systems are a combination of evaporative and non-evaporative (wet and dry) cooling systems. Depending on the ambient temperature, a hybrid cooling tower can operate entirely as a wet cooling tower or as a combined wet/dry cooling tower (TUBITAK MAM, 2016). In areas with limited cooling water availability or high water costs, reducing the amount of make-up water required for cooling by using dry cooling systems or hybrid cooling systems can be an effective solution (TUBITAK MAM, 2016).

- ***Collecting Surface Runoff through Separate Collection Systems for Use as Cooling or Process Water***

  Most industrial facilities generate wastewater from process-related or non-process-related areas. Treating and reusing this wastewater in appropriate applications can lead to significant savings in various industrial facilities. Surface runoff can be collected through a separate system and used as cooling water (TOB, 2021).

- ***Establishing Water Softening Systems to Ensure the Efficient Operation of Cooling Water Recovery Systems***

  Collected cooling water is either reused for cooling or recycled in appropriate processes (EC, 2009). A water softening system is necessary for this system to operate effectively. Although cooling water quality is suitable for reuse in cleaning and irrigation, additional softening may be needed due to the hardness, which could cause corrosion over time. Before cooling water or process water is reused, it should undergo suitable disinfection. Additionally, through appropriate treatment techniques (such as membrane filtration, advanced oxidation, chemical precipitation, and granular activated carbon adsorption), these waters can be reused not only in cooling processes but across all production processes (TUBITAK MAM, 2016). As the hardness of cooling water increases, scale and deposits form on surfaces, negatively affecting heat transfer, reducing energy efficiency, and increasing energy costs. Increased evaporation within the system raises the ion concentration and conductivity of the water. To prevent these issues, conditioning with scale and corrosion inhibitors, disinfection with a biocide to prevent biological growth, conducting chemical and mechanical cleaning of cooling towers at least twice a year, and maintaining low hardness and conductivity levels are recommended (TUBITAK MAM, 2016).

- ***Increasing the Cycle Count in Closed-Loop Cooling Systems and Improving Make-Up Water Quality to Reduce Water Consumption***

  Water is widely used as a coolant in the manufacturing processes and product cooling stages of the industrial sector. Cooling is achieved by recirculating water through cooling towers or central cooling systems. If unwanted microbial growth occurs in the cooling water, chemicals can be added to the recirculated water to control it (TUBITAK MAM, 2016). By optimizing chemical conditioning in the recirculation process, the cycle count can be increased, reducing the amount of fresh make-up water needed and conserving water. Additionally, well-conditioned make-up water can further enhance the cycle count, leading to additional water savings (TOB, 2021).

Best Available Techniques (BAT) for Ventilation and Air Conditioning Systems

- ***Replacing Old Equipment in Ventilation Systems with Ion Exchange Resins Based on Reverse Osmosis and Reusing Water***

  Ion exchange resins used in ventilation systems bring the conductivity of the output water to a level suitable for equipment cleaning. For example, in a facility in Spain, replacing ventilation system equipment with ion exchange resins yielded output water with a conductivity of around 1000 µS, allowing it to be reused within the system (MedClean, n.d.).

- ***Reusing Condensate from Ventilation Systems***

  During the ventilation cycle, high-quality condensate water can be produced. In a facility in Spain, condensate water with a conductivity of approximately 200 µS from the ventilation system is collected in a tank and used for washing in an automatic galvanizing line (MedClean, n.d.).

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