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A CONCISE REVIEW ON VARIOUS FORMS OF WATER IN PROCESS INDUSTRIES: CHARACTERISTICS, QUALITY REQUIREMENTS, AND APPLICATIONS

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Abstract: Water is an essential resource in process industries, serving various functions, including raw material supply, process operations, heat transfer, cleaning, and utility services. Different industrial applications require specific water quality depending on operational conditions, equipment requirements, and product specifications. This review presents a concise overview of the major forms of water used in process industries, including raw water, clarified water, filtered water, soft water, reverse osmosis (RO) water, demineralized (DM) water, ultrapure water, cooling water, boiler feedwater, wastewater, and reclaimed water. Their characteristics, treatment methods, key quality parameters, and industrial applications are discussed. Particular attention is given to important water quality indicators, such as pH, total dissolved solids (TDS), turbidity, hardness, conductivity, silica, total organic carbon (TOC), and microbiological content. The review also highlights the importance of selecting appropriate water treatment technologies to minimize scaling, corrosion, fouling, contamination, and equipment deterioration. Furthermore, the growing importance of wastewater treatment, water recovery, and reuse is emphasized in promoting sustainable industrial operations. Despite advancements in water treatment technologies, challenges such as high energy consumption, membrane fouling, chemical usage, concentrate disposal, and operational costs remain significant. Emerging technologies, including advanced membrane systems, advanced oxidation processes, intelligent water monitoring, and zero-liquid-discharge systems, offer promising opportunities for improving water efficiency and sustainability. Overall, this review highlights the importance of appropriate water quality management in ensuring process efficiency, equipment reliability, product quality, and environmental sustainability across various industrial sectors.

Keywords: *Industrial water; Water quality; Water treatment; Water reuse; Sustainable management.*

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Introduction

Water is an essential resource in process industries, serving as a raw material, process medium, heat-transfer fluid, cleaning agent, and utility. Industries such as oil and gas, petrochemicals, power generation, pharmaceuticals, food and beverages, mining, and manufacturing require water of different quality levels depending on the intended application [1]. Natural water sources contain varying concentrations of dissolved minerals, suspended solids, organic compounds, and microorganisms. Consequently, physical, chemical, and membrane-based treatment processes are employed to produce water that meets specific industrial requirements. The major forms of industrial water include raw, clarified, filtered, softened, reverse osmosis (RO), demineralized (DM), ultrapure, cooling, boiler feed, wastewater, and reclaimed water.

Types of Water in Process Industries

Raw Water:

Raw water is obtained from natural sources, including rivers, lakes, groundwater, and seawater. Its composition depends on the source and may include suspended solids, dissolved salts, hardness, organic matter, and microorganisms [2]. It generally requires pretreatment before industrial use.

Clarified Water:

Clarified water is produced through coagulation, flocculation, sedimentation, and sometimes filtration to remove suspended solids, colloidal particles, and turbidity [3]. It is commonly used as an intermediate water supply for further purification and general utility applications.

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Filtered Water:

Filtered water is obtained by passing water through media filters, cartridge filters, or other filtration systems to remove suspended particles and residual impurities [4]. It is frequently used as feedwater for membrane systems and industrial utility services.

Soft Water:

Soft water is produced by removing hardness-causing calcium and magnesium ions, commonly through sodium-cycle ion exchange [5]. It reduces scale formation in heat exchangers, washing systems, and boiler pretreatment applications.

Reverse Osmosis (RO) Water:

RO water is produced by applying pressure to feedwater across semipermeable membranes, thereby reducing dissolved salts, organic compounds, and other contaminants [6]. It is widely used as process water and as feedwater for further purification systems.

Demineralized (DM) Water:

DM water is produced by removing dissolved ionic impurities through ion exchange, reverse osmosis combined with polishing, or electrodeionization [7]. It has low mineral content and is particularly important in power generation, chemical processing, and high-pressure boiler systems.

Ultrapure Water (UPW):

Ultrapure water undergoes advanced purification involving combinations of RO, ion exchange, electrodeionization, ultraviolet treatment, ultrafiltration, and polishing [8]. It has extremely low concentrations of ionic, organic, particulate, and microbiological contaminants and is essential for semiconductor, pharmaceutical, and other critical manufacturing applications.

Cooling Water:

Cooling water is circulated through heat exchangers and cooling towers to remove heat from industrial equipment and processes [9]. It is generally conditioned using chemical treatment to control scaling, corrosion, fouling, and biological growth.

Boiler Feedwater:

Boiler feedwater is specially treated water supplied to boilers for steam generation [10]. It may originate from DM water or condensate recovery systems and requires appropriate control of dissolved oxygen, hardness, silica, conductivity, and pH to prevent scaling and corrosion.

Wastewater and Reclaimed Water:

Wastewater is generated from industrial operations, equipment cleaning, cooling systems, and process activities, containing varying levels of dissolved chemicals, suspended solids, oils, and organic pollutants [11]. Following suitable physical, chemical, and biological treatment, reclaimed water can be reused for cooling, washing, irrigation, and selected industrial processes.

Comparison of Different Types of Industrial Water

Industrial water types differ in their physical, chemical, and microbiological characteristics depending on the treatment processes employed and their intended applications. Comparing these water types helps identify their key quality characteristics, treatment requirements, and suitability for different industrial operations. Table 1 summarizes the major forms of industrial water and their distinguishing characteristics and typical treatment methods.

Table 1. Characteristics and proposed treatment methods for various of types of water used in process industries

Water type	Main characteristics	Proposed treatment methods
Raw water	Variable dissolved and suspended impurities	Source-dependent pretreatment
Clarified water	Reduced turbidity and suspended solids	Coagulation, flocculation, sedimentation
Filtered water	Reduced particulate matter	Sand, multimedia, or cartridge filtration
Soft water	Low calcium and magnesium hardness	Ion exchange softening
RO water	Reduced dissolved salts and contaminants	Membrane separation
DM water	Very low dissolved ionic content	Ion exchange, RO and polishing
Ultrapure water	Extremely low ionic, organic, and particulate contamination	Advanced multi-stage purification
Cooling water	Heat-transfer water requiring chemical conditioning	Filtration and chemical treatment
Boiler feedwater	High-purity water suitable for steam generation	Deaeration, DM treatment and conditioning
Wastewater	Contains process-related contaminants	Physical, chemical and biological treatment
Reclaimed water	Treated wastewater suitable for designated reuse	Advanced wastewater treatment

INDUSTRIAL APPLICATIONS OF DIFFERENT TYPES OF WATER

The selection of water depends on the process requirements, equipment design, operating conditions, and applicable industry standards (Table 2).

Table 2. Applications of various of types of water used in process industries

Water type	Major industrial applications	Industry examples
Raw water	Initial water supply and pretreatment feed	Oil and gas, mining, power plants
Clarified water	General plant services, filtration feed, firewater storage (subject to specifications)	Refineries, petrochemical plants
Filtered water	RO feedwater, equipment washing, utility services	Manufacturing, chemical plants
Soft water	Boiler pretreatment, washing, heat exchangers	Textile, food processing, manufacturing
RO water	Process water, cooling system makeup, DM plant feed	Refineries, pharmaceuticals, power plants
DM water	Boiler makeup, steam generation, chemical preparation	Thermal power plants, petrochemical industries
Ultrapure water	Critical equipment cleaning and high-purity manufacturing processes	Semiconductor, pharmaceutical, electronics industries
Cooling water	Condenser cooling, heat exchangers, process cooling	Refineries, power plants, chemical industries
Boiler feedwater	Steam generation and turbine-related systems	Thermal power plants, refineries, paper mills
Wastewater	Collection and treatment of industrial effluents	All major process industries
Reclaimed water	Cooling tower makeup, equipment washing, selected process uses	Petrochemical, mining, manufacturing industries

Water Quality Parameters and Typical Requirements

Industrial water quality is assessed using physical, chemical, and microbiological parameters. The required limits vary significantly depending on the application, operating pressure, temperature, equipment specifications, and relevant industry standards. The following table presents indicative characteristics rather than universal acceptance limits. Important: Boiler feedwater and cooling water do not have universal quality specifications; their acceptance limits must be established according to boiler pressure, metallurgy, cooling-system design, chemical treatment programme, and applicable standards such as ASME and relevant industry guidelines (Table 3).

Table 3. Key quality parameters of various of types of water used in process industries

Water type	Key quality parameters	Typical quality considerations
Raw water	pH, TDS, turbidity, hardness, alkalinity, TOC, microbiological content	Highly variable depending on source
Clarified water	Turbidity, suspended solids, pH, alkalinity	Low suspended solids and turbidity
Filtered water	Turbidity, SDI, suspended solids	Low particulate loading, particularly for RO feed
Soft water	Total hardness, pH, conductivity, sodium	Very low residual calcium and magnesium hardness
RO water	TDS, conductivity, pH, silica, TOC, SDI	Significant reduction in dissolved salts and contaminants
DM water	Conductivity, silica, hardness, sodium, TOC, pH	Very low ionic content and negligible hardness
Ultrapure water	Resistivity, TOC, particles, bacteria, silica	Resistivity approaching 18.2 MΩ·cm at 25°C for high-purity applications

Cooling water	pH, conductivity, hardness, alkalinity, chloride, silica, microbiological count	Controlled scaling, corrosion, fouling and biological growth
Boiler feedwater	pH, dissolved oxygen, conductivity, hardness, silica, iron, copper	Strict control of impurities according to boiler pressure and design
Wastewater	pH, BOD, COD, TSS, TDS, oil and grease, nutrients, metals	Contaminant levels depend on industrial process
Reclaimed water	TDS, turbidity, COD, BOD, TSS, microbiological count, nutrients	Quality must satisfy the intended reuse requirements

Conclusion

Different forms of water are indispensable to process industries, with their quality and treatment requirements determined by specific operational and equipment needs. Appropriate water selection and treatment are essential for maintaining process efficiency, equipment reliability, product quality, environmental compliance, and sustainable industrial operations. Industrial water treatment involves challenges associated with high energy consumption, membrane fouling, chemical usage, concentrate disposal, operating costs, and variability in raw water quality. Future developments will increasingly focus on energy-efficient membrane technologies, advanced oxidation, smart water monitoring, digital process optimization, zero-liquid-discharge systems, and greater wastewater recovery and reuse to improve industrial water sustainability.

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