Multi-Stage Water Purification System

Stage 1: Oxidation for Manganese Removal

Stage One removes manganese by first oxidizing the soluble (Mn(II)) form into insoluble manganese oxide (MnO_2) particles, which are then filtered out using either a Greensand filter or an aeration and filtration system. Aeration uses dissolved oxygen to convert Mn(II) to MnO_2, while Greensand filters use a manganese-coated media to catalyze the oxidation and filtration process. Both methods remove manganese to improve water taste and prevent staining.

How the process Work:

1. **Oxidation:**
   Dissolved manganese (Mn(II)) is converted into insoluble manganese dioxide (MnO_2).
   - **Aeration:**
     Air is introduced into the water to provide dissolved oxygen, which oxidizes Mn(II) into MnO2 particles.
   - **Greensand Filtration:**
     The water flows through a filter bed containing Greensand media, which has a manganese-oxide coating. This coated surface acts as a catalyst, promoting the oxidation of Mn(II) into MnO_2.
2. **Filtration:**
   The insoluble manganese dioxide particles are then trapped and removed by the filter media, which can be Greensand or other filter materials like sand.
3. **Backwashing:**
   The filter is periodically cleaned by reversing the water flow (backwashing) to remove the accumulated manganese oxides from the filter bed.

Purpose:

- **Aesthetic Quality:**
  Removes dissolved manganese that causes black staining, bitter taste, and metallic odors in water.
- **Health Considerations:**

Addresses potential health concerns linked to high manganese exposure, although EPA guidelines are typically for aesthetics rather than direct toxicity at lower levels.

- **Preventing Staining:**
  Eliminates manganese deposits that can cause black staining on fixtures and laundry.

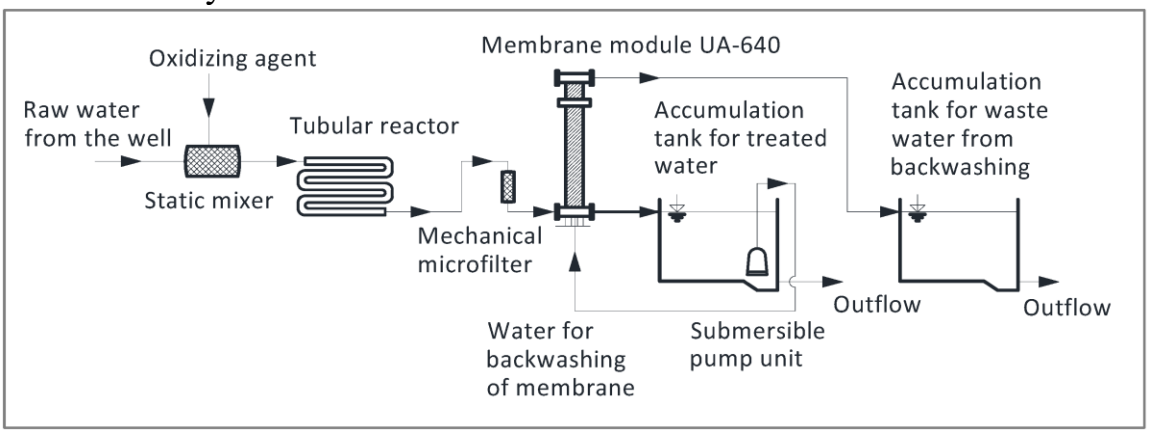

Figure 1:STAGE 1:OXIDATION FOR MANGANESE

Stage 2: Heavy Metal Adsorption and Chemical Reduction

In the advanced adsorption stage, heavy metals like lead (Pb) and mercury (Hg) are removed by activated carbon and KDF media. Activated carbon adsorbs these metals through strong physical and chemical interactions on its high-surface-area pores, while KDF acts as a redox medium. For mercury, KDF can convert toxic Hg^{2+} ions to elemental mercury (Hg^0), which then adsorbs onto the carbon. For lead, both the carbon and KDF media can bind Pb^{2+} ions through complexation and ion exchange, though the specific reactions are complex and not represented by a single universal chemical equation.

Simplified Chemical Interactions:

- **Mercury Removal (Simplified):**
  - **Reduction by KDF:** $Hg^{2+}(aq) + 2e^-$ (from KDF) $\rightarrow Hg^0(s)$
  - **Adsorption by Activated Carbon:** $Hg^0(s)$ + C (activated carbon surface) $\rightarrow$ Hg-C (adsorbed mercury)
- **Lead Removal (Simplified):**
  - **Complexation with Carbon:** $Pb^{2+}(aq)$ + C-OH (carbon surface functional group) $\rightarrow$ Pb-OH-C (complex) + H^+

- **Adsorption with KDF:** The interaction is complex, involving redox reactions and ion exchange, where Pb^{2+} ions replace other ions on the KDF surface, or are oxidized and precipitate.

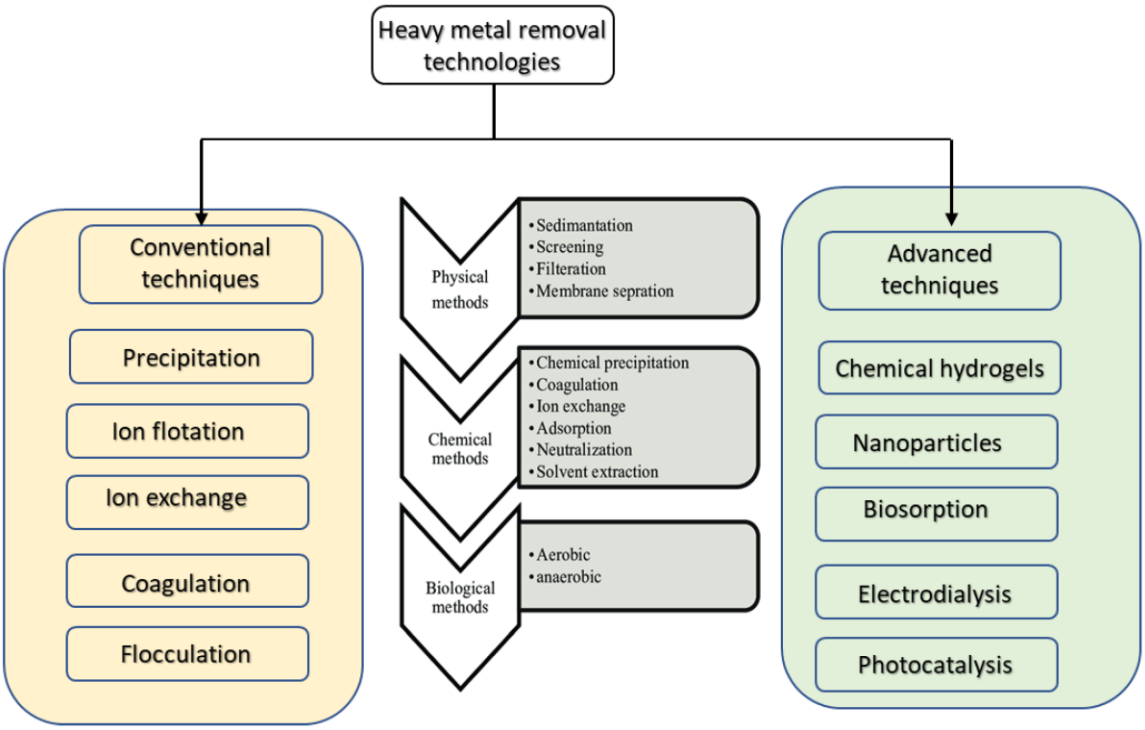

Figure 2:HEAVY METAL ADSORPTION

Stage 3: pH Balancing and Remineralization

Alkaline remineralization reintroduces vital minerals, particularly calcium and magnesium, to purified water, raising its pH and improving taste. A common method involves passing water over a bed of limestone (calcium carbonate) or dolomite (calcium magnesium carbonate), where dissolved minerals, such as calcium, magnesium, and bicarbonate, are slowly added to the water.

The Process:

Mineralization:

The water flows through a bed containing alkaline mineral-rich media, such as limestone ($CaCO_3$) or dolomite ($CaMg(CO_3)_2$).

Chemical Equations

The specific chemical equations depend on the mineral media used, but common examples include:

- Using Limestone (Calcium Carbonate - $CaCO_3$):

- Water dissolves limestone over time:
  $CaCO_3(s) + H_2O(l) \rightleftharpoons Ca^{2+}(aq) + HCO_3^-(aq) + OH^-(aq)$
- Using Dolomite (Calcium Magnesium Carbonate - $CaMg(CO_3)_2$):
- Dolomite dissolves, adding both calcium and magnesium:
  $CaMg(CO_3)_2(s) + 2H_2O(l) \rightleftharpoons Ca^{2+}(aq) + Mg^{2+}(aq) + 2HCO_3^-(aq) + 2OH^-(aq)$
- Reactions with Dissolved CO_2 (often present):
- The introduced bicarbonate ions react with dissolved carbon dioxide to help buffer the pH:
  $CO_2(aq) + OH^-(aq) \rightleftharpoons HCO_3^-(aq)$

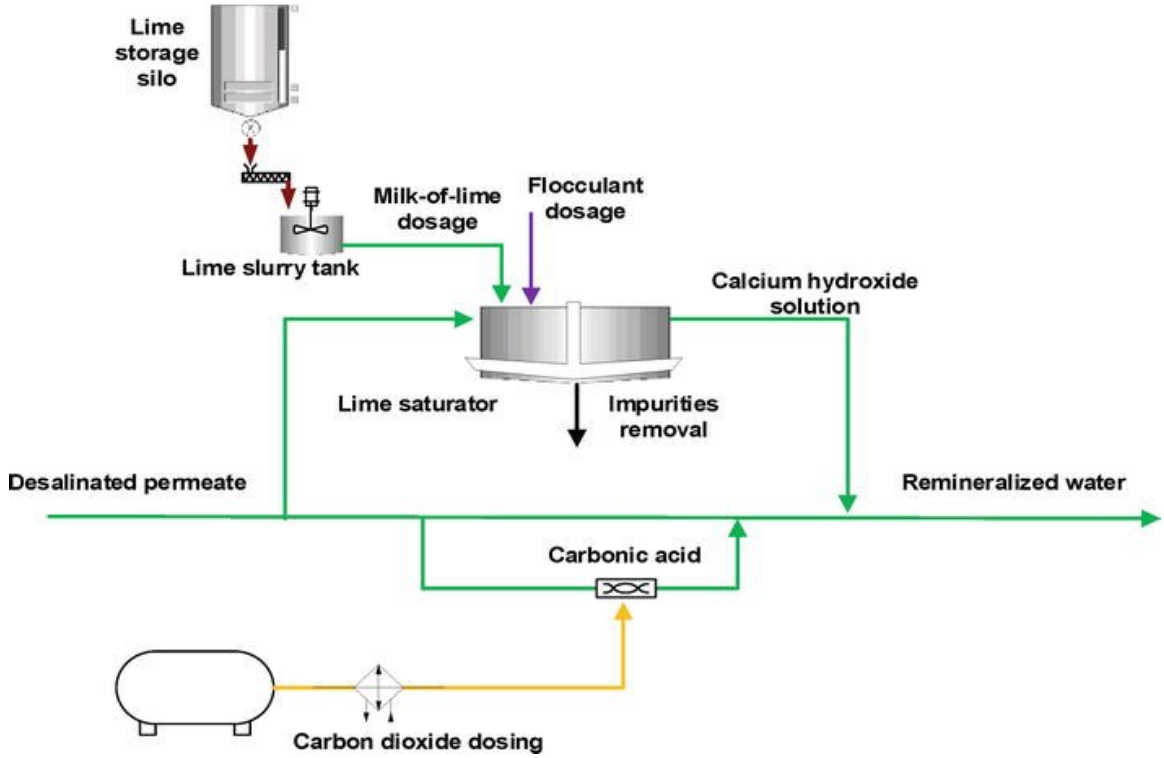

Figure 3:ALKALINE REMINERALIZATION

Smart Water Monitoring & Purification Device:

The system is designed to **detect and purify** five critical parameters:
pH, Lead (Pb), Mercury (Hg), Manganese (Mn), and Magnesium (Mg)
It integrates **ESP32-S3** sensors for real-time data monitoring and uses **multi-stage filtration** for purification.

Major Filtration Stages in the Smart Water Purification Device

Stage	Filtration Process	Purpose / Target	Description

		Pollutant	
Stage 1: Oxidation + Filtration	Greensand or Aeration	Manganese (Mn^{2+})	Oxidizes dissolved Mn^{2+} to insoluble MnO_2, filtered out easily.
Stage 2: Adsorption + Ion Exchange	Activated Carbon + Resin Filter	Lead (Pb^{2+}), Mercury (Hg^{2+})	Heavy metal ions are trapped by carbon pores and exchanged with harmless ions like Na^+ or H^+.
Stage 3: pH Conditioning and Mineral Balance	Calcite Filter + Reverse Osmosis	pH and Magnesium (Mg^{2+})	Adjusts acidity/alkalinity and removes excess minerals for balanced water.

Pollutants and Their Removal Methods with Chemical Reactions

(a) pH – Hydrogen Ion Concentration

- **Problem:**
  - pH measures **hydrogen ion concentration** in water:
  - $\text{pH} = -\log_{10}[H^+]$
  - Ideal **drinking water pH**: **6.5 – 8.5 (neutral to slightly alkaline)** Outside this range, water becomes **corrosive (acidic)** or **scale-forming (alkaline)**.

Adjustment Reactions:

1. Making Water Alkaline (raising pH):

Neutralizes acidity by adding basic compounds such as lime ($Ca(OH)_2$) or soda ash (Na_2CO_3).

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 \downarrow + 2H_2O$$

2. Making Water Acidic (lowering pH):

If pH is too high, acids like CO_2, H_2SO_4, or HCl are added carefully.

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$$

3. Balancing to Neutral (7.0):

Automated pH sensor feedback (e.g., **DFRobot pH Sensor V2**, **Gravity**

Analog pH Meter – available in Pakistan) adjusts chemical dosing dynamically.

(b) Lead (Pb^{2+})

Pollutant:

Lead ions originate from corroded pipes or industrial discharge — **toxic to nervous system**.

Removal Method:

Chemical precipitation & adsorption using lime softening, activated carbon, or ion exchange.

$$Pb^{2+} + SO_4^{2-} \rightarrow PbSO_4 \downarrow$$

or

$$Pb^{2+} + 2OH^- \rightarrow Pb(OH)_2 \downarrow$$

Real Process:

- **Filtration Stage:**
  Activated carbon or reverse osmosis removes Pb ions.
- **R&D Sensors (Pakistan):**
  DFRobot Lead Ion Sensor (ISE), **Atlas Scientific Pb^{2+} ISE Probe** – used with **ESP32** monitoring system.

(c) Mercury (Hg^{2+})

Pollutant:

Mercury arises from **chlor-alkali industries**, **batteries**, and **effluent**; it bioaccumulates in tissues — extremely **toxic**.

Removal Method:

Chemical Reduction and Precipitation

1. Reduction of Hg^{2+} to elemental Hg:
$$Hg^{2+} + H_2 \rightarrow Hg^0 + 2H^+$$
2. Sulfide precipitation:
$$Hg^{2+} + S^{2-} \rightarrow HgS \downarrow$$

Application:

- **Activated carbon adsorption** after precipitation for polishing.
- **Sensor Example (Pakistan): ISE Mercury Ion Electrode (Hg^{2+})** available via **DFRobot** or **Alibaba.pk**.

(d) Manganese (Mn^{2+})

Pollutant:

Occurs naturally or from mine runoff; causes **taste**, **color**, and **scaling** problems.

Removal Method:

Oxidation followed by Filtration

1. Oxidation with Potassium Permanganate:

$$3Mn^{2+} + 2KMnO_4 + 2H_2O \rightarrow 5MnO_2 \downarrow + 4H^+ + 2K^+$$

2. MnO_2 (manganese dioxide) acts as a **self-catalyst** on greensand filter beds.

Application:

- **Stage One** in filtration unit (Greensand or Aeration + Sand filter)
- **Sensor Example: DFRobot Gravity Mn^{2+} Ion Sensor** (available in Pakistan through **ElectronicsPoint.pk** or **PakElectronics.com**)

(e) Magnesium (Mg^{2+})

Pollutant:

Though essential, excess Mg^{2+} contributes to **hardness** of water.

Removal Method:

Ion Exchange or Precipitation (Lime Softening)

$$Mg^{2+} + 2OH^- \rightarrow Mg(OH)_2 \downarrow$$

In Lime Softening:

$$Mg(HCO_3)_2 + 2Ca(OH)_2 \rightarrow 2CaCO_3 \downarrow + Mg(OH)_2 \downarrow + 2H_2O$$

Application:

- **RO + Ion Exchange** to remove residual Mg^{2+}.
- **Sensor Example: DFRobot Magnesium Ion Sensor** (ISE type).

Summary Table — Pollutants and Removal Reactions

Parameter	**Typical Source**	**Removal Method**	**Chemical Reaction**	**Reaction Output**	**Example Sensor (Available in Pakistan)**
pH (H^+)	Acidic/basic imbalance	Neutralization	$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3\downarrow + 2H_2O$	Neutral pH 7 water	DFRobot pH V2, Gravity pH Meter

Parameter	Typical Source	Removal Method	Chemical Reaction	Reaction Output	Example Sensor (Available in Pakistan)
Lead (Pb^{2+})	Pipes, paints, effluent	Precipitation / Adsorption	$Pb^{2+} + 2OH^- \rightarrow Pb(OH)_2\downarrow$	Pb removed as sludge	DFRobot Pb^{2+} ISE Sensor
Mercury (Hg^{2+})	Industrial waste	Sulfide Precipitation	$Hg^{2+} + S^{2-} \rightarrow HgS\downarrow$	Mercury sulfide precipitate	Mercury ISE Probe
Manganese (Mn^{2+})	Groundwater, mining	Oxidation + Filtration	$3Mn^{2+} + 2KMnO_4 + 2H_2O \rightarrow 5MnO_2\downarrow + 4H^+ + 2K^+$	Solid MnO_2 filtered	DFRobot Mn^{2+} ISE
Magnesium (Mg^{2+})	Natural minerals	Lime softening	$Mg(HCO_3)_2 + 2Ca(OH)_2 \rightarrow 2CaCO_3\downarrow + Mg(OH)_2\downarrow + 2H_2O$	Mg precipitated	DFRobot Mg^{2+} ISE