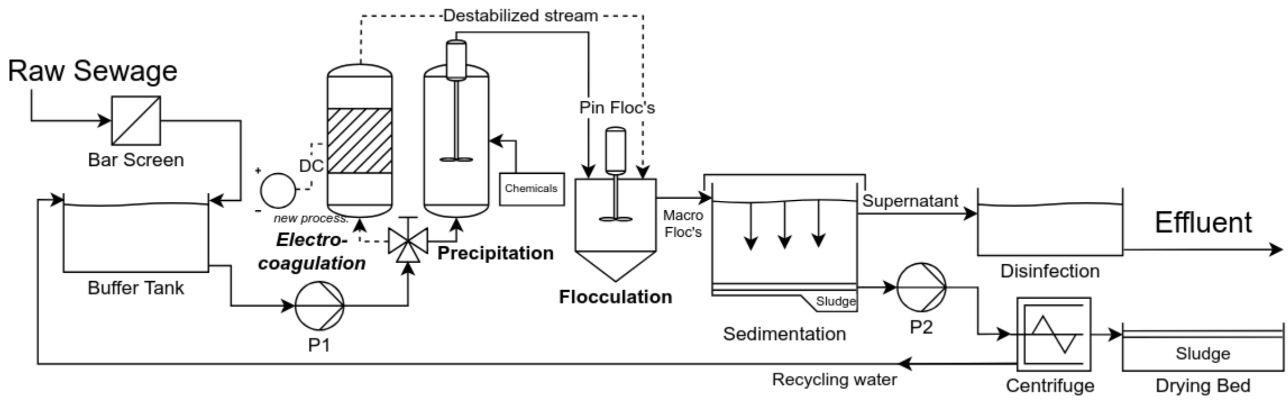
HSLU Hochschule Luzern

Presentation handout

Separation techniques at ARA Rhein WWTP: Precipitation, Flocculation, and EC



Principle of Sustainable Environmental Systems

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1 Introduction

Water is in a constant cycle, being renewed and consumed repeatedly. To minimize the environmental impact of modern civilization, humans have developed complex systems, Wastewater Treatment Plants (WWTPs), to purify the wastewater we produce. They ensure safety and our continued coexistence with nature as we use water as a resource.

Through innovative processes, it has become possible to separate, extract, and neutralize harmful substances in sewage. These include large solids such as plastics and food waste, oils and grease, suspended solids, and organic matter. The subsequent effluent is clean enough to protect the local ecosystem, while the process itself enables the recovery of valuable resources such as phosphorus and energy.

This handout will explore specific separation techniques using ARA Rhein as a primary case study. This facility is particularly relevant due to its mix of communal and industrial treatments.

1.1 ARA Rhein

ARA Rhein is one of the major WWTPs in Switzerland. It is located along the River Rhine, approximately 10 km upstream of Basel. The treatment plant started operations in 1975 (Wikipedia, 2025). In 2019, the plant was modernized by adding a dissolved air flotation unit (ARA Rhein AG, 2019). More investments are being made to make the plant future-proof, with annual investments of 6 to 10 million Swiss francs (ARA Rhein AG, 2025a).

While industrial wastewater makes up only 40% of the hydraulic volume (2.5 billion liters annually), it contributes 90% of the pollution load (450'000 PE). In contrast, communal sources account for the remaining 60% of the volume (3.5 billion liters) but only 10% of the pollution load (50,000 PE) (ARA Rhein AG, 2025b).

To improve energy efficiency, ARA Rhein feeds 6.4 GWh of waste heat generated by the incineration process into the local heating grid. That is 17% of its total energy consumption of 38.2 GWh (ARA Rhein AG, 2025b). Additionally, ash from the incineration is stored in the Elbisgraben landfill for future phosphorus recycling. Also, odorous emissions from communal wastewater are purified to reduce the strain on the surrounding area (ARA Rhein AG, 2025a).

2 Separation techniques

In WWTPs, separation techniques are essential for removing contaminants at different stages of the process. As each method targets a specific pollutant, applying them in the correct order and combination is vital for maximizing the efficiency of the treatment process. At ARA Rhein, the general flow consists of mechanical treatment, chemical treatment, biological treatment, sludge treatment, off-gas treatment, and finally resource recovery and monitoring. Additionally, the WWTP uses two different process flows for the communal wastewater and the industrial wastewater.

The communal wastewater is first processed by mechanical treatment, which consists of a bar screen, a grit chamber and a clarifier that remove suspended solids. Then it passes through a biological treatment where microorganisms remove organic compounds. Finally, the treated water is safely released into the River Rhine, while the sludge is processed in a separate treatment.

The industrial wastewater is treated slightly differently due to the characteristics of the contaminants found in the water. Industrial wastewater often contains fewer big solids and mainly consists of hazardous chemicals. As a result, the industrial wastewater only needs minimal mechanical treatment to ensure safe operation. Importantly, it undergoes chemical treatment and then goes through an additional biological treatment step. Finally, after this pretreatment, the stream joins the biological treatment of the communal wastewater for further cleaning.

The sludge produced by the biological treatment of both the communal and industrial wastewater is then thickened and incinerated, converting it into ash, which is transported to the Elbisgraben landfill (ARA Rhein AG, 2025a).

A detailed diagram (Figure 5) describes the entire process.

Electrocoagulation, flocculation, and precipitation have been chosen from the chemical treatment section for further analysis. In Figure 1, a hypothetical wastewater treatment process visualizes how ARA Rhein could implement the discussed methods.

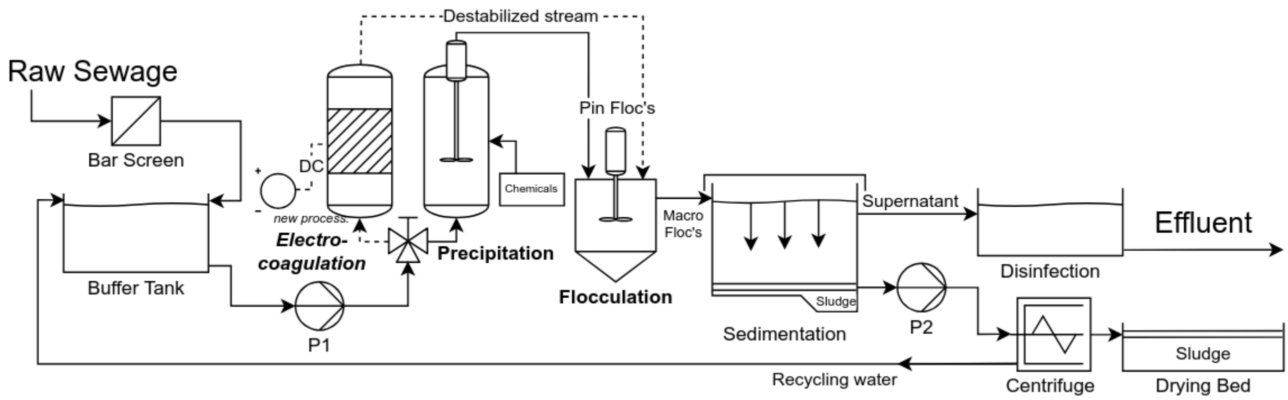

Figure 1: Hypotetical wastewater treatment process including EC, precipitation, and flocculation.

2.1 Precipitation

Chemical precipitation in wastewater treatment is a process in which dissolved pollutants are converted into insoluble solids (precipitates) through the addition of specific chemicals known as precipitants (Kato & Kansha, 2024; Verband Schweizer Abwasser- und Gewässerschutzfachleute, n.d.). In this process, iron or aluminium salts are typically used as reagents, though calcium-based compounds may be used for specific dissolved substances. To remove the precipitates, a physical separation technique such as filtration must follow (Almawatech, 2025).

According to the ARA Rhein treatment scheme, the facility adds a chemical step for industrial wastewater. In this stage, the wastewater is neutralized and pre-clarified. ARA Rhein also has a microflotation system that acts as a precipitation chamber, using polyaluminium chloride along with flocculation methods to ensure effective separation. By combining precipitation with flocculation, a significant portion of non-soluble matter is removed prior to biological treatment (DAS Environmental Experts GmbH, 2023).

The primary advantage of precipitation is the removal of dissolved contaminants, such as phosphates, which generally cannot be eliminated through biological or mechanical treatment alone. This improves effluent quality, allowing ARA Rhein to meet strict discharge standards. Furthermore, the subsequent biological treatment process benefits greatly in efficiency, due to the added concentration of pollutants coming from industrial wastewater sources.

However, the process has disadvantages. The precipitate and pollutants that are captured generate significant quantities of sludge, which needs to be further processed, adding more costs (Koul et al., 2022). Moreover, the efficiency and success of the process heavily depend on controlled pH and reaction conditions. Small deviations from optimal conditions can cause incomplete removal or generate excess sludge.

2.2 Flocculation

Flocculation is a separation method used to remove tiny, suspended particles from a liquid by making them clump together into larger, heavier aggregates called flocs (International Union of Pure and Applied Chemistry (IUPAC), 1972).

2.2.1 Flocculation separation procedure

We consider a system boundary which consists of water containing impurities in the form of tiny particles which are lightly charged and do not settle on their own due to electrostatic repulsion.

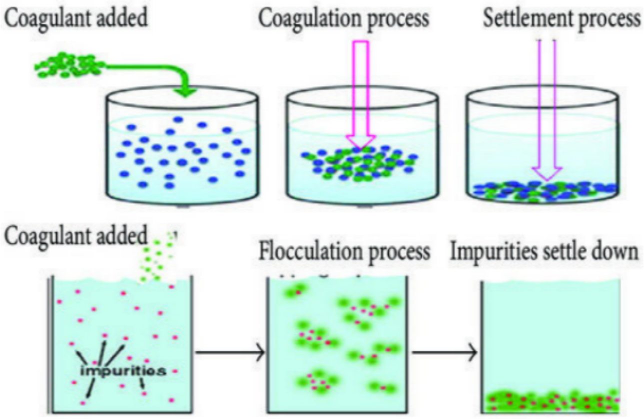

Figure 2: General flocculation process

A compound such as ferric chloride is added to neutralize the charges on the particles, making them less likely to repel each other. Gentle mixing is then applied, and the neutralized particles start colliding and sticking, forming visible flocs. Once the flocs form, they can be removed by sedimentation once they settle to the bottom, or they can be filtered out. Figure 1 illustrates the general process of flocculation as described above (Ion Exchange, n.d.).

2.2.2 Application of flocculation at ARA Rhein wastewatertreatment plant

Flocculation forms part of the chemical treatment steps taken at ARA Rhein WWTP. Wastewater can contain high amounts of insoluble phosphorus compounds which can lead to eutrophication (excessive nutrient enrichment) if released to water bodies (Edmondson, 1970). ARA Rhein utilizes a flocculation-flotation stage to remove the insoluble impurities. Figure 3 illustrates the control volume, enclosed in a dotted region, of the setup at ARA Rhein. The incoming water is dosed with a cationic polymer which acts as the flocculant. The flocculant binds phosphates present in the water. The mixture then flows into a flotation chamber. In this stage, tiny air bubbles are injected into the water and get attached to the flocs, making them buoyant. The flocs then float upwards where they are skimmed off. This process, as applied above, results in $> 90\%$ separation of suspended solids.

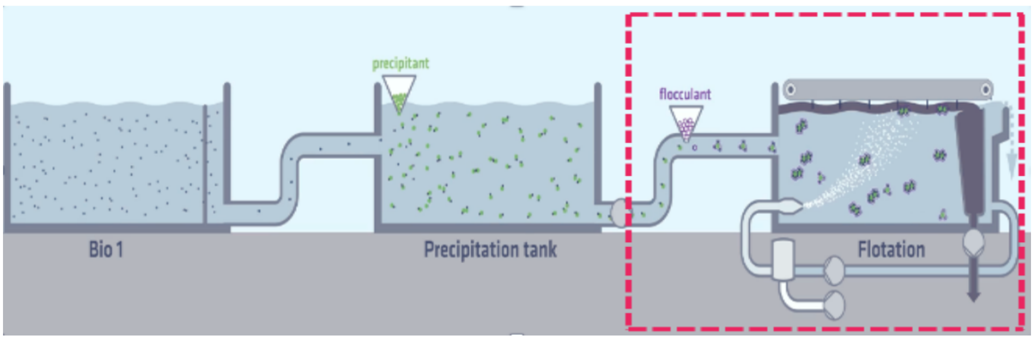

Figure 3: Flocculation-flotation process at ARA Rhein WWTP

2.3 Electrocoagulation

Electrocoagulation (EC) is a chemical separation technique that relies on the controlled sacrifice of a less noble metal in a fluid through the application of electric current to coagulate materials in water.

2.3.1 Anode and Cathode

The anode and cathode are two conductive metal plates (electrodes) connected to a direct current power source. The anode is positively charged, while the cathode is negatively charged.

This positively charged electrode sacrifices itself, oxidizing to cause contaminants in the water to coagulate via its released ions. It is typically made of Al or Fe, which releases Al^{3+} or Fe^{2+} ions upon oxidation.

On the other hand, the cathode is where the reduction takes place, transferring electrons to the water molecules and splitting them to generate gas bubbles, usually hydrogen bubbles, that help float pollutants to the surface.

2.3.2 EC reactor and hydrolysis reaction

In the EC reactor, both electrodes are immersed in water. The anode oxidizes and causes the metal ions to spread into the wastewater, whilst the cathode, reduced in the water, releases hydrogen bubbles. The dissolved metal ions hydrolyze, forming metal hydroxide species, such as $Al(OH)_3$, that act as direct coagulants (Nguyen et al., 2025).

Hydrolysis is a chemical reaction that consists of the scission of a polymer into monomers, with the addition of a water molecule for each covalent bond that is split. In electrocoagulation, this reaction occurs when the anode ions react with water molecules to form insoluble metal hydroxides. Hydroxides act as the active coagulants that neutralize charges and catch pollutants to separate them from the wastewater (Kempegowda et al., 2023).

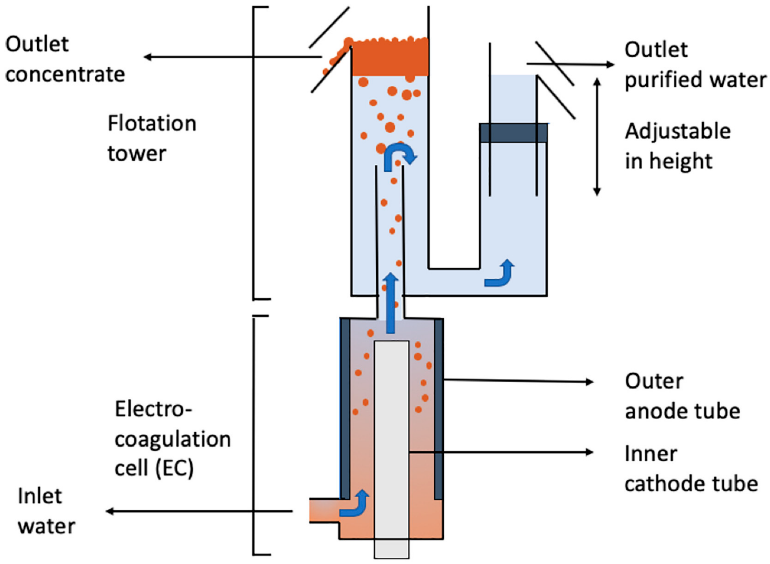

Figure 4: Electrocoagulation reactor schematic

Main reaction (with iron electrodes) (Casillas et al., 2007):

Anode dissolution:

$$Fe \rightarrow Fe^{2+} + 2e^-$$

Cathode reaction:

$$2H_2O + 2e^- \rightarrow H_2 \uparrow + 2OH^-$$

Formation of ferrous hydroxide:

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

Oxidation to ferric hydroxide (Floc):

$$4Fe^{2+} + 10H_2O + O_2 \rightarrow 4Fe(OH)_3 \downarrow + 8H^+$$

Legend:

- $\uparrow$ Release of gas (hydrogen bubbles);
- $\downarrow$ Creation of precipitate (floc).

2.3.3 Potential for ARA Rhein

Currently, ARA Rhein does not utilize electrocoagulation. By installing EC reactors between the buffer tanks and flocculation units, the water cleaning effectiveness would increase. Additionally, it would improve the separation quality of heavy metals and pharmaceutical residues. Furthermore, because EC avoids the addition of counter-ions (like sulfate or chloride found in chemical salts), it has the potential to produce a denser, more stable floc, thereby reducing the overall sludge volume, lowering costs, and increasing capacity.

3 Conclusion

In conclusion, reducing the number of pollutants in wastewater is crucial before reuse or environmental release to minimize contamination and eutrophication. As seen in this study, the process of purifying wastewater can vary depending on the nature of the pollutants present.

The ARA Rhein case study illustrates two main separation techniques and a potential third method: flocculation, precipitation, and electrocoagulation. Precipitation first converts dissolved pollutants into insoluble solids, followed by flocculation, which aggregates these fine particles into larger flocs for easier separation. Furthermore, electrocoagulation was examined as a potential additional step.

With the inclusion of electrocoagulation, ARA Rhein could improve the removal of complex contaminants like heavy metals and pharmaceutical residues. However, it is important to note that sludge is a significant by-product of these processes and requires careful handling and disposal.

List of Figures

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Declarations on the use of AI tools

- "*ChatGPT 5.1*" was used to enhance vocabulary.
  All original sentences originate from our own ideas and were refined with the support of this tool.
  https://chatgpt.com/
- "DeepL" was used as a spell-checker.
  https://www.deepl.com
- "Google Gemini" was used as a fact-checker.
  https://gemini.google.com/app

A Appendix

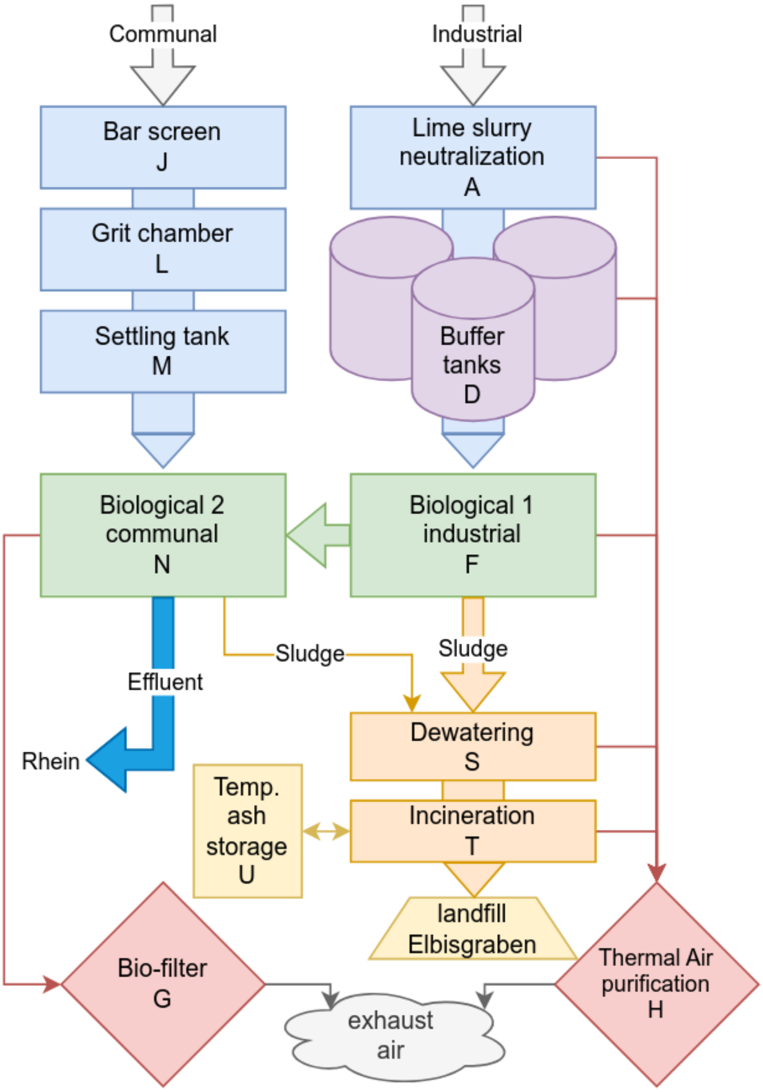

Figure 5: ARA Rhein WWTP process flow diagram

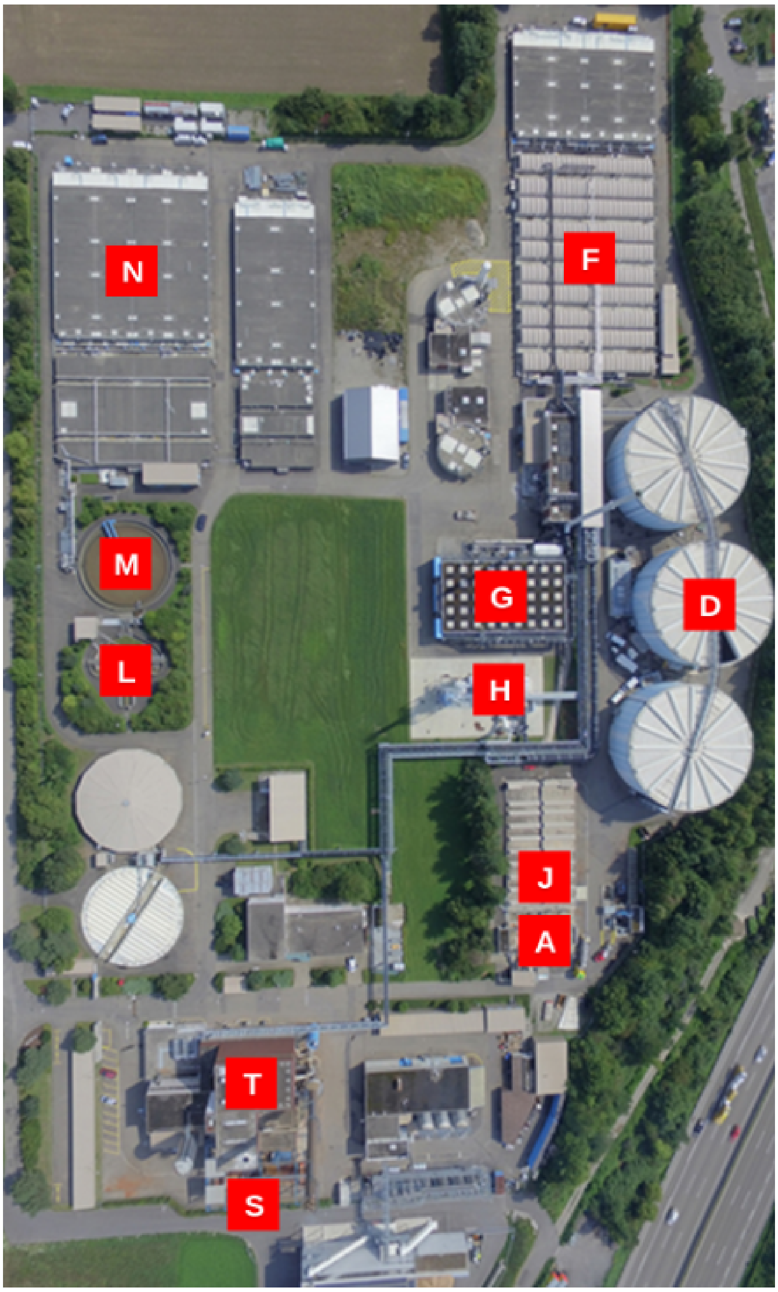

Figure 6: ARA Rhein wastewater treatment plant aerial view