Chemistry at Work

How Chemistry is used in the Water Service

WATER TREATMENT

Everyday, more than 100 water treatment works in Northern Ireland put approximately 680 million litres of water into the supply system. Treating water is a necessary part of the water supply service to make sure that enough clean water is produced under the terms of the Water and Sewerage Services (NI) Order 1973. Untreated water may contain substances which need to be removed. The water that Water Service supplies to homes must be kept free of contamination and Water Service sees this as its highest priority. The method of treating water depends on where it comes from. Treatment works may use one or more of the following chemical processes.

1. Coagulation and Flocculation

Coagulants such as aluminium sulphate may be added to the water to remove colour. This process will be examined in detail later.

2. Disinfection

It is essential that the final treated water should be safe to drink and contain no bacteria that could produce disease. One way to do this is by using chemicals.
Chemicals that can be used are:

a. Chlorine - the most common. When Cl_2 is added to water free from organic matter and ammonia, hypochlorous acid is formed.

$$Cl_2 + H_2O = HOCl + HCl$$

The very weak HOCl is further dissociated to $H^+ + OCl^-$; the hypochorous acid HOCl and hypochlorite ion OCl^- are together known as the ‘free available chlorine’.

b. Ozone

c. Sodium Hypochlorite

3. pH Adjustment

pH is a measure of the alkalinity or acidity of water. If water is too acidic it will corrode metal pipes. If it is too alkaline, it will cause a deposit to form. Natural waters seldom have a pH value below pH 5.5. Soft waters from moorland areas have pH values in the range of 6.0 to 7.0 (sometimes lower, in peaty areas). Waters containing carbonate hardness and little free carbon dioxide have a pH of about 7.5 to 8.0 or over. Waters in the range of 7.0 to 7.3 pH may be regarded as neutral. The Water Quality Regulations (Northern Ireland) 1994 require that water in the distribution lies within the pH range of 5.5 to 9.5. pH adjustment is carried out using calcium hydroxide ($Ca(OH)_2$; lime).

4. Manganese removal

If manganese is not removed it can lead to staining or discoloured water in the distribution system. The removal of dissolved manganese from a water requires a combination of high pH and an oxidant such as chlorine. Manganese precipitates out faster with higher pH values and greater concentrations of oxidant. The reactions taking place in the chemical processes are:

$$2CO_2 + Ca(OH)_2 = Ca\,(HCO_3)_2$$

$$Mn\,(HCO_3)_2 + O + Ca(OH)_2 = MnO_2 + Ca(HCO_3)_2 + H_2O$$

Chemistry at Work

COAGULATION

River and reservoir-stored waters usually contain dissolved (true) colour and finely divided material, often colloidal, which will not readily settle out and cannot be filtered out. Coagulants, usually salts of iron or aluminium, can be added to form solid precipitates termed floc, containing these impurities. The floc can then be separated out using a conventional solid-liquid separation process. The process of flocculation, in which floc growth is encouraged by gentle mixing, is sometimes carried out depending on the requirements of the solid-liquid separation process.
The mechanisms of coagulation are:

1. Charge neutralisation and mutual adsorption.

This requires a coagulant with ions of opposite charge to those of the colloidal particles to neutralise the repulsive charges. The colloids will then adhere to one another by adsorption. This is sometimes referred to as charge destabilisation. The trivalent ions Al^{3+} or Fe^{3+}, which form when aluminium or iron salts are added to water, hydrate to form aquometal complexes $Al(H_2O)_6{}^{3+}$ or $Fe(H_2O)_6{}^{3+}$. These then undergo hydrolytic reactions in which H_2O molecules are replaced by OH^- ions to produce hydroxometal complexes of the form $M(H_2O)_{6-N}(OH)^{n3-n}$, which are involved in charge destabilisation.

The formula for the reaction is simplified as:

$$Al_2(SO_4)_3 + 3Ca(HCO_3)_2 = \\ 2Al(OH)_3 + 3CaSO_4 + 6CO_2$$

2. Precipitation and entrapment.

When the coagulant is added hydroxide precipitates form. These precipitates trap colloidal particles within their structure. In waters with a high colloidal content, the particles act as seed on which the precipitates easily form. This is known as sweep-coagulation.

3. Adsorption onto floc surface.

Once flocs have been formed colloidal particles and dissolved material will be adsorbed on their surface.

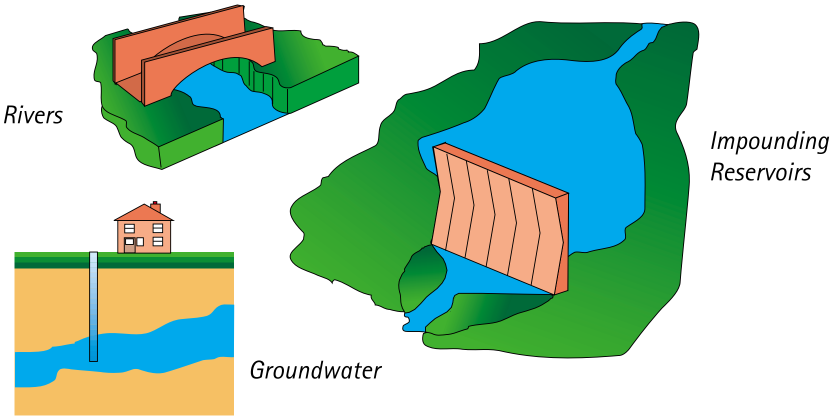
4. Co-precipitation.

Where the coagulant forms precipitates, which, for example, incorporate the humid colour compounds as iron or aluminium humates.

Separation of floc from treated water can be improved by the addition of flocculent aids, such as high molecular weight polyelectrolytes, normally anionic, which help bind the floc together.

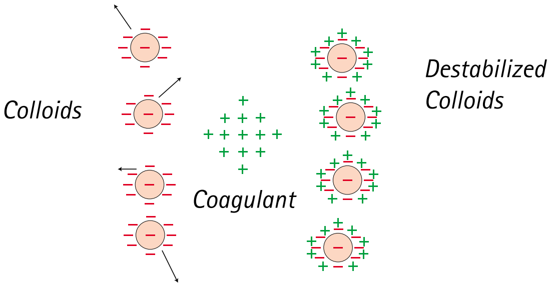
The next stage is to physically separate the floc particles from the water and this is done by sedimentation or flotation (Dissolved Air Flotation; DAF) followed by rapid gravity filtration.

Water Sources



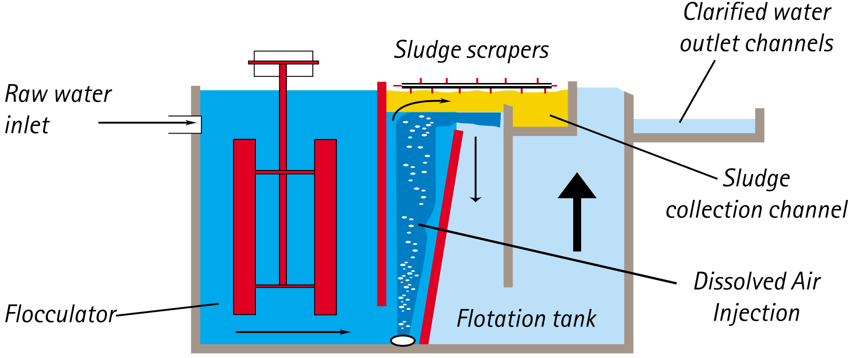
Where Does Water Come From?

Coagulation



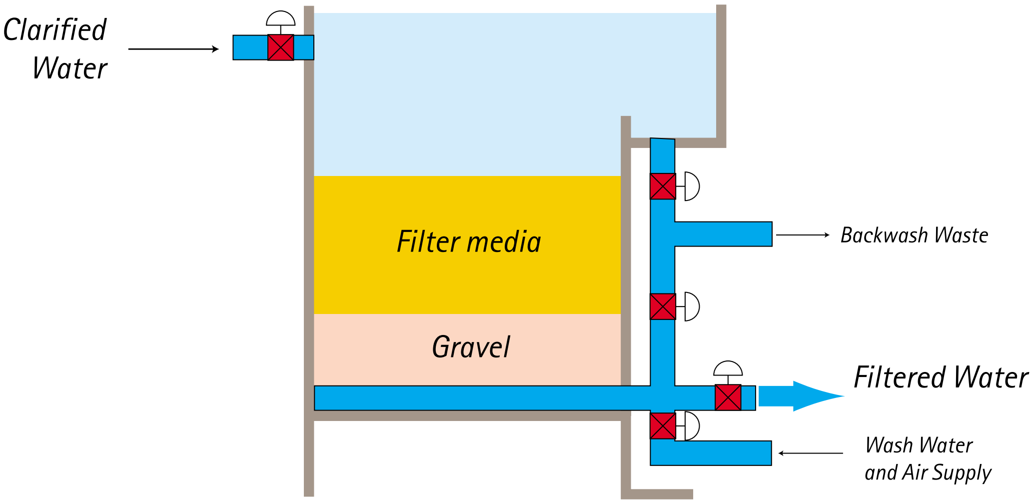
How does Coagulation work?

Clarification



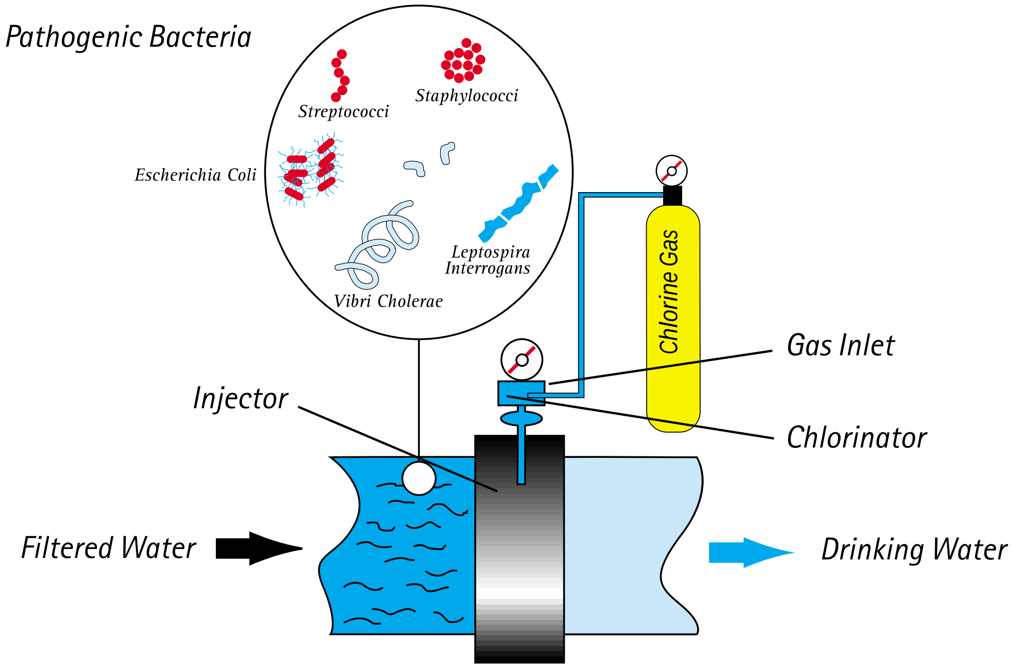
Dissolved Air Flotation Plant

Filtration



The Rapid Gravity Filter

Disinfection



Chlorination

Chemistry at Work

SEWAGE TREATMENT

Sewage includes all domestic waste water from the kitchen, bathroom and often the roof and driveway. Whilst the popular idea of sewage may be a thick lumpy sludge in fact 99% of sewage is water. The treatment process relies on the combination of physical separation of solids from the sewage and the augmentation of biochemical processes to reduce harmful organic and chemical substances. Treatment works may use one or more of the following biochemical processes.

1. Biological activated sludge

Activated sludge may be defined as 'the flocculent microbial mass of bacteria, protozoa, and other microbes with a significant proportion of inert debris, produced when sewage is continuously aerated'. It consists mainly of organisms which are able to metabolize and break down the principal contaminants of wastewater.

The activated-sludge process is a method of treating sewage and other biodegradable wastewaters, by aerating and agitating the liquid in a mixture with activated sludge, and subsequently separating it from the treated effluent by settlement. Most of the separated sludge is then returned for re-use with the excess being removed for disposal as surplus activated sludge.

2. Biological filtration

Settled sewage is passed through a 2 metre deep bed of small stones or other materials (media) using distributor arms. Bacteria, fungi and other organisms living on the media surface breakdown the sewage as it passes through the bed.

3. Phosphate removal

Phosphate is removed from wastewaters in order to prevent the eutrophication (nutrient enrichment) of the receiving waters. This is particularly important for inland waterways such as the Lough Neagh or Lough Erne/systems.

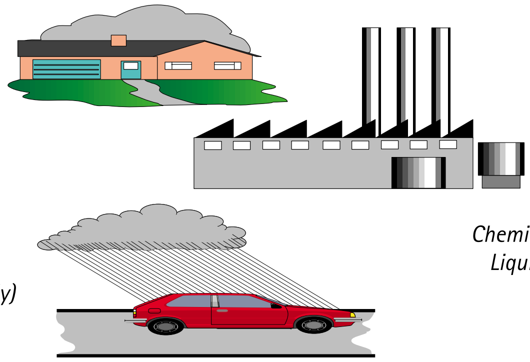
Phosphorous is present in wastewaters in three forms: orthophosphate ion, polyphosphates and organic phosphorous compounds. Polyphosphates can be looked upon as polymers of phosphoric acid from which water has been removed, complete hydrolysis results in formation of orthophosphate. The chemistry of organic phosphates is complicated but their decomposition also leads to orthophosphate. In raw sewage, all three forms are present in significant amounts. After biological treatment the main form of phosphorous in the effluent is orthophosphate. The standard form of orthophosphorous in wastewater is PO_4^{3-}.

When a metal salt (M^{3+}) is added to the wastewater, the precipitation of phosphorous can be expressed as follows:

$$M^{3+} + PO_4^{3-} \longrightarrow MPO_4\downarrow$$

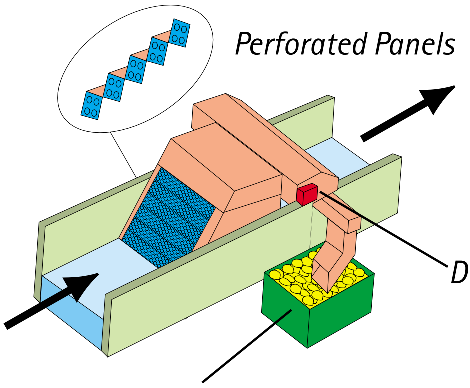
This precipitate is then removed.
The normal metal salt added is Ferric Aluminium Sulphate.

Wastewater Sources



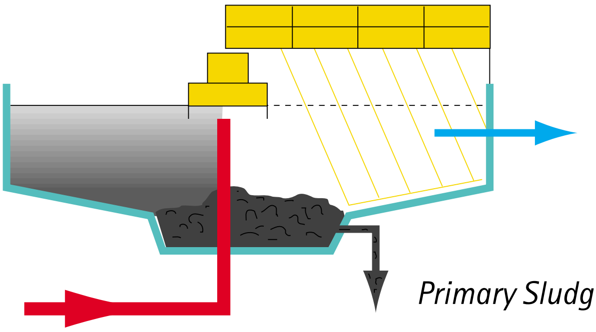
Where Does Sewage Come From?

Screening



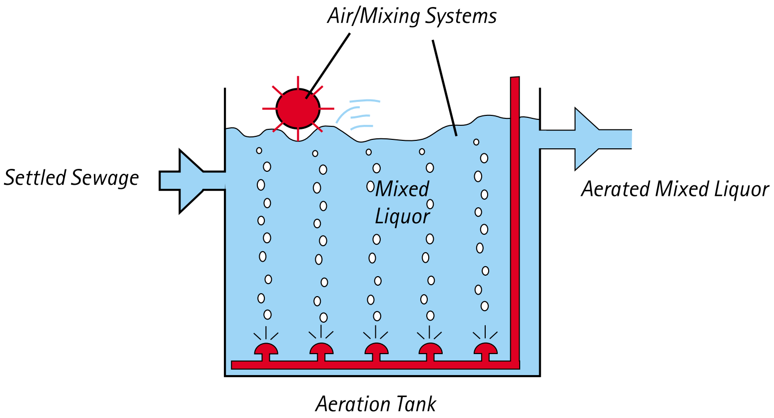
Removal of Plastics & Rags

Primary Settlement



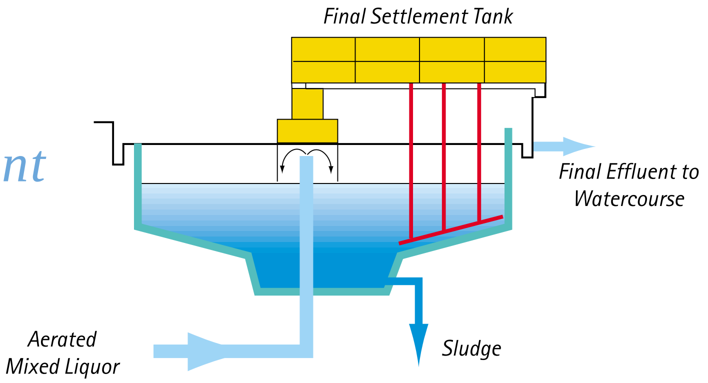
Organic Solids Removal

Biological Treatment



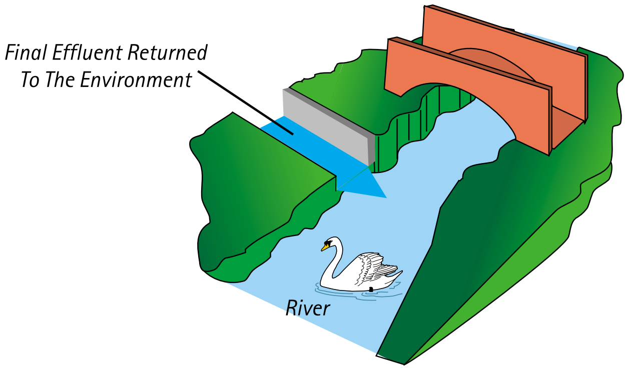
Biochemical Action On Organic Matter

Final Settlement



Final Solids Removal

Final Effluent



Discharge Returned to the Environment