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CHAPTER 8
RESIDUAL MANAGEMENT

While water treatment plants produce safe drinking water, they inevitably produce waste products, as well. In the treatment process of drinking water resources, the contaminants that are unhealthy or undesirable for consumption are removed in water treatment plants. The generated waste products are named as **'residuals'** and may be organic and inorganic compounds in liquid, solid, and gaseous forms depending on quality of the water resources, drinking water production rate, efficiency of the drinking water treatment system, the amount of treatment chemicals used, and type of water resource treated. Residuals commonly generated from coagulation/filtration, precipitative softening plant, membrane separation, ion exchange and granular activated carbon units. The residuals volume at water treatment plants mostly alter seasonally or monthly.

Since residuals are altered forms of contaminants; management of them should be included in management programs for water treatment plants. However, development of a cost-effective plan to remove and dispose of residuals might be complex. Therefore when developing a comprehensive water treatment residuals management plan; form, quantity, and quality of the residuals should be characterized; appropriate regulatory requirements should be determined; feasible disposal options should be identified, appropriate residuals processing/treatment technologies should be selected and a residuals management strategy that meets the goals established for a water treatment facility should be developed.

8.1. Residual Categorization

More than one of the treatment processes listed below are used in water treatment plants and may generate multiple types of residuals;

i. Pre-sedimentation
ii. Coagulation, flocculation, and sedimentation
iii. Precipitative softening

8.1.1. Pre-sedimentation

Pre-sedimentation is the first unit process that is operated at a water treatment plant. Gravity removes suspended solids from source in pre-sedimentation. In the pre-sedimentation process, the efficiency of solids separation and removal depends on the residence time. Sand and grit settle more rapidly than clay, silt and organics. Depending on the composition, 50 to 90 percent of the influent solids can be removed in pre-sedimentation. However; the composition of the solids in the sludge is site-specific. The smaller particles are removed during the coagulation, flocculation, sedimentation, and filtration processes.

8.1.2. Coagulation, Flocculation, Sedimentation

Chemical agent(s) (generally aluminium and iron salts) are added to reduce the negative surface charges of smaller particles by introducing positive ions in order to allow the particulates to agglomerate and settle to the bottom of clarifiers in **coagulation, flocculation, sedimentation** process. The added chemical agent(s) precipitate along with the neutralized suspended solids by gravity. The volume of sludge generated in this process depends on the treatment plant capacity, amount of coagulant or other treatment chemical added, and amount of suspended solids in the source water whereas the characteristics of sludge alter depending on the quality of initial water and the amount and type of coagulant used. For example; higher aluminium concentration in the sludge is expected when aluminium-based coagulant is used. "Coagulation sludge mainly contains the coagulant metal hydroxides along with source water natural organic matter, suspended solids, microorganisms, radionuclides, and other organic and inorganic constituents. The metals found in coagulation sludge include aluminium, arsenic, and occasionally cadmium, chromium, copper, iron, lead, manganese, nickel, and zinc (Cornwell, 1999)."

8.1.3. Precipitative softening

Precipitative softeninig is used to remove divalent ions, mainly calcium and magnesium in water in water treatment plants, by the addition of lime. When lime is added to water, it increases the pH of it and it reacts with the ions to form a precipitate. The precipitate contains calcium carbonate, magnesium hydroxide, other divalent ions, natural organic matter from the source water, inorganics, suspended solids, microorganisms, and radionuclides with a solids content of 2 to 15 percent. It is inert and it has a pH typically higher than 10.5. Arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver can also be found in the softening sludges. The sludge generation rates in lime softening vary according to the ratio of calcium carbonate to magnesium hydroxide and the type of sedimentation tank.

8.1.4. Filtration, microfiltration, and ultrafiltration

Finer particles and metals are removed in water treatment plants by **filtration** process. At some water treatment plants, filtration is the only solids removal step. In water treatment plants; there exist non-membrane filters such as multimedia, slow sand and diatomaceous earth. Besides low-pressure membranes such as microfiltration (MF) and ultrafiltration (UF) can also be used.

Non-membrane filters remove suspended material in water resources. While the water passes through the filter media, suspended solids accumulate in the interstices. As the water runs through the pores and more particles accumulate, the filter performance decreases. At this moment, the filter is taken out of service for backwash which is the process of using clean water to reversely expel the particles collected on the filter media. Clay and silt particles, microorganisms, colloidal and precipitated humic substances, natural organic particulates and precipitates of aluminium or iron used in coagulation are present in filter backwash waters. The number of filters, frequency of backwash, and duration of backwash events affect the volume of filter backwash wastewater generated. The volume is typically between 2 and 5 percent of the finished water produced (U.S. EPA/ASCE/AWWA, 1996). Flow equalization systems are generally designed to recycle the backwash water to the head of the water treatment plant. After backwashing, filters are washed in order to gain adequate filter performance. The spent wash water, which is called “filter-to-waste” is the filter effluent for the first 15 to 60 minutes after start-up following the backwash. The filter-to-waste stream is equalized and returned to the head of the treatment plant.

Filter backwash waste streams are also generated by low-pressure membranes. Low pressure membrane systems are also used to remove suspended solids, turbidity, inorganic and organic colloids, microorganisms; and ultrafiltration is used to remove viruses and some organic compounds. 95 to 99 percent of the total volume of residuals is generated by MF/UF treatment process. To remove some solids prior to the membrane; coagulants, powdered activated carbon (PAC), or other chemicals (e.g., potassium permanganate) as pre-treatment to membrane filtration can be used in some systems. This reduces the backwash frequency. The resulting residuals generally show the characteristics of coagulation sludge. During the membrane cleaning processes, spent chemical cleaning solution residuals are also generated. The chemical cleaning waste includes some remaining active chemical ingredient, and some salts from chemical reactions between the chemicals and foulants, dissolved organic materials, and suspended solids.

8.1.5. Membrane desalination

In water treatment plants, membranes are generally used to remove dissolved solids and ions. They are also used to remove dissolved organics, dissolved gases, biological contaminants, and suspended solids. Reverse osmosis (RO), nanofiltration (NF), electrodialysis (ED), and electrodialysis reversal (EDR) are **membrane desalination** technologies. In order to protect and extend the life of the membrane, the source water prior to membrane desalination is generally pre-treated. In this pre-treatment; to lower pH to between 5.5 and 7.0 acid addition, to prevent membrane fouling anti-scalant addition and to remove suspended particles filtration take place. Backwash waste stream is generated in this filtration step. In membrane desalination systems generated contaminants are concentrated on the membranes for separate disposal. The contaminants characteristics are similar to those of source water, however, if pre-treatment is applied, of ‘course lower levels of certain constituents and particles but higher levels of constituents added in pre-treatment process are expected. For instance, in case of coagulation pre-treatment, inorganic ions, such as sulphate, iron, and aluminium, and polymer is observed and sulphuric acid pre-treatment may increase residual organics.

8.1.6. Ion exchange

Ion exchange is used to reduce hardness of source water. Sodium ions that are contained in the ion exchange resin are replaced with calcium and magnesium ions in water. Nitrates, barium, radium, arsenate, selenite, excess levels of fluoride, lead, and chromate can also be removed in ion exchange unit. The ion exchange material is regenerated when the site capacity is reached. This regeneration produces waste concentrate that contains the source water contaminants. Besides, backwash water and rinse water that is used before and after the regeneration of the ion exchange resin, respectively is generated in ion exchange process, as well.

8.1.7. Activated carbon (adsorption process)

Adsorption is used to remove organic materials, taste, odour, synthetic organic compounds and disinfection by-products. Granular activated carbon is the most common adsorptive media in adsorption process. In **activated carbon adsorption**, ions or molecules in the water is removed by enabling them adsorbed onto the treatment media. Backwash water and spent media are generated as residuals. As the treatment process goes on, when the pollutants are no longer removed from the influent because of the filling of adsorption site (breakthrough), backwashing of the filter bed should be performed to disengage solids that have been entrapped in the filter bed. Breakthrough occurrence depends on the concentration of the pollutant contaminants being removed. Backwash water typically contains the removed contaminants and some granular activated carbon. The volume and quantity of the granular activated carbon backwash stream depends on the influent source water quality. The spent carbon is regenerated or disposed. Regeneration of the spent carbon is done by thermal means and does not generate a wastewater stream.

Common pollutants found in water treatment plant residuals have potential environmental impacts on the receiving environment therefore; they should be handled within the water treatment plant. Suspended solids for example; may settle in the receiving water and form bottom deposits, creating anaerobic conditions; increase turbidity and decrease light penetration in receiving waters, thus limit the growth of plantation that serves as habitat for aquatic organisms; provide a medium for the transport of other sorbed pollutants; clog fish gills and alter the chemistry of natural waters. Metals are potentially toxic to aquatic organisms, including fish and have the potential for bioaccumulation and biomagnification in aquatic food chains. Chemicals used for disinfection like chlorine and chloramines can react with organic compounds in receiving waters to form toxic compounds. Exceeded chloride levels in wastewater discharges can disrupt ecosystem structure and impair their use as source waters for potable water supplies. Sudden pH changes can kill aquatic life in receiving water bodies. Ammonium and ammonia nitrogen is toxic to aquatic life and can reduce dissolved oxygen concentration that is vital for microbial activity. Together with phosphorus, they are the limiting nutrients and cause eutrophication. Exposure to radionuclides increases the risk of cancer.

8.2. Regulatory Requirements

The hazardous level of materials in waste generated from water treatment process generally depends on the volume of the material extracted from raw water, and the attention needs to be paid to the lowest acceptable presence of a substance per volume of treatment. This lowest level is mostly defined by local/international laws-regulations and standards. To comply with the legal requirements and to avoid health and environmental impacts, knowledge of the lowest acceptable levels of substances in treatment waste has the utmost importance.

The most common pollutants regulated in general permits include aluminum, iron, manganese, pH, settleable solids, total residual chlorine (TRC), and total suspended solids (TSS). Limits of chlorides and total dissolved solids (TDS) may be required for membrane desalination and ion exchange plants.

To comply with the legal requirements, the below actions can be taken;

- Provide comprehensive and timely information on investigations into exceedances of the parametric values.
- Implement an optimisation programme for chemical dosing and review/upgrade of chemical dosing processes in supplies in order to reduce trihalomethanes and aluminium exceedances.
- Meet the disinfection criteria.
- Implement adequate out of hours response backed up by suitable, real-time monitoring of process parameters and response to alarms
- Deliver resilient treatment plants able to cope with severe weather and changes in the nature of raw water sources.
- Develop and implement National Drinking Water Incident Response Plans to cover emergency situations.
- Develop a structure for minimum qualification, training and experience standards for water service employees in key operations positions (for example supervisors and plant operators).
- Implement measures to improve quality and consistency of management and operation of water supplies.
- Improve communications between local authority personnel on the management and operation of public supplies.

8.3. Treatment Options

Control technologies and management practices are used in water treatment plants to improve the prevention, treatment, disposal, and discharge of water treatment residuals. This helps treatment plants to meet standards, improve water quality, reduce treatment system operation costs and provide energy savings.

Pollution prevention (e.g., process modifications) and waste reduction (e.g., resource recovery) opportunities in water treatment plants are the preliminary steps in residual management, which aims the reduction of the generation of residuals. Optimizing intake water conditions, filter media, pH to reduce coagulant chemicals, reducing softening chemicals by monitoring source water hardness, returning backwash water and filter-to-waste to the head of the source water treatment plant for reuse, reusing precipitative softening chemicals, recovering treatment chemicals coagulants and salt can provide waste reduction and help residual management.

Unavoidable residuals from the water treatment operations can be treated in water treatment plants prior to final waste management such as land application, disposal and discharge. The treatment options for residual management in water treatment plants are;

- Separation of solids from water
- Precipitation of chemicals
- Increase in oxygen content
- Removal of chlorine
- Adjustment of pH

8.3.1. Separation of solids from water

The principle objective of solids removal systems is decreasing the volume of water while increasing solids content. Enough dry solids percentage depends on desired properties for handling, transport and disposal options available. Thickening/dewatering is often for this purpose. The objective of thickening is to increase the solids content of the residuals. This is important in the reduction of the capital and operating costs of the continuing treatment. The most common **thickening** technologies are gravity settling, dissolved air flotation, and gravity belt (Table 8.1)

In gravity settling, solids are separated (thickened) from water by using gravity within the designed residence times. In dissolved air flotation, which is the most common of several flotation separation technologies, the floating material is the thickened solid and skimmed off. If space is limited in water treatment plant area, or if gravity settling or flotation do not provide the desired solids thickening, then gravity belt thickener can be used as an alternative. They are simple designs and require minimal operator but they generate another residuals stream (wash water) and usually require use of a solids conditioner and maintenance. Supernatant from the thickening operation is recycled or discharged. The thickening operation is followed by mechanical dewatering, the next solid/water separation step.

Mechanical dewatering is used for additional volume reduction and concentration of solids. Since source water, site, and other conditions vary from facility to facility, the systems, needs, and constraints should be thoroughly assessed in order to select the mechanical dewatering equipment that best suits the utility's specific requirements. Selecting the right equipment will ensure optimum performance. Belt filter presses, plate and frame filter presses, and centrifuges are commonly used. For all mechanical dewatering systems pre-conditioning is generally required. Mechanical forces are applied during dewatering, thus, some water is released from the sludge depending on the characteristic of the sludge. Each mechanical dewatering device applies forces in different ways; therefore, the resulting cake dryness varies. These technical systems require a high degree of operator supervision and training. They are rarely cost efficient for small systems.

In belt presses feed solids usually are introduced into a feed box via pumping and distributed across the dewatering surface under atmospheric pressure. As water drains through the pores, a thin layer of cake is formed which builds up as the sludge is moved into the shear zone and pressure zone.

Pressure filters (e.g., plate and frame filter press, diaphragm filter press) the sludge is pumped at high pressure in between the filter plates and force the liquid out while retaining the solids.

Centrifugal dewatering is a process that centrifugal force is applies to ensure separation of solids from liquid. Centrifuges have some advantages, like; its being totally enclosed, continuous operation, having relative ease of operation, high throughput and cake solids, high solids capture, and being compact and having space-saving design.

Following collection and thickening, the sludge can be further concentrated or dewatered by **non-mechanical dewatering** methods, as well. Lagooning, drying on sand beds, natural or artificial freezing and thawing (physical method), and chemical conditioning are typical non-mechanical sludge dewatering methods.

In lagoons and storage ponds the residuals are spread out, exposed to the air and allowed to dry by evaporation. Application of this method depends on the land availability, evaporation rates and ground water contamination concerns.

An improvement over the sludge lagoon is the sludge drying bed which incorporates a permeable medium and a system of under drainage. The climate and land availability affect the choice of this method. Where the application is possible, sand drying beds are effective and relatively inexpensive method of dewatering water treatment plant residuals. Sand drying beds (gravity drainage+evaporation), freeze-assisted sand beds (allowed to freeze and then thaw either naturally or mechanically; mostly used for alum residuals), vacuum-assisted systems (applying pressure to speed up the drying process) and solar drying beds (where climate is sufficient) are the non-thermal drying bed technologies. Thermal drying technology is generally used to solve problems with pathogen control, odour control, and storage problems and is not widely used.

Coagulant sludge usually requires solids removal systems. It usually has a 0.5 to 2.0 present solids concentration. Coagulant sludge can contain high percentage of gelatinous, hydroxide precipitates depending on the total suspended solids concentration of the source water. Softening sludge is easier to dewater and compact than coagulation sludge. Softening sludges are generally dense, stable, and inert materials.

Table 8.1. Comparison of Solids Removal Technologies: Solids Concentration After Treatment by Residuals Type

Solids Removal Treatment	Solids Concentration for Treated Lime Softening Residuals	Solids Concentration for Treated Coagulation Residuals
Thickening		
Gravity Thickening	15–30%	1–3% (low TSS) 5–30% (high TSS)
Flotation Thickening	Not available	2–4%
Gravity Belt	Not available	2.5–4.5%
Mechanical Dewatering		
Scroll Centrifuge	55–65%	20–30%
Belt Filter Press	50–60%	1 –20% (Alum) 4–50% (Alum, TSS)
Plate (or Pressure) Filter	55–70%	35–45%
Diaphragm Filter Press	50–70%	30–60% (Alum with lime conditioning)
Non-Mechanical Dewatering		
Storage Lagoon	50–60%	7–15%
Sand Drying Bed	50%	20–25%

Source: U.S. EPA, ASCE, and AWWA, 1996.

8.3.2. Precipitation of chemicals

Chemical precipitation is used to remove dissolved metals from residuals by the addition of a precipitating reagent. This treatment is applicable to liquid waste streams, generated in filter ion exchange and membrane desalination concentrates. Mostly hydroxide is used as precipitating reagent. Lime, quicklime, soda ash, or caustic soda can be added to introduce the hydroxide ions. Sulphide and ferrous salt can also be used depending on the metals present in the residuals. Chemical precipitation of the residuals is commonly used to remove aluminium, antimony, arsenic, cadmium, chromium, copper, iron, lead, mercury, selenium, silver, thallium, or zinc removal.

8.3.3. Increase in oxygen content

Generally, oxygen is added to residuals prior to discharge in order to control biological oxygen demand discharges and increase dissolved oxygen levels.

8.3.4. Removal of chlorine

After disinfection, free or total combined chlorine residual remaining can be observed which is toxic to aquatic life. This is removed by dechlorination through the addition of optimum dose of sulphur chemicals like sulphur dioxide, sodium sulphite, sodium bisulfide, sodium metabisulfide, and sodium thiosulfate.

8.3.5. Adjustment of pH

Chemical additions in treatment operations to improve treatment performance, alter the pH of source water is altered during treatment. To adjust the pH to range between 6 and 9, acids or bases are added.

8.4. Disposal Options

Some residuals generated in treatment plants; such as leaves, limbs, logs, plastic bottles, and other large floating debris which are separated from initial screening process, are relatively easy to handle and can be disposed of at conventional solid waste landfills. However, most other residual waste streams are more complex and require advanced processing and disposal methods to protect human health and the environment.

Selection of an alternative disposal method should be based on both economic and regulatory bases. The type and characteristics of slugde generated is also important in deciding disposal or reuse alternative. Besides landfilling, reuse as a soil amendment, discharge to a wastewater collection system, codisposal with wastewater biosolids and reuse in building or fill materials are available alternatives for disposal or reuse of residuals.

The most common disposal method for water treatment plant sludge is landfilling. Depending on test solutions to determine whether it is toxic or not, the type of landfill is decided for final disposal.

For land application (reuse as soil amendment) of water treatment plant residuals, it should be tested to see whether it is hazardous or not, as well. The crop being grown, chemistry of the soil, and sludge properties are important in deciding land application method. Coagulant sludge, lime-soda softening sludge, nanofiltration concentrate and slow sand filter washing can be applied to land. The ideal land application is on non-food chain crops, mine reclamation areas, and forests. However; it should be taken into consideration that land application can result in increased concentration of metals in the soil and thus groundwater and in less productive soils.

Wastewater generated in water treatment processes, such as filter backwash water, can be recycled to the head of the source water treatment plant. To reduce the impact of intermittent high volume flows from backwashing operations, flow equalization is used. For brine waters, ocean disposal is an alternative.

To read more;

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QUESTIONS AND ANSWERS FOR BOOK CHAPTER 8

Q1. Please list the treatment processes used in water treatment plants which may generate multiple types of residuals.

A1.
Pre-sedimentation
Coagulation, flocculation, and sedimentation
Precipitative softening
Filtration, microfiltration, and ultrafiltration
Membrane desalination
Ion exchange
Activated carbon (adsorption process)

Q2. Please choose "true" or "false" for the following sentence.
"Improvement of communications between local authority personnel on the management and operation of public supplies is not important to comply with regulatory requirements for residual management. "
a) True b) False

Q3. Which one of the followings is one of the most commonly used **thickening** technologies for the removal of residuals?

a) Belt filter press
b) Dissolved air floatation
c) Belt filter press
d) Scroll Centrifuge
e) Plate filter

Q4. Following collection and thickening, the sludge can be further concentrated or dewatered by **non-mechanical dewatering** methods, as well. Which one of the following can not be given as an example to **non-mechanical dewatering** methods?

a) Lagooning, drying on sand beds
b) Natural or artificial freezing and
c) Thawing (physical method)
d) Chemical conditioning
e) Gravity thickening

Q5. Some residuals generated in treatment plants; such as leaves, limbs, logs, plastic bottles, and other large floating debris which are separated from initial screening process can be disposed to ____.

A5. Some residuals generated in treatment plants; such as leaves, limbs, logs, plastic bottles, and other large floating debris which are separated from initial screening process can be disposed to <u>conventional solid waste landfills.</u>

Q6.______________________ is used to remove dissolved metals from residuals by the addition of a precipitating reagent which is applicable to liquid waste streams.

A6. Chemical precipitation is used to remove dissolved metals from residuals by the addition of a precipitating reagent which is applicable to liquid waste streams.