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Maximizing Effectiveness: Chemical Process and Methodology Optimization in Water Treatment Plant

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Abstract
Water is one of the most important components for all forms of life. It is obligatory in the maintenance of life on earth. A water treatment plant (WTP) has been established at KUET with a view to supplying potable water in the residential area of the university. The main goal of this study is to is to investigate the working principles of KUET water treatment plant, with the goal of identifying best practices and potential areas for improvement. This study revealed that the nearest ponds and shallow tube wells are considered as the promising option of raw water source due to the salinity in groundwater of Khulna town area. However, during the monsoon season, the plant's performance may be affected by flooding and high levels of turbidity in the source water. The plant's performance was evaluated by monitoring various water quality parameters such as pH, color, turbidity, iron, total dissolved solids (TDS), and chloride. The results showed that the plant was able to consistently meet the Bangladesh Standards for Drinking Water Quality for all of these parameters, indicating that the plant is operating effectively. The study also found that the plant's performance can be improved by regularly maintaining and upgrading the equipment, as well as by implementing a comprehensive monitoring and management system.

Keywords: Treatment Plant, Performance efficiency, Turbidity, Color, Working Principle

1. Introduction

Water is one of the vital components of the physical environment. Safe, adequate and accessible supplies of water are the basic needs and essential components of primary health care. Inadequate provision of safe drinking water is one of the main origins of communicable diseases and allied health risk. Therefore, providing safe drinking water is one of important public health priorities in the recent age. The World Health organization (WHO) estimated that up 80% of all sickness in the world is caused by inadequate sanitation, polluted water or unavailability of safe water (Ibrahim et al., 2014; Dhara et al., 2023; Khalekuzzaman et al., 2024). Ullah et al. (2023) and Molla et al. (2023&2024) with Rahman et al. (2014 & 2023) undertake a comprehensive investigation to determine the optimal scenario for job shop production for operational improvement. Some of them also consider supplier selection weightage with ergonomics factor. Some people's findings have significant implications, particularly in the realm of reducing state-by-state accident rates for effective accident mitigation strategies. Building on this foundation, they also employ the Value Stream Mapping (VSM) method, incorporating a robust and effective arithmetic process.

This method proves instrumental in our ongoing research, especially in the development of a laboratory platform tailored for students with a keen interest in production activities. The insights gleaned from these studies not only contribute to the enhancement of production processes but also align with our broader goals of promoting safety and efficiency in manufacturing environments, ultimately fostering a rich learning experience for our research (Biswas et al. (2024), Noman et. al. (2024,2017),).

Over the last half-century, there has been an increasing tendency of population settlement in developing countries like Bangladesh. Increase in human population pose a great pressure on provision of safe drinking water especially in developing countries (Hossain et al., 2015). Water treatment plants play a critical role in providing safe and clean drinking water to communities (Muller 1977; Khalekuzzaman et al., 2024; Dhara and Fayshal et al., 2024). However, the efficiency and effectiveness of these plants can vary depending on a number of factors, including the source of the water, the treatment processes used, and the management and operation of the facility (Okonkoet al., 2009). The water treatment process can vary depending on the source of the water and the desired level of purification, but typically includes a combination of physical, chemical, and biological processes (Amber et al., 2004). Buian et al. (2024) and Iqtiar et al. (2024) elaborate on issues related to the production and processing of hydrothermal liquefaction (HTL) through their comprehensive papers. Jamil et al. (2024) delve into the intricacies of optimizing strategies in the processes of mechanical material characterization, addressing challenges associated with variations in material properties. Concurrently, Mustofa (2020) provides insights into incorporating these strategies within the framework of advanced methods for characterizing materials, establishing a comprehensive approach.

The objective of this paper is to investigate the working principles of water treatment plants, with the goal of identifying best practices and potential areas for improvement. This research will begin by reviewing the different types of water treatment plants and the various processes that are used to purify and disinfect water. The working principles of these processes and the equipment used in water treatment plants will also be examined. Through this research, we aim to identify best practices for water treatment plant design, operation, and management, as well as potential areas for improvement. The results of this research have the potential to inform the design and operation of future water treatment plants, in order to ensure that communities have access to safe and clean drinking water.

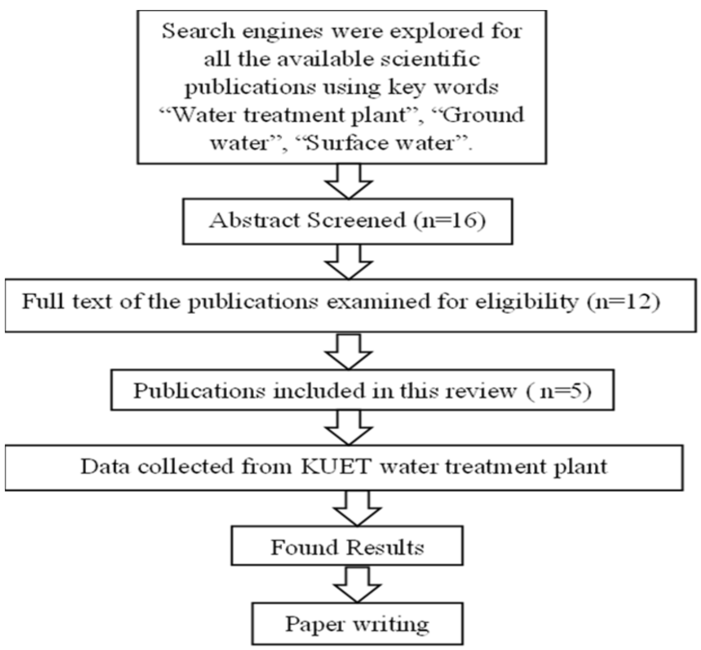

Figure 1: Flow diagram showing the procedure used for selection of publications for this review.

2. Materials and Methodology

The following search engines were explored for all available scientific publications relating to wastewater treatment in Bangladesh.

i. ResearchGate (https://www.researchgate.net/)

ii. ii. Google Scholar (https://scholar.google.com/)

We also used the Google search engine (www.google.com) to find the scientific literature published in regional journals. The search terms were 'Water Treatment Plant', 'Bangladesh', 'groundwater', and 'surface water'. There was no restriction in relation to the year of publication. All documents that were published before the time of assessment were retrieved for this study. As the number of published studies is limited, we included partial matches, reviews, opinion papers (field data), conference papers, unpublished reports, theses, scientific reports, and other publications in the grey literature. A total of 00 publications were found using the above search criteria. The flow diagram shown in figure- X shows the selection criteria of the publications used for this review.

Results and Discussion

Pre- Chlorination

Pre-chlorination is a process used in water treatment plants to disinfect water before it enters the main treatment process. The process involves the addition of chlorine, or a chlorine-based compound, to the water before it enters the plant. The purpose of pre-chlorination is to kill or inactivate any microorganisms that may be present in the water, such as bacteria, viruses, and parasites. This helps to reduce the risk of contamination and the spread of waterborne diseases. "Figure 02" functions as an illustrative reference delineating the pre-chlorination process. This diagram visually elucidates the infusion of chlorine or chlorine-based compounds into the water at the plant's primary ingress point.

The specific methods used for pre-chlorination can vary depending on the type of water being treated and the desired level of disinfection. Common methods include the use of chlorine gas, sodium hypochlorite solution, or calcium hypochlorite pellets. The amount of chlorine added to the water during pre-chlorination is typically determined by the plant operator based on the water quality and the desired level of disinfection. The water is then sent through the main treatment process, where it undergoes further purification and disinfection. It's worth mentioning that pre-chlorination is not always necessary, but it's a common practice in water treatment plants where the water source is surface water. The main reason is that surface water is more susceptible to contamination from microorganisms and other impurities, so pre-chlorination is used as an added layer of protection.

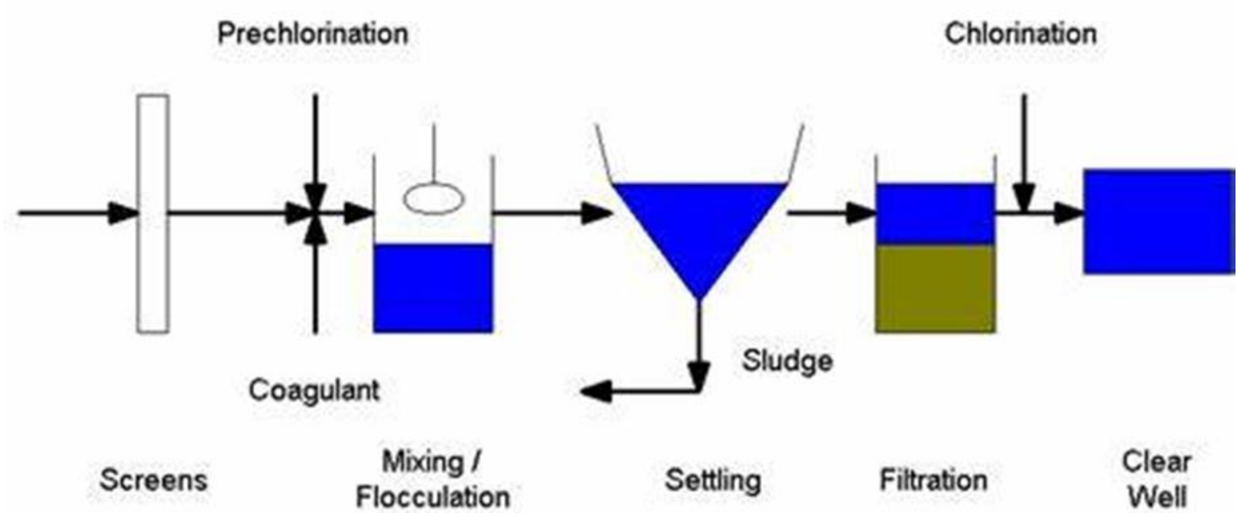

Figure 2: Pre-chlorination process

Flocculation tank

Flocculation is a process used in water treatment plants to remove small suspended particles from water. It is typically used in combination with coagulation, which is the process of adding chemicals to the water to cause small particles to clump together, forming larger particles called flocs. The flocculation process typically involves slowly mixing the water and flocculant chemicals in large tanks called flocculation basins or clarifiers." Figure 03" illustrates the flocculation process, which relies on a purposefully designed flocculation tank, also known as a clarifier. The tank, as depicted using low-speed mechanical mixers or paddles, agitates the water and causes the flocs to form. The mixing is done gently so that the flocs can grow in size without breaking apart. The flocs then settle to the bottom of the tank and are removed by sedimentation. The water at the top of the tank is clear and free of large particles, and it can be sent to the next step in the treatment process. Several researchers previously used GIS to analyze LU/LC pattern and other assessment that also could be implement in the water treatment sector (Fayshal et al., 2023; Fayshal et al., 2024; Hasan et al., 2023; Mizan et al., 2023; Uddin et al., 2023; Uddin et al., 2024).

Flocculation can effectively remove a wide variety of suspended particles, including clay, silt, algae, and bacteria. It is an important step in the water treatment process, as it removes particles that can clog filters and reduce the efficiency of other treatment steps. The specific chemicals used for flocculation will depend on the type of water being treated and the type of particles that need to be removed. Commonly used flocculant chemicals include aluminum sulfate, ferric chloride, and polyelectrolyte.

Figure 3: The coagulation/flocculation tank with two variable speed mixers

Settling chamber

A settling chamber, also known as a sedimentation tank or clarifier, is a process used in water treatment plants to remove solid particles that have been made heavier by coagulation and flocculation. The process involves allowing the water to flow into a large tank where the particles settle to the bottom due to their weight. The water enters the tank at one end and flows slowly through it, allowing the heavier particles to settle to the bottom of the tank. The settled particles form a layer of sludge on the bottom of the tank, which is removed by a scraper or suction system. The clarified water is then collected at the other end of the tank and sent to the next step in the treatment process. the operational aspects of a settling chamber are depicted in “Figure 04”. Settling chambers are typically used to remove large particles such as sediment, algae, and other organic matter. They are an important step in the water treatment process, as they remove particles that can clog filters and reduce the efficiency of other treatment steps. The design of a settling chamber may vary depending on the specific application, but they generally have a rectangular shape and are designed to maximize the surface area and detention time of the water. This helps to ensure that the particles have enough time to settle before the water exits the tank. It's worth mentioning that settling chambers need to be cleaned and maintained regularly to remove the accumulated sludge and ensure their efficiency.

Figure 4: Illustration of the Settling Chamber Process in Water Treatment.

Mixing chamber

A mixing chamber is a process used in water treatment plants to mix chemicals or other substances into water. The process is typically used as part of the coagulation and flocculation process, where chemicals are added to the water to cause small particles to clump together and form larger particles that can be more easily removed. The mixing chamber is a container, typically made of concrete or steel, that is used to mix the water and chemicals. The water is pumped into the chamber and the chemicals are added to the water through a series of nozzles or injection points. The water is then mixed using mechanical mixers or paddles, which agitate the water and ensure that the chemicals are evenly distributed. The specific chemicals used for coagulation and flocculation will depend on the type of water being treated and the type of particles that need to be removed. Commonly used chemicals include aluminum sulfate, ferric chloride, and polyelectrolyte.

Mixing chamber is an important step in the water treatment process as it helps to ensure that the chemicals are evenly distributed throughout the water, which helps to ensure that the particles clump together and settle out of the water more effectively. The mixing chamber is typically followed by a flocculation chamber and sedimentation tank, where the particles are allowed to settle out of the water. It's worth mentioning that, the design of a mixing chamber is crucial to ensure efficient mixing, and the design will depend on the flow rate of the water, the chemical dosage, and the mixing time.

Distribution chamber

A distribution chamber, also known as a splitter box or flow divider, is a process used in water treatment plants to evenly distribute water flow among multiple treatment processes or stages. It is typically used to divide the flow of water into multiple channels, each of which leads to a different treatment process or tank. The distribution chamber is typically located at the beginning of the treatment process, before the water enters the main treatment tanks or processes. The water is pumped into the chamber and then evenly distributed among the different channels using a series of nozzles or dividers. Figure 06 visually depicts the operation of the distribution chamber.

The purpose of the distribution chamber is to ensure that the water flow is evenly divided among the different treatment processes, which helps to ensure that the water is treated effectively and efficiently. It also allows the plant operators to control the flow rate and volume of water that is sent to each process, which helps to optimize the overall treatment process. It's worth mentioning that the design of a distribution chamber should be suitable to the flow rate and volume of water that needs to be distributed, and it should be able to distribute the water evenly and prevent clogging. In summary, the distribution chamber is an important component in a water treatment plant that helps to ensure that the water is evenly distributed among the different treatment processes, ensuring that the water is treated effectively and efficiently.

Roughing filter

Roughing filters are a type of filtration process used in water treatment plants to remove large particles and debris from water. The process involves passing the water through a bed of coarse material, such as gravel or anthracite coal, which acts as a filter to remove the particles. The water is pumped into the top of the filter and flows through the bed of coarse material. As the water flows through the bed, the large particles and debris are trapped in the spaces between the particles of the filter material. The filtered water then flows out of the bottom of the filter, while the trapped particles remain in the filter bed. Roughing filters are typically used as a pre-treatment step before water is sent to other processes such as sedimentation, or other types of filtration methods. They are particularly useful for removing large particles such as sediment, algae, and other organic matter that can clog other types of filters and reduce their efficiency. In" Figure 07 " we visualize and break down the essential steps of the Roughing Filter Process in Water Treatment. This graphical overview captures the filtration method, showcasing how large particles and debris are effectively removed.

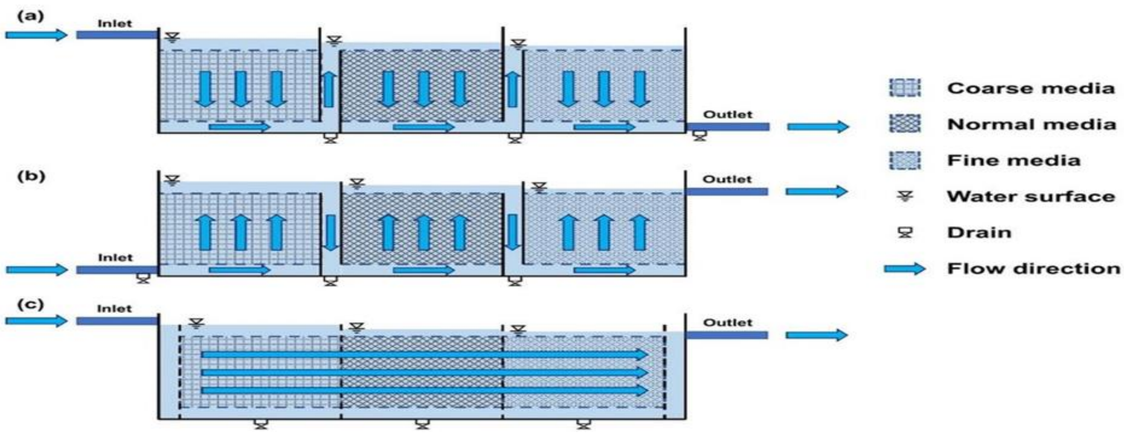

Figure 5: Diagram of both horizontal and vertical roughing filters: (a) down-flow configuration, (b) up flow configuration, and (c) horizontal-flow configuration

Roughing filters typically require regular maintenance, such as backwashing, which involves reversing the flow of water through the filter to remove the trapped particles and debris. The filter bed must also be cleaned and replaced periodically to maintain its efficiency. It's worth mentioning that roughing filters can be used in different forms, such as rapid sand filters, gravity filters, or pressure filters. Each one of these has its own advantages and disadvantages depending on the specific application

Sand filter

Sand filters are a type of filtration process used in water treatment plants to remove small suspended particles from water. The process involves passing the water through a bed of sand, which acts as a filter to remove the particles. The water is pumped into the top of the filter and flows through the bed of sand. As the water flows through the sand, the small particles are trapped in the spaces between the grains of sand. The filtered water then flows out of the bottom of the filter, while the trapped particles remain in the filter bed. A clearly visual depiction of the sand filtration process in water treatment is presented in **"**Figure 08**"**, providing significant insight into the filtration mechanism. Sand filters are typically used as a final step in the water treatment process, after other processes such as coagulation, flocculation, and sedimentation have been used to remove larger particles. They are particularly useful for removing small particles such as silt, clay, and bacteria that can pass through other types of filters.

Sand filters typically require regular maintenance, such as backwashing, which involves reversing the flow of water through the filter to remove the trapped particles and debris. The filter bed must also be cleaned and replaced periodically to maintain its efficiency. It's worth mentioning that sand filters can be used in different forms, such as rapid sand filters, gravity filters, or pressure filters. Each one of these has its own advantages and disadvantages depending on the specific application. Additionally, some water treatment plants may use multi-media filters that use layers of different types of media such as sand, gravel, and anthracite coal, which can increase the efficiency of the filtration process.

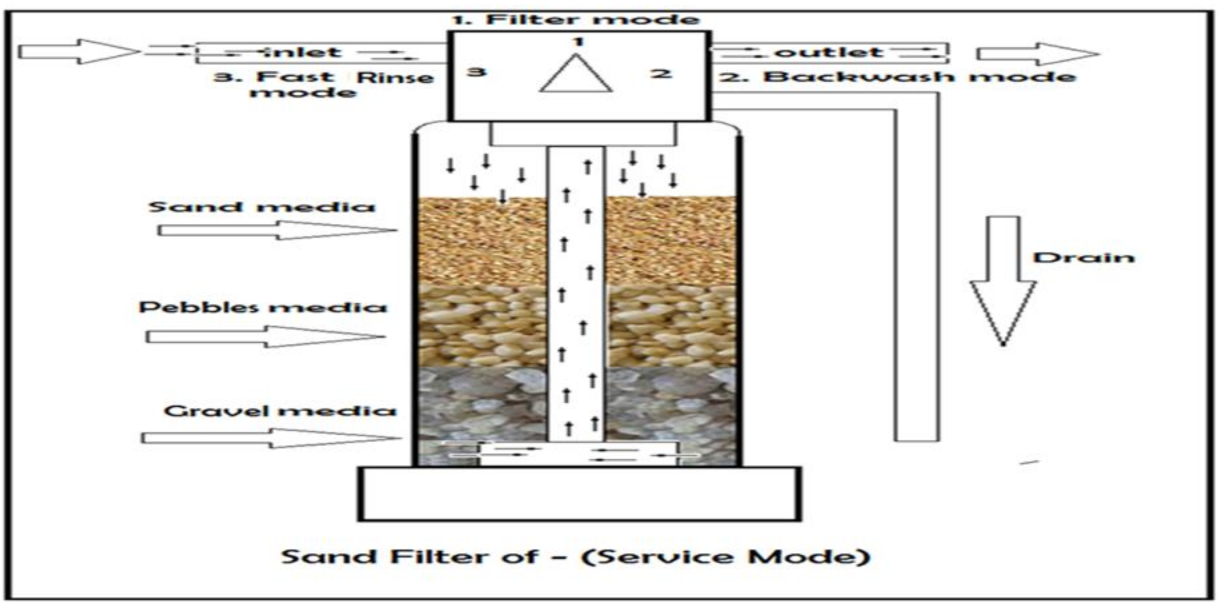

Figure 6: This graphic provides a comprehensive look at the Sand Filter Process.

Reserve tank

A reserve tank, also known as a clear well or storage tank, is a component of a water treatment plant that is used to store treated water before it is distributed to customers. The tank is typically located near the end of the treatment process, after the water has undergone purification and disinfection.

The reserve tank serves several purposes:

- It provides a reliable and consistent supply of treated water to customers, even during periods of high demand or unexpected fluctuations in water flow.

- It allows operators to monitor the water quality and make adjustments to the treatment process as needed.
- It allows the plant to store water for emergency use, such as in case of equipment failure or power outages.
- It allows the plant to maintain a certain chlorine residual in the water, which helps to ensure that the water remains safe for consumption.
- The reserve tank is typically made of concrete or steel and is designed to hold a large volume of water. It is also typically located above ground and is equipped with level sensors and overflow protection to ensure safety and compliance with regulations.

It's worth mentioning that the design of a reserve tank should be suitable to the flow rate and volume of water that needs to be stored and it should be able to protect the stored water from external factors such as sunlight, pollution, and temperature changes. Additionally, the tank should be equipped with a system to prevent backflow of water and maintain water quality.

Post-chlorination

Pre-chlorination is a process used in water treatment plants to disinfect water before it enters the main treatment process. The process involves the addition of chlorine, or a chlorine-based compound, to the water before it enters the plant. The purpose of pre-chlorination is to kill or inactivate any microorganisms that may be present in the water, such as bacteria, viruses, and parasites. This helps to reduce the risk of contamination and the spread of waterborne diseases.**”** Figure 10**”** displays a diagram of the post-chlorination procedure, which serves as a supplementary element to the initial stage of pre-chlorination in water treatment.

The specific methods used for pre-chlorination can vary depending on the type of water being treated and the desired level of disinfection. Common methods include the use of chlorine gas, sodium hypochlorite solution, or calcium hypochlorite pellets. The water is then sent through the main treatment process, where it undergoes further purification and disinfection. The amount of chlorine added to the water during pre-chlorination is typically determined by the plant operator based on the water quality and the desired level of disinfection. Also, the water is generally held in a contact tank for a specific amount of time to ensure that the chlorine has enough time to disinfect the water. It's worth mentioning that pre-chlorination is not always necessary, but it's a common practice in water treatment plants where the water source is surface water. The main reason is that surface water is more susceptible to contamination from microorganisms and other impurities, so pre-chlorination is used as an added layer of protection. Additionally, the process should be done in compliance with the regulations of the relevant authorities and should be regularly monitored to ensure the safety of the water.

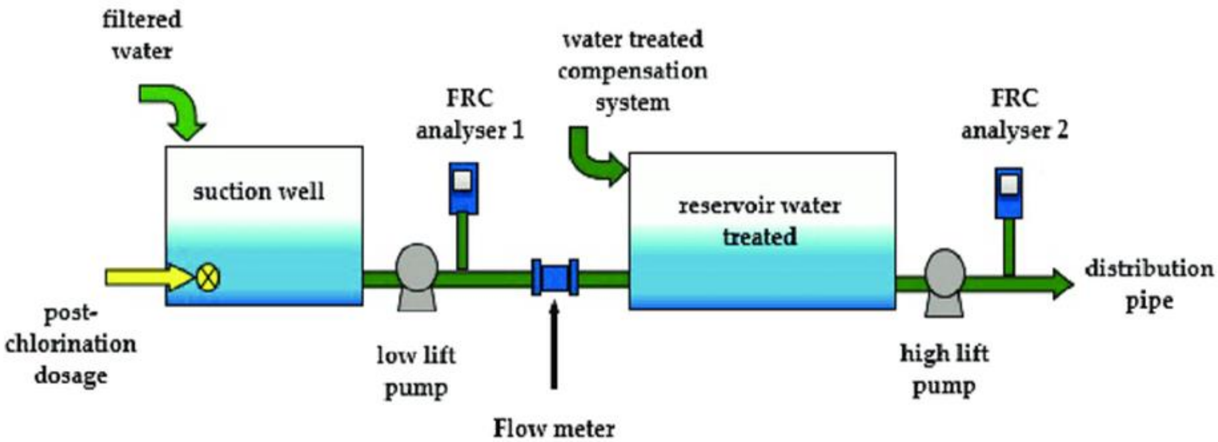

Figure 7: Outlines an overview of the process that occurs after chlorine treatment.

Water delivery

Water delivery is the process of transporting treated water from a water treatment plant to customers through a network of pipes, pumps, and storage tanks. The process is critical for ensuring that customers have a reliable and consistent supply of safe and clean drinking water. The process typically begins with the water being pumped from the reserve tank or clear well, which is a storage tank where the treated water is held before distribution, through a series of pumps and valves to increase the pressure. The water is then sent through a network of pipes, which can include both above-ground and underground pipelines, to the customers. The water delivery system is designed to ensure that the water is delivered to customers at the appropriate pressure and flow rate, and that the water quality is maintained throughout the distribution process. This may include the use of meters, valves, and other control devices to regulate the flow and pressure of the water. It's worth mentioning that the water delivery process also includes water treatment plant monitoring, which is the process of monitoring the water quality and system performance to ensure that the water meets regulatory standards and customer needs. This may include the use of online monitoring systems, manual sampling, and laboratory testing to ensure that the water is safe and compliant with regulations. In summary, Water delivery is a vital process in the water treatment plant, it ensures that treated water is delivered to customers efficiently, safely, and in compliance with regulations.

Conclusions

The research on the working principle and performance evaluation of the KUET water treatment plant in Khulna-9203, Bangladesh has shown that the plant effectively purifies source water from the nearly ponds and shallow tube wells using a combination of physical, chemical, and biological treatment processes. The plant is able to remove impurities such as turbidity, total dissolved solids (TDS), and other contaminants to provide safe and clean drinking water to the university campus and surrounding areas. The plant's performance was evaluated by monitoring various water quality parameters such as pH, color, turbidity, iron, total dissolved solids (TDS), and chloride. The results showed that the plant was able to consistently meet the Bangladesh Standards for Drinking Water Quality for all of these parameters, indicating that the plant is operating effectively. However, during the monsoon season, the plant's performance may be affected by flooding and high levels of turbidity in the source water. The study also found that the plant's performance can be improved by regularly maintaining and upgrading the equipment, as well as by implementing a comprehensive monitoring and management system. In conclusion, the KUET water treatment plant is able to provide safe and clean drinking water to the university campus residential areas. However, steps should be taken to ensure that the plant's performance is not affected during the monsoon season and to continuously improve the plant's performance.

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