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Structural Analysis and Design of Water Treatment Plant Structures - A Review

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Abstract: Water treatment plants (WTPs) play a critical role in ensuring the supply of clean and potable water. The structural integrity of WTPs is paramount to their efficiency and longevity. This review paper examines the various structural components of WTPs, the analysis methods employed, and the design considerations that govern their construction. It explores traditional and modern approaches in structural design, emphasizing load considerations, seismic analysis, material selection, and sustainability aspects. The study aims to consolidate knowledge from various research studies and standards to provide a comprehensive understanding of structural analysis and design in water treatment facilities.
Keywords: Water Treatment Plant, Structural Analysis, Seismic Design, Material Selection, Load Considerations, Sustainability, Finite Element Method (FEM)

I. INTRODUCTION

Water treatment plants are essential infrastructures that ensure safe drinking water by removing contaminants through physical, chemical, and biological processes. The structural components of these plants must withstand various loads, including hydrostatic, seismic, and environmental loads, making their design a complex engineering challenge. This paper presents a review of the methodologies and advancements in the structural analysis and design of WTP structures. Water is one of the most fundamental resources necessary for sustaining life, economic development, and environmental balance. It plays a crucial role in various sectors, including agriculture, industry, and domestic usage. However, with the increasing global population, rapid urbanization, and expanding industrial activities, the demand for clean and safe water has escalated significantly. This growing demand presents challenges related to water quality, availability, and sustainable management, necessitating the development of effective water treatment facilities to ensure a continuous and safe water supply for human consumption and other essential activities. A conventional water treatment plant (WTP) is designed to purify raw water from natural sources such as rivers, lakes, and underground reservoirs. These plants remove contaminants, including suspended solids, dissolved substances, microorganisms, and chemical pollutants, ensuring that the treated water meets the necessary health and safety standards. The water treatment process typically includes several key stages: coagulation, flocculation, sedimentation, filtration, and disinfection. Each of these processes plays a vital role in removing specific impurities, improving water quality, and making it safe for consumption. The effectiveness of these treatment processes determines the overall efficiency and reliability of a WTP. The importance of a well-designed water treatment system is emphasized in various national and international regulatory frameworks. In India, the Atal Mission for Rejuvenation and Urban Transformation (AMRUT) 2.0 guidelines and the Central Public Health and Environmental Engineering Organization (CPHEEO) Manual provide comprehensive directives for planning, designing, and operating water treatment plants. These guidelines focus on optimizing the performance of WTPs while ensuring environmental sustainability and cost-effectiveness. They advocate for the adoption of advanced technologies, energy-efficient solutions, and best management practices to improve water treatment efficiency and distribution systems. AMRUT 2.0 aims to enhance water supply coverage in urban areas, ensuring equitable access to safe drinking water for all citizens. The program emphasizes sustainable water management, reduction of water losses, and the use of smart technologies in water treatment and distribution networks. The CPHEEO Manual, on the other hand, serves as a technical reference for engineers and planners, providing detailed recommendations on the design, construction, operation, and maintenance of WTPs. Adhering to these guidelines ensures that water treatment facilities are built with high efficiency, durability, and cost-effectiveness, thereby maximizing their operational life and serviceability. The increasing levels of water pollution further highlight the necessity of an efficient water treatment system. Industrial discharge, agricultural runoff, domestic sewage, and other pollutants contribute to the degradation of water quality, posing serious health risks to humans and aquatic life. Contaminants such as heavy metals, organic compounds, pathogens, and excessive nutrients must be effectively removed to prevent waterborne diseases and environmental hazards.

Conventional WTPs are designed to tackle these issues through systematic treatment processes that target a wide range of impurities and ensure compliance with drinking water standards prescribed by organizations such as the World Health Organization (WHO) and the Bureau of Indian Standards (BIS). Moreover, the financial and operational sustainability of water treatment plants is a key consideration in their design and implementation. Factors such as initial capital investment, energy consumption, operational costs, and maintenance requirements significantly influence the feasibility and long-term performance of WTPs. Integrating energy-efficient technologies, automation, and innovative treatment methods can enhance the cost-effectiveness of water treatment while minimizing environmental impacts. The use of renewable energy sources, such as solar and wind power, for plant operations can further contribute to sustainability and resilience against energy price fluctuations. This study aims to design a conventional water treatment plant that adheres to the AMRUT 2.0 guidelines and CPHEEO Manual, ensuring the provision of safe, reliable, and cost-effective water purification solutions. By following these well-established frameworks, the proposed WTP will contribute to sustainable water management, support urban infrastructure development, and improve public health outcomes. The study will also explore advancements in water treatment technologies, innovative design considerations, and best practices to optimize plant efficiency and effectiveness. Ultimately, the research will provide insights into developing a robust water treatment system that meets the increasing demands of urban populations while promoting environmental sustainability and resource conservation.

II. LITERATURE REVIEW

A. Overview of Water Treatment Systems

Water treatment systems play a crucial role in ensuring the availability of clean and safe drinking water. These systems are designed to remove physical, chemical, and biological contaminants from raw water sources such as rivers, lakes, groundwater, and reservoirs. The treatment process typically consists of multiple stages that address different types of pollutants to produce water that meets regulatory quality standards. Water treatment can be broadly classified into conventional and advanced treatment methods. Conventional water treatment systems include processes such as coagulation, sedimentation, filtration, and disinfection, which are widely used due to their reliability and cost-effectiveness. Advanced treatment methods, on the other hand, involve membrane filtration, reverse osmosis, ultraviolet (UV) disinfection, and advanced oxidation processes, which are employed in cases where higher purification levels are required, such as in industrial applications or desalination projects. The choice of a water treatment system depends on several factors, including the quality of raw water, population demand, regulatory guidelines, economic feasibility, and sustainability considerations. As urbanization and industrialization continue to grow, the demand for efficient and sustainable water treatment systems has become increasingly important. Government initiatives like AMRUT 2.0 and guidelines set forth by CPHEEO provide a framework for designing and implementing effective water treatment systems to meet current and future needs.

1) Design of Water Treatment Plant at Ponukumadu Village (2021) By U. Pallavi, K.N.D.V. Prasad, J. Tarun Manikanta, B. Vijaya Lakshmi, A. Jyothsna

The study by U. Pallavi et al. (2021), focuses on the *Design of Water Treatment Plant at Ponukumadu Village*, Andhra Pradesh, India, addressing the necessity of assessing surface water quality and its suitability for drinking purposes. The research highlights that Ponukumadu village, located in Nandivada Mandal, Krishna District, relies on surface water collected from Krishna River through the Nehrelli channel, stored in a pond spanning 5 acres with depths varying from 4 to 6 feet. With a population of 650 as per the 2021 Census and a water tank capacity of 40,000 liters, the study systematically evaluates water quality parameters, including chemical, physical, and biological properties, crucial for determining the effectiveness of traditional drinking water treatment processes such as coagulation, flocculation, sedimentation, filtration, and disinfection. The authors emphasize the importance of optimizing each treatment unit based on influent water quality to achieve desired effluent standards during both design and operational stages, thereby ensuring safe drinking water supply for the rural community. The findings contribute significantly to the field of environmental engineering by providing a practical framework for water treatment plant design tailored to local conditions, reinforcing the necessity of site-specific water treatment solutions in rural India.

2) Design of Water Treatment Units for Kumarakom Panchayath, Kerala (2021) By Haritha M, Rajalakshmi R S

In Kumarakom Panchayath, a local government area in Kerala, India, the primary causes of water quality deterioration are identified as the discharge of domestic and municipal wastes, along with terrestrial runoff from seepage sites. To address this issue, the design of a water treatment plant for Kumarakom Panchayath was undertaken.

A proposed layout of the plant was developed, incorporating key treatment components such as screens, cascade aerators, a flash mixer, a clariflocculator, a rapid gravity filter, and a chlorinator. This paper presents the design of the flash mixer unit, rapid sand filter, and chlorinator for the plant. To begin with, a physico-chemical analysis was conducted by collecting and analyzing water quality data from Kumarakom Panchayath. The parameters assessed included pH, turbidity, hardness, alkalinity, acidity, sulphates, chlorides, residual chlorine, nitrates, iron, dissolved oxygen, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and the most probable number (MPN) of coliform bacteria. Subsequently, a population forecast was carried out based on survey data to estimate the required capacity of the treatment plant. Using this information, a comprehensive layout of the plant was developed. Finally, the design of individual treatment components was completed based on the water quality parameters and projected plant capacity.

3) *Hydraulic Design Concept of 6.60MLD Water Treatment Plant (2024) By Abhijit Mangaraj, Smrutirekha Sahoo, Ananya P. Parida*

The 6.6 million liters per day (MLD) water treatment plant (WTP) in Belpada Village, Odisha, is designed to meet increasing water demand while ensuring public health through effective treatment processes. Sourcing raw water from the Tel River, the plant follows a structured treatment process, including aeration, sedimentation, filtration, and disinfection. This paper outlines the hydraulic design, treatment schemes, and structural components of the WTP. Design calculations, based on CPHEEO standards, are discussed, covering hydraulic detention times, surface loading, filtration rates, and sludge management techniques. Water treatment plant (WTP) design plays a critical role in delivering safe drinking water, particularly in regions with high population density and industrial growth. The Belpada Village WTP incorporates a cascade aeration system for contaminant removal. This study focuses on hydraulic and process design, emphasizing flow rates, detention times, and surface loading parameters in compliance with Central Public Health and Environmental Engineering Organization (CPHEEO) standards.

4) *Water treatment process using conventional and advanced methods: A comparative study of Malaysia and selected countries (2021) By N H Pakharuddin, M N Fazly, S H Ahmad Sukari, K Tho and W F H Zamri*

Water treatment is the process of removing all those substances, whether biological, chemical, or physical, that are potentially harmful to the water supply for human and domestic use. This treatment helps to produce water that is safe, palatable, clear, colorless, and odorless. The basic steps of water treatment include coagulation, precipitation, filtration, and disinfection. Water treatment before supplying water to consumers is essential to improve water quality to create a sustainable life. Water treatment can eliminate potential or certain harmful substances in the water to prevent the consumption of contaminated water sources that can cause potential health problems. Therefore, it is important to establish a water treatment facility with sufficient capacity to remove pollutants according to standards before being supplied to consumers. In this study, the focus of the discussion is on the use of river water as a source of water for consumers in Japan, Australia, Canada, and Malaysia after a water treatment process. This paper reviews the recent progresses of water treatment process using both conventional and advanced methods. A brief discussion on the water quality index of each country's rivers is presented. Several potential applications of Industrial Revolution 4.0 technology in the water treatment process are discussed. Adoption of the industrial revolution of technology in water treatment may provide many benefits to this field and excavate more potential improvement. This paper will deliver a scientific and technical overview and useful information to scientists, engineers, and stakeholders who work in this field.

5) *Use of water treatment plant sludge in high-rate activated sludge systems: A techno-economic investigation (2023) By Hazal Gulhan, Reza Faraji Dizaji, Muhammed Nimet Hamidi*

The disposal of sludge generated in water treatment plants (WTPs) remains a significant environmental and economic challenge. Traditionally, coagulants like aluminum sulfate ($Al_2(SO_4)_3$) and ferric chloride ($FeCl_3$) are used in WTPs, leading to the accumulation of sludge, which is often discarded in landfills. However, the increasing focus on sustainable development has encouraged the utilization of WTP sludge in wastewater treatment processes. Gulhan et al. (2023) investigated the feasibility of using WTP sludge in a high-rate activated sludge (HRAS) system as a substitute for conventional coagulants. Their study found that iron sludge exhibited superior treatment efficiency compared to alum sludge. When applied in a pilot-scale HRAS system, iron sludge at a dosage of 20.1 ± 1.6 mg dry sludge/L wastewater improved the removal efficiency of particulate chemical oxygen demand (pCOD) from 74% to 81%. Additionally, it enhanced sludge settleability by increasing the median particle size from 96 ± 3 to 163 ± 14 µm. However, the biochemical methane potential (BMP) of the HRAS process sludge decreased by 8.9%, indicating a trade-off between enhanced treatment performance and reduced biogas production.

A techno-economic analysis revealed that the integration of WTP sludge into the HRAS process reduced overall operational costs by 11% without significantly impacting the effluent quality index (EQI). These findings suggest that reusing WTP sludge in HRAS systems can provide mutual benefits for both water and wastewater treatment plants, promoting a circular economy approach in environmental engineering. Future research should focus on optimizing sludge dosages, evaluating long-term performance, and exploring potential applications in full-scale treatment plants.

6) Structural Ceramics Modified by Water Treatment Plant Sludge (2020) By Alexander Orlov, Marina Belkanova & Nikolay Vatin

Water treatment plant (WTP) sludge has gained attention as a potential material for modifying and improving construction materials, particularly structural ceramics. Orlov et al. (2020) investigated the feasibility of using aluminum-containing WTP sludge as a burning-out additive in ceramic brick production. The study aimed to optimize the conditions under which sludge from a large city's WTP could enhance ceramic properties. The raw water used in the treatment process belonged to the hydrocarbonate class with low turbidity (1.5–40 mg/L kaolin). The sludge was collected from sedimentation tanks and dewatered using lime or a freezing-thawing method before being introduced into clay mixtures in varying proportions (5% to 20% by weight). The incorporation of 20% WTP sludge improved brick properties by reducing the sensitivity of clay to drying and lowering the density of the ceramic by 20%. Simultaneously, the compressive strength of the ceramics increased from 7.0 MPa to 10.2 MPa. The research further indicated that pre-treating WTP sludge through the freezing-thawing method led to superior ceramic brick characteristics. These findings suggest that aluminum-containing WTP sludge, when processed appropriately, can serve as a valuable modifying additive in ceramic production. By repurposing WTP sludge in this manner, the study promotes sustainable waste management practices and contributes to circular economy principles in the construction sector. Future research should explore the long-term durability of such modified ceramics, assess their environmental impact, and investigate the economic feasibility of large-scale implementation.

B. Conventional Water Treatment Processes

Conventional water treatment processes have been widely adopted for municipal water supply projects due to their effectiveness in treating raw water with varying levels of contamination. The primary stages of a conventional water treatment plant include intake, aeration, coagulation and flocculation, sedimentation, filtration, and disinfection. The process begins with water intake from a surface or groundwater source, followed by aeration to remove dissolved gases and improve oxygen levels. Coagulation and flocculation involve the addition of chemicals such as alum or ferric chloride to destabilize suspended particles, allowing them to aggregate into larger flocs. These flocs are then removed in the sedimentation stage, where the water is allowed to settle in large basins. The clarified water undergoes filtration, typically using sand, gravel, or activated carbon filters, to remove finer particles and remaining impurities. Finally, disinfection is carried out using chlorine, ozone, or UV radiation to kill harmful pathogens and ensure microbiological safety. Sludge generated during sedimentation and filtration processes is managed through proper disposal or treatment methods. The conventional treatment process is cost-effective and capable of handling a wide range of water quality issues, making it the preferred choice for most municipal water supply systems. However, in areas with high levels of industrial pollution or emerging contaminants, additional advanced treatment technologies may be required to enhance water quality.

C. AMRUT 2.0 Guidelines for Water Supply Projects

The Atal Mission for Rejuvenation and Urban Transformation (AMRUT) 2.0 is a government initiative aimed at providing universal water supply coverage and improving urban infrastructure across Indian cities. Launched as an extension of the original AMRUT program, AMRUT 2.0 emphasizes sustainability, technological advancements, and efficient water management strategies. The guidelines for water supply projects under AMRUT 2.0 focus on ensuring access to safe drinking water, reducing non-revenue water losses, promoting water conservation, and incorporating smart water management systems. The program encourages the use of energy-efficient pumps, metering systems, and leak detection technologies to improve the operational efficiency of water treatment plants. Additionally, it promotes the adoption of decentralized wastewater treatment solutions and encourages water recycling and reuse to reduce dependency on freshwater sources. The AMRUT 2.0 framework aligns with the Sustainable Development Goals (SDGs) by advocating for sustainable urban water management practices. Funding for water supply projects under AMRUT 2.0 is provided based on project feasibility, impact assessment, and adherence to prescribed guidelines. The mission also emphasizes capacity building, skill development, and the use of digital tools such as Geographic Information Systems (GIS) and Supervisory Control and Data Acquisition (SCADA) for real-time monitoring and management of water supply infrastructure.

By integrating innovative approaches and smart technologies, AMRUT 2.0 aims to enhance the resilience and efficiency of urban water treatment systems across India.

D. CPHEEO Manual Standards and Recommendations

The Central Public Health and Environmental Engineering Organization (CPHEEO) has developed comprehensive guidelines and standards for water supply, treatment, and distribution in India. The CPHEEO Manual provides technical recommendations for designing, operating, and maintaining water treatment plants to ensure compliance with water quality standards. The manual outlines best practices for various treatment processes, including intake structures, chemical dosing, sedimentation, filtration, and disinfection. It also sets standards for water quality parameters such as turbidity, pH, dissolved oxygen, and microbial contamination. The CPHEEO guidelines recommend appropriate hydraulic and structural design considerations to optimize plant efficiency and durability. Additionally, the manual provides guidance on selecting suitable construction materials, ensuring proper sludge management, and implementing safety measures in water treatment plants. One of the key aspects of CPHEEO recommendations is the emphasis on water conservation and sustainable resource management. The guidelines encourage the adoption of rainwater harvesting, groundwater recharge, and wastewater reuse to address the growing demand for clean water. Furthermore, the CPHEEO Manual aligns with national and international standards, including those set by the Bureau of Indian Standards (BIS) and the World Health Organization (WHO), to maintain consistency in water treatment practices across different regions. By following CPHEEO standards, municipalities and water utilities can ensure the provision of safe and reliable drinking water while minimizing environmental impacts and operational costs.

E. Case Studies on Existing Water Treatment Plants

Studying existing water treatment plants provides valuable insights into the challenges and best practices in water treatment infrastructure. Several case studies across India and other countries highlight the effectiveness of conventional treatment processes and the impact of modernization efforts. One notable example is the Nagpur Water Treatment Plant, which has successfully integrated advanced filtration techniques and real-time monitoring systems to enhance water quality and efficiency. Another case study from Bengaluru demonstrates how the implementation of SCADA technology has improved the operational efficiency of the city's water treatment and distribution network. Similarly, the Delhi Jal Board's water treatment plants have adopted innovative sludge management techniques and energy-efficient pumps to reduce operational costs. International case studies, such as the Singapore Water Treatment System, showcase how advanced membrane filtration and desalination technologies can complement conventional treatment processes to meet increasing water demands. Additionally, case studies on small-scale decentralized treatment plants in rural areas highlight the importance of low-cost, community-based solutions for improving water access in underserved regions. These case studies emphasize the significance of adopting best practices, leveraging technology, and ensuring regular maintenance to enhance the performance and sustainability of water treatment plants. By analyzing these real-world examples, this study aims to incorporate key lessons into the design of a conventional water treatment plant that aligns with AMRUT 2.0 and CPHEEO guidelines.

1) Study of Water Treatment Plant Jalgaon (2018) By Gaurank Patil, Bhalchandra Sambrekar, Gaurav Dukare, Parth Kansagara, Ashutosh Hingmire

Water treatment is an essential process to ensure the availability of clean and safe water for human consumption. Efficient water treatment plants (WTPs) play a crucial role in removing contaminants and pathogens from raw water sources to maintain public health. The study by Patil et al. (2018) provides an analytical review of the Jalgaon Water Treatment Plant, operated by the Jalgaon Municipal Corporation, highlighting its design components and necessary modifications. A typical WTP consists of several stages, including coagulation, sedimentation, filtration, and disinfection. The Jalgaon WTP follows a conventional treatment process to meet water quality standards. The study details key design components such as intake structures for drawing raw water, coagulation and flocculation units for destabilizing suspended particles, sedimentation tanks for settling heavier particles, filtration systems comprising sand and gravel filters, and disinfection processes using chlorine to eliminate harmful microorganisms. These stages collectively enhance treatment efficiency and ensure potable water supply. However, several challenges exist, including aging infrastructure requiring upgrades, the need for advanced water quality monitoring techniques, and the necessity of optimizing treatment processes such as coagulation and filtration to improve resource efficiency.

The study suggests modifications such as the automation of treatment processes and the exploration of alternative disinfection methods to reduce chlorine dependency. Addressing these challenges would improve plant performance and ensure long-term sustainability. The findings emphasize the importance of maintaining and upgrading WTPs to enhance operational efficiency and water quality.

Future research could explore the integration of advanced treatment technologies like membrane filtration and bio-treatment processes for better water quality management and environmental sustainability.

III. PROPOSED METHODOLOGY

A. Selection of Design Parameters

The selection of design parameters is a critical step in the planning and development of a conventional water treatment plant. These parameters are determined based on various factors, including raw water characteristics, expected water demand, regulatory guidelines, and site-specific constraints. The key design parameters include flow rate, detention time, filtration rate, chemical dosing requirements, and hydraulic gradients. The capacity of the treatment plant is based on projected population growth and per capita water consumption, ensuring that the facility can meet future demands. Other important parameters include turbidity and suspended solids removal efficiency, disinfection contact time, and sludge management provisions. Design parameters must comply with CPHEEO guidelines, BIS standards, and AMRUT 2.0 recommendations to ensure water quality and operational efficiency. Additionally, considerations such as redundancy in critical components, energy efficiency, and automation for process control play a significant role in optimizing plant performance.

1) Design Period

Clause 2.2.6: Water Supply projects may be designed normally to meet the requirements over a thirty-year period after their completion. The time lag between design and completion of the project should also be taken into account which should not exceed two years to five years depending on the size of the project. The thirty-year period may however be modified in regard to certain components of the project depending on their useful life or the facility for carrying out extensions when required and rate of interest so that expenditure far ahead of utility is avoided. Necessary land for future expansion/duplication of components should be acquired in the beginning itself. Where expensive tunnels and large aqueducts are involved entailing large capital outlay for duplication, they may be designed for ultimate project requirements. Where failure such as collapse of steel pipes under vacuum put the pipe line out of commission for a long time or the pipe location presents special hazards such as floods, ice, and mining etc. duplicate lines may be necessary.

Clause 2.2.6 of Manual stipulate design period, for some components it may be modified depending on its useful life, facility for carrying out extensions when required and interest rate so that expenditure far ahead of utility is avoided. Land for future extension should be acquired in beginning itself. Project components may be designed to meet the requirements of the following design period.

Table 3.1: Design Period

SN	Data Source	Design period in years
1	Storage by dams	50
2	Infiltration Works	30
3	Pumping	
	i. Pump house (civil works)	30
	ii. Electric motors and pumps	15
4	Water treatment units	15
5	Pipe connection to several treatment units and other small appurtenances	30
6	Raw water and clear water converting mains	30
7	Clear water reservoirs at the head works, balancing tanks and service reservoirs (overhead or ground level)	15
8	Distribution system	30

B. Population Forecast and Water Demand Estimation

Accurate population forecasting and water demand estimation are essential for designing a water treatment plant with adequate capacity to serve the intended population over its design life. The population forecast is determined using methods such as arithmetic increase, geometric progression, and logistic curve models, considering historical census data and growth trends. Water demand estimation includes domestic, industrial, commercial, institutional, and firefighting requirements, along with an allowance for transmission losses and leakage. The per capita water consumption is determined based on CPHEEO recommendations, which typically range from 135 to 150 liters per capita per day (LPCD) for urban areas. Peak demand variations and seasonal fluctuations are also considered to ensure reliable water supply during high-demand periods. The calculated demand influences the sizing of intake structures, treatment units, storage reservoirs, and distribution systems.

1) Per Capita water Supply

- Factors affecting consumption: Larger the city, more rate of consumption. Individual bungalows consume more than flats. Slums consume less water. In hot weather consumption is more. The consumption rate is less in metered areas than that area where charges are levied on flat rate basis.
- Domestic: Clause 2.2.8.3 of manual stipulate maximum water supply of 70 LPCD for towns without sewerage, 135 LPCD for towns with sewerage system existing/contemplated and 150 LPCD for metropolitan and Mega cities with sewerage system existing/contemplated. Where water is provided through PSPs 40 LPCD should be considered. The un accounted for water is not included in above per capita supply. The LPCD figures include water for commercial, institutional and minor industries. However, the bulk supply to such establishments should be assessed separately.
- Clause 2.2.8: The Environmental Hygiene Committee suggested certain optimum service levels for communities based on population groups. In the Code of Basic Requirements of Water Supply, Drainage and Sanitation as well as the National Building Code, a minimum of 135 lpcd has been recommended for all residences provided with full flushing system for excreta disposal. Though the Manual on Sewerage and /sewage Treatment to conserve water, a minimum of 135 lpcd in now recommended. It is well recognized that the minimum water requirements for domestic and other essential beneficial uses should be met through public water supply. Other needs for water including industries etc. may have to be supplemented from other systems depending upon the constraints imposed by the availability of capital finances and the proximity of water sources having adequate quantities of acceptable quality which can be economically utilized for public water supplies.

Table 3.2: Recommended Per Capita Water Supply Levels for Designing Schemes

SN	Classification of towns/cities	Recommended Maximum Water Supply Levels (lpcd)
1.	Town provided with pipes water supply but without sewerage system.	70
2.	Cities provided with piped water supply where sewerage system is existing / contemplated.	135
3.	Metropolitan and Mega cities provided with piped water supply where sewerage system is existing contemplated.	150

- Un accounted for Water: The unaccounted-for water in Indian cities is very high-some 40-50%. However, the target should be to reduce it to 15%. Accordingly, while designing a scheme provision of 15% for UFW/NRW should be taken and old schemes should be rehabilited to bring UFW/NRW to 15% level.
- Fire Fighting: Clause 2.2.8.3b of manual provide for firefighting demand as a coincident draft on the distribution system along with a normal supply. Provision in kl/day of $100*\sqrt{P}$ (where, P=population in thousands) may be adopted for communities larger than 50000. It is usual to provide for firefighting demand as a coincident draft on the distribution system along with the normal supply to the consumers as assumed A provision in kiloliters per day based on the formula of $100\sqrt{p}$ where, p = population in thousands may be adopted for communities larger than 50,000. It is desirable that one third of the fire-fighting requirements from part of the service storage. The balance requirement may be distributed in several static tanks at strategic points. These static tanks may be filled from the nearby ponds, streams or canals by water tankers wherever feasible.

- Institutional: The water requirement for institutes / industries/ hotels/ hostels and hospital be taken separately as per Clause 2.2.8.3c of Manual. The water requirements for institutional should be provided in addition to the provisions indicated in (a) above, where required, if they are of considerable magnitude and not covered in the provisions already made. The Individual requirements would be as follows:

Table 3.3: Institutional Needs

SN	Institutions	Liters per Head per Day
1.	Hospital (including laundry)	
	(a) No. of beds exceeding 100	450 (per bed)
	(b) No. of beds not exceeding 100	340 (per bed)
2.	Hotels	180 (per bed)
3.	Hostels	135
4.	Nurses' homes and medical quarters	135
5.	Boarding schools / colleges	135
6.	Restaurants	70 (per seat)
7.	Airports and sea ports	70
8.	Junction Stations and intermediate stations where mail or express stoppage (both railways and bus stations) is provided	70
9.	Terminal stations	45
10.	Intermediate stations (excluding mail and express stops)	45 (could be reduced to 25 where bathing facilities are not provided)
11.	Day schools / colleges	45
12.	Offices	45
13.	Factories	45 (could be reduced to 30 where no bathrooms are provided)
14.	Cinema, concert halls, and theatre	15

Industrial: Clause 2.2.8.3d of Manual gives water requirement of different industries. While the per capita rates of supply recommended will ordinarily include the requirement of small industries (other than factories) distributed within a town, separate provisions will have to be included for meeting the demands likely to be made by specific industries within the urban areas. The forecast of this demand will be based on the nature and magnitude of each such industry and the quantity of water required per unit of production. The potential for industrial expansion should be carefully investigated, so that the availability of adequate water supply may attract such industries and add to the economic prosperity of the community. As can be seen from the tabulation, the quantities of water used by industry vary widely. They are also affected by many factors such as cost and availability of water, waste disposal problems, management and the types of processes involved. Individual studies of the water requirement of a specific industry should, therefore, be made for each location, the value given below serving only as guidelines. In the context of reuse of water in several industries, the requirement of fresh water is getting reduced considerably.

Table 3.4: Industrial Needs

Industry	Unit of Production	Water Requirement in Kilolitres per Unit
Automobile	Vehicle	40
Distillery	Kilolitre Alcohol	122-170
Fertilizer	Tonne	80-200
Leather	100 Kg (tanned)	4
Paper	Tonne	200-400
Special quality paper	Tonne	400-1000
Straw board	Tonne	75-100
Petroleum Refinery	Tonne (crude)	1-2
Steel	Tonne	200-250
Sugar	Tonne (Cane crushed)	1-2
Textile	100 Kg (goods)	8-14

C. Raw Water Quality Analysis

Raw water quality analysis is conducted to determine the physical, chemical, and biological characteristics of the water source, which directly influence the treatment process selection and design parameters. The key parameters analyzed include turbidity, suspended solids, pH, alkalinity, hardness, dissolved oxygen, iron and manganese content, microbial contamination, and presence of heavy metals or emerging pollutants. Water quality testing is performed using laboratory analysis and field sampling techniques in accordance with BIS 10500 and WHO drinking water standards. If the raw water is sourced from a river or reservoir, seasonal variations in water quality are also considered. The results of the analysis guide the selection of appropriate treatment processes, chemical dosing rates, and filtration methods to achieve the desired treated water quality.

1) Quality Standards

- Physical & Chemical: Clause 2.2.9 of Manual Table 2.2 gives recommended guidelines for physical and chemical parameters on the principal that safe water is an obligatory standard and physical and chemical qualities are optional within a range. The objective of Water Works Management is to ensure that the water supplied is free from pathogenic organisms, clear, palatable and free from undesirable taste and odour, of reasonable temperature, neither corrosive nor scale forming and free from minerals which could produce undesirable physiological effects. The establishment of minimum standards of quality for public water supply is of fundamental importance in achieving this objective. Standards of quality form the yardstick within which the quality control of any public water supply has to be assessed. Sanitary inspections are intended to provide a range of information and to locate potential problems. The inspections allow for an overall appraisal of many factors associated with a water supply system, including the water works and the distribution system. Moreover, such an appraisal may later be verified and confirmed by microbiological analysis, which will indicate the severity of the problem. Sanitary inspections thus provide a direct method of pinpointing possible problems and sources of contamination. They are also important in the prevention and control of potentially hazardous conditions, including epidemics of water borne diseases. The data obtained may identify failures, anomalies, operator errors and any deviations from normal that may affect the production and distribution of safe drinking water. When the inspections are properly carried out at appropriate regular intervals and where the inspector has the knowledge necessary to detect problems and suggest technical solutions, the production of good quality water is ensured. The evolution of standards for the quality control of public water supplies has to take into account the limitations imposed by local factors in the several regions of the country. The Environmental Hygiene committee (1949) recommended that the objective of a public water supply should be to supply water "that is absolutely free from risks of transmitting diseases, is pleasing to the senses and is suitable for culinary and laundering purposes" and added that "freedom from risks is comparatively more important than physical appearance or hardness" and that safety is an obligatory standard and physical and chemical qualities are optional within a range. These observations are relevant in the development of a country-wide programs of protected water supply systems for communities big and small, making use of the available water resources in the different regions, with a wide variation in their physical, chemical and aesthetic qualities, that can be achieved by communities in due course within the limits of their financial resources. The Immediate need is for minimum standards consistent with the safety of public water supplies. Considering the standards prescribed in the earlier Manual and further development in the international standardization and the conditions in the country, the following guidelines are recommended.

Table 3.5: Physical and Chemical Quality of Drinking Water

SN	Characteristics	Acceptable	Cause for Rejection
1	Turbidity (NTU)	1	10
2	Color Units on Platinum Cobalt Scale	5	25
3	Taste and Odour	Unobjectionable	Objectionable
4	pH	7.0-8.5	<6.5 or >9.2
5	Total Dissolved Solids (mg/l)	500	2000
6	Total Hardness (as $CaCO_3$) (mg/l)	200	600
7	Chlorides (as Cl^-) (mg/l)	200	1000
8	Sulphates (as SO_4) (mg/l)	200	400
9	Fluorides (as F^-) (mg/l)	1	1.5
10	Nitrates (as NO_3) (mg/l)	45	45
11	Calcium (as Ca) (mg/l)	75	200
12	Magnesium (as Mg) (mg/l)	≤30	150

Heavy Metals and Other Contaminants

SN	Characteristics	Acceptable	Cause for Rejection
13	Iron (as Fe) (mg/l)	0.1	1
14	Manganese (as Mn) (mg/l)	0.05	0.5
15	Copper (as Cu) (mg/l)	0.05	1.5
16	Aluminium (as Al) (mg/l)	0.03	0.2
17	Alkalinity (mg/l)	200	600
18	Residual Chlorine (mg/l)	0.2	>1.0
19	Zinc (as Zn) (mg/l)	5	15
20	Phenolic Compounds (as Phenol) (mg/l)	0.001	0.002
21	Anionic Detergents (as MBAS) (mg/l)	0.2	1
22	Mineral Oil (mg/l)	0.01	0.03

Toxic Materials

SN	Characteristics	Acceptable	Cause for Rejection
23	Arsenic (as As) (mg/l)	0.01	0.05
24	Cadmium (as Cd) (mg/l)	0.01	0.01
25	Chromium (as Hexavalent Cr) (mg/l)	0.05	0.05
26	Cyanides (as Cd) (mg/l)	0.05	0.05
27	Lead (as Pb) (mg/l)	0.05	0.05
28	Selenium (as Se) (mg/l)	0.01	0.01
29	Mercury (total as Hg) (mg/l)	0.001	0.001
30	Polynuclear Aromatic Hydrocarbons (PAH) (µg/l)	0.2	0.2
31	Pesticides (Total) (mg/l)	Absent	Refer to WHO guidelines

Radioactivity

SN	Characteristics	Acceptable	Cause for Rejection
32	Gross Alpha Activity (Bq/l)	0.1	0.1
33	Gross Beta Activity (Bq/l)	1	1

- Bacteriological Quality: Clause 2.2.9 of Manual, Table 2.3 gives recommended guidelines for Bacteriological quality.

Table 3.6: Microbial Water Quality Guidelines

Organisms	Guideline Value
All water intended for drinking	
E. coli or thermotolerant coliform bacteria	Must not be detectable in any 100-ml sample
Treated water entering the distribution system	
E. coli or thermotolerant coliform bacteria	Must not be detectable in any 100-ml sample
Total coliform bacteria	Must not be detectable in any 100-ml sample
Treated water in the distribution system	
E. coli or thermotolerant coliform bacteria	Must not be detectable in any 100-ml sample
Total coliform bacteria	Must not be detectable in any 100-ml sample. In case of large supplies, where sufficient samples are examined, must not be present in 95% of samples taken throughout any 12-month period.

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- Virological Quality: Drinking water must be free of human enteroviruses to ensure negligible risk of transmitting viral infection. Clause 2.2.9 of Manual, Table 2.4 gives recommended treatment for different water sources to produce water with negligible virus risk. Drinking water must essentially be free of human enteroviruses to ensure negligible risk of transmitting viral infection. Any drinking-water supply subject to faecal contamination presents a risk of a viral disease to consumers. Two approaches can be used to ensure that the risk of viral infection is kept to a minimum: providing drinking water from a source verified free of faecal contamination, or adequately treating faecally contaminated water to reduce enteroviruses to a negligible level. virological studies have shown that drinking water treatment can considerably reduce the levels of viruses but may not eliminate them completely from very large volumes of water. Virological, epidemiological, and risk analysis are providing important information, although it is still insufficient for deriving quantitative and direct virological criteria. Such criteria cannot be recommended for routine use because of the cost, complexity, and lengthy nature of virological analysis, and the ract that they can-not detect the most relevant viruses. The guideline criteria shown in table 2.4 are based upon the likely viral content of source waters and the degree of treatment necessary to ensure that even very large volumes of drinking water have negligible risk of containing viruses. Ground water obtained from a protected source and documented to be free from faecal contamination from its zone of influence, the well, pumps, and delivery system can be assumed to be virus-free However, when such water is distributed, it is desirable that it is disinfected, and that a residual level of disinfectant is maintained in the distribution system to guard against contamination.

Table 3.7: Water Source and Recommended Treatment

Type of Source	Recommended Treatment
Ground Water	
Protected, deep wells; essentially free of faecal contamination	Disinfection
Unprotected, shallow wells; faecally contaminated	Filtration and disinfection
Surface Water	
Protected, impounded upland water; essentially free of faecal contamination	Disinfection
Unprotected impounded water or upland river; faecal contamination	Filtration and disinfection
Unprotected lowland rivers; faecal contamination	Pre-disinfection or storage, filtration, disinfection
Unprotected watershed; heavy faecal contamination	Pre-disinfection or storage, filtration, additional treatment, and disinfection
Unprotected watershed; gross faecal contamination	Not recommended for drinking water supply

- Frequency of Sampling: The minimum number of samples to be collected from distribution system should be as per Table 15.1 of Manual.

Table 3.8: Water Sampling Guidelines Based on Population Served

Population Served	Maximum Intervals Between Successive Sampling	Minimum No. of Samples to Be Taken from Entire Distribution System
Up to 20,000	One month	One sample per 5,000 of population per month
20,000 - 50,000	Two weeks	One sample per 5,000 of population per month
50,001 - 100,000	Four days	One sample per 5,000 of population per month
More than 100,000	One day	One sample per 10,000 of population per month

D. Treatment Process Selection

Based on raw water characteristics and regulatory requirements, the most suitable treatment processes are selected to ensure safe and high-quality drinking water. Conventional treatment processes include pre-sedimentation, aeration, coagulation-flocculation, sedimentation, filtration, and disinfection. In cases where the raw water has high organic content, taste, or odor issues, advanced processes such as activated carbon filtration or ozonation may be incorporated.

If the raw water has excessive hardness, a softening process using lime or ion-exchange resins may be required. The treatment process must be designed to achieve compliance with CPHEEO guidelines, ensuring efficient removal of contaminants while optimizing chemical usage and operational costs. The integration of automation and real-time monitoring is also considered to enhance process efficiency and reliability.

1) *Source of Water Supply*

a) Surface Water: Water collected from precipitation, Lakes, ponds, Dams, Rivers, Irrigation canals, sea water, waste water reclamation etc are surface sources. Study the availability and relative costs of supplying water and then decide source. The raw water from lakes, ponds, dams and rivers is extracted by constructing floating or fixed Intake. Intake can be with pumping sets on it or only draw water and through conduit carry to a suction well from where it is pumped. Clause 5.2.7.1 (c) stipulate design considerations. Rate of Silting in dams, Clause 5.2.7.1 (g(i)), stipulate 0.1 to 0.2 hectare meters per year per sq.kilometre. Evaporation in dams, Clause (5.2.7.1 (g(ii)), stipulate 2-2.5 m/year. NOIGEN-101 mixture of Cetyl and Stearyl alcohols indigenously available may be used for suppressing evaporation from lakes and reservoirs by spraying on water surface. A dose of 1.2 kg/hectare/day is adequate for wind velocities below 8 km/hour. NThe intake structures design should provide for withdrawal of water from more than one level to cope up with seasonal variations of depth of water. Under sluices should be provided for release of less desirable water held in storage. In the design of intake, a generous factor of safety must be allowed as forces to be resisted by intakes are known only approximately. The intake in or near navigable channels should be protected bu clusters of piles or other devices, against blows from moving objects. Undermining of foundations due to water currents or overturning pressures, due to deposits of silt against one side of an intake structure, are to be avoided. The entrance of large objects into the intake pipe is prevented by coarse screen or by obstructions offered by small openings in the crib work placed around the intake pipe. Fine screens for the exclusion of small fish and other small objects should be placed at an accessible point. The area of the openings in the intake crib should be sufficient to prevent an entrance velocity greater than about 8 meters per minute to avoid carrying settleable matter into the intake pipe. Submerged ports should be designed and controlled to prevent air from entering the suction pipe, by keeping a depth of water over the port of at least three diameters of the port opening. The conduit for conveying water from the intake should lead to a suction well in or near the pumping station. For conduits laid under water, standard cast iron pipe may be used. Larger conduits may be of steel of concrete. A tunnel, although more expensive, makes the safest conduit. The capacity of the conduit and the depth of the suction well should be such that the intake ports to the suction well should be such that the intake ports to the suction pipes of pumps will not draw air. A velocity of 60 to 90 cm/s in the intake conduit with a lower velocity through the ports will give satisfactory performance. The horizontal cross-sectional area of the suction well should be three to five times the vertical cross-sectional area of the intake conduit. The intake conduit should be laid on a continuously rising or falling grade to avoid accumulation of air or gas pockets of which would otherwise restrict the capacity of the conduit.

- Silting: Loss of capacity due to the deposition of silt in a reservoir may impair, if not destroy, the usefulness of the reservoir in a few years. It may be minimized by proper site selection, erosion control, reservoir operation and desilting works. The reservoir site may preferably be chosen on a non-silt bearing stream, or the reservoir may be located in a basin off the main channel so that heavily silt-laden waters may be by-passed around the basin. Reservoirs should be located on the smallest drainage area possible. The rate of silting (hectare meters per year per sq. kilometer) under Indian conditions varies from 0.1 to 0.2. After silt has been deposited in a reservoir, there is no practicable method, widely applicable, for removing it other than to operate gates in the dam to flush out the silt to some extent at times of high stream flow. Dredging is expensive and the disposal of the dredged material presents a serious problem. Soil erosion and control are closely related to the silting of reservoirs since without erosion there would be no silting. Erosion prevention methods recommended for soil conservation include proper crop rotation, ploughing on contours, terracing, strip cropping, protected drainage channels, check dams, reforestation, fire control and grazing control. Hence it is necessary to provide for silting capacity for all impounding reservoirs, based on studies or data pertaining to similar catchments.
- Evaporation: By evaporation, a process by which water passes from the liquid state to the vapour state, water is lost from water surface and moist earth surfaces. Hence it is of importance in determining the storage requirements and estimating losses from impounding reservoirs, and other open reservoirs. Evaporation from water surface is influenced by temperature, barometric pressure, mean wind velocity, vapour pressure of saturated vapour and vapour pressure of saturated air and dissolved salt content of water. The evaporation loss in storage tanks in India amounts to 2-2.5 m/year. It is essential that the available surface

storage is adequately protected from evaporation as losses upto 30% can be reduced economically. A number of liquid and solid organic compounds have the property of spreading on the water surface and forming a thin film. It is possible to select organic compounds which give monomolecular films and are capable of expansion and contraction by wave action thus being undamaged under field conditions. Such a monomolecular film offers resistance to the evaporating water particles as a result of which the rate of evaporation is reduced. Hexadecanol or Cetyl alcohol and Octadecanol or stearyl alcohol or a mixture of these two chemicals is commonly used for suppressing evaporation from lakes and reservoirs. NOIGEN-101, which is mixture of Cetyl and Stearyl alcohols and indigenously available may be used for suppressing evaporation from lakes and reservoirs by spraying on water surface so as to cover the entire surface with this film. The chemical can be used in solution, in powder form or as an emulsion. Spraying in powder form is the simplest and most widely used process. A dose of 1.2 kg/hectare/day is adequate for wind velocities below 8 kmph.

b) Ground Water: Hydrogeological Map of the area published by CGWB should be referred to know hydrogeological conditions, ground water potential and quality. Depleting water table over the years indicate more withdrawal of water than the recharge and ground water extraction from such areas should be restricted. Open well (Shallow well/dug well/sunk well), bored well, infiltration galleries and radial wells are used to abstract ground water.

2) Water Treatment Plant

a) Aeration: Aeration is to add oxygen in waters deficient in oxygen or for expulsion of carbon di oxide, hydrogen sulphide and other volatile substances causing taste and odour or to precipitate impurities like iron and manganese. Limitations: Aeration requires significant head of water. Water is rendered more corrosive after aeration when dissolved oxygen content is increased though in certain circumstances it may be otherwise due to removal of carbon di oxide. For taste and odour removal, aeration is not highly effective but can be used in combination with chlorine or activated carbon to reduce their doses.

b) Types: Spray aeraters in which water is sprayed through nozzles in atmosphere. Water fall/multiple tray aeraters/cascade aerators in which water falls along steps/trays in small height and pass through media. In diffused aeration air passes through water.

c) Chemical Handling & Feeding: Feeding can be dry or in solution. Solution is fed through controlled feeders which are gravity or pressure type. There should be atleast 2 tanks for each chemical feed & capacity of each to hold 8-hour requirement. Freeboard should be atleast 0.3 m. Coating with bituminous tank for alum tank necessary but for corrosive chemicals lining of rubber/PVC/Epoxy resin required. Lifting tackle to lift chemicals to solution tank required for gravity feed. Each tank should be provided with atleast 0.75 m wide platform, railing of 0.75 m height be provided on platform. Platform should have 2 m clear head room & top of solution tank should not be higher than 1 m from floor of platform. Manual mixing for plants upto 2.5 MLD and for higher capacity mechanical mixers/compresses air/recirculation required. To regulate dose solution feed device is used by means of orifice rotameter/positive displacement pump/weir. Constant head orifice is the most common device.

d) Chemical Storage: A storage of 3 months is advisable. In cases where major storage is provided at a place away from the feed equipment, a week's storage space should be provided near the plant. Storage should be damp proof & properly drained. For chemicals in bag, stack height should not exceed 2 m.

e) Coagulation & Flocculation: Coagulation is produced by the addition of a chemical and rapid mixing (flash mixing) for obtaining uniform dispersion. Flocculation formation of settleable particles (floc) is achieved by gentle and prolonged mixing. Good flocculation with minimum coagulant dose and in least time occurs within optimum pH zone. Flocculation Time: usually require 15-30 minutes in summer and 30-60 minutes in the colder months. Hydrated lime or soda ash may be used when increase in hard ness is to be avoided. When ferrous sulphate is used as a coagulant pH should be above 9.5 to ensure complete precipitation of the iron. Coagulant aids: a chemical which when used along with main coagulant, improves or accelerates the process of coagulation and flocculation by producing quick-forming, dense and rapid settling flocs. Finely divided clay, fullers earth, bentonites and activated carbon, polyelectrolytes are commonly used coagulant aids.

3) Rapid Mixing

a) hydraulic jump, loss of head is 0.3 m, residence time 2 seconds, G value 800/sec,

b) Baffled Channel Mixing: Velocity in channel section 0.6 m/s. Baffle subtends angle of 40-90 degree with the channel wall. Minimum velocity while negotiating baffle is 1.5 m/sec. Minimum free board of 0.15 m provided.

c) Mechanical: Rapid rotation of propeller type impellers, speed ranging from 400-1400 rpm or more. Turbine type or paddle type also used. Detention time of 30-60 sec is provided. Velocity gradient of atleast 300/sec required. Power requirements are 1-3 watts cum/hour of flow. Ratio of impeller dia to tank dia is 0.2 to 0.4 and the shaft speed of propeller greater than 100 rpm imparting a tangential velocity greater than 3 m/sec at tip of blade. The ratio of tank height to dia of 1:1 to 3:1 is preferred for proper dispersal. Slow Mixing or Stirring: Desirable value of G in a flocculator vary from 20 to 75/sec and G*t (t is detention time) from 2 to 6*10^4 for aluminium coagulant and 1 to 1.5*10^5 for ferric coagulants. The usual detention time is 10-30 minutes. Tapered Flocculation: To ensure maximum economy in the input power and to reduce possible shearing of particles floc formation, tapered flocculation is sometimes practised. The value of G in a tank is made to vary from 100 in the first stage to 50-60 in the second stage and then brought down to 20/sec in the third stage in the direction of flow.

4) Types of Slow Mixers

a) Horizontal Flow baffled Flocculators: Suitable for small plants. Water depth not less than 1 m, water velocity in the range of 0.10-0.30 m/sec. Detention time 15-20 minutes. spacing between baffle walls atleast 0.6 m, Clear spacing between the end of each baffle and the wall is about 1.5 times the distance between the baffles but not less than 0.6 m.

b) vertical flow Baffled flocculator: Water depth varies 1.5 to 3 times the distance between baffles, water velocity 0.1-0.2 m/sec. Detention time and spacing between baffle walls as for horizontal type. it is used for medium and large plants.

5) Sedimentation

Plain Sedimentation: It is usually employed as a preliminary process to reduce heavy sediment loads from highly turbid waters prior to subsequent treatment such as coagulation/filtration. Settling Velocity of Discrete Particles is as per clause 7.5.2. Clariflocculators are videly used across country. The coagulation and sedimentation processes are effectively incorporated in a single unit in the clariflocculator. 2 or 4 flocculating paddles are placed equidistantly.

a) Tank Dimensions: Rectangular tanks length is commonly upto 30 m but larger lengths upto 100 m have been also adopted. length to width rato is 3:1 to 5:1. Circular tanks upto 60 m in diameter are in use but are generally upto 30 m to reduce wind effect. Square tanks are generally smaller usually sides upto 20 m. square tanks with hopper bottoms having vertical flow have sides generally less than 10 m to avoid large depths. Depths commonly used are 2.5 to 5 m with 3 m being a preferred value. Bottom slopes may range from 1% in rectangular tanks to about 8% in circular tanks. The slope of sludge hopper ranges from 1.2 V:1H to 2 V:1 H. Surface loading and detention periods for various types of sedimentation tanks are given in clause 7.5.6. Inlets & Outlets: Normal weir loading s are upto 300 cum/day/meter.

b) Sludge Removal: In circular tanks where mechanical scrappers are provided, the floor slopes should not be flatter than 1 in 12, to ensure continuous and proper collection of sludge. For manual cleaning slope should be above 1 in 10. Power requirements are about 0.75 watt/sqm of tank area. The scrapping mechanism is rotated slowly at 30-40 minutes in one revolution or tip velocity of scrapper should be around 0.3 m/min or below. For sludge blanket type vertical flow settling tanks the slope of hopper should not be less than 55 degrees to horizontal.

c) Tube Settlers: Tube settlers allow high loading rates and used for improving the performance of existing basins and also as a sole settling unit.

6) Filtration

a) Slow SandFilter: Requires large land, sand and labour and as such may suit only for small capacities. It may be cost effective for rural and small communities. The design guide lines are given in table 7.3 of manual.

b) Rapid Gravity Filters (RGF): The distinctive features of RGF compared to slow sand filtration is careful pretreatment, higher filtration rate, coarser but more uniform filter media, backwashing by reversing flow. Standard filtration rate is 4.8-6 m/hour. Practice is tending towards higher rate (upto 10 m/hour) with better pretreatment and use of coarser sand (effectve size 1mm). Maximum area of one filter bed 100 sqm consisting of two halves of 50 sqm is recommended for plants greater than 100 mld. Also, for flexibility of operation a minimum of 4 beds should be provided which can be reduced to 2 for smaller plants. Where filters are located on both sides of a pipe gallery, length to width ratio of filter bed is found to be 1.11 to 1.66 averaging about 1.25 to 1.33. A minimum overall depth of 2.6 m including free board of 0.5 m is adopted. It is not necessary to provide roof over the filters. The operating gallery should be roofed. Effectve size of sand shall be 0.45 to 0.7 mm, uniformity coefficient 1.7 to 1.3, ignition loss should not exceed 0.7% by weight, soluble fraction in hydrochloric acid shall not exceed 5% by weight, silica content not less than 90%, specific gravity 2.55 to 2.65 and wearing loss shall not exceed 3%. Usually, depth of sand should be 0.6 to 0.75 m but for higher rate filtration when coarse medium is used deeper sand beds are suggested. Standing depth of water over filter varies from 1 to 2 m and free board of 0.5 m.

c) Under Drainage Systems: In case of central manifold and laterals (lateral pipes can be of CI, plastic, AC, concrete or other material) . A non ferous drain system is preferable where water has a low pH and is corrosive and when the correction for pH has to follow the filtration process. However, AC pipes have a tendency to dissolve away in presence of low pH alum treated waters.), perforations vary from 5 to 12 mm in diameter and should be staggered at a slight angle from vertical axis of pipe, spacing of perforations in laterals may be 80 mm for 5 mm perforation to 200 mm for 12 mm perforation. Ratio of total area of perforations to total cross sectional area of lateral should not exceed 0.5 for perforations of 12 mm and should decrease to 0.25 for perforations of 5 mm. Ratio of total area of perforations to the entire filter area may be about 0.3%. The ratio of length to diameter of the lateral should not exceed 60. The spacing of laterals closely approximates the spacing of orifices and shall be 300 mm. The cross-sectional area of manifold should be preferably1.5 to 2 times the total area of the laterals.

d) Filter Gravel: Size of gravel varies from 50 mm at bottom to 2 to 5 mm at the top with a depth of 0.45 m. In case of porous plate floor supported on concrete pillars, bottom gravel not required.

e) High-Rate Backwash: Back wash pressure is about 5 m in underdrains so as to expand sand 130-150% of its undisturbed volume. Normally wash water rate where no other agitation is provided is 600 lpm/sqm for a perid of 10 minutes. For high-rate wash pressure may be 6-8 m and wash water rate of 666-750 lpm/sqm for 6-10 minutes. Capacity of back wash storage tank must be sufficient to supply wash water to two filter units at a time where the units are 4 or more.

f) Air Wash system: Free air at 600-900 lpm/sqm at 0.35 kg/sqcm is forced through underdrain for a period of 5 minutes following which wash water is introduced at a rate of 400-600 lpm/sqm. In the practice of backwashing employing air and water wash together air is applied at a rate of 45-50 m/hour and water at 12-15 m/hour.

g) Dual Media Filters: Two media of different density and sizes are used. Top layer consists of lower density material like coal having larger particle size. Lower layer is higher density material like silica sand and have smaller diameter particles. In India anthracite coal is not easily available, the coarse material may consist of high grade bituminous coal or crushed coconut shell can be used. The effective size of coal (specific gravity 1.4) is usually 1 mm (0.85-1.6 mm range) with uniformity coefficient of 1.3 to 1.5 and depth of 0.3 to 0.4 m. The finer media-layer usually consists of 0.3-0.4 m thick silica sand (specific gravity 2.65) with effective size of around 0.5 mm (0.45 to 0.60) and uniformity coefficient of 1.3 to 1.5. In case of crushed coconut shell used as coarse media, the size ranges from 1 to 2 mm with depth of 0.3 -0.4 m, uniformity coefficient below 1.5, specific gravity 1.4, The sand used in conjunction with crushed coconut shell has effective size varying between 0.44 to 0.55 mm, uniformity coefficient below 1.5, sand depth 0.3 to 0.4 m. Filtration rate range recommended is 7.5 to 12 m/hour. The back wash rates of 700-900 lpm/sqm are used.
Multi Media filter: Normally contain three media such as anthracite coal, silica sand and garnet sand with specific gravities 1.4, 2.65 and 4.2.

h) Performance of Rapid Gravity Filter: Filtrate turbidity should be less than 1 NTU,should be free from colour (3 or less on cobalt scale), filter run be not less than 24 hours with a head loss not exceeding 2 m, wash water consumption less than 2% of filtered quantity.

i) Disinfection: Satisfactory disinfection is obtained by prechlorination to maintain 0.3 to 0.4 mg/l free available residual throughout treatment or 0.2 to 0.3 mg/l free available residual in the plant effluent at normal pH values. At higher pH of 8 to 9 at least 0.4 mg/l is required for complete bacterial kill with 10 minutes contact time. For 30-minute contact time dosage reduces to 0.2 to 0.3 mg/l. Normal concentration of chlorine destroys organisms associated with typhoid fever, dysenteries and various gastrointenestinal disorders. Cysts of E. histolytica causing amoebic dysentary are inactivated at higher dose of 0.5 mg/l of the free residual chlorine. To inactivate virus 0.5 mg/l of free chlorine for one hour contact time is required.Where water supply is infested with nematodes 0.4 to 0.5 mg/l of free available residual chlorine for six hour contact time is required. Application: Bleaching powder solution used for disinfecting small quantities and addition of gaseous chlorine through vacuum chlorinaters for bigger quantities (as Bleaching powder is costlier than chlorine gas)are commonly used.

E. Hydraulic Design Considerations

Hydraulic design plays a crucial role in ensuring the smooth operation of a water treatment plant by maintaining appropriate flow rates, pressure levels, and head losses throughout the system. Key hydraulic considerations include the design of pipelines, pumping stations, distribution networks, and gravity-based flow mechanisms. The velocity of water flow in conduits and channels must be maintained within recommended limits to prevent sedimentation and excessive head losses. Hydraulic calculations ensure proper sizing of sedimentation tanks, filter beds, and chemical dosing systems to optimize treatment efficiency.

F. Structural Design Aspects

The structural design of water treatment plant components involves considerations related to load-bearing capacity, seismic resistance, durability, and material selection. The design of tanks, reservoirs, and treatment units follows IS 456:2000 (Reinforced Concrete Design Code) and IS 3370 (Code for Water Retaining Structures). Factors such as soil conditions, foundation stability, wind loads, and earthquake resistance are considered in structural calculations. Corrosion-resistant materials such as epoxy-coated steel or high-grade concrete are used to enhance the longevity of structures exposed to water and chemicals. The structural design also incorporates safety features such as access platforms, drainage systems, and emergency overflow provisions.

IV. CONCLUSION

The structural integrity of water treatment plants is crucial for their long-term performance and sustainability. Ensuring the durability and safety of WTP structures requires a comprehensive approach that integrates advanced analytical methods, innovative materials, and robust design principles. The adoption of modern structural analysis techniques, such as finite element modeling and seismic evaluation, allows engineers to predict and mitigate potential structural failures. Additionally, the use of high-performance materials, including fiber-reinforced concrete and corrosion-resistant steel, enhances the lifespan of these structures, reducing maintenance costs and improving efficiency. Sustainability is another key aspect, as the incorporation of green building materials and energy-efficient designs contributes to environmental conservation and resource efficiency. Future research should focus on optimizing structural designs for cost-effectiveness while maintaining high standards of durability and safety. The integration of smart monitoring systems in WTP structures can provide real-time data on structural health, facilitating proactive maintenance and reducing unexpected failures. With ongoing technological advancements, the structural design of WTPs will continue to evolve, ensuring resilient and efficient infrastructure capable of meeting the growing demand for clean and safe water.

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