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Design, development, and implementation of an automated system for cleaning overhead water tanks: a review

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This review explains how household tank cleaning maintains water quality efficiency and safety through improved methods and automated systems. Researchers detailed the development process for this thorough analysis, showing that automated tank cleaning remains vital for protecting health and quality while guaranteeing product characteristics and water quality standards. Research reveals diverse cleaning approaches starting with basic manual methods and progressing to specialized automated solutions for overhead water. When used with advanced brush gear motors and control mechanisms, automated systems demonstrate effective removal of biofilm sludge and other foul materials. Point-of-use water filtration systems deliver superior water quality and defend against hazardous contaminants found in water. The introduction of automated systems provides solutions to manual cleaning problems because it improves performance while guaranteeing protection and delivering environmental benefits to operations. Underdeveloped areas present ongoing challenges due to unsupportable cleaning and storage practices that cause microbial contamination problems. A solution to these gaps requires technological progress along with public education programs including complete governmental regulations. Automated cleaning systems for overhead water tanks require systematic creation followed by development and final deployment to achieve universal clean water safety. Through innovations and community participation, people will drive sustainability in water management which will secure healthier futures worldwide through industrial cleaning systems that service overhead water tanks. Modern automation fills a critical need to solve traditional problems while leveraging new technological advancements that boost water quality performance and efficiency levels. Visual illustrations of the tank design solutions and cleaning systems appear in the study to help readers better comprehend the information.

Keywords: Automation, robotics, tank cleaning, water contamination, cylindrical water tank.

INTRODUCTION

Overhead water tank cleanliness stands as a critical component for achieving both safe water storage and protecting health. Frequent tank maintenance protects against corrosive elements and foreign contaminants while blocking sediment accumulation which allows precise pollutant analysis together with reduced operational hazards. A designated cleaning program ensures safety at all times while decreasing potential risks to both people and the environment and provides vital access to pure safe drinking water. Every individual uses roughly 181.5 gallons of water during their yearly consumption. The Central Pollution Control Board partners with State Pollution Control Boards along with Committees to assess the water quality of aquatic resources at 4,484 locations spread throughout India's rivers, lakes, ponds, and tanks. Memorandum data shows that 57% of all inspected sites fulfill the biological oxygen demand (BOD) standards [38]. Widespread water contamination results in cholera, typhoid hepatitis, and gastroenteritis which, according to UNESCO's 2021 World Water Development Report, bring 829,000 deaths annually from diarrheal illnesses. The crisis of maintaining clean water reserves in household storage tanks becomes critical because 71% of Indians depend on such tanks. The combination of minimal understanding of expensive manual cleaning practices and inconvenient barriers facilitates the growth of pollutants like algae and silt. Water tank inspections show disturbing evidence that household tanks contain dangerous microbial infections alongside pollution from chemicals. These cross-contaminants endanger residents who depend on tank-stored water for their drinking and household needs. The widespread use of cylindrical overhead tanks throughout the world does not match their level of proper maintenance. The presence of pollutants in residential water tanks creates major public health problems. People who drink polluted water risk developing skin and respiratory infections along with cancer and several other health difficulties. Communities must make infrastructure improvements possible and enforce regular testing as well as maintain strict schedules to minimize these safety risks. Automated tank cleaning systems

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represent a promising innovation that solves current challenges while giving communities access to clean drinking water.

Impact of various contaminants on water quality

Microorganisms: Bacteria, viruses, and parasites are prevalent impurities encountered in water reservoirs, giving rise to waterborne ailments like cholera, typhoid fever, and dysentery. The introduction of these microorganisms into aquatic systems frequently occurs *via* sewage and agricultural runoff.

Chemical pollutants: Various chemicals, including heavy metals (e.g., lead, mercury, arsenic), pesticides, fertilizers, pharmaceuticals, and industrial chemicals, possess the capability to seep into water reservoirs from diverse origins such as industrial emissions, agricultural runoff, and improper household chemical disposal. These compounds have the potential to inflict harm on human health and the ecosystem, resulting in enduring health complications.

Nutrient pollution: Elevated quantities of nutrients, specifically nitrogen and phosphorus, have the potential to induce eutrophication in aquatic environments. This phenomenon arises when nutrient concentrations stimulate the proliferation of algae and various aquatic flora, culminating in the formation of algal blooms. These blooms can diminish oxygen levels within the water, leading to the mortality of fish and detrimental effects on other aquatic organisms. Nutrient pollution is frequently linked to runoff from agricultural activities, sewage discharges, and urban runoff.

Sedimentation: Erosion of soil from construction sites, agricultural fields, and deforested regions can result in sediment accumulation in aquatic ecosystems. Excessive sedimentation can compromise water quality by elevating turbidity, diminishing light penetration, and suffocating aquatic habitats. Moreover, it can facilitate the transportation of additional pollutants, including nutrients and heavy metals, that adhere to soil particles.

Acidification: The phenomenon of acidification is primarily attributed to acid rain, which is a result of the emission of sulfur dioxide and nitrogen oxides from industrial activities and vehicular emissions. This environmental issue can lead to the acidification of water bodies, especially freshwater ecosystems, consequently posing a threat to aquatic life, particularly delicate species like fish and amphibians, and causing disruptions to ecological processes.

Thermal pollution: Thermal pollution is characterized by the discharge of heated water from industrial operations and power plants into water bodies, increasing water temperature. This elevation in temperature can lead to thermal pollution, which in turn can decrease oxygen levels, enhance susceptibility to diseases in aquatic organisms, and induce changes in the distribution and behavior of species.

Emerging contaminants: The detection of emerging contaminants, including pharmaceuticals, personal care products, and endocrine-disrupting chemicals, is on the rise within water sources. Despite being present in low concentrations, these substances can pose significant risks to both human health and the environment. The long-term impacts of these contaminants are still under investigation.

Total dissolved solids (TDS) is a key parameter to identify the usability of water for various purposes which further influences consumer preferences. Elevated TDS levels in household water tanks can result from different factors, including poor water quality, lack of regular cleaning, and corrosion of tank materials. For example: the presence of arsenic in water, as observed in some regions, emphasizes the importance of effective water filtration systems like reverse osmosis (RO).

Elevated TDS levels in household water tanks can be attributed to several factors, including:

- Poor water quality: if the source water has high TDS levels, it can also lead to increased TDS in the stored water.
- Lack of regular cleaning: over time, contaminants in the water can accumulate in the tank, increasing the overall TDS concentration.
- Corrosion of tank materials: certain tank materials, such as galvanized steel, can corrode over time, releasing metals into the water and contributing to higher TDS levels.
- Understanding of TDS levels in drinking water for safe consumption:
- It has been established that a TDS level <50–250 parts per million (PPM) is to be considered low-level contamination, as it is deficient in minerals including zinc, magnesium, and calcium.
- The ideal TDS level for drinking water at 300 PPM and 500 PPM is considered perfect, as it is most likely that the water has minerals in it and doesn't taste flat.
- The water with 600–900 PPM is not considered very good and to filter such a TDS level, the use of a reverse osmosis system is required.

- The TDS level in the range of 1000 and 2000 PPM is extremely bad and drinking such water is not advised.
- Ultimately, water having TDS beyond 2000 PPM is not acceptable because it is considered hazardous and cannot be adequately filtered by standard home filters.

RO systems in households

Household reverse osmosis (RO) systems play a vital role in purifying drinking water by utilizing a semipermeable membrane to dissolve solid particles, including contaminants like arsenic. In various regions facing water quality challenges, residents commonly install RO systems as a precautionary measure. Connected to household water tanks, these RO systems act as a reliable defense against inorganic contaminants. Household reverse osmosis (RO) systems are often connected to household water tanks to provide a continuous and convenient supply of purified water for various domestic needs. The integration of RO systems with household tanks serves several important purposes as given below.

Continuous supply of purified water: RO systems are designed to remove impurities, including contaminants like arsenic, from the water. By connecting these systems to household water tanks, residents ensure a consistent and readily available source of purified water for drinking, cooking, and other everyday activities.

Storage and accessibility: Household water tanks serve as storage units, allowing residents to store a significant volume of purified water. This is particularly useful in situations where the demand for clean water may vary throughout the day. Connecting RO systems to these tanks enables the accumulation of purified water for later use [37].

Reduced dependency on municipal sources: In areas where the municipal water supply may not meet the desired quality standards, or in regions facing water scarcity issues, households often rely on RO systems to purify available water sources. By connecting RO systems to household tanks, residents can create a self-sustaining water supply system independent of external sources. Cost-effective solution: By connecting RO systems to existing household water tanks, residents can leverage their investment in infrastructure. This integration is often a cost-effective way to enhance the overall water quality in a household without the need for extensive modifications.

Cost-effective solution: Water contamination data underscores the essential health and safety: Maintaining a consistent supply of purified water is required for the health and safety of residents. Connecting RO systems to household tanks ensures that the water stored is free from harmful contaminants, contributing to the overall well-being of individuals and families. Water contamination data underscores the essential need for regular tank cleaning which consists of mainly two methods: traditional cleaning and automatic cleaning methods.

1. Improved water quality: RO systems effectively remove a wide range of contaminants, including chlorine, lead, arsenic, and other harmful substances, providing clean and safe drinking water.

2. *Better taste and odor:* By removing impurities, RO systems can enhance the taste and odor of water, making it more pleasant to drink.

3. Healthier drinking water: With contaminants removed, RO systems provide healthier drinking water, reducing the risk of consuming harmful substances that may be present in tap water.

4. Convenience: Having an RO system at home eliminates the need to buy bottled water, saving money and reducing plastic waste.

Traditional cleaning methods: Traditional cleaning methods, involving manual labor and mechanical systems like high-pressure water jets, are time-consuming and may not effectively remove contaminants. Manual cleaning poses health risks for workers exposed to chemicals and bacteria, and the overall inconvenience contributes to the neglect of tank maintenance. This underscores the necessity for an advanced solution, such as the proposed automatic tank cleaning robot. Despite the longstanding reliance on traditional cleaning methods, they are accompanied by various disadvantages. The manual labor involved in the scrubbing and washing of tanks, for example, is not only time-consuming but also labor-intensive. Additionally, the efficacy of these methods in eliminating persistent contaminants like biofilm and scale accumulation is frequently constrained. Furthermore, the dependence on mechanical systems such as high-pressure water jets may not consistently produce satisfactory outcomes. In certain instances, these techniques may lead to harm to the tank surfaces or fail to access specific areas, resulting in pockets of contamination being left behind.

Moreover, manual cleaning presents notable health hazards to workers who are exposed to hazardous chemicals and bacteria found in the tank environment. Inadequate protective equipment and ventilation systems can result in respiratory problems, skin irritations, or other health issues for workers. The inconvenience associated with traditional cleaning methods also contributes to the negligence of tank maintenance in some scenarios. Owing to the time and exertion demanded, cleaning timetables may be postponed or disregarded, culminating in the accumulation of contaminants and jeopardizing water quality. Given these obstacles, there is a distinct necessity for a sophisticated solution capable of surmounting the constraints of traditional cleaning methods. The suggested automatic tank cleaning robot provides a promising substitute. By capitalizing on automation and cutting-edge cleaning technologies such as robotic arms and sensor-based navigation systems, the robot can clean tanks efficiently and effectively without manual intervention.

Figure 1. The interior view of an overhead water tank

Automatic tank cleaning systems

Automatic tank cleaning robots emerge as a promising solution to address the shortcomings of traditional methods. These robots are equipped with sensors to assess the interior of tanks and high-pressure water jets to remove contaminants. The automation ensures thorough and uniform cleaning, eliminating the need for human intervention and making the process environmentally friendly. In addition to their sensor-equipped and high-pressure water jet functionalities, automatic tank cleaning robots frequently integrate sophisticated technologies such as machine learning and AI algorithms. These advancements empower the robots to adjust their cleaning approaches based on the specific attributes of the tank and the nature of contaminants present, thus enhancing both efficiency and efficacy.

Automatic tank cleaning systems commonly feature remote monitoring and control capabilities. This functionality enables operators to supervise the cleaning process in real-time, make necessary modifications, and receive detailed reports on cleaning performance. The implementation of remote monitoring not only boosts the overall efficiency of the cleaning operation but also reduces the likelihood of accidents or operational downtime. The utilization of automatic tank cleaning robots leads to decreased consumption of water and cleaning substances when compared to conventional techniques. Through precise targeting of cleaning areas and avoidance of unnecessary waste, these systems support water conservation initiatives and contribute to reducing the environmental impact associated with industrial cleaning procedures.

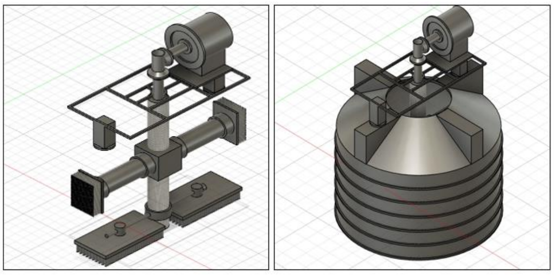

Figure 2. Design of automated tank cleaning system

Need for automation

The term a*utomation* covers a wide range of technologies, that seek to decrease human participation in the processes, human-centered approaches in automation, which focus on utilizing human abilities more efficiently rather than eliminating human involvement in production. This approach recognizes the need for highly qualified and motivated workers to operate, maintain, and repair automated systems [3]. These technologies mainly do this through predesigned controlling of actions, interconnecting subprocesses, and decision logic into machines. Improvements in reliability, completeness, efficiency, convergence, sensitivity, verification, and stability are the primary goals of automation research, which employs new methods, models, and approaches to achieve this goal [5]. The benefits of automation that have been mentioned include reduced production costs, increased efficiency, increased competitiveness, and higher productivity. Additionally, there is hope for a more pleasant work environment that is less burdened by physical demands and monotony [1]. Several fields have recognized the importance of automation, including intelligent control, learning, energy management, aerospace control, and manufacturing systems [2]. Upgrading existing machinery to increase automation is one way to lessen the impact of displacement, but it also increases the need for workers and their wages [4].

The application of robotics in these sectors aims to improve efficiency, accuracy, and productivity, as well as reduce costs and human error. In Manufacturing, robots can perform repetitive tasks with precision and speed, leading to increased production rates and improved product quality. In the services industry, robots can assist with tasks such as patient care, housekeeping, and information retrieval, enhancing the overall customer experience [6]. Robotics refers to the field of study and development of robots, which are machines capable of performing tasks autonomously or with minimal human intervention. Robotics is extensively used in the manufacturing industry to improve productivity and efficiency, and service robots assist human beings, typically by performing a job that is dull, distant, dangerous, or repetitive. Robots can perform tasks more efficiently than humans and can work continuously without breaks. They can also handle heavy loads and perform repetitive tasks with precision [7].

Service robots that are used in cleaning offer numerous benefits. They improve efficiency by working continuously without fatigue, ensuring consistency through pre-programmed routines, and accessing hard-to-reach or hazardous areas. Additionally, they save time and resources, enhance cleaning quality with advanced technology, and prove cost-effective in the long term. Furthermore, cleaning robots promote health and safety by reducing human exposure to hazardous environments, even service robots equipped with a LIDAR sensor and a web camera, allowing for the development of more complex methods for the cleaning robots to clean, uneven areas and designed for collision-free navigation [8].

Smart cleaning robot reduces the human interaction in the cleaning process, making it simpler and automatic [9]. Robotic cleaners have gained significant interest in recent years due to their effectiveness in assisting humans in floor and tank cleaning programs in various settings such as homes, hotels, offices, and hospitals. The use of robotics in cleaning saves labor costs and eliminates the need for human intervention, making it an affordable and efficient solution where the cleaning robot is a type of mechanical and electrical product designed for sweeping and dusting, offering a more convenient alternative to traditional vacuums [10].

Tank maintenance is crucial in many industries, including paint, oil, pharmaceuticals, and fast-moving consumer goods. Many small-scale enterprises still use manual tank cleaning, although it is a time-consuming and labor-intensive procedure [13]. In industrial processes, low performance and inefficiency have been caused by a lack of cooperation and planning for maintenance [11]. Tank capacity and product quality can be negatively impacted by the build-up of oil residue, particularly in the oil sector. As a result, it is essential to routinely clean the tanks and remove the oil sludge [12]. Several obstacles prevent Total Productive Maintenance (TPM) from being successfully implemented in organizations [4]. In the process industry, where dependability is essential for costly specialized equipment and stringent environmental regulations, maintenance plays a major role in the overall production environment [14]. The necessity for automated and more effective cleaning techniques is highlighted by the risks to worker safety associated with manual tank cleaning.

One of the drawbacks of manual tank cleaning is that it requires human operators to enter the tank, which raises safety issues [15]. Water is wasted during this labor-intensive manual procedure that necessitates emptying the tank before cleaning [16]. Tank leftovers from petroleum sludge can lower tank capacity and lower product quality in the oil sector [17]. High-efficiency robotic or automated cleaning techniques that minimize tank downtime and do not require personnel to enter limited locations are now needed in the oil sector [18]. These techniques, including the Martin systems and MEGAMACS, provide more safety, speedier cleaning, and the capacity to extract a sizable quantity of oil from the sludge [19].

Introduction to automatic tank cleaning robot (ATCR)

Automated tank cleaning robots, or ATCRs, are designed to clean tanks automatically, eliminating the need for manual cleaning. The ATCR is made up of many components, including a cleaning robot, water jet, suction pump, sensors, linear movement ladder, and rotating arrangement. A cleaning brush and water jet can be used to clean the base and walls of the tank while the suction pump removes the sludge deposits. ATCR technology was driven by the need to improve existing tank sludge cleaning processes. Early testing of the ATCR prototype has as its primary goal cleaning domestic water tanks. With the introduction of automated tank cleaning robots (ATCRs) what we know as the tank cleaning process has changed to a labor-free process. Consisting of different units such as cleaning robots, water jets, vacuum pumps, sensors, linear movement ladders, and rotating arrangements, ATCRs are specifically designed to eliminate tanks of different sizes and shapes from the inside. These robotic systems include cleaning brushes and high-pressure water jets that are used to clean tank surfaces very fast and effectively. The sludge deposits extracted by a suction pump are a guarantee of a thorough cleaning process. The development of ATCR technology is bearing on the need to improve existing tank cleaning techniques, especially given the obstacles that are inherent with sludge extraction. First, the initial testing of ATCR prototypes is mostly related to the cleaning of domestic water tanks, where the aim is to make water cleaner, safer, and easier to use. ATCRs are configured with advanced sensors that are capable of live tank readings and the status of the cleaning process. These sensors are an integral component of the identification of contaminants, measurement of tank levels, and detection of obstacles, thus guaranteeing precise and accurate clean-up actions. Besides that, the modular structure of ATCRs assures flexibility in terms of tank configurations to be used which makes them applicable to any cleaning job. In addition, the ATCR technology is an environmentally friendly tool that deals with efficient use of water and reduction of chemical usage during the cleaning process. Through minimizing water wastage and pollution, ATCRs promote eco-friendly actions and their compliance with environmental regulations. To summarize, the incorporation of ATCRs in tank cleaning technology marks significant progress in terms of safety, efficiency, and environment-friendliness while keeping the tanks clean and hygienic in the different fields of industry. Identified the need for automating tank cleaning to reduce downtime, improve safety, and ensure thorough cleaning of industrial tanks. Feasibility analysis was conducted to evaluate potential ROI and challenges.

Working mechanism of ATCR

Robotic cleaning and maintenance systems are equipped with a multitude of sensors and cameras for monitoring and navigational functions. These sensors allow the robot to change its location by determining how far it is from the surface. Furthermore, cameras are used to capture images of the robot's environment, allowing for real-time control and observation. The integration of cleaning tools and equipment is a crucial aspect of these systems. For example, cleaning robots are equipped with rags and brushes to clean the floor. Some systems even include spraying nozzles to apply cleaning agents to the surface. By combining these technologies, cleaning procedures become more effective and efficient, improving the overall cleanliness and user experience of the robotic systems. Besides the robot cleaning upgrade that is equally positive, it also comes with a lot of other effects such as high performance and efficiency that make the robots great providers of cleaning, and users have a good experience. ATCRs are the ones that would have the ability to do those works themselves by going to the tank locations where they will consider the right tools and methods to use in those areas. Besides, the system of remote monitoring will provide the operators with the possibility to look at the process of cleaning from a distance where they can see the process at a long distance. Similarly, they can speed up each phase with less time spent and swift resolution of any unanticipated problem. The ATCR application will help clean water tanks and in addition, it will make the water system to be safe and reliable.

CONCLUSION

Public health protection product quality maintenance and water quality compliance depend on automated tank cleaning procedures. Research sheds light on different cleaning strategies which extend from manual approaches and specialized automatic systems designed for industrial applications. Automated systems that integrate brush gear motors and control mechanisms can delete biofilm while removing sludge and contaminants for advanced water quality maintenance and hazardous substance protection. The systems overcome manual cleaning constraints through efficiency improvements and enhanced safety while delivering environmental advantages. Microbial contamination in addition to waterborne health risks occurs because underdeveloped regions struggle with improper cleaning techniques and insufficient storage measures. Bridging these gaps requires:

1. Automated cleaning solutions experience technological improvements.
2. Formatted public education materials need to teach people about how vital maintaining clean water standards is.
3. The government needs to establish complete regulatory frameworks to implement required standards.

The implementation of automated cleaning systems requires a systematic approach to design development and deployment to achieve universal water safety. Sustainable water management development depends on cleaning technology innovation together with community engagement in water-related activities. Societies benefit from technological advancements because these improvements create healthy societies while delivering safe water solutions to global communities.

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