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Research Article

Practical Analysis of Tap Water Dissolved Solids Efficient Reduction

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Abstract: Water is an essential component in the manufacturing of oral solid dosage forms in the pharmaceutical industry. The objective of the present study is to develop a compact and easy-to-maintain one-platform solution for generating high-purity water with near to zero Total Dissolved Solids (TDS) and low conductivity for pharmaceutical applications. To achieve this objective, different purification methods were explored and integrated into a single platform. The purification process involved the use of Electro-Deionization (EDI) in combination with double-pass Reverse Osmosis (RO), an activated carbon filter, water softeners, and micron filtration. The resource water was carefully selected based on specific criteria to ensure the quality of the final purified water. The developed one-platform solution successfully produced purified water with near to zero TDS and a conductivity level below 1 micro siemens/cm^2. The integrated approach involving EDI and double-pass RO, along with supplementary filtration and treatment steps, proved to be highly effective in achieving the desired purity levels. The study demonstrated that the suggested one-platform solution is a reliable and efficient method for the production of high-purity water in the pharmaceutical industry. This system offers an easily maintainable and compact solution, making it suitable for various other industries such as semiconductor manufacturing and electric power generation where purified water with zero TDS is required. By providing a robust water purification process, this solution contributes to enhancing the quality and safety of pharmaceutical products and other critical applications that rely on ultra-pure water.

Keywords: Double Pass Reverse Osmosis, Electro-Deionization, Pre-Filtration, Production of Purified Water, Zero Total Dissolved Solid.

1. INTRODUCTION

The resource water with the lack of quality grades does not meet the required standards of pharmaceutical use. To meet such requirements, there is a need to have a real solution that can lead to the production of water with near zero total dissolved solids (TDS) [1]. Past studies on the production of purified water have focused on water treatment with a limited production rate rather than the complete solution to produce purified water with a production rate of almost 3000 Liter/Hour. Systems integrated with RO can achieve a such rate of production easily because two-stage RO can produce purified water at 80 % of the rate of production [1]. This phase-by-phase water treatment provides a one-platform solution for individuals to produce water with near zero TDS under certain source water parameters.

Conventionally, ion exchange techniques are used for purifying water, but micron filtration and membrane filtration are becoming very popular to demineralize water, followed by electro-deionization (EDI) which offers nonstop operation [2]. The polarity and hydrogen bonding in water give it special chemical characteristics. It can thus dissolve, absorb, adsorb, or suspend a wide variety of substances, including pollutants [3]. So, dissolved water ions can easily be separated into dilute and concentrated columns of EDI. EDI technology emerged almost 50 years ago, latterly it was utilized to remove metallic elements from radioactive wastewater [4]. Furthermore, novel tailored applications are specifically addressed, including heavy metal ion removal, water desalination, and low-level radioactive waste removal [5]. The continuous EDI (CEDI) technology has been used for over 20 years and is

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well-acknowledged for producing ultrapure water for industrial use [5]. EDI contains ion exchange resin beads that enhance the water flow rate and transfer cations and anions from a dilute column to a concentrated column. A stream of water passes through the concentrated column, and all absorbed cations and anions are washed away and returned to the feed tank. A pure water stream from the dilute column is fed to the storage tank for product usage.

An auto-chlorination system is a water treatment system that uses chlorine to disinfect organic and inorganic compounds found in water [6]. Chlorine is a powerful disinfectant that is effective at killing a wide range of microorganisms, including bacteria, viruses, and algae. It is commonly used in water treatment systems to purify drinking water, swimming pool water, and industrial process water. An auto-chlorination system typically consists of a chlorine storage tank, a feed pump, and a control panel. The feed pump is used to deliver a precise amount of chlorine to the water being treated, based on the specific needs of the system. The control panel is used to monitor and adjust the chlorine dosage as needed. Auto chlorination systems are designed to be easy to use and maintain, with automated controls and monitoring systems that make it easy to maintain the correct chlorine levels in the water. They are often used in a variety of applications, including drinking water treatment, swimming pool water treatment, and industrial process water treatment. Chlorine disinfection treatment of resource water has been widely employed in wastewater reclamation plants to control RO membrane biofouling [7]. There are some chlorine-resistant bacteria (CRB) that can survive even in the presence of residual chlorine such as there is a risk of pathogenicity, antibiotic resistance, and microbial growth. But there is still no accepted method to evaluate chlorine resistance germs and CRB [8].

A feed water pre-treatment plant is a system that is used to prepare raw water for use in a steam boiler or other industrial process of pharmaceutical. The purpose of the pre-treatment plant is to remove impurities from the raw water that could cause problems in the downstream equipment, such as corrosion or scaling. There are several different types of pre-treatment plants, depending on the specific needs of the process and the quality of the raw water. Chemicals are added to the raw water to cause small particles to clump together, forming larger flocs that are easier to remove. The flocculated water is then allowed to settle so that the heavier flocs will sink to the bottom of the tank and can be removed. The water is then passed through a filter, which removes any remaining particles or impurities. The specific treatment steps and equipment used in a feed water pre-treatment plant will depend on the quality of the raw water and the specific needs of the process. In general, the goal of the pre-treatment plant is to provide clean, pure water for use in the industrial process, while also protecting the downstream equipment from corrosion and other problems caused by impurities in the water. The added chlorine is disinfected in the feed water pre-treatment plant, resulting in the water being odorless, and lowering its hardness. A pretreatment unit, a treatment unit, a structure for storing and distributing water, equipment for monitoring and controlling the process, and chemical cleaning and sanitation systems are all included in a water treatment system used in the pharmaceutical industry [3].

A form of water treatment device called an activated carbon filter makes use of activated carbon to purify water. It is especially effective at adsorbing pollutants from water because activated carbon is an extremely porous, ultra-fine type of carbon with a very large surface area. Water pollutants, such as chemicals, contaminants, and odors, are frequently removed from water using activated carbon filters. These are particularly good at getting rid of heavy metals as well as organic and inorganic substances like chlorine, pesticides, and herbicides. Water is passed over a bed of activated carbon in activated carbon filters by high-pressure pumps which then absorb the pollutants from the water. Pressure-driven processes are used when the removal of suspended solid and organic elements like bacteria are the primary targets [4]. A prevalent issue is the high groundwater hardness that generates scale deposition on electrodes that irreversibly affects the treatment effectiveness and their lifetime. Electrochemical water softening as a preliminary step for electro bioremediation of nitrate-contaminated groundwater. The contaminants are subsequently trapped in the carbon and the water is collected on the other side of the filter. Both a solo treatment system and a bigger water treatment system can make use of the activated carbon filter [9]. Activated carbon filters are commonly used in a variety of applications, including drinking water treatment, industrial water treatment, and air purification. They are generally easy to maintain and operate, and they can be an effective way to improve the quality of water by removing a wide range of impurities. They can also be aligned in carbon nanotube for capacitive deionization for effective utilization [10].

Ultraviolet (UV) water treatment is a process in which water is exposed to UV light to kill or inactivate microorganisms such as bacteria, viruses, and protozoa. This process can be used to treat drinking water, swimming pool water, and wastewater [11]. UV water treatment systems typically consist of a UV lamp and a chamber through which the water is passed. The UV lamp emits UV light, which is absorbed by the water as it flows through the chamber. UV light damages the DNA or RNA of any microorganisms present in the water, rendering them harmless. UV water treatment is a chemical-free method of water treatment that is effective at reducing the concentration of a wide range of microorganisms in water. It is commonly used as a supplement to other forms of water treatment, such as filtration and disinfection with chemicals like chlorine.

Ecosystems are becoming increasingly polluted, necessitating sustainable pollution removal techniques. Ultra-pure water is ideal for various industries, and electro-deionization (CEDI) is an effective method for removing ionic chemicals from polluted waters. CEDI offers promising wastewater treatment technologies, eradicating contaminants like ionizable compounds and hazardous chemicals. Innovative materials are being developed to improve CEDI's performance, with ion-exchange resins and membranes being the focal point [13, 14].

An EDI plant typically consists of a series of modular cells that contain ion exchange resins and electrodes. The water to be treated is passed through the cells, and the ions in the water are attracted to the oppositely charged electrodes and exchanged with the ions in the resin. This process removes the ions from the water, leaving behind pure, deionized water. EDI plants are often used to produce high-purity water for a variety of applications, including laboratory use, pharmaceutical manufacturing, and electronics manufacturing. They are known for their high efficiency and low maintenance requirements and are often preferred over other water purification technologies due to their ability to produce water with very low levels of impurities. EDI plants are often used as a final step in water purification systems after the water has already been treated by other methods such as RO or ion exchange. They are particularly useful for producing high-purity water because they can remove a wide range of impurities, including ions, dissolved solids, and organics, to very low levels. Pretreatment, treatment, water storage, distribution, and loop structure, as well as chemical cleaning and sanitization systems, make up the four units that make up the water treatment system. Deionization and RO are the two steps that make up the treatment unit [3].

Cartridge filter is used to remove impurities from water. The filter cartridge is made of a porous material, such as a synthetic fiber or a sintered metal, and has very small pores that are typically measured in microns. Different concentration technologies and energy supply systems are compared to find economically feasible and environmentally friendly treatment systems. The investigated chains include Multi-Effect Distillation (MED), Membrane Distillation (MD), and the coupling of Reverse Osmosis and Membrane Distillation (RO-MD) [12].. The filter cartridge is placed in a housing, and the water is passed through the cartridge as it flows through the housing. The impurities in the water are trapped on the surface of the cartridge, while the purified water passes through and is collected on the other side. Micron cartridge filtration systems are used in a variety of applications, including drinking water treatment, industrial water treatment, and swimming pool water treatment. They are generally easy to operate and maintain, and they can be an effective way to improve the quality of water by removing a wide range of impurities. There are many different types of micron cartridge filters available, with different pore sizes and materials to suit different water treatment needs. It is important to choose the appropriate filter for the specific impurities that need to be removed from the water. Emerging contaminants, including pharmaceuticals, pesticides, and nanomaterials, are found in various water sources and can cause endocrine disruption and toxic effects. Nano-particles, known as new generation nano absorbents, are used to remove these pollutants [13].

In the context of sanitization, a heat exchanger can be used to heat water or other fluids to a high temperature to kill bacteria and other microorganisms. This is often done as part of a water treatment process to produce clean, sanitized water for use in industrial processes or drinking. Several different types of heat exchangers can be used for sanitization, including shell and tube heat exchangers, plate and frame heat exchangers, and spiral heat exchangers. The specific type of heat exchanger used will depend on the specific needs of the application, such as the flow rate and temperature of the water, the type of heat source being used, and the space available for the heat exchanger. Heat exchangers for sanitization are typically designed to be easy to operate and maintain, with automated controls and monitoring systems to ensure that the water is heated to the appropriate temperature for the required amount of time.

RO is a water treatment technology that uses a semi-permeable membrane to remove impurities from water. It is often used to produce purified water for a variety of applications, including drinking water, laboratory water, and industrial process water. In a double-pass RO system, the water is passed through the RO membrane twice. The first pass removes a large portion of the impurities from the water, while the second pass further purifies the water by removing any remaining impurities. The double-pass RO membrane system is an alternative efficient method to remove total organic carbon (TOC) in the production of pure water [14]. This two-step process can produce water with a very low TDS level, making it suitable for applications that require extremely pure water. Double-pass RO systems are generally more efficient and effective at purifying water than single-pass systems, as they can remove a higher percentage of impurities. RO can reduce conductivity and TDS reaches 81 % and 82 %, even the conductivity and TDS of water produced can reach zero micro siemens/cm^2, 0 ppm [15]. However, these are also more expensive and require more space and equipment than single-pass systems.

Caustic soda, also known as sodium hydroxide, is a chemical that is often used in water treatment plants to adjust the pH of the water and remove impurities. In a purified water plant, a caustic soda dosing system may be used to add a precise amount of caustic soda to the water to adjust the pH or to remove impurities such as dissolved solids or organic contaminants. A caustic soda dosing system typically consists of a storage tank for the caustic soda, a pump to deliver the caustic soda to the water, and a control panel to monitor and adjust the dosage as needed. The caustic soda is typically added to the water in a controlled manner, to avoid over-dosing or under-dosing the water. Caustic soda dosing systems are often used as part of a larger water treatment process, in conjunction with other treatment methods such as filtration, RO, or ion exchange. These are generally easy to operate and maintain, and can be an effective way to adjust the pH of water or remove impurities. However, it is important to use caution when handling caustic soda, as it is a strong alkali that can be harmful to the skin and eyes. In the present research work, a series of water treatment methods are used jointly to get purified water of TDS near zero and conductivity < 1micro Siemens/cm^2 but also purified water free of several undesired organic elements.

2. MATERIALS AND METHODS

In the present study various water treatment methods have been used, which are described here. The first one is sand filtration, where instead of passing water through small orifices through which particles are unable to pass, water runs through a bed of filtration media measuring 0.45 mm. The installation layout of the sand filter is shown in Figure 1.

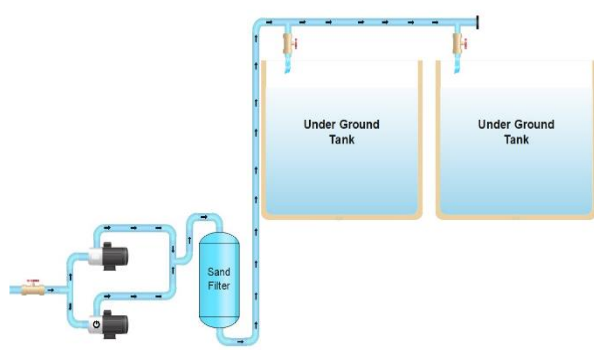

Fig. 1. Water circulation through the Sand filter

Table 1. Specifications of Equipment & material used for the sand filter system

S. No.	Description	Range
1	Power	4HP
2	Flow Rate	100 GPM
3	Pump Material	SS-304
4	Pressure Drop	5 Psi
5	Flow Rate	100 GPM
6	Filtration Chamber	42” x 72”
7	Valve System	5 Valve Battery
8	Pipeline Material	UPVC Sch-80
9	Media	Gravels and Silica Sand

There is an automatic vent device, which helps to remove excess air, created due to water turbulent flow inside the filtration chamber. This excess air can cause jerks during the continuous operation of the filtration chamber. A mixture of filtration media up to a depth of 3 ft was used, which added more clarity to the water up to 20–25 microns. The details of the sand filter are given in Table 1.

A multifaceted filtration method was used by the sand filter. Near the top of the filter bed, coarser, lighter media were used to capture large particle debris. Particles that were as small as 25 microns were trapped by finer, heavier media at successively lower media levels as smaller particles continued to descend. Following backwashing, layer separation is possible because of the disparities in medium densities. The shape of the filter is both attractive and functional. The spherical top and bottom ends of the tank was designed to give uniform flow from both the inlet distribution and outlet collection assemblies. The system provided adequate distribution to uniformly expand the filter bed during backwash, and the entire media bed was utilized during the filter cycle. High-quality, cleaned, and graded silica, 0.45 mm grade, and in the sand filter shell, accurate bedding in sizes of 1/2”, 3/4”, and 1/4” was used.

The auto-chlorination system helps to maintain the chlorine level in the water as per water testing results and the microbial growth rate. Low-pressure circulation pumps were installed in parallel, one operational, and the other on standby, to circulate the water.

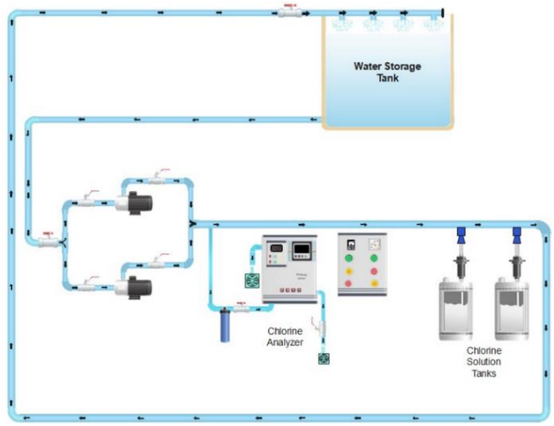

Fig. 2. Schematic diagram of auto chlorination system

During circulation, liquid chlorine was added through dosing pumps. The circulation pumps have alternated their operation after some time to avoid overheating. The dosing pumps was kept running until the desired chlorine level was achieved in the water reservoir. When the desired level of chlorine is achieved, the dozing pump stops automatically, and when the chlorine level drops, it restarts automatically. A chlorine analyzer sensor was installed in this circulation circuit to analyze the chlorine level. The chlorine dosing system layout is shown in Figure 2. The specifications of the equipment are given in Table 2.

Table 2. Specifications of equipment used in auto chlorination system

S. No	Description	Range
1	Power	1HP
2	Flow Rate	30-40 GPM
3	Pump Material	SS-304
4	Capacity	5 L/H at >5bar
5	Chlorine Sensor	1
6	PH sensor	1
7	Temperature Sensor	1
8	% Of Active Chlorine	12% - 15%
9	Chemical Name	Sodium Hypo chloride
10	Flammability	Non-Flammable

The third method is pre-treatment system, the equipment details are as follows: Polypropylene cable, wound around a polypropylene core, makes up these wound cartridges. They are suitable for the removal of fine materials, such as sand, silt, scale, invisible sludge, and rust particles, and they work

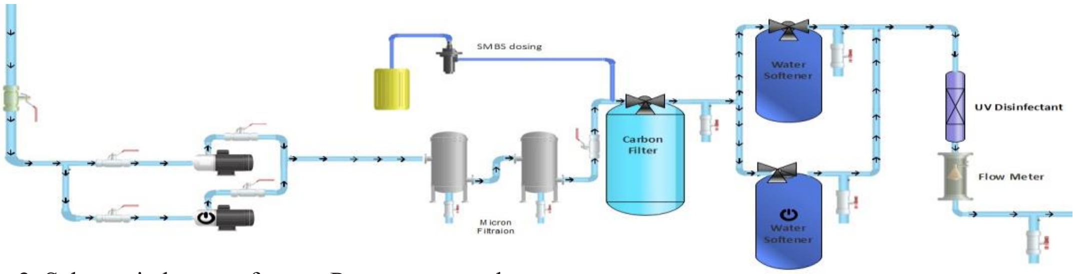

Fig. 3. Schematic layout of water Pre-treatment plant

well with the majority of acids, alkalis, corrosive fluids, and gases. As a result, they are an excellent yet affordable option for residential, commercial, and agricultural uses. The details of the cartridge filters are given in Table 3.

An activated carbon filtration using granular activated carbon (GAC) has been selected as the technique to remove organic pollutants from water. Additionally, GAC filters can be used to remove chlorine and hydrogen sulfide, two elements that give water a bad taste and smell.

Table 3. Specifications of equipment used in Pre-treatment plant

S. No	Description	Range
1	Pump Power	3HP
2	Water Flow Rate	50 GPM
3	Pump Material	SS-304
4	Filter Length	20”
5	Level of filtration	5-Micron & 1-Micron
6	Cartridge Qty.	20” – 7 No.
7	Chemical Name	Sodium Metabisulphite
8	Dosing rate	5 L/H
9	Solution Tank Capacity	80 Liter or as per operation hours

The layout of the water softening system is shown in Figure 3. While, the specifications of the GAC filter are given in Table 4. As water passes through softener vessels, water minerals can be removed from the water by using strong cation-resin beads that attract and hold them. The water transferred to the next step for further purification.

It is usually necessary that the hardness of EDI feed water should be less than 1.0 ppm [16]. As the water passes through softener vessels, strong cation-resin beads attract and holds water minerals, removing them from the water. The softened water then moves on to the next stage of treatment. So, for the sake of the production of purified water, the layout of the procedure is shown in (Figure 4). The technical parameters for consideration of water softeners are listed in Table 5.

Table 4. Technical specifications of GAC filter

S. No	Description	Range
1	Vessel Size	30” x 72”
2	Media	Activated carbon
3	Flow Rate	50 GPM
4	Iodine Number	950
5	Feed water PH	6.6 to 7.8

3. RESULTS

3.1 Conductivity Test Results

Conductivity is a measure of a substance’s ability to conduct electric current. A conductivity test is a laboratory test that measures the electrical conductivity of a substance. This test is often used to measure the concentration of ions in a solution, as the concentration of ions is directly related to the conductivity of the solution. Conductivity tests can

Table 5. Water softener vessel and used material specifications

S. No	Description	Range
1	Type	Automatic twin alternating
2	Flow	50 GPM
3	Feed Hardness	170 ppm
4	Output Hardness	< 2ppm
5	Resin	Strong Cation
6	Vessel Size	30” x72”
7	Resin in Vessel	400 Liters
8	Salt per Regeneration	60 Kg
9	Regeneration After	10 Hrs.

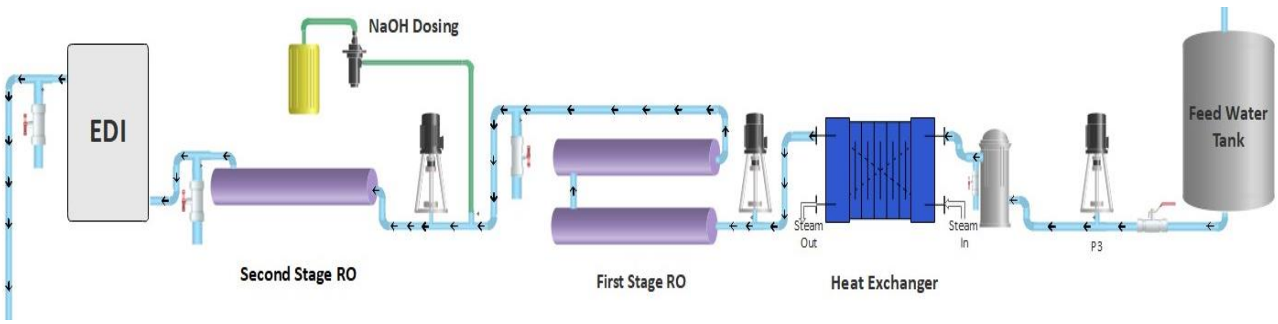

Fig. 4. The layout of EDI-based purified water plant

be used to measure the purity of water, determine the presence of contaminants in a sample, and monitor the quality of water in industrial processes. The fourteen days' conductivity test results are shown in Figure 5.

3.2 Microbiological Test Results

A microbiological test is a type of laboratory test that is used to identify, quantify, or detect the presence of microorganisms in a sample. These tests can be used to identify the presence of bacteria, fungi, viruses, or other types of microorganisms. Microbiological tests are often used in the medical field to diagnose infections, as well as in the food and water industries to ensure the safety and quality of products. After the performance qualification of the purified water plant, fourteen days of purified water testing was executed to identify the presence of any kind of harmful microorganisms. These results are shown in Figure 6.

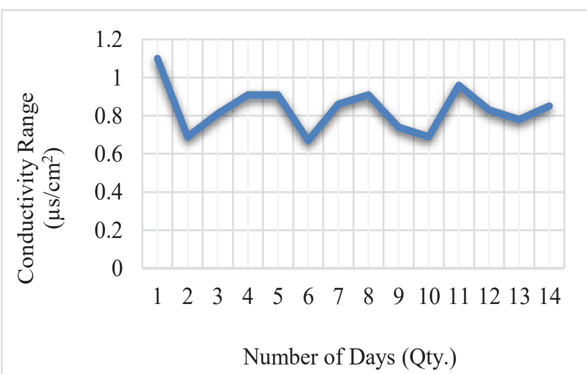

Fig. 5. Purified water conductivity testing results

3.3 TDS Results

TDS is a measure of the amount of dissolved inorganic and organic substances present in a water sample. A total dissolved solids test is a laboratory test that measures the concentration of dissolved solids in a water sample. This test is often used to determine the quality of drinking water and to monitor the concentration of contaminants in water sources.

TDS cannot be easily measured, except under controlled conditions. TDS are measured by the well-known expression: TDS = K. EC

The electrical conductivity (EC) is multiplied with factor "K" depending upon the salinity of water, the value of 0.5 to 0.75 is used depending

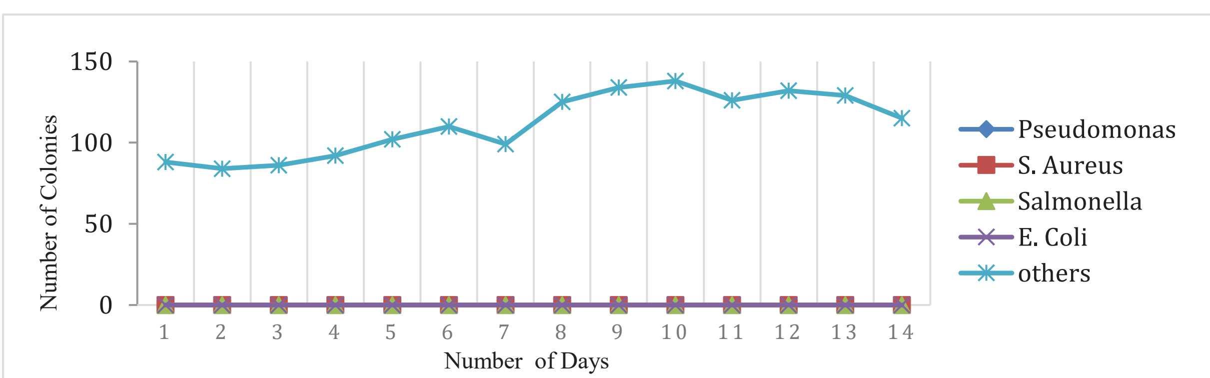

Fig. 6. Purified water Microorganism testing results

on the salinity of the water [17]. In this study we used a value of 0.5, the fourteen days' test results are shown in Figure 7.

4. DISCUSSION

The research paper discusses the production of purified water with near-zero TDS and low conductivity for use in the pharmaceutical industry and other applications. Water quality is crucial for the safety and efficacy of pharmaceutical products, and the widespread adoption of purified water with zero TDS is evident in various industries. The study investigates various purification methods, including EDI integrated with double-pass RO, microfiltration, and UV filtration. The experimental setup is used to produce purified water with near-zero TDS and conductivity below 1 micro siemens/cm^2. The proposed one-platform solution is compact and easy to maintain, offering practical and cost-effective water purification solutions.

As discussed in TDS results and graphically demonstrated in Figure 3 and Figure 4, tap water is used in various industries, however purification is necessary. Ultrafiltration, nanofiltration, reverse osmosis, and membrane distillation processes affect treated water quality. Nano filtration removes dissolved organic carbon, and RO rejects TDS at 99.7% Micropollutants are a growing concern in municipal wastewater treatment plants, posing a threat to aquatic ecosystems and drinking water resources. Powder activated carbon (PAC) is a promising technology to reduce micropollutants and ecotoxicity in receiving waters [18]. Furthermore, effective layout of water treatment equipment also played important role. Like, sand filter removes salinity and does micron filtration of tap water. Same is the case with water pre-treatment system, it reduces water pungent smell, extra chlorine and hardness making water odorless.

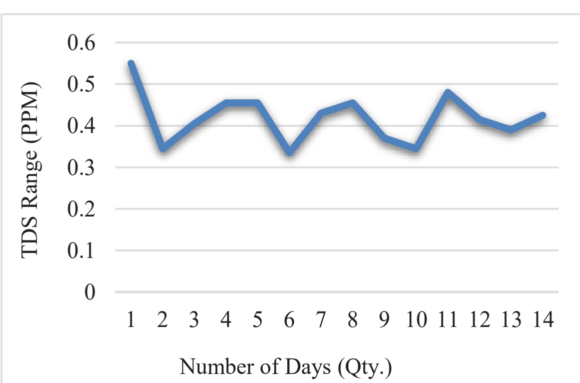

Fig. 7. Purified water TDS testing results

To determine if the water quality is adequate for pharmaceutical industry mass production, fourteen days of water testing, including TDS identification and microbiological growth, were undertaken. We can simply determine the total dissolved solids value, which is not easily calculated by other generally available equipment, close to decimals using the results displayed and the relation between TDS and conductivity that is given. The TDS value fluctuates depending on the type of tap water used and how frequently the equipment used in water treatment needs to be maintained.

The study investigates the correlation between TDS and Electrical Conductivity in natural waters like fresh water, sea water, and tender coconut. Results show that 96% of TDS variability can be attributed to EC in sea water [19]. The study's success opens up new possibilities for pharmaceutical manufacturers and other industries, potentially leading to more efficient and sustainable water purification practices. The discussion acknowledges limitations and suggests avenues for future research to improve the proposed system, explore other purification methods and address specific challenges in industrial settings.

5. CONCLUSIONS

In the pharmaceutical sector, particularly in the creation of oral solid dosage forms like creams, ointments, and gels, water is essential. Pharmaceutical, semiconductor, and electric power generation industries all depend on pure water with no TDS. This research paper has highlighted the method of generating high-purity water with near-zero TDS from resource water that meets specific criteria. The study demonstrated that different purification methods, such as EDI integrated with double-pass RO, ultrafiltration, microfiltration, and UV filtration, are beneficial in achieving this goal. The research work has provided a reliable and efficient method for producing high-purity water with near to zero Total Dissolved Solids (TDS) and low conductivity, which is crucial for manufacturing oral solid dosage forms in the pharmaceutical industry. This advancement ensures the quality and safety of pharmaceutical products, ultimately benefiting patients who rely on these medications for their health. By developing a one-platform solution that produces purified water of such high purity levels, the research work contributes to enhancing the quality and safety of pharmaceutical products. High-purity water is essential for ensuring that medications are free from contaminants that could adversely affect patients' health. The developed water purification system has potential applications beyond the pharmaceutical industry. Industries such as semiconductor manufacturing and electric power generation, which also require ultra-pure water with zero TDS, can benefit from this compact and easily maintainable solution. This broadens the impact of the research across various critical sectors. The integrated approach involving Electro-Deionization (EDI) and double-pass Reverse Osmosis (RO) can contribute to resource conservation. By effectively removing impurities and achieving high-purity water, the system may reduce water wastage and optimize the utilization of available resources. The one-platform solution can lead to cost savings in water purification processes for the pharmaceutical industry and other sectors. By streamlining different purification methods into a single system, the need for multiple equipment and maintenance costs may be minimized.

Future research could focus on assessing the scalability of the one-platform solution and its applicability in large-scale industrial settings. Investigating the challenges and opportunities for implementing this system on an industrial scale could be beneficial. Research could be conducted to evaluate the long-term performance and reliability of the one-platform solution. Assessing how the system performs over extended periods and under different operating conditions would help build confidence in its stability and effectiveness. Understanding the environmental impact of the water purification process is crucial. Future research could explore the energy consumption and waste generation associated with the developed system, aiming to optimize the process to minimize its environmental footprint. Conducting comparative studies between the developed one-platform solution and other existing water purification technologies would help identify strengths and weaknesses. Such studies could guide industries in selecting the most suitable water purification method based on their specific requirements and constraints. Research efforts could be directed toward automating the purification system and incorporating advanced monitoring and control technologies. Automation can lead to improved efficiency, reduced human error, and increased overall system performance. Investigating the potential for water reuse and recycling within the developed system could further enhance resource sustainability. Research could focus on identifying safe and effective ways to recycle purified water for other non-critical applications within the industries.

6. CONFLICT OF INTEREST

Authors declare no conflict of interest.

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