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Design and Operation of Water Treatment System for Central Sterile Supply Department Based on Energy Conservation and Consumption Reduction

Yuanlian Zhao, Jie Yang, Anchan Zhou, Yue Xie

(*Central Sterile Supply Department of Affiliated Hospital of Zunyi Medical University, Zunyi, Guizhou 563003 China*)

ABSTRACT: Objective The present study scientifically and reasonably designs a water treatment system for the central sterile supply department (CSSD) to achieve standardized water use, ensure the safety of instrument treatment, and reduce water resource waste. **Methods** Following the principle of using water in the CSSD, the design concept of the water treatment system is sorted out, and the implementation plan of the water treatment system is scientifically designed. Two sets of water treatment systems are connected in parallel to ensure an uninterrupted water supply in case of equipment failure. At the same time, the concentrated water produced during the production of pure water and the hot and soft water for sterilization cooling is recycled and reused, and the relevant operation of the water treatment system is monitored. **Results** Pure water and soft water were sampled from the sampling ports of the water treatment system. The conductivity monitoring of pure water was qualified. The hardness of the soft water was once found to be unqualified, but after replacing the failed resin, the hardness test passed. About 10 tons of concentrated water as well as about 30 tons of hot and soft water were recycled and reused daily. **Conclusion** When designing a water treatment system, it is necessary to fully understand instrument processing capacity and the usage of softened and purified water in the hospital, configure equipment according to peak usage, and recycle concentrated water and water for sterilization to achieve the goal of energy conservation and consumption reduction.

KEY WORDS: Central sterile supply department; Water treatment system; Operation; Energy Saving

Introduction

The central sterile supply department (CSSD) is an important department for controlling nosocomial infection. The cleaning, disinfection, and sterilization processes of instruments are directly involved in the occurrence of nosocomial infections in patients[1]. Water is an important medium for cleaning, disinfecting, and sterilizing medical instruments. Rationally and compliantly using water is a prerequisite for guaranteeing the quality of sterilization and supply. Therefore, CSSD managers are required to address the issue of how to optimize water selection in each step to improve the cleaning quality, reduce water consumption, and prevent water wastage. The Affiliated Hospital of Zunyi Medical University is a tertiary general hospital with 2, 800 open beds, an annual surgical volume of approximately 90, 000 operations, and a high volume of surgical instruments and clinical diagnostic and therapeutic items to be processed. In August 2021, the new CSSD was completed and put into operation. During the construction, we made a comprehensive and scientific design for the water treatment system. The system has been in operation for more than 2 years, showing qualified water qualities, stable operations, and favorable effects of water recycling and reuse. The present study reports the design and operation of the system as follows, expecting to be beneficial and supportive to counterparts.

1 Materials and methods

1.1 Materials

In this study, two water treatment systems of a Chinese brand were used, consisting of sand filter, carbon filter, softener, polishing filter, reverse osmosis (RO) membrane, brine drum, booster pump, water storage tank, connecting line, water meter installed in each line, total dissolved solids (TDS) calculator, and rapid analytical reagent for water treatment.

1.2 Methods

1.2.1 Principles of water selection in CSSD

1.2.1.1 Specifications and requirements for water in CSSD

To guarantee the quality of water in CSSD, the Chinese health industry standard (WS 310—2016) stipulates the type of water and water quality standard used in CSSD as follows[2]. Cleaning water supplied should consist of tap water, hot water, soft water, and purified water. The quality of tap water should comply with the provisions of GB 5749. Soft water should be used for rinsing and washing. The conductivity of water for final rinsing and sterilization should be ⩽15 μS/cm (25℃) (Grade 1 RO purified water). The conductivity of water for steam sterilization should be ⩽5 μS/cm(25℃) (Grade 2 RO purified water).

1.2.1.2 Properties of water for cleaning and sterilization in CSSD

According to WS310.1—2016, CSSD should have soft water and purified water. Soft water has the characteristics of a weak alkaline and chelating agent, applied in the initial and main washing of medical devices. It achieves a reliable cleaning effect and enhances the cleaning efficacy of detergents (e. g., multi-enzymatic detergents). In addition, soft water has a low production cost, conducive to lowering the cost of water. Purified water has excellent adsorption and high purity, being available for the rinsing and disinfection of medical devices, which maximizes the removal of residual detergents or microorganisms on the instruments and effectively prevents impurities in the water from contaminating the instruments in the cleaning and disinfecting process[3].

1.2.1.3 Properties of water for autoclave sterilization

Water for autoclave sterilization is used in evacuation and sterilization cooling. Its quality directly affects the operation and service life of the sterilizer[4]. Some manufacturers of international mainstream brands of autoclave sterilizers recommend soft water without limescale to be accessed to run the sterilizer because tap water has high hardness (high calcium and magnesium ions) and is easy to accumulate limescale, which reduces the performance of the vacuum pump and damages the system. Ultimately, the performance of the sterilizer is affected, and its service life is shortened.

1.2.1.4 Properties of water for steam sterilization

If the cleanliness of the water for steam sterilization is not acceptable, the impurities in the steam may adhere to the surface of the surgical instruments, resulting in watermarks and stains on the instruments after sterilization, thus reducing the sterilization effect[5-6]. WS 310.1—2016 requires that the conductivity of the water for steam sterilization should be ⩽5 μS/cm (25℃). Steam quality depends on the purity of the water used for steam sterilization. Specifically, the higher the purity of the water and the fewer the impurities, the purer the steam produced and the better the steam penetration. The penetration of steam directly affects the effectiveness of sterilization. In addition, the purer the steam, the more contaminated packs such as yellow packs due to impure steam residue after sterilization are prevented.

1.2.2 Design concept of water treatment system in CSSD

1.2.2.1 Estimation of water consumption

In this study, the principle of water usage in CSSD of our hospital is "soft water mostly used and purified water as a supplement". Soft water is used for initial washing, rinsing, primary rinsing of instruments, and autoclave sterilizer operation. Purified water is used for the final rinsing of instruments, hot water disinfection, and the production of sterilizing steam. Therefore, before the water treatment system is designed, the water consumption of soft water and purified water should be estimated.

Estimation of soft water. It includes water for mechanical cleaning, manual cleaning, and steam sterilization, as follows. (1) Water for mechanical cleaning: It is mainly used for spray cleaning and sterilizing machines and usually completes a running cycle per hour, taking 3~4 times of soft water (1~2 times of initial rinsing, once of enzyme washing, and once of initial rinsing); each time the amount of water taken is 30~50 L, so the maximum water consumption of each running cycle is 200 L. (2) Water for manual cleaning: Water consumption includes rinsing, brushing, and ultrasonic-assisted cleaning processes; every 100 pieces of instruments cleaned consumes 150~200 L of soft water. (3) Water for operation of autoclave sterilizer: It usually completes one running cycle per hour; water consumption is 300~400 L for domestic sterilizers and 300~800 L for imported sterilizers.

Estimation of purified water. It includes water for mechanical cleaning, manual cleaning, and steam sterilization, as follows. (1) Water for mechanical cleaning: The spray cleaning and sterilizing machine takes 2 times of purified water (once for final rinsing and once for hot water sterilization) per operating cycle, with a volume of 30~50 L per time and maximum water consumption of 100 L per operating cycle. (2) Water for manual cleaning: It is mainly used for the final rinsing of instruments, consuming 80~100 L of purified water per 100 instruments. (3) Water for steam sterilization: The steam consumption per operating cycle is 80~120 kg for domestic sterilizers and 30~100 kg for imported sterilizers (depending on size). Estimation is made according to the steam consumption provided in the instructions of the sterilizer manufacturer.

The CSSD in our hospital is equipped with 5 automatic spray cleaning and sterilizing machines, 1 four-compartment long cleaner, 1 large object cleaner, 1 decompression boiling cleaner, 4 autoclave sterilizers (2.0 m^3), 2 autoclave sterilizers (0.8 m^3), and 3 manual wash tanks (including luminal cleaning). The daily instrument processing capacity is estimated to be about 55 pots for instrument cleaning and 60 pots for sterilization. With standard loading, the steam consumption for 1 pot of autoclave sterilizer (2.0 m^3) is 31 kg, and the consumption for 1 pot of autoclave sterilizer (0.8 m^3) is 19 kg. The default is 1 kg of steam from 1 L of water. The estimated daily water consumption in CSSD is shown in Table 1. The frequency of water intake, amount of water intake, and steam consumption for the cleaner and sterilizer in Table 1 were provided by the manufacturer's engineers. Sterilizer steam and chilled water consumption given by the manufacturer are the results of tests with standard loads. In practice, the consumption of steam and chilled water increases with the change in loading capacity. Combined with the actual operation and pipeline deterioration, chilled water is designed at 1.5 times, and steam consumption is designed at 2 times. The peak of water consumption should be fully considered, and equipment with sufficient water production per hour as well as corresponding soft water and pure water tanks should be provided.

1.2.2.2 Recycling of concentrated water

During the production of purified water, about 50% of the soft water is converted into concentrated water that cannot pass through the RO membrane[7-8] and is usually disposed of as wastewater. Concentrated water is high sodium salt soft water. Sodium ions do not cause scaling, and it has excellent abrasive effect and reliable decontamination effect when used for cleaning of instruments. The recycled concentrated water met the water requirements of the industry and is safe to use for instrument cleaning and sterilizer running[7-8]. Concentrated water should be recycled in order to prevent water wastage.

1.2.2.3 Recycling of water for sterilization

Autoclave sterilization is considered to be the most dominant sterilization method in CSSD due to its effectiveness, low cost, safety, and environmental friendliness[9]. In autoclave sterilization, chilled water was added to the sterilizer in large quantities at the end of evacuation and cooling to increase efficiency and shorten the sterilization cycle time. This chilled water is soft water that has been filtered and soft-

Table 1 Estimated daily water consumption in CSSD

Equipment	Number [unit(s)]	Estimated instrument processing capacity per day [pot(s)]	Estimated soft water consumption (volume of water per intake × frequency of intakes × number of pots)	Estimated Grade 1 purified water consumption (volume of water per intake × frequency of intakes × number of pots)	Estimated Grade 2 purified water consumption
Spray cleaning and sterilizing machine/S-8668	5	35	40 L×3×35=4 200 L	40 L×2×30=24 00 L	/
Four-compartment long cleaner/ S-8668	1	20	40 L×3×20=2 400 L	40L×2×20=1 600L	/
Large object cleaner/9128E	1	3	250 L×2×3=1 500 L	250 L×2×3=1 500 L	/
Decompression boiling cleaner/230	1	3	150 L×2×3=750 L	150 L×2×3=750 L	/
Manual wash tank	3	/	1 000 L	1 000 L	/
Autoclave sterilizer/2. 0 m^3	4	30	810 L×30×1. 5=36 150 L	/	31 L×40×2=2 480 L
Autoclave sterilizer/0. 8 m^3	2	20	270 L×20×1. 5=8 100 L	/	19 L×20×2=760 L
Total estimates			54 100 L	7 250 L	3 240 L

ened. In China, water for sterilization cooling is always discharged as wastewater in CSSD. The temperature of the discharged water ranges from 50 to 70℃, resulting in a large amount of wasted water and heat energy[10]. If it is rationally utilized, it will have the effect of both reducing the discharge and saving the cost.

1.2.3 Implementation of design proposal for water treatment system

The water treatment system consists of water production, supply, and recovery. The installation schematic is shown in Figure 1.

The system consists of two water treatment subsystems, one producing Grade 1 purified water and Grade 2 purified water, and the other producing soft water. The two subsystems are interconnected before the soft water tank to ensure an uninterrupted water supply in the event of a failure of any one unit. The second subsystem has two soft water tanks. Soft water tank 1 receives the soft water produced by the subsystem, and soft water tank 2 receives the concentrated water discharged by the other subsystem when it produces purified water. The two soft water tanks are interconnected to ensure that the recycled concentrated water is used first. Emergency access is provided between Grade 1 pure water and Grade 2 pure water to ensure that the steam generator can supply water in the event of a failure of Grade 2 pure water. Sampling ports are provided at all soft and purified water outlets to monitor water quality. To monitor water production and discharge conditions, water meters are installed in the tap water supply line, soft water production line, soft water supply line, Grade 1 purified water supply line,

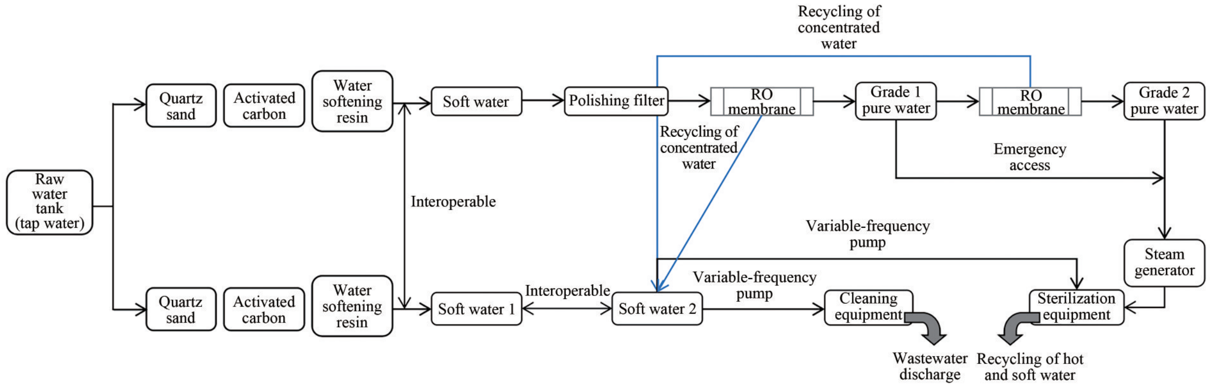

Figure 1 Installation diagram of water treatment system in CSSD

Grade 2 purified water supply line, concentrated water recycling line, Water softener 1 discharge line, Water softener 2 discharge line, and concentrated water discharge line.

1.2.4 Data collection

We designed a "Record of soft water hardness test", "Record of pure water conductivity", "Record of water production", "Record of concentrated water recycling", and "Record of water discharge" to collect relevant data. Soft water hardness was measured using a "rapid analytical reagent for water hardness". Purified water conductivity was observed and recorded simultaneously using a Monitoring display and a TDS calculator. In addition to the monitoring of Grade 1 purified water and Grade 2 purified water, the conductivities of soft water produced by the two soft water systems were tested and recorded using a TDS calculator. The amount of water produced, recycled, and discharged was recorded daily by specialized staff using a water meter.

2 Results

Based on the above design, this study collected relevant test data from June 2022 to May 2023 and the data was analyzed statistically.

2.1 Water quality monitoring

Table 2 shows the results of continuous monitoring for one year after the system had been put into operation for 10 months. The monitoring results show that the conductivities of Grade 1 purified water, Grade 2 purified water, and soft water tend to increase month by month, which should be a result of the extended use of the consumables. The results comply with the range specified in WS 310.1—2016 and meet the requirements for use.

The hardness test of soft water failed after 7 months of follow-up observation. After repeated investigations, it was confirmed that the failure occurred due to the breakdown of the water softening resin. After the resin was replaced, the soft water hardness test was qualified.

2.2 Water consumption

Based on water consumption statistics throughout the year, the estimated water consumption was able to meet the water requirements in CSSD during peak hours (highest from Tuesday to Saturday). Details are shown in Table 3.

2.3 Water recycling

The annual volume of concentrated water recovered from the water treatment system totaled 3, 720 m^3, an average of 310 m^3 per month, or about 10 m^3 per day. This included the concentrated water generated from the production of Grade 1 purified water and Grade 2 purified water. Insufficient ca-

Table 2 Conductivity monitoring of purified water and soft water (Unit of measurement: μS/cm)

Month	Monitoring display		TDS calculator			
	Grade 1 purified water	Grade 2 purified water	Grade 1 purified water	Grade 2 purified water	Soft water in Tank 1	Soft water in Tank 2
June 2022	6. 40	0. 64	5. 60	1. 00	162. 10	165. 40
July 2022	5. 63	0. 56	5. 00	1. 00	165. 43	165. 43
August 2022	5. 64	0. 71	5. 19	1. 09	165. 32	165. 84
September 2022	5. 76	0. 61	5. 00	1. 00	165. 38	165. 45
October 2022	7. 00	1. 38	5. 33	1. 00	165. 33	165. 42
November 2022	7. 41	1. 56	5. 53	1. 00	165. 50	165. 50
December 2022	7. 88	1. 71	6. 48	1. 00	166. 39	165. 97
January 2023	8. 52	1. 74	7. 00	1. 00	167. 00	165. 29
February 2023	10. 73	1. 80	7. 00	1. 00	166. 87	166. 80
March 2023	12. 26	1. 69	8. 10	1. 00	191. 48	197. 97
April 2023	13. 48	1. 43	9. 07	1. 00	212. 07	215. 27
May 2023	13. 30	1. 30	9. 00	1. 00	214. 81	215. 78
Average	8. 67	1. 26	6. 53	1. 01	175. 64	176. 68

Note: The data presented in the table is the average of the sum of the values monitored each day divided by the number of days in the month.

Table 3 Water consumption from June 2022 to May 2023 (Unit of measurement: m^3)

Type of water	Annual water consumption	Average monthly water consumption	Average daily water consumption	Average daily water consumption during peak hours
Tap water	24 113	2 009. 42	66. 06	85. 85
Soft water	14 689	1 224. 08	40. 24	55. 28
Grade 1 purified water	1 771	147. 58	4. 85	6. 57
Grade 1 purified water	636	53	1. 74	2. 29

pacity of the soft water tank resulted in incomplete recovery of the concentrated water. Soft water for sterilization and cooling was recycled into water for domestic use in the hospital, and the recycling volume was about 40 m^3 per day as measured by the water meter.

2.4 Wastewater discharge

The annual tap water consumption was 24,113 m^3, soft water produced was 19,997 m^3, and wastewater was 4,116 m^3. The average daily wastewater discharged was about 11.3 m^3. This wastewater consists of the water that is discharged during the back flushing of the sand filter, carbon filter, and resin tank, as well as during salt absorption. The amount of concentrated water discharged during the production of Grade 1 purified water and Grade 2 purified water is about 2,901 m^3, or about 8 m^3 per day on average. The water discharged is soft water. However, the concentrated water was not completely recycled due to site constraints and insufficient capacity of the soft water tank.

3 Discussion

Water is an important consumable for instrument cleaning; cleaning water is a key factor affecting the quality of cleaning[11]. The water treatment system is necessary for obtaining soft and purified water. The water treatment system consists of sand filter, carbon filter, softener, polishing filter, and RO membrane. Tap water is converted into soft water through a sand filter and carbon filter to remove colloids, suspended solids, microorganisms, rust, etc. In addition, the sodium cation exchange resin is used to remove calcium and magnesium ions from the water. Soft water is then processed through a polishing filter and RO membrane to remove the remaining impurities and microorganisms, thus obtaining purified water. Soft water is used for mechanical and manual cleaning as well as sterilizer evacuation and cooling. Grade 1 RO purified water is used for the final rinsing and sterilization of instrument. Grade 2 RO purified water is used to produce pure steam for autoclave sterilization. Based on the usage above, CSSD should establish a water system with soft water mostly used and purified water as a supplement. According to the actual operation in our hospital, the annual soft water consumption was more than 6 times of the purified water consumption, of which the soft water consumed by the sterilizer operation accounted for about 55% of the total amount, and the soft water consumed by the instrument cleaning and initial rinsing (including mechanical and manual cleaning) accounted for about 45% of the total amount. When designing a water treatment system, it is important to fully understand the instrument processing capacity and consumption of soft water and purified water in the hospital and configure the equipment according to the peak usage. During the design of this system, concentrated water was not fully recycled due to site constraints and insufficient capacity of the soft water storage tank, resulting in a portion of the concentrated water being discharged as wastewater. This will be rectified in subsequent phases so that no water is wasted.

Water for machine cleaning and sterilization shall be provided in accordance with WS 310—2016. Wei et al[7] showed that a combination of using soft water and purified water for instrument cleaning resulted in a better cleaning effect compared to using purified water in the whole process. When Grade 1 purified water and Grade 2 purified water are produced, the water treatment system discharges a large amount of concentrated water that cannot pass through the RO membrane. The concentrated water is soft water, but the content of active sodium ions is higher than that of soft water, and the decontamination effect is significant. Thus, it can be used as a substitute for soft water. The production cost of soft water is much lower than that of purified water. By combining soft water and purified water and recycling concentrated water, water costs can be reduced while maintaining the quality of instrument cleaning. According to the monitoring results, the recycling of concentrated water has no negative effect on the water quality of soft water and purified water and saves a lot of water resources.

Recycled water for sterilization includes condensed water produced from steam sterilization and soft water for sterilizer evacuation and cooling. The condensed water produced from steam sterilization is the condensate of clean steam, which meets the relevant requirements of WS 310—2016.1 and thus is a clean water source; soft water for sterilizer evacuation and cooling does not come into direct contact with sterilized items and thus is clean. Our hospital recycled and reused about 40 m^3 of water for sterilization per day and the water quality was monitored and passed. This effectively reduces the consumption of other fuels and tap water, lowers the cost of wastewater treatment, and thus results in energy conservation and consumption reduction[12].

4 Conclusion

In this study, we optimized the pure water supply system by considering the actual situation of water in CSSD. In addition to the original pure water supply, the water system adopts a principle of "soft water mostly used and purified water as a supplement". Moreover, concentrated water from the production of pure water, as well as pure water and hot and soft water for sterilization cooling, are recycled to achieve not only compliance with the standard requirements but also energy savings and cost reduction. Therefore, this method is worth promoting.

China has a serious shortage of water resources[13]. Thus, every individual is responsible for conserving water, which reflects the importance that modern society attaches to the water environment and ecological environment. Since CSSD has a very high water consumption, rational arrangement of water usage and comprehensive utilization of water resources contribute to achieve the purpose of energy conservation and consumption reduction.

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