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INNOVATIVE SYSTEM FOR ELECTROCHEMICAL ACTIVE CHLORINE PRODUCTION IN COAXIAL AND CABINET-TYPE REACTORS

Zaga Trišović[1], The Academy of Technical Applied Studies Belgrade
Tomislav Trišović[2], Institute of Technical Science Serbian Academy Science and Art, Belgrade
Ana Virginia Socalici[3], University Politehnica, Timisoara, Romania
Corneliu Banesa Birtok[4], University Politehnica, Timisoara, Romania

Abstract: *Drinking water, whether previously purified or not, even if entirely clear, can often be contaminated with bacteria, viruses, or harmful microbes, necessitating disinfection. Disinfection serves as the final and sometimes the sole process in preparing drinking water. This paper presents a solution for the on-demand production of active chlorine (sodium hypochlorite) without the need for storage, aiming to prevent its degradation and ensure the safety of workers during handling.*
Keywords: Drinking water, sodium hypochlorite, chlorine

1. INTRODUCTION

Disinfection of water is most commonly performed using gaseous chlorine and chlorine compounds, during which oxidation reactions predominantly take place. Chlorine readily oxidizes alcohols, aldehydes, amino acids, various inorganic substances, and substances causing water discoloration, among others. Disinfection is carried out by precisely dosing chlorine compounds into the water using a dosing device (such as a dosing pump, dropper, or ejector). These quantities typically range from 0.3 to 0.5 g/m3 and depend on the quality of the filtered water, specifically on the content of substances susceptible to oxidation. These amounts are adjusted so that the disinfected water contains residual chlorine levels of 0.3 to 0.4 mg/l immediately before use. This free chlorine serves as a convenient indicator that an adequate amount of disinfectant has been used, while also preserving the bacteriological safety of the water for a certain period. Chlorination of water serves as both primary and secondary disinfection. This means that chlorine is used for both the primary inactivation of microorganisms in the water and to provide protection to the distribution system through residual action. The residual chlorine aims to maintain biological stability and protect against secondary contamination. Maintaining the biological stability of the system involves keeping the water in a state that does not promote the growth of microorganisms in the distribution system. For small-capacity facilities, disinfection is commonly carried out using sodium hypochlorite, NaOCl. The active chlorine content in the solution is about 15%. Gaseous chlorine is primarily used in high-capacity waterworks but is being phased out from water treatment processes due to the risks associated with handling and storing chlorine gas cylinders. Water solutions of sodium hypochlorite, produced in large petrochemical complexes or on-site generation units, are increasingly being used. In both cases, the water solution of the raw material (chloride salts) and the finished product (sodium hypochlorite) are stored in tanks exposed to atmospheric temperature and, potentially, sunlight radiation. Storage under such conditions triggers a thermochemical reaction in which sodium chlorate is formed from sodium hypochlorite, which is three times less effective in the water disinfection process. This

[1]ztrisovic@atsbb.edu.rs
[2]tomislav.trisovic@itn.sanu.ac.rs
[3]virginia.socalici@fih.upt.ro
[4]corneliu.birtok@fih.upt.ro

problem is particularly pronounced during the hot summer months when the air temperature exceeds 30 degrees Celsius. To prevent the degradation of sodium hypochlorite, climate-controlled storage spaces and containers that do not allow UV radiation must be provided. In addition to hypochlorite degradation caused by heat and UV radiation, there is also spontaneous degradation defined by a half-life of approximately one and a half months. Since the solutions are alkaline, contact with carbon dioxide from the air leads to a reaction with sodium hydroxide, forming sodium carbonate, further complicating the operation of dosing systems by clogging nozzles, pump suction baskets, droppers, and injection valves.

2. BACKGROUND

In recent years, several companies worldwide have developed on-site sodium hypochlorite production devices, but they have mainly presented two design solutions: devices with flow and batch-type reactors, both involving the storage of the resulting sodium hypochlorite solution. These solutions have demonstrated various advantages over gas chlorination technology in practice. However, they tend to be large in size, considerably expensive, and susceptible to the degradation of sodium hypochlorite, particularly when left in the receiving tank for extended periods. When situated in air-conditioned environments, operational costs escalate significantly, which poses a substantial financial burden, especially for devices with smaller capacities. On the other hand, for non-air-conditioned settings, the installation of heat exchangers becomes imperative, both in the reactor itself and in the tank containing active chlorine. To ensure the reliability of the disinfection process, sizable storage tanks are implemented, containing significant amounts of sodium hypochlorite.

This precaution safeguards the continuity of the disinfection process in the event of device malfunctions. The intricate nature of the construction [1-3] justifies the need for product storage, guaranteeing the uninterrupted flow of the dosing process during any necessary device repairs. Similar challenges persist across the operation of batch, flow, and recirculation reactors. The initial prototype of one such device emerged in the USA under 'Capital Controls,' featuring a flow reactor, table salt reservoirs, an active chlorine tank, a water chemical preparation system (for softening), and an active chlorine dosing system. Fully automated, the device operates with minimal human supervision. Similarly structured devices were later developed in our country during the early 1990s, with the first model crafted by 'Fabrika vagona' in Kraljevo and commercially produced by 'Sigma' in Kula. By the late 1990s, various European manufacturers introduced new iterations of these devices, including 'Wallace Tiernen,' 'Fisher Porter,' 'Dinotec,' 'ProMinent,' 'Siemens Plc' OSEC-NXT with a membrane electrolyzer, and 'Water Engineers Ltd.' The designs, though diverse, predominantly rely on flow reactors and the accumulation of active chlorine. Notably, some devices utilize seawater in the electrolysis process to generate active chlorine, such as those from 'EU-CHLOR Ltd' in England and 'Prima Atec' in Korea, employing 'NC' cell types for the conversion of seawater. More recent entrants into the global market, including 'Titanium Tantalum Products Ltd' from India, have introduced electrochemical cells with carbon steel cathodes and titanium anodes activated with RuO2, polarized monopolarly. Asian manufacturers, such as 'IEC Fabchem Limited' in India, 'Water Engineers' in Singapore, 'WestWater Enterprises Pty Ltd.' in Australia, 'Prima Atec Inc.' in Korea, 'Kalf Engineering' in Singapore, and 'Nagpur Aquatech Ltd.' in India, have also developed devices for on-site active chlorine production. These systems are constructed with flow reactors and active chlorine storage, catering to both seawater and table salt solutions for electrolysis.

Cleaning of the electrolyzer is accomplished by ceasing the process, filling the electrochemical cell with an acid solution to eliminate potential limescale buildup, expelling the acid, and resuming electrolysis using kitchen or sea salt. Most of these automated solutions are tailored for large-scale systems generating over 50 grams of active chlorine per hour. This paper introduces a novel device designed to address the limitations observed in previously described systems, primarily focusing on rectifying the issue of sodium hypochlorite degradation. The storage of sodium hypochlorite in tanks exposed to atmospheric temperature and potential solar radiation triggers a thermochemical reaction, converting it into chlorate, significantly diminishing its effectiveness in water disinfection, up to three times less effective. This problem is particularly acute during the sweltering summer months when temperatures exceed 30 degrees Celsius. To counteract the degradation of sodium hypochlorite, the provision of air-conditioned storage facilities and the use of UV-resistant materials for containers become imperative. Apart from causing water contamination with chlorate, which possesses lesser disinfectant properties than sodium hypochlorite, prolonged storage elevates the cost of utilizing this disinfectant solution.

3. PROBLEM STATEMENT AND SOLUTION

To address the noted deficiencies in existing solutions, we have developed a device for active chlorine production featuring a coaxial reactor design. This innovative system generates sodium hypochlorite in quantities precisely matching the demand for water disinfection, eliminating the need for its storage. In our novel coaxial and cabinet reactor solution, the water undergoing chlorination circulates around the reactor housing, ensuring that the electrolyte temperature remains in close proximity to the cooling tap water temperature.

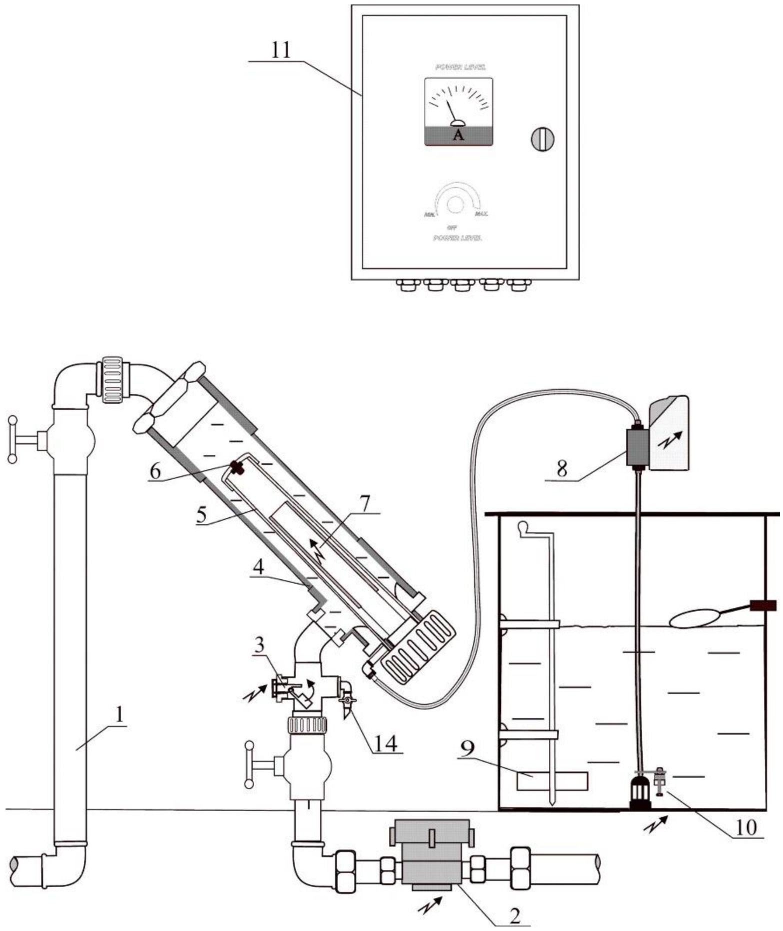

Figure 1. Device for the electrochemical production of active chlorine from dilute chloride solutions with a coaxial reactor mounted on a pipeline

Consequently, the sodium hypochlorite solution produced at the reactor outlet remains below 30°C, considering that tap water typically ranges between 10°C and 20°C. Essentially, the water undergoing chlorination doubles as a cooling agent. This design maintains the outlet temperature below 28°C, minimizing the risk of thermochemical degradation of hypochlorite to chlorate.

Our design circumvents the necessity for a thermoregulator and heat exchanger, only requiring a water flow sensor in the pipeline, leading to substantial simplification and material, electrical component, and automation savings. The device's proper operation is ensured through the installation of two sensors, one for monitoring the water flow to indicate the operational status of the pumping pump and another for the minimum chloride solution to prevent the dosing pump from running dry. The electrolyzer activates only when there is a flow through the pipeline and the chloride solution exceeds the minimum threshold.

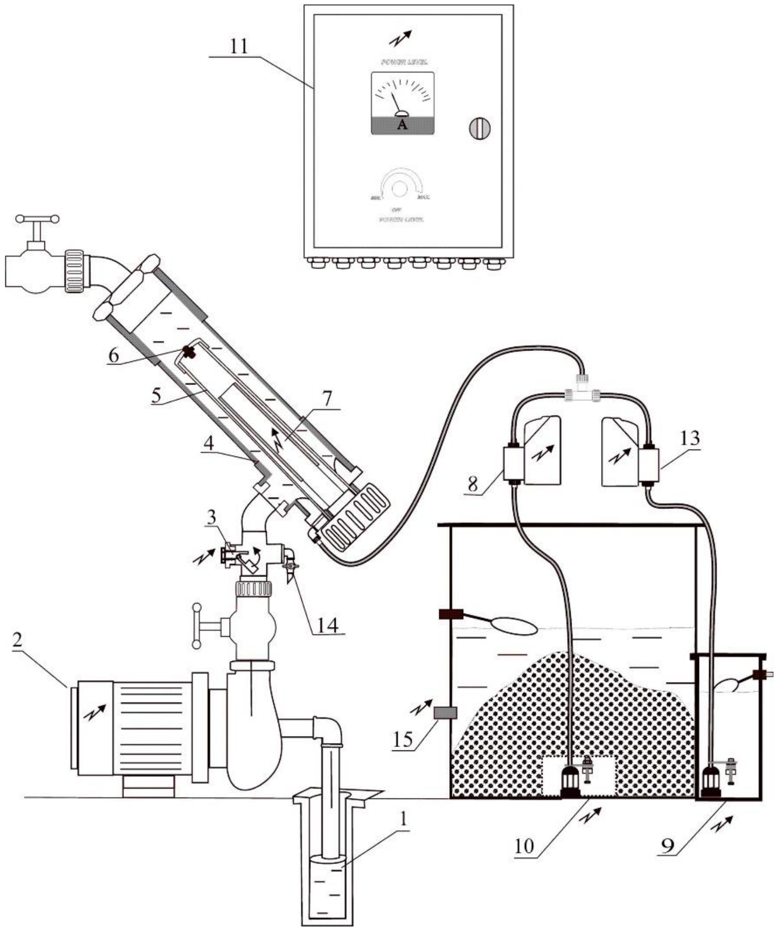

Figure 2. Device for the electrochemical production and dosing of active chlorine from a concentrated chloride solution with a coaxial reactor mounted on the pressure of the pumping pump

Our innovative solution, with its water-cooled coaxial and cabinet reactor, obviates the need for temperature sensors, thermoregulators, and their corresponding automation. Furthermore, the design eliminates the requirement for hydrogen separation and venting, as all reaction byproducts are introduced into the raw water along with the active chlorine. The dosage of active chlorine and hydrogen into the treated water remains below 1 mg, ensuring environmental friendliness. During operation, the dosing pump draws in a diluted chloride solution (3%) (refer to Figure 1). Alternatively, two dosing pumps may be employed, one drawing clean water and the other a concentrated table salt solution, mixed just before entering the reactor to produce a diluted chloride solution (3%) (refer to Figure 2). The frequency of diluting the sodium chloride solution depends on the monitoring intensity, with the option to refill the diluted solution container more frequently (every ten days) in more closely monitored settings. For locations with less frequent monitoring (distant sites), two dosing pumps are used, necessitating a higher input of concentrated salt solution into the container, achieving a 3% solution ratio upon mixing at the reactor inlet.

Within the tubular reactor, chlorides undergo electrochemical conversion to hypochlorite, with the resulting solution passing through a non-return valve before entering the water treatment process. The dosing pump flow, reactor current strength, water flow, and pipeline pressure are regulated based on the water flow and pressure. The minimum pressure requirement in the pipeline is 0.1 bar, with a flow rate of 0.1 liters per second. This device can be conveniently installed on the pump's discharge or suction line (as depicted in Figure 1) or anywhere along the pipeline, necessitating the installation of a flow meter instead of a flow sensor to signal the reactor's activation and operational intensity.

With its straightforward design, modular reactor system, and user-friendly servicing, our system ensures dependable operation and maintenance efficiency.
The device comprises an electric block, a sodium chloride tank, and a hydraulic assembly. The hydraulic assembly is composed of dosing pumps, an inlet valve, a flow sensor, a coaxial reactor or reactor cabinet, and an outlet valve. The sodium chloride solution, sourced from the tank (either 3% or 30% NaCl), is conveyed through the pipeline via dosing pumps. It is then mixed with clean water and subsequently introduced into the coaxial or cabinet reactor through a non-return valve.
Upon entering the reactor, chlorides undergo an electrochemical transformation, with active chlorine being generated at the anode and hydrogen released at the cathode. The resultant reaction products are directed through the upper non-return valve into the water circulating around the reactor housing, simultaneously undergoing chlorination.
Inside the reactor housing, a dosing pump maintains a pressure higher than that in the pipeline, ensuring the continued hydraulic transportation of the reacted solution. Subsequently, the solution is injected back into the pipeline through another non-return valve. This process guarantees that the chloride solution, or the active chlorine solution within the reactor housing, remains at the temperature of the well water (typically ranging between 7°C and 19°C). These optimal conditions facilitate the electrochemical synthesis of active chlorine.

4. CONCLUSION

This paper introduces a cutting-edge device for on-demand sodium hypochlorite production, eliminating the need for storage to prevent degradation and safeguarding workers during handling. The device ensures enhanced reliability in dosing system operations by generating a slightly alkaline solution with a pH of around 8 through the electrolysis of diluted solutions, thereby reducing the impact of CO2 reactions. Notably, this solution prioritizes user and environmental safety and represents a significant innovation compared to preceding methodologies.

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