Analytical study to evaluate the activity of sodium hypochlorite in industrial application conditions to treat water and provide safe drinking water to the population

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Received:29 /11/2022
Accepted:30/3/2023

Abstract:

Clean water is essential for public health, humans cannot survive without water. Pathogens are easily controlled with chlorination but can cause harmful or even deadly outbreaks given conditions of inadequate. chlorinated drinking water systems will remain a cornerstone of waterborne disease prevention and public health protection in the global. No single disinfection method is right for all circumstances due to that We designed the system taking into consideration number of factors and the approach was to match the system's characteristics, needs, resources, and source water quality. The study was focused in Chemical analysis and engineering approach and it was implemented on several sites in Syria knowing that drinking water chlorination is scalable it can provide reliable, cost-effective disinfection for remote rural villages, mid-sized communities, and large cities alike, helping to bring safe water to all. A dose of 0.8 PPM of sodium hypochlorite concentration of 8% was used, which was sufficient to completely eliminate the bacteria based on the percentage of free chlorine remaining which is an important point due to the economic savings achieved which amounted to 331 m3 of sodium hypochlorite annually while sterilizing 800,000 m3⁄day of raw water. Hence there was no need to import water sterilizers from other countries, and self-sufficiency was achieved. Training over 50 engineer and technicians on how to deal with the designed system around Syria in the cities.

Key words: Water disinfection, sodium hypochlorite preparation, pH, turbidity.

دراسة تحليلية لتقييم نشاط هيبوكلوريت الصوديوم في ظروف تطبيق صناعي لمعالجة المياه وتزويد السكان بمياه شرب آمنة

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تاريخ الايداع: 2022/11/29
تاريخ القبول: 2023/3/30

الملخص:

تعد المياه النقية ركيزة أساسية لصحة المجتمع، ويستحيل على البشرية متابعة الحياة بدونها. لذلك كان من السهل التحكم بالمسببات الممرضة في المياه عن طريق تعقيمها بالكلور إذ أنَّ المياه الملوثة ممكن أن تحدث ضرراً بالغاً على صحة الإنسان وفي بعض الحالات قد تؤدي إلى الموت.

يعتبر نظام تعقيم المياه بالكلور من أفضل نظم تعقيم المياه عالمياً، وبالأخذ بالحسبان أنه لا يوجد نظام تعقيم للمياه قابل للتطبيق في جميع الظروف الحيوية والبيئية إلا أنَّ النظام المدروس قد صُمم بناءً على عدد من البارامترات والأسس التي تحقق تعقيماً للمياه بناءً على مصدرها وجودتها.

ركز البحث على التحليل الكيميائي والنهج الهندسي المتبع للحصول على مادة التعقيم، وتم تطبيقه وتجريبه في عدة مواقع سورية، إذ أن الكلور مُعقم فعّال واقتصادي ومثالي لتعقيم المياه في الضواحي والقرى النائية والمدن متوسطة الحجم والمدن الكبيرة على حد سواء.

تم استعمال جرعة 0.8 PPM من هيبوكلوريت الصوديوم بتركيز 8% لتعقيم المياه إذ بينت النتائج تحقيق وفر اقتصادي في كميات الكلور المستعملة في التعقيم، فقد بلغت قيمة الوفر 331 m3 من هيبوكلوريت الصوديوم سنوياً عند تعقيم 800,000 m^3/day من الماء الخام يومياً، بالإضافة إلى تحقيق الاكتفاء الذاتي والاستغناء عن الحاجة لاستيراد معقمات المياه من الدول الأخرى وختاماً تم تدريب 50 مهندس وتقني من جميع انحاء سوريا على طريقة استخدام النظام المُصمم لتعقيم المياه.

الكلمات المفتاحية: تعقيم المياه، تحضير هيبوكلوريت الصوديوم، pH، عكارة.

Introduction:

Of all the advancements made possible through science and technology, the treatment of water for safe use is truly one of the greatest abundant. Clean water is essential for public health, humans cannot survive without water.

In this regard the U.S. National Academy of Engineering (2018) cites water treatment as one of the most significant advancements of the last century (Drinking Water Chlorination, 2022).

Moreover, without filtration and disinfection, the physical removal of particulate matter consumers will be at high risk of contracting and spreading of waterborne diseases.

Providing clean and safe drinking water requires a multi-barrier approach that includes protecting source water from contamination, appropriately treating, filtering and disinfecting raw water, and ensuring the safe distribution of treated water to consumers' taps.

Contaminated drinking water is estimated to cause over 829 000 diarrheal deaths each year, mostly among children (WHO, 2022).

In 2020, 5.8 billion people used safely managed drinking water services through improved water sources located on premises, and are free of contamination and available when needed. The remaining 2 billion people without safely managed services in 2020 included 1.2 billion people with basic services, meaning an improved water source located within a round trip of 30 minutes; while 282 million people with limited services, or an improved water source requiring more than 30 minutes to collect water; 368 million people taking water from unprotected wells and springs; and 122 million people collecting untreated surface water from lakes, ponds, rivers and streams (WHO 2022). Consequently, these people are more susceptible to disease outbreaks.

Even where drinking water treatment is widely practiced, constant vigilance is required to guard against waterborne disease outbreaks caused by bacteria, viruses, protozoa, and toxin-producing algae (WHO, 2022).

Though well-known bacterial pathogens such as toxin-producing Escherichia coli, Salmonella typhi, and Vibrio cholerae as well as viruses are easily controlled with chlorination, they can still cause harmful or even deadly outbreaks given inadequate conditions or no disinfection (WHO, 2022) Globally, at least 2 billion people use a fecally-contaminated drinking water source, which can transmit both chronic (endemic) and acute (outbreak) diseases such as diarrhea, cholera, dysentery, typhoid fever, and polio (WHO, 2018).

During the conventional treatment process, chlorine is added to drinking water as elemental chlorine, sodium hypochlorite solution (bleach), or dry calcium hypochlorite. When applied to water, each of these disinfection methods forms free chlorine, which destroys pathogenic (disease-causing) organisms.

Many important waterborne and emerging diseases are zoonotic caused by pathogens that can spread between animals and humans under natural conditions within wildlife often serving as an important reservoir.

Given chlorine's wide array of established benefits, and despite a range of new and ongoing challenges, chlorinated drinking water systems will continue to be the main pillar of waterborne disease prevention and public health protection in all over the world.

Alternative disinfectants (including oxidants chlorine dioxide, ozone, and UV radiation) (Zeng et al., 2020, 1) ،are available and, in some cases, appear to be gaining greater use especially in combination with chlorine and chloramine technologies (Guo et al, 2020, 3)

Nonetheless, all disinfection methods have unique benefits, limitations, and costs. No single disinfection method is right for all circumstances (WHO chronicle, 2011, 172).

Water system managers should therefore consider these factors and design a disinfection approach to match each system's characteristics, needs, resources, and source water quality.

At the global level, safe drinking water continues to be recognized by the WHO and other international organizations as a critical building block of sustainable development. (WHO, 2018).

Drinking water chlorination is scalable it can provide reliable, cost-effective disinfection for remote rural villages, mid-sized communities, and large cities alike, helping to bring safe water to all.

Furthermore, Taste and Odor Control Chlorine disinfectants reduce many disagreeable tastes and odors. Chlorine oxidizes many naturally occurring substances such as foul-smelling sulfides and odors from decaying vegetation.

1. The importance of research and its objectives:

since water is the basic element for the existence and sustainability of life, and due to its strong association with development, we should provide enough amount of clean water for consumers in society. We thus aim to provide disinfected water with chemical and physical specifications according to WHO standards, to reach this, we designed and implemented a disinfecting system to produce NaOCL mechanically, prepared a disinfecting dose consistent with the nature of Syrian raw water, and eventually trained over 50 engineers and technicians on how to deal with the designed system.

2. Materials and methods:

Considering that we prepared sodium hypochlorite from the reaction of calcium hypochlorite with sodium carbonate, as shown by the equation:

$$Na_2CO_3 + Ca(OCl)_2 \rightarrow 2NaOCl + CaCO_3$$

The following was required:

1. The implemented designed system.
2. Auto ranging EC, TDS, NaCl, Temperature Meter:

seq	reading	rang
1	Accuracy EC	±1% of reading ± (0.05 µs/cm or 1 digit)
2	TDS	±1% of reading ± (0.03 mg/L or 1 digit)
3	NaCl	±1% of reading
4	Temperature	±0.4°C

3. pH Meter: Accuracy @20°C ±0.01 pH
4. Precision Turbidity Benchtop Meter:

seq	reading	rang
1	Accuracy @25°C/77°F,	±2% of reading plus 0.02 NTU (0.15 Nephelos; 0.01 EBC), ±5% of reading above 1000 NTU (6700 Nephelos; 245 EBC)

5. calcium hypochlorite as powder: 360 kg.
6. sodium carbonate as powder: 375 kg.
7. Sodium hydroxide: 1 liter.

A- Experimental procedure:

In order to produce sodium hypochlorite mechanically we designed a system combined of the following items as demonstrated in the diagram below:

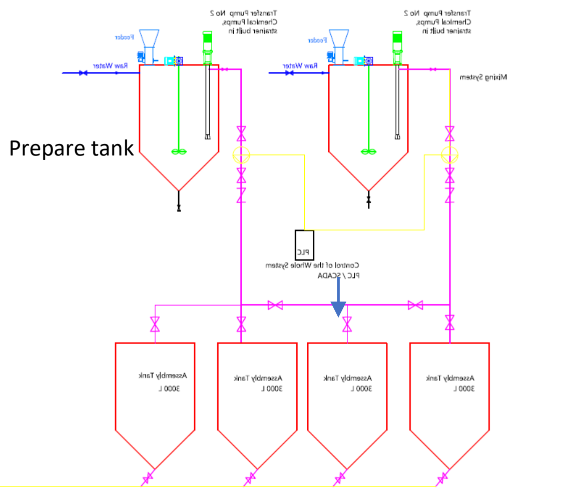

Diagram (1) The flowchart of the designed system

The system was designed based on identifying the flow of water which will be sterilized on a daily basis, and this might vary from day to day, besides to temperature and turbidity variation along the year. We therefore determined the required flow of sodium hypochlorite to obtain complete water disinfecting, and the design dose needed to obtain a sufficient amount of the produced sterilizer.

Referring to the theoretical study, it's been revealed that the most suitable method for producing a bulk amount of sodium hypochlorite is by mixing sodium carbonate and calcium hypochlorite as a powder in a slow motion (Atiemo-Obeng et al., 2004, 591-595), Based on that, we determined the required power and speed of rotation for the electronic mixer; then we noticed that Hygroscopic bulk materials may cause breakdowns in the system if they become lumpy and sticky due to the entry of moisture while adding it to the preparation tank, In addition, accurate metering has become impossible because a homogeneous bulk material flow which is required for precise metering is no longer guaranteed, so we added a dry feeder with Heated nozzles to prevent the entry of more or less humid ambient air into the mixture.

After that, the preparation and assembly tank were sized, besides the transferring pump, then the circulating system was studied hydraulicly (Awatif et al., 2019, 37-55), and eventually, the drainage system was designed based on the German stander for sedimentation which will guarantee the safe disposal of sludge (Awatif et al., 2019 p 74-83).

The experiment was conducted in Dahiet Qudsieh water station, where two samples were prepared; in each of which a 360 kg of calcium hypochlorite and 375 kg of sodium carbonate as a powder were mixed slowly for 7 hours then were elementarily sedimented for 12 hours in a preparation tank, and they were eventually transferred by a transporting pump to an assembly tank and sedimented for 24 hours. Consequently, the following results were taken:

Table (1) results of the preparation experiment for two samples represented by the first sample and the second sample:

Sample name	State	pH	T (°c)	Turbidity (NTU)
First sample	Before starting	8.2	20.6	0.22
First sample	During the mixing process (after 2 hours of mixing)	10.4	26.3	<4000
First sample	After 24 hours of sedimentation	12.6	21	10.52
Second sample	Before starting	8.3	19.9	0.22
Second sample	During the mixing process (after 2 hours of mixing)	10.9	28.5	<4000
Second sample	After 24 hours of sedimentation	12.6	21.2	12.6

Curves representing the behavior of the solution during the preparation process were drawn according to each of the parameters in the previous table, Figure (2) indicates the water's pH behavior during the preparation process. It was observed that the pH value rose sharply during the preparation, as a result of the reaction of hypochlorite Calcium and sodium carbonate which are soluble in water giving an alkaline medium, whereas the pH rise was linear during the settling process, due to the stability of the reaction of the molecule (Boulos,N.S, 2008, 423)

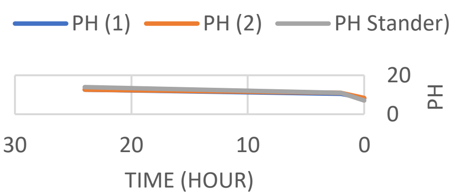

Figure (2) pH change over time for sodium hypochlorite solution during preparation

While studying the samples, a slight increase in temperature was observed, as a result of the reaction of calcium hypochlorite, which dissolves in an exothermic process during the mixing process, followed by a linear decrease in temperature due to the influence of the surrounding medium during the sedimentation process, as shown in Figure:(3)

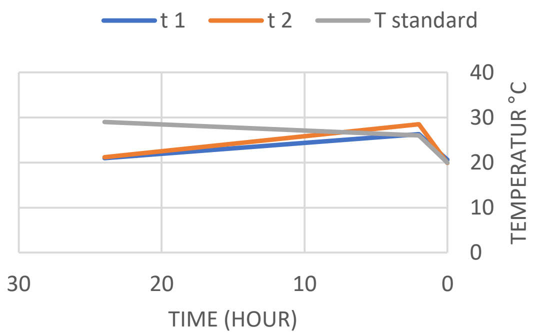

Figure (3) temperature change over time for sodium hypochlorite solution during preparation

Eventually while studying the turbidity values during the preparation process, a sharp rise was observed as a result of the interaction and the addition of solids to a watery medium, as the turbidity meter could not read the value because it was outside its measurement range, and then upon sedimentation, the turbidity decreased to values close to the standard value. And was seen as one line as shown in Figure (4):

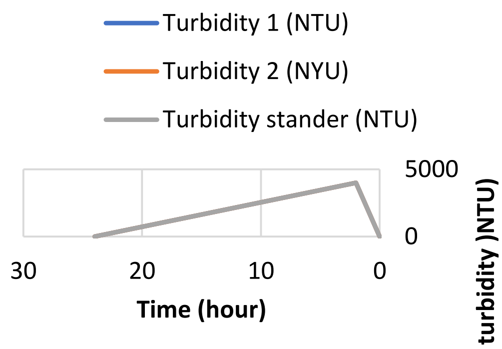

Figure (4) turbidity change over time for sodium hypochlorite solution during preparation

After that we used the produced Sodium hypochlorite samples to sterilize samples of water, we gathered from three main pumping stations in Damascus they are (Al-Fijeh spring, Barada Valley, Marwan Valley)) and experimented for 30 minutes, as shown in table (2), so that to observe the behavior and the mechanism of sterilizer in the water, taking into account that it is considered as the most important experiment, based on which the efficacy of the prepared sodium hypochlorite and its performance were determined for the desired purpose. Furthermore, the test was applied on two types of bacteria; the Escherichia coli, which is a facultative aerobic bacterium that coexists with humans and vertebrates and is opportunistic, while causing diseases at certain times, and the general number of bacteria, as the total estimate of the number of bacteria present in the water generally gives an idea of the degree of bacterial contamination of the water without referring to the bacterial species present in it.

The spreading method was used to isolate the bacteria, where 1 ml of the sterile (diluted) sample was cultured in a nutrient medium (Trigtool 7 agar) placed in a sterile Petri dish and the dishes were incubated at a temperature of 37 °C for 24 h, then the number of colonies growing in the studied sample was calculated.

The diagnosis of E. coli was carried out using the API20E Analytical Profile Index strip using the method of the French manufacturer MérieuxBio, the strips were incubated at 37 °C for 24 h and the results were recorded.

A temperature meter and an electronic pH meter were used, where the device was calibrated and its probe was immersed in 300 ml of sterile sample and left for 10 sec to get the accurate reading, then it was put in the machine for 10 sec to get an accurate reading.

Table (2) results of the preparation experiment for two samples represented by the first sample and the second sample (Hiba, 2022, 8, Al-baath magazine):

Turbidity	Al-Fijeh spring	Barada Valley	Marwan Valley
before disinfection	0.29	0.24	0.46
after disinfection	0.99	0.86	1.11
pH	Al-Fijeh spring	Barada Valley	Marwan Valley
before disinfection	8.76	8.86	8.69
after disinfection	8.34	8.06	8.12
Temperature (°C)	Al-Fijeh spring	Barada Valley	Marwan Valley
before disinfection	12.7	10.5	15.2
after disinfection	12.9	12	15.6
Bacterial Number	Al-Fijeh spring	Barada Valley	Marwan Valley
before disinfection	General number : 300	General number :200	General number : 150
	coliform bacillus: 200	coliform bacillus : 50	coliform bacillus: 125
after disinfection	0	0	0

It is noted that the turbidity value increased when sodium hypochlorite was added (Fig. 5) and this is explained by the interaction of sodium hypochlorite with water and the production of hypochlorous acid (Boulos 2008,423). Despite this increase in the turbidity value, it is still within the range of specification values. (Syrian Standard No. 45/2007).

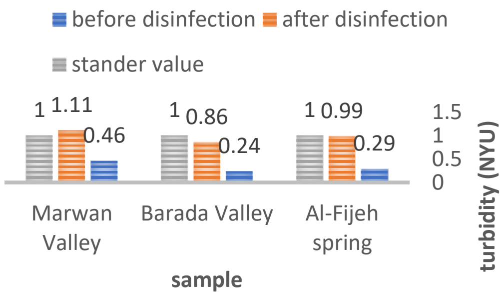

Figure (5) Comparison of the turbidity results of samples with the Syrian standards

It was also observed that the pH function increased when sodium hypochlorite was added to the sterile water in the three samples (Fig. 6), as the presence of an aqueous solution of hypochlorite at a concentration of (0.01N) gives a pH value of (9.7).

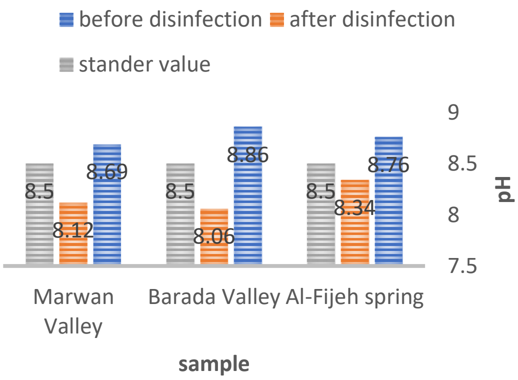

Figure (6) Comparison the results of the PH samples with the Syrian Standards

3. Results:

By comparing the results we obtained from the two experiments with the Syrian standard values and specifications for permissible water, the outcomes were as follows:

3.1. Turbidity:

Figure (5) shows that the turbidity value after sterilization is higher than the ideal value globally for turbidity, but it is within the permissible range and is therefore suitable for drinking according to the Syrian standard specifications.

3.2. pH:

Figure (6) shows that the pH values are close to the international standard value and fall within the best range according to the Syrian standard specifications, which ranges from 6.5 to 9.

3.3. Temperature:

The two experiments did not show a significant increase in temperature, as it is within the permissible range.

Discussions

Syrian surface water is exposed to biological, industrial, nitration and tourism contamination.

To be more specific, the upper surface water in Damascus where the soil has a crust nature is contaminated now and then due to internal flows or its absence; on the other hand, in the south of Damascus the soil is Conglomeratic and easily contaminated due to the repeated sedimentation of Barada and Al-Awaj river; for this reason, all surface water is highly contaminated.

Once the water is not safe neither for drinking nor for irrigation, the soil will be contaminated by unclean water, insecticides, and agricultural pollutants, while this contamination will leak to groundwater and the down lairs of the ground, and therefore resulting in the soil being fully contaminated. As a result, all sources of water need to be disinfected which is the worst- case scenario we might live with since Syria is already suffering from water shortage and Barada river does not reach its estuary; that's why we have been working on the implementation of a mechanical system that produces NaOCl to sterilize water.

The Benefits of Chlorine Disinfectants Potent Germicide Chlorine disinfectants can reduce the level of many disease-causing microorganisms, particularly bacteria and viruses in drinking water to unmeasurable levels which is consistence with the produced sodium hypochlorite which does not affect the nature of sterilized water and remains suitable for drinking according to the Syrian standard specifications in addition to its effective impact on eliminating bacterial colonies.

Biological Growth Control Chlorine disinfectants help to eliminate slime bacteria, molds, and algae that commonly grow in water supply reservoirs, and to control and reduce microorganism-containing biofilms in water distribution systems.

Chemical Control Chlorine disinfectants react with ammonia and other nitrogenous compounds that have unpleasant tastes and hinder disinfection, and they also help to remove iron and manganese from raw water.

A dose of 0.8 PPM of sodium hypochlorite concentration of 8% was used, based on the experiments that took place on the site, which was sufficient to completely eliminate the bacterial colonies based on the percentage of the remaining free chlorine, which was 0.5 PPM, and this is an important point due to the economic savings achieved as a result of reducing the proportion of sodium hypochlorite used in sterilization that amounted to 331 m3 of sodium hypochlorite annually, while sterilizing 800,000 m3/day of raw water.

Accordingly, there was no need to import water sterilizers from other countries since self-sufficiency was achieved.

This is in addition to providing a high degree of safety for workers in the field of preparing sodium hypochlorite, as the preparation process does not require more than controlling the added quantities, which are added and prepared automatically.

Furthermore, Training was given to over 50 engineers and technicians on how to deal with the designed system in Syrian cities demonstrated below:

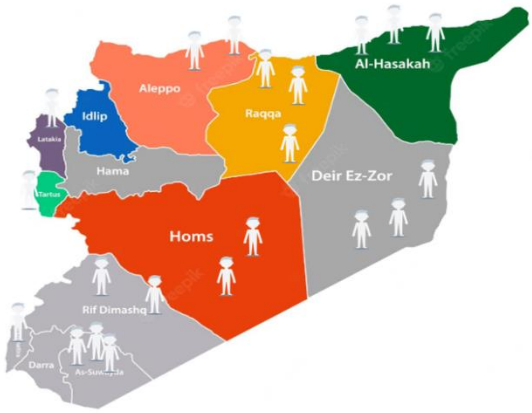

Figure (7) Distributed training for engineers

4. Suggestions and recommendations:

- Studying the possibility of using sterilizers to help eradicate B. Cereus.
- Disseminating the studied system in all Syrian governorates by Taking advantage of the principle of preparing sodium hypochlorite and designing sterilization units with low production capacity and portable for use in sub-pumping stations or in villages.
- Conducting an environmental study for the possibility of benefiting from the produced sodium carbonate and investing it in the pharmaceutical sectors.
- Studying the possibility of applying this project in poor country

Funding: this research is Funded By Damascus University- Funder No (501100020595).

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